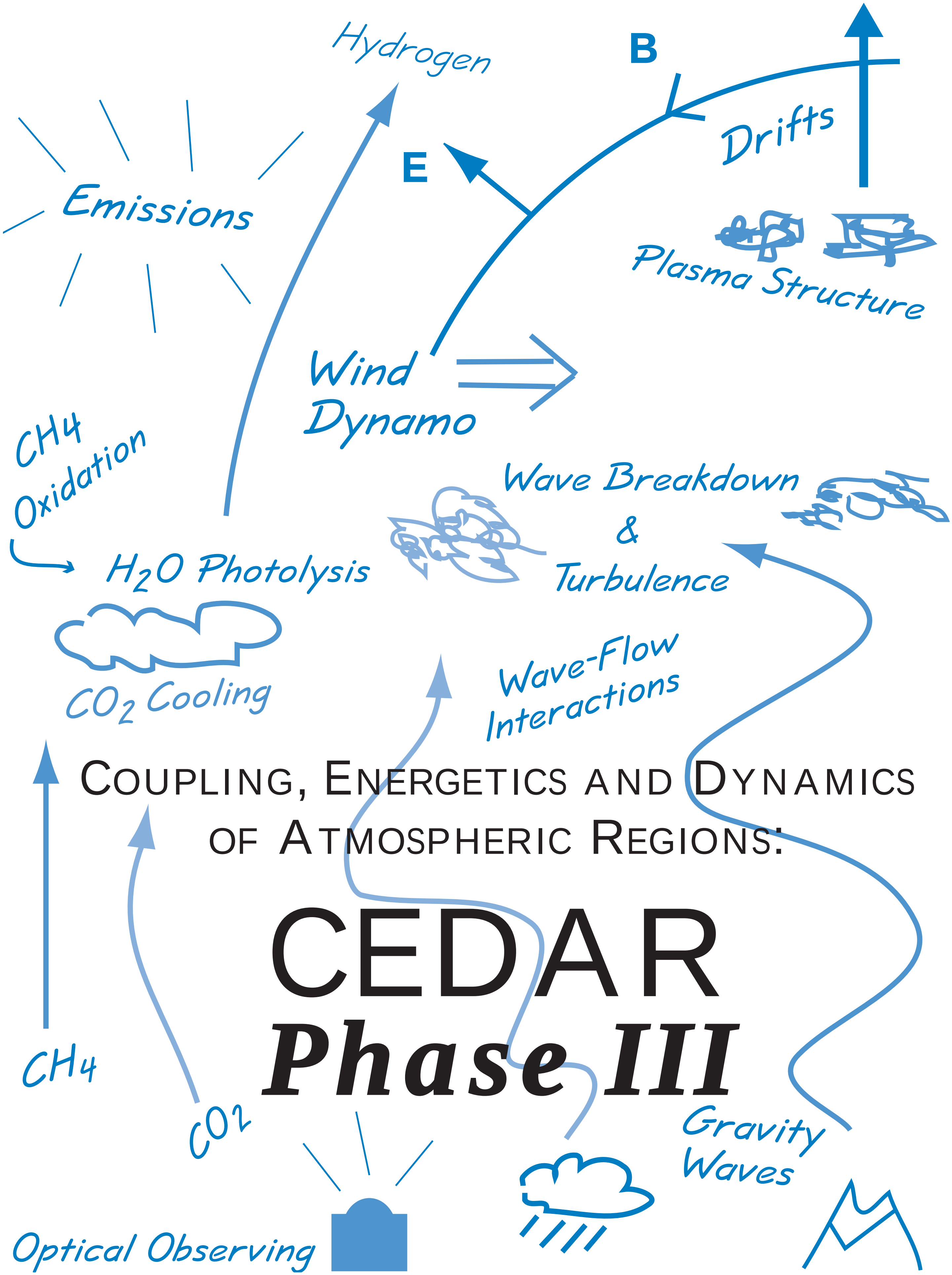
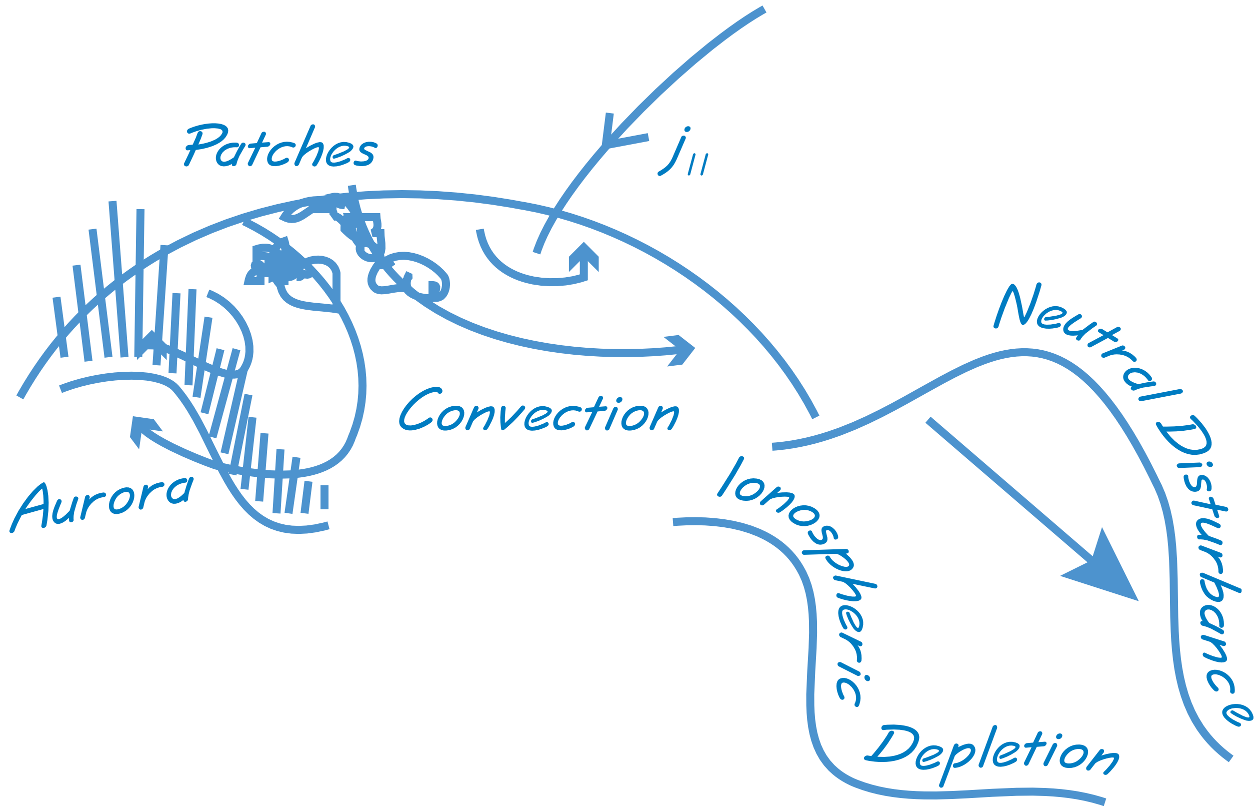
Coupling, Energetics and Dynamics of Atmospheric Regions:

CEDAR *Phase III*





CEDAR Science Steering Committee

1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Christensen	*Christensen*	*Basu*	*Basu*	*Basu*	*Forbes*	*Coakley*	*Fesen*	*Fesen*	*Castleberg*
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Gardner	*Hines*	*Hines*	***Gardner***	***Gardner***	***Kelley***	***Kelley***	*Kerr*	*Kerr*	*Holt*
Killeen	***Killeen***	***Killeen***	*Hines*	*Hecht*	*Killeen*	*Killeen*	*Killeen*	*Mendillo*	*Hysell*
Mendillo	*Mendillo*	*Mendillo*	*Kelley*	*Kelley*	*Larsen*	*Larsen*	*Larsen*	*Sahr*	*Kerr*
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									Taylor

Ex Officio Members

1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
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	Tinsley								

Chairpersons shown in bold

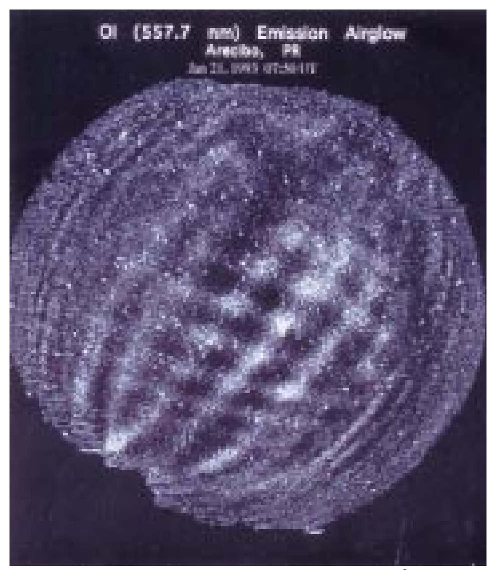
Executive Summary

CEDAR:
COUPLING, ENERGETICS AND DYNAMICS OF ATMOSPHERIC REGIONS

CEDAR is a highly successful research program that started in 1986 as a grass-roots community initiative for instrumentation that would enable state-of-the-art investigations of the Earth's upper atmosphere. Broadened to encompass multiple diagnostic techniques, theory, modeling, and coordinated observational campaigns, CEDAR is today the dominant national and international research program in terrestrial aeronomy. Scientifically, CEDAR is devoted to the characterization and understanding of the atmosphere above ~60 km, with emphasis on the energetic and dynamic processes that determine the basic composition and structure of the atmosphere. Particular attention is given to how these processes are coupled and to the mechanisms that couple different atmospheric regions.


An auroral display at high latitudes.

A primary objective of CEDAR research is to understand changes in the atmosphere over time scales related to both solar and anthropogenic influences. As an element of the U.S. Global Change Program, CEDAR contributes to our understanding of how energy, momentum, and chemical processes originating in the lower atmosphere couple to higher levels, thereby serving as sensitive indicators of small changes through vertical amplification effects. Many of the scientific thrusts of CEDAR also parallel aims of the National Space Weather Program via specification of cause-effect linkages in the geospace environment.

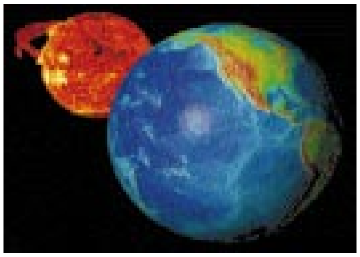


Wave structures in atomic oxygen 5577 Å image.

Following CEDAR's Phase I of active planning and organization, Phase II has marked an extraordinarily productive period of collaborative research projects, multi-site field campaigns, annual workshops, and the active participation of graduate and undergraduate students. A summary of accomplishments during Phase I and Phase II and an assessment of the current status of the CEDAR Program is contained in the *CEDAR Interim Report* published in 1995. While Phase II activities are continuing, a level of maturity has been achieved that is clearly able to realize the full scientific potential anticipated at the inception of CEDAR. It is therefore time to formulate future goals in light of past accomplishments. This report outlines the scientific directions and operational aspects of CEDAR Phase III in an integrated program poised to extend through the next decade.

The major thrust of the present report is the description of *four science initiatives* which constitute the scientific agenda of CEDAR Phase III:

- Coupling With Lower Altitudes
- Solar-Terrestrial Interactions
- Polar Aeronomy
- Long-Term Variations

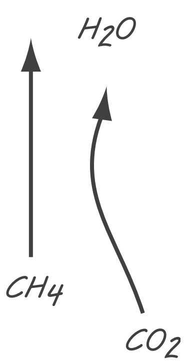


The Sun-Earth System.

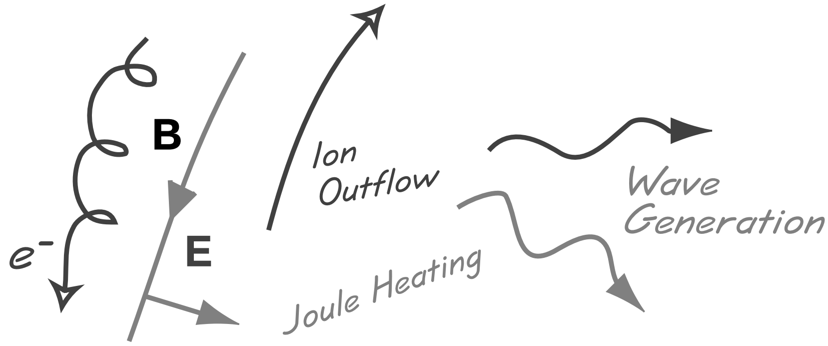
Coupling With Lower Altitudes refers to the study of tidal, planetary, and gravity waves which are primarily forced in the troposphere and stratosphere and are now recognized as having profound influences on the ionosphere-thermosphere-mesosphere (ITM) system. The **Solar-Terrestrial Interactions** initiative strives to understand the response of the global ITM system to solar variations and disturbances over a multitude of time scales. The **Polar Aeronomy** initiative is based on the recognition that limited access to polar regions has prevented an understanding of the fundamental processes that govern the polar atmosphere. This is of particular importance when solar wind induced disturbances at high latitudes drive the energetics and dynamics of the vast atmospheric system at all other latitudes. Finally, given the 10–30 year data sets that are beginning to be realized, and increased evidence of long-term atmospheric variations whose origins remain unknown, the initiative on **Long-Term Variations** seeks to foster measurements and analyses identifying secular atmospheric variations that can be interpreted through atmospheric models.

As a basis for advancing this scientific agenda, brief summaries of capabilities achieved during CEDAR Phases I and II are presented throughout this document. These include highlights from an impressive array of observational and modeling accomplishments. To achieve the goals of the four Phase III science initiatives, a set of new Implementation Requirements are identified and listed below in non-ranked order:

Polar mesospheric ("noctilucent") clouds.



1. Develop instruments that probe new limits of spatial (<< km) and temporal (< minute) resolution of ITM phenomena.
2. Develop capabilities that extend the temporal continuity of measurements so that both day-night and multi-day data streams can be obtained.
3. Complete instrument clusters at the Class I facilities, with particular attention to continuity of vertical coverage from the mesosphere to the plasmasphere.
4. Develop the Polar Cap Observatory with a fully instrumented complement of optical and radio diagnostic capabilities.
5. Develop regional and global networks of distributed measurements using cost-effective systems to complement and extend capabilities at Class I facilities.
6. Promote model development tailored to specific scientific thrusts in magnetosphere-ionosphere-thermosphere-mesosphere coupling, ionospheric plasma structures, and wave source distributions.
7. Develop new modeling capabilities capable of addressing the improved spatial and temporal observations of small-scale processes.
8. Promote data assimilation techniques that enable the coupling of models for different regions.
9. Develop effective strategies for international coordination for satellite-groundbased collaborations and for facilities to respond to solar-terrestrial targets of opportunity.
10. Implement plans for the wide-spread use of electronic communication methods for campaigns, data usage, and archiving systems.

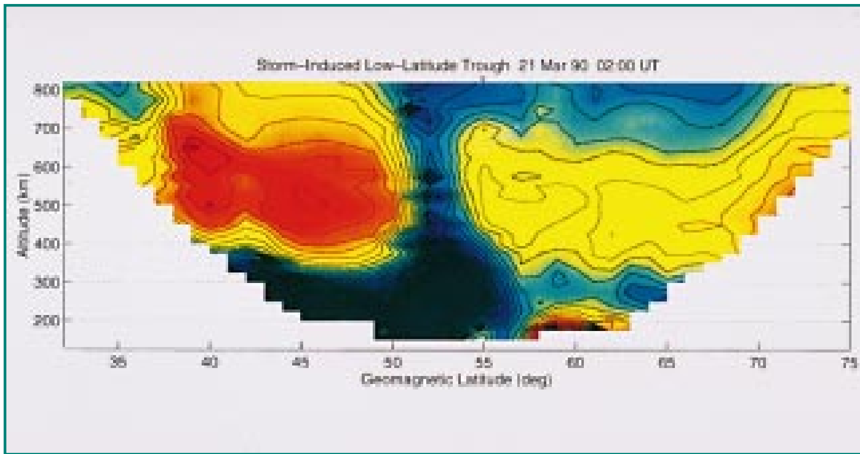


Sondrestrom Class I Facility.

In addition, it is recommended that we maintain the successful methods of CEDAR operations that evolved during Phases I and II, with community guidance of science, annual meetings, workshops, campaigns; promote the professional development of students, outreach activities and programmatic balance between observations, modeling, analysis programs and instrumentation development.

The present report was prepared by members of the CEDAR Science Steering Committee serving during 1994–1997 with inputs from a great many scientists within the CEDAR community. Our success in arriving at such a community consensus document speaks to the true excitement and dedication to CEDAR science goals that we all share.

Solar-Terrestrial Interactions

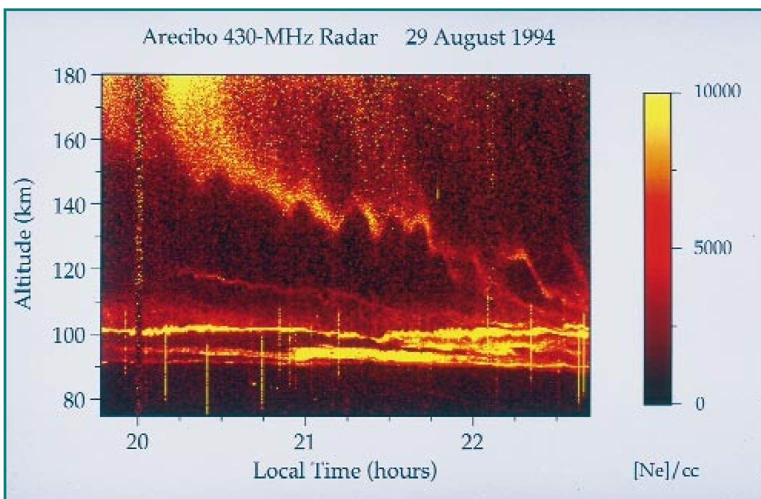


Plasma densities observed by the Millstone Hill incoherent scatter radar during a geomagnetic storm on March 20, 1990, illustrating the characteristic feature known as the "ionospheric trough". These and other manifestations of "space weather" impact the operation of communications systems.

Polar Aeronomy

The aurora is only one manifestation of energy deposition into the polar regions caused by solar wind-magnetosphere interactions.

Coupling With Lower Altitudes



Intermediate and tidal-ion layer motion measured over Arecibo. Long-lived ions accumulate where ion drifts converge, as determined by the tidal wind field. The descending motion of the layers follows the downward phase progression of the tidal motions, and is often modified or interrupted by gravity wave motions.

Long-Term Variations

Is increased occurrence of noctilucent clouds during past decades a harbinger of global change?

Overview

This report defines the scientific scope of CEDAR Phase III, describes the resources needed to attain our scientific objectives, and provides guidance on future operational aspects of CEDAR.

As a result of broad community consensus, the main scientific thrusts of CEDAR Phase III are articulated within four scientific initiatives: **Coupling With Lower Altitudes, Solar-Terrestrial Interactions**, **Polar Aeronomy**, and **Long-Term Variations**. Here we describe each initiative by first presenting the CEDAR Phase I/II accomplishments to date and then the outstanding scientific questions posed for Phase III. In addition, we outline the atmospheric measurements and modeling advances needed to realize our scientific objectives. While we have attempted to make this document comprehensive, it should not be considered all-inclusive; it is important that the CEDAR Program remain flexible and adaptable to scientific discovery, new instrument capabilities, model developments, and community input.

