# MST 10 Tenth International WORKSHOP

**On technical and scientific aspects of MST Radar**

# 2003

Piura Peru
May 13-20

# proceedings

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# Acknowledgments

The organizing committee thanks the support provided by:

- Scientific Committee on Solar-Terrestrial Physics (SCOSTEP)
- International Union of Radio Science (URSI)
- National Science Foundation (NSF), USA
- Atmospheric Radar System (ATRAD), Australia
- Genesys Software, Australia
- Modular antenna radar designs of Canada (MARDOC), Canada
- Consejo Nacional de Ciencia y Tecnología (CONCYTEC), Perú

that allowed the participation of graduate students and young scientists in general, and senior scientists from developing countries. In addition, we thank the hospitality of the Río Verde and El Angolo Hotels in Piura.

The International Steering Group of MST10 is conformed by: J. Röttger (Chair, Germany), J. Chau (Peru), S. Fukao (Japan), E. Kudeki (USA), and R. Woodman (Peru).

Adherent to the International Steering Group are the Chairpersons of the MST Radar Permanent Working Groups: P. Chilson (USA), D. Holdsworth (Australia), G. Nastrom (USA), P.B. Rao (India), and M. Yamamoto (Japan).

Honorary Members of the International Steering Group are: M.F. Larsen (USA), C.H. Liu (Taiwan), A.P. Mitra (India).

The National Organizing Committee of MST10 consists of: R. Woodman (Chair, Instituto Geofísico del Perú (IGP)), J. Chau (Jicamarca Radio Observatory (JRO)-IGP), Antonio Mabres (Universidad de Piura (UDEP)) and Martin Sarango (JRO-IGP).

The Local Organizing Committee of MST10 consists of: Rodolfo Rodriguez (Chair, UDEP), William Ipanaque (UDEP), and Sergio Balarezo (UDEP).

The Program Committee, besides members of International Steering Committee, include the topical Conveners K. Gage (USA), W. Hocking (Canada), D. Hysell (USA), H. Luce (France), A. Muschinski (USA), R. Palmer (USA), I. Reid (Australia), D. Riggin (USA), and D. Thorsen (USA).

# Schedule

| Tuesday May 13 | | Wednesday May 14 | |
|---|---|---|---|
| 8:00 | Registration [1] | 8:00 | Session I.2 |
| 8:30 | Opening Ceremony | 10:10 | Coffee Break |
| 9:30 | Coffee Break | 10:30 | Session I.2 |
| 10:30 | Session I.1 | | |
| 12:30 | Lunch at UDEP (Universidad de Piura) | 12:30 | Lunch on your own [2] |
| 16:00 | Session I.1 | 16:00 | Session I.3 |
| 17:00 | Coffee Break | 17:33 | Coffee Break |
| 17:20 | Session I.2 | 18:00 | Session I.3 |

| Thursday May 15 | | Friday May 16 | |
|---|---|---|---|
| 8:00 | Session I.3 | 8:00 | Session I.4 |
| 10:22 | Coffee Break | 9:25 | Coffee Break |
| 11:00 | Session I.3 | 10:00 | Session I.4 |
| 12:30 | Lunch on your own [2] | 12:30 | Group Lunch at Río Verde Restaurant |
| 16:00 | Group picture & guided Tour to UDEP (Universidad de Piura) & radar | 15:00 | Poster Session II at Río Verde Hotel |
| 19:00 | Poster Session I at Rio Verde Hotel | 19:00 | Public Lectures at UDEP (Universidad de Piura) by B. Balsley and R. Woodman |

| Saturday May 17 | | Sunday May 18 | |
|---|---|---|---|
| 8:00 | Session I.4 | 8:00 | Full-day trip [3] |
| 10:00 | Coffee Break | | |
| 10:30 | Session I.5 | | |
| 12:30 | Lunch on your own [2] | | |
| 16:00 | Session I.5 | | |
| 17:15 | Coffee Break | | |
| 17:45 | Session I.5 | | |
| 20:30 | MST10 Dinner | | |

| Monday May 19 | | Tuesday May 20 | |
|---|---|---|---|
| 8:00 | PWG 1 | 8:30 | Session II |
| 8:30 | PWG 2 | | |
| 9:30 | PWG 3 | | |
| 10:30 | Coffee Break | 10:00 | Coffee Break |
| 11:00 | PWG3 (cont.) | 10:30 | D-E-F Region, PMSE |
| 12:00 | PWG 4 | 11:10 | Meteorology Models |
| 12:30 | Lunch on your own [2] | 12:00 | Lunch on your own [2] |
| | | 13:30 | Sheets, Layers, turbulence, simulations (DNS) |
| | | 14:20 | General Issues |
| 15:00 | Session II | 15:30 | Resolutions |
| | | | Summary |
| | | | Conclusions |
| | | | Closing |
| 16:00 | Coffee Break | | |
| 16:30 | Session II | | |

[1] Pre-registration on Monday May 12 at night, followed by a "Get-together"
[2] followed by traditional nap or by sports/other activities
[3] Piura-Olmos-Túcume-Tumbas Reales de Sipán Museum-Piura

# ABSTRACTS

## Session I.1: Radar scattering processes in the neutral atmosphere

The following three main scattering mechanisms are important for atmospheric radars operating in the UHF/VHF regime: (1) Rayleigh scatter from hydrometeors, insects, etc.; (2) Bragg scatter from turbulent refractive-index fluctuations; (3) Fresnel scatter from refractive-index interfaces that are thin compared to the radar wavelength. Often, more than one of these three scattering mechanisms is relevant to a given observed data set, which may make the unambiguous retrieval of meteorological observables difficult, sometimes impossible. For example, the backscattered power may no longer be interpreted as being related to turbulence characteristics if Rayleigh scatter or Fresnel scatter contributes to, or even dominates the observed backscattered power.

In this session, observational and theoretical investigations (1) on how to separate the effects of different scattering mechanisms in the same data set, and on (2) radar echo characteristics in different radar configurations and their interpretations are presented. Emphasis will be placed on contributions that discuss new observations (e.g., multi-beam, multi-frequency, multi-receiver, and/or multi-regime radar observations, also intercomparisons with in situ measurements) on the basis of innovative, first-principle theoretical analysis.

Conveners:
*H. Luce and A. Muschinski*

## I.1.1 IMPLICATIONS OF DIRECT NUMERICAL SIMULATIONS OF TURBULENCE GENERATION AND MORPHOLOGY FOR DYNAMICS AND RADAR BACKSCATTER

***David C. Fritts***

Colorado Research Associates/NWRA, United States

Direct numerical simulations (DNS) of turbulence generation and morphology now offer highly detailed insights into turbulence transitions, the turbulence cascade, anisotropy, mixing, and effects on the mean environment. These effects also differ, depending on the source of turbulence and the evolution of the large-scale flow. Unstable shear flows lead typically to Kelvin-Helmholtz (KH) instability which is confined in altitude, leads to vigorous mixing about the initial shear layer, and drives both thermal and velocity gradients to the edges of this layer. The sharp gradients arising in this manner, and the eradication of thermal gradients within the mixing layer, have important implications for radar backscatter and inference of atmospheric parameters. A second means of turbulence generation, the breaking of gravity waves, proceeds very differently, and has a quite different turbulence morphology. Turbulence in this case is not confined to a layer, but sweeps through the atmosphere with the wave motion. It nevertheless maintains a maximum intensity that is localized within the wave field. The implications of these two mechanisms for radar measurements will be compared and contrasted.

## I.1.2 COMBINED ST RADAR/BALLOON OBSERVATIONS

***Francis Dalaudier [1], Michel Crochet [2] and Hubert Luce [2]***

[1]Service d'Aéronomie du CNRS, France
[2]LSEET - Université de Toulon et du Var, France

The structure and dynamics of the lower atmosphere are regularly probed by ST radars. Within the same altitude range, in situ measurements can be performed for virtually any local parameter using balloon borne instrumentation through dedicated campaigns. The need to validate radar wind measurements and to understand the details of the radio wave interaction with small scale atmospheric structures soon triggered studies involving both observation techniques. On the one hand, validation of parameters determined on an operational basis, especially the wind profiles, implies the use of simultaneous and co-located measurements. Other studies involving statistical or physical modeling can be conducted without such a spatio-temporal constraint. On the other hand, local parameters measured by balloons are commonly needed within the radar measurement volume in order to interpret observations or to help discriminating hypotheses. The possibility of using nearby in situ measurements depends on the considered parameter and on the needed resolution.

Validations of horizontal wind profiles with a vertical resolution of 150 m were performed during combined radar balloon campaigns. For one case, comprehensive agreement could be achieved and discrepancies were tracked down to a well identified meteorological event. The monitoring of the tropopause height in equatorial region was performed using either radar-deduced wind shears or standard meteorological definition. The vertical and statistical distribution of turbulence parameters such as Cn2 or epsilon, are also frequently compared. Their accurate determination still constitutes a challenge for both remote sensing and in situ techniques.

The understanding of fundamental processes related to instabilities, stratification and mixing benefited from dedicated combined observations, through detailed description of specific events. The mixing layers were observed at various stages of their evolution and the steepening of gradients at their edges is one of the possible generation mechanisms for the ubiquitous temperature sheets.

The improved knowledge of the small scale atmosphere dynamics allows more efficient designs of comparison experiment, taking into account the horizontal and temporal extents of investigated parameters. On the one hand, the modeling of the investigated phenomenon allows much more accurate determination of parameters and is a key ingredient of high resolution radar techniques. On the other hand, the possibility of using vertically separated array of sensors allows in situ investigation of horizontal extent and/or time evolution of the observed structure using successive profiles.

## I.1.3 STATIC STABILITY RETRIEVAL FROM MST RADAR RETURN SIGNAL POWER

***David A. Hooper [1], Johan Arvelius [2] and Kerstin Stebel [3]***

[1]Rutherford Appleton Laboratory, United Kingdom
[2]Swedish Institute of Space Physics, Sweden
[3]Norwegian Institute for Air Research, Norway

The square of the Brunt-Vaisala frequency (SQBVF) is a measure of the atmosphere's resistance to vertical motions, i.e. of its static stability. Knowledge of the variations of this parameter as a function of altitude has a broad range of applications including studies of gravity wave propagation, turbulence generation and tropopause sharpness. It is well known that perturbations of MST Radar return signal power, for a vertically directed beam, are closely related to those of the SQBVF, most notably at the tropopause level. Moreover, the theory of Fresnel scatter suggests a quantitative relationship through consideration of the generalised gradient of potential refractive index; the latter is also dependent on the humidity field in the lowest several kilometres of the atmosphere. This relationship has been demonstrated in a number of different papers and for a variety of purposes. The aim of the current study is to demonstrate that the relationship can be exploited in order to retrieve profiles of the SQBVF solely from those of MST Radar return signal power.

Observations made by ESRAD, the MST radar located at Esrange (the Swedish Space Corporation's rocket range) in northern Sweden, are compared with data from radiosondes launched from the same site. Although the relationship between the humidity field and the radar return signal power is examined, this is primarily for the purpose of determining up to what altitude the humidity contributions are significant; this can be anywhere from the lowest observed altitude up to the tropopause level for an individual case. Above this the profiles of the SQBVF determined separately from radiosonde and radar data are typically well matched, both quantitatively and qualitatively. Significant discrepancies can occur, however, under conditions of untrapped mountain wave activity in the lower stratosphere. This gives rise to large perturbations of the SQBVF which have a limited horizontal extent, of perhaps just a few tens of kilometres; the radiosonde can drift more than 50 km downwind from the radar by the time that it reaches the tropopause level. This emphasises the fact that data from radiosondes launched from a radar site are not necessarily representative of the atmosphere above the radar.

This technique allows studies to be made of changes in the profile of the SQBVF which occur over time scales of a few hours or less; such changes are likely to be missed between radiosonde launches. An application of the technique will be demonstrated in another presentation at this workshop: "Tropopause erosion by mountain wave breaking".

## I.4.524 TROPOPAUSE EROSION BY MOUNTAIN WAVE BREAKING

***David A. Hooper* [1] *and Edward G. Pavelin* [2]**

[1]Rutherford Appleton Laboratory, United Kingdom
[2]University of Reading, United Kingdom

The tropopause represents a boundary between air masses with distinct chemical and dynamical properties. Traditionally it has been thought of as a discrete level at which these properties change sharply. However, in recent years it has become more common to think of a tropopause region, of finite vertical extent, with characteristics intermediate between those of the upper-troposphere and the lower-stratosphere. MST Radars are ideally suited to studying this region, in part because the power of the signals returned from these altitudes is closely related to atmospheric static stability (see "Static stability retrieval from MST Radar return signal power" also presented at this workshop). Previous studies have shown that although the static stability often increases sharply, suggesting that the tropopause region has a very narrow vertical extent, it can also increase much more gradually over an extent of up to several kilometres. The aim of the present investigation is to demonstrate that turbulent mixing caused by mountain wave breaking, at the tropopause level, can lead to a localised erosion of the tropopause sharpness and hence to a broadening of the tropopause region. If the altitude of the chemical tropopause corresponds to that of the thermal (or static stability) tropopause prior to the onset of turbulence, the mixing is expected to give rise to the exchange of upper-tropospheric and lower-stratospheric air.

Data are considered from observations made by the (UK) NERC MST Radar at Aberystwyth in West Wales. Mountain wave activity detected by the radar is typically associated with easterly low-level winds which flow over the nearby Cambrian Mountains. Since the upper-tropospheric/ lower-stratospheric winds tend to be westerly, such low-level conditions often lead to the presence of a critical level, and hence to turbulence generation through mountain wave breaking, around the tropopause level. Several instances have been found for which a decrease in tropopause sharpness, and a broadening of the tropopause region, clearly coincide with the onset of wave-breaking turbulence at the same level. Although it is recognised that such effects will have limited temporal and spatial extents, similar reductions in tropopause sharpness have been observed in connection with synoptic scale features such as within the upper shear region associated with a jet. In the case of the latter, however, the wind speeds are typically so large that the beam-broadening contribution dominates the observed spectral widths. Therefore although the large values of vertical wind shear suggest that turbulence generation is likely, the presence of turbulence cannot be confirmed from the radar observations alone.

## I.1.8 IDENTIFICATION OF TURBULENCE USING VHF RADAR DATA

***Adrian J. McDonald***

Department of Physics and Astronomy, University of Canterbury, New Zealand

Several studies have examined techniques to identify turbulent regions. This study uses the signal statistics of the quadrature components, obtained by coherent VHF radar systems, in an attempt to determine whether these statistics can be used to determine the form of scattering observed and in particular to define regions associated with turbulence. This study compares estimates of the modified Rice parameter, defined in Kuo et al (1987), with the gradient Richardson number determined from ozonesonde and radiosonde data to examine the use of the modified Rice parameter in defining regions of intense turbulence. The relative merit of the modified Rice parameter compared to the anisotropy and the spectral width is also examined. Results from four case studies presented indicate that the modified Rice parameter shows a good qualitative agreement with regions of turbulent generation defined by low gradient Richardson number. However, other case studies show very little correspondence between the modified Rice parameter and the gradient Richardson number. A statistical comparison of the eleven days of data available shows that this parameter can not be used in isolation to define these regions. It is also shown that care must be taken in determining whether ozonesonde/radiosonde data is representative of the conditions observed above the radar site for statistical comparisons to be performed. Further examination of a subset of data, selected using a scheme described in Hocking and Mu (1997), indicates that the modified Rice parameter, the anisotropy and the spectral width should ideally be used in conjunction to identify turbulence.

## I.1.9 ABOUT ASPECT SENSITIVITY AND MULTIPLE LAYERING OF PMSE

***Jürgen Röttger***

Max-Planck-Institut für Aeronomie, Germany

Many observations of Polar Mesosphere Summer Echoes (PMSE) show that the lower PMSE region frequently is aspect-sensitive. An explanation for this phenomenon is not known yet. It is not immediately conceivable that the scattering structures in the electron gas, which originally result from irregularities in the neutral gas, are horizontally elongated at the short Bragg scale of MST VHF radars. It is proposed here that some horizontal structuring at these scales can result from polarization electric fields which are generated by different charging of heavy ions (NLC ice particles) of different sizes.
It is also frequently reported that the PMSE are occurring in a double-layer structure. Although this seems to be dominating on the average, we show that multiple layering is the most common status (but usually eliminated by averaging). The separation of such persistent sheet-like layers can be as small as one kilometer. These thin sheets are explained to occur in regions of lowered temperature due to long-period gravity waves, where ice particle can be formed. These interact with the ionospheric plasma and cause sheet-like PMSE irregularities.

## I.1.11 OBSERVATIONS OF FINE-SCALE STRUCTURE IN THE BOUNDARY LAYER USING THE TURBULENT EDDY PROFILER

***Hui Tong, Venkata Tellabati, Robert D. Palmer et al.***

University of Nebraska, United States

The Turbulent Eddy Profiler (TEP) is a volume imaging 915 MHz radar, designed for highresolution observations of the boundary layer. Researchers at the University of Massachusetts-Amherst designed and built this unique radar with 90 independent receivers allowing the implementation of sophisticated beamforming/imaging algorithms. Using this important capability, estimation of three-dimensional maps of echo power, radial velocity and spectrum width are possible within a 25° cone above the radar. Radial velocity maps can be exploited to generate estimates of the three-dimensional wind field with slightly lower resolution than the original image. First experimental results are presented from the so-called pulse-pair beamforming method which is an efficient algorithm for generating the spectral moments from an imaging radar. The algorithms used for these estimation problems will be discussed along with numerous interesting case studies of boundary layer structure and dynamics.

## I.1.12 PULSE PAIR BEAMFORMING AND THE EFFECTS OF REFLECTIVITY FIELD VARIATIONS ON IMAGING RADARS

***Boon Leng Cheong, Michael W. Hoffman, Robert D. Palmer et al.***

University of Nebraska, United States

Coherent radar imaging (CRI), which is fundamentally a beamforming process, has been used to create images of micro-scale, reflectivity structures within the resolution volume of atmospheric Doppler radars. This powerful technique has the potential to unlock many new discoveries. The Turbulent Eddy Profiler (TEP) is a unique 915 MHz boundary layer radar consisting of a maximum of 90 independent receivers. The TEP configuration allows sophisticated CRI algorithms to be implemented allowing significant improvement in angular resolution. The present work provides a thorough simulation study of some of the capabilities of the TEP system. The pulse pair processor, used for radial velocity and spectral width estimation with meteorological radars, is adapted to the imaging radar case. By numerical simulation, the new technique is shown to provide robust and computationally efficient estimates of the spectral moments. For this study, a new atmospheric radar simulation method is devised. It is shown to be computationally feasible to use tens of thousands of scattering points in the simulation. Previous methods were limited in the number of scatterers due to complexity issues. Radial velocity images from the beamforming radar are used to estimate the three-dimensional wind field map within the resolution volume. It is shown that a large bias can occur using standard Fourier imaging methods. The cause of the bias is reflectivity variations within the resolution volume. Finally, adaptive beamforming methods, such as the Capon algorithm, are proposed as one solution to this significant problem.

## I.1.4 ASPECT SENSITIVE CHARACTERISTICS OF RADAR BACKSCATTERERS AT VHF: SIMULTANEOUS MST RADAR AND GPS SONDE MEASUREMENTS

***A. Ghosh, S. Das, V. Anandan et al.***

National MST Radar Facility, India

Study of aspect sensitivity at VHF in the lower atmosphere is of active interest to the radar community, as it is important to understand the characteristics of the received radar backscatter and shape of the scatterers for better interpretation of the spectrum of the received echo in terms of the atmospheric parameters. The shape and the generation mechanisms of scattering refractive irregularities, at various height levels in ST region, is still under discussion. There are two main causative mechanisms for aspect sensitive radar backscatter (i) specular reflectors and (ii) anisotropic refractive irregularities turbulence. The contribution of each of these mechanism at various height level, however could not be well determined due to lack of simultaneous high resolution radar and in-situ measurements of background atmospheric parameters. Hence, for better understanding the aspect sensitive characteristics of the radar backscatterers, it is necessary to make the high resolution simultaneous measurements of the atmospheric parameters like temperature, pressure, humidity, wind speed and wind shear and the radar reflectivity.

The main objective of the present study is to understand the origin of the aspect sensitivity and characteristics of radar backscatter at VHF. For this purpose a campaign of simultaneous MST radar and GPS sonde (Vaisala type) observations has been carried out from radar site at Gadanki (13.5°N, 79.2°E), a tropical station in India, during the month of September-October, 2002. The results of present analysis has made it feasible to distinguish between refractivity structure at various height levels associated to (i) atmospheric turbulence due to enhanced shears and (ii) vertical refractive index gradients associated to atmospheric stability. The later one is found to be mainly due to temperature gradients, which are the main causative mechanisms for aspect sensitivity of the received radar backscatterers.

## I.1.10 HIGH-RESOLUTION ATMOSPHERIC PROFILING USING SIMULTANEOUS MULTIPLE RECEIVERS AND MULTIPLE FREQUENCIES

***Tian-You Yu [1] and William Brown [2]***

[1]University of Oklahoma, United States
[2]National Center for Atmospheric Research, United States

A novel approach of high-resolution profiling is presented which uses multiple receivers and multiple frequencies simultaneously. Range imaging (RIM), which is also called frequency domain radar interferometric imaging (FII), was developed recently to improve the range resolution of pulsed radar by transmitting multiple shifted frequencies. It has been demonstrated that RIM can reveal fine atmospheric structures. In this work, the idea of RIM is further exploited to include signals from multiple receivers. As a result, spaced antenna (SA) technique can be implemented on resolution-enhanced signals generated using RIM. A high-resolution profile of both echo power and three-dimensional wind field can be measured based on a hybrid use of RIM and SA techniques (RIM-SA).

In this work, simulation results demonstrate the feasibility of RIM-SA to measure wind shears embedded within the radar volume. The applications of RIM-SA in the neutral atmosphere are demonstrated using the multiple antenna profiler radar (MAPR) of National Center for Atmospheric Research (NCAR). A RIM-SA experiment was conducted on April 27, 2002. High-resolution profiles using RIM-SA have shown to be consistent with these profiles which are measured using a single frequency and shorter pulse.

## I.1.501 ATMOSPHERIC REFRACTIVITY PROFILES OVER PIURA ST RADAR

***Rodolfo Rodriguez, Freddy Sosa and Miguel Carrion***

Universidad de Piura, Peru

The Piura ST radar is part of the Trans-Pacific Profiler Network (TPPN) that monitors the atmospheric dynamics along the Equatorial Pacific Ocean. This system is in operation since 1989 and it is located on the northern coast of Peru, one of the most sensitive regions in the world to El Niño-Southern Oscillation (ENSO) phenomenon. In order to complement and understand the atmospheric observations with this radar, meteorological balloon launches have been made concurrently measuring temperature, humidity and pressure profiles. From these balloon data we have deduced the atmospheric refractivity profiles under which the Piura radar system operates. Characteristics and variability of these profiles are shown and discussed in this work.

# I.1.502 OBSERVATIONS OF MESOSPHERE SUMMER ECHOES AT DIFFERENT SITES BETWEEN 54°N AND 79°N USING CALIBRATED RADAR EXPERIMENTS

***Ralph Latteck [1], Werner Singer [1] and Rüdiger Rüster [2]***

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[2]Max-Planck-Institut für Aeronomie, Katlenburg-Lindau, Germany

Polar Mesosphere Summer Echoes (PMSE) have been observed with VHF radars around 50 MHz at various high-latitude locations for more than 20 years. The occurrence and seasonal variation of PMSEs, their dependence on solar and geomagnetic activity, their relation with mesospheric dynamics and possible causes of this phenomenon are widely studied.

A still open question is the inter-comparison of the various radar experiments as well as the latitudinal dependence of the strength of PMSE as most of the observations are based on relative signal-to-noise ratios and not on absolutely calibrated echo power. In addition, absolute measurements allow also the estimation of further physical parameters (e.g. energy dissipation rate). A few radars were absolutely calibrated using comparable methods such as signals from a noise source and from a delay line. These are: the ALOMAR SOUSY radar operated at Andenes/Norway (69°N) from 1994 to 1997, the SOUSY Svalbard radar in operation at Longyearbyen/Svalbard (79°N) since 1999, and the ALWIN radar at Andenes/Norway since 1998. In addition, the OSWIN radar at Kuehlungsborn (54°N) provides also continuous observations of Mesosphere Summer Echoes (MSE) at mid-latitudes since 1998.

The advantages and disadvantages of the calibration techniques are discussed. PMSE/MSE observations from these four locations between 54°N and 79°N are converted to backscatter cross-sections. The sensitivity of the different radar experiments and strong PMSE events are compared on an absolute level.

## I.1.505 VHF-RADAR OBSERVATIONS OF TEMPERATURE SHEETS IN THE STRATOSPHERIC-TROPOSPHERIC REGION

***Siddarth Shankar Das, Karanam Kishore Kumar, A.R. Jain et al.***

National MST Radar Facility, India

Recent observations have reported the presence of very thin temperature sheets, which is one of the probable causative mechanisms for the enhanced Radar Reflectivity at lower stratospheric heights. In spite of several studies on temperature sheets, the uncertainty about the causative mechanism persists due to the lack of high-resolution measurements of temperature and appropriate Radar range resolutions.
This paper reports the observations of temperature sheets carried out during the monsoon and post-monsoon period (July-August-1999, September-2000, September-October-2002) made using simultaneous VHF-Radar and Radio/GPS-Sonde measurements. The Radar reflectivity shows the existence of multiple thin layers at lower stratospheric heights, i.e. above tropopause. Aspect Sensitivity of the Radar echo was also examined to get an idea for the causative mechanism of these thin temperature sheets. Present series of observations show a separation between these layer is ~ 1 km. A detailed spectral analysis of the vertical structure of these thin multiple temperature layers and Radar Reflectivity are used to determine its causative mechanism. Vertical height profiles of temperature and Radar reflectivity show the same vertical wavelengths in the lower stratospheric region. The detailed results of these studies will be presented in this paper.

# ABSTRACTS

## Session I.2: D, E, and F Region Coherent Scattering

This session will be devoted the theory and observation of coherent scatter from ionospheric irregularities at all latitudes. We solicit reports pertaining to such mature fields of study as the auroral and equatorial electrojets, PMSE, sporadic E layers, and equatorial spread F. Recent and planned campaigns like SEEK II, C/NOFS, and CIELO attest to the fact that numerous problems remain unsolved in these areas. In addition, we invite reports on emerging areas of research including long-lived meteor trails, 150 km echoes, daytime spread F, and midlatitude spread F, about which relatively little is known. Novel experimental techniques such as passive radar, networked radar, radar imaging, and coherent scatter Faraday rotation may promote rapid progress in the areas outlined above, and we therefore invite reports describing new experimental radar techniques.

Conveners:
*D. Hysell and R. Palmer*

# I.2.1 RECENT OBSERVATIONS OF E REGION FIELD-ALIGNED IRREGULARITIES AT LOW LATITUDES

***Jorge L. Chau [1], David L. Hysell [2] and Marco A. Milla [1]***

[1]Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima, Peru
[2]Department of Earth and Atmospheric Sciences, Cornell University, Ithaca, New York, United States

We present a summary of recent observations made of E region field aligned irregularities at low latitudes, particularly those from the Jicamarca Radio Observatory (JRO) and those from the Piura VHF radar. Although the observations at JRO (under the magnetic equator, inside the equatorial electrojet (EEJ) region) started more than 40 years ago, there have been very few of them (few hundred hours a year) until the JULIA (Jicamarca unattended long-term investigations of the atmosphere) system started few years ago. Now we are observing more than 2000 hours per year. We report the day-to-day and seasonal characteristics of these echoes. In addition, we present results from recently implemented new observing modes. These new modes allow us to get useful ionospheric parameters from EEJ echoes, e.g., zonal wind profiles, density profiles, electric fields, etc, and also from 150-km echoes. We also summarize the statistical and morphological characteristics of field aligned E region echoes observed with the Piura VHF radar, located just outside the EEJ region. These characteristics are discussed and compared with those from EEJ echoes.

## I.2.2 ROCKET/RADAR EXPERIMENT OF THE E-REGION IONOSPHERE: SEEK-2 (SPORADIC-E EXPERIMENT OVER KYUSHU - 2)

***Mamoru Yamamoto and Shoichiro Fukao***

Radio Science Center for Space and Atmosphere, Kyoto University, Japan

Ionospheric irregularities in the mid-latitude E-region has been one of the study topics for more than ten years. The epoch was the discovery of the quasi-periodic (QP) structure in the E-region FAI (Field-Aligned Irregularity) echoes observed with the MU radar in Japan. We have been extensively studying the phenomena by using HF/VHF radars, ionosondes, optical instruments, sounding rockets, and computer simulation. The QP structures appear in the E-region FAI as a reflection of modulation pattern in the Sporadic-E (Es) layers. The structures are associated with polarization electric field, which suggests strong coupling process between the ionized and neutral atmosphere. Electrodynamic coupling of different altitudes of E-region ionosphere is also an important issue together with E- and F-region coupling processes. Detailed generating mechanism of the QP echoes is, however, still unresolved. In August 2002, we conducted SEEK-2 (Sporadic-E Experiment over Kyushu 2) campaign in Japan under collaboration with many scientists from Japan, USA and Taiwan. Since the SEEK-2 follows the achievements of the first SEEK campaign in 1996, it was extended in some aspects. The SEEK-2 consists of two sounding rockets of Institute of Space and Aeronautical Sciences that include in-situ experiment of electron density, electron temperature, electric field, plasma fluctuation and waves, and geomagnetic field as before. As a new rocket experiment, we conducted rocket-beacon experiment to measure TEC (Total Electron Content) of the Es-layers, and both up-leg and down-leg releases of TMA (Tri-Methyl Aluminum) to measure the neutral winds and waves. From the ground we measured the same observation region of the rockets with two radars of 24.5MHz and 31.6MHz, ionosonde network of Japan, an MF radar, several airglow imagers, and a GPS scintillation-receiver system. We observed intense QP echoes with radars after 23 LT (= UT + 9 hours) on August 3, 2002, and launched rockets into the E-region at 2324 LT and 2339 LT. The operation of the SEEK-2 was very successful as we could select a good event for the launches. All instruments on the rockets worked fine. From preliminary data analyses we are finding that the rockets detected multi-layered Es-layers at 103, 105 and 129km altitudes, and intense electric fields that approach +/-10 mV/m. The rocket-beacon experiment measured horizontal structures of the E-region TEC. The TMA release showed rippled structures which may prove existence of wave or instability in the neutral atmosphere. We now continue efforts for further data analyses. In the presentation we will show more results from the SEEK-2, and discuss newer view of the mid-latitude E-region FAI.

## I.2.3 RADAR OBSERVATIONS OF FIELD-ALIGNED PLASMA IRREGULARITIES IN THE SPORADIC E EXPERIMENT OVER KYUSHU 2 (SEEK-2)

***Susumu Saito [1], Shoichiro Fukao [1], Roland T. Tsunoda [2] et al.***

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Following the success of the SEEK (Sporadic E Experiment over Kyushu) rocket campaign in 1996, a second rocket campaign, SEEK-2, was conducted this summer to better understand the physical processes responsible for the QP echoes found in the nighttime mid-latitude E region. Two ionospheric backscatter radars were installed on the island of Tanegashima to measure the properties of field-aligned irregularities and to provide the launch criteria and timing for the two SEEK-2 rockets. One radar, the Lower Thermosphere Profiler Radar (LTPR, 31.57 MHz), was installed in Minamitane town (30.37N, 130.97E), and the other, a Frequency-Agile Radar (FAR, 24.515 MHz) was installed near Nishino-omote city (30.75N, 131.03E). Strong QP echoes were observed with both radars when the two sounding rockets were launched into the ionosphere, with 15 minutes interval, on 03 August 2002. From the two radar measurements, it was inferred that echoing regions propagated in a southwestward direction at about 30 m/s with spatial separations of 12 - 23 km. These results will be compared with in situ measurements by rocket of electric fields and electron densities, as well as with meteor echo measurements by LTPR of the neutral wind. Interferometric measurements of fine scale structures of QP echoes by LTPR will also be presented.

