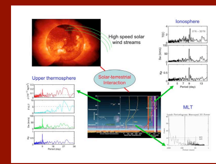
The CEDAR Post

Coupling, Energetics and Dynamics of Atmospheric Regions






http://cedarweb.hao.ucar.edu

Fall 2009 Issue 56

From the CSSC Chair

Welcome to the fall issue of the CEDAR Post. This issue highlights the NSF small satellite program and profiles two missions preparing for launch opportunities. There are highlights and summaries from the CEDAR 2009 summer workshop and community research activities.

Thank you, Dr. Fesen

I want to acknowledge Dr. Cassandra Fesen for her efforts with the CEDAR Program as NSF Aeronomy Program Manager over the past 2.5 years. We wish her the best in her new position as Program Manager for Space Sciences at AFOSR.

CEDAR Strategic Plan

The CEDAR strategic plan is moving forward and significant discussion was dedicated to this new dimension of CEDAR at the recent CSSC meeting held at the NSF Oct 26 and 27, 2009. A draft of the plan should become available by the 2010 summer meeting.

CEDAR Post All Electronic

The CEDAR Post is going completely electronic by next year. Those who want to continue to receive the paper mailings will need to contact Barbara Emery, emery@ucar.edu, to get on the mailing list.

2010 CEDAR Workshop

The 2010 CEDAR workshop will return to Boulder, June 20-25 and will mark the 25th anniversary of CEDAR. Celebratory activities are planned and suggestions are welcome. As details become available, they will be posted on the CEDAR wiki.

We look forward to seeing you!

Jeff Thayer, University of Colorado

INSIDE THIS ISSUE

Updates from NSF

NSF News

ATM is now AGS

The Atmospheric Sciences Division at NSF, known as ATM, has changed its name to Atmospheric and Geospace Sciences, or AGS, in order to better reflect the research thrusts of the division.

New Program Director for Aeronomy

Dr. Farzad Kamalabadi of the University of Illinois at Urbana Champaign will join NSF in November as the Program Director for Aeronomy, replacing Cassandra Fesen who joined the Air Force Office of Scientific Research as the Program Manager for Space Sciences. Dr. Kamalabadi's email address at NSF is fkamalab@nsf.gov.

CEDAR competition

The CEDAR FY10 competition received a total of 35 proposals. There were five collaborations, for a total of 30 independent projects. The total first-year funds requested were about $3M.

MRI Competition

For the FY09 MRI competition, there was one proposal submitted to the Aeronomy program and it was selected for funding. Congratulations to Marilia Samara and Robert Michell of Southwest Research Institute for their project entitled "MRI: Acquisition of a Suite of Advanced Imagers for Auroral and Upper Atmospheric Research".

For the second MRI competition, the Aeronomy Program received five proposals. Over 1200 proposals were submitted to NSF for this competition, so that the success rate is expected to be quite low: around 20%. Decisions are anticipated to be made around December or January.

Space Weather

A Space Weather competition will be held in January 2010. The announcement can be viewed at the NSF website: http://www.nsf.gov/pubs/2007/nsf07520/nsf07520.htm.

Update on Resolute Bay

The North-looking face of the Resolute Bay AMISR (RISR-N) is now operational. The radar was used to support a 10-day incoherent scatter World Day run in September and the data from that shake-down run will soon be available via the Madrigal Database (http://isr.sri.com/madrigal/). A limited set of operating configurations are available at this time, but this suite of options will be expanded in response to user requests. Requests for observing time on RISR-N can be sent to Craig Heinselman (craig.heinselman@sri.com) and Mary McCready (mary.mccready@sri.com), stating desired dates and time of operation, radar modes (if known), scientific objectives, necessary geophysical conditions, and additional instrumentation requirements. Information on AMISR can be found at http://isr.sri.com/iono/amisr/.

The support structure for the South-looking radar (RISR-S) has now been completed. The University of Calgary, in partnership with other institutions in the U. S. and Canada, has successfully secured funds from the Canadian Foundation for Innovation and the Province of Saskatchewan for purchasing antenna panels to populate this AMISR face.

Arecibo heater project

Construction work continues on the high frequency (HF) heating facility at Arecibo with site preparation activities progressing well, including the installation of the surplus transmitters acquired from the U. S. Air Force. The Cassegrain antenna system design is nearing finalization, and antenna fabrication is expected to begin soon. The general expectation is that final commissioning of the HF facility may have to wait until after the 2010 Atlantic hurricane season. Funds for the construction of the heater were provided by NSF, AFOSR, and ONR.

NCAR/HAO News

A search is underway for a new director of the High Altitude Observatory (HAO) at NCAR following Michael Knoelker's decision to leave the post he held for fourteen years. He will remain at HAO as a senior scientist after a one-year sabbatical. Stan Solomon is the acting director while the search is underway. NCAR is also undergoing some internal restructuring; as a result, the director of HAO will report to the director of NCAR, Eric Barron, rather than to the head of the Earth and Sun System Laboratory as in the past.

- Cassandra Fesen, Robert Robinson and Paul Morris, NSF Program Managers

CEDAR Postdoctoral Competition

The FY10 CEDAR Postdoctoral Competition had a near-record number of submissions: twelve proposals. Thanks to the funds received from the American Recovery and Reinvestment Act, the Aeronomy Program was able to make five awards. The successful proposers are listed below in alphabetical order.

Jonathan Fentzke, from the University of Colorado Boulder. Advisor: Xinzhao Chu. He will work with Diego Janches at Northwest Research Institute on Meteoric Smoke Studies at High Latitude using the Poker Flat ISR.

Brian Laughman, from the University of Colorado Boulder. Thesis advisor: David Fritts. He will continue working with Dr. Fritts at Northwest Research Institute on Numerical Modeling of Mesospheric Bores, Nonlinear Ducted Waves, and Interpretation of Observations in the Middle Atmosphere.

Ethan Miller, from the University of Illinois at Urbana-Champaign. Advisor: Jonathan Makela. He will work with Elsayed Talaat at Johns Hopkins University on Coordinated Optical and Radar Observations of the Ionosphere and Thermosphere.

Deepali Saran, from Indiana University. She will work with Tom Slanger at SRI International on Aeronomical and Spectroscopic Studies of Key Airglow Features at High/Low Latitudes.

Brentha Thurairajan, from the U. of Alaska Fairbanks. Advisor: Richard Collins. She will work with Scott Bailey at Virginia Tech, on Polar Mesospheric Cloud Structures as Evidence of Coupling Between the Upper and Lower Atmosphere.

- *Cassandra Fesen, NSF Program Manager*

Update on the NSF Cubesat Program

As part of the American Recovery and Reinvestment Act an additional two CubeSat projects have just been awarded. These were selected amongst the proposals submitted in response to the first CubeSat solicitation in 2008. Both are truly excellent science projects within their area and, in addition, stand out by both being double spacecraft missions, which makes them perfect pathfinders for the ultimate goal of cubesat constellation missions.

The Dynamic Ionosphere CubeSat Experiment (DICE) project is a collaboration between space scientists and engineers at Utah State University, ASTRA LLC, Embry-Riddle University, and Clemson University, led by Geoff Crowley of ASTRA. The mission consists of a set of 1.5U CubeSats each carrying a DC Probe to measure in-situ ionospheric plasma densities, and an Electric Field Probe to measure DC and AC electric fields. The satellites will slowly separate over time to a distance of the order of 300km by the end of the mission. The objective of the project is the accurate identification of storm-time features in the distribution of ionospheric plasma, such as the Storm Enhanced Density (SED) bulge and plume, together with simultaneous co-located electric field measurements, something which have previously been missing. The science questions that the DICE measurements will help address include: the understanding of how exactly the greatly enhanced plasma is formed over the southern USA (the SED bulge) and what is the source of the plasma; what physical drivers are involved in the formation and evolution of the SED plume, and what is their relative importance; and, finally, what is the precise relationship between the occurrence of penetration electric fields, the subsequent expansion of the Appleton anomaly crests, and the development of SED, particularly in terms of why there is an apparent preference for the USA geographic sector.

The Focused Investigations of Relativistic Electron Burst Intensity, Range, and Dynamics (FIREBIRD) project is a collaboration between Harlan Spence of Boston University and Dave Klumpar of Montana State University. The mission consists of a set of 1.5U CubeSats each carrying a single large-geometry-factor, solid-state detector measuring 30keV-3MeV electrons with high time resolution. The satellites will slowly separate over time to a distance of the order of 300km by the end of the mission. The goal of the FIREBIRD mission is to resolve the spatial scale size and energy dependence of electron microbursts in the Van Allen radiation belts. Relativistic electron microbursts appear as short durations of intense electron precipitation measured by particle detectors on low altitude spacecraft, seen when their orbits cross magnetic field lines which thread the outer radiation belt. While microbursts are thought to be a significant loss mechanism for relativistic electrons, they remain poorly understood, thus rendering space weather models of Earth's radiation belts incomplete. FIREBIRD's unique two-point, focused observations at low altitudes will help address three fundamental scientific questions with space weather implications: What is the spatial scale size of an individual microburst?; What is the energy dependence of an individual microburst?; and How much total electron loss from the radiation belts do microbursts produce globally?

For the second CubeSat solicitation with deadline in May 2009 we received proposals for a total of 26 new missions. Like for the first solicitation, the quality of the proposals both in terms of scientific creativity and technological innovation was exceptional. We expect to be able to fund two projects from this solicitation. One award has already been made.

The mission is the CubeSat for Ions, Neutrals, Electron, and Magnetic Fields (CINEMA). PI on the project is Robert Lin of University of California at Berkeley. It is a 3U Cubesat carrying a particle sensor and a magnetometer. The particle instrument is a further development of a particle sensor that was flown on the NASA STEREO mission. The Supra-thermal Electrons, Ions, Neutrals (STEIN) instrument is an enhancement of STEREO/STE, including an electrostatic deflector. CINEMA's STEIN instrument will image ring current and substorm injected particles in local time at a cadence as fast as 30 s (spin period), through 4-20 keV (energy range of the bulk of ring current ions) ENA measurements with high sensitivity and energy resolution (~1 keV). In addition, CINEMA will provide in situ electron and ion measurements extending from ~2-4 keV to ~100 keV from a single detector. The magnetometer will be supplied by Imperial College. It uses a magneto resistive element and will be deployed on a spring-loaded 1m long boom. The measurements from CINEMA will be used to image the ring current and substorm injected particles in local time, provide a quantitative evaluation of ring-current precipitation losses, and measure the scale size of the wave-particle interaction regions.