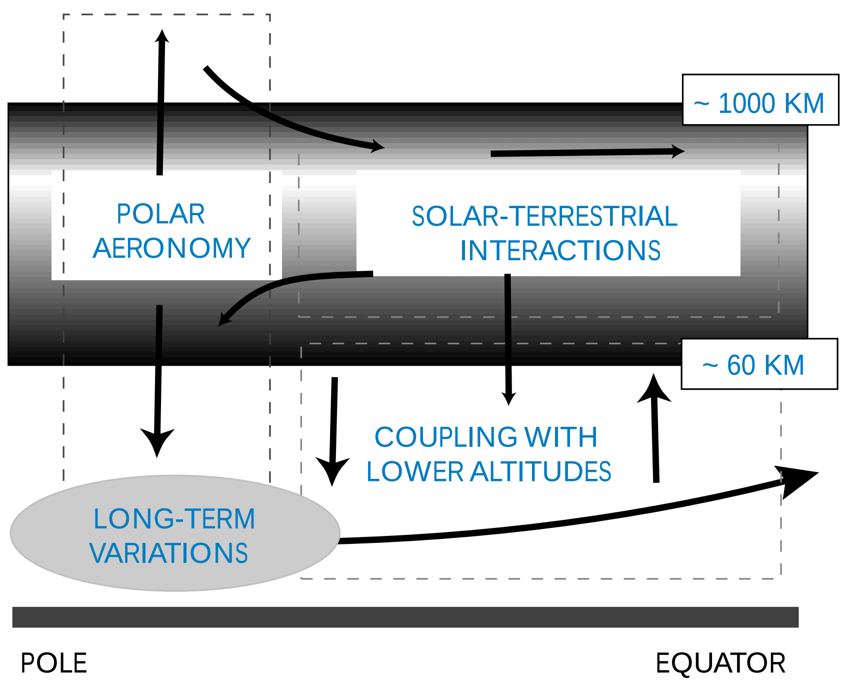
The four science initiatives are linked in many ways and, taken together, constitute a comprehensive program addressing the scientific core of CEDAR research — the processes that govern the composition, structure and variability of the upper atmosphere. Moreover, they address the scientific underpinnings of atmospheric global change, sun-earth connections, and space weather — all with primary focus on the regions above ~60 km.

The **Solar-Terrestrial Interactions** initiative addresses primarily the influences of direct solar photon and particle radiation on the terrestrial system. In addition to its own intrinsic interest, this knowledge is quite important for distinguishing long-term changes due to solar variability from those due to anthropogenic effects — the primary objective of the initiative on **Long-Term Variations**.

The **Coupling With Lower Altitudes** initiative focuses on the chemical, dynamical, and electrodynamical structure and variability of the upper atmosphere and ionosphere due to processes originating in or linked to lower atmospheric regimes. This component of thermosphere-ionosphere "weather" is complementary to that driven by direct solar-terrestrial interactions. In addition, the physics pursued under this initiative is key to understanding long term variations in the mesopause region.

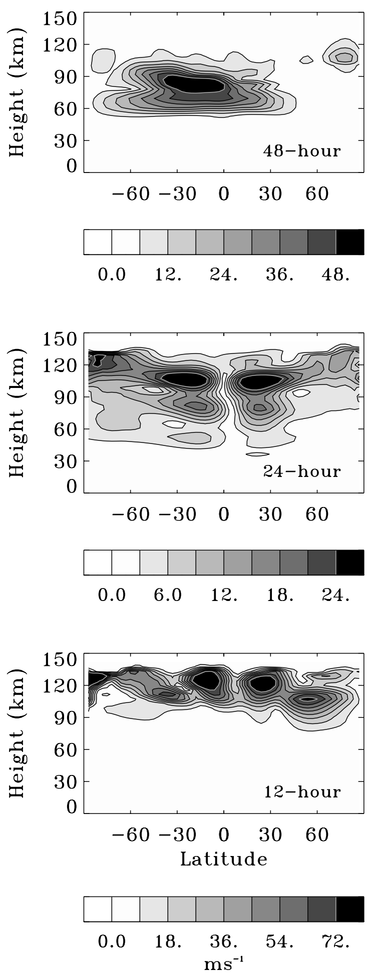
The **Polar Aeronomy** initiative addresses solar and atmospheric coupling, energetics and dynamics at polar latitudes where our understanding is meager and where the potential exists for significant Phase III scientific advances in a number of areas.

Implementation of the CEDAR science agenda requires careful consideration of resource allocation, operational issues, and relationships with other national and international programs. These are addressed in the latter sections of the report.



CEDAR PHASE III SCIENCE OBJECTIVES

Coupling With Lower Altitudes



Global Scale Wave Model (GSWM) simulations of some large-scale wave components excited in the lower atmosphere (i.e., excluding sources of excitation above 80 km.) The field depicted is meridional wind amplitude.

Top: 2-day wave.
Middle: diurnal tide.
Bottom: semidiurnal tide.

This initiative focuses on the Mesosphere and Lower Thermosphere-Ionosphere (MLTI) region of the atmosphere (~60–150 km), its response to forcing mechanisms originating in lower atmospheric regions, and the transmission of these effects throughout the thermosphere-ionosphere system.

Since a major achievement of the CEDAR program has been the realization that coupling between the lower and upper atmosphere is through waves, the cornerstone of this initiative is the study of waves and wave-induced phenomena. These wave studies are crucial in understanding the MLTI region since wave-driven energy and momentum fluxes represent one of the most important sources of MLTI dynamics, thermal balance, and chemistry. The goal of this initiative is to elucidate the MLTI response to waves forced from below and to determine how the effects are transmitted to the atmosphere above.

The fundamental tasks of this initiative are the delineation of the waves' spatial and temporal dependences, followed by the determination of their generation, propagation, and dissipation mechanisms, their heat and momentum fluxes, their interaction with the mean circulation, and their contribution to turbulence and constituent transport. The meaning of the spectra of atmospheric fluctuations needs to be understood, and parallel investigations will focus on wave-driven electrodynamical processes.

Major Achievements during CEDAR Phases I & II

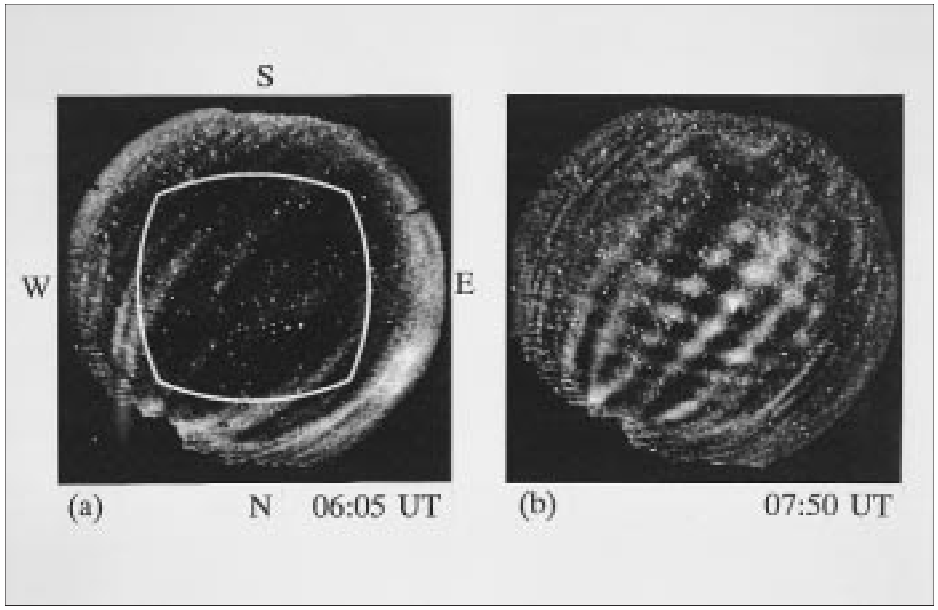
- Identified the key role of gravity waves and tides in the dynamics of the mesosphere and lower thermosphere.
- Discovered the importance of chemical coupling between the MLTI and lower altitudes.
- Initiated the delineation of planetary wave structures as a function of latitude, season, and altitude.
- Identified potential aeronomic implications of tropospheric processes such as convective activity and sprites on the MLTI.
- Discovered waves with inexplicable combinations of periods and zonal wavenumbers in the polar regions.
- Accumulated databases to begin deriving global specifications of wave periods, amplitudes and phases.

Atmospheric Waves

Atmospheric tides, gravity waves, and traveling planetary waves are prominent features of the mesosphere and lower thermosphere. Wave fluxes are the primary means by which dynamics controls the climatological state of the mesosphere and the primary means by which the mesosphere and lower thermosphere are coupled dynamically. However, the basic physics underlying wave dissipation, momentum deposition and turbulence generation is poorly known. In addition, the waves are characterized by considerable day-to-day variability which may be due to transients or to nonlinear interactions among the various wave components.

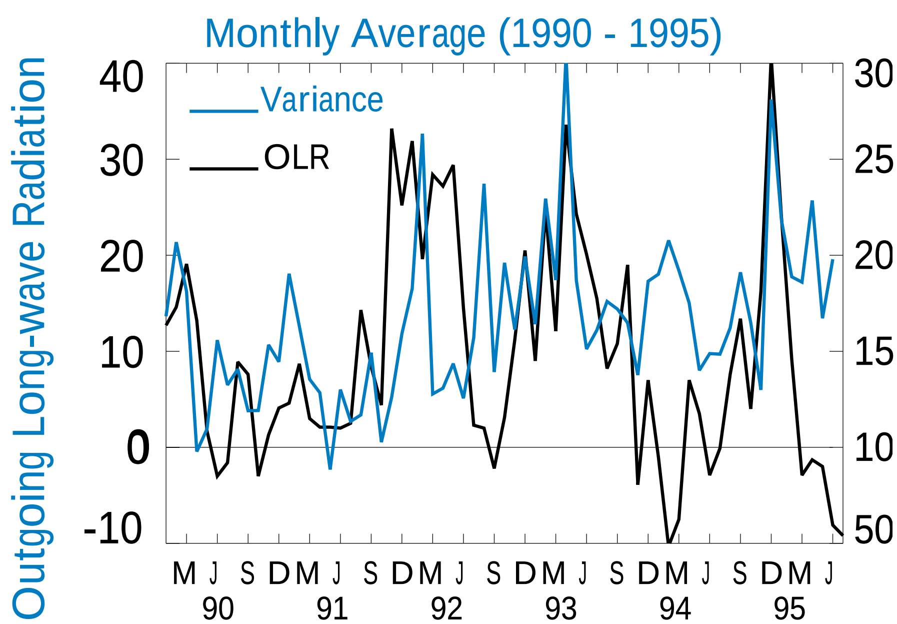
Observational and theoretical studies undertaken during CEDAR Phases I and II indicate that wave modes other than the well-known tidal modes may be important in the lower thermosphere. Some of these may be generated in-situ in connection with strong vertical and horizontal shears which sometimes characterize the lower thermosphere neutral flow. A better understanding of the modes that can be supported and generated within the lower thermosphere circulation system is critical for improved understanding of vertical coupling mechanisms.

A key objective of this initiative is the spectral characterization of the various wave components in winds and temperatures extending from the mesosphere through the thermosphere, and crossing several latitudinal regions. These characterizations will form the basis for investigating wave-wave and wave-mean flow interactions, dissipation mechanisms, and for testing and formulating gravity wave parameterizations. A valuable auxiliary product will be delineation of the mean temperatures and winds.

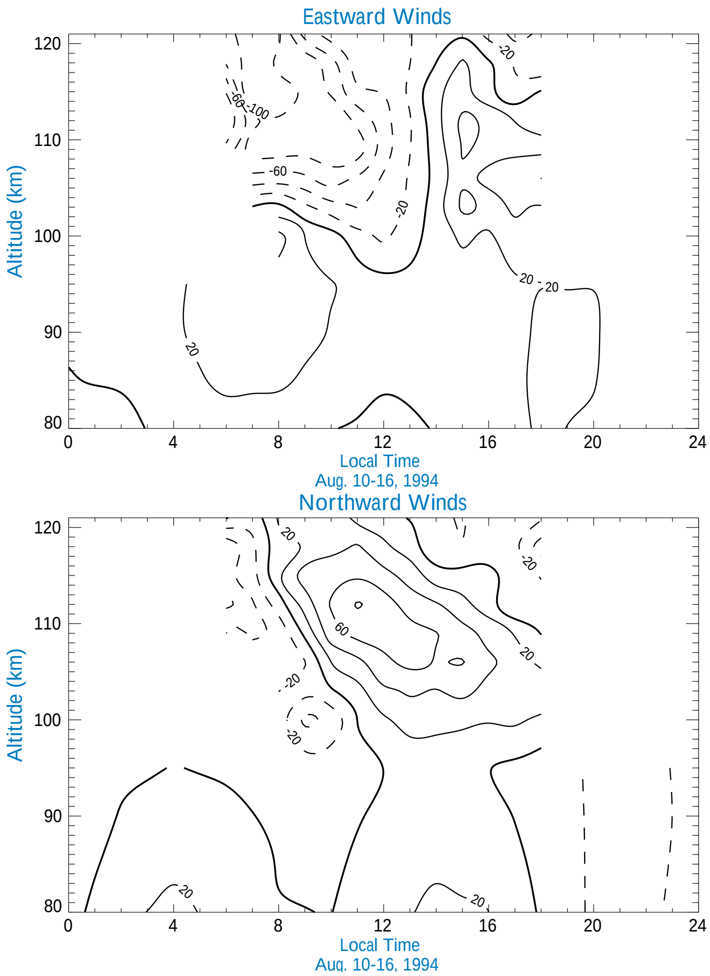


Two examples of extensive quasi-monochromatic gravity wave patterns imaged in the atomic oxygen 5577 Å emission: (a) shows a single wave pattern progressing towards the SW, (b) shows a more complex wave pattern resulting from the addition of a second wave motion progressing towards the NNW. Both images have been flat-fielded to enhance the wave structure. The white border in (a) indicates the 256 km x 256 km spectral sample region.

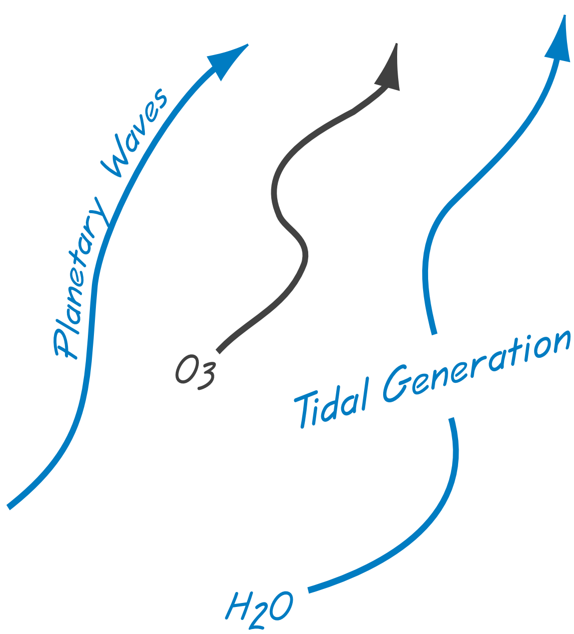
"…the basic physics underlying wave dissipation, momentum deposition and turbulence generation is poorly known."



Short-period gravity wave variances (blue curve) measured in the 82–88 km height range with an MF radar at Christmas Island (2ºN, 157ºW) in the central Pacific, compared with the negative of the equivalent temperature (black curve) of outgoing longwavelength (OLR) radiation measured in the 5ºS–5ºN, 160ºE–160ºW region of the Pacific. Larger numbers for the OLR means colder temperatures, higher clouds and stronger convection. The implication of the positive correlation evident between the curves is that convection is a significant source of upper mesosphere gravity waves.



Eastward and northward wind fields obtained by merging meteor radar data below 100 km from Durham, N.H., and incoherent scatter radar data above about 100 km from Millstone Hill, MA. The structures contain a strong signature of the semidiurnal tide.



Turbulence, Mixing, and Constituent Transport

The MLTI encompasses the transition region from a fully mixed atmosphere to one that is diffusively separated. Since tidal and gravity wave interactions affect eddy diffusion and vertical transport, significant effects on minor chemical constituents are anticipated. Further, the MLTI supports a wide range of wave motions which perturb the densities, temperatures, and local vertical motion field so that wave effects on chemical constituents may be produced through modification of chemical rate constants, three-body reaction rates, and vertical advection.

From the perspective of dynamics, small scale waves control eddy mixing through the turbulence generated when they break. However, the tropospheric sources of these waves are known to be globally heterogeneous. In addition, the filtering of these waves by strato-mesospheric wind systems with significant spatial and temporal variability (due to tides and planetary waves) is expected to result in globally heterogeneous distributions of turbulence and eddy mixing. These interactions and their effects on the MLTI and above remain unexplored and serve as an important focus of Phase III activities.

"A major advance in the first decade of CEDAR was the realization of the important role of gravity waves in the dynamics of the mesosphere and lower thermosphere."

Electrodynamic Coupling

The lower regions of the atmosphere affect the ionosphere through electrodynamic interactions involving upward propagating waves, dynamically induced composition changes, and possibly through upward lightning discharges known as "sprites." At present, our knowledge in each of these areas is rudimentary.

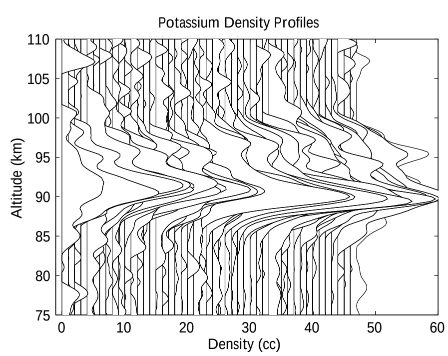
In the low and middle latitude atmosphere, the quiet-time electric potential distribution is frequently ascribed to an atmospheric dynamo driven by tidal winds in the ionospheric E region (~100–170 km altitude). Variations in the neutral dynamics change the ionospheric electric potential, which maps into the F-region (above ~170 km) along the highly-conducting magnetic field lines. At these altitudes, potential differences give rise to E x B plasma drifts that dramatically redistribute (and even destabilize) the ambient plasma.

The penetration of planetary waves into the MLTI region modulates the electrodynamic interactions with periods of several days or more, introducing ionospheric variability into the F region on these time scales. Gravity waves may seed plasma instabilities that can be important in transferring energy and momentum over a broad range of scale sizes, thereby coupling large and small scale processes. The degree of ionospheric variability that can be ascribed to each of the various upward propagating wave components remains unknown, and serves as one focus of CEDAR Phase III investigations.

In the E region, long-lived ions (such as metallic ions) are transported efficiently by tidal winds. The ions accumulate at convergent nulls forming dense layers that descend with the phase of the tides. These metallic layers, which can serve as tracers of atmospheric motions, are coupled to important metal oxide chemistries at lower altitudes and constitute most of the E region conductivity at night. The nighttime conductivity is one of the most poorly known quantities involved in the nighttime coupling of the E and F regions. Further modeling and observational studies of the nighttime E region are crucial for progress in this area.

Electrical discharges into the upper atmosphere over thunderstorms ("sprites") represent a newly-discovered mechanism for coupling the lower atmosphere with the ionosphere. Of particular interest to CEDAR Phase III are the pathways by which the energy in sprites is dissipated in the MLTI regions.

"The degree of ionospheric variability that can be ascribed to each of the various upward propagating wave components remains unknown."



Sequence of potassium density profiles between 70 and 120 km illustrating signatures of waves and tides. Measurements were made with the Arecibo Observatory resonance fluoresecence lidar.

Science Issues — Outstanding Questions

Coupling With Lower Altitudes requires Phase III research on such topics as:

• What parts of the wave spectrum are most important in determining the thermal structure and energy and momentum budgets in the mesosphere-thermosphere-ionosphere?

• To what extent do planetary waves modulate atmospheric tides, and can such modulations of tidal motions in the dynamo region account for ionospheric signatures of planetary wave periodicities?

• What roles do the waves play in driving the E- and F-region drifts and in generation of the E and F region dynamos? Do middle atmosphere electrical processes such as jets and sprites affect ionospheric electrodynamics?

• What are the effects of wave transport on chemically active species in the mesosphere and lower thermosphere?

• Does tidal modulation of wave fluxes contribute to the observed day-to-day variability in the mesosphere and lower thermosphere? Does it control the global heterogeneity in eddy mixing and minor constituent concentrations?

• What is the full role of gravity waves in creating electric fields and in seeding plasma instabilities that dominate space weather effects at equatorial and lower midlatitudes?

Major Achievements during CEDAR Phases I & II

• Utilized multi-parameter data sets to identify causative mechanisms for F-region storm time response.

• Produced climatological models for average electrodynamic drifts at each ISR site.

• Developed new analysis techniques to provide model specification of electric field drivers from the magnetosphere, the disturbance dynamo, and the quiet-time solar dynamo.

• Initiated methodologies for coupling of models and observations of global-scale multi-region aspects of the geospace environment

• Established new techniques to measure light ion composition in the topside ionosphere.