## I.2.4 MID-LATITUDE E-REGION BULK MOTIONS INFERRED FROM COHERENT HF RADAR AND IONOSONDE MEASUREMENTS

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In the mid-latitude E-region there is now evidence that sporadic-E layers and neutral winds are significant in driving the plasma physics in this region. Sporadic-E layers, which drifts with the neutral wind, supply the blobs or patches of metallic ions needed for plasma instability excitation. These bulk or neutral wind motions can be deduced from coherent radar backscatter observations by computing the striation slopes of quasi-periodic (QP) echoes. The Valensole high frequency (HF) radar located in the south of France, which has a large azimuthal scanning capability of 86 deg (26 deg E to 58 deg W), is ideal for deducing zonal bulk motions from QP echoes using azimuth-time-intensity (ATI) analysis. ATI plots show sequential sloping striations of scatter reminiscent of those seen routinely in range-time-intensity (RTI) plots of mid-latitude radars which view the E-region at a fixed azimuth about the meridian. Bulk or neutral wind motions in the E-region may also be determined from angle-of-arrival ionosonde measurements from sporadic-E layers. For a short time during the summer of 1995 a CADI (Canadian Advanced Digital Ionosonde) ionosonde was operated under a portion of the field of view of the Valensole HF radar. Operating in a fixed frequency mode, the CADI instrument was able to measure angle-of-arrival information in two orthogonal horizontal directions and thus deduce drift information on sporadic-E patches which are assumed to drift with the neutral wind. This paper compares the bulk or neutral wind drifts determined using the Valensole HF radar to those determined from a CADI ionosonde located at Termignon. CADI measurements clearly show a strongly westward aligned motion. Such motion is also inferred from the HF data. As such, this initial comparison of measurements agrees well with respect to direction information of the neutral wind flow. However, with respect to the drift velocity magnitudes, the CADI measurements underestimate those from the HF observations. Currently, refinement of the analysis is in progress and cases of eastward motion are being sought.

## I.2.5 THE ROLE OF UNSTABLE SPORADIC-E LAYERS IN THE GENERATION OF MIDLATITUDE SPREAD-F

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There is growing experimental evidence suggesting that some regions exhibiting midlatitude spread F are magnetically linked to patchy sporadic E layers which are unstable to the gradient drift and Farley-Buneman plasma instabilities with the free energy for destabilization provided by enhanced electric fields. To validate this relationship, we have compared E region coherent backscatter and spread F ionosonde recordings from about a hundred days of joint operation during the summer and found indeed that unstable sporadic E layers are accompanied by overhead spread F in a one to one relation. The enhanced electric fields inside patchy sporadic E are thought to be polarization fields set up locally by neutral winds that transport the plasma patches horizontally. The relatively large Hall to Pedersen conductivity ratios at E region altitudes leads to the large electric fields. Moreover, midlatitude echoes were found to associate with mostly westward drifting Es patches with typical scale lengths from 20 to more than 100 km and perturbed eastward electric fields from a few to maybe more than 10 to 15 millivolts per meter. We propose that the enhanced polarization fields set up inside unstable Es patches can easily map up along the field lines to the F region and thus contribute to the occurrence of spread F. This new option for spread F generation is basically an image process that can account for key observational properties of the phenomenon. These include the rapid plasma upwelling and the abrupt changes in height of the F layer, which have been reported in the literature, as well as the scale sizes involved and other morphological characteristics.

## I.2.6 VHF RADAR OBSERVATIONS OF MIDLATITUDE E-REGION IRREGULARITIES AT CAMP SANTIAGO, PR

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We present the statistics and characteristics of VHF radar echoes detected from Camp Santiago, Puerto Rico during three different seasons: (1) Coqui 2 observations conducted during the winter equinox, (2) Coqui 3 during the summer period, and (3) Coqui 2' repeated as a control campaign to repeat the winter equinox but also because Arecibo drifts would be measured. We classify the echoes in two major groups: (1) scattering layers between 90 and 100 km altitude, and (2) scattering layers above 100 km.

In general, scattering layers from 90 – 100 km show strong seasonal variability. For instance, unstructured layers occurring daily in Coqui 2 were only a minor aspect in Coqui 2'. Typical events detected during each campaign mentioned above are examined.We will show that the majority of unstructured VHF echoes from this region can be accounted by a mechanism based on the combined effect of primary/secondary wave generation via gradient drift instability. We will also show that occasionally, VHF echoes from this region are excited by neutral turbulence as suggested by Larsen [J. Geophys. Res., 11, 41 – 4, 1999].

Scattering layers detected above 100 km will be examined as well. Our observations show that descending signatures of these layers can be explained as the consequence of descending plasma layers that are being dumped at lower E-region altitudes due to the action of gravity waves. Overall, our observations show less occurrence of QP echoes in the Puerto Rican sector compared to other mid-latitude observation sites. Our data also suggest that current QP models contain the right ideas to account for QP signatures, but one model is not sufficient to explain different QP events.

## I.2.7 THE 150 KM RIDDLE

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They were first reported by Balsley in 1964 but we still lack an explanation in 2002 as to what causes them: they are the equatorial 150 km VHF radar echoes and the associated meter scale plasma irregularities.

New Jicamarca results on enigmatic 150 km irregularities will be presented: dual-beam measurements with an east-west separation, and two-element interferometry with north-south as well as east-west baselines. Interferometry results show that the irregularities are highly field aligned (more so than electrojet irregularities) but quite unstructured in east-west direction. Temporal variations (~5 min time scale)in echo intensity are almost perfectly synchronous in east and west beam signals detected during the dual-beam measurements.

The observations suggest that conditions which favor the amplification of 150 km irregularities may be modulated by meridional propagating wave systems. Meridional propagating gravity waves, for instance, could cause the formation of descending density layers of mostly metallic composition which in turn may develop the meter scale structures detected by the Jicamarca radar.

## I.2.522 THE ASPECT SENSITIVITY OF RADAR ECHOES FROM THE EQUATORIAL ELECTROJET

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We report here on new 50 MHz radar studies of field aligned irregularities in the equatorial electrojet above the Jicamarca Observatory. This work provides an update of the earlier work of Kudeki and Farley [JGR, 94, 426, 1989]. We used the same interferometry technique, with six north-south baselines as parallel as possible to the magnetic field, but with improved data processing. We were able to observe a wider range of altitudes with improved resolution. Our results resemble those of Kudeki and Farley to some extent, but there are important quantitative differences. The values that we obtained for the rms angular deviation from perfect alignment, $T_{rms}$ (which is variously referred to in the literature as the angular width, or sometimes half width), are significantly smaller than those found in the earlier measurements, and there is less variation with altitude, which is puzzling, since the altitude range of the data covers more than a neutral scale height. Typical values of $T_{rms}$, for low phase velocity, type 2 echoes, range from 0.24 degrees at the bottom of the daytime electrojet to 0.20 degrees at the top. Strong type 1 echoes have considerably smaller values of this angle, however, approaching 0.1 degrees. The presence of the high phase velocity, type 1 waves is usually associated with a significant broadening of the angular spectrum (an increase in $T_{rms}$) of the waves with small phase velocity. In fact this latter width sometimes actually increases with increasing altitude in the vicinity of 104 km, say, when the electrojet is strong. Some of our data, taken during the prereversal enhancement of the ionospheric zonal electric field, shows irregularities extending up to 135 km or so. The Doppler spectra at these altitudes are very narrow, and the values of T rms are around 0.1 degrees. Some of the differences between our present data and the earlier observations of Kudeki and Farley may be a consequence changes in the magnetic declination at Jicamarca over the years; our present baselines are more nearly parallel to the geomagnetic field than was the case in the past.

## I.2.9 VERTICAL GROUP AND PHASE VELOCITIES OF IONOSPHERIC WAVES DERIVED FROM THE MU RADAR AND ITS CO-LOCATED IONOSONDE

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The middle and upper atmosphere (MU) radar (34.85°N, 136.10°E) has been employed to observe the weak incoherent scatter (IS) from free electrons of the ionosphere. On 17 June 2001, the MU radar and its co-located ionosonde at Shigaraki were simultaneously operated. The density profiles obtained from the MU radar are compared with those inverted from ionograms recorded by the ionosonde. It is found that electron densities around the F2-peak of observed by the two sounding systems generally yield a good agreement. A procedure is developed to derive the vertical phase and group velocities of ionospheric waves with 205 to 268-min periods from the MU and ionosonde measurements. Results show that the vertical phase velocities of the waves below and above the F2-peak are about 40 m/s in the upward and downward directions, respectively. The associated group velocities below and above the peak are found to be about 20 m/s in the downward and upward directions, respectively, which suggests that the source of the waves is around the F2-peak.

## I.2.10 THE BEHAVIOR OF IRREGULARITIES IN THE MID-LATITUDE ES REGION OBSERVED WITH THE CHUNG-LI VHF RADAR

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The behavior of quasi-periodic echo structure parameters associated with mid-latitude sporadic E layers observed with the Chung-Li VHF radar located in Taiwan (24.9N, 121.2E; 52MHz) are studied. Observation dates are from 2000/7/3 18LT to 2000/7/11 06LT and observation time is from 18LT to next day 06LT. The quasi-periodic echoes are detected on 7/3 18LT to 21LT.

By radar interferometry, we find that although there are several QP echoes distributed at different ranges at the same time but they concentrated at the same altitude about 98 km to 101 km during the existence of QP echoes respectively. These phenomena reveal that QP echoes may be quasi-point targets move horizontally at constant altitude.

Owing to the above situations, it seems that targets display striations in RTI plots as they pass through the radar volume in horizontal motions at a constant altitude. Range rate of QP echo seems to be like the radial velocity of target. Along a fixed striation, we calculated the velocities of projection in the x,y directions to estimated the radial velocity . Then we compared the estimated radial velocities of different QP echoes with their range rates respectively. We find the correlation coefficient between range rates of QP echoes and estimated radial velocities is 0.8. This result suggests that range rates of QP echoes are similar to the radial velocities of quasi-point targets.

## I.2.11 ON THE ORIGIN OF TWO TYPES OF QUASI-PERIODIC BACKSCATTER AS OBSERVED WITH THE GADANKI RADAR

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Analyzing the field-aligned backscatter observed over Gadanki, India (13.5°N, 79.2°E) we distinguish two types of quasiperiodic backscatter in correspondence with their Doppler signature. The first type is observed below 110 km. In this case the line of sight Doppler velocity associated with each striation presents a vortex like structure. The second type, observed above 110 km, shows a systematic pattern in which the Doppler velocity being dominantly negative (towards the radar) decreases in magnitude with increasing height. The Doppler velocity reverses its sign and becomes dominantly positive (away from radar) above the neutral line. Despite the fact that at the neutral line the Doppler velocity is zero, the power associated with it is maximum. We discuss the origin of both types of these quasiperiodic echoes.

## I.2.12 IN BEAM RADAR IMAGING OF IONOSPHERIC IRREGULARITIES

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We evaluate coherent radar imaging using interferometry with multiple baselines as a tool for probing ionospheric irregularities. Coherent scatter from irregularities in the equatorial and midlatitude ionospheres often arises from spatially compact regions of space rather than as volume scatter. This, the large dynamic range of the targets, their finite aspect width, and the appearance of multiple targets in the radar beam severely limit our ability to determine their bearing and spatial distribution using conventional beam swinging or single baseline interferometry. Radar imaging is needed to resolve ambiguity. However, the imaging problem is under-determined even with dense arrays like the one at Jicamarca, and computationally intensive statistical inverse methods must generally be employed. In this paper, we discuss data inversion using entropy as a regularization metric, derive the error covariance matrix for the imaging problem, and demonstrate the efficacy of the technique with data from low, middle, and high latitudes.

## I.2.13 BEAM BROADENING EFFECT ON THE DOPPLER SPECTRUM OF THE ECHOES FROM IONOSPHERIC IRREGULARITIES LOCALIZED IN SPORADIC E REGION

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The effects of along and transverse radar beam drifts of sporadic E (Es) field-aligned irregularities localized in the expected echoing region on mean Doppler velocity and spectral width are theoretically investigated in this article. We show that the mean Doppler velocity of the irregularities is not only governed by the along and transverse beam drift velocities, but also affected by the mean position and zonal extent of the organized plasma structure in the expected echoing region that can be determined by using IGRF2000. Detailed analysis indicates that the Doppler velocity nearly linearly proportional to the mean angular distance of the irregularities from the radar beam axis decreases with the increase of the horizontal dimension of the plasma structure. Theoretical results also predict that the Doppler spectral width of the Es field-aligned irregularities is not only the function of the transverse beam drift velocity, but also related to the zonal extent of the plasma structure. Quantitative estimation shows that the beam broadening spectral width induced by the geomagnetically zonal drift of the irregularities at the velocity of 150 m/s can be more than 9 m/s if the zonal dimension of the plasma structure located at height 105 km is 5 km. Therefore, it suggests that the beam broadening effect caused by the drift of the field-aligned irregularities across the radar beam in the geomagnetically zonal direction may play a role in broadening the Doppler spectral width, provided the spatial coverage of the irregularities is wide in zonal direction and the component of the transverse beam drift velocity of the irregularities parallel to the major axis of the expected echoing region are large.

## I.2.14 RADAR OBSERVATIONS OF E-REGION IRREGULARITIES AT MILLSTONE HILL

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Coherent scatter from E-region irregularities has been observed at mid to high latitudes for many years using HF, VHF, and UHF radar systems. This type of scatter has often been termed the "radar aurora" and occurs in the E-region of the ionosphere when electric field conditions are strong enough (> ~20 mV/m) to create ion acoustic waves via a two stream instability between the electron and molecular ion plasmas. At high latitudes the electric fields which create this instability are often significantly equatorward of the visible auroral oval. This region of strong electric fields has recently been named Subauroral Polarization Streams (SAPS) and a great deal of progress has been made in understanding these fields in terms of ionosphere-plasmasphere coupling (GRL Foster et. al 2002). I will discuss recent experimental efforts at Millstone Hill to observe this coupling region using coherent scatter from E-region irregularities and other techniques. I will also describe efforts to develop the ISIS Array (Intercepted Signals for Ionospheric Science) which will form a Coherent Radar Network over a large portion of the northern United States and southern Canada. The ISIS Array will be capable of multistatic passive radar imaging of E-region irregularities. In addition to radar observations the Array will be capable of scintillation, tomography, and TEC observations using satellite beacons and GPS signals.

## I.2.16 ELECTRON DIFFUSION IN THE VICINITY OF CHARGED AEROSOL PARTICLES REVISITED: DO WE FINALLY UNDERSTAND PMSE?

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Polar mesosphere summer echoes (PMSE) are extremely strong radar echoes primarily observed in the VHF band (wavelength~6m) in the mesopause region at latitudes poleward of approximately 50N. Such echoes require small scale (~3m) structures in the refractive index which is proportional to the electron number densities at mesospheric altitudes. Neutral air turbulence was proposed as the key mechanism for this structuring earlier but neutral air turbulence alone is far too weak to create such small scale fluctuations. It was therefore proposed that charged aerosol particles reduce the diffusivity of electrons such that small scale structures in the plasma can survive despite molecular diffusion. In situ measurements gave some support for this idea but they frequently showed also that neutral air turbulence is absent at PMSE altitudes which contradicts this explanation. In addition, recent in situ measurements of plasma species in the PMSE environment showed that several quantitative features of the available electron diffusivity-theory were flawed. We have therefore reconsidered microphysical processes of electron diffusion in the presence of positive ions and negatively charged aerosols and have shown that the lifetime of the plasma perturbations is proportional to the square of the aerosol particle radius. For example, the presence of particles with radii larger than ~10nm allows for the existence of electron number density perturbations up to several hours after the initial creation mechanism has ceased. This explains why in situ measurements of neutral air turbulence have repeatedly shown active turbulence in some part of the PMSE layer whereas turbulence was basically absent at other parts. We show that our model is in agreement with ground-based observations of PMSE and with in situ measurements of plasma and neutral atmosphere density variations. We discuss possibilities to test our model further in the future and we propose how to take advantage of PMSE to gain further insight into geophysical processes acting in the mesopause region at high latitudes.

## I.2.519 MULTIPLE LAYER PMSE STRUCTURES: STATISTICAL RESULTS FROM EIGHT YEARS OF PMSE OBSERVATIONS AND POSSIBLE PHYSICAL EXPLANATIONS OF THEIR OBSERVED PROPERTIES

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Polar Mesosphere Summer Echoes (PMSE) have been studied at Andenes (69°N, 16°E), Norway, for eight years using the ALOMAR SOUSY VHF radar (1994-1997) and the ALWIN VHF radar (since 1999). The seasonal variation of PMSE is characterized by a strong increase during end of May, a quite stable level in June and July, and a more gradual decrease during August. During the period from 1 June to 31 July, PMSE characterized by a signal-to-noise-ratio larger than 10 dB have been observed with occurrence rates between 70 and 90 %. One remarkable feature of all PMSE is the fact that the radar echoes often occur in the form of two or more distinct layers that can persist for periods of up to several hours. Until now, the layering-mechanism leading to these multiple structures is not well understood. Based on our observations we study statistical properties of these multiple layer events, like the preferred heights, the mean distances between the layers, as well as their predominant apparent downward motion which is thought to be linked to gravity wave transience. Given the winds derived from the PMSE observations we also aim at an characterization of prevailing gravity wave parameters. Based on these experimental facts, we finally discuss the physical processes that are potentially responsible for the creation of these multiple structures and their inherent properties applying a microphysical model of the generation and growth of mesospheric ice particles.

## I.2.17 ON THE RELATIONSHIP BETWEEN ASPECT SENSITIVITY AND MULTIPLE SCATTERING CENTERS OF MESOSPHERE SUMMER ECHOES: A CASE STUDY USING COHERENT RADAR IMAGING

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The technique of coherent radar imaging (CRI) is applied to examine the angle of arrival of the mesosphere summer echoes (MSE) observed by the OSWIN VHF radar (54.1 °N, 11.8°E). With the high-resolution capability of CRI technique, it is able to find the multiple-scattering-center (MSC) event. An examination of the MSE layer shows that the MSC events occur frequently in the upper portion of the layer. Moreover, the aspect sensitivity of the MSE layer is revealed to vary with the altitude, in which stronger aspect sensitivity is seen at the lower height. In view of these features, the relationship between aspect sensitivity and scattering center is investigated in more detail in this article.

## I.2.18 FURTHER OBSERVATIONS OF PMSE IN ANTARCTICA

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Here we analyze data from the Antarctic summer campaign of 2000. PMSE observations were performed at the Artigas Uruguayan Station (62°11'S 58°54'W) using a 15mx15m Yagi array. We compare the results from Artigas with those obtained in previous Antarctic summer campaigns (published or reported at MST conferences). Previously we had used the Machu-Picchu Station radar using a 50mx50m COCO array. Machu-Picchu and Artigas are separated 30 km, both located on King George Is. in Antarctica.

A strong difference in the magnitude of PMSE between the 2000 and the previous campaigns can be observed for the whole season. Furthermore, it is surprising and intriguing that the ~10 dB smaller Yagi array at Artigas (225 m2) detected stronger echoes than the COCO array at Machu-Picchu (2500 m2). Although it is well known that a Yagi array can be more efficient than a COCO array of similar dimensions, we have found, from calibration experiments (see companion paper, this conference), that this is not enough to explain such a discrepancy.

We have two alternatives to explain these differences: 1) unexpected Machu-Picchu poor performance characteristics of the COCO array that have not been accounted for; or 2) an inter-annual variability in the scattering phenomena (i.e., PMSE).

There are two arguments against the first alternative: 1) we have analyzed Stratosphere-Troposphere power data from Machu-Picchu and Artigas and have found that echo strengths are very similar for the two radars; and 2) the results are similar for the four different antenna systems that we have used at Machu-Picchu; i.e., the three original pointing directions and the new vertical array installed in 1998.

The second alternative is somewhat controversial. Arguments against are: 1) Machu-Picchu observations from 1993 to 1999 do not show significant echo strength differences between campaigns; and 2) annual variation in PMSE have not observed from the Poker Flat data base (B. Balsley personal communications). On the other hand, in favor of the annual variability alternative are the results from Svalbard radar in the Northern hemisphere (K. Kubo and J. Röttger personal communications), that reports a ~10 dB stronger reflectivity from the 2000 PMSE season with respect to the 1999 and 2001 seasons. Since, the annual variability alternative would have to be corroborated in the Southern hemisphere, so there is a need for a third campaign with both the COCO and Yagi antenna systems.

## I.2.19 ANTARCTIC AND ARCTIC PMSES OBSERVED WITH OBLIQUE INCIDENCE HF RADARS - A BRIEF OVERVIEW

***Tadahiko Ogawa***

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Polar mesosphere summer echoes (PMSEs), appearing at altitudes of 80-90 km in the high latitude mesosphere in summer, have been studied by means of vertical incidence VHF-UHF radars at northern high latitudes. It is now known that a vertical incidence HF system is also capable of detecting PMSEs. Thus, PMSEs are popular phenomena at HF-UHF frequencies in the Northern Hemisphere. In the Antarctic, the first PMSE detection was made in 1994 with an MST radar at a Peruvian base. Our knowledge of the Antarctic PMSEs, however, is still very poor because of quite rare observation opportunities, maybe due to the warmer summer mesopause at southern high latitudes and/or a scarcity of radars suitable to PMSE observations.

At present, many Super Dual Auroral Radar Network (SuperDARN) HF radars, equipped with oblique multibeams, are located at northern and southern high latitudes to detect coherent echoes backscattered from electron density irregularities in the E and F region ionosphere. These radars can also detect meteor echoes to derive neutral winds in the lower thermosphere. Peculiar upper mesosphere summer echoes, clearly different from meteor echoes, were first detected in December 1997 with two SuperDARN radars at Syowa Station, Antarctica (69.0 deg. S, 39.6 deg. E). They appear at slant ranges of 180-315 km between 1030 and 1230 UT or between 2100 and 0140 UT, and are characterized by durations of 65-110 min with intermittent subsidence and quasi-periodic oscillations of echo power, Doppler velocity and spectral width with periods of 5-20 min. The echoes are well explained by the PMSE hypothesis. Then, very similar upper mesosphere echoes were observed in the summer of 1999 at four HF frequencies of the SuperDARN radar in Finland. In harmony with these echoes, the Esrange MST radar in Sweden (about 650 km north of the HF radar site) detected typical PMSEs, thus strongly supporting that the Syowa and Finland HF echoes are PMSEs at HF band. Following these findings, a number of HF-PMSEs events have been identified in recent SuperDARN observations.

In this presentation, the above HF-PMSE observations using SuperDARN are briefly reviewed. HF-PMSEs are also compared with simultaneous echoes from medium frequency (MF) radars to demonstrate that there appear no echo enhancements at MF band and that Doppler velocities of HF-PMSEs are nearly equal to neutral winds at 85-90 km altitudes. The routinely-operated SuperDARN HF radars are quite useful to explore Arctic and Antarctic PMSEs. These radars will contribute to the studies of global morphology, long-term variability and north-south asymmetry of PMSEs.

## I.2.20 EISCAT AND SOUSY SVALBARD RADAR OBSERVATIONS TO DEDUCE THE SCHMIDT NUMBER DURING PMSE EVENTS

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The EISCAT Svalbard Radar (ESR) operates on 500 MHz; collocated with it is the SOUSY Svalbard Radar (SSR), which operates on 53.5 MHz. We have used both radars during PMSE coherent scatter conditions, where the ESR can also detect incoherent scatter and thus allows to estimate the electron density. We describe observations during two observing periods in summer 1999 and 2000. Well calibrated signal power was obtained with both radars, from which we deduced the radar reflectivity. Estimating the turbulence dissipation rate from the narrow beam observations of PMSE with the ESR, using the estimate of the electron density and the radar reflectivity on both frequencies we can obtain estimates of the Schmidt number by comparing our observational results with the model of Cho and Kelley (1993). Schmidt numbers of at least 100 are necessary to obtain the measured radar reflectivities, which basically support the model of Cho and Kelley claiming that the inertial-viscous subrange in the electron gas can extend down to small scales of some ten centimeters (namely, the Bragg scale of the ESR).

## I.2.21 PHASE DIFFUSION AND INTERPRETATION OF COHERENT SCATTERING

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The characteristic function for a random walk process yields the complex amplitude of the scattered field from a medium containing refractive index fluctuations. As a phase observable of an electron ensemble, the characteristic function or the scattered field display a relaxation behavior as the electrons diffuse in a scheme described by a diffusion model. The phase relaxation function is found to describe the behavior of the scattered field from subsiding turbulence, considering that stochastic description of turbulent particle movements based on the diffusion model is valid. The phase relaxation function, when identified as the equilibrium linear response or aftereffect function of the fluctuation-dissipation theorem, is the normalized amplitude correlation function of the scattered field from subsiding turbulent fluctuations. The amplitude correlation function ranges from Lorentzian to Gaussian for anomalous diffusion and approaches Lorentzian in the ultimate case of normal diffusion. An extension of the theory for interpreting time evolution of the scattered fields from steady-state turbulence is discussed.

## I.2.501 MORPHOLOGICAL STUDY OF THE FIELD-ALIGNED E LAYER IRREGULARITIES OBSERVED BY THE GADANKI VHF RADAR

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We operated the Gadanki radar on the nights (18 to 06 LT) of June 17-20, July 15-18, and August 19-22 during 1998; on the nights of August 5-12 and August 16-19during 1999. On the other hand, daytime (09 to 18 LT) observations were carried out on June 15-18, July 13-16, and August 17-20 during 1998. The total observation periods are 161 hours for the nighttime and are 68 hours for the daytime observation. By examining the 15-day data set, we present the morphological features of the E region FAI observed by the Gadanki radar. We find:

(1) There are two echoing regions: the lower region between 90 and 100 km ranges and the upper region between 105 and 120 km ranges.
(2) Echoes observed in both the upper and lower regions are similar to type 2 echoes reported by other radars in the mid-latitudes.
(3) Echoes of the lower region may occur in daytime as well as in nighttime. Although there is an observation break between 06 and 09 LT, noontime (11 to 14 LT) seems to be the minimum period of occurrence. QP echoes are commonly detected at the lower region no matter daytime or nighttime and are the so-called “LQP echoes”.
(4) The spectral characteristics of the lower region echoes differ from daytime and nighttime. The mean Doppler velocities are more variant than those of the daytime and the spectral widths are broader in the nighttime.
(5) The upper region echoes appeared only in the nighttime with a maximum period between 23 and 05 LT. Typical QP echoes detected here are similar to those observed at mid-latitudes.
(6) Unlike the value close to zero of the mean radial velocities of the lower E region echoes, a downward velocity is noticed at the upper E region. Both the mean Doppler velocities and the spectral widths are found larger than those of the lower regions.

We also compare the features of the FAI echoes between Gadanki and Piura radars since the geomagnetic latitude of these two radars are close. Although the morphological distribution and spectral characteristics are very similar for those FAI echoes, daytime echoes and the LQP echoes are rarely reported by Piura. It is suggested that the neutral winds may play a role in this discrepancy since those echoes usually occur at the altitudes below 100 km.

## I.2.502 CONTINUOUS WAVE INTERFEROMETER OBSERVATIONS OF MIDLATITUDE E REGION BACKSCATTER

***Christos Haldoupis [1], Alain Bourdillon [2], Anastasios Kamburelis [1] et al.***

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We present midlatitude E region backscatter observations obtained with SESCAT (Sporadic E SCATter experiment), a bistatic 50 MHz continuous wave (CW) Doppler radar located on the island of Crete, Greece, which was operated as a single (east-west) baseline interferometer. The interferometric observations reveal that the aspect sensitive area viewed by the radar often contains a few zonally located backscatter regions, presumably blobs or patches of unstable plasma, which drift across the radar field-of-view with the neutral wind. On average, these echoing regions have mean zonal scales ranging from a few kilometers to a few tens of kilometers and drift with westward speeds from about 20 m/s to 100 m/s, and occasionally up to 150 m/s. The cross-spectral analysis shows that midlatitude type 1 echoes occur much more frequently than has been previously assumed and they originate in single and localized areas of elevated electric fields. On the other hand, typical bursts of type 2 echoes are often found to result from two adjacent regions in azimuth undergoing the same bulk motion westwards but producing scatter of opposite Doppler polarity, a fact that contradicts the notion of isotropic turbulence to which type 2 echoes are attributed. Finally, quasiperiodic (QP) echoes are observed simply to be due to sequential unstable plasma patches or blobs which traverse across the radar field-of view, sometimes in a wave-like fashion.

# I.2.503 THE VERTICAL UP AND DOWN SPECTRAL ASYMMETRY OF THE EQUATORIAL ELECTROJET REVISITED

***Jean-Pierre St.-Maurice [1], R. K. Choudhary [1], Warner L. Ecklund [2] et al.***

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We have studied a particularly strong vertical type I event with the equatorial VHF radar at Pohnpei (6.95°N, 158.19°E, 0.7° magnetic dip). During that event, which lasted several hours, we routinely obtained type I waves of both signs in the vertical beam. There were also quite a few episodes during that time interval for which radar beams 13 degrees to the east and to the west of the zenith received echoes from type I waves of both signs during a 48 s integration time. This data set has allowed us to revisit the question of the equatorial electrojet up and down asymmetry. This asymmetry is known to favor down-shifted (or upward propagating) waves during the daytime electrojet. In our study we have contrasted the spectra obtained in the east and west beams when receiving type I echoes of both signs, in addition to analyzing the vertical beam data. We observed the expected behavior, but with notable exception when asymmetry changed the sign near 104 km, at times when echoes were particularly strong for that height. In the light of this and other findings based on a detailed study of data we have formulated a set of four different mechanism that could be responsible for the up-down asymmetry; one of these was basically proposed by Kudeki et al (1985). Two of the other mechanisms are also non-linear and are based on chemistry, as well as on the role played by the ambient polarization electric field. These mechanisms produce effects that are very similar to the mechanism proposed earlier. It is therefore difficult to distinguish between them. On the other hand, none of these first three mechanisms can explain the anomaly observed above 104 km. To explain this reversal in the asymmetry we need to use nonlocal nonlinear arguments based on the possible presence of a descending layer above 104 km.

## I.2.504 HIGH RESOLUTION VHF RADAR OBSERVATIONS OF DAYTIME QP STRUCTURES IN LOWER E REGION OVER GADANKI

***S. Sripathi, A. K Patra, V. Sivakumar et al.***

National MST Radar Facility, India

In this paper, we present high resolution observations of the daytime quasi-periodic (QP) structures of the lower E region irregularities made using the Gadanki VHF radar. The structures are found to display striations with negative altitude rates of ~ 10 m s-1, periods of 1 - 3 min and vertical wavelength of ~1 km. The Doppler velocities associated with these structures are found to be mostly in the range –20 - 10 m s-1. More importantly, these structures are found to be associated with a descending irregularity layer having descent rate of ~ 0.3 m s-1. The characteristics of these structures although resemble closely to that of nighttime low altitude structures observed earlier at Gadanki as well as at midlatitudes, the periodicities observed during daytime are found to be higher than that observed as few tens of seconds during nighttime. These observations are discussed in terms of their generation mechanism in the framework of the large scale Gradient drift instability and recently advanced theories on well known QP echoes based on atmospheric gravity waves and Kelvin Helmholtz instability. We believe that these structures are generated on the low altitude metallic ion layers formed at the node of the tidal wind field.

# I.2.505 STATISTICAL CHARACTERISTICS OF VHF RADAR OBSERVATIONS OF LOW-LATITUDE E REGION FIELD-ALIGNED IRREGULARITIES OVER GADANKI

***A. K Patra, S. Sripathi, V. Sivakumar et al.***

National MST Radar Facility, India

In this paper, we present the statistical characteristics of the low-latitude (6.30 north magnetic latitude) E region field aligned irregularities observed using the Gadanki MST radar. We present diurnal and seasonal characteristics of a variety of parameters (percentage of occurrence of signal, signal-to-noise ratio, mean Doppler velocity and spectral width). The echoes are observed both during day- and night-time, nighttime being more intense and larger in height extent than daytime. The thickness of the echoing region is minimum during noon and maximum during midnight. The echoes could be observed at altitudes as low as 87 km and as high as 160 km. The percentage of occurrence of signal is found to be as high as 95% during sunrise and 80% just before sunset. Further the E region echoes are stronger and occur more frequently during local summer, and weaker and occur less frequently in winter. We also present some characteristics of the sunset echoes, which we believe that they could be used for studies related to the onset of equatorial spread-F since some of the magnetic field lines of the E region over Gadanki connect to that of the F region over the equator. The mean values of the Doppler velocities above 102 km are about 10 m s-1 upward during daytime and 10 m s-1 downward during nighttime, representing the electrodynamical drift due to zonal electric field. The Doppler velocities below 102 km do not have any specific trend and they are driven mainly by meridional winds.

# I.2.506 MF RADAR AND DIGISONDE MEASUREMENTS OF E-REGION BRAGG SCATTER DOPPLER SPECTRAL BANDS UNDER THE SOUTHERN POLAR CUSP

***Raymond J. Morris [1], David A. Holdsworth [2], Didier P. Monselesan [1] et al.***

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An MF radar and a digisonde were operated concurrently at the polar cusp station Davis (78.0E, 68.6S geographic, 74.6S magnetic), Antarctica during the austral summer of 2002-03. The MF radar transmitted at a single frequency at 1.98 MHz while the digisonde transmitted in a swept-frequency mode from 1.2 MHz to 2.7 MHz. The two independent instruments were programmed to record E-region backscatter from ionospheric irregularities. This paper presents preliminary results from this novel campaign to observe Bragg scatter in the E-region from a multi-instrument campaign. Preliminary results from spectral signal analyses show evidence of Doppler spectral splitting in the respective MF and digisonde processed data which appear to emanate from the same E-region altitude as observed from the different radar techniques. Moreover there is a remarkable tendency for such spectral splitting to occur during intervals of ionosphere slant Es condition (SEC) with lacuna. The plausibility of these spectral splitting events being related to E-region ionosphere plasma instability processes will be discussed.