An extensive national and international team will contribute to the project. Partners include NASA Ames, Inter American University of Puerto Rico, Johns Hopkins University/APL, Kyung-Hee University, Korea, and Imperial College London, U.K. Specifically, KHU will provide a second identical CINEMA spacecraft (in orbit), developed with Korean World Class University (WCU) program funding. The plan is that both spacecraft be launched into high inclination low Earth orbits in 2011 for a one-year nominal science mission. The double CINEMA project will provide unique, high sensitivity ENA mapping and high cadence movies of ring current ENAs in stereo from low earth orbit. It will also make 2-point direct supra-thermal electron and ion measurements in the auroral and ring current precipitation regions and elsewhere in the magnetosphere.

- *Theresa Moretto, NSF Program Manager*

Small Satellite Program

CubeSat-based ground-to-space bi-static radar experiment: Radio Aurora eXplorer (RAX)

Radio Aurora Explorer (RAX) mission is a ground-to-space bi-static radar experiment to measure mid- and high-latitude ionospheric meter-scale field-aligned irregularities (FAI). This is the first CubeSat being constructed under the NSF CubeSat-based Space Weather and Atmospheric Research Program. The project is being carried out jointly by SRI International and the University of Michigan, between September 2008 and August 2011. The first launch opportunity will be via the Department of Defense Space Test Program, currently set for May 2010, aboard a Minotaur-4 vehicle from Kodiak, Alaska. NASA Goddard Space Flight Center's Wallops Flight Facility provides launch support for the mission.

The primary scientific objective of the RAX mission is to understand the microphysics of plasma instabilities that lead to FAI of electron density in the polar lower (80-300 km) ionosphere. Unlike the FAI in the equatorial ionosphere, high horizontal and altitudinal resolution measurements of high latitude FAI have not been possible mainly because it is difficult to achieve a scattering geometry normal to the magnetic field lines, which are nearly vertical in the high latitudes. Coherent scatter radars can be pointed to very low elevations to scatter off normally, however, these radars cannot make height-resolved measurements because the beam width in the vertical direction is too wide or because refraction causes source location ambiguity. Moreover, ionospheric altitudes below ~300 km are beyond the reach of orbiting spacecraft. Sounding rockets measured FAI with the highest altitude resolution, yet they are not sufficiently sensitive to sort out wave energy in magnetic aspect angle.

The RAX mission is specifically designed to remotely measure, with high angular resolution (~0.5°), the 3-D k-spectrum (spatial Fourier transform) of ~1 m scale FAI as a function of altitude, in particular measuring the magnetic field alignment of the irregularities. The spacecraft will measure``radio aurora", the Bragg scattering from FAI that are illuminated with a narrow beam incoherent scatter radar (ISR) on the ground. The scattering locations are determined using a GPS-based synchronization between ISR transmissions and satellite receptions and the assumption that the scattering occurs only inside the narrow ISR beam.

Figure 1 shows a drawing of the irregularities (red wiggles), the magnetic field lines, the radar beam, radio aurora (cones) and the satellite (cubes), and the satellite tracks. The irregularities inside the narrow radar beam and at a given altitude scatter the signals in a hollow cone shape. The thickness of the wall of each cone is a measure of magnetic aspect sensitivity, which is also a measure of plasma wave energy distribution in the parallel and perpendicular directions with respect to the geomagnetic field.

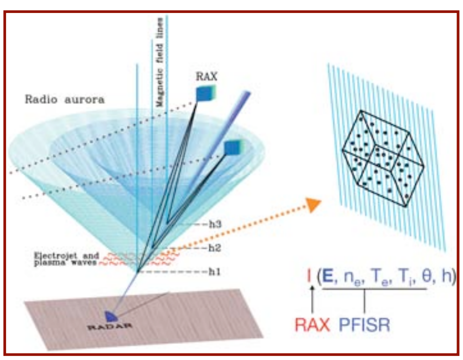


Figure 1. An illustration of the RAX experiment.

The main RAX science data product is I(E, Ne, Te, Ti, h, θ), that is, irregularity intensity (I) as a function of convection electric field (E), electron density (Ne), electron and ion temperatures (Te, Ti), altitude (h), and magnetic aspect angle (theta). RAX measures I, the ISR measures the plasma parameters, and (h, θ) are given by the experimental geometry. Table 1 shows the list of potential plasma waves making up the meter-scale irregularities in the ionospheric E and F regions. Radar returns will be analyzed to identify the waves responsible for radar scatter and to determine the ionospheric conditions leading to the corresponding plasma instabilities.

Plasma wave/instability	Region of observation	Previously detected	Scales
Farley-Buneman	E	Y	0.1 - 10 m
Electrostatic ion-cyclotron	F	Y	1 - 20 m
Post-Rosenbluth	F	N	10 - 20 cm
Lower hybrid	E/F with HF heater	Y	< 1 m
Upper hybrid	> 125 km	N	10 - 15 cm

Table 1. Plasma waves responsible for radar scattering.

Status

The critical design review was held in March 2009. Currently the satellite delivery date is in January 2010. Prof. James Cutler's UMich team is starting satellite vibration/thermal/vacuum testing of an engineering unit in October 2009, and flight unit assembly is scheduled for November 2009. A test version of the radar receiver payload was constructed by SRI in July 2009 and initial data acquisition and radar signal processing software tests were done in August 2009. The flight version of the payload is expected for final integration in early November, 2009.

System capabilities

The payload receiver operates in a snapshot acquisition mode collecting raw samples at 1 MHz for 300 s over

the experimental zone. Following each experiment, the raw data is post-processed for range-time-intensity and Doppler spectrum. The snapshot raw data acquisition enables flexibility in forming different radar pulse shapes and patterns. In addition, PFISR electronic beam steering capability can be utilized for simultaneous multiple beam position experiments.
The system angular and spatial resolutions depend on the scattering geometry which is a function of the satellite position. The radar resolutions at optimal satellite position are ~3-5 km spatial and ~0.5° angular.

In the scattering zone (magnetic aspect angles less than 3°), radar Bragg wavelength also depends on the satellite position and ranges between 0.4-2.0 m, with a concentration near 0.5 m. Also, for a given altitude and magnetic aspect angle, the satellite will cross a cone at two points during a single experiment. The two crossings will provide measurements at two different radar Bragg wavelengths (and flow angles), corresponding to measurements at a pair of k-spectrum points.

The radar sensitivity is nearly (to a few dB) equivalent to that of the mono-static Homer UHF radar which operated from Homer, AK in 1970s. Figure 2 shows the two statistical distributions of Homer radar received power from auroral electrojet irregularities for two different observation periods. The bottom axis is rescaled for RAX.

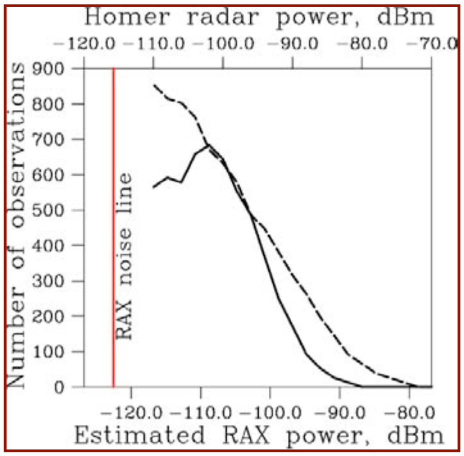


Figure 2. Statistical distribution of RAX received power.

The radar receiver is capable of operation with the 5 UHF ISRs shown in Table 2. The receiver can also operate with the MUIR radar located at the HAARP facility in Gakona, AK, as part of active experiments. However, the sensitivity to HF heater induced artificial FAI has not been calculated.

ISR	Freq. MHz	Power MW	BW	Inv. Lat.
PFISR	449.0	2.0	1.0	78
RISR	443.0	2.0	1.0	81
ESR	500.0	1.0	0.6	75
Millstone	440.0	2.5	0.6	53
Arecibo	430.0	2.5	0.2	34

Table 2. The list of ISRs compatible with the RAX receiver.

The satellite can perform 2-3 experiments per day. Figure 3 shows the 1-min satellite tracks that pass through the scattering zone. There are ~1000 passes good for experiments in the 1- year mission lifetime. However, based on DE-2 electric field statistics, approximately 1 out of 5 experimental passes will have an electrojet speed above the two-stream instability threshold, resulting in electrojet irregularities.

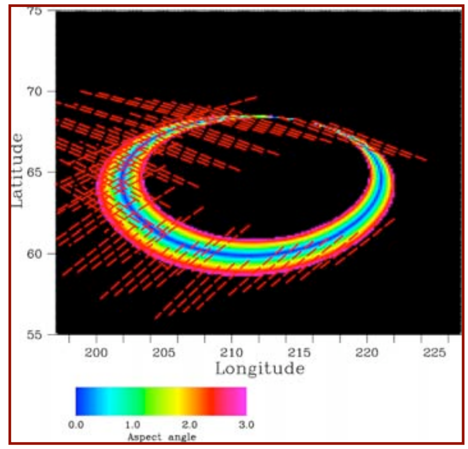


Figure 3. The loci of perpendicularity (< 3°) and 1 min satellite tracks over the experimental zone for 30 days.

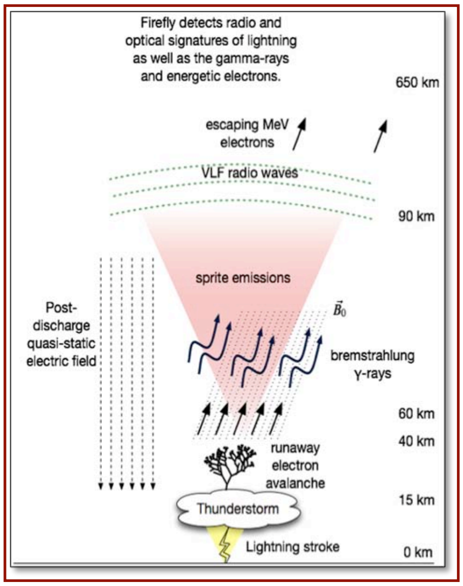
Plans

Once the satellite is launched, after initial checkout, we will start twice-a-day automated experiments with PFISR for six months or until mission objectives are met. Campaign-based experiments with other ISRs and active experiments with MUIR will be planned thereafter based on community input. For further information please contact Hasan Bahcivan (hasan.bahcivan@sri.com) or James Cutler (gwcutler@umich.edu).