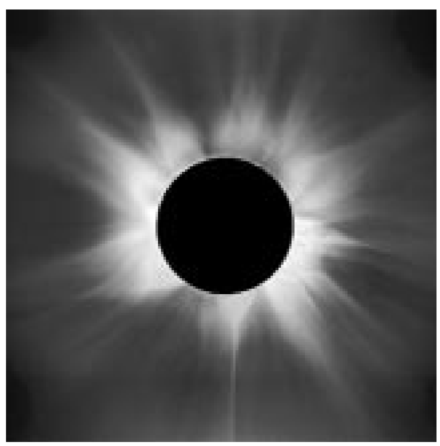
• Described the F-region neutral wind field on diurnal, seasonal and solar cycle time scales at a variety of sites.

• Identified important physical mechanisms controlling the evolution and growth of ionospheric structures and plasma instabilities at high and low latitudes.

SOLAR-TERRESTRIAL INTERACTIONS

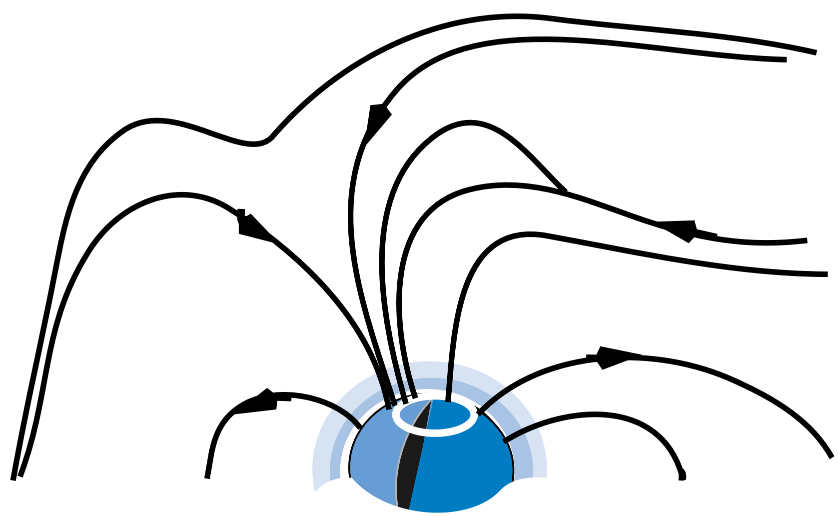
The climatological state of the thermosphere-ionosphere system is now reasonably well understood; the important forcing mechanisms have been identified, and the general characteristics are now embodied in various empirical models. Yet, our knowledge and understanding of the determining factors underlying upper atmosphere "weather," as opposed to a general characterization of the mean climatological state, are still rudimentary. Determining the factors that drive upper atmosphere weather will be a major CEDAR contribution to the National Space Weather Program.

Solar Maximum conditions are expected in 2001.



The purpose of the Solar-Terrestrial Interactions initiative is to advance our knowledge of the coupled thermosphere-ionosphere as a component of the solar-terrestrial system, quantifying responses to the sun's variability via (1) high-latitude magnetospheric interactions and (2) short-wavelength (soft x-ray, EUV) solar radiance absorption.

An underlying goal of this initiative is to trace all the energetic inputs from their origin, through their various transformations (collisional transfer of heat and momentum, exothermic reactions, etc.), to their ultimate dissipation in the terrestrial system. Eventually, such knowledge will form the basis for predictive capabilities that will benefit society through better knowledge of orbital and re-entry drag, by predicting consequences to communications and navigation systems, and by improving commercial power grid reliability.

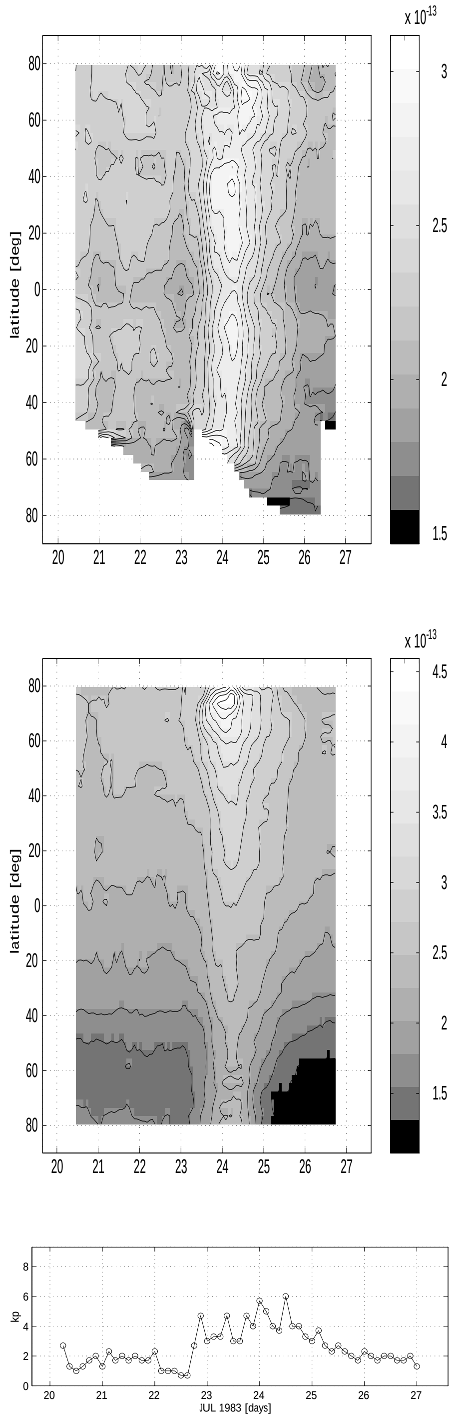


Global-Scale Behavior of the Ionosphere-Thermosphere-Mesosphere System

A central component of CEDAR Phase III is devoted to a comprehensive understanding of the spatial and temporal global development of ionosphere/thermosphere/mesosphere densities, temperatures, composition and winds resulting from direct solar and magnetospheric inputs.

Thermospheric composition, temperatures and winds vary considerably about the mean state, particularly in response to magnetospheric energy sources originating in solar wind disturbances. At high latitudes, densities of the heavier constituents (O_2 and N_2) can increase markedly during magnetic storms, while at some locations the response includes density depletions or dynamical “cells” whose specific features vary with altitude and the levels of solar and magnetic activity. Considerable upwelling also occurs, leading to the migration of density bulges out of the polar regions in ways that depend on local time, season, longitude, and solar activity levels. Energy is also transported equatorward through a variety of propagating wave modes, known as “traveling ionospheric disturbances” (TIDs), whose signatures are particularly evident in ionospheric plasma densities.

“Despite progress in identifying the interrelated processes … data/model comparisons often result in large discrepancies.”

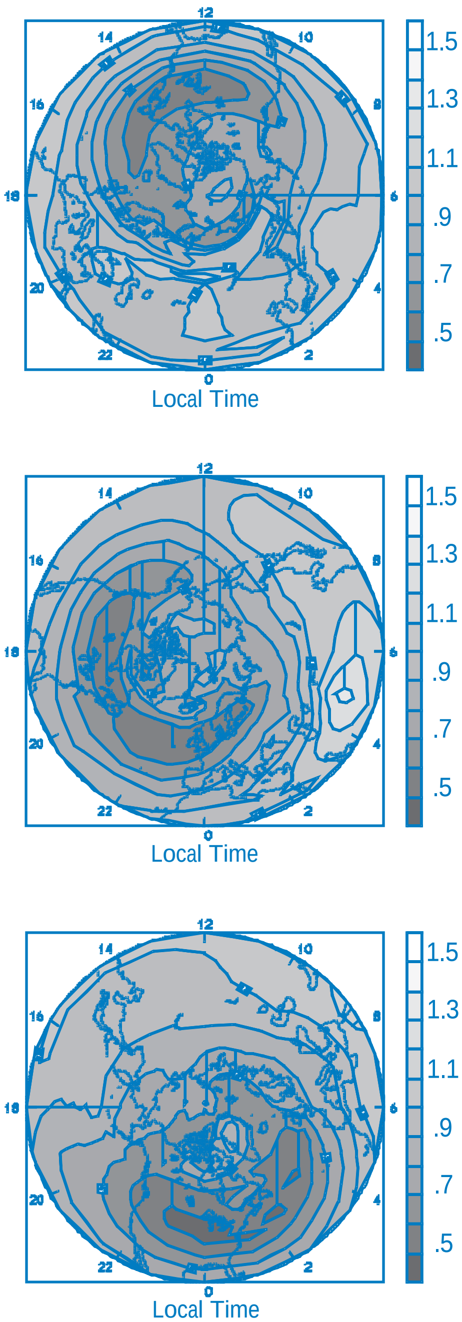


Variations in total atmospheric density at 200 km during a magnetic storm, as measured by the Satellite Electrostatic Triaxial Accelerometer (SETA) instrument. Bottom: Time development of the 3-hourly magnetic index, Kp, during 20–27 July, 1983. Middle: Density response as a function of latitude and time near 1030 LT. Top: Density response near 2230 LT. The day-night and hemispheric asymmetries can be explained in terms of how the solar-driven circulation enhances or diminishes the circulation forced by high-latitude heating processes. The units are 10^{-13} gcm^{-3}.

Despite progress in identifying the interrelated processes governing the thermosphere/ionosphere responses to variable high-latitude energy inputs, instantaneous data/model comparisons often result in large discrepancies. The complications lie in specification of spatial and temporal variability of the sources, interactive neutral-plasma coupling, dependence of the response on local time, and the time histories of all of the above. Understanding how these processes operate during a storm recovery period is also essential for describing the final redistribution of energy and momentum in the system. At low and middle latitudes, coupling between the charged and neutral particles has a profound effect on the composition of the topside ionosphere, on the field-aligned transport of ionization, and on the generation of electric fields. Measurements of the H, O, and He densities in the upper atmosphere are not extensive, yet they are critical to understanding the generation and transport of O^+, H^+, and He^+ in the topside ionosphere. The distributions of the charged and neutral species are very sensitive to solar variations and must be understood to appreciate the role of the nighttime F-region in moderating neutral circulation, and generating electric fields.

Global Scale Behavior of Electric Fields and Currents

Ionospheric electric fields and currents exhibit large variability on temporal scales ranging from a few minutes to several days and on spatial scales ranging from a few kilometers to several thousand kilometers. The importance of coupling between these different scales of variability is unknown. Our knowledge and understanding are particularly deficient with regard to latitude/longitude effects and short-term variability during quiet and disturbed conditions.



Time development and corotation of ionospheric "negative phase" plasma depletion in the Northern Hemisphere F-region during a magnetic storm, as simulated by the Coupled Thermosphere-Ionosphere Model (CTIM). The parameter plotted is the ratio of the peak ionospheric plasma density to a quiet-time reference value. The perimeter latitude is 25°, and the time sequence of the panels is from top to bottom at intervals of 6 hours UT. The plasma depletion is primarily caused by changes in neutral composition.

Electric fields are fundamental to the dynamics and thermal balance of the thermosphere, ionosphere, and protonosphere. During undisturbed conditions, electric field variability is mainly due to dynamo interactions connected with tides, planetary waves and gravity waves, as well as the inhomogenieties these fields produce in ionospheric conductivity, particularly at nighttime.

"Electric fields are fundamental to the dynamics and thermal balance of the thermosphere, ionosphere, and protonosphere."

The nature of the interaction between winds and electric fields, both of which modify the ionospheric conductivity, is poorly understood at present. Perturbations during disturbed conditions result from changes in the high latitude/magnetosphere current systems. These are controlled by the conditions in the Alfven shielding layer of the magnetosphere and by the conductivity structure of the high latitude ionosphere. The disturbance wind dynamo also represents an important contributor to the total electric field during magnetically active conditions. An improved understanding of electric field penetration for different seasons, latitudes, and longitudes is of fundamental importance for studies of the global response of the ITM system. Coordinated observations with increased time resolution and duration, new data analysis techniques, and additional numerical modeling efforts during CEDAR Phase III will provide important new information on the global electric field distribution and on the effects associated with convection enhancements, substorms, and the interplanetary magnetic field (IMF) configuration.

Small-Scale Plasma Structures

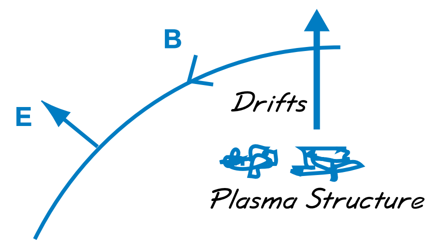
Virtually any sampling of neutral or plasma parameters in the upper atmosphere reveals significant amplitude fluctuations with horizontal scales less than a few hundred kilometers at temporal scales less than a few hours. In the neutral atmosphere, these features may be ascribed to gravity waves propagating upward from lower atmosphere regions and from impulsive disturbances produced in the auroral zones by particle and Joule heating. In the plasma, the larger scale features are produced by variations in the ionization and transport properties while the smaller scale features arise from plasma instabilities that form on the gradients of the larger features. At high latitudes, large-scale features called "patches" and "blobs" are produced by temporal variations in the convection of solar-produced ionization through the cusp and by prolonged dwell times in regions of discrete energetic particle precipitation. Small-scale structures may be produced by E X B drift instabilities and by velocity shears, but the relative importance of these mechanisms at different locations is poorly understood.

At low latitudes, large-scale F-region structures arise from the Rayleigh-Taylor instability and waves in the lower ionosphere are suspected to provide the seed from which structures grow. The penetration of magnetospheric electric fields to low latitudes may also initiate growth or suppression of plasma structures. Thus, the conditions determining the variability in the appearance and growth of these large-scale disturbances are not yet understood. This lack of understanding is reflected in further uncertainties about the global distribution and amplitudes of the smaller-scale structures they produce. At both high and low latitudes, steep plasma density gradients and strong Hall currents in the

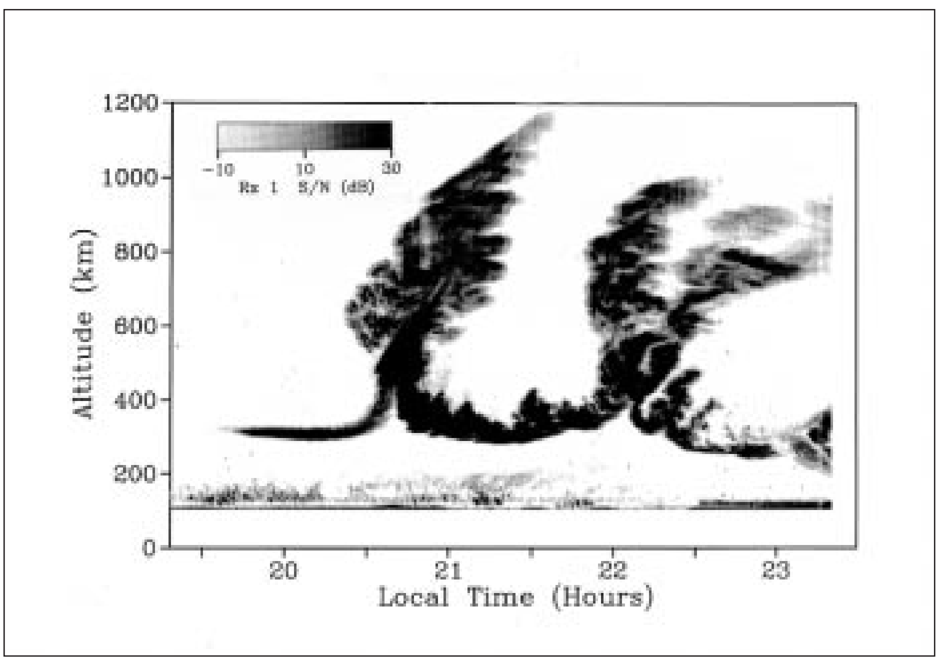
E-region also drive plasma instabilities which in turn produce intense small-scale waves. These waves are readily detected by ground-based systems and serve as a diagnostic for studies of space weather disturbances in the ITM system.

From a practical standpoint, small-scale ionospheric structures impact the operation of commercial and military navigation, communication, and surveillance systems, and so knowledge and predictive capabilities in this area represent significant benefits to society.

At the same time, from the CEDAR Phase III science perspective, deeper insights into these phenomena are intrinsically important for a more fundamental understanding of the interaction between the Sun and the Earth's thermosphere/ionosphere system.



"…small-scale ionospheric structures impact the operation of commercial and military navigation, communication, and surveillance systems, so knowledge and predictive capabilities in this area represent significant benefits to society."



A range-time-intensity plot of backscattered power from a series of highly structured spread-F plumes as seen by the Jicamarca radar on October 17, 1994. These echoes are from 3-meter structures that are aligned along the magnetic field.

Science Issues — Outstanding Questions

Solar-Terrestrial Interactions challenges for the future are embodied in the following research questions:

- How do electric fields, composition changes and neutral dynamics interplay to determine the latitude/longitude, seasonal, local time and UT dependences of ITM storm response?

- To what degree do global ionosphere/thermosphere features, including the distributions of irregularity structures, depend on orientation of the interplanetary magnetic field?

- To understand the origins of local and regional features in ionospheric and thermospheric structure, what are the required spatial and temporal resolutions and accuracies in the determination of energetic sources?

- What is the relative importance of thermosphere-ionosphere perturbations due to meteorological influences in comparison to those originating from the magnetosphere? How do these vary with height?

- What are the spatial scales and response times of the processes controlling the global electric field distribution?

- How do ambient conditions influence the appearance of equatorial plasma structures & their evolution?

- How do soft X-ray/EUV solar fluxes influence the hourly and daily variability of the ionosphere/thermosphere system?

Polar Aeronomy

Major Achievements during CEDAR Phases I & II

• Characterized compositional changes during geomagnetically active times from auroral observations and identified mesoscale perturbations in thermospheric neutral density cells.

• Identified and characterized unique mesospheric phenomena such as noctilucent clouds and polar mesosphere summer echoes.

• Observed and assimilated interplanetary magnetic field effects on polar ion convection and neutral wind vortices.

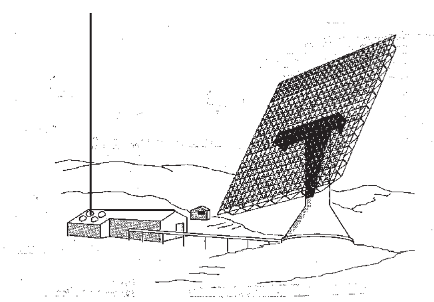
• Recognized and evaluated geomagnetic storm-time effects on polar parameters and processes.

• Identified the evolution and characterized the electrodynamics of F-region patches and sun-aligned arcs.

The Polar Aeronomy Initiative recognizes the potential for important scientific advances in aeronomic research on the mutual interaction between atmospheric regions at high latitudes. This initiative is to provide a major missing piece in our understanding of the multi-dimensional view of the global upper atmosphere. The issues involve a wide range of chemical, dynamical, thermodynamical, and electrodynamic coupling mechanisms throughout the vertical column, extending from the mesosphere to the exosphere and magnetosphere above both poles.

A major contribution to the polar aeronomy initiative, and to solar-terrestrial research in general, will be the development of the Polar Cap Observatory (PCO) in Resolute Bay, NWT. The 1989 workshop report "A Polar Cap Observatory" outlines the scientific impetus for developing such a facility. The PCO will include state-of-the-art optical and radio instrumentation, including an incoherent scatter radar, whose combined measurements will fill an observational void and significantly advance our knowledge of the upper atmosphere deep within the polar cap. The scientific results from other world-class facilities for upper atmospheric research attest to the greatly enhanced productivity that emerges when aeronomic parameters measured by both optical and radar instrumentation are combined. A collective multi-dimensional view of the polar upper atmosphere and its processes is a major challenge within this initiative, with the planned Polar Cap Observatory playing a pivotal role in meeting this challenge.

"A collective, multi-dimensional view of the polar upper atmosphere and its processes is a major challenge within this initiative, with the planned Polar Cap Observatory playing a pivotal role in meeting this challenge."