## I.2.507 ROCKET OBSERVATION OF ELECTRIC FIELD CONDUCTED IN THE SEEK-2

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The quasi-periodic (QP) radar echoes of the ionospheric irregularities in the midlatitude E-region was first observed with the MU radar and studied for more than ten years. It has been revealed that the QP echoes tend to appear in the post-sunset period during the summertime with periods of 2--15 minutes and generation of the QP echoes are correlated with sporadic-E (Es) layers. From the rocket experiment "SEEK" conducted in 1996, the intence electric field of more than 10 mV/m associated with the QP echoes was detected. Recently, the new model to explain such a large electric field by the internal structure of a Es layer was proposed. Further, we can examine the generation of polarization electric fields with our computer simulation model.

On August 3 in 2002, the two sounding rockets were successfully launched as a major part of the "SEEK-2" campaign. We conducted the measurements of an electric field, an electron density, a neutral wind, a horizontal distribution of Es layers, etc., at almost the same time. Both DC and AC electric fields were measured with two pairs of the orthogonal double probes. We will present the detailed results of the electric field measurements and other related observations in the SEEK-2, and compare those results with the simulation study of generation of polarization electric fields.

## I.2.509 FAST TYPE-I WAVES IN THE EQUATORIAL ELECTROJET: EVIDENCE FOR NON-ISOTHERMAL ION-ACOUSTIC SPEEDS IN THE LOWER E REGION

***Jean-Pierre St.-Maurice [1], R. K. Choudhary [1], Warner L. Ecklund [2] et al.***

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There is plenty of evidence to suggest that the phase velocity of large amplitude irregularities produced by the modified two-stream and the gradient-drift instabilities are the same as the threshold speed, namely, the nominal ion-acoustic speed in the modified two-stream case. In this context, it is rather puzzling to note that the phase velocity of type-I waves in the equatorial electrojet is known to easily exceed 400 m/s during strong electrojet conditions. This is puzzling because the ion-acoustic speed of the medium is expected to be 100 m/s slower than these observations. Explaining the observations as an increase in the nominal ion-acoustic speed through much higher neutral temperatures than expected or through electron heating by plasma waves is problematic at best. The first explanation violates everything we know about the neutral atmospheric temperature near the mesopause, while in the latter case, we only have to recall the emerging view that electron heating is done, at high latitudes, by parallel wave fields and that there is no evidence for the existence of such fields in the equatorial case. By contrast, we show that, contrary to what is normally assumed, electron thermal fluctuations cannot be neglected in the theoretical treatment of the instability when the ion collision frequency becomes large compared to the wave frequency and the wave aspect angle is small. These electron thermal fluctuations are caused by electron adiabatic heating and cooling effects related to the wave dynamics. When the electron thermal fluctuations are included in the calculations the derived instability threshold speeds match the upper limit reached by the observations. The increase becomes detectable at 108 km altitude and increases rapidly with decreasing altitude to become roughly 1.5 times as large as the isothermal ion-acoustic speed below 100 km altitude. We show in this paper that the new threshold speed provided by the non-isothermal threshold calculations provides an excellent match for the largest vertical type-I phase speeds that were observed during a very strong daytime electrojet event.

# I.2.511 PRELIMINARY STATISTICAL ANALYSIS OF THE CHARACTERISTICS OF METEOR ECHOES COLLECTED USING AN ALL-SKY METEOR RADAR AT PIURA, PERU

***Elias M. Lau, Susan K. Avery and James P. Avery***

University of Colorado, United States

During the mid 1990's a Meteor Echo Detection and Collection (MEDAC) system was attached to the VHF wind profiler located at Piura, Peru to detect and collect meteor echoes, and provide measurements of winds in the mesosphere and lower thermosphere. Data analysis revealed the presence of long-duration meteor echoes mainly when pointing perpendicular to the magnetic field lines (north beam of the VHF wind profiler). An all-sky meteor radar with interferometry capability was recently installed at Piura to collect data from a large portion of the sky, therefore increasing the amount of available data while providing accurate estimates of the angle of arrival of these echoes. This poster will present a preliminary statistical analysis of the meteor echoes collected with this new radar.

## I.2.512 OBSERVATIONS OF METEOR-HEAD ECHOES USING THE JICAMARCA 50 MHZ RADAR IN INTERFEROMETER MODE

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We present results of recent observations of meteor-head echoes obtained with the high power-aperture Jicamarca 50 MHz radar. This type of observations has not been made in the past at Jicamarca, mainly because of the existence of strong equatorial electrojet (EEJ) echoes at similar heights. However, we have recently implemented a new mode that allows us to discriminate meteor-head echoes not only from weak EEJ echoes but also from the strong meteor-trail echoes. We give a detailed description of the technique that allows us to get estimates of the radial velocities (using a matched filter and from the range vs. time relationship of the echo), direction of arrival (using interferometry), absolute geocentric velocities, absolute geocentric decelerations, etc. Statistics will be presented for these and other variables for the observations made during the Leonids 2001 and 2002 meteor showers and control days.

## I.2.516 SEARCH FOR PMSE MF CHARACTERISTICS (OTHER THAN SIGNAL)

***Chris Meek***

University of Saskatchewan, Canada

Meek et al.(MST7:Hilton Head Is. Nov 1995, in STEP Handbook July 1996 ...) and Bremer (G.R.L.,23,1075-1078,1996) showed , by comparison with data from the Alomar VHF radar at Andenes, strong evidence that PMSEs are visible at MF (2.78MHZ) at Tromso (69N, Ramfjordmoen site).

This paper examines auxilliary MF data parameters: can we identify characteristics of PMSE at MF which can be used for detection where there is no VHF radar to confirm - e.g. Saskatoon (52N)? MF parameters available from the Saskatoon analysis (now used at Saskatoon, London, Platteville, Tromso) are signal strength ( and 3Km "shear" ) at all heights (40-133Km); and Doppler velocity, angle of arrival phases, 2-D ground pattern(if the fast fading criterion is passed); and if the data pass the moving-pattern criterion (normalized time discrepancy), the wind, a second 2-D pattern estimate, and pattern time decay.

If identification is possible, a continuous 15 year data set (Saskatoon) is opened up for PMSE study.

## I.2.517 OBSERVATIONS OF PMSE USING RANGE IMAGING (RIM) ON THE EISCAT VHF RADAR: PHASE CALIBRATION ISSUES

***Jose R. Fernandez [1], Robert D. Palmer [1], Phillip B. Chilson [2] et al.***

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The goal of this research is the detailed study of the morphology and small-scale verticalstructure of extremely intense radar echoes from the polar mesopause called polar mesosphere summer echoes (PMSE). As previous work has shown, PMSE have exhibited strong aspect sensitivity often confined to thin regions at the bottom of the PMSE layer. To attain this goal, the authors have implemented the multiple-frequency imaging method, called Range IMaging (RIM), on the EISCAT VHF radar located in Tromsø, Norway. To date, the authors havedesigned, planned, and conducted two experimental campaigns with the EISCAT VHF radar during the summers of 2001 and 2002. Throughout this study, the challenges of implementing RIM on the EISCAT radar have become apparent. The most difficult challenge was caused by the general multi-static design of the EISCAT observatory. This design results in a receiver phase that is inherently different from the transmitter phase. Therefore, a robust phase calibration method was needed of which numerous suboptimal methods exist. A novel phase calibration technique will be presented based on Genetic Algorithms, which are a family of fast search algorithms using evolutionary rules. Validation of the new method is provided using numerical simulations. Furthermore, preliminary results from PMSE observations using this method with the EISCAT VHF radar will be presented.

# I.2.520 PMSE, NLC AND TEMPERATURE OBERVATIONS DURING THE ROMA-2001 CAMPAIGN ON SVALBARD

***Marius Zecha [1], Jürgen Röttger [2], Franz-Josef Lübken [1] et al.***

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A campaign called ROMA-2001 with simultaneous measurements of polar mesosphere summer echoes (PMSE) by the Sousy Svalbard Radar (SSR), noctilucent clouds (NLC) by a potassium lidar, and temperatures by meteorological rockets were performed close to Longyearbyen on Svalbard (78N) in summer 2001. Here we present the results of the PMSE analysis in intercomparisons with the thermal structure and the NLC occurrence. The very low temperatures in the upper mesosphere measured from mid July until end of August allow the existence of water ice particles and a saturation degree larger then unity assuming reasonable $H_2O$-values. We found a very close correlation between the seasonal/height variation of PMSE, and atmospheric regions where temperature measurements indicate super-saturation. PMSE and NLC were found nearly permanent and during approximately 70 percent of the observation period, respectively. Generally, PMSE and NLC were observed at altitudes with super-saturation and their lower sectors coincide and are located at the lower height limit where ice particles can exist. But PMSE extend to higher altitudes compared to NLC.

## I.2.521 RESULTS OF SEVERAL YEARS MSE OBSERVATIONS AT KÜHLUNGSBORN (54N)

***Marius Zecha, Jürgen Bremer and Peter Hoffmann***

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Very strong echoes from upper mesospheric heights in polar regions are observed by VHF radars in summer for several years. This so-called polar mesosphere summer echoes (PMSE) have typical occurrence rates of more than 20 hours per day during their main season in June and July. Corresponding mesosphere summer echoes (MSE) at mid-latitudes are a relative rare phenomenon in contrast to PMSE. Based on four years nearly continuous VHF radar measurements we present results of MSE observations at Kühlungsborn (54N, 12E). MSE are normally observed between the end of May and the middle of August. The mean daily occurrence rates show strong day-to-day variations with maximum values of some few hours. They are observed only during daytime with a maximum near noon. The comparison of the MSE occurrence rates with the electron densities leads to the conclusion that MSE can only be observed if the electron density is above about 500 el./cm3. MSE are more or less regularly observed in the summer mesosphere between 80 km and 90 km, but they show a markedly dependence on altitude with a maximum incidence near 85 km. Generally MSE returns are weaker than PMSE, but also strongest mesosphere summer echoes exceed more than 20 dB signal noise ratio (SNR). We show their characteristics due to volume scattering and specular partial reflection, their very strong aspect sensitivity, the influence of turbulence, and relationships between these parameters. All parameters describing the MSE scattering process support an increasing turbulent and isotropic structure with height.

## I.2.522 VHF RADAR OBSERVATIONS ON METEOR INDUCED TURBULENT PLASMA IRREGULARITY LAYERS

***R. Selvamurugan***

National MST Radar Facility

Appearances of enhanced layer of ionization during increased meteor shower activity have shown a tendency of strong meteor echoes to transform as layer structures similar to the blanketing Es layer. The thickness of this layer is found to be very thin as the echoing regions are confining to only two or three range bins (<3 km) in the height range of ~93 km. This behavior in particular is characteristic of the normal blanketing Es-layer. The spectral characteristics show that the layer tends to become unstable with time generating plasma turbulent irregularities within. The ionized layer persisted for a sufficiently long period (~2 min) in comparison to the short-lived specular echoes, which normally last for few milli seconds scattered from meteor traces observed simultaneously. The signal-to-noise ratio of the signal obtained from the layer is in the range of ~6 dB. The strength of the signal is sufficiently strong and the echo power is of the order of the power normally found with blanketing Es type of layers with ionospheric measurements. Conversely, the signal strength is relatively weak compared to the specular echoes from meteor traces with the Signal-to-Noise ratios are of the order of ~30 dB that were recorded during the same period. However, the blanketing Es layer can appear and persist for relatively a longer period compared to the one observed in the present case, provided, the background ionization, wind shear and most importantly the ambient electric field are conducive to the existence of the layer.

# ABSTRACTS

## Session I.3: Winds, waves and turbulence in the lower and middle atmosphere and the lower thermosphere

This session will examine recent developments in the areas of studies of observations of dynamical motions in the middle atmosphere and lower thermosphere. Topics of particular interest include wave-wave interaction, wave sources and generation mechanisms, wave deposition processes, non-linear interactions, wave propagation studies, turbulence anisotropy and turbulent transport processes, but other papers on related topics will also be considered. Correlations of wave events as a function of height are also of interest. Multi-instrument studies are especially encouraged, and inter-comparisons of different techniques are considered to be important. One area of special interest is studies of wave velocity amplitudes and variability in the region above 90 km altitude, with particular interest in determining the frequency of occurrence of large amplitude events and large wind velocities (up to 100 m/s and higher) in this region.

Conveners:
*W. Hocking and M.Larsen*

## I.3.1 COMPARISONS OF FULL CORRELATION ANALYSIS (FCA) AND IMAGING DOPPLER INTERFEROMETRY (IDI) WINDS USING THE BUCKLAND PARK MF RADAR.

***David A. Holdsworth [1] and Iain M. Reid [2]***

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[2]Department of Physics and Mathematical Physics, University of Adelaide, Adelaide, SA, Australia

The results from two and a half years of on-line winds observations obtained using the full correlation analysis (FCA) and a variant of imaging Doppler interferometry (IDI) for the Buckland Park MF radar are presented. These results are addressed in terms of volume scatter arguments, which suggest the IDI winds will be overestimated in the volume scatter situation. Although the distribution of IDI effective scattering positions are consistent with those expected based on volume scatter arguments, the IDI and FCA winds show excellent agreement in both magnitude and direction, both for short (2 minute) and longer term (hourly, daily, weekly).

## I.3.2 PRECISION OF SPACED-ANTENNA WIND ESTIMATES: THEORETICAL AND SIMULATED RESULTS

***Richard J. Doviak [1], Guifu Zhang [2], Stephen A. Cohn [3] et al.***

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Formulas for calculating the theoretical precision of horizontal wind measured with spaced-antenna (SA) wind profilers are developed and compared with results obtained from simulations for conditions of high signal to noise ratios. These theoretical formulas, applied to three different methods of wind estimation, explicitly relate the precision of wind measurement to radar and atmospheric parameters (e.g., aperture illumination distribution, Bragg scatter correlation lengths, etc). Formulas for Briggs= Full Correlation Analysis, the Intercept method, and the Slope at Zero Lag method are presented for two implementations-1) estimating parameters for assumed Gaussian shaped correlation functions and 2) a direct finite difference method where this assumption is not necessary. For each wind measurement method and implementation, these formulas are compared with results from simulations, and are used to evaluate, as an example, the theoretical performance of MAPR, NCAR=s 915 MHz, Multiple Antenna Profiling Radar to estimate wind and turbulence. Using the formulas, we also compare the theoretical performance of MU radar observations of stratospheric wind, with simulated results given by Kawano et al., [2003]. Small differences (i.e., a theoretical error of 3.1 vs. simulated errors of 2.7 m s-1) are explained.

## I.3.3 WIND AND TURBULENCE MEASUREMENTS BY THE MIDDLE AND UPPER ATMOSPHERE RADAR USING UCAR-STARS METHOD

***Alexander A. Praskovsky [1], Eleanor A. Praskovskaya [1], Gernot Hassenpflug [2] et al.***

[1]National Center for Atmospheric Research (NCAR), United States
[2]Radio Science Center for Space and Atmosphere (RASC), Kyoto University, Japan

The Middle and Upper Atmosphere radar (MUR) is one of the world's most flexible and powerful MST radars which makes it a natural testbed for evaluation of data analysis techniques. The UCAR-STARS is a new spaced antenna (SA) method of data processing that deploys the different order cross and auto structure functions of the received signal's power for retrieving the mean horizontal velocity components and turbulence characteristics of a scattering medium. The abbreviation stands for the "University Corporation for Atmospheric Research - STructure function Analysis of Received Signals".
Using the MUR data collected in a SA mode at height from 5 km to 15 km above the radar, the mean horizontal winds and turbulence intensity are retrieved by STARS as well as by another SA technique, the Holloway - Doviak (HAD) method; the DBS results are used as the reference for evaluating the techniques. Measurements with three configurations of receiving antennas at several averaging times are presented and discussed.
The signal-to-noise-ratio (SNR) in a SA mode after 128 coherent integrations exceeds approximately 0 dB at height from 5 km to approximately 10 km, and it is often much below 0 dB from 10 km to 15 km. The mean horizontal wind speed components retrieved by the SA methods (STARS and HAD) are in good agreement with those by DBS when SNR exceeds approximately 0 dB. At SNR below 0 dB, an agreement between SA and DBS measured mean winds is quite poor. The intensity of the vertical turbulent velocity component measured by STARS is in excellent agreement with that by HAD. The DBS measured spectral width is too strongly affected by the beam broadening for providing the turbulence intensity. The DBS measured mean wind speed components do not vary significantly with time at any height, and they vary quite smoothly with the height. On the contrary, the STARS results clearly show waves in a horizontal direction with a period of approximately 45 min. - 1.5 hour, and in a vertical direction with a wavelength of approximately 1 km - 2 km. The waves can also be seen in the HAD results. It is not yet determined whether the waves are real, or result from the measurement errors. It is found that the MUR signals contain a narrow-band component of yet unidentified physical nature. The narrow-band component is strongly pronounced at low SNR, and it is taken into account by neither STARS, nor HAD. This component may result in wave structures produced by SA methods, and it can be the reason for a poor agreement between DBS and SA methods at low SNR. Detailed study of the narrow-band component in the MUR signals is the major task for a future study.

## I.3.4 RANDOM ERROR ANALYSIS OF SPACED ANTENNA TECHNIQUE FOR CORRELATION LENGTH MEASUREMENTS

***Gernot Hassenpflug, Mamoru Yamamoto and Shoichiro Fukao***

RASC, Kyoto University, Japan

Spaced antenna observations using the method of Doviak and Holloway et al permits estimates of horizontal scatterer correlation lengths independent of the antenna parameters. The use of correlation lengths and angular aspect sensitivities in the study of turbulence structures and radar scattering is an incentive to study the error in estimating these parameters. Random error associated with spaced antenna observations was estimated and related to measurement of turbulence structure correlation lengths.

First, random error contribution to the total observed fluctuations of estimated parameters was estimated. The random error estimation was based on estimation of mean population correlation functions. The uncertainty in parameters was expressed in terms of the cross-correlation coefficients at time-zero-lag, and these coefficients' uncertainty. The results showed good agreement when compared to fluctuations of the observed parameters averaged over a short period of observation in which time fluctuation can reasonably be considered negligible. Second, the use of error estimation was applied to data screening. Third, the effects of antenna aperture size, baseline length and anisotropy on the expected random error are discussed, as is the contribution of non-Gaussian and spurious signal correlations to the total auto- and cross-correlation. The last topic provides a means to optimize baseline lengths, and transmitter and receiver antenna aperture sizes for a given experiment. An estimate of the lower limit of the resolution of the spaced antenna configuration is possible using the error analysis described, by choosing a relative error of, for example, 50% as a criterion for minimum resolution.

## I.3.6 METEOR AND LIDAR WIND COMPARISONS FROM MAUI, HAWAII

***Steve Franke [1], Wayne K. Hocking [2] and Gary Swenson [1]***

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A SKiYMET radar has recently been installed on the island of Maui in Hawaii, at the foot of Mount Haleakala. Winds and temperatures have been recorded continuously since last May. At the same time, a large telescope on the top of the mountain has been used for lidar measurements of winds and temperatures, but on a campaign basis. Results of comparisons of wind measurements by the two different methods are presented. Correlations are among the best ever presented in the literature. Large winds are especially evident above 90 km altitude, and tidal amplitudes can easily exceed 60 m/s. Results of these comparisons will be presented.

## I.3.8 LONGITUDINAL AND LATITUDINAL DEPENDENCY OF THE INFLUENCE OF STRATOSPHERIC CIRCULATION DISTURBANCES ON THE MESOSPHERIC WIND FIELD

***Peter Hoffmann, Werner Singer, Erich Becker et al.***

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Continuous MF radar wind observations allow detailed investigations of the upper mesosphere circulation in winter and its coupling with the lower atmosphere. During winter the mesospheric/lower thermospheric wind field is characterized by a strong variability. Causes of this behaviour are planetary wave activity and related stratospheric warming events. Reversals of the dominating eastward directed mean zonal winds in winter to summerly westward directed winds are often observed in connection with stratospheric warmings. Here we are focussing on the longitudinal and latitudinal dependence of the amplitudes and durations of the mesospheric wind reversals for case studies comprising three major stratospheric warmings and one strong minor warming observed during winter 1998/99 and 2000/2001, respectively. The observations are based on MF radar wind measurements at high latitudes in Andenes (69° N, 16°E) and Poker Flat (65°N, 135° W) as well as at mid-latitudes in Juliusruh (54° N, 13 °E) and Saskatoon (52°N, 107°W). Additionally, temperatures derived form meteor radar observation at Juliusruh show an cooling in the mesosphere during the stratospheric warming.
First comparison with modelling results using the Kühlungsborn Mechanistic general Circulation Model (KMCM) confirm the observed latitudinal dependence of the reversal or weakening of the mesospheric zonal wind with a reduction of this effect towards the equator. Furthermore, the observations of the meridional wind at high latitudes as well as the modelling results show an enhancement of a planetary wave 1 in the mesosphere during the appearance of major stratospheric warmings.

## I.3.10 SPORADIC E LAYER DEPENDENCE ON PLANETARY WAVES: AN EVENT STUDY SHOWING AN INDIRECT RELATIONSHIP THROUGH MODULATED ATMOSPHERIC TIDES.

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A large amplitude, 7-day period westward propagating S = 1 planetary wave (PW) has been reported from ground radar and satellite wind measurements in the mesosphere-lower thermosphere (MLT) during the second half of August and well into September, 1993. Following recent suggestions that planetary waves might play a role in the formation of midlatitude sporadic E layers (Es), we have analyzed, for the period from August 1 to September 30, 1993, the sporadic E critical frequency (foEs) time series from 8 midlatitude ionosonde stations covering a longitudinal zone from about 580 E to 1570 W. The analysis revealed that all 8 station foEs data showed a strong 7-day periodicity, occurring concurrently with the 7-day planetary wave reported elsewhere. Using independent methods for the analysis of the foEs time series, we computed identical estimates for the propagation direction, zonal wavenumber and phase velocity of the 7-day wave which are in agreement with those reported from radar and satellite neutral wind MLT measurements. This provided the first direct proof in favor of a PW role on Es formation. This PW - Es relationship was investigated further by considering the variations in the mesospheric neutral wind measured with radars in Canada and UK.

Our analysis showed clearly that Es is affected indirectly by the PW through the action of the diurnal and semidiurnal tides which are strongly modulated by the same PW, apparently through a nonlinear interaction process at altitudes below 100 km. This 7-day PW modulation was found to be clearly present simultaneously in the amplitude of the zonal 12-hour tidal wind, the meridional 24-hour tidal wind, and in both, the 12-hour and 24-hour periodicities which existed in the foEs time series. These results suggest an explanation for the observed relation between sporadic E layers and planetary waves.

## I.3.11 RADAR, OPTICAL AND SATELLITE STUDIES OF CLIMATOLOGY AND EFFECTS OF ATMOSPHERIC GRAVITY WAVES AND TURBULENCE

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Some results of studies of climatology of internal gravity waves (IGWs) in the middle and upper atmosphere are presented. MST and MF radars give information about seasonal and interannual changes of the mean winds and IGW variances at different altitudes in the atmosphere. These changes of IGW intensity may be produced by respective changes in the background fields of wind and temperature in the lower and middle atmosphere, which make changes in IGW generation and propagation conditions. New measurements of global structure of irregular variations in the lower and middle atmosphere with low-orbit satellites receiving signals of GPS system give information about distribution of zones of increased IGW and turbulence intensity and wave generation. Increased variances of the atmospheric refraction index are observed in the regions of tropical deep convection and midlatitude tropo-stratospheric jet streams. Multi-beam MST radar observations give information about mesoscale nonlinear IGW sources in the tropo-stratosphere. Numerical simulation of propagation of IGW spectrum is capable to explain radar observations of IGW seasonal variations at different altitudes. Numerical models give information about sensitivity of general circulation of the middle atmosphere to global inhomogeneity of IGW sources observed with radars and GPS satellites. Combined MST radar, optical and balloon observations may give new information about wave and turbulent transport of atmospheric gas species in the lower and middle atmosphere.

## I.3.15 INTERACTING GRAVITY WAVES ABOVE A MID-LATITUDE JET STREAM

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Interactions between gravity waves of different scales are thought to be important in determining the overall spectrum of wave activity in the atmosphere. Measurements will be presented here from the UK MST Radar facility at Aberystwyth in Wales, which show clearly the result of an interaction between a small-scale mountain wave and a large-scale inertia-gravity wave.

In this case study, the inertia-gravity wave modified the background wind profile above the jet sufficiently to induce critical levels for the mountain wave. This lead to the breaking of the mountain wave, and the generation of a layer of turbulence that was clearly aligned with a phase front of the large-scale wave.

As well as being a novel illustration of wave interaction processes in the atmosphere, these measurements also illustrate an interesting mechanism for the generation of turbulence in the tropopause region.

## I.3.16 STUDIES ON WINDS AND MOMENTUM FLUXES USING UHF RADAR OBSERVATION OVER GADANKI (13.5°N, 79.2°E)

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Wind information obtained from UHF radars observations at Gadanki (13.5°N, 79.2°E) are utilized for the present study. These studies are related to ten clear air echo days in each month for the observation period of one year i.e. from April 1999 to March 2000. Diurnal, Monthly and Seasonal variations of horizontal winds and momentum fluxes are studied. Zonal winds are found to be westward in summer , post monsoon and winter seasons, eastward in monsoon season. Meridional winds are found to be northward in summer and southward in post monsoon and monsoon seasons. Zonal and Meridional momentum fluxes show upward around noon time in summer and downward in winter seasons. Seasonal variations show similar features of diurnal variations in all the measurements. Detailed results are given later.

## I.3.18 GRAVITY WAVE STUDIES IN THE MIDDLE ATMOSPHERE FROM THE INDIAN MST RADAR USING HODOGRAPH TECHNIQUE

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We have observed wind motions from ground to mesosphere using the Indian MST radar during daylight hours from 1000 – 1600 hours from July 1998 in a campaign mode two days every month. Gravity waves with fairly sinusoidal oscillations in the vertical wave field are evident from the observations. They were characterized by a vertical wave length of about 2 – 12 km and intrinsic period of about 8 hours. The spectral analyses were carried out to bring out the vertical wave number spectra in the mesosphere using the linear gravity wave relationship. A hodograph was plotted on these days to explain the statistical characteristics of gravity waves. Two typical examples of gravity wave propagation in the troposphere are shown here. Hodograph explains us that at lower heights and in the mesosphere there exists waves of different periods. The arrows present the propagation direction of the gravity wave. Vertical profiles of wind fluctuations in the mesosphere appear to be a superposition of gravity waves of various vertical scales and propagation direction. The dominant component of wave period gravity waves are characterized by long wavelength and wave period.

## I.3.19 DEEP PENETRATIVE CONVECTION AND GENERATION OF WAVE OSCILLATION OBSERVED WITH THE CHUNG-LI VHF RADAR

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During passage of typhoon Lekima in September 2002 over Taiwan several strong convection events were observed with the Chung-Li VHF Radar. Some of these were reaching unusually high altitudes up to 14 km. We describe an example of the life cycle of an outstanding event. It was created at the altitude (bright band), where latent heat was released by condensation, which could be recognized by the formation of precipitation. The convection funnel moved upward and accelerated to a maximum velocity of 3 m/s. The rate of motion of the radar reflectivity structure was similar to the measured vertical velocity. Close to its maximum height extreme turbulence was observed. The profile of potential temperature, which we got from nearby radiosonde measurements, showed moderate stability in the altitude of upward motion. The region around 14 km, which was finally reached by the convection funnel, showed increased static stability. In this region the convective event was overshooting and thereafter reversed its upward velocity to downward. We then observed a damped oscillation with period of about 12 minutes. This event can be regarded as direct proof of gravity wave generation by penetrative cumulus convection.

## I.3.21 NUMERICAL SIMULATION OF RADAR-BACKSCATTER FROM TURBULENT STRUCTURES GENERATED BY DIRECT NUMERICAL SIMULATION OF THE FLUID EQUATIONS

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Characterization of radar backscatter from soft targets such as atmospheric turbulence has been traditionally described statistically. This approach has yielded much insight into methods that extract parameters such as wind speed from the radar signal. Now computer simulations of turbulence generated by a variety of mechanisms are available at very high resolution and computer simulations of electromagnetic wave propagation are available that can propagate a radar signal through the realistic turbulence structures. In this way a radar signal can be reconstructed from the simulated backscatter and the signature of the different types of turbulence can be investigated. Previous results (Gibson-Wilde et al.) will be presented along with some new results showing how the combination of these two types of simulations can be used to study radar backscatter from the atmosphere in detail.

## I.3.37 HIGH RESOLUTION BACKSCATTER PROBING OF THE MST REGION AT JICAMARCA

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Backscatter MST radar data illustrating the current high-resolution capabilities of the 50 MHz Jicamarca system will be presented and discussed. The data were collected using nearly the entire average power capacity and the bandwidth of the Jicamarca radar system. This was achieved by using coded pulses (complementary pairs) with a 150 m baud length and 64 bauds, and a 200 km IPP. The power and the antenna aperture were shared equally between four antenna beams pointed off-zenith in N, S, E, and W directions by 2.5 degrees. Results from a three-day experiment conducted in July 2002 frequently show very thin mesospheric layers and wave structures in the backscattered power intensity. Furthermore, sheared flows are frequently detected within such layers of a few range gate (150 m) widths, indicating that (a) the layers may be a consequence of dynamic instabilities, and (b) the effective resolution of the measurements are not too far off the nominal resolution of 150 m established by the baud length and matched filtering. Thus, the current capabilities of the Jicamarca MST system are suitable for the studies of mesospheric shear-driven instability processes.

## I.3.24 WAVES AND INSTABILITIES IN RECENT MESOSPHERIC OBSERVATIONS AT JICAMARCA

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First results from a three-day run in July 2002 of the Jicamarca radar in the MST momentum flux mode are discussed. The radar was operated with 150 m altitude resolution, thus showing mesospheric daytime echoes (~ 0700 – 1700 LT) with very fine detail of layers and wave structures. Mesospheric echoes were observed on each of the three Days 199-201: fine sheets around 65 km, the common wider layers around 70-75 km, and more patchy features around 80 km. Echoes on Day 201 were ubiquitous, presumably due to higher solar flux and x-ray flares observed during that period. The RTI diagrams often exhibit positively or negatively sloped regions of enhanced power within the layers, sometimes connected with shear zones in the background wind. These structures may indicate dynamical instabilities and/or secondary waves generated by instability processes. The new results will be discussed in the context of previous mesospheric campaigns.

## I.3.25 TURBULENT DIFFUSIVITY INFERRED FROM MST RADAR MEASUREMENTS IN THE FREE ATMOSPHERE : A REVIEW

***Richard Wilson***

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During the few past decades atmospheric radars have proved to be powerful tools for studying atmospheric dynamics - especially small scales motions associated with inertial turbulence. The present paper focuses on estimates of turbulent diffusivity from MST radar measurements in the free atmosphere (thus excluding the boundary layer). An overview of the major properties of turbulence in stratified fluid is first presented. In particular, the mixing process is discussed from an energetic point of view. The basic hypotheses relating radar measurements to turbulence parameters are also examined. The diffusive and mixing properties of atmospheric (or oceanic) turbulence depend both on turbulence intensity and on the spatial and temporal distribution of turbulent layers. These two points will be further discussed. Several methods for evaluating the turbulence dissipation rates have been proposed, one from the radar reflectivity, the other from the velocity variance of small scale motions. The capabilities and limitations of these methods are discussed. Those radar measurements which have sufficiently high resolution have revealed a lot about the spatial and temporal distribution of turbulent patches in the atmosphere. A key point in evaluating an effective diffusivity property of turbulence is to take into account the intermittent nature of atmospheric turbulence. Several parameterization schemes incorporating some statistical properties of turbulent patches, such as layers depth, life time or turbulent fraction, have been proposed. An evaluation of turbulent diffusivity from radar measurements relies on several factors, some of these factors being measured quantities (Cn2, dissipation rates), some others cannot be, in most cases, directly estimated, (the fraction of the sampled volume filled with turbulence or the local stratification). Some implications are discussed.

# I.3.26 SIMULTANEOUS OBSERVATIONS OF ATMOSPHERIC TURBULENCE IN THE LOWER STRATOSPHERE FROM BALLOON SOUNDINGS AND ST RADAR MEASUREMENTS

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A field campaign combining in situ and radar measurements, both with very high resolution, was conducted during April 1998 in St Santin (south of France). One objective of this campaign was to characterize the small scale turbulence of the atmosphere from simultaneous observations of both in-situ temperature fluctuations, and turbulent energy (kinetic and potential) dissipation rates inferred from radar data. The purpose of the present paper is to compare and discuss some properties of atmospheric turbulence observed from simultaneous and independant measurements.