- *Hasan Bahcivan, SRI International*

An Brief Update on the NSF Firefly CubeSat Program

Firefly is the second CubeSat (4.0 kg, 10 x10 x 34 cm) funded by the National Science Foundation as part of a series of CubeSat missions focused on the study the Earth's upper atmosphere and space weather. Firefly will investigate in depth the linkage between lightning and Terrestrial Gamma-Ray Flashes (TGFs) by combining a gamma-ray/electron scintillation detector, VLF radio receiver, and optical photometers to perform the first simultaneous measurements of lightning and TGFs from a single platform.



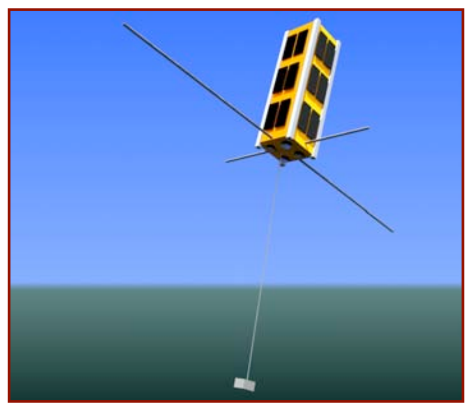
Early space-based observations of TGFs by the Compton Gamma Ray Observatory (CGRO) and the Reuven Ramaty High-Energy Solar Spectroscopic Imager (RHESSI) showed that TGFs are brief (1 ms long) and intense (flux higher than a solar flare, spectrum harder than cosmic gamma ray bursts) bursts of gamma-rays originating from the Earth's atmosphere during times of intense thunderstorm activity. Such emissions are of inherent interest as they possibly result from the most powerful natural particle acceleration process on Earth, in which thermal electrons are energized to tens of MeV in less than 1 millisecond. These energized electrons create bremstrahlung gamma and x-rays, which can be observed from orbiting platforms, and the electrons themselves, may escape to magnetospheric altitudes and populate the inner electron radiation belt.

Firefly's primary goal is to unambiguously determine if TGF are produced by lightning, and to determine the characteristics of lightning that produce the fluxes of gamma rays observed at high altitude. This information will strongly constrain the processes that accelerate electrons above thunderstorms. Specifically, Firefly will address the following questions:

- What types of lightning do and do not produce TGFs?
- What is the occurrence rate of weak TGFs?
- How strong are TGFs, and to what extent were previous measurements affected by pileup and detector limitations?
- What is the relative timing of gamma ray, optical, and VLF signatures of TGFs?
- What are the characteristics of energetic electrons associated with TGFs?

The primary scientific instruments onboard Firefly are the gamma-ray detector (GRD), which will measure the energy and arrival time of x-ray and gamma-ray photons as well as the energetic electron flux, and the Optical Lightning Detector (OpLiDe) that detects the arrival time of the optical signal associated with lightning. Both of these systems are capable of time tagging the arrival of events to within a microsecond of on-board time. The GRD consists of a scintillator crystal (phosphor sandwich design or "phoswich"), comprised of a GYSO(Ce) and Europium doped CaF2 in a light-tight enclosure; a "Burle Planacon" photomultiplier converts the scintillation light into an amplified electrical signal for detection.

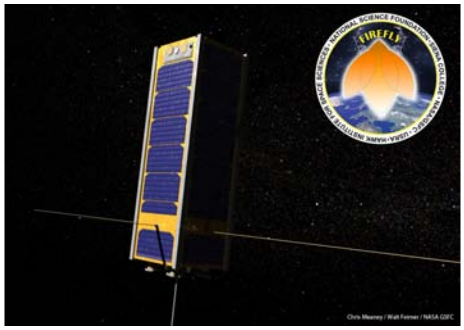
At NASA/GSFC, University of Maryland undergraduate engineering students helped design and test a prototype of the GRD electronics during their 2009 summer internship and successfully discriminated between energetic electrons (which produce a long-decay-time pulse of scintillation light) and energetic gamma-rays (rapid-decaying pulse). Preliminary estimates indicate that Firefly will be sensitive to electrons in the energy range of 2 to 5 MeV and photons from approximately 50 keV to 10 MeV; higher energy photons should be detectable, but not fully resolved. The bench-top set-up (including front-end electronics and prototype detector) will be further characterized at the GSFC electron beam facility and tested from 150 keV up to 1.6 MeV. Monte Carlo-type simulations of radiation interactions in the spacecraft and detector are also underway using GEANT, the open-source toolkit designed for high-energy physics applications.



The OpLiDe design is also completed and currently in the construction/testing phase at Siena College. This instrument will help definitively determine the portion of the lightning event during which the gamma rays were generated, which will in turn lead to an understanding of the fundamental physics involved in the generation of TGFs. The OpLiDe is constructed by using four overlapping

Hamamatsu silicon PIN photodiodes which provide localization of lightning to one of twelve regions. Three photodiodes will have visible/wide pass band filters, while the fourth will have a narrow band OI 777.4 nm spectral filter. The inclusion of the 777.4 nm filter will enable some discrimination of lightning and sprites, and will provide information on the lightning current moment waveforms. Students have been actively involved in the calculations for the field of view of OpLiDe and the design of the field stop for each of the OpLiDe detectors.

A secondary experiment, which will greatly expand the quality of the science for Firefly, is the VLF receiver. This instrument consists of a 1.6 m tip-to-tip dipole antenna that will be deployed to measure electric field signatures in the range of 500 Hz to 500 kHz using selectable filters set at 16 kHz, 32 kHz, and 500 kHz. Students are developing modules in Matlab that will process the data received from the VLF receiver. Some of these algorithms include variable filters and FFTs. Other Siena College student activities in support of Firefly include the analysis of the orbital parameters for the Firefly mission, the design of an inexpensive ground station, and the design of the Firefly mission logo.



The Firefly team is a collaborative effort between the NASA/GSFC, USRA and Siena College, with the Hawk Institute for Space Sciences serving as the spacecraft bus provider. Students are, and continue to be, involved in all aspects of the project, from design and development, through fabrication and test, to mission operations and data analysis; so far, 16 undergraduate and high school students have significantly contributed to the project. Firefly will help to train undergraduates, as they get hands-on experience designing, building, testing, and operating the spacecraft, as well as analyzing the data. These students will get a chance to travel to national meetings to talk about their work on Firefly, and to learn from other scientists and developers in the CubeSat community. Local high school students and interns will also have access to the Firefly data, educational materials. Finally, the Firefly project will fund the installation of two World Wide Lightning Location Network VLF ground stations, one at Siena and another at the Universidad Interamericana de Puerto Rico, providing student access to a tool that can be used for many data analysis projects, and that will be a permanent addition to the educational infrastructure at these institutions. Firefly will support the development of a website, with continuous updates on the development of the instrument and spacecraft, and on-orbit mission status, open access to the data and science results. Firefly is scheduled for launch in August 2010, and will be delivered to the launch vehicle in spring 2010. Visit http://fireflycubesat.org/ for updated information.

- *Allan Weatherwax, Siena College; Doug Rowland, NASA/GSFC; Joanne Hill, USRA; Joe Kujawski, Siena College*

Announcements? Accolades? Accomplishments?

Please continue to submit information to the Post editor at Jeffrey.thayer@colorado.edu

CEDAR Workshop 2009

Summary of 2009 Workshop

The CEDAR (Coupling, Energetics and Dynamics of Atmospheric Regions) Workshop for 2009 was held at the Eldorado Hotel in Santa Fe, New Mexico from Sunday June 28 through Thursday July 2. A total of 354 participants, 96 coming to CEDAR for the first time, came from 75 institutions, 12 outside the United States and Puerto Rico. There were 48 universities, 20 laboratories, and 7 small businesses. Of the 138 CEDAR students and post-docs, 42 were undergraduate students compared to only 25 last year and previous years. There were 4 students from foreign universities or labs in Brazil (1), Peru (2), and the West Indies (1), with 2 other students from Romania and Georgia visiting US institutions. There were 34 more participants this year in Santa Fe compared to last year in Utah, 24 more students (mostly undergraduates), and 10 non-students.

We continued the CEDAR Wikipedia wiki for the workshop at http://cedarweb.hao.ucar.edu available to all participants to upload their presentations and link them via editing, or to make comments on the Forum. The tutorials and other plenary talks are linked via the agenda, workshop descriptions and presentations are linked on the workshop list, and posters on the poster list. Major materials will also be moved to the archive of old meetings.

The theme of the Student Workshop on Sunday was "How Can We Probe the Upper Atmosphere?" arranged by Marco Milla of the University of Illinois. Keynote talks were by Mike Kelley of Cornell University and John Foster of the Massachusetts Institute of Technology (MIT). Since Mike Kelley did not make it to the student workshop, video clips from his Cornell Space Weather class were played instead. Six tutorials on radars, lidars, satellites, GPS systems, imagers, and rockets were then given in two concurrent sessions. These talks and others are available in .pfd form via the agenda on the wiki. After 4 PM, the students had free time for the annual soccer game at Fort Marcy Park. The student social events were mostly arranged by Jonathan Fentzke of the University of Colorado, who was the second year student on the CSSC (CEDAR Science Steering Committee). The new student representative joining Marco is Elizabeth Bass of Boston University.