Energetics and Neutral Dynamics

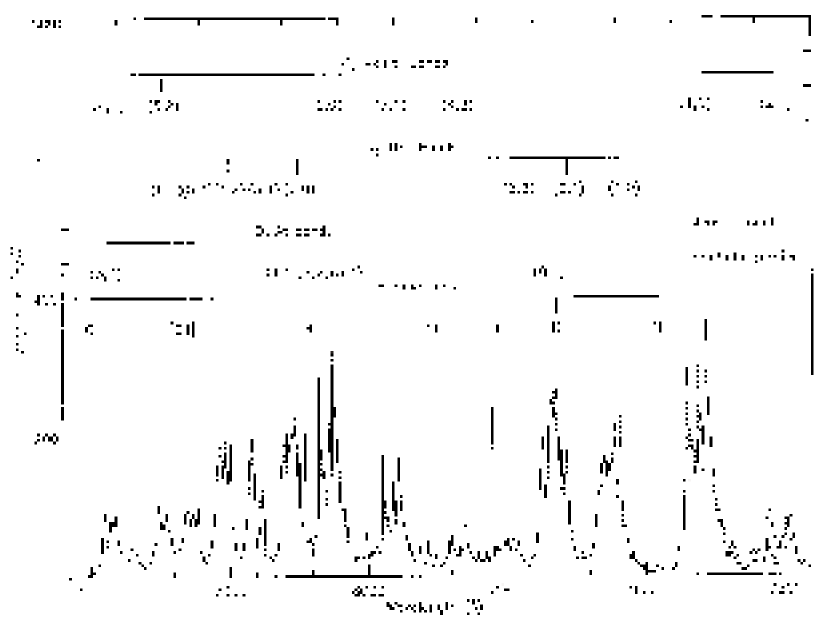
The diverse geophysical phenomena observed in the polar regions reflect the unusual blend of energy sources known to be important to the atmosphere at lower latitudes. These include solar UV/EUV radiation, electromagnetic energy transfer, energetic particle precipitation, atmospheric waves and tides, and magnetospheric waves. An important goal of the polar initiative will be to determine the precise influence of these energy sources on composition, dynamics, and chemistry and the distribution of these sources in altitude and latitude.

In polar regions, neutral winds and their dynamical feedback create a complicated chain of cause and effect with other aeronomic processes that is presently not well understood. This is especially true in the E region. In this altitude regime, the neutral dynamics are strongly influenced by electric fields of magnetospheric origin, pressure gradients established by Joule and particle heating, and momentum forcing by waves. These sources of momentum and heat vary with spatial and temporal scales beyond those currently achieved in coupled ionosphere-thermosphere models; moreover, observations are sparse, especially over the polar cap. Limited data bases of polar E-region wind measurements show the winds to be quite variable. Moreover, observations invariably show unusually large wind speeds associated with increased magnetic activity while numerical models generally predict winds significantly smaller than the observations.

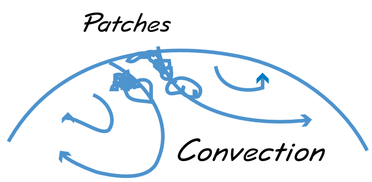
Vertical winds not only influence the local atmosphere but significantly impact many measurement techniques that assume the vertical winds to be small. Yet, vertical winds are a poorly measured and modeled quantity that are thought to be of significant magnitude at polar latitudes. Reliable measurements and modeling of vertical winds in the MLTI polar region will be a major component of this initiative.

The variability and magnitude of light ion outflow from the polar cap is also poorly known, yet this flux is thought to be a significant component of global escape into the magnetosphere. Quantification of the strength and variability of the "polar wind" is a long-standing goal of polar aeronomy research now to be realized in Phase III.

*"In polar regions,
neutral winds and their dynamical feedback
create a complicated chain of cause and effect
with other aeronomic processes
that is presently not well understood."*



Auroral spectrum recorded with one second exposure of a Class I imaging spectrograph. Continuous and dotted curves represent measurements and model calculations, respectively.



"Improvements in measurement capabilities of plasma structures can provide important clues to the underlying processes which formed them; moreover, these structures can serve as dynamical or chemical tracers to help elucidate the physics of related phenomena."

Plasma Electrodynamics and Structure

Electrodynamic and plasma structures of the polar regions span a broad range of temporal and spatial scales as exemplified by such features as sporadic E layers, F-region patches, polar holes, auroral arcs, convection patterns, and substorms. Improvements in measurement capabilities of plasma structures can provide important clues to the processes which formed them; moreover, these structures can also serve as dynamical or chemical tracers to help elucidate the physics of related phenomena. For example, patches are a tracer of global ionosphere-thermosphere electrodynamics: tracking them across the polar cap from their source (pre-cusp) to where they become boundary or auroral blobs defines the time history of global convection. Analysis of the evolution of patch shapes not only helps define the source structuring mechanism but also subsequent small-scale changes in the convection electric field.

Plasma electrodynamics is intimately related to plasma structure: both require high temporal and spatial resolution measurements of basic ionospheric parameters to characterize their interdependencies. Because of the current difficulty in obtaining reliable measurements of these parameters simultaneously throughout the polar region, results on ionospheric electrodynamics and plasma structure at very high latitudes are far from complete. The Polar Cap Observatory will enable important advances in research on the electrodynamics and plasma structures central to this CEDAR Phase III initiative.

Neutral and Ion Composition

The composition of the upper atmosphere is one of the key parameters needed in many polar aeronomic studies, and yet it is still poorly represented by theoretical models and undersampled by measurement techniques. The required vertical profiles span a wide range of phenomena from the complex molecules and ions that exist in the D-region (~60 km) to the basic F-region distributions of molecular and atomic ions above 200 km during periods of quiet and enhanced geomagnetic activity. Fundamental calculations of collision frequency and conductivity in the high-latitude E region are directly dependent on the neutral and ion composition.

Minor species, such as nitric oxide, with its high latitude origins in nitrogen molecules vibrationally excited by particle precipitation and its key role as a cooling agent for the thermosphere, are also of prime importance to CEDAR Phase III science. On the topside of the polar F region, polar wind processes such as charge exchange modulate the height distribution of the light neutral and ion populations very differently than they do at lower latitudes. The uncertainty in their abundances also impacts measurement techniques of other parameters. Phase III improvements in composition measurements and modeling will yield fundamental advances in polar aeronomy research.

Aerosol Formation and Charging

A major discovery during CEDAR Phases I and II was the very large radar returns known as polar mesosphere summer echoes (PMSE) that appear to be related to charging of small aerosols above the noctilucent cloud (NLC) zone.

This has introduced the emerging field of dusty/icy plasma physics to polar aeronomy. Meteoric dust and smoke particles, themselves related to NLC formation, are subject to similar charging physics. During CEDAR Phase III the potential exists for major advances in our understanding of metallic atom layers and the interactions between smoke and dust particles with atmospheric water vapor, clouds and chemical reservoirs.

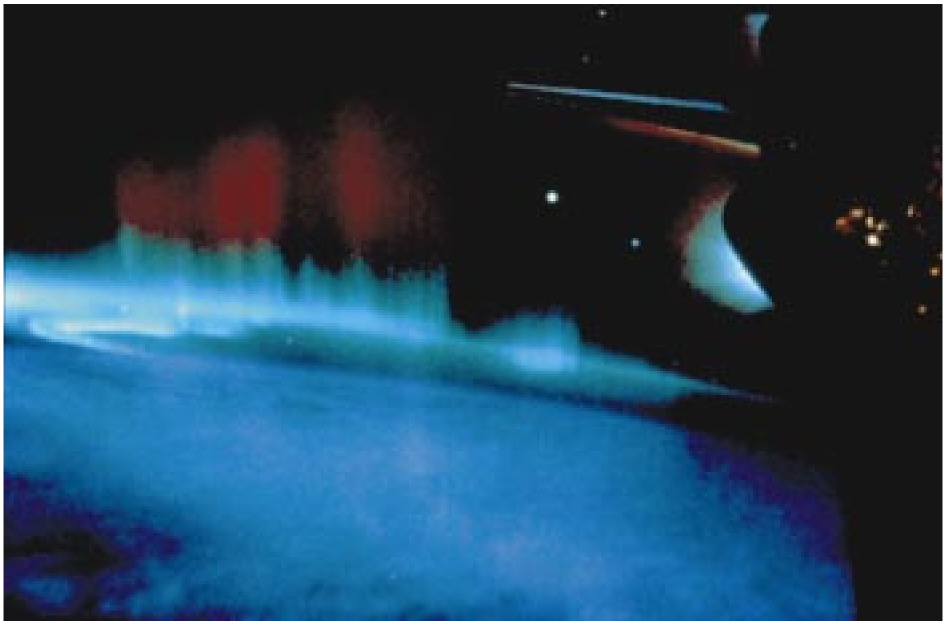
Auroral Emissions and Forms

Auroral emissions represent a major feature of the high-latitude atmosphere. They are the direct manifestation of energized particles interacting with the Earth's upper atmosphere. The aurora serves as a visual aid for studying events that occur farther out in space since auroral emissions and forms map to energetic plasma populations in the magnetosphere. Auroral particle heating of the upper atmosphere is also a key area of study because its effects upon the atmosphere can often exceed those generated by Joule heating.

Auroral emissions occur at both radio and optical wavelengths and involve a complex interaction between charged and neutral particles. For the Polar Aeronomy Initiative to succeed, analyses of these emissions and the various forms of aurora (arcs, rays, bands, etc.) require instruments capable of monitoring rapidly evolving auroral patterns, as well as instruments capable of probing the charged and neutral state of the ionosphere and thermosphere on the same small temporal and spatial scales.

"The composition of the upper atmosphere is one of the key parameters needed in many polar aeronomic studies, and yet it is still poorly represented by theoretical models and undersampled by measurement techniques."

The aurora as seen from space.



Science Issues — Outstanding Questions

• How are composition, density and heating influenced by the auroral characteristic energy and energy flux?

• What is the magnitude and temporal variability of the polar wind?

• What are the underlying physical causes of interhemispheric differences in observed aeronomic parameter at polar latitudes?

• What are the dynamical influences on the polar MLT region from magnetospheric, solar and meteorological sources of energy? What are the roles of chemical heating, LTE and non-LTE effects, ion-neutral chemistry, gravity wave momentum and energy deposition, Joule heating, and energetic particle precipitation?

• How do the relationships between electron density, conductivity, neutral and ion composition, ion convection, and neutral winds influence polar electrodynamics? How do they regulate the energy flux between the ionosphere and magnetosphere at high latitudes?

• What is the time history of electric potential voltage across the polar caps? What is the shape & size of the polar cap in response to this voltage?

• How does the interaction between large-scale circulation and gravity waves impact the presence of NLCs and PMSEs in the polar regions?

• What are the relationships between meteoric input, ionospheric plasma and minor neutral layers in the MLT region?

Long-term Variations

A prominent accomplishment of the CEDAR Program has been the development of observational tools capable of isolating long term composition, temperature, and dynamical changes in the mesosphere and thermosphere. CEDAR modeling efforts have established that long term composition and thermodynamic changes are quite possible in these regions in response to chemical and thermal changes in the lower atmosphere. These models further establish that small changes occurring in the lower atmosphere are likely to trigger larger, more easily detected changes in the mesosphere, thermosphere, and exosphere. These CEDAR accomplishments make the evaluation of long term trends a natural focus of Phase III modeling and measurement efforts.

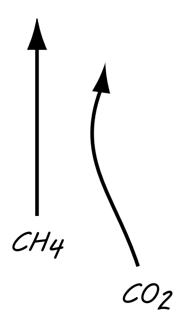
Since the recognition that catalytic chemical cycles are deleterious to the ozone layer, it has become apparent that our atmosphere is experiencing profound changes in trace chemical composition. Of particular relevance to the atmosphere above 60 km are the dramatic increases in CO_2, CH_4, and N_2O concentrations measured in the lower atmosphere. These species (particularly CO_2) and a variety of chemical by-products are important radiative cooling agents in the upper atmosphere. CEDAR Phase II modeling efforts showed that a doubling of CO_2 and CH_4 can produce temperature reductions of 5–10 K in the mesosphere and tens of degrees in the thermosphere. Models also generally concur that these minor species changes can enhance upper atmospheric atomic hydrogen densities by more than 50%.

The controversy over the possible existence of a "global warming" trend near the Earth's surface is well-known. While relatively small (2–4 K) projected increases in the global mean surface air temperature can produce dramatic climate changes, our ability to extract the existence of such trends from the natural variability of the system is very limited. In the upper atmosphere, however, the magnitudes of anticipated effects increase with altitude, and such trends are superimposed on a more benign background than exists in the troposphere. The extreme sensitivity of the mesosphere, thermosphere, ionosphere, and exosphere to thermal chemical and dynamical forcing originating at lower levels, combined with recent observational evidence, suggests that this atmospheric regime may provide quantitative early evidence of global atmospheric change.

For some parameters, and at some locations, data have already been compiled for more than two decades. A challenge for Phase III will be to characterize long term changes in upper atmospheric temperature, composition, and winds, and to demonstrate the ability to distinguish changes due to solar effects from those caused by anthropogenic effects. CEDAR Phase III research will provide the measurement and modeling framework for such studies.

Major Achievements during CEDAR Phases I & II

- Detected an increase in H in the upper atmosphere extending beyond one solar cycle.
- Modeled specific changes of thermosphere temperature and composition in response to increasing CH_4, CO_2, and N_2O.
- Modeled the long-period evolution of NLCs in response to increasing mesospheric H_2O and decreasing temperature.
- Demonstrated by modeling that h_mF2 and Ti will decrease in response to thermospheric cooling.
- Established NLC detection using lidars deployed at high latitudes.
- Initiated long-term databases containing mesospheric temperatures and winds.



"The extreme sensitivity of the mesosphere, thermosphere, ionosphere, and exosphere to thermal, chemical and dynamical forcing originating at lower levels…suggests that this atmospheric regime may provide quantitative early evidence of global atmospheric change."

It is extremely important to establish a program for the continuous monitoring of key atmospheric parameters through future decades. It is also important to evaluate the existing CEDAR Data Base within the context of long term trends. Issues such as calibration and consistency need to be addressed. Long-term atmospheric variability associated with inter-solar cycle UV and EUV radiance variability is also poorly understood. Establishing the atmosphere's response to long term solar variability should thus be an integral element of CEDAR Phase III research activities.

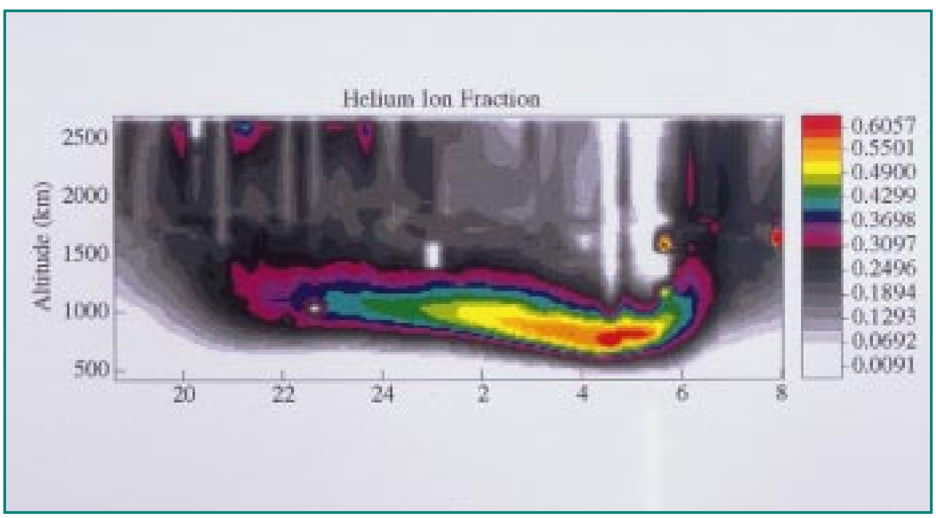
> "It is extremely important to establish a program for the continued monitoring of key atmospheric parameters through future decades…"

Thermosphere, Ionosphere, and Exosphere

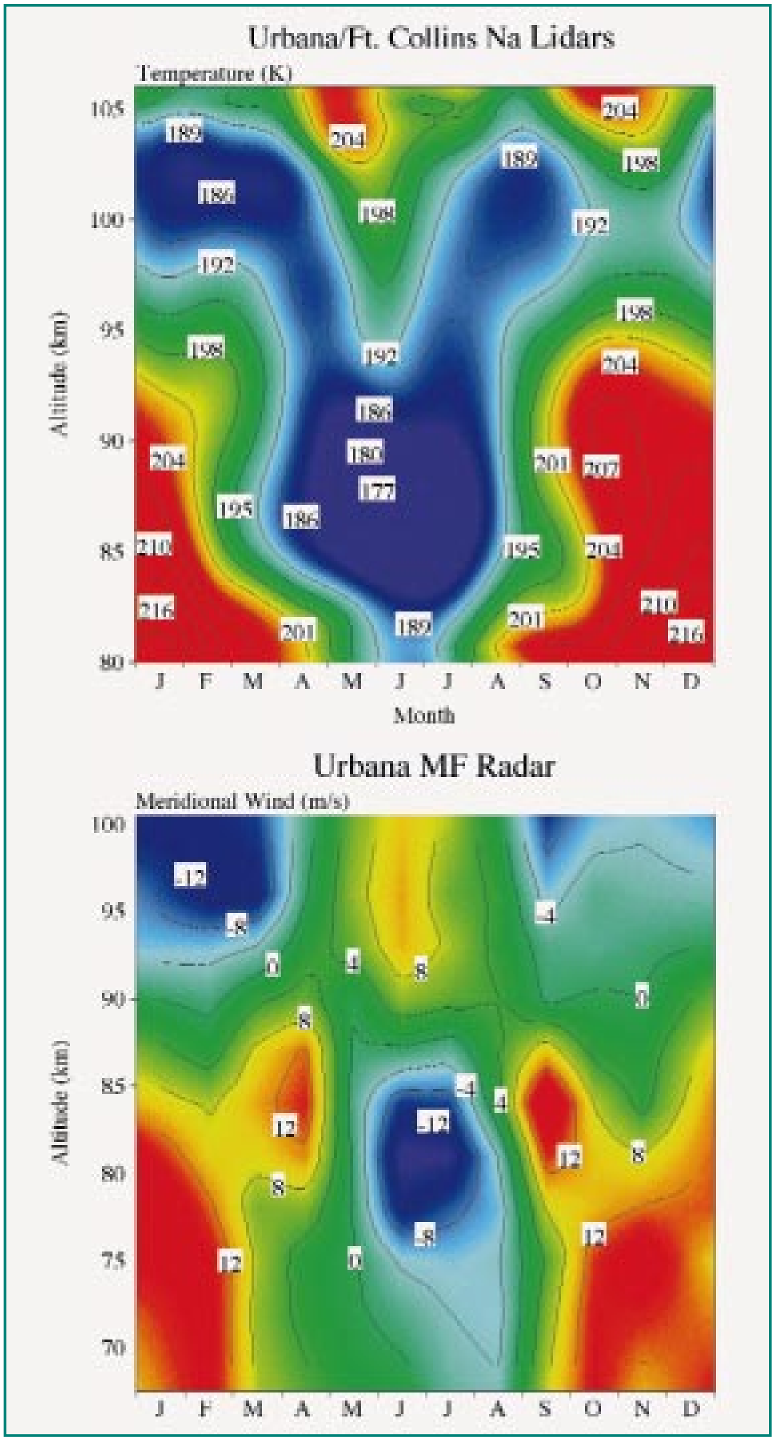
Neutral Temperatures and Densities. Models indicate that the middle and upper thermosphere is the region expected to display the largest thermal response to enhanced radiative cooling due to changes in minor molecular species. An extensive database of neutral temperatures from incoherent scatter radar and 6300 Å Fabry-Perot measurements now exists. Previous CEDAR studies of these thermospheric parameters reveal differences under apparently "identical" solar minimum conditions (as indicated by ground-based proxies of solar activity during solar cycle 21 and 22). Similar long term data sets of other thermospheric parameters are also available, many with broad geographical coverage. Given the enhanced sensitivity of high altitude neutral species to thermal structure, thermospheric neutral densities may reveal the most robust evidence of secular changes in the thermosphere. The full assessment of past measurements and continuation of these data streams present an excellent opportunity to evaluate long term neutral temperature variability during Phase III.