The PROUST ST radar is a UHF (961~MHz) pulsed Doppler radar allowing high resolution measurements. The range resolution is 30~m, the integration time being reduced to 51~s. The large Cassegrain antenna (2000~m$^2$) pointing in the vertical direction, gives an angular resolution of 0.3\degre in the E-W direction and 1.1\degre in the N-S direction.

During the continuous radar measurements, seven instrumented balloons were launched from a nearby site, about 40~km East of the radar site (dominant wind being directed westward). Every gondola carried a Vaisala RS80G sonde including a GPS transponder, thus allowing mesoscale temperature and horizontal wind estimation. Three of the gondolas, referred as SFT (Structure Fine de Température) carried high resolution temperature and pressure sensors. The high resolution temperature profile had a vertical resolution better than 20~cm and a noise level corresponding to 5-8~mK~rms. The following points will be discussed:

- High resolution in situ measurements make clear the fact that classical PTU soundings are not sufficient to characterize the background (or reference) state of the atmosphere (for turbulence studies at least). Thin turbulent layers, about 30-50~m depth, were observed within a weakly stable atmosphere. High resolution temperature profiles clearly show that all these layers are associated with a local enhancement of the stability, such an enhancement not being resolved by standard PTU sampling.
- Atmospheric turbulence is observed from radar to occur in thin layers of depth ranging from some ten to a few hundred meters. In a first attempt, we were not able to identify any turbulent layers simultaneously observed by radar and in situ measurements. The implications will be discussed.
- A profile of refractivity as well as its spectrum were estimated from the balloon data in the lower stratosphere. Dissipation rates of potential and kinetic energy are obtained from the radar data. The statistical properties of small scale turbulence inferred from both instruments are compared and discussed.

## I.3.27 NEW MST RADAR METHODS FOR MEASURING THE TURBULENT KINETIC ENERGY DENSITY

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For many years the turbulence kinetic energy density (TKE) has been measured with radars using the spectral-width method. The (turbulent spectral width)^2, which is proportional to TKE, is obtained by subtracting the contribution of wind and shear broadening from the (observed spectral width)^2. In order to calculate the correction term, the horizontal wind velocity and vertical shear as well as the geometry of the pulse volume, especially the effective beamwidth, must be known. When the wind speed is large, small errors in these parameters can cause large fractional errors in (turbulent spectral width)^2.

In order to obviate this difficulty, we have developed new MST radar methods for measuring TKE. These methods differ from most previous methods in that they are comparative; i.e., they infer the TKE by comparing effectively simultaneous observations made with different radar settings.

The dual-beamwidth method (Van Zandt et al., 2002) replaces the correction term involving the beamwidth, wind velocity, and shear with a term involving only the ratio of the two beamwidths, which is known better than the beamwidths themselves.

The dual-beamwidth method assumes that for both beamwidths the same fraction of the pulse volume is filled with turbulence. In the other extreme, when a single turbulent layer dominates the reflectivity in the volume, the TKE of the layer can be inferred by the new dual-azimuth method, which will be described.

New experiments at the MU radar using the dual-beamwidth and dual azimuth methods, together with the conventional single-beamwidth spectral-width method, will be reported.

Van Zandt et al., A dual-beamwidth radar method for measuring atmospheric turbulent kinetic energy density,

# I.3.28 MEASUREMENTS OF ATMOSPHERIC TURBULENCE WITH THE DUAL-BEAMWIDTH METHOD USING THE MST RADAR AT GADANKI, INDIA

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Variation of turbulent kinetic energy per unit mass (st2;sigma-sub-t-squared)) with height and time of day are studied using a modified dual-beamwidth applied to data in a pilot study conducted using the MST radar at Gadanki, India, during April 24-29 and May 9-10, 2002. The beamwidth of the Gadanki radar when the full antenna is used is 2.9 degrees; by disconnecting a portion of the antenna a second beam with width 4.8 degrees was formed. Observations with the two beamwidths were interleaved each hour during this pilot study. Also, the oblique beams were formed using two separate zenith angles, 10o and 15o. The prevailing horizontal winds were light (<15 ms-1) at most heights in April and increased to over 25 ms-1 near the tropopause during May. Among other results, we find that winds and turbulence from the two zenith angles are the same. Winds and turbulence from opposing beams in the same plane are the same. During light wind conditions, from the modified dual-beamwidth method and the traditional spectral width method are the same; however, during stronger winds (>12 ms-1) the corrections applied in the traditional method are often larger than the observed spectral widths indicating a problem. Values of st2 are about 10-1 m2s-2 at 3.6-7.5 km and about 10-2 above 9 km. The diurnal range of st2 is about 5 dB in the troposphere with maximum values during the afternoon; at higher levels there is not a strong diurnal signal in these data.

## I.3.29 WEATHER RADAR OBSERVATIONS OF TURBULENCE AND SHEAR

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Spectrum width has the potential to improve the interpretation of weather radar data and warnings of hazards to safe flight. However, the use of spectrum width data has been very limited, at least compared to reflectivity and Doppler velocity. This is due in part to the difficulty in relating width to meteorologically significant phenomena, and in part to the fact that radar artifacts easily corrupt spectrum width data. An analysis of data collected by a large number of weather radars in the USA, has lead to the conclusion that reliable interpretation requires careful editing of the data fields. Examination of edited data fields and calculation of volumetric median spectrum widths values and their classification into categories of weather types has lead to interesting results. For example, steady-state well-organized tornadic storms appear to have median values (<2 m/s) equal to that found in fair weather, whereas squall lines have the largest values (up to 6 m/s). Furthermore, the capability of a Doppler radar to resolve range and velocity ambiguities depends on the width. We present spectrum width statistics, classified by weather types.

Observations of spectrum widths in stratiform precipitation reveals layers of spectrum widths as large as 10 m/s. We separate the contributions from shear and turbulence to show that shear contributes mostly to these regions of abnormally large shear. The separated turbulence field reveals patches of enhanced turbulence, or sub-resolution volume shear, and these appear to be created by breaking K-H waves within the resolution volume of the radar. The identification of levels of layers of high turbulence and/or sub-resolution volume shear could have application to improve the safety and comfort of flight.

## I.3.31 ESTIMATION OF TURBULENCE ENERGY DISSIPATION RATE AND VERTICAL EDDY DIFFUSIVITY WITH THE MU RADAR RASS

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We have conducted RASS (Radio Acoustic Sounding System) observations with the MU (Middle and Upper atmosphere) radar on 28-31 July 1994 at Shigaraki, Japan (34°51' N, 136°06' E) and determined the characteristics of turbulence energy dissipation rate (e) and vertical eddy diffusivity (K) in the tropopshere and lower stratosphere. We have first examined the accuracy of the Brunt Väisälä frequency squared (N2) derived from RASS temperature profiles. Then, e and K are determined by using N2 and the Doppler spectral with of turbulence echoes (o2turb). We found that the structures of e and K are sometimes affected by the local variations of N2. We found that sometimes e became small, even though o2turb was large, because N2 was small. On the contrary, K was enhanced due to small N2, although o2turb was small. We have a plan to continue this study by applying data obtained from EAR-RASS.

## I.3.33 A NEW APPROACH TO FAST AND ACCURATE CALCULATION OF SPECTRAL BEAM-BROADENING FOR TURBULENCE STUDIES.

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The most accurate parameterization for determination of spectral beam broadening for use in turbulence estimation is a full multi-variate integral calculation, as presented in detail by Hocking, JATP, vol 45,89-102,1983. However, for real-time calculations such a scheme can be computationally slow, and various approaches have been used to introduce faster methods. The most common procedure is to represent the wind field as a combination as a mean and a wind shear component. This procedure is limited in its flexibility, and cannot deal with situations where the wind has higher order curvature. It also does not allow for the effects of different layer thicknesses, pulse widths and so forth.

In this paper, a new scheme is introduced which permits very fast and efficient application of the full integral equation, and produces results which are accurate to within 1%, but which can deal with generalized wind profiles (include non-linear ones), any layer thickness, and any pulse length.

## I.3.34 POSSIBLE CROSS-TROPOPAUSE TRANSPORT PROCESSES IN THE TROPICS

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Dynamical transport across the tropical tropopause region, 15-17km, directly or indirectly controls the stratospheric photochemistry and the Earth's radiative balance by determining the concentrations of minor constituents and particles there. However, the transport mechanism has not been well understood yet due to scarcity of observations. In this paper, we will discuss two processes that seem to be related to this mechanism, Kelvin-Helmholtz instability and breaking of an equatorial Kelvin wave, obtained with the Equatorial Atmosphere Radar in Indonesia (EAR; 0.20S, 100.32E, 865 m above sea level).

In November 2001, the EAR observed a continuous strong eastward wind shear (10-50 m/s/km) of westward wind, and the radar echo layer tilted downward to the west in the region 0-1 km above the tropopause. The vertical wind was always upward in the same region. During the same period, the Richardson number was continuously less than 0.5 and sometimes less than 0.25, indicating that the Kelvin-Helmholtz instability frequently occurred there. The existence of the tilted radar echo layer can be explained by KHI billows. Also, the observed updraft has been found spurious, being caused by the KHI induced tilted echo layer and by the strong westward wind.

During November 19-23, a significant enhancement of turbulence was observed with the EAR in the tropopause region intermittently for about 5 days. The turbulence intensity estimated from the power spectral width during the period was up to a factor of five times larger in kinetic energy than that in other periods. Further analyses have confirmed that the enhanced turbulence was convectively generated in the breaking phase of an equatorial Kelvin wave. Between July and December 2001, we observed three more prominent cases of the turbulence generation by breaking Kelvin waves in the tropopause region.

## I.3.39 UPPER MESOSPHERE TEMPERATURE CHANGES OBSERVED IN PMSE AND INCOHERENT SCATTER DURING A STRONG POLAR CAP ABSORPTION EVENT

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Middle of July 2000 an extremely strong solar proton event happened (named “Bastille II”), which caused a major polar cap absorption due to the strong increase of D-region electron density by high energy particle precipitation. The concurrent ionospheric disturbances led to enhanced electric fields, which caused an increase of the ion drift and the neutral wind in the lower thermosphere and possibly the upper mesosphere as well. Through the enhanced ion drag increases of temperature are usually resulting. We tried to recognize this in observations of PMSE with the SOUSY Svalbard Radar and of incoherent scatter with the EISCAT Svalbard Radar. We find two independent observations, which indicate a potential temperature increase of the upper mesopause region due to ion heating:

(1) During the strongest D-region electron density enhancement we recognized a disappearance of PMSE above 86 km lasting over a fraction of a day. This could be explained by disappearance (melting) of ice particles due to heating

(2) We also recognized that the incoherent scatter spectrum above the PMSE region was wider than estimates deduced from temperature profile models. This can be explained by a temperature enhancement.

We also estimated the heating rate from the incoherent scatter electron density and the electric field measured with the ESR. The heating rate of a few Kevin per day, which was deduced with conventional assumptions, however, cannot fully explain the temperature increases needed to explain the observations (1) and (2).

## I.3.40 COMPARISON OF WIND AND TEMPERATURE ESTIMATES MADE USING THE BUCKLAND PARK ALL-SKY INTERFEROMETRIC METEOR RADAR AND COLOCATED INSTRUMENTS

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A new all-sky interferometric radar system has been developed and installed at the Buckland Park field site. First results of the wind and temperature analyses are presented. The wind estimates are compared with those obtained using the co-located MF radar, while the temperature estimates are compared with those obtained using co-located a CCD airglow imager and a CCD spectrometer.

## I.3.41 METEOR RADAR TEMPERATURES COMPARED WITH OH* OBSERVATIONS AND CO-LOCATED LIDAR AND ROCKET MEASUREMENTS

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Meteor radars can be used to estimate temperatures in the mesopause region after different techniques. The most promising method provides absolute measurements of a height-averaged temperature at about 90 km based on the height dependence of the meteor decay times (ambipolar diffusion coefficient). The method requires an approximation of the mean temperature gradient at the peak altitude of the meteor layer. An improved temperature-gradient model for mid-latitudes has been derived from potassium lidar observations at Kuehlungsborn (54N) and OH* rotational temperatures measured at Wuppertal (51N) in combination with meteor decay times obtained at Juliusruh (55N). Mean temperatures are daily averages, or even 2 or 3 day averages.

The second method for determining temperatures uses the direct measurement of the ambipolar diffusion coefficient in conjunction with pressure data to estimate temperatures. Pressure data from empirical models are often too unreliable, therefore pressure data derived from rocket-borne falling spheres measurements are used for a reliable temperature determination. Co-located meteor radar measurements and falling sphere soundings are conducted in 2002 at Andenes (69N) and allow the estimation of meteor temperature profiles in a height range between 82 km and about 94 km.

## I.3.5 COMPARISON OF DBS AND SA WINDS: PRELIMINARY RESULTS WITH INDIAN MST RADAR

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The Indian MST radar, which is designed for Doppler beam swinging (DBS) mode is operated in spaced antenna (SA) mode on experimental basis to measure the winds in the height range of 4-10km. The array can be divided along any one of the principal directions facilitating the SA mode of operation with antenna separation either in East-West or North-South direction. The full array (32x32) is used for transmission where as the central two 8x32 modules with 32m-separation are used for reception. The single back-end of receiver is switched between the two antenna modules, which have dedicated front-ends. A coded pulse of width 16ms with a baud length of 1ms is used with an inter-pulse-period of 1ms. The signals from a single antenna module are coherently averaged over 16 pulses before the receiver is switched to the next module. A complex time series of 2048 points is recorded per frame and the data is separated in off-line processing. The 1024 points of each antenna module are again compressed to 512 by applying off-line coherent integration, which gives record length of 32s with a resolution of 0.064s. Data is collected over 42 range bins from 3.6-9.9 km height range with a resolution of 150m. The clutter signals are removed by a process of subtracting the average value from the time series data. The complex auto and cross correlation functions are computed using the time series data. The time displacements of the peaks of the cross correlation functions are used to calculate the “apparent velocity”. The apparent velocities are compared with the DBS winds obtained before and after the SA experiment. The results show good agreement for zonal component. The magnitude of SA apparent velocity is 5-15% higher than the DBS velocity for 90% of the range bins. The poor comparison between SA and DBS for the meridional component is attributed to the very low velocities (< 3m/s) and the large base line distance (32m) in the NS direction. Full correlation analysis (FCA), which gives the true velocity, is not used at present. Future SA experiments will be carried out with smaller antenna separations.

## I.3.17 SHORT PERIOD GRAVITY WAVE MAGNITUDES AT EQUATORIAL LOW LATITUDE MESOSPHERE-LOWER THERMOSPHERE (MLT) REGION

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The gravity wave influencing the dynamics of the Mesosphere Lower Thermosphere (MLT) region on the time scales of few minutes to less than an hour has been obtained using Indian MST radar data operated in meteor mode. The gravity wave periods in the zonal and meridional planes are separately obtained. Indian MST radar in its full array mode was operated and has provided the gravity wave amplitudes with the height resolution of 1.2 km and time resolution of a few seconds. The time periods (10-45 min) obtained with the zonal and meridional direction also indicates that the gravity waves grow to very greater amplitudes (4ms-1) when it reaches the lower thermosphere levels as it vertically travels from mesosphere. The variance amplitudes found in the upper mesosphere imply that the wave most often can break at 100 km level. This perhaps explains the mesospheric inversions often reported with the LIDAR temperature measurements over Gadanki.

## I.3.30 TURBULENCE STUDIES USING UHF RADAR OBSERVATIONS OVER GADANKI (13.5°N, 79.2°E)

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Wind information and doppler moments obtained from UHF radar observations for a period of one year (April 1999-March 2000) are used to study the diurnal, monthly and seasonal variation of turbulence. Turbulence studies are made using Turbulent Kinetic Energy (TKE), Spectral widths, Signal to Noise Ratio (SNR) and Refractivity Structure Constant (Cn2). From the diurnal observations TKE is found to be maximum around noon time and minimum in the night time indicating maximum turbulence in the day time. Spectral widths and SNR observations indicate the intensity of turbulence and mixing depth (height of the boundary layer) in different seasons. Peak SNR indicates the evaluation of boundary layer representing Mixing level depth or turbulent region. The peak of SNR is low during early hours after sunrise and goes on increasing with time and attains maximum around noon time, a sudden fall due to dissipation and again increasing due to Nocturnal inversion. Spectral widths and refractivity structure constant shows maximum in summer which show the intensity of the turbulence. Detailed results are given later.

## I.3.38 MESOSPHERE-LOWER THERMOSPHERE NEUTRAL WIND OBSERVATIONS USING METEOR TRACES AS TRACERS

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The Indian MST radar in meteor mode has been operated with its narrow beam configuration while the transit of intense Geominid meteor shower occurred during 13/14th December 2001. The observation was conducted with the beam width of 3° in the observational plane unlike the earlier attempts of configuring the MST radar antenna array in the wide beam mode in the orthogonal plane for meteor detection. The observation has provided the wind information with height resolution of 1.2 km and 16s time resolution for the first time in the low latitude MLT region over Gadanki (13.5° N, 79.2° E). The signal-to-noise ratios of these echoes are of the order of 30 dB and above. The winds retrieved using the Doppler shift obtained from the radar echoes are consistent and enable the estimation of gravity/tidal wave periods. This observation enunciates to have regular observations on MLT winds during meteor shower occurrences using Indian MST radar.

## I.3.501 APPLICATION OF THE UCAR-STARS METHOD TO ATMOSPHERIC SPACED ANTENNA RADARS

***Eleanor A. Praskovskaya [1], Alexander A. Praskovsky [1], Dennis M. Riggin [2] et al.***

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UCAR-STARS is a new data processing technique for spaced antenna profiling radars. The abbreviation stands for the "University Corporation for Atmospheric Research - STructure function Analysis of Received Signals". STARS is based on analysing the different order cross and auto structure functions of the received signal's power for retrieving the mean horizontal velocity components and turbulence characteristics of a scattering medium. Overview of the UCAR-STARS method is presented, and the major steps of the data analysis technique are illustrated. Examples of the STARS measurements with the NCAR Multiple Antenna Profiler at different atmospheric conditions are presented and discussed. The mean horizontal winds and turbulence intensity for all three velocity components are compared with simultaneous measurements by sonic anemometer; a reasonable agreement is found in most cases. The major focus of the paper is on the Saura and Rarotonga MF radars.
Measurements of the mean horizontal wind speed components and turbulence intensity at height from 50 km to 100 km with temporal resolution 1 - 2 min. are presented and discussed. Propagation of atmospheric waves both in horizontal and vertical directions is demonstrated. Whenever is possible, the STARS retrieved mean horizontal wind speed components are compared with those by FCA and DBS methods as well as meteor scatter radars.

# I.3.502 MEASUREMENTS OF WINDS AND MOMENTUM FLUXES IN THE MLT USING THE DUAL-BEAM SYSTEM AT ARECIBO

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A dual feed system that was made operational at Arecibo Observatory during 2001 allows the Vincent and Reid technique to be used to measure the horizontal wind (one component), the vertical wind and momentum flux. Oservations were made using the 430 MHz radar during the daylight hours of October 22-23, 2001 with an east/west viewing geometry. Data sets were obtained using the coded-long-pulse and double-pulse techniques to evaluate the optimal measurement strategy for future experiments. The observations spanned the upper mesosphere and lower thermosphere (approximately 90-140 km). Statistical uncertainties and possible biases resulting from asymmetries between the Gregorian and line-feed beams are discussed.

## I.3.504 MU RADAR ESTIMATION OF DOWNWARD TURBULENT OZONE FLUXES NEAR THE TROPOPAUSE

***Nikolai M. Gavrilov* [1] *and Shoichiro Fukao* [2]**

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A numerical simulation shows that sharp change of vertical temperature gradient near the tropopause may produce an increase in the amplitudes of IGWs propagating upward from the troposphere, wave breaking and generating of increased turbulence. This may make the middle latitude tropopause more transparent for the transport of admixtures between the troposphere and stratosphere. An increase in the turbulent diffusivities at altitudes near and above tropopause is usually observed with the MU radar in Shigaraki, Japan (35 N, 136 E). Turbulent diffusion coefficient calculated and measured with the MU radar are of 1 - 10 m$^2$/s in different seasons. They lead to the estimation of vertical ozone flux from the stratosphere to the troposphere of the order of (1 - 10)x10$^{14}$ m$^{-2}$ s$^{-1}$, which is comparable with usually supposed ozone downward transport with the general atmospheric circulation. Therefore, local enhancements of IGW intensity and turbulence at tropospheric altitudes over mountains due to their orographic excitation and due to other wave sources may lead to the changes in tropospheric ozone and the total ozone over different regions. Possibilities are considered of using simultaneous MU radar measurements of turbulent diffusivity and ozonosonde measurements for estimating of the ozone turbulent transport through the tropopause.

## I.3.505 LARGE VELOCITIES MEASURED AT MF AND HEIGHTS ABOVE 100KM: REAL OR SPURIOUS?

***Chris E. Meek***

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The MF data sets for Tromso, Platteville, Saskatoon have been scanned for large speeds (e.g. > 150 m/s); these data (particularly at Tromso) usually occur at heights greater than we normally use, and are rejected by our criteria: >170 m/s to get rid of "spurions", and sometimes reject signals at or above the max-signal-height which should get rid of oblique echoes (max gate is 133Km virtual height), and also by our virtual height limit criterion ( <= 94Km in summer, <= 105Km in winter) which is necessary to insure that the daytime and nighttime real heights are the same. After that, statistical averaging over all values (e.g. mean monthly day), minimizes their effect. Here we look at them separately, and show that they tend to occur in the daytime, usually winter late afternoon, are not spurious, and also contain a tidal signal(in seasonal averages). Data from a separate experiment (a non-coherent system run in winter 1987-88) which looked for signal peaks from ~64-350Km (virtual height) will be used to argue that we can sometimes see through the daytime E-region. Although these high speed data tend to occur in "clumps", it is difficult to estimate height shears, because the heights are still virtual, and the real height separation could be much less than the nominal gate separation.

# I.3.506 OBSERVATIONS IN THE TROPICAL TROPOPAUSE REGION WITH THE EQUATORIAL ATMOSPHERE RADAR (EAR)

***Hiroyuki Hashiguchi, Masayuki K. Yamamoto, Shoichiro Fukao et al.***

RASC, Kyoto University, Japan

Now there are many controversies about the airmass motions in the tropical tropopause layer (TTL). The Equatorial Atmosphere Radar (EAR), located at the equator in West Sumatra, Indonesia (0.2S, 100.32E, 865 m above mean sea level), is a 47-MHz clear-air Doppler radar. The EAR has observed three-dimensional wind velocities and the intensity of turbulent eddies with half the radar wavelength (about 3 m) in the troposphere and the lower stratosphere (2-20 km) since July 2001. A clear-air VHF Doppler radar receives the strong echo around the tropopause due to the rapid increase of static stability in the region. The scattered signals in the region come from the horizontally stratified echo layer (Fresnel reflection). By using these properties, we determined the tropopause height (Radar Tropical Tropopause: RTT) from the height profiles of echo power and echo power aspect ratio.

The height of RTT was compared with the height of lapse-rate tropopause determined by the radiosonde soundings at Kototabang, and its correspondence was excellent. The height of RTT was almost corresponding to the maximum of the westward wind (20-35 m/s), and the strong vertical shear of zonal wind (10-50 m/s/km) was observed in the region 0-1 km above RTT. The spectral width observed in the zonal direction (0.7-1.2 m/s in eastward beam) was greater than that in the meridional direction (0.5-0.9 m/s in northward beam), because the vertical shear of horizontal wind generates turbulence and the vertical shear of zonal wind was stronger than that of meridional wind.

Yamamoto et al. [2003] showed that vertical wind measured with the vertical beam was continuously upward in the region 0-1 km above the tropopause in November 2001, and it contained a spurious-updraft component caused by the tilted echo layer generated by the KHI billows and the strong westward wind. Upward wind is measured with the vertical wind in the region 0-1 km above the tropopause was observed throughout July-December 2001, which suggests the frequent occurrence of KHI not only in November 2001 but also in the long term. To avoid the effects of spurious vertical wind component caused by tilted echo layer generated by KHI billows and the strong westward wind, vertical wind was calculated with two symmetric meridional beams (NS vertical wind), which is little effected by the tilted echo layer and the horizontal wind to the vertical wind measurement. The NS vertical wind also showed updrafts with the magnitude of 1-5 cm/s.

## I.3.507 MERIDIONAL NEUTRAL WINDS DERIVED USING THE E REGION FIELD ALIGNED IRREGULARITIES (FAI) AS TRACERS OVER GADANKI AND A COMPARISON WITH MODEL AND HRDI DATA

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We have derived the meridional neutral winds in the E region altitudes using the field aligned irregularities observed by the Gadanki VHF radar. It may be mentioned that wind information at this height region is limited and episodical and hence continuous measurements of winds at this height region are of significant value. The observations were made along the north bearing (130 off zenith) of the Gadanki radar beam that satisfies the perpendicularity condition with the earth's magnetic field lines at E region heights. Hence, the radar detects the secondary plasma irregularities present in the meridional plane transverse to the magnetic field. For the radar geometry used here, the irregularities especially in the collision dominated E region will be driven by both meridional neutral wind and the zonal electric field. Using the dispersion relation of the gradient drift instability and model values of the collision and gyro frequencies of the electrons and ions, we have estimated the zonal electric field and meridional neutral winds. While deriving meridional neutral winds, the contribution from the zonal electric filed has been taken into consideration. The estimated winds have been compared with the model and UARS-HRDI satellite data. We found that the model wind amplitudes are quite low as compared to that observed here whereas the HRDI winds are found to be comparable. The results show that the semidiurnal component is more dominant in comparison to that of the diurnal component. We also present the seasonal characteristics of these winds.

## I.3.508 LIDAR OBSERVATIONS OF MIDDLE ATMOSPHERIC GRAVITY WAVE ACTIVITY OVER A LOW LATITUDE

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Gravity waves play a major role in transporting the momentum and energy in the middle atmosphere. These waves, having their source at lower heights, propagate upwards and deposit energy through wave breaking and dissipation process in the mesosphere, thereby significantly altering its thermal structure and wind pattern. Rayleigh Lidar, providing high resolution temperature profiles for the height range of 30-80 km, offers a valuable means to study the propagation characteristics of the gravity waves in the middle atmosphere as well as their saturation, breaking and dissipation processes. The Lidar studies of middle atmospheric gravity waves have been made mostly at mid– and high latitudes and hardly any at low latitudes.

In this paper, we present the first observations on the low latitude middle atmospheric gravity wave characteristics using the Rayleigh/Mie lidar facility established at the National MST Radar Facility, Gadanki (13.5°N; 79.2°E) under a joint programme with Communication Research Laboratory of Japan. The lidar has been operational since March 1998, collecting data on both Mie and Rayleigh channels with height and time resolutions of 300 m and 250 s respectively. The Rayleigh channel data provide high-resolution temperature profiles over the height range 30-80 km. For the present study, a running average window of 3 range bins (900 m) and 4 time samples (1000 s) has been applied before subjecting the data to wave analysis. The spectra were computed for two height ranges, 30-50 km and 50-70 km for which the signal-to-noise ratio is fairly good. The spectra cover the periods ranging 1000 s – 4.5 hours and vertical wavelengths ranging 900 m – 19.2 km. The data showing striking gravity wave activities were analyzed to obtain the frequency and wave-number spectra for four seasons, summer equinox, winter equinox, summer and winter. The time periods of propagating gravity waves are found to range 1 – 4.5 hrs and their vertical wavelengths range over 5-20 km. The seasonal dependence of gravity wave activity has shown that the activity is maximum during equinox and minimum during winter. To examine the wave saturation process, the frequency and the vertical wave number spectra have been computed. The frequency spectra followed –5/3 power law for wave periods less than ~1 hr and the wave number spectra followed –3 power law index for vertical wavelengths less than ~2 km.

## I.3.509 APPLICATION OF THE DUAL-BEAM WIDTH METHOD TO A NARROW BEAM MF RADAR FOR ESTIMATION OF SPECTRAL WIDTH

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Spectral widths observed by narrow beam VHF/UHF Doppler radars are used to estimate turbulent energy dissipation rates. In case of broader beams, the observed spectral widths have to be corrected for the influence of beam and shear broadening using simultaneously measured horizontal winds. VanZandt et al. developed a new dual-beam width method to estimate the turbulent component of spectral width from MST radar observations without any additional assumptions and tested it successfully for the troposphere.

In summer 2002 the new Saura MF radar was put into operation on the Andoya island in Norway. The system has high flexibility in antenna beam forming allowing off-zenith beams with different beam widths down to half power beam widths of 7.2°. In addition, the beam steering capabilities of the Saura MF radar and the nearby located ALWIN VHF radar provide common volume observations at mesospheric altitudes in summer during the appearance of PMSE.

Experiments with different beam widths have been carried out with the MF radar to test the dual-beam width method for mesospheric applications. We compare spectral width estimates from both the single-beam width and the dual-beam width method on a case study basis and present results of common volume observations in the VHF and MF frequency range.

# I.3.511 OBSERVATIONS OF LOW-LEVEL ATMOSPHERIC JET OVER GADANKI

***K. Chandra Reddy, D. Narayana Rao, A.R. Jain et al.***

National MST Radar Facility, India

Characteristics and evolution of the low-level jet (LLJ) over Gadanki valley have been investigated using Lower Atmospheric Wind Profiler (LAWP) winds data for the periods during April 1999 to September 2000.

It is found that the maximum wind speed (the jet speed) varied from 12 to 25 m s-1 at the height range around 2 km. It is persistied for more than 5 days. Low level jet extention can be seen from 1 – 4 km at the peak of the event. The low-level jets exhibit significant diurnal variation. LLJ showing wave like nature along with wind speed and direction were relatively constant in the core region. The generation, maintenance, and strength of the LLJ are very sensitive to the parameterization of turbulent mixing in the Boundary layer. thus, the Turbulent Kinetic Energy (TKE) and the magnitude of the turbulent fluxes associated with LLJ are presented. The effects of the LLJ with boundary layer depth and synoptic-scale flow are also studied.

# ABSTRACTS

## Session I.4: Meteorological Phenomena and Applications

This session is concerned with recent developments in Doppler radar profiling in the lower neutral atmosphere, especially studies of lower atmospheric phenomena made with profilers in combination with other instruments during field campaigns. Topics of interest include the assimilation of profiler data in meteorological models, quality control of profiler data, operational networks of profilers and the impact of profiler data on forecasting. Of special interest are studies that demonstrate the utility of profiling for quantifying the vertical structure of turbulence, humidity, cloud and precipitation fields including drop size distributions and their variability

Conveners:
*K. Gage and D. Riggin*

## I.4.1 IMPROVING MESOSCALE ANALYSIS AND PREDICTION USING WIND PROFILER DATA

***Steven E. Koch***

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The ability to operationally detect mesoscale phenomena with scales of several hundred kilometers and a few hours has been made possible by the NOAA Profiler Network (NPN) over the central United States since the early 1990s. These “clear-air” Doppler profilers operating at a frequency of 404.37 MHz measure radial velocities at 36 gates along one vertical and two off-vertical beams with a vertical spacing of 250 m and 1000 m in the “low” and “high” modes, respectively. The low mode provides measurements from 0.50 to 9.25 km and the high mode from 7.50 to 16.25 km every 6 min. The NPN data have proven to be extremely useful in weather forecasting through its display on the Advanced Weather Interactive Processing System (AWIPS), which is the primary means by which operational weather forecasters examine NPN data. These profiler data also positively impact mesoscale numerical weather prediction models, notably the Rapid Update Cycle (RUC) running operationally at the National Centers for Environmental Prediction (NCEP). This presentation will show current capabilities on AWIPS for displaying profiler data, then presents several promising new methods for mesoscale analysis and display, and ends with a brief review of the impacts of profiler data on RUC analyses and forecasts.

Although the AWIPS displays are useful, they are inadequate for determining the vertical structure and dynamics of mesoscale phenomena, such as fronts and gravity waves. In addition, no knowledge is obtainable from these displays about the thermodynamic and mass fields associated with mesoscale features. One of the new methods proposed for operational consideration is two-dimensional vertical circulation analysis computed from single profiler time-height displays. This technique includes a novel method for synthesizing the vertical beam and kinematic estimates of vertical motion in regions of identified hydrometeor contamination. A second new technique is simple thermal advection retrieval from a single profiler (or Doppler radar VAD) display, and its application to the identification of cold fronts aloft. The third method to be mentioned in this presentation is a full thermodynamic retrieval performed upon a network of VHF profilers using the divergence equation to provide meaningful mesoscale fields of geopotential height and temperature. This method allows for mass changes related to ageostrophic motions in the retrieval. The presentation will end with a briefing on the impact of NPN data on the RUC model forecasts of winds. Sensitivity studies performed at the Forecast Systems Laboratory show that profiler impact is pronounced at all levels below the flight-level of commercial jet aircraft, and increases with decreasing forecast period and size of the domain. These results suggest that a truly national network of VHF profilers would produce positive impacts for longer periods of time and over larger areas.

