VOLUME 1 JULY, 2020

COUPLING, ENERGETICS AND DYNAMICS OF ATMOSPHERIC REGIONS (CEDAR) STUDENT NEWSLETTER

"MAPPING OUT THE FUTURE DIRECTIONS OF SPACE PHYSICS AND AERONOMY"

This newsletter summarizes the specialized space physics and aeronomy talks given by esteemed scientists during the 2020 virtual CEDAR. The goal of this newsletter is to reflect on how graduate/undergraduate students benefit from CEDAR. This year CEDAR was held virtually and was attended worldwide as depicted on the next page. Graduate and undergraduate student volunteers from all over the world took leadership roles and worked diligently to complete this initiative.

Briefly, CEDAR includes a dedicated student day followed by 20-30 special sessions. Student day talks are targeted to give an overview of general concepts and provide possible future directions of different research areas to the student attendees while the special sessions talks are focused on giving updates on particular areas of research.

Matthew Grawe - Outgoing Student Representative
Komal Kumari - Present Student Representative
Meghan LeMay - Incoming Student Representative

IN THIS ISSUE

PHOTO CREDITS: ARCTICKINGDOM.COM

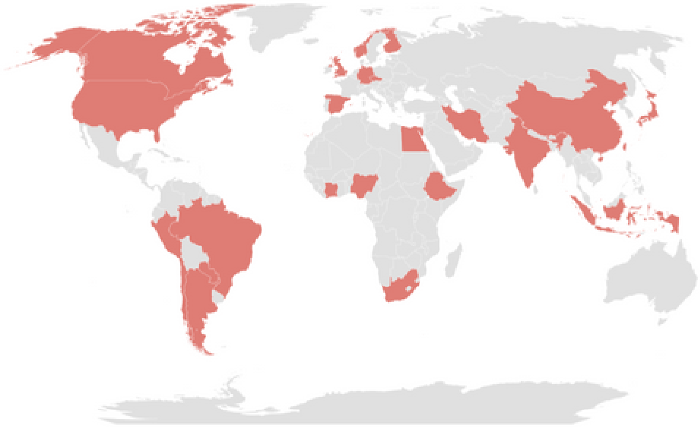
PROLOGUE

CEDAR 2020 IN NUMBERS

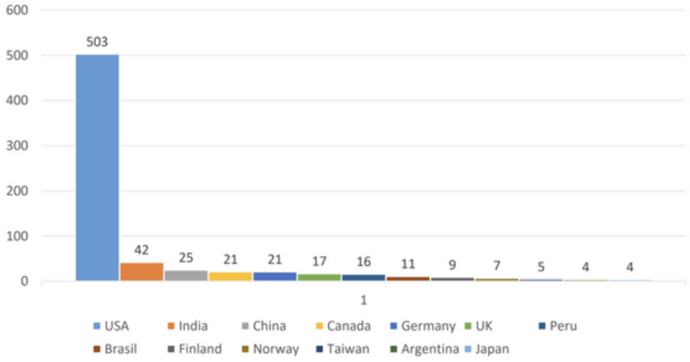
The virtual Coupling, Energetics and Dynamics of Atmospheric Regions (v-CEDAR) 2020 reached more than 700 participants around the world. The bar plot shows the countries with more than 3 participants. More than 200 students participated in the Student Day Workshop on June 21st!

In general, we had 195 senior, 129 mid-career, and 143 early career scientist. Regarding the student population, we had 191 graduate and 47 undergraduate students.

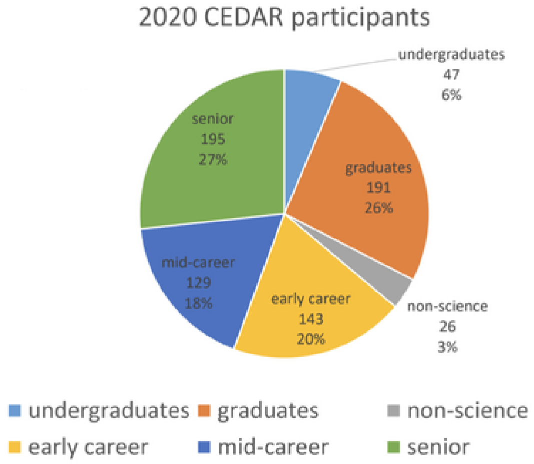
In order to share the science during CEDAR 2020, the Slack mobile and desktop application was extensively utilized. There were 232 member in 13 public channels created for the different topics. More than 160 messages were sent the week before CEDAR workshop and 1933 messages during the main event. From those, 33% were sent in public channels, and 67% were direct messages.