F-region T_i, h_mF2, and N_mF2. Recent models have shown that the F-region ion temperature (particularly the nighttime T_i) is a potential indicator of secular thermal change. Similarly, the altitude of the F2 peak (h_mF2) has been modeled to drop significantly (tens of km) in response to a cooling F-region, and that altitude change is expected to trigger a decrease in N_mF2. These parameters are supplied routinely by the UAF radar chain to the CEDAR database, and a wealth of N_mF2 data are also available from a distributed array of ionosondes. In a fashion similar to the retro-analysis of neutral temperatures, the existing data base should be evaluated for calibration and analysis consistency. The ISR and ionosonde data bases, if properly calibrated, present CEDAR Phase III with an obvious opportunity to evaluate long term trends and to isolate a possible inter-solar cycle component of long term variability.

Exospheric H Abundance and Escape. Following chemical cycling and transport across the turbopause, hydrogenous species ultimately appear in the upper thermosphere in the form of atomic hydrogen which can subsequently escape by thermal or charge exchange mechanisms. Due to the long mean free path between collisions in this region, H atoms arrive at the exobase from a broad spatial region in the lower atmosphere. Thus, the upper thermosphere and exosphere are excellent regions to evaluate the globally averaged effect of methane increases in the lower atmosphere. Two independent CEDAR data sets spanning more than a decade appear to support model results projecting an increase of H abundance in the upper thermosphere. However, interpretation of these observations of the Balmer-alpha emission is limited by their sporadic temporal availability and measurement and calibration uncertainties. Continuation of these long term data sets, with improved sensitivity, seasonal coverage, and careful calibration, is needed for further progress. An improved understanding of Balmer-alpha variability (relative to light ion composition, solar effects, and storm-time behavior) is required, as are other techniques that evaluate changes in upper atmospheric hydrogenous species, including H^+ and OH.



Helium ion fraction in Earth's exosphere as measured by the Arecibo IS radar. Long-term trends in exospheric abundances of H, He, H^+, and He^+ may represent manifestations of global change at lower heights.



Monthly climatologies of mesosphere/lower thermosphere (MLT) temperatures and meridional winds observed by Na lidar and MF radar systems at the University of Illinois and Colorado State University.The temperatures were derived by combining more than 1200 hours of lidar observations made on 222 nights at Ft. Collins, CO and Urbana, IL. Observations of MLT temperature and other parameters will be needed over the next decade in order to ascertain whether global change is taking place in the upper atmosphere

Mesosphere and Lower Thermosphere

Temperatures and Winds. Model estimates suggest a decline in MLT temperature associated with increases in CO_2 and N_2O concentrations. Evidence for such effects can be inferred from Lidar, OH rotational temperature, and OI 557.7 nm Doppler measurements. However, model investigations to date have addressed only the thermodynamic and radiative transfer aspects of the problem for a global mean. Long-term thermal changes drive dynamical changes by altering both vertical and horizontal temperature gradients and hence horizontal winds. Changes in stratospheric and mesospheric mean circulation modify the filtering of gravity waves whose momentum deposition strongly influences the mesopause temperature structure. For the mesopause region, therefore, the investigation is as much a dynamical problem as a chemical one — due to the strong mutual coupling between these processes. During Phase III, modeling efforts in this area must seek to incorporate all of the interactive processes in a self-consistent fashion. These studies also need to be complemented with evaluations of solar contributions to atmospheric variability.

Noctilucent Clouds (NLCs). The roughly 1% per year increase in tropospheric methane experienced over recent decades should be manifested by change in mesospheric water vapor concentrations since oxidation of methane is responsible for about half the water vapor in the mesosphere. CEDAR modeling studies predicted that a colder and wetter mesopause may have led to the onset and first detection (in 1885) of NLCs at latitudes sufficiently equatorward to be visible during twilight conditions. In addition, a substantial cooling (about 0.5 K/year) has occurred over the past several decades at the mesopause, much higher than expected from CO_2 increases. The colder and wetter mesopause may be responsible for the nearly-doubled occurrence rate of NLCs observed since the early 1960's. To explain these rapid changes requires some additional cooling mechanism(s) not presently considered in models (e.g., increased gravity wave flux, or a change in the filtering of gravity waves due to shifts in the mean stratospheric winds). Thus, the predication by CEDAR models of an equatorward advance in NLC occurrence in the next century when CO_2 and CH_4 are doubled may well be realized over a much shorter time scale (in decades at the present rate of cooling).

Average number of nights per year, (N), on which noctilucent clouds were reported from north-west Europe. These data were obtained from a linear fit to data with the effect of solar activity removed.

Year	(N)ights
1960	17
1965	23
1970	29
1975	35
1980	41
1985	47
1990	53

Since NLCs may be an intriguing visual indicator of long term global change, and given recent advances in their detectability with lidar and imaging techniques, the study of this phenomenon is an important aspect of Phase III studies of long term variability. Models of NLC formation must be further developed so that nucleation processes, effects of the ambient vertical winds, and other keys to NLC formation and latitude migration become better understood. An understanding of solar cycle changes and of relatively short-term variations in NLC frequency (i.e., those associated with tides, planetary waves, semiannual and QBO variations) will also help to isolate inter-annual and long-term variability. Multi-instrument observations of NLCs and quantification of ambient atmosphere parameters are central to this effort. CEDAR Phase III will strive to develop new techniques to derive the concentrations of minor species (particularly the chemical by-products of CH_4, CO_2, and N_2O) to better constrain cooling rates and models for NLC condensation pathways.

Science Issues — Outstanding Questions

To achieve CEDAR Phase III objectives in the studies of **Long-Term Variations,** questions that need to be addressed include the following:

• Which identified long term trends can be ascribed to inter-solar cycle variability and which to changes in atmospheric composition at low altitudes?

• Are composition changes, temperature changes, or dynamical changes primarily responsible for changes in NLC occurrence frequency? How are these parameters related?

• What are the cloud physics issues associated with NLCs? What are the condensation nuclei, and does NLC occurrence frequency depend strongly on their variability?

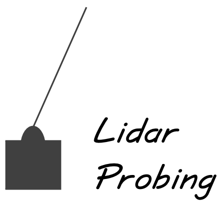
• Can long-term trends in mesospheric temperatures and winds, distinct from solar cycle or local dynamical effects, be clearly established?

• In the thermosphere and in the F-region, can long-term trends in neutral density and temperature, peak electron density, and height of the peak be established?

• Will an apparent trend in upper thermospheric and exospheric hydrogen column abundance persist through subsequent solar cycles?

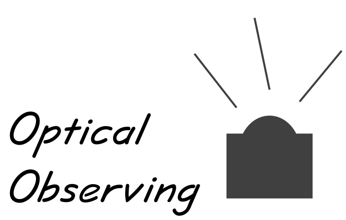
Resources

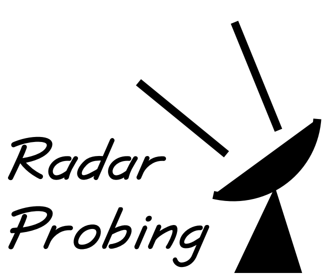
Instrumentation



Introduction

At its inception, the CEDAR Initiative was based on the critical need to invigorate the aeronomy community's observational capabilities in optical remote sensing of the upper atmosphere. Developments in detector capabilities, primarily using image intensifiers and new CCD technologies, have revolutionized the field during CEDAR Phases I and II. At the same time, and using a different set of new technologies, radio diagnostic systems and capabilities have been significantly improved and expanded. Today, as a basis for Phase III, there is a remarkably comprehensive set of state-of-the-art diagnostic systems to support individual and community-wide initiatives. In this section, a brief review of observational capabilities is presented. Additional needs in instrumentation and a full discussion of modeling requirements are given in the following section.





The CEDAR community develops and utilizes a broad spectrum of instruments to investigate the atmosphere above 60 km. The capabilities of some of these instruments are depicted on page 29. These instruments include Incoherent Scatter Radars (ISR), Mesosphere-Lower Thermosphere Radars [MLTR, a collective term for medium frequency (MF) or spaced-antenna drift radars, meteor wind radars, and Mesosphere-Stratosphere-Troposphere (MST) radars], digital ionosondes (DGS), Ionosondes (ION), Fabry-Perot Interferometers (FPI), Michelson Interferometers (MI) Lidars (LDR), and Imagers. A comprehensive summary of current instruments, funded all or in part by CEDAR resources, is tabulated on pages 26–28. These systems and new facility initiatives such as the early Polar Cap Observatory (EPCO) testify to the vitality of the CEDAR infrastructure.

Instruments evolve with technological improvements, and state-of-the-art techniques and automation are rapidly incorporated into new instruments.

Brief summaries of instrument capabilities and technology upgrades realized during CEDAR Phase I and II are described below:

Radio

Incoherent Scatter Radars (ISRs)

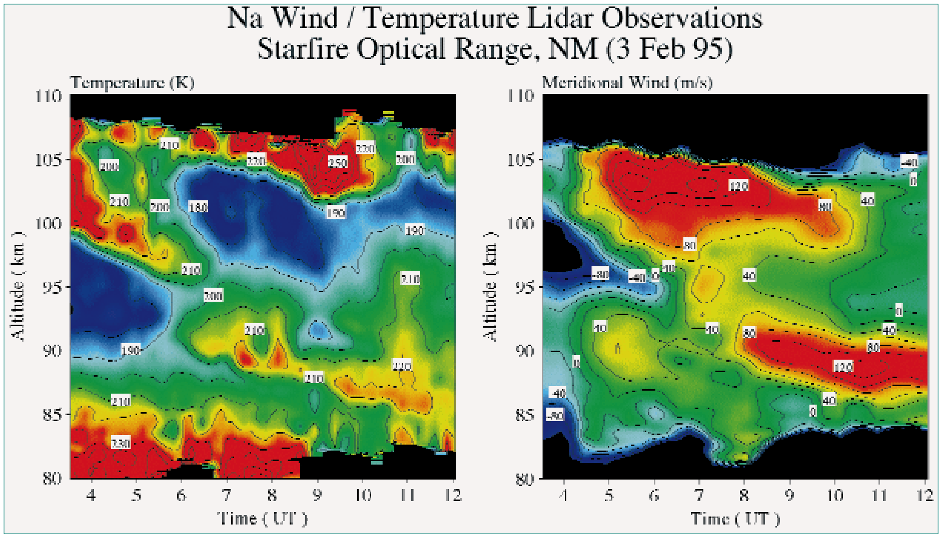
Incoherent scatter radar is the single most powerful ground-based technique for observations above 100 km and is responsible for almost all measurements between 100 and 170 km. The four NSF sponsored ISRs are located at the Upper Atmospheric Facilities (UAF) sites in Sondrestrom (Greenland), Millstone Hill (Westford, MA), Arecibo (Puerto Rico) and Jicamarca (Peru). Most of the ISRs have implemented new phase-coding techniques which permit simultaneous E and F-region coverage with good time resolution. Lag-profile measurements provide further improvements in accuracy and time resolution by preserving all information in the incoherent scatter signal. Improved analysis methods, including full-profile analysis and multi-ion composition determination in the topside ionosphere, now take full advantage of the improved measurement techniques.

The Millstone Hill Class 1 Facility.

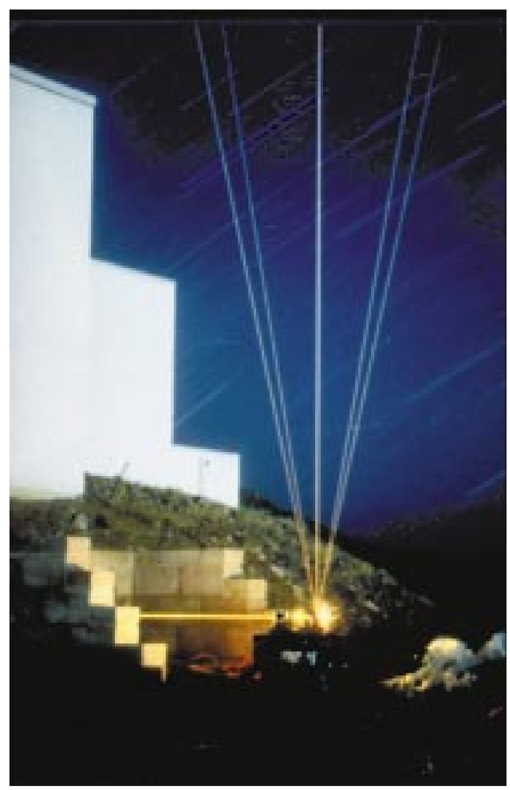
Optical

Lidars

During CEDAR Phase II, no new technology has contributed more to the science goals of CEDAR below 100 km than lidars. These include resonance lidars tuned to various alkali metals near the mesopause and Rayleigh lidars of the backscatter and Doppler type. The broad and narrow band resonance systems provide high-resolution measurements of wave dynamics, ion-neutral chemistry (including thin layers), temperatures, and winds in the 80–110 km region. The Rayleigh systems provide important measurements relating to vertical coupling processes. Contributions to CEDAR Phase III science goals will continue from existing instruments, especially as the power and aperture of lidar systems increase with the aid of new technologies.



Above: Contour plots of tempratures and meridional winds measured by the Na lidar using the 3.5 meter diameter telescope at the Starfire Optical Range, NM.



Lower right: Time-lapse photo of the Na wind/temperature lidar in operation at Starfire Optical Range, New Mexico. The laser beam was scanned in five directions so that all three wind components and temperature could be measured.

Mesosphere-Lower Thermosphere Radars (MLTRs)

Neutral winds in the 80–100 km region are measured by this broad grouping of radars that are generally capable of continuous wind observations over long duration. Advances in data processing for these instruments have yielded knowledge on the dynamics of the upper mesosphere, including gravity wave scales. Small VHF radars can also be used to detect charged mesospheric ice related to noctilucent clouds.

High Frequency (HF) Radars

HF radars sense the backscatter from ionospheric irregularities in the E and F regions. As a Doppler radar, they provide line-of-sight plasma irregularity drift speeds and, in most cases, spatial information on irregularity structures. When used in a network at high latitudes, they provide a comprehensive view of convection patterns.

Ionosondes

State of the art, automatic soundings of the bottomside ionosphere are generally available at the four UAF sites. A global network of modern digital ionosondes, created primarily by non-NSF sources, is used widely by CEDAR scientists. In the presence of irregularities, plasma drift measurements can be obtained from ionosondes equipped with spatially-distributed receiver systems.

Satellite Radio Beacon (SRB) Receivers

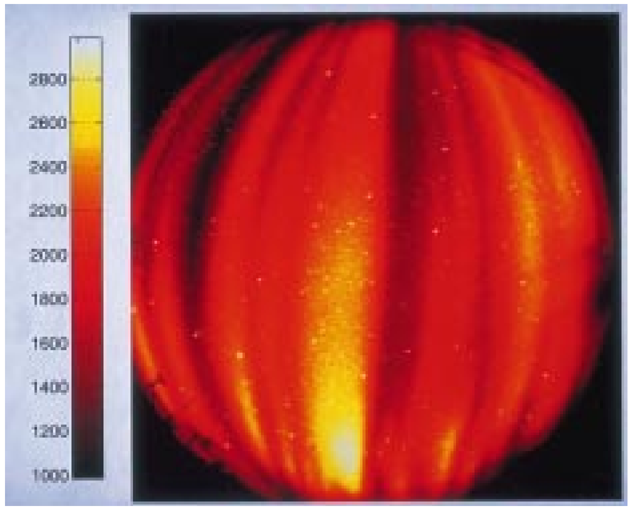
SRB observations provide scintillation measurements used to study small scale plasma irregularity occurrence and drift patterns. SRB receivers that measure total electron content (TEC) are also used increasingly in radio tomography studies of F-region structure. The emerging network of SRB receivers developed to observe Global Positioning System (GPS) satellites provide a powerful new technology for global and regional studies of ionospheric space weather effects upon small scale irregularities and total electron content.

Imagers

The film-based all sky cameras of pre-CEDAR days have now been replaced by state-of-the-art wide angle imaging systems that use image-intensified and/or high efficiency “bare CCD” technologies. These provide high time resolution, low light level capabilities with photometric calibration of all aeronomic optical phenomena (aurora, SAR arcs, airglow and gravity wave patterns). The two-dimensional nature of images provides both context for other line-of-sight measurements as well as self contained optical science yield, particularly in the case of gravity wave studies. New “temperature imagers” will contribute to CEDAR Phase III gravity wave studies.

Fabry-Perot Interferometers (FPIs)

Fabry-Perot interferometers have supplied the major source of thermospheric neutral temperatures and winds to the CEDAR Data Base. FPIs are typically configured for either high or low spectral resolution depending on the species and therefore altitudes to be observed. Although traditionally characterized by very small spatial fields of view, array detection systems developed in Phase II have expanded FPI system capabilities to all-sky measurements of Doppler profiles. Steady advances in sensitivity have also been realized by using high quantum efficiency CCDs. New infared (IR) detectors and improved methods of making daytime observations at visible wavelengths are actively being developed for Phase III use.



Equatorial airglow depletions (dark bands) observed with 6300 Å imager at Christmas Island, September,1995.

Michelson Interferometers (MIs)

Michelson interferometers are of two types, scanning instruments used for Fourier Transform Spectroscopy (FTS) and fixed-path Doppler Michelson interferometers used for wind measurements. Instruments have been manufactured for rotational temperature measurements of OH airglow, with an accuracy of 2 K.

Spectrometers

Ultraviolet (UV) and visible spectrometers have been developed with improved detection and imaging capabilities. IR spectrometers have evolved with new imaging capabilities. All these types support spectroscopic studies of atmospheric processes. Multi-site imaging spectrographs provide a new optical tomographic capability for the study of the altitude dependence of airglow, auroral and gravity wave structures.

The Arecibo Class 1 Facility.

National and International Resources

Since the CEDAR program is aimed at studying the coupling of various regions of the atmosphere on a global scale, the importance of strong collaboration with other national and international programs has been an essential element in its success. Instrumentation located in other countries have been involved in global campaigns and scientists from around the world have participated in the analysis of the resulting data and in the CEDAR Workshops. CEDAR cooperation with the NSF programs on Geospace Environment Modeling (GEM) and SUNRISE, with the National Space Weather Program (NWSP), with NASA spaceflight programs, DoD's environmental research efforts, and with the Solar-Terrestrial Energy Program (STEP) and its follow-up efforts has clearly been a benefit to all and will continue in CEDAR Phase III.

Class 1 Facilities

The CEDAR community has made significant advances in the development of its "Class I" facilities. Class I facilities consist of optical and radar instrument "clusters" collectively capable of multi-parameter observations spanning the vertical column above about 60 km up to about 1000 km, and at some sites well beyond 1000 km. Due to logistical considerations and the latitudinal placement of the ISRs, the Class I facilities have been developed at the ISR sites. The Class I facilities are complemented by a large number of other instruments located at a variety of sites, as is evident in the CEDAR data base listing.

The accompanying table gives the instrument matrix for the Class I facilities at present, including those at nearby locations. Clearly, great strides have been made to achieve this impressive array of instruments. There are also a variety of reasons why there are different complements of instruments at each site. A major initiative at NSF is underway to create a fully-instrumented Polar Cap Observatory (PCO) and this is included in the table in its current "Early PCO" status.

The Jicamarca Class 1 Facility.