## I.4.3 MESOSCALE ALPINE PROGRAMME (MAP): SYNERGIES BETWEEN WIND PROFILERS AND DOPPLER WEATHER RADARS

***Monique Petitdidier [1], Vladislav Klaus [2] and Pierre Tabary [2]***

[1]CNRS/CETP, France
[2]Meteo France, France

During the Mesoscale Alpine Programme experiment (MAP), UHF and VHF wind profilers were installed in a zone scanned by the weather radars. In the case of convection or cloud, the profilers provide a time-height representation of the advected cloud system that can be hard to interpret because the internal evolution of the system is likely to be important.
Synergy between Doppler weather radars and wind profiler was explored in two ways using MAP experiment data. Petitdidier at al.(2000) pointed out the interest to include in a Dual-Doppler wind synthesis VHF wind profile data. Tabary and Petitdidier (2001) used VHF radar data to validate a new VAD algorithm. From the profile intercomparison, are deduced orographic characteristics of the wind direction during 12 days out of 10 Intensive Observing Periods (IOP), characterized with precipitations on the Lago Maggiore zone(Tabary and Petitdidier, 2002).
In the paper, we take advantage of common observing volumes of the Monte Lema Doppler weather radar (ML) and the VHF wind profiler to study the VHF vertical-beam echoes. The Doppler weather radar provides the reflectivity at different elevations over a range of several tens kilometres. In the ML data reduction, an average reflectivity is computed over the VHF location and Monte Lema radar, and the number of cells covered by the cloud. Radiosoundings were also included. The first interest is to observe what happened above the wind profiler and the evolution. The second interest is to interpret the VHF vertical-beam echoes in particular the effects of humidity, precipitation and convection.

## I.4.4 MESO-ALPHA-SCALE WIND FIELD AND PRECIPITATING CLOUDS IN TYPHOON 9426 (ORCHID) OBSERVED BY THE MU RADAR

***Yoshiaki Shibagaki [1], Manabu D. Yamanaka [2], Minori K. Fukase [3] et al.***

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A general structure of Typhoon 9426 (Orchid) up to the lower stratosphere including the inner core region was observed by the MU (middle and upper atmosphere) radar in 29-30 September 1994.

In this study, a meso-alpha-scale wind field and meso-beta and -gamma scale features of precipitating clouds in the typhoon were investigated. The kinematic structure in the front and rear of the typhoon was quite different because of its transition from mature to decaying stages and an asymmetric distribution of cloud and precipitation.

In front of the typhoon, the meso-alpha-scale wind field was characterized by a cyclonic rotation with the maximum at low level, outflow regions tilted outward with height, and vertical motions affected by convection and topography. In the vicinity of the typhoon center, the tangential wind had a vertical spiral structure for the center, considered to be resulted from deformation of the center of the decaying typhoon.

In the rear of the typhoon without precipitating clouds, the cyclonic wind became weak, and the outflows and vertical motions as seen in the front were not detected. In front of the typhoon, an eyewall and wide rainband were observed. In the eyewall, a meso-gamma-scale remarkable updraft associated with an outflow region, considered to be a part of vertical circulation, was found in the upper troposhere. The outflow region tilted outward was originated from the area of maximum radial shear of the low-level cyclonic wind. It was extended to an updraft region within an upper-level band-shaped cloud, located far from the typhoon center. The wide rainband (50-70 km width) was located at the outer edge of the band-shaped cloud, and it lasted in the development of the upper-level cloud. It was accompanied by the tilted outflow region to 6 km altitude, the bottom of which was located at the maximum of the cyclonic wind. A narrow rainband (20-40 km width) that a lifetime was quite short (1.5 hours) was also observed by the boundary layer radar (BLR) at another site. An outflow region with the tilted structure was present in the outer part (convective portion) of the rainband, and its bottom was not associated with strong cyclonic wind as seen in the wide rainband.

## I.4.6 RANGE, RESOLUTION, AND SAMPLING

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The processing of MST radar signals sampled at a given range has been discussed extensively in the literature. These topics include time-domain averaging of the signal, calculation of the average power spectra, and estimation of the moments of the signal in order to measure parameters such as reflectivity and radial velocity. The procedures for combining the sampled parameters to create parameter profiles in range are not as well defined.

The range response to the atmosphere of an MST radar is determined in large part by the range-weighting function of the instrument. This function is determined by the transmitted pulse length and the receiver bandwidth, and can be used to define the range resolution of the radar system. The range-dependent signal out of the radar receiver is sampled at different times to obtain the data from each range. The spacing of these samples is often set to be the pulse length, so that the data from each range sample is independent of the other samples. When one examines the output of the receiver with the idea of sampling in range so that one can reconstruct the signal in range, then the Nyquist criteria suggests that the sample spacing should be two or more samples every pulse length, or what is sometimes called "over-sampling". These ideas are explored using a simulation of the radar response and radar data.

This discussion has applications in several areas of profiling, such as interpolation of the wind profiles to uniform vertical grids, the use of height continuity for signal quality control, and studies of the vertical structure of the atmosphere. There are also other related applications such as studies of the differential phase shift of radar signals in precipitation where the understanding of sampling in range is important.

# I.4.16 AN OBSERVATIONAL STUDY ON INTRASEASONAL VARIATIONS WITH EQUATORIAL ATMOSPHERE RADAR(EAR) IN WEST SUMATERA, INDONESIA

***Hiroyuki Hashiguchi, Tri H. Seto, Shoichiro Fukao et al.***

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The equatorial atmosphere over Indonesia seems to play an important role upon global change of the earth's atmosphere. In order to observe the phenomena in the whole troposphere and the lower stratosphere (2-20km) in the equatorial region, we installed the equatorial atmosphere radar (EAR) in Kototabang, West Sumatera, Indonesia(0.20S, 100.32E). The EAR has good time and height resolutions of about 85 sec and 150 m, respectively, and has been continuously operated since July 2001. Intraseasonal variations, which is one of the most dominant variations in the tropics, has be studied using the EAR in Indonesia. Eastward propagating super cloud cluster (SCC) known as intraseasonal variation (ISV) or Madden Julian oscillation (MJO) clearly appeared in GMS IR data (TBB) over the radar site(0.2S) during June 2002. There was a good correlation between TBB and 2-4 km averaged daily zonal wind obtained with the EAR on that period. Namely, when enhanced convection existed in the west side of the EAR site, easterlies or weak westerlies were observed with the EAR, and conversely when enhanced convection was situated in the east side of the EAR site, westerlies were observed. We investigated the relation between 2-4 km averaged zonal wind and variance of vertical wind obtained with the EAR. Strong variance of vertical wind was observed when easterlies or weak westerlies were observed, and conversely weak variance of vertical wind was observed during strong westerlies. Regardless of the direction of 2-4 km averaged zonal wind, variance of vertical winds weakened above the tropopause height (about 16 km).

## I.4.9 A COMPREHENSIVE STUDY ON TROPICAL MESOSCALE CONVECTIVE SYSTEMS USING VHF AND UHF RADARS OVER A TROPICAL STATION

***Karanam Kishore Kumar and A.R. Jain***

National MST Radar Facility, India

A large number of recent observational studies of mesoscale systems have been signifying a renewed interest in tropical mesoscale convective systems (TMCS) and their impact on general atmospheric circulation and hence the global climate. There is a need to thoroughly understand each and every physical process associated with these systems, so that one can exactly parameterize them for improved numerical weather models. Thus, a need of global climatology of the convective systems has been driving many research groups across the globe to carry out various experiments to explore such systems. In this regard, several campaigns have been carried out to study the convective systems over Gadanki (13.5°N, 79.2°E), a tropical station in India, using VHF and UHF radars. Structure and Dynamics of the convective systems are among the central objectives of these campaigns.

The height-time sections of several convective systems are studied to explore their reflectivity, turbulence and vertical velocity structure. The observed systems are classified into single, multi and super cell systems and height- time sections of the same are presented. It has been observed that most of the convective systems at this latitude are multi cell systems. It has been noted that the vertical velocity cores play a significant role in providing heavy rainfall observed at the surface. Simultaneous VHF and UHF radar data are used to classify the observed precipitating systems as convective, transition and stratiform regions. Composite height profiles of vertical velocities in these regions were obtained and the same were compared with the profiles obtained at other geographical locations. These composite profiles of vertical velocity in the convective region of TMCS have shown their peak in the mid troposphere indicating that the maximum latent heat being released at those height regions. These profiles are very important for numerical simulations of the convective systems, which vary significantly from one geographical location to the other.

## I.4.10 VHF RADAR REFLECTIVITY AND RAINFALL RATE DURING TYPHOON PASSAGES OVER TAIWAN

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During September and October 2002 three typhoons passed the island of Taiwan. The Chung-Li VHF radar was operated continuously during most of these events. We will discuss the radar reflectivity structures, which differ significantly between these typhoons. We often find periodically recurring convection episodes in the meso-beta scale, which reach up to the middle and partially upper troposphere. Additionally the rainfall rate was measured and we compare this with the radar reflectivity and vertical velocity due to convection, measured with the radar.

# I.4.11 VERTICAL STRUCTURE OF RAIN DROP SIZE DISTRIBUTIONS RETRIEVED FROM PROFILER OBSERVATIONS

***Christopher R. Williams [1] and Kenneth S. Gage [2]***

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The vertical structure of reflectivity provides important information on the dynamical and microphysical processes of precipitating cloud systems. In Tropical precipitation, the reflectivity vertical structure can be used to identify the range of precipitation processes from the young, dynamically vigorous cells to the mature, brightband resolved stratiform rain. Vertically pointing Doppler profiling radars provide high vertical resolution observations of the precipitating cloud systems that advect overhead. When they are deployed in the Tropics for long periods of time (for seasons and years), the profilers sample the wide range of precipitation systems that are present in that region.

Methods have been developed that estimate the rain drop size distribution (DSD) from the observed Doppler velocity spectra measured by vertically pointing profilers. The uncertainties of these retrievals are dependent on the uncertainties of the vertical air motions during the observations. Thus, DSD retrievals during stratiform rain have smaller uncertainties than retrievals during convective rain.

A UHF profiler (915 MHz) was placed on the island of Legan located on the Kwajalein atoll in the Marshall Islands from July 1999 through February 2003. Analyses of the first year of observations indicate that the vertical structure of reflectivity and DSDs are different for convective and stratiform rain. For convective rain (~6,600 profiles with rain at the surface), the mean reflectivity decreases by about 4 dBZ from the surface to 3.5 km, and the mean rain drop diameter, Dm, decreases by about 0.5 mm from the surface to 3.5 km. For stratiform rain (~5,400 profiles with rain at the surface), the mean reflectivity increases by about 1 dBZ from the surface to 3.5 km, and the mean rain drop diameter is nearly constant with altitude.

A description of the DSD retrieval methodology using profiler observations and the analysis of the vertical structure from convective and stratiform rain regimes observed at Legan Island will be presented at the conference.

## I.4.12 DERIVING DROP SIZE DISTRIBUTION FROM VHF AND UHF DOPPLER RADAR SPECTRA

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VHF and UHF Radars operating at 53 MHz and 1357 MHz are used to retrieve Drop Size Distribution from a long lasting rainfall event observed in Gadanki (13.5°N, 79.2°E) during the period 1999-2000. Sensitive VHF Doppler radars have a capability to detect echoes from both refractive index irregularities and precipitation particles. The UHF radars are highly sensitive to precipitation echoes. Clear air velocity information is retrieved from VHF radar. The purpose of this paper is to estimate the Drop size distribution N(D), the mean vertical velocity and turbulence using Doppler spectra obtained by VHF Doppler radar. We estimated turbulence as well as the mean vertical velocity, the N(D) parameters, deduced from a least-squares fit approach.

## I.4.13 RAINDROP SIZE CHARACTERISTICS OF AUSTRALIAN CLOUDS

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A calibrated boundary-layer wind profiler operating at VHF is used to retrieve the characteristics of precipitating clouds observed at Buckland Park, South Australia. These retrievals are made at heights ranging from as low as 600 m above the ground to the freezing level. Time resolution of the data ranges from 1 to 4 minutes, depending on the case. A Fourier-transform based deconvolution routine is used to make the retrievals. Other instrumentation at the site includes a disdrometer, 2 tipping bucket rain gauges and an automatic weather station.

A variety of precipitation types have been observed with the radar, ranging from heavy convective showers and mesoscale convective systems to lightly raining stratocumulus clouds. The retrievals from the radar reveal the vertical structure of the precipitation as it forms, evolves and decays, including the effects of size sorting.

The results from the lowest available range gate of the radar are compared to the disdrometer to determine the accuracy of the precipitation retrievals. Preliminary results suggest the slopes of an exponential fit for the radar data are too large, a result of the wide spectral widths in many of the cases. This result agrees with retrievals performed on simulated spectra.

# I.4.14 MICROPHYSICAL AND KINEMATIC CHARACTERISTICS OF MONSOON PRECIPITATING CLOUDS USING WIND PROFILERS AND DISDROMETER AT GADANKI, INDIA

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This paper describes research on the microphysical (i.e., drop size distributions) and kinematic (i.e., vertical air motion) properties of precipitating cloud systems using co-located 135.7 MHz-lower atmospheric wind profiler (LAWP) and 53-MHz Indian MST Radar measurements at Gadanki, India. We developed “parametric moment” method (based on non-linear least square fitting procedure) to retrieve both the vertical air motions and the drop size distribution parameters from the VHF wind profiler data. The model uses the Indian MST radar data to extract the clear air vertical velocity information and to isolate the portion of the spectra associated with precipitation scatter. The model then examines the UHF data to fit the precipitation component of the spectra with an assumed functional form (i.e., Gamma and Exponential). Along with the raindrop size distribution (DSD) parameter, reflectivity, liquid water content, and rain rate can be retrieved. The VHF/UHF wind profiler, AWS, disdrometer and optical rain gauge data collected from September 1997 – August 2000 has been utilized for the present study. Results indicate that the wind profiler retrieved DSD closely match independent DSD measurements from disdrometer at Gadanki, suggesting that the profiler technique could be used to calibrate scanning radar estimates of rainfall (i.e., Z-R techniques). Moreover, because the profiler technique can retrieve the vertical structure of microphysical and kinematic parameters, the effect of precipitating clouds on the larger scale environment can be estimated through diabatic heating and moistening rates. Such information can provide critical ground truth for future space-borne platforms (e.g., GPM) that will attempt to measure the spatial and temporal variability of rainfall and latent heat production. We developed an algorithm based on Williams et al (1995) to classify the precipitating clouds into three (Convective, Transition and Stratiform) categories. Diurnal variations of the occurrence of precipitating clouds over Gadanki showed that the precipitation occurs in the afternoon and the peak of the stratiform cloud comes after the peak of the convective cloud. The precipitating cloud systems, which occur in the early morning, are dominated by stratiform cloud. Concerning seasonal variations of the precipitating clouds, we found that the occurrence of the stratiform precipitating clouds are more frequent in NE (October- December) monsoon, while the occurrence of convective precipitating clouds are predominant in SW (July-September) monsoon. Wind profiler and disdrometer analysis/results shows clear seasonal dependence raindrop size distribution characteristics in SW monsoon and NE monsoon periods over Southern India. We also found that during SW monsoon precipitation generally have more big drops than in NE monsoon. During the SW monsoon most of the precipitating cloud systems are associated with lightening and mesoscale convection activities and also short lived (~ 1 – 2 hours) with high intensity of rainfall. Whereas NE Monsoon cloud systems are cyclonic in nature and occurrence of stratiform precipitation is dominant.

# I.4.505 RAINDROP SIZE DISTRIBUTION ESTIMATED FROM THE EAR OBSERVATION IN INDONESIA

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In recent years, several techniques have been developed to estimate raindrop size distribution from the echo power spectrum obtained with VHF radar. It has been demonstrated that the VHF Doppler radars are capable of simultaneously detecting two distinct echoes, one from the clear-air turbulence and the other from hydrometeors. EAR (Equatorial Atmosphere Radar) has been operated in Indonesia almost continously since its installation in June 2001. Observation of rainfall parameters in maritime continents is very essential for the study of microphysics within the tropical convection. In this paper, vertical profiles of raindrop size distribution are estimated from the EAR observation, using a non-linear least-square fitting technique. Preliminary results will be presented.

## I.4.503 CONTINUOUS OBSERVATIONS OF HUMIDITY PROFILES WITH THE MU RADAR-RASS

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In this study a radar remote-sensing technique of a humidity profile is improved in order to determine continuous time-height variations of humidity. The volume reflectivity and turbulence energy dissipation rate were measured with the MU radar for 7 days in July, 1999. Temperature profiles were also provided by combining the RASS technique with the MU radar. Profiles of the water vapor mixing ratio were estimated by solving a differential equation of mixing ratio versus height. We have modified the method by Tsuda et al., (2001) so as to achieve a continuous monitoring of humidity profiles. incorporated in the retrieval algorithm constraint of integrated water vapor referring to simultaneous GPS measurement. The inferred humidity profiles agreed well with simultaneous radiosonde results at 1.5-7.5 km. The radar-derived humidity fluctuated with a typical time scale of a few hours which cannot be resolved with radiosondes. The time-height structure of the radar-derived humidity was investigated by referring to meteorological radar results. The behaviour of rain clouds passed over or near to the MU radar coincided well with rising radar-derived humidity. We are applying our technique to a boundary layer radar (BLR) which covers 0.2-2 km height. A combined BLR and a VHF radar such as the MU radar or the Equatorial Atmosphere Radar (EAR) observation will provide an entire profile of humidity. This new aspect of the study is also described.

## I.4.17 TROPOSPHERIC WIND MEASUREMMENTS WITH THE PIURA BOUNDARY LAYER RADAR DURING EXTREME RAINFALL EVENTS IN 2002

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For the purpose of understanding the atmospheric conditions during extreme rainfall events in Piura, manifested on instantaneous river discharge records during the period March-April 2002, the horizontal and vertical wind measured with the troposphere boundary layer radar (BLTR) were selected to describe its time evolution during these events. The results were compared with the analysis made for dry days.

A systematic difference was sought, particularly in the hours preceeding the rain, as this information could be useful for forecast purposes. The results from these analysis were then compared with numerical simulations made with PennState/NCAR Mesoscale Model version 5 (MM5), to understand the three dimensional flow structure related to the profiles observed by the BLTR.

# I.4.18 FOEHN IN THE RHINE VALLEY AS SEEN BY A WIND-PROFILER-RASS SYSTEM AND COMPARISON WITH THE NONHYDROSTATIC MODEL MESO-NH

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One of the scientific objectives of the Meso-scale Alpine Programme (MAP) addressed the four-dimensional variability of the Foehn flow in the Rhine valley. of special interest was the investigation of the dynamical processes which determine the spatial extension and the temporal variation of the Foehn. The experiment was conducted from Sept.7th to Nov.15th 1999, including 10 intensive observing periods (IOP) with Foehn. The following unique observing network was deployed:
- 9 radio sounding stations with three hourly soundings launched during the IOPs.
- 2 wind profilers, one with RASS,continuous operation.
- 3 sodar,continuous operation.
- 2 lidar,
- 2 aircraft,
- numerious automatic and micro-meteorological stations for meteorological and chemical measurements,
- special instrumentation like a scintillometer, constant level balloons, one tethersonde, a cable car sonde and several video and photo cameras.

Results of one of the major Foehn events (IOP 15, 4. - 6. Nov. 1999) will be presented in a more detailed view. This Foehn episode lasted more than two days and the Foehn wind was descending slowly but steadily from higher altitudes (> 2000 m) down to the valley floor pushing away the cold air pool shortly before the sudden end of the Foehn.

Our paper will be devided into two parts: Part 1 presents the description of our Profiler-RASS system. It has a 5-beam geometry for two bistatic radiofrequency (rf) and for one acoustic (a) antennas. The rf and a antennas are emitting continuous waves that are frequency modulated with a saw tooth (FM-CW-Doppler-RADAR), to provide high average transmitted power. Thanks to this unique technical design redundant wind profiles are derived for both the clear air and the RASS signal with high resolution in time and height. The temperature profiles are estimated simultaneously from the RASS signal.
Part 2 is devoted to the introduction of the model design of the non hydrostatic model MESO-NH and the comparison of the simulation to the observations. With two nested models (mesh 10 and 2.5 km) in a two way interactive mode, the descent of the simulated Foehn air near the valley floor agrees very well, although the simulated depth of the cold pool is too thin. Different initializations and an additional third model (mesh 625m) are tested to better simulate the cold pool and the arrival of the Foehn at the ground.

## I.4.19 STUDY OF A MESOSCALE LAND-TO-SEA LOW-LEVEL JET WITH A NETWORK OF UHF WIND PROFILERS: CASES OF THE MISTRAL WIND

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The Mistral is a frequent wind, usually strong, blowing in southeastern France and in the northwestern Mediterranean sea area. It occurs in synoptic situations roughly characterized by a northwersterly or northly horizontal pressure gradient. Cold and dry air mass, channelled within the Rhône valley axis (located between two major mountain ranges), reaches the so called French Riviera coastal area and accelerates above the sea while rotating eastward around the Genoa Gulf low-pressure center. The Mistral influence can extend up to the middle troposphere but maximum wind speed, usually between 20 and 50 m/s, is observed in the 500-1500 m-altitude atmospheric layer. This feature allows the Mistral to be considered as a low-level jet. Moreover, its horizontal, vertical and temporal variabilities are typically at mesoscales. Up to now, to our knowledge, despite the strong impact of this wind regime for the meteorology of the concerned areas, the temporal evolution of its vertical structure above the coastal region has never been considered. Two recent field campaigns, MAP (fall 1999) and ESCOMPTE (summer 2001), give us the opportunity to carry out such a study mainly thanks to a UHF wind-profilers mesoscale network deployed near the Mediterranean coast. UHF radars provide vertical profiles, from about 100 m up to 2-4 km with a 75-m and a 5-min vertical and time resolutions, respectively, and allow the atmospheric boundary layer (ABL) vertical structure to be investigated. Therefore, they are very well suited for the investigation of the low-level mesoscale dynamic aspects of the Mistral. Our purpose here, is to present and to analyse UHF radar data obtained during six cases of Mistral in order to (1) verify some basic knowledges of this wind regime, (2) better understand the mechanisms leading to the temporal variability, sometimes very rapid, of its vertical structure, (3) show its interactions with the ABL and (4) present the first results of comparisons with mesoscale model simulations. Our main results can be summarized as follows.
(1) The eastward rotation of the wind between the Rhône valley exit and 80 km to the east along the coast is observed and, as expected in such coastal areas, the air masses are found to be globally subsident. Strong differences in wind observations made simultaneously by radars installed 10 to 50 km apart prove the mesoscale aspect of the Mistral.
(2) At least in two cases, the upper limit of the Mistral goes from 3-4 km (deep Mistral) down to 1 km (shallow Mistral). This behaviour is attributed to variations of the dynamic and orographic upstream conditions. Our observations are compatible with a downslope wind due to the air mass passage over the upstream main obstacles.
(3) UHF radars measurements allow turbulent parameter to be calculated, i.e. the $C_N^2$ from the reflectivity and the turbulent dissipation ratefrom the Doppler peak spectral width. The temporal evolution of the ABL height can be derived from these parameters. Preliminary observations suggest that, even in warm summer cases for which the ground heating is intense, the Mistral modifies the expected ABL structure.
(4) A comparison between UHF radar wind data and wind simulations made by the French non-hydrostatic mesoscale model, meso-NH, has been made for the strongest Mistral case. The Mistral occurrence and the wind strengths and directions are well reproduced by the model, a deep-to-shallow Mistral transition is well simulated but much later than observed and the duration of the regime is strongly overestimated by the model. The explanations for the discrepancies are still to be investigated.

# I.4.20 RADAR OBSERVATIONS OF INERTIA-GRAVITY WAVES OVER NORTHERN GERMANY

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An inertia-gravity wave event over Northern Germany between the 17 and the 19 December 1999 is investigated. It has been recently shown (Peters et al, 2003), that these waves are generated by an upper tropospheric jet in connection with a poleward Rossby wave breaking event. The properties of the inertia gravity waves are analysed by continuous VHF radar measurements with the OSWIN radar at Kühlungsborn (54.1°N, 11.8°E) and supplemented by a series of 3 hrly-radiosonde ascents. The diagnostic results based on a linear theory show a characteristic horizontal wavelength of about 890 km and a vertical wavelength of about 2-3 km in the stratosphere and about 3.3 km in the troposphere. In addition, the spatial structure of these waves is studied with help of the data of the 482 MHz wind profiler at Lindenberg (52.2°N, 14.1°E), separated by about 300 km from the Kühlungsborn radar. Based on wavelet transformations of both data sets, the dominant vertical wavelengths for constant times as well as the dominant periods for constant altitudes are comparable. Temporal and spatial differences of the observed waves are discussed using the results of complex cross-spectral analyses of the results of both radars.

# I.4.21 WIND PROFILER AND TOWER OBSERVATIONS OF GRAVITY CURRENT AND RELATED SOLITARY WAVE

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Gravity currents are ubiquitous mesoscale phenomena in the atmosphere, for example, land- and sea-breezes, gust front and katabatic flow are types of gravity currents. Haase and Smith (1989)showed a prefrontal near-surface stable layer that is as deep as the gravity current can support the generation of a deep vertical propagating wave by the collision with the gravity current. In that case, the gravity current head separates from the feeder flow to form waves, and the wave disturbance is moving faster than its parent gravity current. These waves are weakly nonlinear waves and are classified into two types, bore and solitary wave. We observed a katabatic flow with a wind profiler/RASS and a meteorological tower on 30 Dec.1997 (Adachi and Kobayashi,2000, MST-9).The distance between the profiler and the tower is less than 300 m. This study is to investigate the gravity current in the katabatic flow and a solitary wave which was observed ahead of the gravity current.

Observation
Time-height cross sections of wind vectors and temperature derived from wind profiler /RASS and tower associated with the gravity current are indicated in Fig.1.ind direction was easterly (from the ocean)up to about 500 m and the temperature at the surface was about 6 °C until about 16 Z. The wind direction changed to northwest after 16 Z and surface temperature decreased to 4 °C. This figure also shows that the depth of this gravity current is about 100 m, and the near-surface inversion layer (stable-layer)ahead of the front is as deep as a gravity current. The front-normal winds relative to the motion of the front measured with the tower are shown in Fig.2.Also shown in the display is the contoured and shaded (>6 °C)temperature field. Front passage is characterized by a convergence in the front-normal wind component at 16 Z, and the contour of 0 m/s is almost accordance with the contour of 6 °C. This figure also depicts the "nose "of the gravity current as indicated by Simpson et al.(1977),but the "head " is not clear.. The vector field obtained by combining the front-relative wind and vertical motion components derived from tower, and the wind profiler is presented in Fig.3.Dark shaded areas show upward air motions (>0.1 m/s)and white areas show downward air motions or no measurement because of RASS observation. The wave from 16:20 Z to 16:40 at an altitude of 150 m is the KH wave because the Ri in this region is less than 0.25 (not shown),while the strong vertical air motions from 16:00 Z to 16:15 Z result from the conflict between the gravity current and the stable layer ahead of the front as documented by Jin et al.(1996).This figure also depicts the upward air motion aloft at 15:45.This air motion is trustable, because both the tower and the wind profiler observed it simultaneously. Moreover, the time trace of surface pressure depicts a pressure elevation at that time as denoted by an arrow in Fig.4.These features well agree with the solitary wave simulated by Rottman and Einaudi (1993).

Conclusion
We observed the gravity current with the wind profier/RASS and the tower. The two-dimensional flow and the surface pressure trace show that there was a solitary wave ahead of the gravity current. This solitary wave is classified into the BDO type, because the maximum of the vertical air motion occurs at the top of the region (Rottman and Einaudi,1993).

## I.4.22 ADVANCED MEASUREMENTS OF ATMOSPHERIC TURBULENCE WITH SPACED ANTENNA PROFILING RADARS: THE FIRST RESULTS

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The UCAR-STARS method is applied to spaced antenna profiling radars for retrieving the mean horizontal wind speed components and turbulence characteristics of a scattering medium. Intensity of three turbulence velocity components $s_u$, $s_v$, $s_w$, and the horizontal shear are estimated.

The wind and turbulence measurements are demonstrated for the NCAR Multiple Antenna Profiler (MAPR). Measurements are executed for 16 and 23 November, 1998 at temporal resolution 34 s. Experimental errors of estimates are presented as well. The STARS results at 300 m above ground are further averaged over 5 min. interval and compared with those from a sonic anemometer and the FCA method. Good agreement is demostrated in most cases.

## I.4.23 THE INCLINATION OF REFLECTIVITY STRATIFICATIONS

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It is commonly known that VHF radars observe thin laminae of refractivity structures (reflectivity stratifications). Spatial interferometry shows that these laminae are frequently not horizontally stratified. This can be particularly pronounced during mountain lee wave events, but also occur very regularly in synoptic-scale disturbances. We discuss the different scenarios of inclination angle and measured velocity component when: (1) The scattering/reflecting layer, i.e. a lamina of changes in refractivity, is aligned on an isentrope (constant level of potential temperature) and the streamline of airflow is along the isentrope, (2) the lamina is not aligned on the isentrope and the streamline is parallel to the isentrope, and (3) the lamina is aligned on the isentrope but the streamline is not parallel to the isentrope. Which of these scenarios is occurring in reality determines the accuracy of velocity measurements with MST radar.

## I.4.24 ESTIMATION OF MOMENTUM AND VIRTUAL SENSIBLE HEAT TURBULENT FLUXES WITH AN UHF/RASS WIND PROFILER. COMPARISON WITH IN SITU MEASUREMENTS

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UHF wind profiler has proved to be a very useful tool for the investigation of the convective Atmospheric Boundary Layer (ABL) with a very good temporal and vertical resolution. Previous studies have demonstrated its ability to retrieve wind velocity field and mixing height. UHF Doppler spectral width contains another important information about the structure of the ABL related to the dynamic turbulent mixing. When equipped with RASS, making use of the interaction between radio and acoustic wave, a UHF-RASS system can provide vertical profiles of the air virtual temperature. The spectral width of the "acoustic echo" contains also an important information on turbulent thermal fluxes. We present some results on the retrieval of dynamic and thermal fluxes mainly based on the two types of spectral widths.

First, momentum fluxes are evaluated using a four-beam observation method. They are deduced from the combination of wind velocity spectral width measurements obtained by two opposite beams. Second, we have investigated several possibilities to evaluate the vertical virtual sensible heat flux using the height of the boundary layer, the temperature, the spectral width of the vertical velocity and of the "acoustic echo" deduced from the UHF-RASS profiler.

In situ measurements obtained from tall masts and aircraft flights during several field campaigns are used to validate the results attached to these different remote sensing techniques.

## I.4.501 TYPHOON SPIRAL BAND STRUCTURES OBSERVED WITH A WIND PROFILER NETWORK

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We have investigated the characteristics of the wind behavior associated with Typhoon 0221 (Higos), which was observed with the wind profiler network and DATA acquisition system (WINDAS), which consists of 25 L-band boundary layer radars (BLRs), of Japan Meteorological Agency (JMA) and a L-band BLR of Communications Research Laboratory, simultaneously. This typhoon passed FROM the south of Japan to the north along the east side of Japan islands, and landed at 20 LST (11 UTC) on October 1, 2002. The central pressure of this typhoon was about 960 hPa at the typhoon's landing. So the typhoon remained strongly while the typhoon passed. We found FROM the averaged horizontal winds obtained by 6 BLRs that there were inflow and outflow below and above 2 km in height during the typhoon center's approaching, and there existed outflow below 6 km in height and strong counter-clockwise winds within 300 km in distance FROM the typhoon center after the center's passing, whose features are similar to the previous results obtained by a VHF wind profiler, the MU radar. We also found that the fluctuating component of the radial wind was nearly strong around the rainbands, and the fluctuation of the wind was coming to the typhoon center with a counter-clockwise rotation. We could reveal these characteristics for the first time by using the DATA of the wind profiler network. We will discuss the relationship between this fluctuation and the rainbands and/or the moving speed of the typhoon.

## I.4.502 THE EFFECT OF PRECIPITATION ON CLEAR-AIR RETURNS OF VHF RADAR

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Several authors have recently indicated that reductions in the signal strength of clear air returns can be observed at low altitudes in regions of precipitation. This study uses data from the NERC MST radar facility in Aberystwyth (52.4°N, 4.1°W) and co-located tipping bucket rain gauge data to determine whether this effect can be observed for all periods where high rainfall rates were observed at the ground. The period selected for examination includes all of the days where a peak rainfall rate of 1mm/h was observed in 2001. The magnitude of the change in signal power and any variations in the spectral width of the Doppler spectra are also examined. Use is also made of UHF radar data and Meteosat satellite data to examine a number of interesting case studies and to better define the meteorological situation observed above the radar site. This data is further examined to determine whether the theoretical mechanisms proposed thus far can be used to explain these case studies. Finally, initial data from the Canterbury University Stratosphere Troposphere Radar (CUSTAR) at Birdlings Flat in New Zealand (44oS, 173oE) and data from nearby rain gauges is examined to determine whether the reduction observed in the signal power from clear air echoes can also be observed by this system. The effect of different signal processing schemes on the observed changes is also examined in detail. In particular the effect of the use of the Hildebrand and Sekhon method of noise level determination is studied.