Worldwide distribution of CEDAR2020 participants.



Countries with more than 3 participants.



CEDAR 2020 participant distribution

Communication rates through Slack App

STUDENT VOLUNTEERS

Special Thanks!!

Matthew Grawe received the B.S. degree in electrical engineering with highest honors and the M.S. degree in electrical and computer engineering from the University of Illinois at Urbana-Champaign in 2015 and 2017, respectively. He is currently pursuing a Ph.D. in electrical and computer engineering at the University of Illinois at Urbana-Champaign. He is the recipient of numerous awards, including two (2018, 2019) AGU Outstanding Student Presentation Awards (OSPAs), two poster prizes at CEDAR (2015, 2017), and the Y.T. Lo Outstanding Research Award from the University of Illinois at Urbana-Champaign in 2019. Matthew also currently serves as a student representative on the CEDAR Science Steering Committee (CSSC). His research interests lie in utilizing signal processing, machine learning, and remote sensing techniques to predict the effects of space weather on geomagnetically-induced currents and to understand geological and atmospheric phenomena.

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Komal Kumari received her Integrated B.S.-M.S. degree in Physics in 2015 from the Indian Institute of Science, Education and Research (IISER) Kolkata in India. She is currently a Ph.D. student in the Department of Physics and Astronomy at Clemson University. Her Ph.D. research is focused on understanding the short-term tidal variability in the upper atmosphere (~80-100 km). She is a recipient of the Outstanding Student Paper Award (OSPA) at the AGU fall meeting in 2017 and the Student Poster Honorable Mention (MLT) Award at CEDAR in 2018. She also serves as the student representative on the NSF/CEDAR Science Steering Committee (CSSC). Her interests focus on the study of the coupling of global-scale atmospheric waves at low-mid latitudes. Her expertise includes satellite data analysis, especially long-term time series analysis, developing statistical tools etc., and comparative analysis of aeronomy (GCM, data assimilation) models and observations.

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Meghan LeMay graduated from the University of Illinois at Urbana-Champaign with a B.S. in Electrical Engineering in 2018. She is currently a third year Electrical Engineering PhD candidate at Boston University. This year she is the incoming student representative for the CEDAR Science Steering Committee (CSSC). Her research mainly focuses on using Global Navigation Satellite System (GNSS) and various instruments as an ionospheric diagnostic at high latitudes. Her research interests include machine learning, data fusion, and digital signal processing.

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Fan Yang received his B.S. degree in Space Physics in 2016 from the University of Science and Technology of China (USTC). He is currently a Ph.D. candidate in the Department of Physical Sciences at Embry-Riddle Aeronautical University. His Ph.D. research is focused on understanding the stability and effect of turbulence in the upper atmosphere (80-100 km). He has worked on instabilities and their relationship with GWs with different scales using ALO Na Lidar data and MSIS model. He currently studies the effects of turbulence using Lidar observations. He plans to study the structure function with Lidar data and the new meteor radar data at ALO. Additionally, his interests include data mining and machine learning.

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Deepthi Ayyagari completed her Bachelors degree in Aeronautical Engineering in 2013 and holds a Master's degree in Satellite Meteorology & Weather Informatics from Jawaharlal Nehru Technological University Hyderabad (JNTUH), India. She was awarded the Academic Achiever Award of IST, JNTUH for securing highest score during her Master's degree for the academic years of 2013-16. She was selected for the DST-Inspire Fellowship based on her academic performance in 2017. Currently, she is a DST- Inspire Research Scholar and the IEEE Student Branch Chair, Discipline of Astronomy, Astrophysics and Space Engineering at Indian Institute of Technology Indore. Her research top includes on of the country's most prestigious projects NavIC performance analysis over Indian EIA region. Apart from her Ph.D topics her research interests lie in the study of the ionospheric - troposphere coupling, acoustic gravity waves, cloud physics, orographic rainfall analysis and sea surface data analysis, Her basic skills includes MatLab programming and VBA-Macros for data analysis, especially GNSS and NavIC