Instruments at UAF/CEDAR Facilities

Site	Radar: IS	MLT	Lidar	Ionosonde	Imager	Spectrometer	FPI	Magnetometer
EPCO		✗		✗	✗	VIS IR	✗ (6300 Å)	✗
Sondrestrom	✗		✗ (Rayleigh) ✗ (Na Resonance)	✗	✗	UV VIS IR	✗ (6300 Å)	✗
Millstone Hill	✗	✗ (Durham)		✗	✗		✗ (6300 Å) ✗ (6300 Å for all-sky) ✗ (6300 Å for dayglow, other) ✗ (5577 Å)	
Arecibo	✗	✗ (Aguadilla)	✗ (Rayleigh) ✗ (Na & K Resonance)	✗		VIS	✗ (6300 Å) ✗ (6563 Å, or other)	
Jicamarca	✗	✗		✗	✗ (Arequipa)		✗ (6300 Å) (Arequipa)	✗ (Huancayo)

CEDAR Supported Instrumentation

Instrument & Primary Measurements	Site of Regular Operation	Spectral/Frequency Range	Contact/e-mail
INCOHERENT SCATTER RADARS			
Ionospheric plasma density,	Sondrestrom, Greenland	1290 MHz	J.Kelly/kelly@sri.com
temperatures & velocity	Millstone Hill Observatory, MA	440 MHz	J. Foster/jcf@hydra.haystack.edu
	Arecibo Observatory, Puerto Rico	430 MHz	C.Tepley/craig@naic.edu
	Jicamarca, Peru	50 MHz	D. Farley/donf@ee.cornell.edu
MF RADARS			
• Winds & tides (~70–100 km)	Aguadilla, Puerto Rico	1.95 MHz	M. Ierkic/ierkic@exodo.upr.clu.edu
• Winds (~70–100 km)	Barking Sands, Kauai, HI	1.98 MHz	D.C. Fritts/dave@leonardo.colorado.edu
OTHER RADARS & RADIO			
Frequency Agile Radar			
Mesospheric winds, plasma irregularities	EPCO, Resolute Bay, Canada, & campaigns	2–50 MHz (2 instruments)	R.Tsunoda/Tsunoda@unix.sri.com
SuperDarn HF Coherent Scatter Radar Network			
Polar convection	Arctic & Antarctic regions	8–20 MHz	R. Greenwald/ray_greenwald@jhuapl.edu
Julia Radar			
Equatorial spread-F & sporadic-E	Jicamarca, Peru	50 MHz	B. Balsley/balsley@terra.colorado.edu
MEDAC Radar			
Winds (~70–100 km)	Biak, Indonesia; Christmas Island; Darwin, Australia; Piura, Peru (Attached to ST radars; 4 instruments)	50 MHz	S.Avery/savery@numbat.colorado.edu
Meteor Radar			
Winds (80–110 km)	Durham, NH	38.6 MHz	R. Clarke/ron.clark@unh.edu
Digital Ionosonde			
Ionospheric layer heights	Bear Lake Observatory, UT	1.6–15 MHz	F.T. Berkey/berkey@psi.sci.sdl.usu.edu
Scintillation Receivers			
Equatorial F-region scintillations	Ancon, Peru	244 MHz,L-band	C.E. Valladares/cesar@dl5000.bc.edu
LIDARS			
Rayleigh Lidar			
Relative density, waves, temperature	Utah State University, UT	532 nm	V.Wickwar/wickwar@aeronomy.cass.usu.edu
(30–90 km); also NLC backscatter ratio	Sondrestrom, Greenland	532 nm	J.Thayer/jeff_thayer@qm.sri.com
Doppler Rayleigh Lidar			
Relative density, winds temperature & aerosols (up to 60 km)	Arecibo Observatory	532 nm	C.Tepley/craig@naic.edu
Na Resonance Lidar			
• Na density, waves (80–110 km)	Sondrestrom, Greenland	589 nm	J.Thayer/jeff_thayer@qm.sri.com
• Na density, waves (70–120 km)	Poker Flat, AK	589 nm	R. Collins/rlc@hoffa.gi.alaska.edu
• Temp., winds, Na density (~80–100 km)	Ft. Collins, CO	589 nm	C-Y She/joeshe@lamar.colostate.edu
Na Wind-Temperature Lidar			
Wind, temperature, Na density (80–105 km)	Urbana Atmospheric Obs., IL	89 nm	C.S. Gardner/cgardner@uiuc.edu
Na Density & Rayleigh/ Aerosol Lidar			
Relative density (30–80 km) & aerosols	South Pole Atmospheric Research Laboratory	532 nm	G.C. Papen/gpapen@uiuc.edu
Tunable Resonance Lidar			
Temperatures, winds & metal densities (~80–110 km)	Utah State University, UT	589; 732–770 nm	V.Wickwar/ wickwar@aeronomy.cass.usu.edu
	Arecibo Observatory	589; 730–800 nm	C.Tepley/craig@naic.edu

Instrument & Primary Measurements	Site of Regular Operation	Spectral/Frequency Range	Contact/e-mail
IMAGERS			
All-Sky Imager			
• Auroral structure	Longyearbyen, Svalbard	–Broad-band	R.W. Smith/bblw@geewiz.gi.alaska.edu
	Poker Flat, AK	Visible–	T. Hallinan/thallinan@giuaf.gi.alaska.edu
	Sondrestrom, Greenland	Visible emissions	R. Rairden/ rairden@agena.space.lockheed.com
• Auroral and airglow structure	Millstone Hill Obs., MA, & Arequipa, Peru	Visible emissions	M. Mendillo/ mendillo@buasta.bu.edu
	EPCO, Resolute Bay, Canada, & Peach Mountain, MI	Visible & NIR emissions (2 instruments)	Q.Wu/ Qwu@engin.umich.edu
• Mesospheric and lower thermospheric wave structure	Campaigns	Visible & NIR emissions	G. Swenson/ swenson1@uiuc.edu
	Bear Lake Observatory, UT & campaigns	Visible & NIR emissions	M.J.Taylor/ taylor@psi.sci.sdl.usu.edu
Airglow Imager			
Mesospheric airglow intensity & temperature	Campaigns	NIR O_2 (0,1) and OH (6,2) band	J. Hecht/jim_hecht@qmail2.aero.org
Mesospheric Temperature Mapper			
Mesospheric temperature & intensity structure	Bear Lake Observatory, UT & campaigns	NIR OH (6,2) band	M.J.Taylor/taylor@psi.sci.sdl.usu.edu

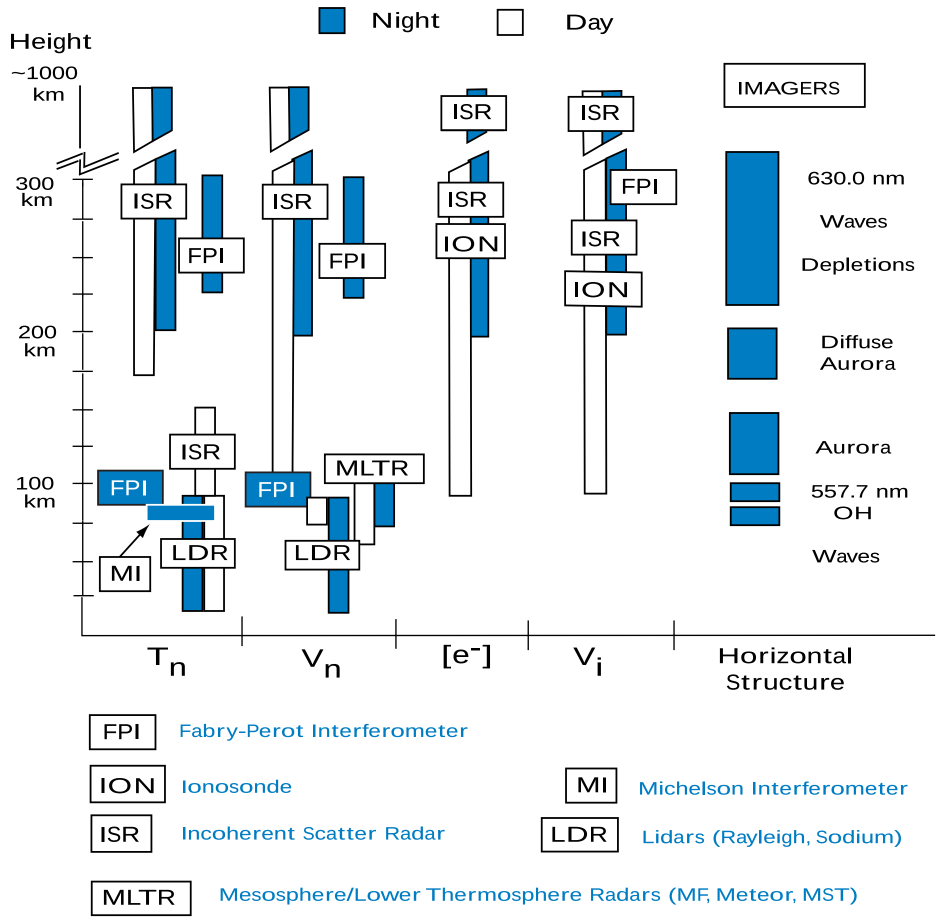
Instrument & Primary Measurements	Site of Regular Operation	Spectral/Frequency Range	Contact/e-mail
FABRY-PEROT INTERFEROMETERS			
Multiple Etalon FPI			
Mesospheric & thermospheric winds	Millstone Hill, MA; campaigns	550–1100 nm	R. Kerr/kerr@moe.bu.edu
Triple Etalon FPI			
Daytime & nighttime thermospheric winds	Millstone Hill Observatory, MA	630 nm	M. Coakley/mmc@themis.haystack.edu
All-Sky Doppler Interferometer			
Mesospheric and thermospheric winds & temperatures	Millstone Hill Observatory, MA	500–850 nm	M.A. Biondi/biondi+@pitt.edu
All-Sky Imaging FPI			
Mesospheric & thermospheric winds	Poker Flat, AK	550–850 nm	M. Conde/conde@giuaf.gi.alaska.edu
GaAs Imaging FPI			
Mesospheric & thermospheric winds	Bear Lake Obs., UT	843 nm, 630 nm	V.Wickwar/ wickwar@aeronomy.cass.usu.edu
Circle-to Line FPI			
Mesopause region winds & temperatures	EPCO, Resolute Bay, Canada	892.0 nm	Q.Wu/Qwu@engin.umich.edu
Auroral FPI			
Auroral dynamics	Sondre., Grnlnd.; Poker Flat, AK	777.2 nm	J. Hecht/jim_hecht@qmail2.aero.org
Narrow Field Imaging FPI			
Mesospheric & thermospheric winds	Poker Flat, AK	558–866 nm	R.W. Smith/bblw@geewiz.gi.alaska.edu
Narrow Field Scanning FPI			
Mesospheric & thermospheric winds	Longyearbyen, Norway	550–840 nm	R.W. Smith/bblw@geewiz.gi.alaska.edu
	Poker Flat, AK	558–866 nm	G. Hernandez/
	South Pole, Antarctica & Mt. John, New Zealand	550–860 nm	hernandez@u.washington.edu
Single Etalon FPI			
• Mesospheric & thermospheric winds	Millstone Hill Optical Facility, MA	500–950 nm	D. Sipler/dps@hyperion.haystack.edu
• Thermospheric winds	Millstone Hill Optical Facility, MA	630 nm	D. Sipler/dps@hyperion.haystack.edu
	Thule & Sondrestrom, Greenland (2 instruments)	557.7 nm 630.0 nm	R. Niciejewski/rickn@umich.edu
	Arecibo Obs., Puerto Rico	630 nm	C.Tepley/craig@naic.edu
• Exospheric studies/mesospheric winds	Arecibo Obs., Puerto Rico	656 nm; 557 nm	C.Tepley/craig@naic.edu
• Mesospheric, lower thermospheric winds	Peach Mountain, MI	557.7 nm; 892.0 nm	T. Killeen/tkilleen@umich.edu
	WatsonLk.,Can;Antofagasta,Chile	630 nm	T. Killeen/tkilleen@umich.edu
	Arequipa, Peru	630 nm	J. Meriwether/meriwej@prism.clemson.edu

CEDAR Supported Instrumentation (continued)

Instrument & Primary Measurements	Site of Regular Operation	Spectral/Frequency Range	Contact/e-mail
MICHELSON INTERFEROMETERS			
• Auroral and airglow emissions	Poker Flat, AK	1000–1600 nm	R.Smith/bblw@geewiz.gi.alaska.edu
• Airglow emission spectra	Thule, Greenland; Watson Lake, Canada; Peach Mountain, MI	NIR	R. Niciejewski/rickn@umich.edu
• Mesospheric OH intensity & temperature	Utah State University, UT & campaigns	1000–1700 nm	P. Espy/sdlpespy@cc.usu.edu
• Airglow and aurora, planetary waves, tides & gravity waves, atomic & molecular processes	Longyearbyen, Svalbard Sondrestrom, Greenland EPCO, Resolute Bay & Eureka, Canada; South Pole; Daytona Beach, FL	1000–1700 nm (6 instruments)	A. Sivjee/sivjee@bart.db.erau.edu
SPECTROMETERS			
Meridian Imaging Spectrograph			
• Auroral emissions	Poker Flat, AK	400–850 nm	H.Nielsen/hnielsen@giuaf.gi.alaska.edu
•Auroral and airglow emissions & altitude profiles: (COTIF tomographic system)	Block Island, RI,	400–800 nm	M. Mendillo/ mendillo@buasta.bu.edu
	Cornish, ME	400–800 nm	
	Farmington, ME	500–700 nm	
CCD Spectrograph			
Airglow and aurora, planetary waves, tides & gravity waves, atomic & molecular processes	Longyearbyen, Svalbard Sondrestrom, Greenland EPCO, Resolute Bay & Eureka, Canada	300–1000 nm (4 instruments)	A. Sivjee/sivjee@bart.db.erau.edu
Large Slit Imaging Spectrometer			
Auroral and airglow emissions	Campaigns	556–750 nm	W. Swift/swift@uahoal.optics.uah.edu
Imaging Spectrometer			
Auroral emissions	Sondrestrom, Grnlnd.; campaigns	visible	G. Swenson/swenson1@uiuc.edu
Magneto-Optic Doppler Spectrometer			
Na intensity and mesospheric winds	NIWOT Ridge, CO	589 nm	B. Williams/biff@hao.ucar.edu
1-m Ebert-Fastie Spectrometer			
• Auroral emissions	Poker Flat, AK; Longyearbyen, Norway	400–840 nm (3 instruments)	C.S. Deehr/cdeehr@giuaf.gi.alaska.edu
• Airglow emissions	Arecibo Obs., Puerto Rico	300–950 nm	C.Tepley/craig@naic.edu
1/2-m Ebert-Fastie Spectrometer			
Auroral emissions	Longyearbyen, Norway	400–840 nm	C.S. Deehr/cdeehr@giuaf.gi.alaska.edu
Ebert-Fastie Spectrometer			
Auroral and airglow emissions	South Pole, Antarctica	400–840 nm	A. Sivjee/sivjee@bart.db.erau.edu
UV Spectrometer			
Auroral emissions	Sondrestrom & Thule, Greenland	Near-UV (2 insts.)	R. Niciejewski/rickn@umich.edu
PHOTOMETERS			
Meridian Scanning Photometer			
Auroral emissions	Longyearbyen, Norway (5 chnls.)	428–840 nm	R.W. Smith/bblw@geewiz.gi.alaska.edu
	Poker Flat, AK (4 channels)	428–840 nm	R.W. Smith/bblw@geewiz.gi.alaska.edu-
Multi-channel Photometers			
Auroral and airglow emissions	South Pole, Antarctica	Visible & NIR	A. Sivjee/sivjee@bart.db.erau.edu
Auroral Photometers			
Auroral emissions	Poker Flat, AK; Sondrestrom, Greenland	Visible & NIR	J. Hecht/jim_hecht@qmail2.aero.org
Dual Channel Tilting Filter Photometers			
Airglow emissions	Arecibo Obs., Puerto Rico	NUV–NIR	C.Tepley/craig@naic.edu

These instruments have been used for CEDAR related science and were supported in whole or in part by the CEDAR program.

Selected Ground-Based Measurement Capabilities



The CEDAR Data Base

The CEDAR Data Base has been an important component of CEDAR throughout its first decade. Its roles have included collecting, organizing, preserving, distributing and promoting data and model results submitted to the Data Base.These roles will remain important as CEDAR moves into Phase III.

An NCAR technical report has recently been published which details the current status of the Data Base and makes a number of recommendations regarding future directions. Of particular relevance to CEDAR Phase III are the following important points:

• High priority should be placed on utilizing current user interface technologies (e.g., access via the World Wide Web) so that simple point-and-click access is available.

• The Phase III Data Base should include both centralized and distributed components, with some of the data distribution functions shifted from NCAR to other sites.

• The community should continue to adhere to the CEDAR format for data archiving of altitude profile observations and this format should be adopted as a standard for campaign initiatives and collaborations via the Internet.

• A CEDAR format needs to be established to better accommodate images.

• CD-ROM technologies should be investigated as an alternative for archiving and distributing CEDAR data.

Phase III Implementation Requirements

"For the success of CEDAR Phase III science initiatives, the continued development of instruments which push the limits of spatial and temporal resolution is a central requirement."

The twin foci of CEDAR activities are often described as observations and theory/modeling. These are broad terms that capture the essential aspects of upper atmospheric research, and so they are used here to order a series of recommendations that will cast Phase III goals into an operational framework.

Measurement Requirements

In order to realize the goals set forth in previous sections, some key measurements and measurement philosophies require attention during CEDAR Phase III. These are described below.

Increased Spatial and Temporal Resolution

In the mesosphere, thermosphere and ionosphere, our knowledge of small-scale structure, specifically its origin, evolution, and interaction with ambient or large-scale phenomena, are poorly understood. During CEDAR Phases I and II, increasing the spatial and temporal resolution of measurements inevitably led to the appreciation of entirely new processes or levels of understanding that are fundamental to progress in studying atmospheres and geophysical plasmas. The development of sudden sodium layers, wavenumber spectra of gravity waves, turbulent dissipation rates, penetration of magnetospheric electric fields, plasma instabilities and irregularities, and transient auroral forms are just a few examples of phenomena requiring increased resolution. Different investigations frequently require different instrumentation with different (and not always compatible) measurement characteristics. For example, airglow and aurora have very different time and space scales.

Optical measurements (imaging, photometric, spectrographic and interferometric) of auroral events must be done at high temporal (~0.1 sec) and spatial (~50 m) resolution. Such stringent requirements are not essential for airglow measurements where sensitivity is paramount. For imaging studies of small scale auroral structures, fields of view far below all-sky modes (~15º, ~60º) are needed. For the success of CEDAR Phase III science initiatives, the continued development of instruments which push the limits of spatial and temporal resolution is a central requirement.

Vertical Coverage

Understanding the vertical coupling between atmospheric regions is a basic tenet of the CEDAR Program. A highlight of CEDAR Phase II was the development and deployment of radar and optical instruments capable of remotely accessing the region between about 60 and 100 km. These efforts should continue. High priority should be given to completing the "instrument clusters" envisaged at the inception of CEDAR, i.e., to providing routine, complementary measurements throughout the mesosphere/thermosphere/ionosphere vertical column at the Class I facilities. The development of promising instrumentation or techniques for acquiring measurements from the much-neglected 100-170 km region should be especially encouraged.

Temporal Continuity

The science that can be derived from continuous data, whether the inherent time resolution is 1 minute, 1 hour, or 1 day, is significantly more valuable than data series with gaps. Many instruments are currently capable of making measurements only during day or night. High priority should be placed on development of new technologies that extend the temporal continuity of existing instruments, and to the collocation of instruments with complementary capabilities. For example, Phase III should initiate the period when daytime optical measurements become a routine capability for aeronomy.

"Phase III should initiate the period when daytime optical measurements becomes a routine capability for aeronomy."

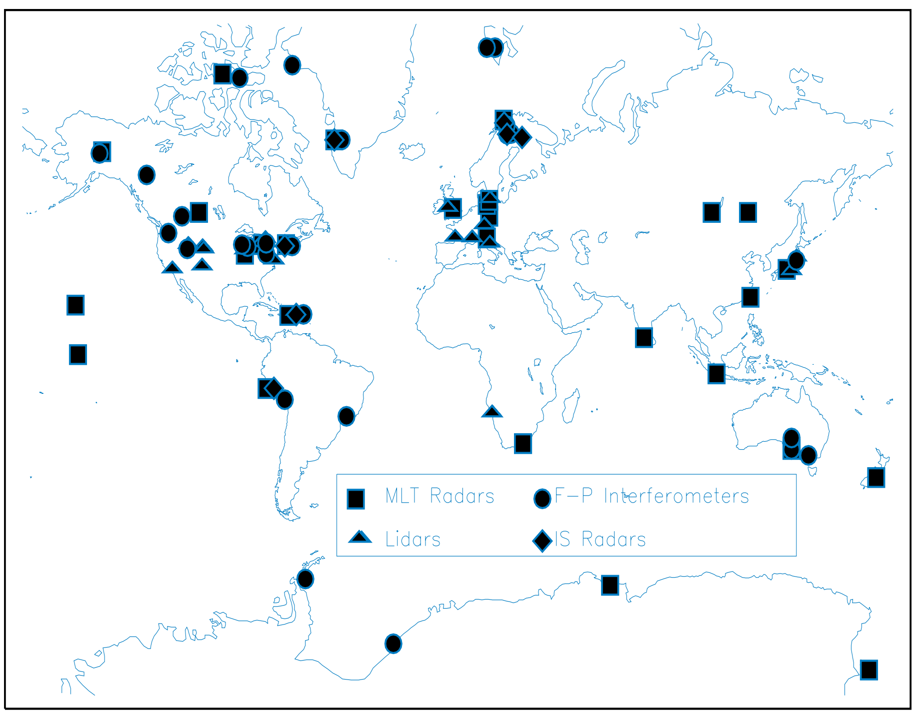
Temporal continuity is also necessary for the investigation of phenomena with time scales of days or greater. In this case, day/night continuity is secondary in importance to obtaining, for instance, a daily measurement at one local time for investigation of day-to-day variability connected with planetary waves or variations in EUV radiance. Investigation of the development of and recovery from a magnetic storm may typically require dedicated measurements over 4–10 days. Delineation of long-term trends can only be achieved from measurement continuity (and consistency) over decades. Serious consideration needs to be given to long-term support of certain facilities or instruments in order to provide data needed for global change assessments.