# I.4.504 OBSERVATIONS OF TROPICAL PRECIPITATION SYSTEMS WITH THE EAR, BLR AND RAIN RADAR

***Yoshiaki Shibagaki [1], Toshiaki Kozu [2], Toyoshi Shimomai [2] et al.***

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The Indonesian maritime continent is one of the regions in which active convections frequently appear. To understand atmospheric wave sources and heat engines affecting the upper atmosphere and global circulation, the CPEA (Coupling Process of Equatorial Atmosphere) project started from Aug. 2001, mainly utilizing the equatorial atmosphere radar (EAR) at Kototabang, Sumatra Island.

The EAR is powerful instrument for observations of convective activity, because it has the capability of vertical profiling of wind field including vertical motion with fine resolution. Near the EAR site, a L-band boundary layer radar (BLR) and X-band rain radar have been operated.

In the simultaneous observation of these radars, the kinematic structure and behavior of precipitation systems around Kototabang were studied. We report preliminary results of the radar observation during 24 Sep-25 Nov in rainy season 2002.

In the analysis period, the easterly wind was predominant in the whole troposhere. Precipitation systems showed a diurnal variation with a peak in the evening. In the latter half of the period (24 Oct-25 Nov), they were active from the early evening to the late night almost every day. The diurnal variation of precipitation around Kototabang was related to the passage of a cloud system moving from Kalimantan Island or the east coast of Sumatra Island. When the passage time of the cloud system was the late evening, a mesoscale convective precipitation appeared in the early evening. It was accompanied by a remarkable updraft extending up to the upper troposhere. It consisted of several convective cells. While the pre-existing cell in the west part of the convective precipitation decayed, new cell formed in the east part of one. In the evolution of the convective precipitation, it moved eastward in opposite direction for the environmental wind (easterly wind). At 1-2 km in height, the BLR data presented strong westerly wind while the convective precipitation appeared. It is considered that the convective precipitation formed in the low-level convergence between the westerly wind in a local circulation and the environmental wind. Meanwhile, the abovementioned low-level westerly wind and convective precipitation did not appear when the cloud system passed in the night. In the passage of the cloud system, convective systems embedded within a wide stratiform precipitation were seen. An updraft and downdraft extending the vertical direction coexisted within the precipitation system.

## I.4.506 SEVERE WEATHER OBSERVATIONS USING VHF/UHF ATMOSPHERIC WIND ROFILERS OVER INDIA DURING 1999

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In the Indian monsoon region, an extensive study using sophisticated and collocated measurements has not been carried out to understand the mesosocale convective systems (MCS) and tropical cyclonic storm. For the first time, in India at Gadanki the collocated facility of Indian MST radar, lower atmospheric wind Profiler (LAWP), disdrometer and optical rain gauge (ORG) observations are used for understanding the severe tropical weather systems. Wind profilers can obtain only the temporal variation of the vertical profiles of wind velocities over the radar but cannot directly observe the spatial structure of the severe weather systems. Results from a variety of weather/storm systems will be shown to relate the vertical draft structure and the microphysics. The summer/winter monsoon precipitating cloud systems are associated with frontal systems, thunderstorms, cumulus convection, flow instability in the jet stream, and the interaction of airflow with topography will be discussed during presentation. Two severe cyclones were formed in the Bay of Bengal, crossed east coast (at Orissa) during the month of October 1999. These were country's worst cyclones in the recent past causing a severe damage to property and colossal loss of life. The INSAT-2E and Meteosat satellite data were also utilized for explaining the severe tropical cyclones. The first was a cyclonic storm formed in the Bay of Bengal on October 17,1999. The influence of the cyclone over Gadanki was clearly documented by the LAWP and disdrometer. Mesoscale precipitating clouds were developed due to warm moist air mass transported from the cyclone, and passed over the wind profiler site with northwesterly direction and crossed east coast of near Gopalpur (Orissa) around mid-night of October 17,1999. The second depression was formed in the Bay of Bengal on 27 October 1999 and acquired Intensity of a Super Cyclonic Storm by midnight of October 28,1999. The LAWP observations (from 27-30 Oct. 199) showed that the horizontal winds moving in a northwesterly direction and crossed Orissa coast near Paradip by forenoon of October 29, 1999. It practically remained stationary over the same area for more than 24 hours and weakened into a Cyclonic storm on 30th October evening. Thereafter this cyclone weakened and moved northeasterly and then drifted southwestwards where it slowly dissipated. During the presentation, the microphysical (i.e., drop size distributions) and kinematic (i.e., vertical air motion) properties of two tropical cyclonic storms will be discussed in detail.

## I.4.507 STUDY OF TROPICAL PRECIPITATION WITH RESPECT TO RAIN DROP SIZE DISTRIBUTION AND UHF DOPPLER RADAR SPECTRA

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In the present paper tropical precipitation characteristics have been studied using rain Drop Size Distribution (DSD) models, namely Exponential and Lognormal model and radar doppler spectra. Model coefficients have been obtained by the moments regression method using the Joss-Waldovgel Disdrometer data. Model coefficients are estimated in terms of rainfall rate (R). The models are validated using observed disdrometer DSD measurements. The chi square- error has been found out for the model estimation of rainfall rate and radar reflectivity factor for both exponential and lognormal models and it is noted that lognormal distribution result in a better fit. The relationship between rainfall rate and the various DSD moments viz., total number of drops (Nt), liquid water content (W), optical extinction coefficient (S), microwave attenuation coefficient (A) and radar reflectivity factor (Z) has been found out for convective and stratiform type of rains. The simultaneous observations of observed DSD and the vertical height profiles of the UHF /VHF Doppler radar back scattered power in terms of signal to noise ratio have been used to classify convective and stratiform type of rains. Case studies for the convective and stratiform events have been presented in detail. The dependency of the DSD model parameters such as N0, L for exponential model and Nt, m, s2 for lognormal model have been examined with respect to convective and stratiform precipitation rain events. The shape of the DSD with different types of rain has also been examined.

## I.4.508 THREE DIMENSIONAL STRUCTURE OF RAIN ASSOCIATED WITH INDIAN MONSOON DEEP CLOUD SYSTEMS OBSERVED BY TRMM PRECIPITATION RADAR AND METEOSAT

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Monsoon variability has been viewed as a manifestation of the vagaries of the deep cloud systems embedded within the Tropical Convergence Zone (TCZ). For the first time, we have an opportunity to understand the rain structure observed by the Precipitation Radar onboard TRMM in three dimensions associated with monsoon deep cloud systems both over the Indian land region and the sarrounding oceans. Composites of rain distribution in space covering the entire Indian land region, Bay of Bengal, Indian ocean and Arabian sea, have been constructed during active and break spells over which the monsoon fluctuated during 1998 and 1999. Based on such distributions crucial regions of intense rain and no rain have been identified. An attempt is being made to understand the causal factors for such disparities in the rain organization.

A striking new observation, the rapid southward propagation of deep clouds on diurnal scale embedded in the northward migrating structures of strong convection from equator to ~20N, is made for the first time over the monsoon region from an analysis of high resolution pixel observations measured by IR and WV channels onboard METEOSAT. It is inferred that diurnal wave shows out of phase relation between land and oceans and is strongest in deepest clouds over both central parts of India and Bay of Bengal.

An attempt has been made to understand the processes governing the rain occurring at various locations of the propagation of these deep cloud systems. Vertical structure of rain inferred from an analysis of TRMM Precipitation measurements show two prominent patterns of distribution in the vertical 1. rain shows an increase with height from near surface up to ~ 4 km and then a continuous decreasing trend 2. rain shows a continuous monotonic decreasing trend with heightfrom near surface in the vertical.

# I.4.509 APPLICATION OF LOWER ATMOSPHERIC WIND PROFILER FOR MONITORING MEIYU/BAIU WINDS AND PRECIPITATING CLOUD SYSTEMS

***Krishna Reddy, Biao Geng and Hiroyuki Yamada***

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For the first time Frontier Observational Research System for Global Change (FORSGC) deployed a Lower Atmospheric Wind Profiler (LAWP) with Radio acoustic sounding System (RASS) at Dongshan (31deg. 4'47" N; 120deg. 26'3" E), along with three X-band Doppler radars and three automatic weather stations for understanding the formation mechanism and the three-dimensional international structure of mesoscale convective systems traveling in the Meiyu/Baiu frontal systems in the downstream of Yangtze River. RASS-wind profiler was installed along with the Doppler radar, micro rain radar, automatic weather station in the premises of the Dongshan Meteorological Observatory, in the Jiangsu province, 80 km west of Shanghai, PR China. Dongshan site is ideal because of the surrounding vegetation and some rural houses. The site is located in the peninsula of the Taihu Lake, which is the largest in China about 2425 sq km. We operated all the instruments during two intensive observational periods (IOP) from June & July in the year 2001 and also 2002. Due to the presence of abundant amount of moisture in the lower and middle troposphere during heavy rainfall enabled good measurements up to 12 km altitude, a range much greater than the LAWP could reach in clear-air days. The two IOP data analysis suggested that the heavy (Mesosocale systems) precipitation tended to occur when the southwesterly low-level jet became strong. A series of RASS observations taken at intervals of 30 min also shows the development and structure of convection in the boundary layer. Observational results also indicate that the LAWP could help to improve the understanding of the atmospheric processes involved in severe weather during typhoon, clod front passage. On sunny days, wind profiler observational results shows that CBL height at experimental site varies between 1 and 1.55 km and the CBL evolution depends on variety of factors and is not simply related to any local surface meteorological variables. The low boundary heights at Dongshan during June and July are probably related to low Bowen ratios (ratio of sensible to latent heat flux at the surface) and very high humidity. The CBL depth also indicates the prevailing synoptic situations during the Meiyu/Baiu season. We also attempted to understand the evolution of the turbulence structure of the atmospheric boundary layer, with an emphasis on the nature of the decay of turbulence during morning and evening transition period. RASS/Wind profiler and AWS observation shows that the trigger of Gravity wave Soliton could be due to the collision between lake breeze and sea breeze within small area from inertial oscillations, baroclinity, terrain slop, radiative cooling at the surface and in the air. Gravity wave Soliton is suggested to play an important role in organization and trigger the precipitation band and CAT (Clear Air Turbulence). During the heavy rainfall it is apparent that the LAWP can be used to provide clues for the forecasting of the maximum strength of winds and the arrival times of strong winds and gales.

## I.4.510 BOUNDARY LAYER RADAR OBSERVATIONS OF BAIU-FRONTAL MESOSCALE CONVECTIVE SYSTEMS IN THE LEEWARD SIDE OF SMALL ISLANDS (KOSHIKIJIMA LINES)

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Meteorological applications of the UHF-band wind-profilers (so-called boundary layer radars) are rapidly progressed in Japan. In order to understand the structures and mechanisms of mesoscale convective systems (MCSs) associated with the Baiu front, a special observational campaigns called X-BAIU have been conducted in East China sea and Kyushu Island, located in the western part of Japan, from 1999 to 2002. We installed a boundary layer radar (BLR) at the western side of Kyushu Island to observe the inner structures of MCSs seen frequently in the observational area.
In this study, we notice line-shaped MCSs generated by some mountains of Koshiki Island, called "Koshikijima line", and reveal vertical profiles of wind and stability by using the BLR and GPS-sonde soundings. While the Koshikijima line is observed, Kyushu Island is located in the warm sector of a cyclone, and covered by southwesterly winds and a moist convectively unstable atomosphere associated with the cyclone. The direction of the line extends to the leeward of the mountains (Koshiki Islands), and the line lasts for about half a day with the development and weakening. From the results observed by the BLR, we find that the vertical shear of horizontal wind, especially of the component normal to the line, is about 3 m/s/km or larger without depending upon whether the Koshikijima line exists or not. We have observed Koshikijima lines also in 1999, of which the development is much larger than that in 2002. Differences between the cases in 1999 and in 2002 are found in relative humidity and horizontal wind speed. In 2002, relative humidity and horizontal wind speed in the lower troposphere below about 3km altitude are about 80 percent and 20 m/s, respectively, which are both smaller than those in 1999. We consider that the lower humidity and the smaller horizontal wind speed contribute to the shorter lifetime and the suppressed development in 2002.

## I.4.511 VHF RADAR OBSERVATIONS OF WEAK ECHO REGIONS IN TROPICAL MESOSCALE CONVECTIVE SYSTEMS

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National MST Radar Facility, India

It is very important to interpret the VHF radar echoes from clear-air in terms of background atmospheric parameters, especially, temperature and humidity. The dominant scattering mechanism responsible for echoes observed by VHF radar is Bragg scattering, which arises from inhomogenities in radio refractive index (function of temperature and humidity) caused by atmospheric turbulence. Turbulence mixes the refractive index profile and the associated gradients so that random irregularities of the refractive index result. Recently, VHF radar observations carried out in the month of September 2001 to explore the mesoscale convective systems over Gadanki revealed the weak echo regions (WER). Height -time section of radar echo power has shown a WER in the height region of 4 – 10 Km, which is believed to be first of its kind over Gadanki.

A hypothesis has been developed to explain the formation of WERs. Because of the intense updraft in the convective cloud, ambient air will be entrained into the convective cloud through the lateral cloud boundary. The more intense the updraft is, the more effective the entrainment will be. Since the ambient air is dry and cool, its mixing with warm and saturated cloud air will decrease both the mixing ratio and temperature of the air in the cloud. The decrease of the mixing ratio through the turbulent mixing process will lower the gradient of the potential refractive index and hence lower the radar reflectivity from turbulent refractivity fluctuations. The rotation of the cell also aids the thorough mixing of air masses. Thus, these weak echo regions in the VHF radar observations are believed to be due to the thorough mixing of air masses at those heights due to the rotation of the cell.

## I.4.514 TROPOSPHERIC WINDS MEASURED WITH THE PIURA ST RADAR: NORMAL VS. "EL NIÑO 1997-98" CONDITIONS

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The Piura ST (Stratosphere-Troposphere) radar was installed by NOAA Aeronomy Laboratory in 1989 as part of a Trans-Pacific network of wind profilers to study the lower atmospheric dynamics associated with El Niño phenomenon. In this work we summarize the statistical characteristics of the horizontal winds observed over Piura between 1991 and 2002. The behavior of the horizontal wind components are shown and discussed as a function of their altitudinal, diurnal and seasonal behavior. The analyses have been done for both normal conditions (periods without El Niño) as well as for the strong 1997-98 event. In addition, the horizontal wind characteristics are shown for the two seasons prior to the El Niño 1997-98 event. Our results suggest the existence of two potential precursors in the upper tropospheric horizontal winds when a strong event is involved.

## I.4.515 TROPICAL ATMOSPHERIC BOUNDARY LAYER STUDIES USING WIND PROFILER AT GADANKI, INDIA

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Lower Atmospheric Wind Profilers (LAWP) has been in continuous successful operation at Gadanki (13.5°N, 79.2°E), India since November 1997. This paper highlights results of LAWP observations until September 2000. Gadanki is an intrinsically interesting site because of the influence of the local topography (is rather complex with a number of hills and a very irregular mix of agricultural, small-scale industrial, and rural population centers), in addition to the strong variation in surface heat flux that occurs between the summer and winter months. Evolution of the convective boundary layer (CBL), vertical wind structure and the turbulent characteristics deduced from the Doppler spectral widths linked through the vertical air velocity are studied. Gadanki-LAWP revealed diurnal variations of the strongly mixing atmospheric boundary layer (ABL) on almost all cloudless days in the tropical region, in the dry and wet seasons. The rate of dissipation of turbulent kinetic energy (epsilon) profiles indicate that the maximum dissipation rate is in the lower heights around noontime and it is also showing a decreasing tendency with height. Radar Reflectivity (SNR) observational results also shows that after sunrise, the CBL forms and grows rapidly through the morning. The growth may continue in the afternoon or the CBL height may stabilize, depending on the synoptic conditions and the amount of surface buoyancy flux. We found that there are two types of strong echo structures appearing systematically in the tropical PBL with diurnal variations on clear days during wet season. The first type is the striking appearance of an echo layer ascending from below 300 m (in the morning) to above 3-5 km (in the afternoon), which was identified with a diurnal variation at the top of the mixing ABL. Another type is, an elevated layer echo appearing at 2-3 km height from almost all the times, which seems to be coincident with humidity gradient. From the wind profile observations we found, with a few exceptions, that the drier period has higher boundary layer when compared with the wet period indicating that in wet season most of the net solar radiation, evaporated the moisture rather than heating the surface, and therefore contributed a little to the buoyant force. Some features of the tropical PBL observed here have not yet been found in mid-latitudes. Diurnal variation of wind direction within ABL is found to be easterly or southeasterly in dry season whereas in wet season the winds are blowing from west or southwest (except monsoon depression and cyclones). The seasonal variation of horizontal winds indicates the presence of low-level nocturnal jet apart from the tropical easterly jet. The results also suggest that it is an important ingredient in the initiation of thunderstorms and mesocale convective systems during monsoon break period over this region.

## I.4.516 A FINE STRUCTURE OF ZONAL AND MERIDIONAL WIND VELOCITY DUE TO RAIN RATE ANOMALIES OVER SUMATERA ISLAND OBSERVED WITH THE EAR

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We have conducted a new Equatorial Atmosphere Radar, EAR a collaboration project between Radio Science Center for Space and Atmosphere (RASC), Kyoto University, Japan and the Indonesian National Institute of Aeronautics and Space (LAPAN) at Kototabang, Bukittinggi, West Sumatera, Indonesia (100.32°E, 0.2°N). Since this region is mostly effected by the Monsoon climate variability, we are interest to investigate a fine stucture of zonal and meridional wind velocity variation (monthly) in the troposphere and lower stratosphere with a good time and spatial height resolution related to the rain rate anomalies over this region. First, we investigate the rain rate anomalies period of 1998 to 2002 obtained by TRMM data analysis. We found that the enhancement of rain rate anomalies was occurred during September to November 2002. Then, we tried to compare with the zonal and meridional wind velocity variation in the same period. We found a good agreement between EAR and TRMM data in determining a fine stucture of rain rate anomalies over Sumatera island.

# I.4.519 THE SIGNATURE OF MID-LATITUDE CONVECTION OBSERVED BY MST RADAR

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The magnitude of tropospheric vertical velocities observed by MST Radars at mid-latitudes is typically no more than 0.1 m/s. Occasional periods characterised by magnitudes of the order of 1 m/s are usually associated with mountain wave activity. Convective events are recognised to be an even more significant source of vertical velocity activity at equatorial latitudes where the magnitudes can be of the order of 10 m/s. However, mid-latitude convection, for which the magnitudes are comparable with those for mountain wave activity, has received relatively little attention. The aim of the current study is to establish the characteristics of mid-latitude convection, as observed by MST Radar, which distinguish it from mountain wave activity. Attention is primarily focused on observations made by the (UK) NERC MST Radar at Aberystwyth (52.4 degrees North) with complementary information being provided from satellite observations.

The key distinguishing feature is the rate of change of vertical velocity as a function of time. Mountain waves are assumed to be stationary with respect to the topographic features which generate them. In principle, therefore, a radar is expected to observe a constant phase of a wave. The fact that the observed phase varies as a function of time is attributed to small variations in the speed and/or direction of the low-level (wave-forcing) wind. The time scale for vertical velocity reversals is typically an hour or more; in the case of convective activity, however, it is of the order of minutes. Furthermore the time-altitude regions of vertical velocity activity attributed to convection are often characterised by enhanced values of (observed and beam broadening corrected) spectral width and occasionally of signal strength.

The MST Radar at Aberystwyth uses the Doppler beam swinging technique in order to derive the three dimensional wind. The basic observation sequence includes the vertical beam pointing direction and 4 off-vertical directions at 90 degree azimuth intervals. This allows each component of the wind vector to be estimated from 3 different beam direction combinations. Although these estimates are typically closely matched, they can differ significantly under conditions of convective activity. This has implications both for data reliability flagging and for the correction of spectral widths.

# I.4.520 PRELIMINARY OBSERVATIONS OF CONVECTIVE BOUNDARY LAYER OVER GADANKI (13.5°N, 79.2°E) USING UHF WIND PROFILER

***Karanam Kishore Kumar and A.R. Jain***

National MST Radar Facility, India

Knowledge of the planetary boundary layer is very important as it plays a vital role in various atmospheric processes such as convection triggering, turbulent transport of variety of quantities e.g. latent heat, pollutants, momentum etc, and development of low-level jet. Among al these, there has been an increasing interest in the boundary layer convection studies, as it plays an intriguing and important role in many weather prediction and air-quality models. Convection triggering in the boundary layer, which can lead to the menacing thunderstorms, remains largely unexplored. Various processes involved in the convection triggering in the boundary layer are yet to be explored for better parameterization of such processes in the numerical models.

A convection campaign has been carried out during May-August 1999 employing UHF wind profiler at National MST radar facility, Gadanki (13.5°N, 78.4°E). During July- August, simultaneous radiosonde observations have been carried out to complement the UHF wind profiler observations. UHF wind profiler data have been used to study the pre-convective environments in pre-monsoon and monsoon periods. These observations are used to estimate the convective boundary layer height and evolution of the same in non-convective, pre-monsoon and monsoon convective days. Horizontal winds, Vertical shears of horizontal winds and vertical velocity fluctuation are also examined in these three different environments. A well-distinguished feature is observed in the pre-convective environments, which can be used as a precursor for the convection triggering. In the non-convective environments the CBL has peaked in the mid-day and suddenly descended to lower altitudes and showed decreasing trend thereafter. In pre-monsoon convective environments, CBL has continued to grow after mid-day also and shallow CBL has been observed during the monsoon days. The intriguing result from these studies is the distinguishable CBL evolution observed in the pre-convective environments of monsoon and pre-monsoon periods.

## I.4.521 STUDIES ON MOMENTUM FLUXES USING MST RADAR WINDS OBSERVED AT GADANKI (13.5 N, 79.2 E), INDIA

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VHF and UHF Doppler radars provide a unique database to estimate the vertical flux of horizontal momentum in the troposphere and lower stratosphere. Estimation of the momentum flux involves two methods: 1) using three beams - one vertical and two oblique, and 2) using four beams - two pairs of oblique beams systematically offset from the vertical. The rapid steerability of the Indian MST radar allows to make three-and four-beam measurements simultaneously. The momentum fluxes measured by the two methods are almost the same for wind fluctuations in a fairly long-period range (longer than 5 h). We choose frequency bands corresponding to periods of 30 min-2 h, 2-8 h, 2-16 h and 2-24 h. Vertical profiles of the zonal and meridional momentum flux in each frequency band were found to be consistent, in general, with the total flux. Zonal fluxes were small at lower levels and increasingly negative (westward) at higher heights. The dominant contributions to the meridional flux occur in the low-frequency band.

## I.4.522 ESTIMATION OF THE TROPOPAUSE HEIGHT USING THE VERTICAL ECHO PEAK AND ASPECT SENSITIVITY CHARACTERISTICS OF A VHF RADAR

***Bok-Haeng Heo [1], Kyung-Eak Kim [2], Bernard Campistron [3] et al.***

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Enhancement of the vertical echo power of VHF radars often occurs at or above the tropopause, and the characteristics of vertical echo peaks has been used to estimate the tropopause height.

The previous methods, such as specular reflection method, Zachs method, maximum echo power method and maximum echo power gradient method, require to establish limit of estimated height interval and are not relevant to the estimation of the tropopause height when there were more than two peaks due to cloud layer, precipitation layer, or inversion layer in the profile of vertical echo power.

In the present study a new method for estimating the tropopause height using VHF radar data was suggested. The present method employed an aspect sensitivity characteristics to distinguish the reflection echo layer due to the tropopause from other peak echo layers and estimated the tropopause height without limit of estimated height interval. The method was evaluated by applying to time series of a VHF radar data and comparing between the tropopause heights determined from rawinsonde data and radar data.

## I.4.523 TROPOPAUSE FLUCTUATIONS DURING THE PASSAGE OF A TROPICAL CYCLONE

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Tropopause, the interface between troposphere and stratosphere, is characterized by the hydrostatic stability and plays key role in Stratosphere Troposphere Exchange (STE). Radars in VHF range, probing at vertical incidence, gives rise to strong echoes from the stable regions of the atmosphere, which can be utilized to monitor stable layer structures associated with the tropical tropopause. MST Radars also show sharp enhancement in power and Signal to Noise Ratio (SNR) at tropopause height. By using the received echo power the cold point tropopause (CPT) and WMO/Lapse rate tropopause (LRT) can be calculated. The tropopause can also be determined by seeing the level where there is sudden increase in SNR. Using these methods the tropopause fluctuations associated with the passage of a cyclonic storm over Indian subcontinent is studied. A tropical cyclone formed as a low pressure on October 14th, 2001 in the west central Bay of Bengal developed into deep depression by October 15th morning. This system intensified into a cyclonic storm on the same day evening, crossed over the MST Radar site at Gadanki (13.5°N, 79.2°E), India on October 16th morning. The 90-year climatological mean tropopause over the station during October is 16.4 km. From the SNR plots we can observe that the tropopause is approximately at 16 km, which is seen to be moving up after a few hours. At the time of this storm passage, a sudden decrease in the tropopause height from 16 to 12 km is noted. This drop in the tropopause height occurred within 3 hours. After the passage of the storm the tropopause returns to its normal position. CPT and LRT determined from the echo power are also showing the same behaviour to that deduced from the SNR. The minimum height of the tropopause is found to be 12.5 km at 1030 LT, which is exactly at the time of passage of the storm over the radar station.

# ABSTRACTS

## Session I.5: Operational Aspects and Recent System Developments

In this session we seek to focus on aspects related to the technical performance of radar systems and multi-instrument measurements. We solicit papers pertaining to all aspects of technical performance of current and/or proposed facilities, including the unique problems associated with operation of remote stations. These aspects include, but are not limited to, pros and cons of system configurations and measurement methods. We would also like to address how multi-instruments can be used together to augment scientific research as well as how measurements from diverse instruments (including models) may be appropriately compared.

Conveners:
*I. Reid and D. Thorsen*

# I.5.1 THE WIND PROFILER NETWORK OF JAPAN MET AGENCY

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1. Introduction

In April 2001 the Japan Meteorological Agency (JMA) started the operation of the Wind Profiler Network and Data Acquisition System (WINDAS). The network consists of twenty-five 1.3GHz wind profilers installed across Japan and a control center at the JMA headquarters in Tokyo. The number of profilers was increased from 25 to 31 in April 2003.

2. Objectives of WINDAS

As announced at the MST9 and COST76 Workshop (Ishihara and Goda, 2000) the major objective of WINDAS is to provide initial wind fields for the operational numerical weather prediction (NWP) models. The data have been put onto GTS (Global Telecommunication System) every hour for global exchange since April 2002.

3. Characteristics of WINDAS

In order to detect and predict mesosocale severe rain storms, the interval of the wind profiler sites ranged from 67 to 262 km, and is 130 km on average. The profilers of WINDAS were designed based on the technologies developed by RASC of the Kyoto University. The characteristics of WINDAS are as follows: 1) high transmitting power (1.8kW), 2) high antenna gain (33dB), 3) up-to date pulse compression technique (8 bits coding), 4) clutter fences to prevent ground clutter, 5) automated data quality control, and 6) remote operation of the wind profilers from the control center in Tokyo.

4. Data Quality Control and Data Accuracy

The processes specific to WINDAS are the estimation of Doppler spectrum moments using the Gaussian function fitting developed by RASC and the quadratic surface check for wind components produced by JMA. Height coverages of wind measurements by WINDAS were 6 to 7 km in moist summer and 3 to 4 km in dry winter. The measurement error of WINDAS was evaluated by comparisons with the model forecast winds. There are no differences between WINDAS and rawinsonde winds in RMSEs, which indicates that the accuracy in the wind measurements of WINDAS is comparable to that in rawinsonde measurements. Echoes from migrating birds have appeared mostly in the night of spring and autumn under the fair weather conditions. The quality control to detect migrating bird echoes has been introduced into the signal and data processings since December 2001.

5. Impact on NWP

The 4-dimensional variational data assimilation scheme (4D-VAR) has been introduced in the Mesoscale Model since April 2002 to make the best use of the potential of WINDAS being capable of continuous measurement of winds aloft. The combination of WINDAS data and the 4D-VAR has well improved the accuracy of the numerical forecast for the severe rainstorm as will be presented in the MST-10 workshop.

## I.5.3 BOUNDARY LAYER AND TROPOSPHERIC RADAR SYSTEMS FOR ENSO STUDIES IN NORTHERN PERU

***Danny E. Scipión [1], Jorge L. Chau [1] and Luis A. Flores [2]***

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As part of a Peruvian effort to improve the Peruvian capabilities to study El Niño phenomenon in northern Perú, the Instituto Geofísico del Perú (IGP) has acquired two new Boundary Layer and Troposphere Radar (BLTR) systems. In May 2000, one of them was installed at Universidad de Piura, where there is an existing wind profiler (Piura ST) for tropospheric and lower stratospheric measurements. The BLTR system now complements the existing ST system, by measuring the boundary layer. Moreover, there is a common region (between 3 and 7 kms) that has been observed concurrently with the two systems. We will present wind comparisons between these two systems, working at the same frequency but using different techniques (Doppler beam swinging vs. spaced antenna). In addition, we will present wind comparisons with pilot balloon winds and with NCEP reanalysis winds. The second BLTR system has been installed in the lowest part of the Andes in northern Peru (~200 kms south east of Piura). The idea is to monitor the wind dynamics at the border of the Atlantic and Pacific basins. The wind dynamics of both systems will be discussed and compared.

## I.5.5 MOVEABLE UHF RADAR PROFILER/DISDROMETER SYSTEMS AS A CALIBRATION STANDARD

***Wallace L. Clark [1], Kenneth S. Gage [1], Christopher R. Williams [2] and Paul Johnston [2]***

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A critically important task for many types of radar work is reflectivity calibration. The obvious, and probably most thorough, method of calibrating is to bring the reflectivity observed from a standard calibration target into line with the value expected. However, the near vertical orientation of profiler/MST radars makes use of such artificial targets quite difficult. Fortunately, in locations where it rains, raindrops can serve as the calibration target. The relation between drop-size distribution (DSD) and reflectivity is well developed and may be measured for any given period of time by a collocated surface disdrometer. The near vertical orientation of profilers and MST radars is nearly optimum for such a comparison, though it is required that a fully recovered range gate in the far field of the antenna be less than a few hundred meters above the surface. Commercial disdrometers are readily available that are rugged, stable over periods of years, and thus suitable as a field reference standard. This technique has been used many times over the years for scanning radar calibration, even though the geometry between scanning radars and a surface disdrometer is generally not so ideal.

Since small profilers such as the AL (NOAA Aeronomy Lab) UHF/disdrometer systems are quite moveable, they can serve as traveling reference standards for larger systems for which the low range gate requirement is not fulfilled. When collocated with such systems, the calibration system reflectivities become a transfer standard wherever range gates do coincide. Over the last few years the AL has been using this calibration technique throughout the ground validation campaigns of the NASA/NASDA Tropical Rainfall Measuring Mission (TRMM). The results of these campaigns suggest that calibration accuracies within a dBZ or so are obtainable, and the technique has been used for verification, and in at least one case, correction of scanning radar observations. It has also been found easy and beneficial to use this calibration procedure to monitor the health of radar systems, thus allowing timely correction of occasional system component failures.

## I.5.6 PERFORMANCE ENHANCEMENTS TO THE VHF BOUNDARY LAYER TECHNIQUE

***Brenton G. Vandepeer, Brian M. Fuller, Adrian J. Murphy et al.***

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Recent years have seen an increased interest in the scientific and operational applications of VHF boundary layer radar systems. Such systems are now emerging as viable alternatives to the more expensive traditional UHF profilers and provide significant performance improvements in some areas. In particular, the higher altitude performance of the VHF systems is of note, with higher-powered systems potentially reaching the tropopause and beyond. Traditionally, the focus of most VHF boundary layer radar designs has been the extension of the height coverage to the lowest possible altitudes, usually to the detriment of the higher ranges. It is possible, however, through the use of novel multiplexing techniques to maximise boundary layer performance at the lowest heights without sacrificing the upper-tropospheric returns. In this presentation we describe some of these techniques and demonstrate their efficacy using the example of an operational system. We present results showing the altitude performance of the boundary layer troposphere radar system, and demonstrate that the temporal resolution of the results are not degraded as a consequence of the multiplexing techniques utilised.