The CEDAR Prize Lecture was given in the Monday plenary session by Mike Nicolls of SRI International on “New observational capabilities for studying plasma and neutral dynamical processes using incoherent scatter radar”. Three tutorials were presented on the following days by Daniel Marsh of the National Center for Atmospheric Research (NCAR) on “Whole Atmosphere Community Climate Model (WACCM) studies of the upper atmosphere”, Anthea Coster of MIT on “Mid-latitude electrodynamics”, and Jordi Puig-Suari of California Polytechnique on “Strategies for successful cubesat development”. These and some of the student workshop talks were video-taped and are available on DVDs as well as in pdf files on-line. Please contact Brian Day of Daylight Productions and Rentals (brian@daylightav.com) if interested in obtaining DVDs and copy in Barbara Emery (emery@ucar.edu).

The CEDAR Science Steering Committee chair, Jeff Thayer of the University of Colorado talked a couple of times about CEDAR strategic planning for the next decade. Science highlights were given by Victor Pasko of the Pennsylvania State University, Tony van Eyken of SRI, Meers Oppenheim of Boston University, Michael Mendillo of Boston University, Jiuhou Lei of the University of Colorado, Mike Kelley of Cornell University, Rod Heelis of the University of Texas at Dallas, and Larisa Goncharenko of MIT. We heard two final CEDAR post-doc reports from Joseph Comberiate of the Applied Physics Lab at John Hopkins University and Carlos Martinis of Boston University. Interim post-doc reports were given by Guiping Liu of the University of California at Berkeley and by Stan Briczinski of the University of Wisconsin. Most of these talks are available in .pdf form from the agenda. Including the Student Workshop, there were 25 workshops total, the same as last year, where the workshop descriptions and some of the talks given are available in pdf form in links from the workshop list.

There were 152 posters at the Monday Mesosphere-Lower-Thermosphere (MLT) and Tuesday Ionosphere-Thermosphere (IT) poster sessions, 18 more than last year, mostly from students. There were 99 student posters, 22 with undergraduate first authors. 70 posters were in the student poster competition, including 16 presented by undergraduates. Prizes were a certificate, various cash prizes, and text books. The judges picked first place winners from each session who received $125 each and a second edition of the book by Michael Kelley of Cornell University, “The Earth’s Ionosphere: Electrodynamics and Plasma Physics”: Sebastien de Larquier, Masters student of Victor Pasko at the Pennsylvania State University with MLTS-03, and Edgardo Pacheco, PhD student of Rod Heelis at the University of Texas at Dallas with MDIT-03. Second place winners ($100 and an IOU for the forthcoming second edition of Schunk and Nagy, ‘Ionospheres: Physics, Plasma Physics and Chemistry”) were: Chihoko Yamashita, PhD student of Xinzhao Chu at the University of Colorado with MLTS-08, and Richard Todd Parris, PhD student of Bill Bristow at the University of Alaska with ITIT-17. Honorable mentions ($75 plus the Schunk and Nagy book) were: Jonathan Sparks, undergraduate student of Diego Janches at the University of Colorado with METR-03, and Padmashri Suresh, Masters student of Charles Swenson of the Utah State University with ITIT-26. There were three undergraduate honorable mentions ($50 each) from the IT session: Glenn Sugar of Boston University (EQIT-21), Matthew Sunderland of Penn State (ITIT-24), and Jonathan Thompson of Utah State (MDIT-10). The judges also liked posters by Loren Chang (MLTT-01, U CO) and Katelynn Greer (MLTS-09, U CO) from the MLT session, and posters by Tzu-Wei Fang (EQIT-11, NCAR and National Central University in Taiwan), Ethan Miller (EQIT-09, U IL), and Ellen Pettigrew (SOLA-07, Dartmouth) in the IT session. Thanks to Mike Kelley of Cornell, Andy Nagy of the University of Michigan, and to Bob Schunk of Utah State for providing books for the poster prizes. Thanks also to all the judges who spent so much of their time judging the posters, and thanks to all the students who participated in the student poster competition.

We took a 48-passenger bus from Boulder, Colorado to Santa Fe and back with about 20 passengers. This bus was then used to take the students back and forth from Fort Marcy Suites and on field trips. The field trips were to Tin-Nee-Ann Trading Company on Monday and to Bandelier National Monument on Thursday.

The 2010 CEDAR Workshop will return to the University of Colorado in Boulder, Colorado from Sunday June 20 (Student Workshop) to Friday June 25. In 2011, we go back to Santa Fe, New Mexico for a joint meeting with GEM in the new Santa Fe Convention Center from Sunday June 26 (CEDAR and GEM Student Workshops) to Friday July 1. Everyone, including students, will be in several nearby hotels (Eldorado, Hilton, La Fonda, Inn of the Governors).

- *Barbary Emery, NCAR*

2009 CEDAR Prize Lecture

The 2009 CEDAR Prize lecture was awarded to Dr. Michael Nicolls of SRI International for recent achievements in developing experimental techniques, modeling and theory that have significant impact on the CEDAR community. This award recognizes his recent impressive work on advancing the PFISR measurement capabilities and outstanding contributions to the midlatitude and equatorial aeronomy studies using Arecibo and Jicamarca radars.

In his Prize Lecture, Dr. Nicolls summarized theoretical, experimental, and observational advances in the incoherent scatter radar technique and discussed their potential for numerous applications, focusing on plasma line and gyro line as new plasma diagnostics tools (Nicolls et al., 2006, Bhatt et al., 2008, Janches and Nicolls, 2007). The broader impact of this work includes better use of incoherent scatter technique, with independent measurements of Ne and Ti, capability for measurements of ion fraction in the F1 region, light ion fractions, and detailed gravity wave studies.

Innovative measurements with PFISR include D-region observations with high spectral resolution of ~1Hz and simultaneous determination of zonal, meridional and vertical winds at few minutes temporal resolution and <1 km altitude resolution. These measurements can be used to determine the propagation directions of inertial gravity waves, and, in combination with ray tracing techniques, to possibly determine the source of the waves. These techniques make use of the PFISR pulse-to-pulse beam steering techniques, which have also been applied to investigate the sources of F-region gravity waves (Vadas and Nicolls, 2009).

PFISR spectral observations of Polar Mesospheric Summer Echoes at 450-MHz frequency (Nicolls et al., 2009) have been interpreted as indication of active neutral air turbulence occurring within the radar field-of-view. Measurements with ISRs are showing that the causal mechanisms for PMSE seem to be understood, and allow for the interpretation of PMSE in terms of turbulence theories. These studies demonstrate how PMSE can be used to study the microphysics and charging of mesospheric ice particles, and help the research community to understand anthropogenic influences on the mesospheric environment.

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Vadas S. L. and M. J. Nicolls, Temporal Evolution of Neutral, Thermospheric Winds and Plasma Response using PFISR Measurements of Gravity Waves, J. Atmos. Solar-Terr. Phys, 71, 740-770, 2009.

- Larisa Goncharenko, MIT Haystack Observatory

2009 CEDAR Student Workshop Summary

The annual CEDAR student workshop was held on June 28, 2009 at El Dorado Hotel in Santa Fe, New Mexico. In total, 138 students attended the meeting, and seventy of them were first-year CEDAR students. The goal of the workshop was to provide the students with a general overview of the different types of instrumentation that CEDAR researchers use in their investigations. The workshop was titled “How can we probe the upper atmosphere?”

In the morning, Dr. Richard Behnke (NSF’s representative) officially opened the workshop and Dr. Jeff Thayer (CSSC chair) introduced the CEDAR program to the students. The first presentation was a video on a historical overview of aeronomy instrumentation given by Dr. Michael Kelley from Cornell University. Next, the students had the opportunity to learn specific details about different types of instruments. Three mini-tutorials on: radars (Jorge Chau/Roger Varney), lidars (Xinzhao Chu), and satellite missions (Robert Pfaff) were offered in parallel during the morning session. Later, after lunch, there were three other talks on GPS systems (Jonathan Makela), rockets (Gerald

Lehmacher), and imagers (Carlos Martinis) that completed the instrument tutorials. These tutorials described how each instrument worked, how data can be acquired and processed, and what physical parameters can be measured. The workshop concluded with a plenary talk given by Dr. John Foster (MIT Haystack Observatory's director) that discussed the "next generation" of instruments that will enhance the research capabilities of our community.

After the end of the workshop, the students had the opportunity to enjoy the beautiful weather and activities organized by second year student rep Jonathan Fentzke from the University of Colorado at Boulder. Students and 'students at heart' headed to the playing fields at nearby Fort Marcy for ultimate frisbee and the annual CEDAR soccer game. Many in the CEDAR community were educated in the game of futbol by colleagues and students from South America with many interesting scoring opportunities that included an emulation of Maradona and la mano de Dios. Students were also able to enjoy the volleyball court, swimming pool, and recreation facility. In addition to the workshop, students were also able to enjoy a student reception, and share breakfast with the NSF representatives. Marco now succeeds Jonathan as the second year student representative and the CSSC welcomes the incoming first year student representative Elizabeth Bass from Boston University.

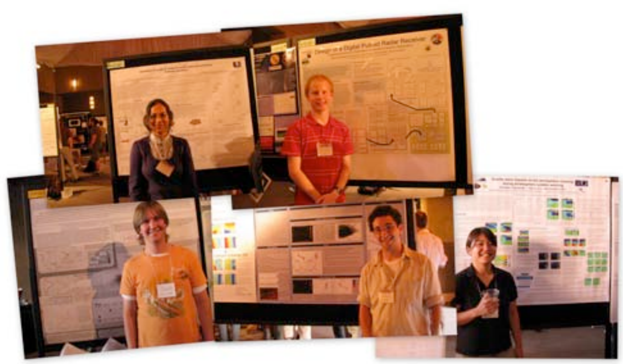
- Marco Milla, University of Illinois at Urbana-Champaign

2009 Student Poster Session

Diego Janches, Mike Ruohoniemi, Bill Bristow and Susan Scone of the CSSC, with the help of Susan Baltuch and Barbara Emery, organized this year's poster competition. There were 74 student posters entered in the competition with 17 undergraduates presenting (out of 154 total posters). Posters were divided into two groups, Mesosphere – Lower Thermosphere (MLT) and Ionosphere – Themosphere – Magnetosphere (ITM), based on predetermined topical categories.

As always the success of the poster competition relies on the dedication of volunteer judges who give up valuable networking and socializing opportunities to perform the difficult task of identifying winners from the pool of outstanding posters in the competition. The two nights of competition were judged separately by two groups of six judges. We thank the 12 judges who performed this important task admirably.