Distributed Measurements

Clustered instruments provide the ideal approach to address coupling between various atmospheric regions and processes in the vertical column. The Class I observatories form a near-meridional chain to study latitudinal coupling of the ITM region from the equator to the auroral region and, with the PCO, to the polar region. Simultaneous data from these facilities can be used to advance significantly our understanding of latitude coupling and propagation processes involving electric fields and traveling atmospheric disturbances. At the present time the longitude structure of the mesosphere-thermosphere system is relatively unknown.

Temporal data near the mesopause indicate that large planetary wave oscillations (with periods between 2 and 20 days) exist, but there is much disagreement on their longitude structure. Similarly, in the study of ionospheric storms, marked longitude effects are just beginning to emerge from modeling studies, but appropriate data sets are often unavailable to test predictions. International collaborations provide an opportunity to extend the spatial coverage in latitude and longitude to achieve a truly global description of the ITM. Carefully planned additions to the network (see the figure below) of specific measurement sites may provide the needed global information at rather modest cost. This concept was strongly endorsed in the original CEDAR document and remains a high priority item for CEDAR Phase III.

Locations of CEDAR-Related Ground-Based Instrumentation



Satellite Coordination

Over the next decade a number of atmospheric, solar, and magnetospheric parameters will be monitored with a unique suite of satellites. Some of these missions will provide important measurements of composition, dynamics, and energy sources and fluxes in the ITM. Clearly the synergy afforded by these opportunities should be fully exploited by the CEDAR community to maximize the science returns. Past collaborative efforts with the UARS satellite investigators demonstrated the value of such interaction. Current opportunities exist for collaboration with the MSX, TERRIERS, SNOE, DMSP, FAST, and SAMPEX satellites and the ISTP fleet of WIND, POLAR, and GEOTAIL satellites. Planning is underway for extensive collaboration with TIMED. It is recommended that all opportunities for collaboration with satellite programs be vigorously pursued during CEDAR Phase III.

Data Validation

Efforts should be made to compare and calibrate measurements obtained by different instruments and to resolve discrepancies in ITM observations obtained by different observing methods. Common volume and coincident experiments are essential. Common analysis procedures and algorithms should be used as much as possible in order to focus on differences in data, not in data analysis. The joint use of satellite and ground-based data for collaborative studies also underscores the need for cross-validation and consistency among the various measurements.

ACRONYMS AND TERMINOLOGY

CEDAR	Coupling, Energetics and Dynamics of Atmospheric Regions
DMSP	Defense Meteorology Satellite Program
EPCO	Early Polar Cap Observatory
FAST	Fast Auroral Snapshot (satellite)
GEM	Geospace Environment Modeling
GGS	Global Geospace Study; USA component of ISTP includes satellites named POLAR, WIND, GEOTAIL (joint with Japan)
ISTP	International Solar-Terrestrial Program (satellite program)
ITM	Ionosphere, Thermosphere and Mesosphere
MLT	Mesosphere and Lower Thermosphere
MSX	Midcourse Space Experiment (satellite)
SAMPEX	Solar Anomalous & Magnetospheric Particle Explorer (sat.)
SNOE	Student Nitric Oxide Explorer (satellite)
STEDI	STudent Explorer Demonstration Initiative: Program of small, inexpensive university-built satellites
STEP	Solar-Terrestrial Energy Program
SunRISE	Radiative Inputs of Sun to Earth
TERRIERS	Tomographic Experiment using Radiative Recombinative Ionospheric Euv and Radio Sources (satellite)
TIMED	Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (satellite)
UARS	Upper Atmosphere Research Satellite

Nomenclature — Neutral Atmosphere Regions:

Troposphere	0–12 km (domain of daily weather)
Stratosphere	12–50 km (includes ozone layer)
Mesosphere	50–90 km (lowest temperatures near 85–90 km)
Thermosphere	90–600 km (diffusive separation of gases)
Exosphere	Above 600 km (atoms can escape)

Nomenclature — Plasma Regions:

D-Region	60–85 km; positive and negative heavy molecular ions produced by cosmic rays, Lyman-a solar radiation, and energetic particles
E-Region	85–150 km; positive ions produced by soft x-rays and ultraviolet from the sun
F-Region	150–1000 km; atomic ions produced by solar UV and several ion-neutral chemistry processes
Plasmasphere	Region of ionospherically produced cold plasma populating geomagnetic flux tubes that usually corotate with the Earth. The outer boundary of the plasmasphere occurs along magnetic field lines extending to 3–5 earth radii
Magnetosphere	Region extending to many earth radii in which plasma motion controlled by geomagnetic field and solar wind interaction

Nomenclature — Radio Diagnostics:

ISR	Incoherent Scatter Radar
MLTR	Mesosphere-Lower Thermosphere Radars
SRB	Satellite Radio Beacon
RF	Radio Frequency. *Bands below:*
VLF	Very Low Frequency (< 30 kHz)
LF	Low Frequency (30–300 kHz)
MF	Medium Frequency (300 kHz–3 Mhz)
HF	High Frequency (3–30 MHz)
VHF	Very High Frequency (30–300 MHz)

UHF Ultra High Frequency (300–3000 MHz)
SHF Super High Frequency (3000–30,000 MHz)
L-band 1–2 GHz
S-band 2–4 Ghz
C-band 4–8 GHz
X-band 8–12.5 GHz
K-band 12.5–40 GHz
Scintillation Irregular variations in the amplitude or phase of a radio signal passing through the ionosphere that is caused by the presence of small-scale plasma structures
Ionosonde MF/HF sounder of ionospheric structure
f_oF2 Plasma/Critical/Penetration frequency of the F-region
N_mF2 Maximum electron density of ionosphere
h_mf2 Height of maximum electron density of ionosphere

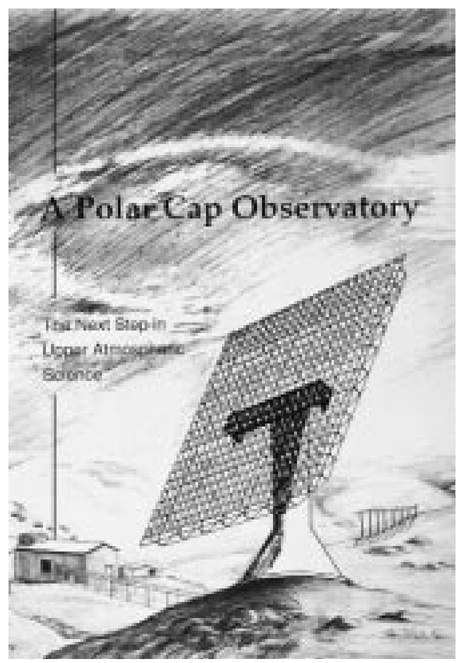
Nomenclature — Optical Diagnostics:
UV Ultra-Violet radiation
EUV Extreme Ultra-Violet Radiation
FPI Fabry-Perot Interferometer
LIDAR LIght Detection And Ranging
CCD Charge-Couple-Device (detector for digital imaging)

Some Upper Atmospheric Phenomena:
NLC Noctilucent Cloud
PMSE Polar Mesosphere Summer Echoes (refers to radar returns)
Es Sporadic-E: transient thin layers of electron density
ESF Equatorial Spread-F (small-scale electron density irregularities at equatorial and low latitudes)
Airglow Optical emission from atoms or molecules excited via chemistry
Aurora Optical emission from atoms or molecules excited by the impact of energetic electrons or ions from the magnetosphere
SAR arc Stable Auroral Red arc (6300 Å)
Airglow Depletions Optical signatures of depleted plasma regions (“bubbles” or “plumes”) containing ESF plasma irregularities
Electrojet Regions of enhanced atmospheric currents near 100 km caused by horizontally streaming electrons; both auroral and equatorial electrojets occur
Plasma Convection Joint motion of ions and electrons due to electric fields in the presence of geomagnetic field; Velocity = ExB/B^2
Precipitating Particles Downward flux of high speed electrons and/or ions along Earth’s magnetic field lines. Energization occurs in magnetosphere; particles’ impact can ionize atmosphere and cause aurora
Trough Region of reduced F-region electron density. The so-called Main Trough occurs in sub-auroral latitudes, bounded on the equatorward side by the midlatitude ionosphere and on the poleward side by the auroral ionosphere.
L-Value Equatorial crossing distance of a dipole field line, measured in units of the earth radius
Plasma Blobs Large-scale regions of enhanced electron density found in auroral oval (containing small-scale irregularities)
Plasma Patches Regions of small-scale electron density irregularities in polar cap (containing small-scale irregularities)

Polar Cap Observatory

The creation of the fully-instrumented Polar Cap Observatory (PCO) is a central requirement for CEDAR Phase III. Its role extends beyond the Polar Aeronomy issue to encompass all four of the Phase III science initiatives. An operational PCO at the time of the upcoming solar maximum (~2001) is a high priority.

“The creation of the fully-instrumented Polar Cap Observatory (PCO) is a central requirement for CEDAR Phase III.”



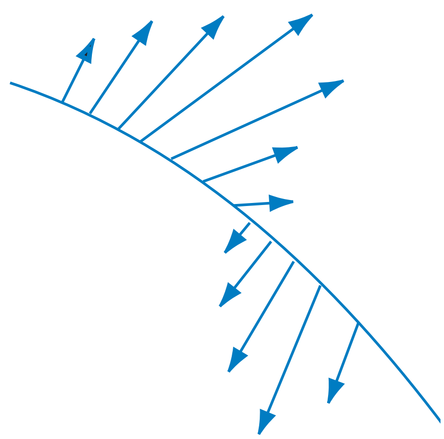
Model Development and Theory Requirements

Global first-principles models that self-consistently couple together plasma and neutral chemistry, dynamics, and electrodynamics play key roles in portraying the physics of solar-terrestrial interaction and in interpreting observations. In this area, NCAR's TIME-GCM represents one of the great achievements of the CEDAR Program. Phase III measurement accomplishments will be used to further advance model development. For example, new composition and thermal information can be used to improve photoelectron models by the inclusion of light neutrals as a source of photoelectrons at high altitudes. Similarly, light ion measurements can be used to improve and advance the modeling of the nighttime maintenence of the F-region peak and its altitude evolution. Analytical modeling and laboratory measurements of cross sections and reaction rates continue as important needs for improved modeling efforts in CEDAR Phase III.

There also exists a wide spectrum of mechanistic models, empirical models, and specialized first-principles models that are devoted to understanding specific phenomena or processes, and which also serve to advance our field. Across this spectrum of models, there exist some developments that must occur in order to meet the challenges of the next decade. These requirements are described next.

Magnetosphere-Ionosphere-Thermosphere Coupling

Coupling of the magnetosphere with the thermosphere-ionosphere must be investigated in models where the conductivities, field-aligned currents, electric potential, and neutral winds are handled interactively and self-consistently. Parameterization of magnetospheric processes that reflect substorm processes and the effective conductivity of the magnetosphere as a function of space and time will be required to advance these models.

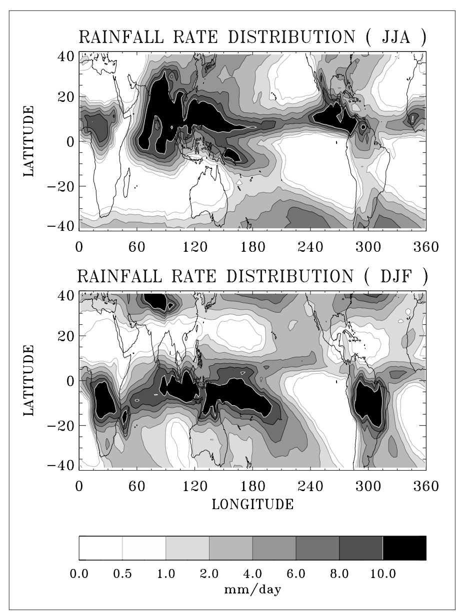


Ionospheric Plasma Structure

Modeling the formation and evolution of plasma structures requires a determination of the temporal and spatial scales that are effective in current closure and momentum transfer processes. The links between the rate of development of ~Km-scale features and the underlying state of the ionosphere and thermosphere can be investigated efficiently with modeling efforts that are validated and constrained by multi-parameter observations.

Wave Source Distributions

The source distributions of waves which significantly contribute to the momentum and energy budgets of the mesosphere and thermosphere need to be better specified. For the tides, in addition to accurate UV/EUV sources, requirements are improved knowledge of tropospheric water vapor distributions, stratospheric ozone densities, and latent heat release by tropical convective sources, including their altitudinal, latitudinal, longitudinal, and seasonal variations. For gravity waves, detailed understanding and specification of wave sources due to topography, convective activity and wind shears are required. Further development of theories describing gravity wave dissipation, momentum deposition, turbulence generation, and constituent transport will improve model capabilities.



Satellite-based rainfall rate distributions averaged over seven years for June/July/August (top) and December/January/February (bottom). Data were acquired from the "Global Precipitation Climatology Project." The areas of high rainfall rate correspond to regions of deep convective activity, and hence may represent pseudo source distributions for convectively generated gravity waves (refer to figure on page 7).

Resolution

Increased temporal and spatial resolutions must be implemented in current CEDAR models, possibly through adaptive/embedded gridding schemes. These are needed for examination of high-latitude plasma-neutral coupling processes, auroral region effects, wave phenomena, development of local and mesoscale structures which spawn instabilities, fine structure, and gravity wave/tide interactions.

Small-scale Processes

Small-scale phenomena (~10's–100's Km) such as gravity waves and wave-wave interactions can be important, even dominant, drivers of atmospheric dynamics, thermodynamics and chemistry. The sensitivity of the mesosphere to gravity wave effects underscores the need for proper treatment of these phenomena in models attempting to ascertain global change effects in the mesosphere. For example, the baroclinic instability in the mesosphere and its role in wave generation and amplification require further investigation. Incorporation of such processes in global atmosphere models often requires formulation and implementation of gravity wave parameterizations. Gravity wave parameterization schemes are currently highly controversial and these must continue to be developed, debated and tested.

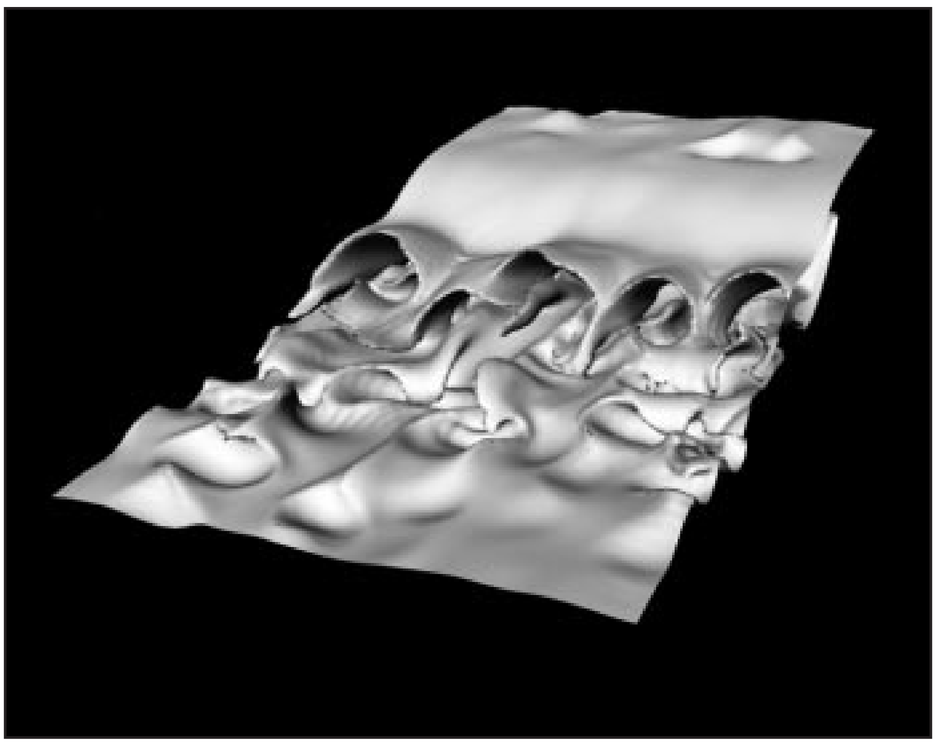
Models describing the non-linear development of plasma instabilities are required to simulate the spectral density of irregularities and their orientation with respect to gradients in the background. Such models are essential to the interpretation of measurements to come from Phase III observations with increased temporal and spatial resolution.

Data Assimilation

Increasingly sophisticated theoretical models and the emerging large atmospheric data base should be fully exploited by application of data assimilation methods similar to those already well developed for the ocean and lower atmosphere. Success has already been demonstrated within the context of high-latitude electrodynamic modeling by the AMIE (Assimilative Mapping of Ionospheric Electrodynamics) algorithm. Progress in this area would allow us to "fill in" regions void of data to better delineate tides, planetary waves, mean flows and interactions, and to link together diverse observations, such as composition measurements at one location with dynamical measurements at another.

Forecasting

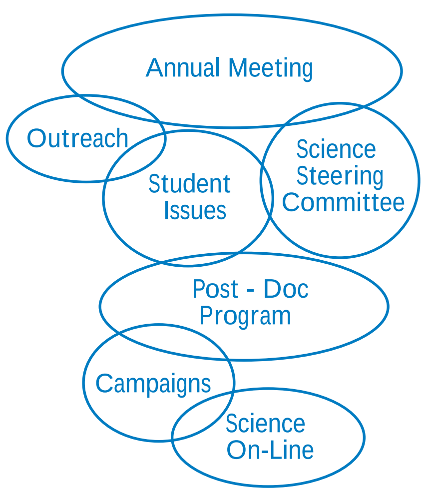
The mark of a mature science is its ability to predict effects from known input. Upper atmospheric research may well achieve this goal by the end of a fully successful CEDAR Phase III. Thus, forecasting capabilities should be developed and tested as a means of assessing our knowledge and understanding of solar-terrestrial interactions. Within the context of contributions to the National Space Weather Program, this is a particularly timely and appropriate effort and one where CEDAR research efforts can be immediately useful to society.



Simulation of wave breaking due to initial convective and secondary dynamical instabilities using a spectral compressible model employing a mesh of 192 x 96 x 129 collocation points. The wave is propagating outward and the surface is a constant potential temperature.

Operation of CEDAR

> *"To guide, manage, encourage, and nurture the CEDAR enterprise is a responsibility that falls upon no single constituency of the community, but upon all."*



The CEDAR community is composed of a very broad mixture of scientists, engineers, research administrators and students. Research activities are conducted at universities, government labs, industrial research groups and small private companies. The diversity and depth of this total cohort of involved researchers is remarkable; it is the human base upon which the success of CEDAR continues to evolve. To guide, manage, encourage, and nurture the CEDAR enterprise is a responsibility that falls upon no single constituency of the community, but upon all. In this section we describe several facets of this community-wide team effort that are the sources of strength and vitality propelling us into CEDAR Phase III.