## I.5.7 TOWARD A MULTISENSOR GROUND BASED REMOTE SENSING STATION

***Catherine Gaffard, Tim Hewison and John Nash***

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Future UK operations require several sites using ground based remote sensing techniques to provide an upper air network with better spatial and temporal resolution than currently exists. There is currently a network of 5 wind profiler that covers the UK and winds are operationally assimilated in our global and mesoscale model. Our goal is to get a continuous monitoring of the first 3km of the troposphere to improve the humidity field and the boundary layer description for numerical weather prediction (NWP). A part of our work is to investigate how a synergy between different ground based remote sensing instruments, like wind profiler, radiometer cloud radar and lidar ceilometer could meet our user needs. A 12-channel microwave radiometer has been recently bought and a low cost cloud radar is under development in order to carry on this work.

Radiosondes have been launched over 3 days at Camborne in the far Southwest of England in May 2002. Launches have been done at hourly intervals for 8 hours to provide “ground truth” with high resolution for 3 cases study. The radiometer measurements show the general evolution of the atmosphere but cannot detect detailed structures of the temperature and humidity profile. In contrast, the signal to noise ratio of the wind profiler reveals lots of structure linked to change in the refractive index. The location of such discontinuities could be used in the radiometer retrieval to improve the vertical resolution of the retrieved profile. This paper will compare time height series of wind profiler signal to noise ratio with time height series of gradient of refractive index from radiosonde measurement.

Most of the wind profiler structures in the signal to noise ratio correspond to variations in the gradient of the refractive index as seen by the radiosondes. Further quantification of the mixing may explain enhanced signals that are not associated with strong variation in the refractive index.

## I.5.506 DIGITAL RECEIVER TECHNOLOGY AT JICAMARCA

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Nowadays technology, particularly the one related to the mobile communications industry, is not expensive. At the Jicamarca Radio Observatory we are taking advantage of it, by using commercial chips for fast analog/digital (A/D) conversion and filtering. The A/D conversion (12 bits) is done at the output of the receiving antenna at 64 MHz, then in phase (I) and quadrature (Q) components as well as receiving-amplifying, base band conversion and filtering are also done on the digital filter. The digitized signals are input to a PC via the PCI bus at high speed (up to 80 MHz). Therefore, our current development is allowing us to performed experiments where high dynamic range is needed (for example simultaneous echoes from both coherent scatter and incoherent scatter), perfect filtering and I and Q components. Moreover, we have already synchronized several digital receivers allowing us to perform multiple receiving experiments (e.g., interferometry). We will present a detailed description of the system as well as preliminary observations of equatorial electrojet and equatorial spread F echoes, where high dynamic range is needed.

## I.5.8 APPLICATIONS IN CALIBRATION AND BEAMFORMING WITH THE TURBULENT EDDY PROFILER

***Paco López Dekker and Stephen J. Frasier***

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The Turbulent Eddy Profiler (TEP) developed by the Microwave Remote Sensing Laboratory at the University of Massachusetts is a volume imaging radar wind profiler operating at 915 MHz. Illuminating a 25 degree cone, it simultaneously records echoes on a hexagonal array of 60-90 receiving elements. A variety of signal processing techniques are applicable to data recorded by TEP including DBS and SA techniques for horizontal winds. Various digital beamforming algorithms are applied to generate 3-D radar images of the atmospheric boundary layer. Phase synchronization of the receiving elements is required for successful operation. Because the system is designed to be deployed at different locations, and under varying conditions, it is important to have a good phase calibration scheme. We have applied a variety of techniques including spatial correlation based and minimum entropy methods. Spatial correlation based methods rely on having a statistically uniform scene, so that the correlation coefficient between adjacent antenna elements is known a priori. The difference between the measured and predicted correlation coefficients can be used to calibrate the individual array elements and receivers. The algorithm is robust and computationally efficient, but it makes a strong assumption about the statistics of the scene, which are only satisfied after averaging over a relatively long period of time. The minimum entropy method assumes that phase errors in the individual elements result in blurring of the resulting beamformed image. Hence, the method consists in finding the set of calibration coefficients that maximize the contrast of the resulting images. The algorithm is mathematically more complex and computationally more expensive, and it is difficult to characterize the error of the resulting calibration vector. However, in many cases it has been found to converge faster to a calibration vector consistent with the one obtained using the correlation method. It benefits from the presence of sharp features, like point targets (e.g birds) that hinder the correlation based method, but it performs poorly if the scene is smooth.

## I.5.9 ELECTRONIC DIGITAL BEAMFORMING IMPLEMENTATION FOR RADARS

***Richard Ney, S. Bonaimé, F. Dolon et al.***

CETP/IPSL, France

The classical papers of Barton (1980) and Steyskal (1987) on digital beamforming describe the complete capabilities of the concept. It was emphasized in the 80’s that the cost of the whole digital system was beyond the financial capabilities of Research Institutes. The permanent decrease of the cost of digital components and the parallel increase of their performances allow now to many users to access full Digital Beamforming. CETP has developed for the GPR (a 2-5 MHz pulsed Ground Penetrating Radar) of the space Martian NetLander Mission a very compact electronic unit which performs the signal generation, transmission and reception for up to 3000 range gates. The radar is dedicated to the Subsurface and the Ionosphere sounding of Mars.
Actually each electronic unit can be associated to each antenna of an antenna network. This architecture is very flexible and allows Digital Beamforming for both transmission and reception, or if desired for reception only.
The hardware can be applied to many radars in the HF and VHF bands. The analog receiver can be replaced by a digital receiver which implements the ADC at the HF or VHF level, digital demodulation and matched filtering on the I and Q baseband signals.
The paper presents the complete hardware with the main characteristics. Some operational results which demonstrate the capabilities of the system are presented. Extension of the hardware to higher frequencies is analyzed.

Barton, P., (1980). Digital beam forming for radar. IEE Proceedings, Vol. 127, Pt. F, N°4, August, pp. 266-277.
Steyskal, H. (1987). Digital Beamforming Antennas. Microwave Journal, January 1987, pp. 107-124.

## I.5.515 POINT-TO-POINT VHF COMMUNICATIONS VIA THE EQUATORIAL ELECTROJET

***Martín F. Sarango, Jorge A. Chocos, Ronald F. Woodman et al*.**

Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Peru

The statistical analysis and conclusions from experiments conducted by Cohen and Bowles in 1963, Romero et al. in 1968, and Valladares and Woodman in 1975, suggested the possibility of exploiting VHF scatter propagation for equatorial communication circuits. Even more, the use of weaker, faster fading night-time signals for telecommunications may also be feasible.

This paper will report the first results from a VHF radio-link between Lima and Paracas (~200 Km to the south of Lima), in Peru, using the Equatorial Electrojet (EEJ) as dispersion media. The ultimate objective of this effort is to establish point-to point wireless communications employing ionospheric (EEJ) forward scatter propagation.

A MATLAB simulation program has been used to study the communication channel as well as different modulation schemes. The results from these studies have been used to design the test-link between Lima and Paracas. Two transmit-receive stations have been installed at these locations using five-element Yagi antennas and 200W VHF transceivers. Digital input and output data connection is used to send/receive data to/from a portable PC for off-line analysis. System geometry and configuration as well as simulation and first communication results will be presented.

## I.5.11 ON-LINE ADAPTIVE DC-CLUTTER REMOVAL

***Jürgen Röttger***

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ST radar observations are always affected by partially strong clutter echoes from nearby mountains and other fixed targets. This clutter is usually minimized by antenna optimization by means of suppressing horizontal side-lobes. The thereafter still remaining DC component is removed by either interpolating the zero-frequency component in the Doppler spectrum or by the so-called DC subtraction. The former method eliminates a significant part of the signal or may even fail, when the atmospheric echo has a very narrow Doppler spectrum. The latter method is usually done off-line on the raw data.
Here the design proposal of an digital hardware filter is presented, which allows on-line adaptive narrow-band-pass filtering (notching) for all individual range gates. It can be easily implemented into all MST radar systems and, due to its recursive and adaptive design, removes only a very negligible part of the atmospheric signal. Standard DC-removal methods are not required after this real-time notch-filtering.

## I.5.513 ON THE RADIATION EFFICIENCY OF COCO ANTENNAS

***Martín F. Sarango, Ronald F. Woodman and Darwin N. Cordova***

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In the summer of 2000 we installed a Yagi array at the Artigas Uruguayan Base in King George Is, Antarctica. We originally planned for a simultaneous run with the Peruvian MST radar at Machu-Picchu, also at King George Is. However, due to logistical problems with the latter system the simultaneous observations were not performed. The Machu-Picchu antenna is of the COCO (coaxial-collinear) type with a ~10 dB larger physical antenna aperture than the Yagi array. To our surprise, the PMSE echoes at Artigas were stronger than the ones previously observed at Machu-Picchu for the same time of the year. In order to determine if the differences can be attributed to antenna performance or to a large PMSE annual variability, we have proceeded to make an experimental calibration of the performance of both systems, mainly of their antennas. This experiment has been carried out at the Jicamarca Radio Observatory using equatorial electrojet echoes and a third common receiver antenna for the comparison. We have determined that the COCO antenna gain has to be corrected by an efficiency factor of ~7 dB over whatever is the efficiency of the Yagi array. Part of the loss in efficiency is of ohmic nature and part is due to an uneven current distribution in the COCO line elements.

## I.5.13 NEW APPROACHES TO POLAR ATMOSPHERE STUDIES USING RADARS

***Masaki Tsutsumi***

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Development of new applications to existing HF and MF radar systems in polar regions and a new MST/IS radar project at Syowa station (69S, 39E), Antarctica are introduced.

SuperDARN HF radar network, which widely covers both Arctic and Antarctic regions, has been providing valuable information on F-region plasma motion as well as E-region field aligned irregularities. Recently other types of echoes such as meteor echoes and polar mesospheric summer echoes were also reported to exist in the HF radar data. If properly applied, the radars will become powerful tools for the study of polar mesosphere and lower thermosphere. We newly developed a time series analysis method without changing the existing transmitting pulse sequence, which is used for the auto correlation function measurement. This method has been successfully applied to meteor wind measurement. Details of this technique is presented in a separate presentation.

MF radars are now the most commonly used system to observe winds in the mesosphere. They utilize partial reflection echoes from weakly ionized atmosphere. We found using Syowa MF radar system that significant number of meteor echoes were also detected at night from 90 to 110 km or even higher. Although the observation is limited to night time under geomagnetically quiet conditions, combination of this technique with the conventional correlation technique can greatly widen the height coverage of MF radar systems.

Each atmospheric radar has its advantages and limitations. Recent studies demonstrate the importance of quantitative understanding of various processes in the polar atmosphere, including the formation and termination of ozone holes and the coupling of the polar ionosphere with the lower and middle atmosphere. Wide height coverage and high time-height resolutions are required. An MST/IS radar is the only technique to meetthese requirements. Inter-hemispheric differences such as topography and the separation between the geographic and geomagnetic poles will cause different dynamic processes between the hemispheres, which emphasizes the equal importance of both Arctic and Antarctic observations. However, there is no MST/IS radar in the Antarctic region.

`Program of the Antarctic Syowa MST/IS Radar (PANSY)` is the one which will fill the major gap in the global radar network. Syowa station is already equipped with various observation tools such as an MF radar, two SuperDARN HF radars, Fabry-Perot imager and other optical instruments, which will provide complementary data set for PANSY radar.
The unique location of Syowa under the auroral zone also provides an advantage in the study of coupling processes between polar neutral and ionized atmospheres. An active phased array system with about 1000 crossed Yagi antennas and the peak transmitting power of about 500 kW is planed. Feasibility studies at Syowa station such as antenna field survey and ground-scatter measurements started recently.

## I.5.14 DIFFERENTIAL ABSORPTION MEASUREMENTS USING THE BUCKLAND PARK MF RADAR

***Rupa Vuthaluru [1], David A. Holdsworth [2], Robert A. Vincent [1] et al.***

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The differential absorption experiment (DAE) was first proposed in the 1950's for the estimation of mesospheric and lower thermospheric electron density using MF/HF radars. The technique was used extensively until the late 1970's, when interest in the technique declined, due to experimental limitations and questions regarding the assumptions of the technique. This paper describes the application and results from the implementation of the DAE for Buckland Park MF (BPMF) radar. The results are generally consistent with those expected for solar control. However, diurnal assymetry consistent with the large "puzzling" diurnal asymmetry of NO density measured by HALOE/UARS is observed, as well as night-time enhancements suggestive of ionisation sources other than from solar control. The effects of solar flare and solar proton events are also investigated.

# I.5.15 A NEW NARROW BEAM MF RADAR AT 3 MHZ FOR STUDIES OF THE HIGH-LATITUDE MIDDLE ATMOSPHERE: SYSTEM DESCRIPTION AND FIRST RESULTS

***Werner Singer [1], Ralph Latteck [1] and David A. Holdsworth [2]***

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A new narrow beam MF radar has been installed close to the Andoya Rocket Range as part of the ALOMAR observatory to improve the ground based capabilities for studies of the dynamical status (small scale features, turbulence) of the upper mesosphere. The characteristics of radio wave scatterers can be studied in a wider frequency range by common volume observations with the ALWIN MST radar at 53.5 MHz.. In addition, the new radar allows the analysis of the upper atmosphere in conjunction with rocket soundings. The system operated at 3.17 MHz was put into operation in July 2002. Doppler beam steering technique as well as spaced antenna applications can be applied. The main feature of the new radar is the transmitting/receiving antenna which is formed by 29 crossed half-wave dipoles arranged as a Mills-cross. The spacing of the crossed dipoles is 0.7 wave lengths resulting in a minimum beam width of about 7° (FWHP, one way). Each dipole is fed by its own transceiver unit with a peak power of 2 kW (phase controlled on transmission and reception) providing high flexibility in beam forming and pointing as well as o- and x-mode operation for differential absorption measurements. Off-zenith beams towards N, S, E, W and NW, NE, SE, SW at 7.3°/10.2° can be formed. In addition, beams with different widths at the same pointing angle can be formed. For multiple receiver applications four independent receiving channels and two additional crossed dipole arrangements are available.
Observations of interleaved Doppler winds, spaced antenna winds using Full Correlation Analysis and IDI technique are discussed in relation with simultaneous observations from nearby located MF/HF/VHF radars (VHF Doppler/spaced antenna winds, wide beam MF spaced antenna winds, all-sky meteor radar winds). First results of momentum flux measurements using co-planar beams and of turbulent parameters (mean turbulent velocities, energy dissipation rates) are presented.

## I.5.16 CURRENT STATUS OF THE WIND PROFILER NETWORK IN EUROPE (CWINDE) AND THE AIMS OF THE EUMETNET PROJECT WINPROF

***John Nash, Catherine Gaffard, Tim Oakley and Turp Myles***

Met Office, United Kingdom

Development of real time networking of wind profiler radars in Europe was co-ordinated by the COST76 action from 1995 to 2001. This involved the co-operation of National Meteorological Services, Research institutes, Universities and industry {COST 76 Final Report, 2003). The CWINDE demonstration experiment established a hub for a real time network. This monitored the data availability and quality directly with plots displayed on a relevant web page[1] and also through comparison of measurements with numerical weather prediction models first guess fields.
([1] www.metoffice.com/research/interproj/cwinde/index.html.)

For two years the Met Office continued to collect wind measurements both from wind profilers, whilst replacement network structures were prepared. During this time the availability of data varied, with large data gaps from some of the main profilers as development work continued. However, the origin of some outstanding faults with the systems were identified and rectified.

This situation changed in late 2002 with the establishment of a EUMETNET [Western European Meteorological Services] project for operational wind profilers designated WINPROF. WINPROF is being managed by Deutsche Wetterdienst for two years, with subcontracts for part of the project work placed with Met Office(UK) and Meteo Suisse. Doppler Weather radar winds from OPERA, the equivalent EUMETNET weather radar project will also be monitored through the WINPROF hub. Some additional development work on wind profilers is now also currently incorporated within the COST 720 project, on Integrated Vertical Profiling systems for temperature, humidity and cloud

The current European wind profiler network consists of 20+ systems sending data to the Met Office, who operate the hub and act as the project office. The table below details the wind profiler systems currently connected to CWINDE and their data availability during Jan 02. Also connected to CWINDE are 27 weather radars (reporting VAD winds) and 2 SODAR's.

| System | Country | Real time data | | System | Country | Real time data |
|---|---|---|---|---|---|---|
| Aberystwyth (MST) | UK | 90% | | Dunkeswell (LT) | UK | 97% |
| South Uist (LT) | UK | 97% | | Wattisham (LT) | UK | 95% |
| Camborne (LT) | UK | 97% | | | | |
| Le Ferte Vidame (MST) | France | 89% | | Nice (LT) | France | 91% |
| Clermont Ferrand (MST) | France | 91% | | Toulouse (MST) | France | 69% |
| Lannemezan (MST) | France | 91% | | Maragianne (LT) | France | 56% |
| Lindenberg (ST) | Germany | 89% | | Lindenberg (LT) | Germany | 84% |
| Vienna (LT)<br>Innsbuck (LT) | Austria<br>Austria | 94%<br>98% | | Salzburg (LT) | Austria | 97% |
| Payerne (LT) | Switzerland | 59% | | Cabauw (LT) | Netherlands | 78% |
| Kiruna (MST) | Sweden | 91% | | Andennes (MST) | Norway | 92% |

The main objectives of the WINPROF programme are:
1. Harmonise and improve the existing exchange of wind profiler data in Europe.
2. Run and further develop a network hub for data processing and quality evaluation.
3. Integrate new wind profiler systems.
4. Establish appropriate quality control procedures.
5. Define general quality standards for operational use.
6. Work on improved processing algorithms to improve data quality/availability.
7. Provide expert support to members for wind profiler installations.

This presentation will detail the current status of the wind profiler network in Europe and the future plans in association with the WINPROF programme.

# I.5.17 A DECADE OF SCIENTIFIC CONTRIBUTIONS FROM INDIAN MST RADAR AND FUTURE DEVELOPMENTS

***D. Narayana Rao***

National MST Radar Facility, Gadanki, India

Indian MST radar has been established in August 1994 as a major facility at Gadanki (13.47° N; 79.18° E), a tropical station in India with a peak power aperture product of $3X10^{10}$ $Wm^2$. The radar has been potentially used for various studies related to atmospheric structure, dynamics and coupling processes including the characteristics of the plasma irregularities. Recently in collaboration with Communications Research Laboratory, Japan new experimental systems v*iz*., (i) Lower Atmospheric Wind Profiler (LAWP), (ii) A ND-YAG Lidar (iii) A disdrometer and (iv) An Optical Rain Gauge (ORG) have been collocated at National MST Radar Facility (NMRF). These systems are very much complementary to the MST radar and added a new dimension to scientific utilization of NMRF.

Boundary layer characteristics were studied making use of LAWP and the boundary layer height was observed to be as high as 2-3 km in the afternoon hours when the convective plumes may be seen pushing the boundary layer height. Simultaneous MST radar, LAWP and radiosonde observations are used to obtain vertical profiles of turbulence parameters such as eddy dissipation rate ($\varepsilon$), eddy diffusivity ($K_h$) and buoyancy scale size ($L_B$). MST radar observations at Gadanki have shown multiple layers of high reflectivity in troposphere and stratosphere and these layers persisted for many hours. Experiments were conducted to study atmospheric convection and significant mass flux is also noted to exchange between troposphere and stratosphere during convection. Precipitating systems are classified as stratiform and convective making use of the simultaneous observations from MST radar, LAWP and Disdrometer. Radar bright band characteristics were studied. Z-R relations were derived for different precipitating systems and for the two monsoons. Several passages of cirrus clouds have been investigated using simultaneous observations of MST radar and collocated Lidar to understand the dynamics and microphysics near the cloud boundaries. Vertical profiles of temperature were obtained from MST radar observations by identifying the Brunt-Vaisala frequency from the spectra of the vertical wind. Experiments were also conducted to retrieve humidity profiles from MST radar observations.

Equatorial wave campaigns have been carried out in a coordinated manner. Atmospheric temperature and wind profiles were obtained from almost ground to about 80 km. Studies were carried out to characterize the atmospheric waves, especially the short period ones such as tides and gravity waves.

The MST radar has been operated in ionospheric coherent backscattered mode for mapping the structure and dynamics of the E and F region field aligned irregularities. QP echoes associated with backscatter from E-region field-aligned irregularities were also studied.

The NMRF is augmenting the Indian MST radar as coherent imaging Radar for interferometric studies, which include Space Domain Interferometry (SDI), Frequency Domain Interferometry (FDI), and Image Doppler Interferometry. Augmentation of MST radar as coherent imaging radar would overcome some of the limitations of the present system, which makes use of the Doppler Beam Swinging (DBS) method. In SDI mode, it would be possible to determine the distribution of the backscatterers within each range cell, their horizontal correlation length and horizontal motion along the base line. SDI will be quite useful to provide three-dimensional mapping of refractive index irregularities, to study anisotropy in the wind field, precipitation and convective events, turbulence generated during lightning, evolution and decay of meteor trails and three-dimensional structure of ionospheric irregularities.

## I.5.510 INSTRUMENTAL ERRORS IN RADAR PHASE CALIBRATION AND ASSOCIATED CORRECTION

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National MST Radar Facility, India

The new generation MST radars/wind profilers use phased antenna arrays to steer the beam in different directions. The total array is connected to several distributed transmit/receive channels. The pointing accuracy of the beam depends on the phase error distribution across the distributed channels. Phase calibration, employed to correct these phase errors, involves two steps; a) measurement of the differential phases (or phase errors) among the channels and b) applying appropriate correction phases into the channels to neutralize the phase errors. Both steps are prone to errors. The instrumental inaccuracies cause errors in the measurement of differential phases whereas the finite resolution of the phase shifters introduces quantization errors in the phase-shifts to be introduced into the channels. The quantization error is small or negligible (±0.7deg for an 8-bit digital phase shifter) when compared to the measurement errors due to instrumental inaccuracies in the measurement setup. In general, part of the radar system, mainly the receiver IF amplifier chain and quadrature detector will be employed into the set up to measure the differential phases. A zero-beat signal will be sent through the channels sequentially, down converted first to IF, which will be passed through the IF section of the receiver, then converted to base-band (video) in the quadrature mixer. The monitoring points at IF or video outputs can be used to measure the phase of all distributed channels. However, it is worth mentioning that the phase measurement at video point is more convenient than at the IF output. Major instrumental inaccuracies include the gain fluctuation in the IF section of the receiver and phase and amplitude (gain) imbalances in the quadrature detector. It is very difficult to isolate and remove the errors due to inaccuracies in IF amplifier chain. But it is quite possible to remove the errors caused due to inaccuracies in the quadrature mixer. In this paper a method is presented to separate the error components due to IF and video sections and a technique is demonstrated to remove the error component due to quadrature mixer imbalances. It is shown that the peak-to-peak phase error after video correction is limited to that caused by the inaccuracies in IF section. An experimental setup is devised to quantify the phase and gain imbalance factors of the quadrature mixer, which are essential to carry out the above correction. This experiment has been carried out with Indian MST radar at Gadanki. The peak-to-peak phase error measured at IF and video outputs is 7 and 15 deg respectively, which indicates that the errors due to inaccuracies in IF and video sections are 7 and 8 deg respectively. The phase and gain imbalance factors of the quadrature mixer are measured to be 5 deg and 7.8% respectively. These factors are used in the correction to remove the errors due to video section. After video correction the peak-to-peak phase error has been reduced from 15 to 9 deg. The error present in the measurement even after applying video correction is attributed to the inaccuracies in IF section.

# I.5.501 ANTENNA BEAM VERIFICATION AND CALIBRATION USING COSMIC NOISE

***Trevor Carey-Smith, Adrian J. McDonald, Jack Baggaley et al.***

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To obtain accurate vertical wind measurements using a VHF radar, the pointing direction of the antenna beam must be known precisely. In this study, different methods of beam verification using cosmic noise sources have been investigated. With data obtained from the new Canterbury University Stratosphere Troposphere Radar (CUSTAR) in Christchuch, New Zealand, the antenna's pointing direction has been derived by comparison with discrete radio sources and also a 45 MHz sky map. The results indicate that if a sky survey is available at a similar frequency and latitude to that of the radar then the optimum method of verifying the beam pattern is to perform a cross-correlation between the sky survey and the background noise measured by the radar. Additionally, a method for the calibration of antenna loss using a sky map is detailed along with its strengths and limitations.

## I.5.502 ARECIBO UHF CALIBRATION USING NEXRAD , DISDROMETER AND RAINGAUGE DATA

***Monique Petitdidier and Petronille Kafando***

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During the thunderstorm experiment conducted at Arecibo Observatory in September-October 1998 different instruments were running. The main drawback of the UHF radar is the lower altitude threshold limited at 6km, altitude above or nearly at the freezing level. Then, a direct calibration with the disdrometer, as it is usually done, is not possible. The idea is to use an intermediate instrument, the NexRad radar, located at Cayey , PR, that scans the volume observed by the UHF radar. The combination of UHF and VHF radar observations provides the vertical fall speed.

The process is done in several steps. The first one consists of the NexRad calibration with the disdrometer and raingauge in the area of the UHF radar. Preliminary work was done by Briceno and ierkic (2002) all over Puerto Rico with raingauges. Relationships between the NexRad reflectivity and the rain fall rate are deduced according to stratiform or convective events. The second step consists of the UHF reflectivity calibration and the hydrometeor identification by comparison with the NexRad data. This last step will be discussed in details.

## I.5.503 THE DESIGN OF A NEW MEDIUM SCALE MULTIMODE ST RADAR: ARCHITECTURE, SIMULATIONS AND TRADE-OFFS.

***Yves J. Barbin [1], Hubert Luce [2], Fabien Ghio [2] et al.***

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Wind profiling and atmospheric dynamics studies have usually been performed by powerful instruments. Beamforming of antenna arrays associated with Doppler methods, various signal correlation methods applied with more or less spaced antennas, high resolution data processing methods have each shown their relevance. For instance, the one megawatt Middle and Upper atmosphere Radar (MUR) has all these capabilities, but it is a fixed position observatory.
On the other hand, LSEET developped and still operates a small radar for general purposes called MiniVHF (16 dipole antennas), aimed at boundary layer and troposphere studies.
We now propose to build a new “mezzo” instrument, with a 144 or 256 antenna array arranged in 16 small square subgroups, associated with a multi channel receiver (one receiver per subgroup and distributed transmitter amplifiers).
Our objective is to design a versatile radar, i.e. efficient in the main observational modes: Doppler Beam Swinging, Spaced Antennas, coupled with multi frequency interferometry. The feasability study framework includes a reasonable cost goal, modular designs using straightforward modern HF and digital architecture, and a strong Electromagnetic Auto-Compatibility concern. Computer simulations will help us to evaluate how trade-offs are possible, and will drive critical decisions.

## I.5.504 COMPARISON OF WIND ESTIMATION ERRORS FOR THE SPACED ANTENNA TECHNIQUE

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Full correlation analysis (FCA) has been applied for the spaced antenna (SA) technique. FCA estimates wind parameters by fitting theoretical equations to correlation functions. We technically employ Gaussian fitting to limited range of correlation functions, however, correlation functions also include noise and tail, which causes some estimation errors.
In this presentation, We estimate random errors in the SA wind by means of simple computer simulations, and discuss relations between estimation errors, noise, and Gaussian fitting range.

## I.5.507 EXPERIMENT AND ANALYSIS TECHNIQUES USED FOR THE BUCKLAND PARK ALL-SKY INTERFEROMETRIC METEOR RADAR

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A new all-sky interferometric radar system has been developed and installed at the Buckland Park field site. A description of this radar system is presented, along with the details of the experiment and analysis techniques developed. Initial results are presented, indicating the radar produces count rates between 5000 and 7000 meteors per day.

# I.5.509 METEOR ECHO RETRIEVALS USING COLLOCATED NARROW-BEAM RADAR AND ALL-SKY INTERFEROMETER AT PIURA, PERU: COMPARISON OF MEASURED WINDS

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During the mid 1990's a Meteor Echo Detection and Collection (MEDAC) system was attached to the VHF wind profiler located at Piura, Peru to detect and collect meteor echoes, and provide measurements of winds in the mesosphere and lower thermosphere. Classification of underdense meteor echoes is performed prior to wind calculation. Analysis of the data coming from this narrow-beam radar raised the possibility that some of the meteor echoes were collected through an antenna sidelobe instead of the main lobe. Therefore, uncertainty regarding our height and wind estimates was also raised. An interferometer was installed next to the narrow-beam antenna to provide accurate estimates of the angle of arrival (AOA) of meteor echoes and, hence, get accurate estimates of heights and wind profiles. We will compare the AOA's measured by the interferometer with those assumed by the narrow-beam system and the effects of the AOA issue on the wind estimation.

# I.5.511 NEW SUPERDARN RAW TIME SERIES ANALYSIS METHOD AND ITS POSSIBLE APPLICATIONS TO UPPER AND MIDDLE ATMOSPHERE RESEARCHES

***Masaki Tsutsumi and Akira S. Yukimatu***

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There are currently 16 SuperDARN HF radars deployed surrounding the Arctic and Antarctic regions. Those radars employ an auto-correlation function (ACF) method to obtain Doppler information from F- and E-regions in spite of the fact that received signals are mostly coherent field aligned irregularity (FAI) echoes. This is because the radars are specially designed to detect signals over 3000 km away from the radar site for the study of horizontal plasma convection pattern.

On the other hand recent studies found that the radar data also contain non-FAI echoes such as meteor echoes and polar mesospheric summer echoes (PMSEs), showing the great potential of the SuperDARN radars for the study of mesosphere and lower thermosphere (MLT) [e.g., Hall et al, JGR, 1997; Ogawa et al, GRL, 2002]. For the analyses of these echoes, however, time series is more preferable than ACF data. There are also needs for time series analyses from ionospheric studies on physical mechanisms of a variety of Doppler spectral properties in various geophysical regions.

We therefore have developed a new raw time series analysis method (of all the receiver I/Q signals), but without changing the normal SuperDARN ACF pulse sequence. This was successfully achieved because one multi-pulse sequence (currently 7 pulses) is about 100 msec long, which can be regarded as unevenly spaced 'single pulse' operation for targets at relatively close to the radar such as meteor trails. Echoes overlapped by strong range aliasing echoes should be carefully removed before further analyses. We installed this new code at the SENSU Syowa SuperDARN radars in Antarctica in October 2001. This new technique was first applied to SuperDARN meteor wind measurements. The unevenly sampled raw time series is processed to detect only underdense meteor echoes to deduce line-of-sight neutral wind velocities and decay time constants. By using diffusion coefficients deduced from the decay constants as height information, we successfully obtained the structure of a downward phase propagating semi-diurnal tide, which has not previously been achieved by analysing normal SuperDARN ACF data [Yukimatu and Tsutsumi, GRL, 2002]. Applying the new method to all the SuperDARN radars will provide a unique longitudinally extended meteor radar network at high latitudes in both hemispheres, which can effectively contribute to MLT region dynamics.

The technique, comparison with MF radar winds, and some shortcomings to overcome are presented.

## I.5.516 QUALITY CONTROL FOR DOPPLER WIND PROFILERS USING NIMA

***Corinne S. Morse [1], Robert K. Goodrich [2], Larry B. Cornman [1] et al.***

[1]National Center for Atmospheric Research, United States
[2]Unational Center for Atmospheric Research, Department of Mathematics, University of Colorado, Boulder, United States

NCAR's Improved Moments Algorithm (NIMA) for Doppler wind profilers has been shown to provide better winds and range coverage compared with traditional peak picking algorithms. NIMA utilizes 2d analysis of the spectral surface, fuzzy logic, and image processing techniques to identify atmospheric features which are used to identify the atmospheric spectral signal and calculate the moments. NIMA has been used operationally for over five years with three 915 MHz profilers in Juneau, Alaska to produce ten-minute average winds and more recently to produce rapid-update winds for use in a prototype wind hazard warning system for the Juneau International Airport. NIMA is shown to provide improved moments under a variety of challenging conditions including clutter, radio-frequency interference, and low signal to noise. Examples of NIMA performance are shown along with a discussion of the current state of the algorithm and plans for future improvements.

## I.5.517 RADAR CONTROLLER

***Aditi B. Kolatkar and Denise Thorsen***

University of Alaska, Fairbanks, United States

Increasingly, radar stations contain multiple radar systems, each individually controlled. Non-standard control requires that a user of multiple systems learn each system separately. Additionally, multiple radar controllers make coordination of multiple systems difficult. The Remote Sensing Lab at University of Alaska – Fairbanks, is building a generic radar controller that can be used to operate any pulsed radar system or multiple radar systems simultaneously. Technicians at radar stations where this controller is deployed will only need to know how to operate a single system rather than many. Additionally, campaigns using multiple radars can be coordinated through a single radar controller. The University of Alaska generic radar controller is a microcontroller based PC card with a minimum of 16 control pulses. Each pulse can be individually programmed to provide pulses of 100 ns duration up to several milliseconds and variable pulse repetition intervals.