33 student posters were entered in the Monday evening MLT competition, and 41 student posters were in the Tuesday ITM competition. Judging was performed in two stages. For each night of the competition, every poster was first judged on its stand-alone merit without the student present. Students were then interviewed by anonymous judges and a group of finalists were determined. To determine a first-prize and honorable mention, each of the six judges visited the remaining posters in the pool of finalists. This year, the honorable



mention in the MLT competition went to an undergraduate student, Jonathan Sparks of the University of Colorado, for his study of the altitude distribution of micrometeors. MLT second prize went to Chihoko Yamashita of the University of Colorado, and first prize went to Sebastian de Larquier of Penn State. In Tuesdays ITM competition the honorable mention went to Padmashri Suresh of Utah State, second prize went to Todd Parris of the University of Alaska, and first prize went to Edgardo Pacheco of University of Texas Dallas. In addition, there were three undergraduate posters that were judged to be outstanding.

As in previous years it was acknowledged that the quality of posters in the competition has risen to a very high level. The quality of the posters makes the judging a difficult but enjoyable task. This year was no exception with many outstanding posters. We offer a few suggestions to keep in mind when preparing posters for next year's competition:

Written Poster:

- **Should be clearly visible from several feet away**
- **Label figures and figure axes**
- **Tell a story of your research**
- **Organize like a journal article**
- **Title (headline)**
- **Abstract**
- **Sections and figures**
- **Details**

Oral Presentation:

- **Do not just read your poster**
- **Tell your story**
- **Use your figures as talking points**
- **Practice your presentation**
- **Do not be afraid to admit you don't know something**

Most of all, keep up the good work! Thanks to the students for putting together so many outstanding posters this year. Thanks again to Susan and Barbara, and to the dedicated judges.

- Bill Bristow, University of Alaska

Five of the six poster winners with their prize books.

2009 CEDAR Workshops

The CEDAR community has long emphasized its annual topical workshops as the high point of community research activities. Each year, the community comes together to report on their scientific progress and discuss future research directions and collaborative projects during 2-4 hour workshop sessions sponsored by the leaders of ongoing CEDAR working groups. The establishment of such working groups, and the creation of new ones, is a CEDAR grassroots enterprise which actively encourages both graduate and undergraduate participation.

Enthusiastic convener interest during this year's three and a half day CEDAR meeting in Santa Fe led to a record number of 25 topical workshops, of which eight were held during well-attended evening sessions. This year's meeting was also unique in that many conveners incorporated panel discussions into the session agendas in addition to the more typical scientific progress reports. The active participation of the audience during these discussion sessions was a clear indication of the success and popularity of this format. CEDAR student participation during the sessions was high as usual, with students not only giving talks and asking questions, but also frequently serving on the discussion panels themselves.

A particular highlight of the meeting was a session early in the week focused on the community-wide strategic planning for the evolution of CEDAR science in the context of other geoscience disciplines (conveners: J. Thayer and L. Paxton). Apart from such programmatic sessions, scientific topics covered during the sessions were broad, ranging from long-standing areas of active CEDAR research to specific observational techniques or platforms. Specifically, the meeting featured six workshops focused on the mesosphere/lower thermosphere (MLT) region and six which were focused on the coupled thermosphere/ionosphere (TI) region. Two sessions were geared towards magnetosphere/ionosphere coupling and thus attracted some attendees from the GEM community, whose annual meeting was held in Santa Fe during the week prior. This year, three sessions were focused on space-based platforms such as cubesats as well as larger planned missions (GOLD and C/NOFS), and another three featured discussions and scientific reports on current and best practice techniques for observation and modeling of the upper atmosphere. Finally, two of the sessions featured a timely emphasis on the recent minimum of solar cycle 23, which has been uniquely quiet.

In summary, this year's topical workshops were a tremendous success, owing to the enthusiastic support of both conveners and the audience. For more information on the specific sessions, detailed descriptions can be found online, at: http://cedarweb.hao.ucar.edu/wiki/images/7/73/CEDAR09_Workshop_Descriptions.pdf.

- Lara Waldrop, University of Illinois

2009 CEDAR Tutorials

Dan Marsh of the Atmospheric Chemistry Division (NCAR) gave a tutorial on global modeling entitled “WACCM studies of the upper atmosphere”. The purpose of the tutorial was to alert the CEDAR community to progress that has been achieved in developing “whole atmosphere” general circulation models. This was a very timely subject for a tutorial because these models are essential for studying the dynamical and chemical coupling between the upper and lower atmosphere, a theme that will be one of the major thrusts of CEDAR science in the next decade.

Dan took as his example the Whole Atmosphere Community Climate Model, which has been developed at NCAR over the past decade and combines Ray Roble’s TIME-GCM for the upper atmosphere with Byron Boville’s CCM family of lower atmosphere models. WACCM is the atmospheric component of the Community Climate System model, which couples the atmosphere, the cryosphere, the oceans and land. The standard version of WACCM extends from the surface to 140 km, with a resolution of 1-2 km in the stratosphere and ~3 km in the MLT. The horizontal resolution is 1.9° x 2.5° (lat x lon). Gravity waves are generated by convection, frontal systems, and orography. There is a fairly comprehensive description of ozone-relevant neutral chemistry in the stratosphere/mesosphere, and ion chemistry in the E region. Specifically for the upper atmosphere, WACCM includes: solar variability; chemical heating; airglow; EUV and x-ray ionization; and auroral processes such as ion drag and Joule heating.

After a general description of WACCM, Dan described four diverse research topics in which he has been involved with the model. The first was Atmospheric Tides (in collaboration with Anne Smith and Rolando Garcia), where WACCM does an impressive job reproducing the structure of the migrating and non-migrating diurnal tides observed with the SABER and TIDI instruments on the TIMED satellite, although the modeled tidal amplitudes are smaller than observed. The second topic was the extension of WACCM up to 500 km in the middle thermosphere (a project led by Han-Li Liu). This version of the model (termed WACCM-X) is already showing promising agreement with observations of the O/N2 ratio, winds and tides.

The third topic was polar mesospheric clouds (in collaboration with Aimee Merkel). In order to capture the small-scale vertical structure of these clouds, the resolution of WACCM was increased to 124 levels with 0.5 km resolution near the mesopause. Microphysical processes such as ice nucleation, growth and sublimation, as well as transport by advection, diffusion and sedimentation are all included. Dan showed rather encouraging comparisons of WACCM results with satellite observations of the seasonal and geographic extent of the ice clouds. Particularly impressive was a very close simulation of the changes in cloud albedo between 1980 and present, in both hemispheres.
For his final topic Dan chose the meteoric sodium layer. This is a work in progress but is already showing some intriguing results. A detailed Na chemistry scheme has been put into WACCM. Even with a rather crude meteor input function, Dan was able to reproduce quite well the characteristic features of the layer (peak height, top and bottom scale heights). He then showed an amazing movie of the global Na layer column density, which captured all the short-term variability due to tides and waves in the MLT.

Finally, Dan pointed out the WACCM is a community model, available from NCAR.

- John Plane, University of Leeds

Anthea Coster of MIT Haystack Observatory presented a tutorial on “Electrodynamics in the Mid-Latitudes.” This tutorial encompassed a wide range of topics in mid-latitude electrodynamics, including the ionospheric trough region, dynamo winds and electric fields, electrostatic traveling ionospheric disturbances, and storm time electric fields. The seminar began with the definition of “what are the mid-latitudes.” For example, when auroras are seen as far south as Texas and Colorado, does this mean that the majority of the US is in the auroral regions? Or, during these same large geomagnetic storms, when the peaks of the Appleton anomaly move further poleward (to 30 degrees and higher) and exhibit large increases in TEC, does this mean that part of the mid-latitudes has been engulfed by an equatorial phenomenon? How does one define the mid-latitudes during these large storm periods?

The tutorial then described the different conductivities in the E and F region. These varying conductivities largely define the electric fields that develop in the mid-latitudes. Following this, the ionospheric dynamo region, a region controlled by the distribution of winds and the distribution of electrical conductivity in the ionosphere, was discussed. The maximum Pedersen conductivity in the ionosphere is where the ion neutral collision frequency is approximately equal to the ion gyrofrequency. This region is confined to a rather narrow range of height at ~ 125 km. Electric fields are generated in this region by thermospheric winds and tides. The unresolved issue of the F-layer height bands observed by Behnke, JGR, 1979 was also discussed. These height bands have now been shown to be related to GPS and all-sky camera images of nighttime medium-scale traveling ionospheric disturbances. Finally the various electric fields that are imposed on the ionosphere by the magnetosphere during large geomagnetic storms were discussed. For example, it is observed that in the mid-latitudes during large geomagnetic storms there is uplift in the F2 layer prior to the increase in the ionization density. This uplift can be caused either by winds or by electric fields. During large geomagnetic storms, electric fields in the mid-latitude ionosphere are generated from the disturbed wind dynamo and are imposed from the magnetosphere (penetration electric fields, subauroral polarization stream). The talk concluded by suggesting that the system-science approach being adopted by CEDAR is a necessary requirement to obtain a complete understanding of mid-latitude electric fields.

- Jeff Thayer, University of Colorado

Jordi Puig-Suri of the California Polytechnic University at San Luis Obispo presented a tutorial on CubeSats entitled "Strategies for Successful CubeSat Development". The purpose of the tutorial was to alert the CEDAR community to a nascent in-situ small satellite bus for CubeSats. This is a timely subject that relates to both the new NSF small satellite initiative and the small satellite CEDAR workshop. Jordi began by discussing the history of the CubeSat beginning with its inception in 1999 at Cal-Poly & Stanford as the "shipping container" of the space age. The CubeSat was developed to provide a simple standard, one that can be managed within the typical academic environment. As conceived, CubeSats utilize off the shelf components and are compatible with the P-Pod deployer. P-Pod can hold up to 3-1U or 1-3U CubeSats and acts as a "satellite Pez-Dispenser", using a spring to eject the satellites from the primary launch vehicle. CubeSats can piggy back, in their P-Pods, on launches of larger satellites.