CEDAR Science Steering Committee

The CEDAR Science Steering Committee (CSSC) should continue to serve as the body of community representatives that sets directions and agendas for the CEDAR Program and that interacts with the National Science Foundation on behalf of the community. The table on the inside front cover summarizes the past and present CSSC membership. The CSSC should continue to meet twice a year and to take a pro-active role in formulating scientific plans, monitoring progress, and interacting with the CEDAR community. The recent addition of an international representative for a term of one year recognizes the importance of international collaboration within CEDAR. The appointment of a student representative, also for a one year term, has served the Committee well and will be continued.

Annual Meeting

The annual CEDAR Meeting, traditionally held in Boulder, CO, is necessary for the vitality of the program and must be continued. The Steering Committee needs to assess continually the functionality of the meeting's many workshops in light of ongoing CEDAR activities and interest, and to modify its structure as necessary to maintain an energetic and motivating environment. The workshops also serve to coordinate our collaborations with other national and international programs, such as GEM, SUNRISE, TIMED, and STEP. As the next generation of CEDAR scientists, students are encouraged to attend and to participate actively in the workshops, tutorials, and organization of CEDAR.

CEDAR Science On-Line

We are in the midst of a communication revolution and CEDAR must continue to capitalize on the latest network advancements in order to accomplish the best science most effectively. Where practical and advantageous, remote continuous autonomous operation of CEDAR instruments ought to be encouraged. Computer-aided collaborations, CEDAR Data Base use, and CEDAR program information should be available to the CEDAR community over the World Wide Web. Computer-aided collaborations and real-time access to data and predictive models should be encouraged. The CEDAR data format should be adopted as a standard for real-time data transfer.

Examples of CEDAR Supported Campaigns

Acronym &	Campaign Description	Years
ETS	Equinox transition study	1985
GTMS	Global thermospheric mapping study	1985–87
HLPS	High latitude plasma structures	1986-
MLTCS/LTCS	Mesosphere and lower thermosphere coupling study	1986-
GISMOS	Global incoherent scatter meseaurements of substorms	1987–93
GITCAD	Global ionospheric thermospheric coupling and dynamics	1987–88
MAPSTAR	Mesospheric airglow structure and radiance study (workshops only)	1987–91
SUNDIAL	Study of global-scale ionosphere	1985–
AIDA	Arecibo initiative for the dynamics of the atmosphere	1988–90
CHARM	Collaborative H-alpha radar measurements	1989–91
ALOHA	Airborne & ground observations of Hawiian airglow	1990; 1993
STORM	Study specific ionospheric-thermospheric storm intervals	1990–
ARIA*	Rocket measurement of thermospheric dynamics	1992–95
AURORAL SPECTROSCOPY	Multi-station study of auroral emissions	1992–95
CADRE	Coupling and dynamics of equatorial regions	1992–94
MISETA	Multi-instrument study of equatorial thermospheric aeronomy	1992–
ANLC	Airborne and ground noctilucent cloud campaign	1993
10-DAY RUN	Coordinated radar and optical studies during January	1993
MALTED	Equatorial rocket, radar and optical dynamics studies	1994
CARMEN	Coordinated Arecibo related mesoscale experiments - tropical aeronomy	1996–
MSX*	Correlative CEDAR studies with MSX satellite	1996–
POLITE	Plasmaspheric observations of light ions in topside and exosphere	1996–

** Ground coordinated measurements only*

Campaigns

The initiation and execution of coordinated campaigns represent a major accomplishment of the CEDAR program. The campaigns are the major means to bring together scientists with common goals, focusing their measurement and modeling studies on specific scientific goals. To maximize the scientific return from campaigns, these recommendations are given:

NCAR Electra aircraft — Aloha/ANLC Campaign.

1. Campaigns should have a clearly identified focus and objective. Campaign descriptions, including dates and points of contact, should be advertised through electronic means.

2. Campaign studies should strive for closure. Projects and campaigns should establish milestones by which progress can be addressed. Identifying a key person in charge is important. Dedicated workshops, held separately from the annual CEDAR meeting, are helpful and very productive when planned carefully.

3. Campaign data should be accessible to the community through the CEDAR Data Base at the site of the campaign or its organizer.

4. The CEDAR community and, when appropriate, the CSSC should formulate plans for campaign usage of the chain of incoherent scatter radars and associated clustered diagnostics to achieve maximum progress toward the Phase III science initiatives. Such plans should include the optimization of World Day runs for the study of long term trends, the accommodation of multi-day runs, and the flexibility to respond to solar-terrestrial targets of opportunity. Coordination with related international efforts, including the ISR observation schedule and STEP campaigns, is clearly required.

Program Balance

Demands on CEDAR funds have continued to grow for the operations and maintenance of existing facilities, deployment of new instrumentation, and scientific analysis of observational and modeling results. The CEDAR program has been successful in maintaining an appropriate balance among these demands in the past, recognizing that all aspects of the program need to be advanced. Concerns occasionally arise in the distribution of funding between analysis activities and instrumentation development due to the different scales of funds required for the two areas. It has been recognized at various times in the CEDAR history that special proposal competitions have to be planned to enable the development of instrumentation that will serve to improve the overall capabilities of the program and allow continued progress in scientific studies. It is important that such flexibility be continued within the annual CEDAR competition so that further growth in instrumentation and analysis activities can continue.

The underlying driver for all CEDAR projects, whether instrument development, campaign observations, modeling or analysis, must be motivated by scientific contributions to the CEDAR program objectives. It is recommended that this issue be addressed annually at the Fall meeting of the CEDAR Science Steering Committee so that the projected CEDAR competition opportunities are clearly stated in the NSF announcements. The evaluation of proposals should be conducted so that instrument development proposals compete among themselves and scientific analysis proposals compete among themselves, and that proper balance is maintained. A quantitative report on this balance of support should be prepared to allow an annual examination of this balance to insure that it is maintained.

Outreach Activities

The relevance of CEDAR to global change objectives needs to be articulated better to the general public. The annual meeting is a powerful tool to focus such discussions; individual efforts must also be encouraged. Outreach through science writing, home pages, and public appearances represent avenues to reach outside the CEDAR community. The expanded involvement of undergraduates in the CEDAR program should be encouraged. The new National Space Weather Program provides new opportunities to bring our discipline to the public's attention. Serious consideration should be given to creating a special outreach coordinator for the CEDAR program.

Summer students at the Arecibo Class I Facility.

Outreach participants at the Millstone Hill Class I Facility.

Student Issues

CEDAR is widely recognized for its involvement and integration of graduate and undergraduate students in its research program. CEDAR has supported the travel and housing accommodations for students to attend the annual meeting. Students are involved in all aspects of CEDAR, including serving on the CEDAR Science Steering Committee, organizing a student-run workshop at the annual meeting, and participating in poster sessions. The unique opportunities afforded by CEDAR and the cross disciplinary nature of CEDAR prepares students for future employment in areas both within and outside of atmospheric research. The skills developed by students involved in CEDAR include experimental and theoretical research methods, computer programming, graphics, data base management, and oral and written presentation techniques — all skills that are useful to both academic and non-academic future employers.

The following actions will serve our student population responsibly:

❶ Provide fundamental and broad education in the classroom and beyond. An innovative CEDAR method has been the annual one day "school" prior to the June CEDAR Meeting. It has dealt with such topics as experimental techniques, common methods of spectral and statistical analysis, and the underlying physics, chemistry, and photochemistry, of the upper atmosphere. This school should be continued and expanded to include community issues of public outreach and science policy

❷ Continue student-run workshops to provide an avenue by which students can meet and discuss their common issues and to have a forum for the NSF and the community to respond to those concerns.

❸ Provide information about employment not only within the CEDAR science community but also in industry and non-technical areas. Elements of this should include a comprehensive registry of CEDAR-supported graduates' subsequent employment, active distribution of information about post-graduate opportunities within the CEDAR community, and contemporary advice and counsel from the engineering and business communities.

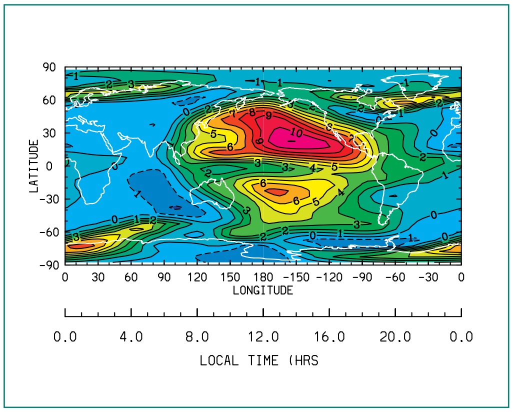
❹ Continue to provide leadership opportunities. CEDAR's students have done relatively well in gaining employment both within our community and in fields unrelated to atmospheric science. This is due to the broad experimental and theoretical experience that CEDAR students acquire and to the prominent role of collaboration in CEDAR science. Students need to capitalize on these unique opportunities and explore and define their role within the CEDAR community.

❺ Continue the Post-Doctoral Research Program. The CEDAR Post-Doc program has been very successful in providing new Ph.D. scientists with the opportunity to continue in aeronomical research as a career. Ideally, it is an opportunity to move beyond the specific topics of dissertation research, with broadened exposure to new in-depth methods of research and to collaborations with new colleagues. In addition, host scientists benefit through an augmentation of their research programs via the presence of new junior colleagues. The program should continue to be flexible in offering one to three post-docs per year, depending on the qualifications of the applicants, the merit of the proposed research, and the availability of resources.

CEDAR Post-Doc at work at the Millstone Hill Class I Facility.

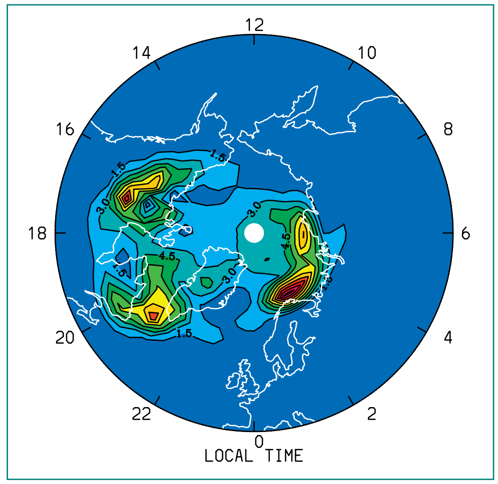
An Aeronomic Community Model: The NCAR Thermosphere-Ionosphere-Mesosphere Electrodynamics General Circulation Model (TIME-GCM)

Solar-Terrestrial Interactions



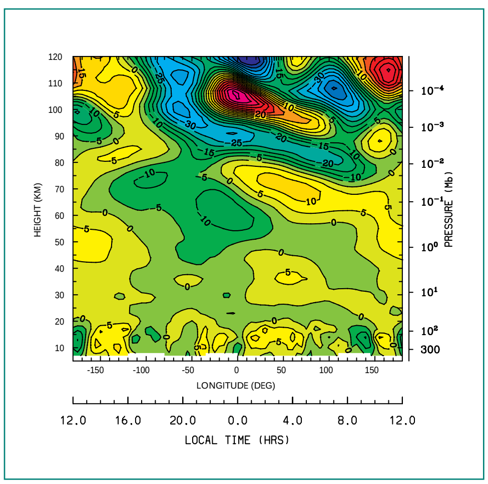
Modeled difference in total electron content (TEC) with respect to quiet-day background at the peak of the substorm on 18 October 1995, illustrating enhancements in the equatorial Appleton anomaly and in the high-latitude auroral regions.

Polar Aeronomy



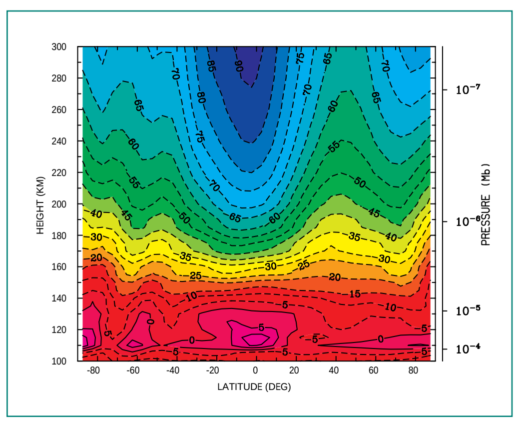
Model Joule heating rate (mW/m^2) at the peak of the substorm on 18 October 1995. The heating rates are derived through assimilation of various ground-based and satellite data.

Coupling With Lower Altitudes



Modeled neutral meridional wind (m/s) at 17.5 ºN. In this simulation the TIME-GCM is flux-coupled to the NCAR Community Climate Model (CCM3) near 30 km altitude, thus introducing lower atmospheric variability into the upper atmospheric system.

Long-Term Variations



Modeled difference in temperature resulting from a doubling of global CO_2 concentrations. Note the 5–10 K warming below 130 km and the 30–80 K cooling above about 160 km. This is one demonstration of the model's capabilities to explore the effects of anthropogenic change on the Earth's upper atmosphere.

The TIME-GCM is a community model developed at the High Altitude Observatory, National Center for Atmospheric Research. The model is based on first-principles, and self-consistently includes the interactions between radiation, major and minor species concentrations, ionospheric chemistry, thermal balance, electrodynamics, airglow emissions, and neutral dynamics from about 30 km altitude. External forcings include those originating in the lower atmosphere, particle and field effects from the magnetosphere, solar photon radiation, and parameterized coupling to the plasmasphere.

The CEDAR Post-Doctoral Fellows

Student and Year	Ph.D. Institution and Post-Doctoral Institution	Research Topic	Present Position
Stan Solomon (1987, 1988)	University of Michigan, 1987 HAO/NCAR	Airglow and Auroral Emissions Modeling	Research Associate University of Colorado
Julie Moses (1988, 1989)	University of California, LA, 1989 HAO/NCAR	Ionospheric Convection During Substorms	Research Associate Queen Mary and Westfield College
Jean Lilensten (1989, 1990)	University of Grenoble, 1989 HAO/NCAR	Transport of Suprathermal Electrons in the Auroral Ionosphere	Research Scientist CNRS
John Sahr (1990, 1991)	Cornell University, 1990 Cornell University	Design of New Data Acquisition System for JRO	Assistant Professor University of Washington
Dave Knudsen (1990, 1991)	Cornell University, 1990 Max-Planck-Institut für Extraterrestrische Physik	Incoherent Scatter Radar Spectrum Distortions from Intense Auroral Turbulance	Assistant Professor University of Calgary
Dan Senft (1991, 1992)	University of Illinois, 1991 University of Illinois	Na Wind/Temperature Lidar Studies of Mesopause Dynamics	Senior Engineer Rockwell Power Systems
C. Peymirat (1992, 1993)	University of Paris, 1991 HAO/NCAR	Couple the Thermosphere Ionosphere Electrodynamics General Circulation Model	Maitre de Conferences Universite de Versailles
Rick Doe (1994, 1995)	Boston University, 1994 SRI	Nightside Signatures for the Polar Cap Boundary	Research Physicist SRI
Wei Deng (1995)	University of Michigan, 1994 Millstone Hill Observatory	Global Study of Tides During LTCS Campaigns	Software Engineer Boston Technological Corporation
Susan Nossal (1995, 1996)	Univ. of Wisconsin, Madison, 1994 Arecibo Observatory & HAO/NCAR	Investigation of the Upper Atmospheric Hydrogen Boundary by Linking Fabry-Perot Observations with Upper Atmosphere Models	Research Associate Univ. of WI, Madison
Larissa Goncharenko (1996)	Kharkov State Polytechnic (Master's Degree), Ukraine, 1988 Millstone Hill Observatory	Data Analysis of Lower Thermosphere Using Millstone Hill Radar Observations	Post-Doctoral Fellow
Jirong Yu (1996)	Colorado State University, 1994 University of Illinois	Observational Studies of Tidal Perturbations in Mesopause Region Winds & Temperatures.	Senior Engineer Science & Technology Corp.
Victor Pasko (1996, 1997)	Stanford University, 1996 Stanford University	Electrodynamic Coupling of the Troposphere & Mesosphere in Thunderstorm Regions	Post-Doctoral Fellow Stanford University
Biff Williams (1997, 1998)	Univ. of Colorado, Boulder, 1997 Colorado State University	Mesopause Tides Based on Extensive MODA and Sodium Lidar Data Sets	Post-Doctoral Fellow

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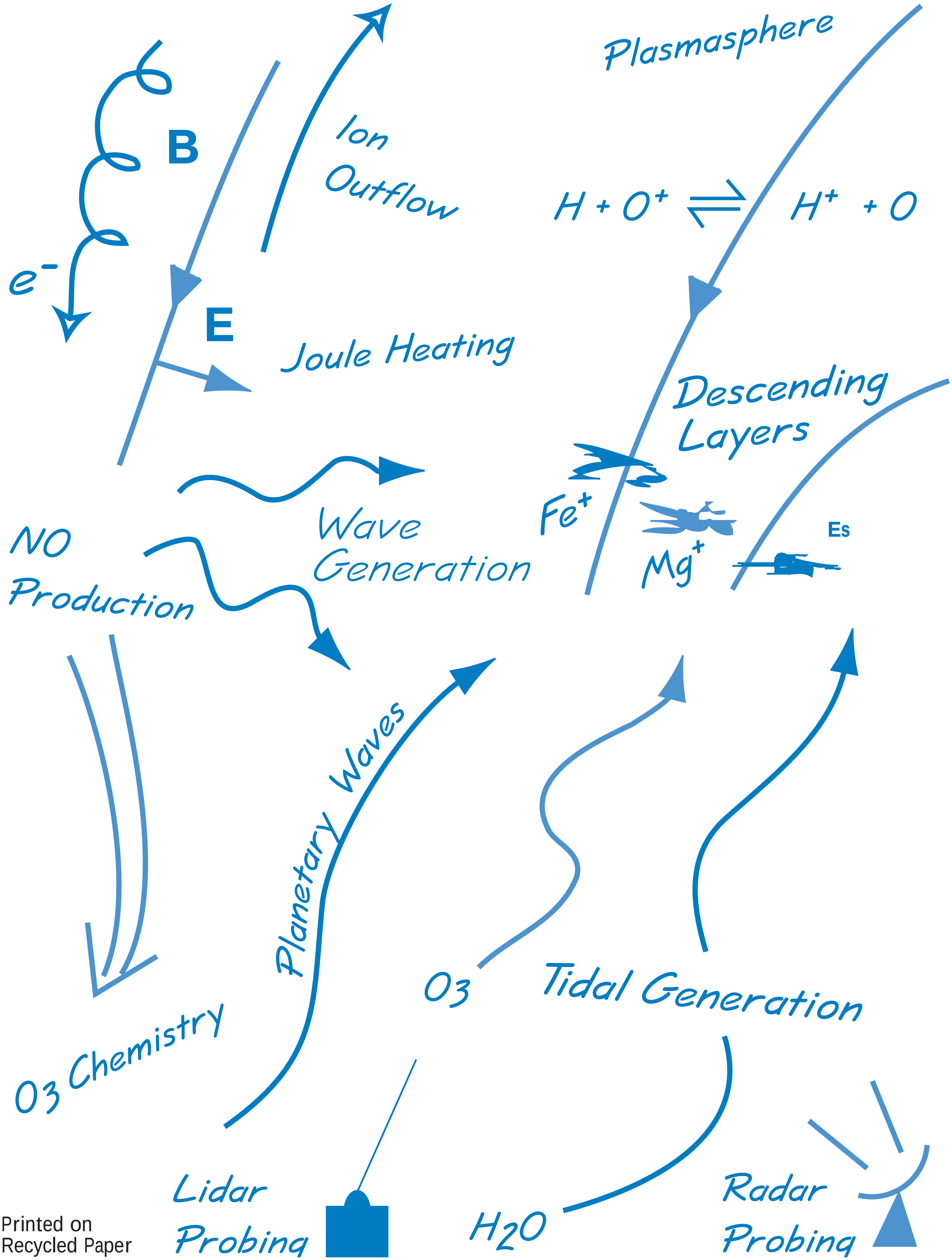

B
e^-
Ion Outflow
Plasmasphere
$H + O^+ \rightleftharpoons H^+ + O$
E
Joule Heating
Descending Layers
Fe^+
Es
Mg^+
Wave Generation
NO Production
Planetary Waves
O_3
Tidal Generation
O_3 Chemistry
Lidar Probing
H_2O
Radar Probing