# I.5.518 SOUSY RADAR AT JICAMARCA: SYSTEM DESCRIPTION AND FIRST OBSERVATIONS

***Ronald F. Woodman and Otto Castillo***

Radio Observatorio de Jicamarca, Instituto Geofísico del Perú, Lima, Peru

Few months ago the Max Planck Institute for Aeronomy in Germany donated the SOUSY radar to the Jicamarca Radio Observatory (JRO) of the Instituto Geofísico del Perú. This system was operational at the Harz, Germany, since the late 1970’s and we expect to make the first measurements at JRO by March 2003. Two characteristics that differentiate this radar from the Jicamarca radar are its bandwidth, permitting an altitude resolution of 50 meters, and the wide and agile steerability of its antenna (± 15o). This addition to the Jicamarca facilities will make possible a number of new ionospheric and atmospheric studies that will be discussed. The antenna design has been changed a square array of 16x16 antenna array have been installed instead of a circular configuration and will be initially setup to point to a fixed position (15oS). The control and processing system is being upgraded to state-of-the-art technology similar to the current Jicamarca system. The fixed-antenna position, although not ideal, will allow us to test the capability of the SOUSY system to measure the meridional wind at F-region heights, the only ionospheric parameter of importance that cannot be measured reliably at Jicamarca. By the time of the conference we expect to present the first measurements of this new system, not only from ionospheric echoes, but also from atmospheric echoes obtained with high altitudinal resolution.

## I.5.519 THE EQUATORIAL ATMOSPHERE RADAR (EAR): SYSTEM AND NEW RESULTS

***Shoichiro Fukao , Hiroyuki Hashiguchi , Mamoru Yamamoto  et al.***

Radio Science Center for Space and Atmosphere, Kyoto University, Japan

An MST radar with an active phased-array antenna system, called the Equatorial Atmosphere Radar (EAR), has been operated at the equator near Bukittinggi, West Sumatra, Indonesia (0.20S, 100.32E, 865 m above sea level) since July 2001.
The EAR operates at 47.0 MHz with a peak output power of 100 kW. The EAR uses a circular antenna array, approximately 110 m in diameter, which consists of 560 three-element Yagi antennas. Each Yagi antenna is driven by a solid-state transmitter-receiver module. This system configuration allows the antenna beam to be steered electronically up to 5,000 times per second. The scientific objective of the EAR is to advance the knowledge of dynamical and electrodynamical coupling processes in the equatorial atmosphere from the near-surface region to the upper atmosphere.
This paper reviews the system description of the EAR, and describes first observational results of the equatorial atmosphere and ionosphere made for the first time in the West Pacific.

## I.5.520 THE NERC MST RADAR FACILITY AT ABERYSTWYTH

***David A. Hooper [1], Catherine Gaffard [2], Emily G. Norton [3] et al.***

[1]Rutherford Appleton Laboratory, United Kingdom
[2]Met Office, United Kingdom
[3]University of Wales Aberystwyth, United Kingdom

The number of instruments associated with the UK NERC (Natural Environment Research Council) MST Radar Facility at Aberystwyth (http://mst.nerc.ac.uk) has increased over the last few years. In addition to the 46.5 MHz MST Radar there is a climate data logger (for measuring surface temperature, pressure, humidity, rainfall and incoming solar radiation), a wind-vane and anemometer mounted on a 10 m tower, a 1290 MHz mobile boundary-layer wind-profiler, a mobile ozone lidar, a static ozone/aerosol/water-vapour lidar and a GPS water vapour receiver.

The mobile boundary-layer wind-profiler and lidar are owned by the University of Wales Aberystwyth under UFAM (University Facilities for Atmospheric Measurement). Other instruments and facilities within this pool are spread across different University departments within the UK. These instruments are primarily intended for use in field campaigns but the Aberystwyth components are operated at the NERC MST Radar site in-between. The static ozone/aerosol/water-vapour lidar is also owned and operated by the University of Wales Aberystwyth.

The GPS water vapour receiver is one of several owned and operated by the Met Office within the UK. These are part of a Europe-wide network to assess the operational potential for a ground-based GPS system to provide near-real-time observations of integrated water vapour (under COST-716). The Met Office also operated a 915 MHz boundary-layer wind-profiler at the MST Radar site between November 1999 and March 2002.

Data from the MST Radar, climate data logger, wind-vane and anemometer, and Met Office's boundary-layer wind-profiler are freely available to academic researchers through the British Atmospheric Data Centre (http://badc.nerc.ac.uk).

## I.5.521 VHF ATMOSPHERIC AND METEOR RADAR INSTALLATION AT DAVIS, ANTARCTICA: PRELIMINARY OBSERVATIONS

***Raymond J. Morris* [1]*, Damian J. Murphy* [1]*, Iain M. Reid* [2] *et al.***

[1]Australian Antarctic Division, Australia
[2]University of Adelaide, Australia

A 55 MHz VHF atmospheric radar was commissioned at the high-latitude station Davis (78.0E, 68.6S geographic, 74.6S magnetic), Antarctica during the austral summer of 2002-03. This paper presents an overview of this new facility and describes aspects of the design tailored for the harsh Antarctic conditions. The radar specifications as developed by Atmospheric Radar Systems will be given together with an account of the proposed science to be conducted. The radar commenced observation with 20 kW of transmitted power in mid February 2003, and is scheduled to be upgraded to 120 kW of transmitted power and a beam steering capability from October 2003. Some initial troposphere and stratosphere region wind observations will be presented.

# I.5.522 VORTICAL MOTIONS OBSERVED WITH THE NEW MCGILL VHF RADAR AND ASSOCIATED DYNAMICAL CHARACTERISTICS

***Wayne K. Hocking [1], Edwin F. Campos [2] and Isztar Zawadzki [2]***

[1]University of Western Ontario, Canada
[2]McGill University, Canada

A new ST radar located at Montreal, Canada, is described: The McGill VHF Wind Profiler. This radar has been operational since May 2002, and it is located at 45°24’33”N, 73°56’12”W, at an elevation of 30 m above sea level. It operates at a frequency of 52.0 MHz, and samples a high range between 1.5 km and 20.5 km with a resolution of typically 500 m, using better resolution at lower heights and poorer resolution at upper altitudes. A boundary layer mode will be added in due course.

Some typical data from the system are presented, as well as preliminary analysis regarding strong vortical motions. Due to the geographical location of the radar, the passage of the upper-troposphere, mid-latitude jet stream is quite frequent. Strong vortical motions have been observed during these events, and wind directions can often rotate by a full 360 degrees in only a few hours. Such structures can be quite deep, extending several kilometers up in the troposphere. Comparisons between the winds measured by the radar and the winds obtained by operational meteorological numerical models during these events are also discussed.

# I.5.523 A NEW MINIRADAR PROJECT TO INVESTIGATE THE URBAN CANOPY : THE CURIE (CANOPÉE URBAINE RADAR POUR L'INVESTIGATION DES ECHANGES : CANOPY URBAN RADAR FOR INVESTIGATION OF EXCHANGES)

***Christophe Le Gac [1], Richard Ney [2], Hervé De Feraudy [1] et al.***

[1]CETP, France
[2]CNRS/CETP, France

After many years of deep investigation on the Atmospheric Boundary Layer (ABL) using Sodar, (see for example Weill et al., 1978 and Weill, 2002, to quote some papers and to investigate in what domain acoustic sounders are not appropriated), it became obvious that in acoustically noisy atmosphere, it was very difficult to obtain accurate wind profiles in the lower part of the ABL and consequently in the whole ABL. For that noisy case several commercial acoustic sounders deliver wind information from approximated relationships which are only fulfilled in homogeneous sites. This limited wind profiling sounding range which is obvious in cities is also observed in other domains such as sea surface profiling, (Weill et al.; 1995). It must be emphasized that in urban canopy where many scientific questions are related to wind dynamics, traffic noise makes the acoustic signal not practicable. These features have led us to develop a new X band Doppler radar to document this atmospheric domain since electromagnetic waves are not perturbed by traffic acoustic noise. The task is however difficult since for an equivalent level of atmospheric turbulence, the electromagnetic waves are known to be less efficient, (Little; 1972).
1) In a first part we discuss the existing concepts of short range radars and we point out the inadequacy of FMCW techniques developed in the 70's and more recently the impressive FMCW radar developed by Eaton et al. (1995). As indeed our main goal is a very small, cheap and efficient radar for the close range of the boundary layer between 20 m and 500 m typically with a 20 m vertical resolution, a product which is lacking a FMCW radar development does not seem to be realistic mainly since a huge decoupling between transmitter and receiver is very difficult to be realized, very costly and will make hazardous the determination of the lowest gates.
2) We discuss the concept of a new profiling X band radar using a low transmission peak power and the technical issues to be solved in order to a priori cancel ground clutter inherent to urban profiling. Other limitations which have to be solved are also indicated. The minimum of turbulence intensity and the technical characteristics necessary to make relevant Doppler sounding are also investigated.
3) As a conclusion we present the main characteristics of the CURIE prototype which is being developed at CETP.

# ABSTRACTS

## SESSION PWG 1: System Calibrations and Definitions

A proper calibration of UHF/VHF wind profilers and MST radars is essential for the determination of atmospheric backscattering cross sections. Knowledge of the cross sections is used, for example, to obtain absolute radar reflectivities and their variation as function of time, location and meteorological condition. The System Calibrations and Definitions Permanent Working Group has the major task of defining such calibration procedures. Invited speakers will provide inputs on such topics as the use of sky maps as means of getting antenna efficiencies, the impact of ionospheric absorption on these sky maps, and the use of noise injection from hot loads. These will lead to open discussions among participants. Additionally, several definitions and terminologies have been introduced into the MST radar and wind profiling community. Based on a summary presented by the PWG chair persons there will be a debate as to which terms should preferably be used for particular parameters and widely applied methods.

Conveners:
*P. Chilson and J. Röttger*

# MST RADAR CALIBRATION TO OBTAIN ABSOLUTE SIGNAL POWER

***Jürgen Röttger***

Max-Planck-Institut für Aeronomie, Germany

To compare radar reflectivities of radars at different locations and different frequencies as well as to get a realistic estimate of scatter cross sections or reflection coefficients, the radars have to be well calibrated. The usually deduced signal-to-noise ratio is a most unsuitable parameter for this purpose (which often is not even properly defined), since the noise depends on frequency, siderial time, interference, radar system parameters etc. A calibration method is presented, which is applied with the SOUSY Svalbard Radar, resulting in estimates of an equivalent signal temperature (as compared to the equivalent noise temperature). This can be used to get the absolute signal power, which can be converted into radar reflectivity by including the radar system parameters, such as transmitted power, antenna gain, losses etc.

# ABSTRACTS

## Session PWG 2: Data Analysis, Validation and Parameter Deduction Methods

This working group will examine signal processing techniques used for MST radars. Topics of interest include general pre-processing (e.g., interference and clutter removal, noise level estimation), analysis techniques (e.g. Doppler, full correlation analysis, interferometry) and statistical inversion methods (e.g. maximum-likelihood methods), and post analysis techniques (e.g. consensus averaging, outlier removal, data quality indicators). Related topics such as parameter comparisons and assimilation of multiple source data into physical models for "most likely parameter" estimation will be discussed. Invited speakers will provide presentations on these topics with the aim of stimulating discussion on how current techniques may be improved.

Conveners:
*D. Holsworth, M. Yamamoto, and E. Kudeki*

# PARAMETER COMPARISON METHODS IN GEOPHYSICAL STUDIES

***Wayne K. Hocking***

University of Western Ontario, Canada

Simple linear regression is often an inadequate method to use for comparison of data acquired using different techniques in the geophysical sciences. Almost invariably all techniques have implicit errors, and spatial and temporal separations between measurements can exacerbate these differences. In this paper we present a more generalized procedure for fairer comparison between different techniques, which not only permits a more balanced study but also offers the possibility of determining the errors associated with each technique.

# FULL CORRELATION ANALYSIS: ANALYSIS MODEL, DATA SELECTION, QUALITY INDICATORS FOR SASKATOON-TYPE MFR DATA

***Chris E. Meek***

University of Saskatchewan, Canada

Correlation analysis assumes stationary statistics - viz. constant (and single) ground pattern motion, 2-D shape, scale, and "decay" rate. Most imagined departures from this model act to reduce the correlation values, which in practice, reduces the calculated speed. For example if there are independent multiple pattern motions, the correlation due to each is expected be smaller since the variance of one motion does not contribute to the correlation of the others.

In practice one analysis is applied to all data because it is (virtually) impossible to characterize each fading pattern as to its ionospheric cause and apply an appropriate analysis. In the first place those analyses are not known (nor the causes) and must be inferred by comparison with other data from experiments measuring slightly (or not so slightly) different parameters - or from models whose similarity to the real physical situation is unknown.

Data selection is usually based on fading rate, signal to noise level, and "normalized time discrepancy" - a parameter which should be zero for a moving pattern of the model described above. It can also involve the comparing the shape of the correlations to the assumed shape - usually Gaussian.

A simple post analysis quality indicator is just the density of successful analyses, which suggests quasi-stationary statistics. Another is rms normalized short-time differences in wind: (v1-v2)/(v1+v2). However since records are generally several minutes long, real wind changes may also contribute. This cannot detect a bias in speed (compared to other experiments), just internal data consistency. But it is ideal for showing the effects of system changes.

# NEW METHODS TO DEDUCE GRAVITY WAVE PARAMETERS FROM RADAR DATA

***F. S. Kuo, C. H. Liu, K. Y. Chen et al.***

Institute of Space Science, National Central University, Chung-Li, Taiwan

Vertical velocity data of the SOUSY Svalbard Radar (SSR) and the Chung-Li VHF Radar (CLR) were analyzed with two new methods:

(1) The so-called Gray-Scale method of Kuo allows the deduction of phase and group velocity of gravity waves and the separation of upward and downward moving waves. This method was applied to long data sets of vertical velocity obtained with the SSR during quiet and strong lee wave events. We assume that certain events had been found, which result from the generation of secondary waves.

(2) The Hilbert spectrum method, which is an advanced wavelet analysis applied in cases of non-linear and non-stationary time series, was utilized for analyzing a Kelvin-Helmholtz instability event observed with the CLR. By these means we can separate different wave modes.

# PARAMETRIC ESTIMATION OF SPECTRAL MOMENTS OF OVERLAPPED WEATHER DOPPLER ECHOES BY THE USE OF HIGH-RESOLUTION ALGORITHMS

***Eric Boyer [1], Monique Petitdidier [2] and Pascal Larzabal [1]***

[1]SATIE/ENS de Cachan, France
[2]CETP, France

The purpose of this work is the estimation of Doppler echoes spectral moments even in the case of strongly overlapped echoes. In such cases, Fourier like techniques provide poor results because of the lack of resolution. In a recent paper [1], we proposed the use of the MUSIC algorithm for the estimation of the first spectral moment of the echoes and we pointed out the very good resolution of this estimator in comparison with Fourier-like techniques. However, this method doesn't provide the two other spectral moments of interest (the zeroth and the second moment of the echoes).

To fill this lack, we propose the use of Stochastic Maximum Likelihood (SML) and subspace-based methods (WPSF algorithm) for a joint estimation of spectral moments. Both methods are based on a parametric modelisation of the covariance matrix of the time series. The statistical performance (theoretical and empirical by Monte Carlo simulations) of estimators are compared with the Cramer-Rao lower bound.

The proposed methods are validated on the VHF and UHF times series obtained during Thunderstorm observations at the National Astronomy and Ionosphere Center, Arecibo, PR during September and October 1998. The results obtained confirm the great potential of the method, particularly the SML method. We indeed managed to separate the contribution of the wind echo and the hydrometeor echo by the use of the only UHF time series. The reconstructed wind profile and reflectivity profile are in agreement with the corresponding profiles obtained by the use of a classical Fourier technique based on both VHF and UHF time series.

[1] Boyer E., Petitdidier M., Corneil W., Adnet C. and Larzabal P., Application of model-based spectral analysis to wind profiler radar observations. Annales Geophysicae 2001, vol.19.

# ABSTRACTS

## Session PWG 3: Accuracies and Requirements for Meteorological Applications

Observations from MST radars are finding increased application in meteorology. This workshop will deal with the accuracy, precision, and sampling requirements for those applications. Discussions will include known practical or theoretical limitations of the technique as applied in various climatic/synoptic settings (such as mid-latitude vs. tropical, tropospheric vs. stratospheric, etc.) and for observation of various meteorological variables (wind, temperature, humidity, precipitation, tropopause height, frontal surfaces, etc.). Other general or specific topics are welcome; please send your suggestions to the conveners.

Conveners:
*G. Nastrom and J. Chau*

## PROFILER ACCURACY

***Paul E. Johnston***

CIRES/NOAA Aeronomy Laboratory, United States

Classic instruments, such as voltmeters and thermometers, rely on carefully maintained standards for calibration and evaluation of instrument precision and accuracy. For MST radars, there are no calibration standards for winds and other parameters measured by these instruments. There have many comparisons with other wind-measuring techniques that give some clues as to the accuracy of profilers. Drawing on this body of literature and other calibration results can give clues as to the accuracy of the instrument. In many cases, the accuracy determination becomes a measure of geophysical noise and not a true determination of the accuracy of the instrument.

There are situations where the instrument operations can be improved to provide better data. There are also situations where the instrument will give inaccurate information. A discussion of some of these cases, and some lessons that we can learn to better operate profilers will be presented.

# ABSTRACTS

## SESSION PWG 4: International Collaborations

The session on international collaborations would be devoted primarily to four topics of current interest:

- On geographic dependence of Polar Mesospheric Summer Echoes (PMSE) - An International Observing Program. The discussion on this would aim at evolving a coordinated multi-national program for a comparative study of the intensity of PMSE at different latitudes and longitudes.
- International Multi-instrumented Campaigns: Under this the outcome of three major campaigns, a. SEEK-2 (Sporadic E Experiment in Kyushu-2), b. MUTSI (MU radar Temperature Sheets and Interferometry) and c. CPEA (Coupling Processes in the Equatorial Atmosphere), would be reviewed and recommendations made for possible follow-up campaigns.
- Multinational Atmospheric radar Projects: Collaborations of developed and developing countries. Two specific topics have been identified for detailed discussions under this item: a. TRAINER (TRopical Atmosphere INdonesian Equatorial Radar) - a potential RASC-DLR-LAPAN-ISRO collaborative program and b. ISAR (International Schools on Atmospheric Radar).
- Future direction of international collaboration with EISCAT. The discussions on this would be aimed at formulating EISCAT - based collaborative programs on middle and lower atmosphere research.

Conveners:

*P.B. Rao, S. Fukao, R. Woodman & J. Röettger*

## AN ONGOING JAPANESE PROJECT: COUPLING PROCESSES IN THE EQUATORIAL ATMOSPHERE

***Shoichiro Fukao***

Radio Science Center for Space and Atmosphere, Kyoto University, Japan

The Western Pacific region called the Indonesian Archipelago is the center of intense atmospheric motions and global atmospheric changes. The mechanisms of the atmospheric changes and fluctuations, however, have not yet been made clear due to the sparseness of observational data in that region. The current project of Japan called Coupling Processes in the Equatorial Atmosphere (CPEA) studies dynamical coupling processes in the equatorial atmosphere, primarily through atmospheric waves, from near the surface to the upper atmosphere/ionosphere by conducting various observations in the Indonesian equatorial region, centered on the Equatorial Atmosphere Radar (EAR). The EAR has been operated right at the equator in West Sumatra, Indonesia (0.20°S, 100.32°E, 865 m above sea level) since March 2001 under the bilateral collaboration between the Radio Science Center for Space and Atmosphere, Kyoto University and the National Institute of Aeronautics and Space (LAPAN) of Indonesia. This project is scheduled for the period from September 2001 to March 2007.

# REPORT ON THE THIRD INTERNATIONAL SCHOOL ON ATMOSPHERIC RADAR – ISAR3 – HELD IN NOVEMBER/DECEMBER AT THE ABDUS SALAM INTERNATIONAL CENTER FOR THEORETICAL PHYSICS IN TRIESTE, ITALY

***Jürgen Röttger***

Max-Planck-Institut für Aeronomie, Germany

This school was the third in its role following ISAR-1 in 1988 in Kyoto, Japan, and ISAR-2 in 1995 in Hilton Head, USA. These schools are part of the activities in the scientific and engineering community using radars for studies of the Earth's atmosphere and ionosphere. In particular the mesosphere-stratosphere-troposphere (MST) radars have become major research tools in these applications. A proper knowledge of the basic methods, proper analysis, validation and interpretation of the acquired data, basing on the main theoretical background of atmospheric physics, informatics and technology is demanded for such efficient applications. The school ISAR-3 was particularly held for the purpose of training young researchers and students, who are active in or have proven relations to this area, or could certify a solid interest and a sound perspective on this research and this technique.
The school covered the main subjects of fundamentals of atmospheric radar, hardware and basics of signal acquisition, data analysis and special applications such as interferometry, scattering of radar waves, atmospheric winds waves and turbulence, meteorology of the troposphere and the stratosphere, the mesosphere and the aeronomy of the lower ionosphere. Besides lectures also interactive computer training was applied, intense group and individual discussions were held, and the participants were given opportunity to present short papers on their own research or education.

The school ISAR-3 was held at the excellent premises of the Abdus Salam International Center for Theoretical Physics (ICTP) in Trieste, Italy, which also provided the majority of funding for these school activities. Additionally the ISAR-3 was sponsored and funded by the Scientific Committee on Solar Terrestrial Physics (SCOSTEP) and the International Union of Radio Science (URSI). From a total of 140 applicants 28 participants were selected. These were from 17, mostly developing, countries.

The lecturers, well known as researchers in the MST radar field, were Prof. P. Chilson, USA , Prof. S. Fukao, Japan, Prof. W. Hocking, Canada, Prof. R. Palmer, USA, Prof. S. Radicella, Italy, Prof. D.N. Rao, India, and Prof. J. Röttger, Germany. The latter acted as school director, codirected by Prof. Rao and Prof. Radicella.
Our thanks are directed to ICTP for providing the funding, facilities, housing, food, administration and school secretariat as well as outstanding computing support and well-equipped lecture and training halls. This helped very impressively to hold the ISAR-3 in a very suitable environment and most pleasant atmosphere.

The highly positive response of the students of ISAR-3 on the performance of this school and the obvious great demand for this kind of education and training let us hope that we may have ISAR-4 at the same place in 2004 or 2005.

# ABSTRACTS

## Session II.E: NOVEL PERSPECTIVES AND UNSOLVED ISSUES SESSIONS

Conveners:
*P. Chilson, S. Fukao & J. Röttger*

# II.E.1 AN ADAPTIVE CLUTTER REJECTION SCHEME FOR MST RADARS

***Toru Sato and Kazunori Kamio***

Department of Communications and Computer Engineering, Kyoto University, Japan

## Background and Objectives

Clutter rejection is among the most important issues in radar signal processing, for which adaptive antenna technique is a powerful means. Compared to other applications of the adaptive antenna, however, atmospheric radars require strict conditions; The main antenna beam pattern should not be altered since the target region is defined by its shape. Especially, the loss of the antenna gain should be kept to no more than about 0.5dB in order to maintain the high sensitivity of the system. Also, clutter from surrounding mountains is often stronger than the desired weak scattering from atmospheric turbulence. Here we propose a new algorithm which satisfies the above conditions, and confirm its capability by applying to actual radar data.

## Proposed System and Algorithm

We consider the MU radar of Kyoto University, Japan, as an example. We regard the entire array of the radar as a single main antenna, and arrange a receiving sub-array consisting of several antenna elements, of which the complex weight (amplitude and phase) is controlled for adaptation, around the main antenna. By controlling the weight of only the sub-array, complexity of the adaptive processing is drastically reduced. Also, this system can be easily applied to existing radar systems.

Principle of conventional DCMP(Directionally Constrained Minimum Power) algorithm is to minimize the output power under the constraint of a fixed output power at a desired direction. Here we further apply an alternate condition that forces that the norm of the weight should be less than a given value, which is set to be sufficiently lower than the main lobe level, but not to affect the weight control of the sidelobe region. This second constraint assures that the entire main lobe pattern is not affected by the weight control. Here we call this algorithm as `DCMP Constrained Norm' (DCMP-CN) in contrast to conventional DCMP. This minimization problem with an equality constraint and an inequality condition is solved by using penalty function method.

## Performance with Real Data

We examined the performance of the proposed scheme by applying to the data taken with the MU radar. Three antenna elements at the outer edge of the main array are separately connected to receivers to constitute the sub-array. The main beam of the antenna is pointed to 10 degree from zenith. While the conventional DCMP method can suppress the spike at zero Doppler velocity in the echo power spectra, which corresponds to the ground clutter, it causes a side effect of increased noise level. In contrast, the proposed DCMP-CN successfully suppresses the clutter component without affecting the atmospheric or noise components of the spectra. It should be noted that we assume no information on the echo power spectrum such as the narrow clutter spectrum, so that the technique can be, in principle, applied to suppress any type of clutters.

The major limitation of the current algorithm is that the covariance matrix of the received signal should be averaged for a period longer then the correlation time of the signal in order to discriminate it from the clutter. It is thus difficult to cancel clutters with rapid change of directions, such as airplane echoes. Even for such cases, however, limited suppression is achieved, which is quite helpful in further reduction via various signal processing techniques.

## II.E.2 DIAGNOSTIC CAPABILITIES OF MEASUREMENTS OF BACKSCATTER ANISOTROPY

***Wayne K. Hocking***

University of Western Ontario, Canada

The study of anisotropy in backscatter from radio-wave scatterers has had a long history, and has played a significant role in helping to establish the importance of anistropic turbulence in the atmosphere. The assumption of isotropy in turbulence is simply not valid at these scales. It has also been instrumental in permitting recognition of the importance of specular reflectors in the atmosphere. The degree of anisotropy can sometimes be used as a measure of atmospheric stability, and can be used to define the height of the tropopause. New developments with the J.S. Marshall VHF radar at McGill University have shown new evidence that this same parameter can be used as a forecast diagnostic for rain and precipitation, especially during non-winter months. The history of anisotropy will be discussed, previous applications summarized, and the new evidence will be presented.

## II.E.3 WHAT IS THE FUTURE OF THE MULTI-FREQUENCY TECHNIQUES?

***Hubert Luce***

LSEET/Toulon University, France

Since the radial resolution of MST radars is limited by their pulse length, dual frequency-domain interferometry (FDI) and multi-FDI (called FII/RIM) techniques have been proposed by different authors and applied to different VHF and UHF radars with various high-resolution data processing methods. Simulations and observations proved in the past that these techniques have considerable potentialities for detecting very thin atmospheric structures, invisible when using the standard mode. Some recent results will be shown. However, can we be confident about the (multi)FDI observations? Especially at VHF, are the images the signature of real atmospheric structures? Should we introduce new filtering methods and/or other approaches for processing the data? All the questions will be debated during the brain-storming.

# II.E.5 WHAT IS TURBULENCE SEEN BY VHF RADAR?

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Most analysis techniques applied to MST radar signals base on the presumption that basic rules of statistics can be applied, which describe the nature of turbulence. Experimental evidence, though, exists that MST radar echoes are from an inhomogeneous, partially quite non-turbulent medium, which seldom does comply to Gaussian statistics for typically applied averaging periods. Since this had been known from the beginning of atmospheric radar observations, in particular when applying VHF radars, a brief historical reminder will be presented here. It will be stressed that observations with high angular and range resolution are needed (requiring particular system adjustments) to fully understand the “turbulence scattering mechanism” causing the VHF radar echoes. These could replace the sophisticated statistical data analysis methods, which require assumptions on the statistical properties of the scattering/reflecting medium, which may not replicate nature.

## II.E.7 APPLICATIONS OF A WORLD-WIDE NETWORK OF MESOSPHERIC RADARS, WITH SPECIAL EMPHASIS ON THE COLUMBIA SPACE SHUTTLE DISASTER

***Wayne K. Hocking [1], N. Mitchell [2], Steve Franke [3] et al.***

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Dynamical motions in the mesosphere are some of the most intense in the Earth's atmosphere. Gravity waves, tides and planetary waves are in continual complex motion, and hurricane-strength winds exceeding 80 m/s (300 km/hr) are not unusual. Intense turbulence dissipation is not uncommon. The region is, however, often ignored, largely because (i) it is high above our heads and (ii) densities are so low that the impact of the motions are diminished compared to interactions in the much more dense troposphere.

The region also has the possibility to affect rocket and Shuttle launches, but in general the effects are not severe because of the diminished densities at these heights. However, extrema in dynamical quantities can possibly have an impact. In this talk, we demonstrate the value of a world-wide network of middle atmosphere radars for understanding this region, and as a particular example we use data from a network of equatorial radars to reconstruct the wind field experienced by the Space Shuttle Columbia during its final minutes. An important result is a large wind shear deduced to have occurred at 60 to 65 km altitude over Texas at the time that Columbia passed through, due to an unfortunate alignment of the 2-day wave and the diurnal tide. The extent to which this may have contributed to the destruction of Columbia is under investigation.

## II.E.8 THE STRUCTURE FUNCTION-BASED APPROACH TO DATA ANALYSIS FOR SPACED ANTENNA RADARS: A COMPARISON WITH TRADITIONAL TECHNIQUES

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Traditional methods of data analysis for spaced antenna (SA) radars deploy cross and auto correlation functions (CF) and spectra (SP) of multiple received signals for retrieving the mean velocity components, turbulence intensity, and other characteristics of a scattering medium. Cross and auto structure functions (SF) represent an alternative tool for such an analysis. The major advantage of the SF-based approach with respect to the CF and SP-based approaches is that SF of received signals can be derived and applied to practical measurements for any order equal or larger the second; the higher-order SF provide supplemental information about a scattering medium. On the contrary, only the second order CF have been used in SA methods, and SP are the second order functions as well. Other advantages of the SF-based approach are the following:

- Relations between parameters of SF and characteristics of the diffraction pattern and a scattering medium can be derived with a smaller number of less restrictive assumptions than the corresponding relation for CF and SP. More universal and asymptotically exact equations for SF provide a deeper insight and more rigorous theoretical background for SA methods.
- Turbulence characteristics can be related to the SF parameters more rigorously than to parameters of CF and SP. Moreover, the intensity of all three turbulent velocity components and the higher-order moments of the vertical component can be estimated with SF. These characteristics can be estimated with neither CF, nor SP-based techniques.
- Contrary to CF, SF are not very sensitive to noise components with a large temporal correlation lag such as ground clutter and point targets.
- Using SF-based approach, one can increase signal-to-noise-ratio of received signals by applying highly overlapping receiving antennas. The major shortcomings of the SF-based approach with respect to the CF and SP-based approaches are the following.
- SF can be applied only to scalar processes such as the signal's power or amplitude. This results in losing information on the radial (vertical) mean velocity component.
- SF are much stronger affected by noise with a zero temporal correlation lag (a white noise) than CF and SP. Therefore, more sophisticated noise treatment is required for SF-based methods than that for CF and SP-based methods.
- SF-based approach imposes more restrictive limitations on a SA radar than CF and SP-based approaches. In particular, it requires the receiver centers to be closer to each other, and the sampling interval to be smaller.

It is concluded that, depending on measurement conditions, characteristics of a scattering medium can be estimated more effectively with either CF and SP, or SF. The SF-based approach can become a useful alternative to the CF and SP-based approaches, and a combination of several techniques may be optimum.

# II.E.9 VHF PARASITIC RADAR INTERFEROMETRY FOR MST ZENITH SOUNDING

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With only occasional breaks during the past 3 years the Manastash Ridge Radar has been providing continuous, unattended Range-Doppler studies of meter-scale irregularities in the high latitude ionosphere. This radar observes the scatter of commercial FM broadcasts, and by fully decorrelating the transmitted signal with the scattering signal superb range, Doppler, and time resolution is achieved with very low cost, negligible interference, and inherent operator safety.

A very similar system could in principle support MST radar studies. Such a system would include a pair (or a network) of geographically distributed receivers, with typical spacing of 100 km. These receivers would be synchronized with GPS clocks, and provide near-zenith sounding with a forward scatter path. This geometry would provide access to decameter irregularities and sharp gradients. With the provision of an interferometric antenna system, it should be possible to detect some or all components of drifts, as well as layer tilts.

Although this bistatic topology immediately resembles the Manastash Ridge Radar, some differences will arise for MST work. First, the scattering cross section of the MST targets is smaller than that of E region irregularities. This can be addressed by building larger antenna systems. However, the Doppler content of MST echoes is much smaller than auroral turbulence, and this will permit tens of dB greater sensitivity through coherent integration. In order to achieve this sensitivity, higher synchronization performance may be required from the GPS clocks; this performance may be obtained by using ground clutter to measure net phase and frequency difference between clocks.

We will show examples of MRR power spectra and interferometry, and provide possible scenarios for MST observations at low and high latitudes.

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