CubeSat missions are flourishing with 28 missions on orbit (out of 44 launched) and over 100 developers worldwide. The future of CubeSats looks bright. The discussion then turned to the space science applications of CubeSats with the presentation of several CEDAR science missions, including SRI's RAX mission and the University of Illinois CubeSat photometer mission, Ion 1. The success of the CubeSat standard can be attributed to its open source nature combined with the ability of the P-Pod to protect the launch vehicle and primary payload. Jordi emphasized this was a grass roots effort, begun and led by universities, with industry and government agencies joining later.

The discussion then moved to a comparison of "Big Space" versus "Little Space". The development of the CubeSat standard has led to greater access to space; however, this advantage is coupled with the negative that not all instruments or sensors can fly on one CubeSat. CubeSat missions can complement current large satellite missions such as C/NOFS. New technologies can optimize the satellite bus, with software functionality replacing hardware and attitude control systems constructed on side panels, allowing for larger more sophisticated payloads.

In conclusion, CubeSats provide a growing platform for space science, with frequent launches and operating at a scale easily manageable in a typical academic department. The higher risk tolerance in the CubeSat community allows for rapid development of satellite systems, mission redundancy and the creation of constellations of satellites.

- John Noto, Scientific Solutions Inc.

Additional 2009 CEDAR Tutorial materials as well as other CEDAR 2009 Workshop information can be found on the CEDAR Wiki - http://cedarweb.hao.ucar.edu/wiki/index.php/2009_Workshop:Main.

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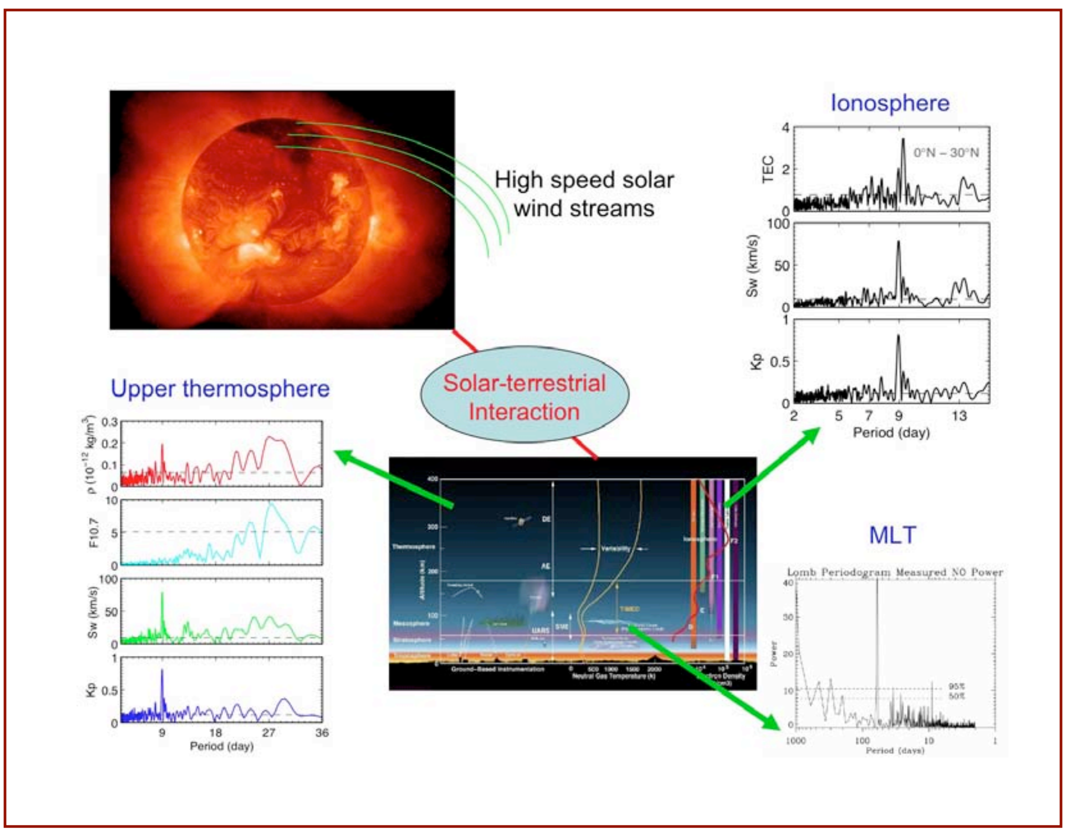
The impact of high speed solar wind streams on the thermosphere/ionosphere

Coronal holes of substantial size near the Sun-Earth line can create high speeds in the solar wind. These high speeds can interact with the slower solar wind in interplanetary space leading to disturbances in the solar wind called corotating interaction regions (CIRs). These disturbances lead to modest enhancements in Earth's geomagnetic activity with typical Kp values near 4. Coronal holes can persist for many solar rotations on the solar surface. Consequently solar wind disturbances occur at harmonics of the solar rotation period leading to recurrent geomagnetic activity. Nonrecurrent geomagnetic disturbances are associated with coronal mass ejections (CMEs) where solar material is catastrophically ejected from the Sun. These events are most numerous during solar maximum and typically do not persist beyond a solar rotation. CMEs may augment CIRs, but the recurring periodicity in CIRs enables a correlation analysis with periodicities in geomagnetic activity and changes in the ionosphere-thermosphere system. The polar coronal holes extend towards the ecliptic plane during the descending phase of the solar cycle making these disturbances most frequent approaching and during solar minimum.

Oscillations at multi-day periods (near 5.5, 7 and 9 day subharmonics of solar rotation) associated with recurrent high speed solar wind streams were recently discovered in the thermosphere and ionosphere properties [Lei et al., 2008a, 2008b; Mlynczak et al., 2008; Thayer et al., 2008; Crowley et al., 2008]. Recent studies demonstrate that the 9-day solar wind variations during the decline phase of solar cycle 23 are due to the existence of a triad of solar coronal holes distributed roughly 120 degrees apart in solar longitude. Thus, a new solar-terrestrial connection has been established between the corotating solar coronal holes on the solar surface and the variations in the Earth's thermosphere/ionosphere vis-à-vis the high-speed solar wind streams and the subsequent recurrent geomagnetic activity variations (see Figure 1).



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- *Jiuhou Lei and Jeff Thayer, University of Colorado*

Two-dimensional Turbulence, Space Shuttle Plume Transport in the Thermosphere, and a Possible Relation to the Great Siberian Impact Event

Noctilucent clouds (NLC), or night-visible clouds, are the highest clouds in the earth's atmosphere, forming near 85 km in the summer polar region [Gadsen and Schroeder, 1989]. Interestingly, they have been observed several days after the launch of the space shuttle. The main engine of the space shuttle combines liquid oxygen and hydrogen, 300 metric tons of water vapor are deposited off the southeastern coast of North America in the height range of 100 to 115 km with every launch.

On 8 August 2007, Space Shuttle Endeavor was launched and, within two days, the brilliant NLC display shown in Figure 1 was observed over Alaska. The photograph was taken on 11 August 2007 at 0919 UT using a wide-angle (70 degree field-of-view) lens. It is clear from Figure 1 that the display had a horizontal extent of hundreds of km. As further evidence that the NLC display in Figure 1 was related to the shuttle launch, a resonant iron lidar near Fairbanks detected a high altitude and very intense iron layer. Both of these features were totally unexpected based on global circulation models for the lower thermosphere. Similar observations were made following the 7 August 1997 launch of Discovery [Stevens et al., 2003] and again after the 16 January 2003 launch of Columbia [Stevens et al., 2005].

The unexpected rapid polar transport and the rapid expansion of these plumes are the phenomena we explore in Kelley et al. [2009]. In addition, we apply these results to the observations of very bright night skies at midnight over Britain one to three days after the Great Siberian Impact Event in the summer of 1908. These observations can only have been due to a NLC because of the requirement for a very high altitude scattering source.

Our hypothesis is that these wind fields are the source for 2-D turbulence in the lower thermosphere. The generalized Coriolis frequency is , where is the usual Coriolis frequency, is the plasma density, is the neutral mass density, is the component of the geomagnetic field along the Coriolis vector, and is the ion gyrofrequency. The hydromagnetic contribution, which has as its origin the E-region Hall current, is typically larger than the usual Coriolis frequency in the altitude range of 100 to 105 km.

The theoretical studies cited above suggest that the shuttle plume observations in solstice conditions can be explained by the effect of the inverse energy cascade in 2-D turbulence. This same hypothesis can also be used to explain the rapid expansion of the plumes. The noctilucent cloud shown in Figure 1 clearly has a large horizontal extent and, as mentioned above, observations of the shuttle plume also show a very large horizontal expansion of the plumes with time.

We now apply these results to observations of the night sky a few days after the Great Siberian Impact Event of 30 June 1908. On that date, the impact of an object of extra-terrestrial origin leveled 9000 km2 of forest near the Tunguska River in Siberia [Whipple, 1930, 1934]. Many researchers recorded, for example, that "suddenly, after 10 pm (G.M.T.), a sheet of cirrostratus appeared in the NNW, making it seem, by the sun's reflection, almost as bright as daylight", and on 1 July at 10 pm, "traces of cirrus from west—extremely light night". Noctilucent clouds such as the one shown in Figure 1 can have an appearance similar to cirrostratus clouds. Whipple reported that "on the morning of July 1 it was broad daylight at 01:15 LT".

These observations seem to clearly demonstrate that considerable water vapor was released at high altitude during the event. This water vapor would have been transported and dispersed by the same process as the space shuttle plume discussed above and thus, it is very likely that the impacting body had the character of a dusty snowball, as a comet is often described.

- M. C. Kelley, Cornell University

Figure 1. Photograph of noctilucent clouds taken from Donnelly Dome near Fairbanks, Alaska, looking toward the northwest with a wide-angle lens. (Photo courtesy of M.J. Taylor and C.D. Burton, CASS, Utah State University.)

Effects of Thunderstorms and Lightning in the Upper Atmosphere: Report on AGU Chapman Conference at Penn State

The Chapman Conference of American Geophysical Union titled "The Effects of Thunderstorms and Lightning in the Upper Atmosphere" was held at Penn State University, State College, Pennsylvania, on May 10-14, 2009 (see conference poster below). The conference was convened by Davis Sentman, professor of physics at the University of Alaska, Fairbanks; Jeff

Morrill, a research physicist at the Naval Research Laboratory; and Victor Pasko, associate professor of electrical engineering at Penn State. The conference coincided with the 20th anniversary of the first recorded image of a transient luminous event in the upper atmosphere by John R. Winckler of the University of Minnesota, and was a culmination of the dynamic growth of research on Transient Luminous Events (TLEs) and Terrestrial Gamma Ray Flashes (TGFs) during last two decades.

TLEs are large-scale optical events occurring at stratospheric and mesospheric/lower ionospheric altitudes, which are directly related to the electrical activity in underlying thunderstorms. The Chapman Conference poster shown below provides an illustration of a `sprite' type of TLEs observed over a Nebraska thunderstorm in 1999. Other types of TLEs are also known and commonly referred to as `elves', `halos', `blue jets' and `gigantic jets'. TGFs are transient flashes of energetic radiation in the Earth's atmosphere with photon energies up to 10 to 20 megaelectron volts, which last from a fraction of millisecond to several milliseconds. These flashes were first discovered from the Earth orbit and represent an example of energetic coupling between the troposphere and upper atmospheric regions. Since discovery of TLEs and TGFs more than 400 papers have been published in refereed literature on related subjects, and among other conferences the dedicated workshops on the upper atmospheric effects of thunderstorms have been held at annual CEDAR meetings since 1999 to 2008 (inclusive).

The total number of participants who attended the Chapman Conference was 110, representing 16 countries, including Brazil, Canada, Denmark, France, Fiji, Greece, Israel, Italy, Japan, the Netherlands, Norway, Russia, Spain, Taiwan, United Kingdom and United States (see group picture below). Among the conference participants 30 were students and 41 received some form of financial support to attend the meeting. The conference was attended by many scientists from the US organizations, which have been traditionally represented in CEDAR community. These include: Duke University, Florida Institute of Technology, Los Alamos National Laboratory, Naval Research Laboratory, Penn State

Group photo of participants of the AGU Chapman Conference on the Effects of Thunderstorms and Lightning in the Upper Atmosphere. Additional information about the conference can be obtained from http://www.agu.org/meetings/chapman/2009/bcall/

University, Stanford University, University of Alaska Fairbanks, and Utah State University.

Conference participant presentations will be published as a collection of articles in a special section of the Journal of Geophysical Research-Space Physics. The submission period to this special section had been completed on August 31st, 2009 and at the time of this writing at the end of November of 2009 18 papers have been either already published or accepted for publication. The special section can be accessed at: http://www.agu.org/journals/ja/special_sections.shtml?collectionCode=THUNDER1&journalCode=JA.

Funding for the conference was provided by the National Science Foundation (NSF), Office of Naval Research (ONR), Air Force Office of Scientific Research (AFOSR), and European Office of Aerospace Research and Development (EOARD). Conveners would like to express special thanks to program directors who supported this Chapman Conference: Cassandra Fesen (NSF-Aeronomy), Brad Smull (NSF-Physical and Dynamic Meteorology), Stefan Thonnard (ONR), Kent Miller (AFOSR), and George York (EOARD).

- *Victor Pasko, Penn State University*

The Chapman Conference poster featuring a massive sprite event over a Nebraska thunderstorm captured from the Wyoming Infrared Observatory 18 August 1999. The colorized image was obtained using a high-speed 1000 fps camera. The top of the diffuse, upper portion of the sprite is at about 90 km altitude, and the bottom of the lower tendrils is at about 50 km. [Image from Stenbaek-Nielsen et al., GRL, 27, 3829, 2000].

C/NOFS Mission

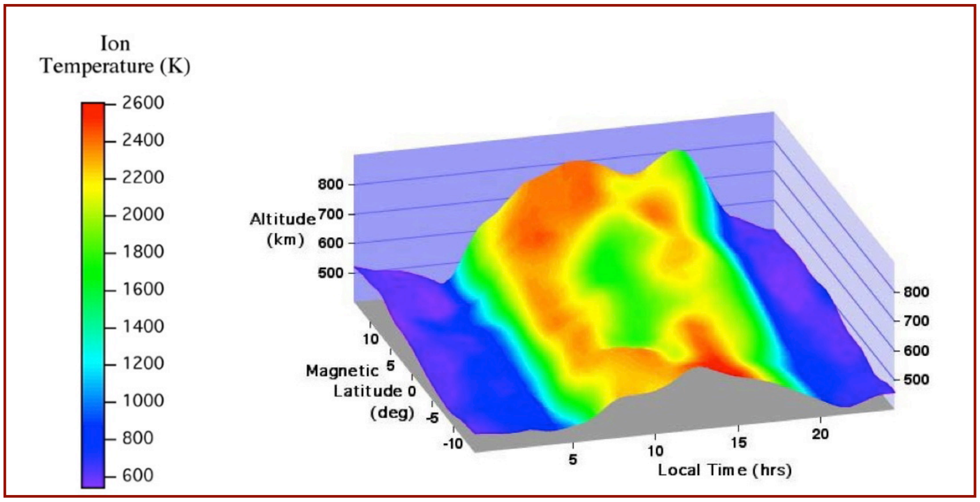
While it was not the original intent to fly the C/NOFS mission during solar minimum, in fact the radio flux from the Sun is at the lowest levels ever seen in the space age., this circumstance has enabled the discovery of some apparently unique features of the low latitude ionosphere and thermosphere.

Extraordinarily low levels of the solar ionizing flux are associated with low temperatures for the neutral atmosphere and F-region densities that appear at much lower altitudes than would be seen at high solar activity levels. The GPS occultation experiment aboard the C/NOFS satellite indicates that the F-peak never rises above 350 km in the equatorial region and thus the satellite, with perigee near 400 km and apogee near 850 km, is always above the F-peak. A measure of the extent of the ionosphere is provided by the location of the O+-H+ transition height and the CINDI instrumentation on C/NOFS is able to provide the constituent ion concentrations that allow this location to be identified. We discover that the transition height is as low as 450 km at night and rises only to 850 km during the daytime. At perigee, near 400 km altitude, the ionospheric and thermospheric temperatures are about the same and measurements confirm that indeed the atmosphere is cold, near 600 K during the night rising to only 800K during the daytime (Fig. 1). The cold neutral atmosphere lies predominantly below the satellite with neutral helium being the dominant constituent near 450 km altitude. The low thermospheric densities encountered by the satellite produce a drag that is very small leading to very small changes in the apogee altitude over the lifetime of the satellite.

The ionosphere and thermosphere are strangely reproducible on a day to day basis with very low charged particle densities appearing just before sunrise and peak ion densities appearing in the afternoon. The persistence of the F peak below the satellite suggest that the daily ExB drift motions of the plasma produce much smaller vertical excursions of the layer than would appear at solar maximum. In particular the evidence for a pre-reversal enhancement near dusk that elevates the layer to altitudes near 400 km and above is essentially missing. C/NOFS measurements have confirmed these suspicions and revealed the consequences for ionospheric irregularities by direct measurements of both the large-scale electric field distribution and the plasma structures.

The VEFI instrument on the C/NOFS satellite has described the local time variation of the electric field at the dip equator. These initial findings confirm that indeed a pre-reversal enhancement upward drift near dusk is largely absent. In addition it is found that the upward drift, which is expected to prevail throughout the day, is largely confined to the hours between sunrise and local noon. In the afternoon hours the drifts are very small and may even be weakly downward. The impact of these drifts on the state of the F region is responsible for the distribution of equatorial plasma structures that is also unique to the extreme solar minimum conditions. While the appearance of plasma structures have the expected longitude and seasonal dependencies, the maximum occurrence frequency occurs after midnight in all circumstances. It appears that in the absence of significant uplift of the ionosphere by ExB drifts, the growth of plasma structures may be dependent on the chemical recombination rate in the bottomside ionosphere.

- *Rod Heelis, University of Texas at Dallas*



The temperature at the O+/H+ transition height shows that the ionosphere and thermosphere are very cold at night and that the ionosphere occupies a relatively small volume above the Earth's surface.

How fluctuations in the ionosphere linked to sudden warming in the stratosphere?

Noting that earlier investigations have proposed that lower atmospheric processes account for some ionospheric variability, L. Goncharenko and colleagues from MIT Haystack Observatory and Jicamarca Radio Observatory studied episodes of sudden stratospheric warmings, which occurred in 2008 and 2009. They found that at middle latitude ionospheric variations that could not be explained through the seasonal trends, solar flux, and geomagnetic activity were instead correlated with fluctuating temperatures in the stratosphere, demonstrating a link between the lower atmosphere and the ionosphere that has been previously unobserved (Goncharenko and Zhang [2008]). As sudden stratospheric warming is a high-latitude event, the most unexpected change observed during these warming episodes is a large semidiurnal variation in low-latitude plasma velocities, with upward plasma transport in the morning hours, followed by the downward transport in the afternoon hours (Chau et al. [2009]). The electron density data from GPS receivers reveal an enhancement of equatorial ionization anomaly in the morning and suppression in the late afternoon, as result of this plasma motion. The observed control of daytime equatorial anomaly has major practical space weather implications. From numerical studies in collaboration with NCAR (H. Liu), these observations are interpreted in terms of large changes of atmospheric tides from their nonlinear interaction with planetary waves, which becomes strong during sudden warmings. The changes in tides modulate the ionospheric E-region (~100 km) dynamo electric field, which maps to ionospheric F-region altitudes (~250-400 km). These studies provide evidence of a global scale link between the processes in the stratosphere and ionosphere, both of them generated by a common lower atmosphere disturbance.

"Somehow, the stratosphere above the North Pole was linked to the ionosphere above Massachusetts, some 100 km higher and 4000 km south" - Jon Cartwright. Story on research linking processes in the stratosphere and ionosphere is featured in Oct. 3, 2009 issue of New Scientist (Phantom storms: How our weather leaks into space, by Jon Cartwright, New Scientist, 2009, #2728, p. 44-47, or http://www.newscientist.com/article/mg20427281.600-phantom-storms-how-our-weather-leaks-into-space.html).

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Chau J. L., B. G. Fejer, and L. P. Goncharenko (2009), Quiet variability of equatorial ExB drifts during a sudden stratospheric warming event, Geophys. Res. Lett., 36, L05101, doi: 10.1029/2008GL036785.

- *Larisa Goncharenko, MIT Haystack Observatory*

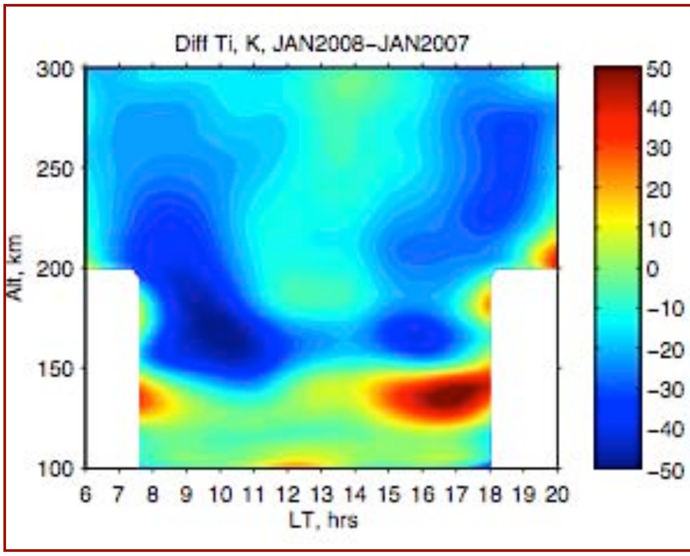

Figure 1. Variation in mid-latitude ion temperature observed during stratospheric warming as compared to baseline data. A warming is observed in the lower thermosphere at ~120-140 km, accompanied by a 20-75K cooling above ~140 km. It is well established that stratospheric warming is accompanied by mesospheric cooling. These observations show for the first time that areas of warming and cooling extend to altitudes of upper thermosphere (~300 km). From Goncharenko and Zhang [2008].

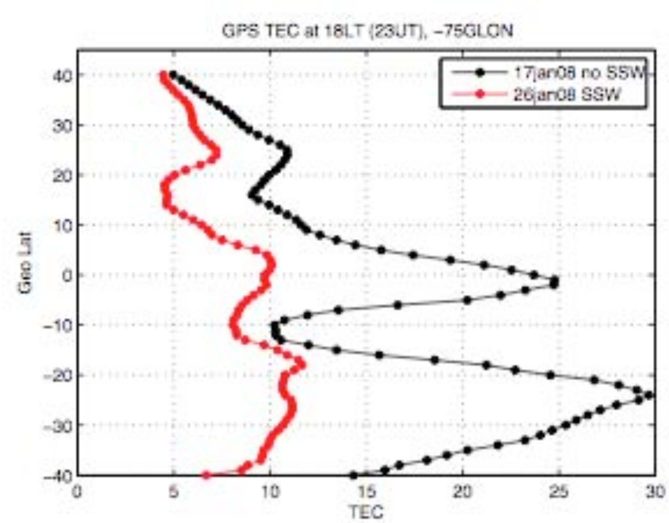

Figure 2. Comparison of GPS TEC along 75oW longitude before stratospheric warming (black) and during stratospheric warming (red) in the afternoon sector (18LT). During stratospheric warming, the afternoon equatorial anomaly is suppressed by a factor of 2-3, which is comparable to variations observed during major geomagnetic storms. Enhancement of equatorial anomaly is observed in the morning sector.

Remote Sensing Lower Thermosphere Wind Profiles Using Non-Specular Meteor Echoes

To understand energy and momentum transport by tides, planetary waves, and gravity waves, researchers need accurate knowledge of winds in the mesosphere and lower thermosphere (MLT) [Clemesha, 2002]. Since this region is inaccessible to the highest flying balloons and lowest orbiting satellites, it can only be explored by remote sensing techniques and rockets. Over the past six decades, over 400 rockets have released chemical tracers to measure winds in the MLT at a cost exceeding half a billion dollars [Larsen, 2002]. In Oppenheim et al. [2009] we showed how researchers can obtain similar measurements by tracking non-specular meteor trail echoes.

Like specular meteor radars - a method of monitoring MLT winds used since the 1950s this new method takes advantage of the billions of meteors that enter the atmosphere every day, leaving behind plasma trails which the neutral wind blows around. However, instead of using a small radar to track the entire trail, this method uses a large radar to follow reflections from plasma irregularities that develop in or near many trails [Oppenheim et al., 2000]. This requires a radar with interferometric capabilities which can point roughly perpendicular to the geomagnetic field. Using the 50MHz radar at the Jicamarca Radio Observatory, detailed wind profiles with an altitude resolution of less than a few hundred meters about every 10 minutes between 93 and 110 km altitude, as described below.

Data Collection and Analysis

Data was collected at the Jicamarca Radio Observatory (JRO), located near the geomagnetic equator , in July ’05 and ’07. The radar transmitted with the entire 18,000 element array and received the return signal with 3 quarter sections of the array, enabling the use of interferometry to find a meteor’s position within the beam. Since the radar collected 5000 measurements per second per altitude bin, a 25s meteor will have 125,000 data points per altitude bin. Figure 1 shows one of the longest and strongest meteors with a persistent trail.

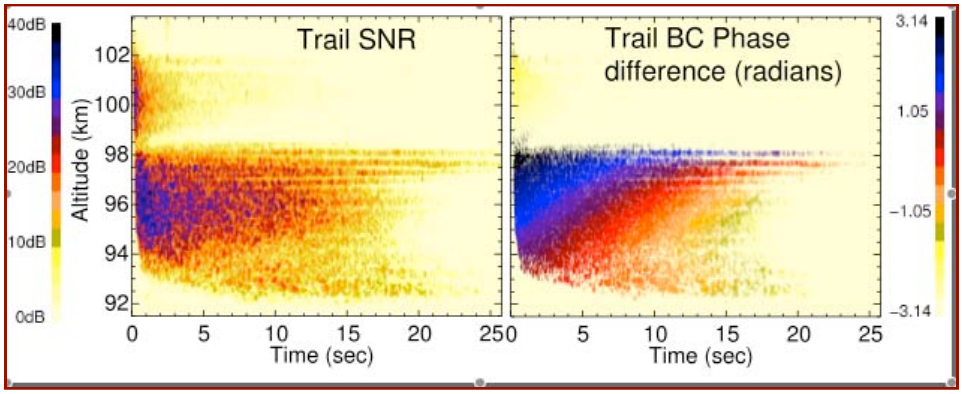

Figure 1. Long trail from July 12, ’05 data set. Left image shows the SNR in dB and the right one shows the phase difference between the B and C quarters of the antenna array. Phase information is only shown for regions where the SNR exceeds 10 dB, the Doppler is less than 150 m/s and a cross-channel coherence exceeds 95%. This meteor caused both a head and a non-specular trail echo but the head cannot be seen on this time-scale. The data gap at 98.5km altitude occurs because the meteoroid passes through a null in the antenna pattern. This can be determined by tracking the head echo position versus the known beam pattern and because both the head and the trail vanish at this same time. The striations late in time span at least 6 pixels from peak to peak and result from unknown causes. Such striations appear only in some meteors.

Even long, strong meteor trails generally span less than six kilometers in altitude. However, in a 2 minute period, JRO will often detect more than a dozen meteors lasting 10s or longer. Figure 2 shows two wind profiles obtained by combining all the meteors in 32 two 15-30 minute data intervals. These measurements extend from 93 km to 109 km. The east winds have less variability than the north winds.

One can immediately see that, at a given altitude, the wind velocities are roughly consistent from trail to trail, though with an error level that greatly exceeds the statistical error level shown. The zonal (East) wind data is more consistent from meteor to meteor than the meridional (North) ones. Between 94 and 103 km all the meteors give similar velocities at a given height. Above this height, the ’07 data shows a considerably larger range of wind speeds. The ’07 zonal wind data between 103.5 and 105km altitude derives from only one meteor and ranges between -80m/s and +40m/s, and shows a large amount of variability. Above that altitude, between 105 and 109 km, we have 2 meteors which have roughly the same mean of 35 m/s, but one meteor shows quite a lot of shear while the other indicates a relatively constant wind profile. Further experimentation and refinement of the data analysis technique should enable us to improve this consistency.

The wind profiles detected via non-specular trail echoes are consistent from meteor to meteor and with previous rocket data. In order to have a higher degree of confidence in this method, a validation study is needed, possibly at the Kwa jalein rocket range. One straightforward method would be to use a rocket-borne chemical release at the same time a radar monitors non-specular trails. Agreement between these two methods, would give us a high degree of confidence in this new technique. We expect to continue developing this technique to enable high-resoultion monitoring of lower thermospheric winds.

Acknowledgements

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- Meers Oppenheim, Boston University

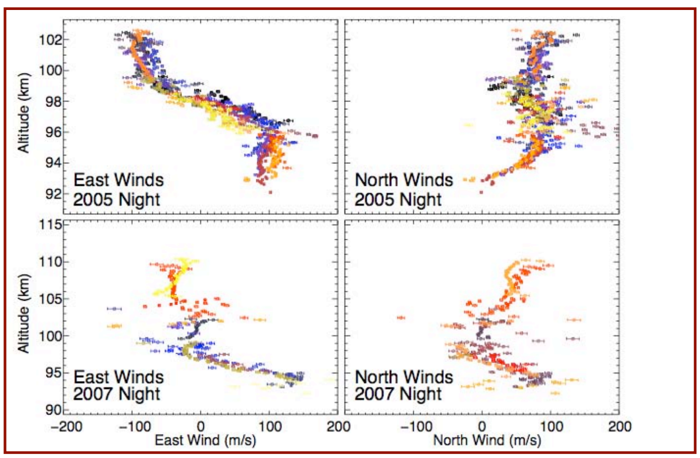

Figure 2. Horizontal wind velocities vs. altitude from 2 data sets. The upper profiles show the zonal (East) and meridional (North) meteor winds from the time interval 0401 to 0437 July17, '07 while the lower ones show 0342 to 0401 from July12, '05. Each trail was assigned a distinct color. Much of the '07 data set had a channel receiver timing off set which added a large systematic error to the BC phase data, making only the longest duration trails useful. We used all data where the error in the slope was less than 10m/s.

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