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Edith Macotela received her B.S. degree in Physics in 2009 from the San Luis Gonzaga University in Peru. She received her M.S degree in Geospace Science and Applications in 2015 from the Mackenzie Presbyterian University in Brazil. She just finished her graduate studies in physics at the University of Oulu in Finland. In August 2020, she is starting a 2-year postdoc fellowship at the Leibniz-Institute of atmospheric Physics in Germany. She is a recipient of the Young Scientist Award (YSA) at the URSI-AP meeting in 2019. She also organizes the VLF/ELF Remote Sensing of Ionospheres and Magnetospheres (VERSIM) Journal Club monthly meetings. Edith investigates the behavior of the lower boundary of the ionosphere under perturbative influence of external phenomena originated at Earth, in our solar system, or even much further away. She has experience in handling and interpreting data from different physical parameters recorded by ground-based and satellite sensors. Currently, she is studying the coupling between the D region ionosphere and the mesospheric dynamics and their possible connection to lower atmospheric forcing at mid and high latitudes.

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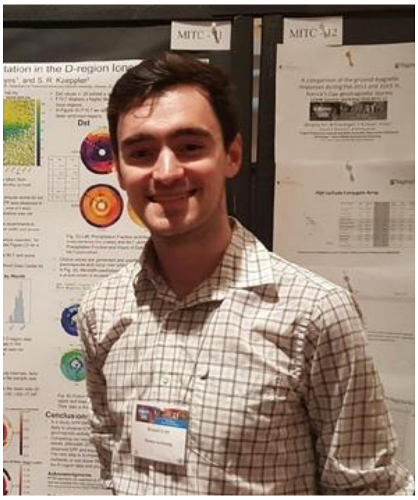

Robert Irvin received a B.S. degree in physics from Purdue University in 2018 and is currently pursuing a Ph.D. degree in electrical and computer engineering at the University of Illinois at Urbana-Champaign. He was the recipient of the undergraduate honorable mention poster prize at the CEDAR workshop in 2018. His research interests include ion-neutral coupling in the Ionosphere-Thermosphere-Magnetosphere, incoherent scatter radar observations, and ground based observations of hydrogen airglow.

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Aidan Montare is an electrical engineering student at Case Western Reserve University in Cleveland, Ohio, U.S. At Case Reserve, he is a researcher with HamSCI, the Ham Radio Citizen Science Investigation, where he studies the ionosphere via amateur radio. He is also the current president of the Case Amateur Radio Club, W8EDU. Outside radio, Aidan enjoys anthropology, music, and art.

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Gonzalo Cucho-Padin received the B.S. degree in electrical engineering from the Pontifical Catholic University of Peru in 2007 and the M.S. degree in Computer Science from the University of Central Florida in 2016. He is currently pursuing the Ph.D. degree in electrical and computer engineering at the University of Illinois at Urbana-Champaign. Mr. Cucho-Padin was the recipient of the Best Student Poster prize at the NSF-sponsored Coupling, Energetics, and Dynamics of Atmospheric Regions (CEDAR) workshop in 2018, and the Yuen Tze Lo Outstanding Research Award from the University of Illinois at Urbana-Champaign in 2020. He also was selected to receive the Vela Fellowship from Los Alamos National Laboratory in 2020. His research interests include inverse problems in space science, such as tomographic reconstruction of the hydrogen geocorona; data assimilation, signal processing techniques, and machine learning with application in the field of remote sensing.

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Aurora López Rubio received her B.S. and M.S. degree in Aerospace Engineering at Universidad Politécnica de Madrid, Spain in 2017 and 2019, respectively. She also received her M.S. degree in Mechanical and Aerospace Engineering at Illinois Institute of Technology, Chicago in 2019. She is currently pursuing a Ph.D. in Mechanical and Aerospace Engineering, also at Illinois Institute of Technology in the Space Weather Lab. She has worked on ionospheric irregularity monitoring with GNSS data and now she is working on a data assimilation method for estimation of physical drivers of Earth's ionosphere, also using GNSS observations.

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Arunima Prakash holds a bachelor's degree in Electronics and Communication Engineering from SRM University, India. In her undergraduate tenure, Arunima was a part of the student satellite team of SRM University (SRMSAT), leading the Space Flight Dynamics Division of the team for two years. She has to her credit the best paper award at the National Conference on Microelectronics, Embedded and Communications held at SRM University, Chennai. In 2017, she was selected as a special student at Massachusetts Institute of Technology. At MIT she was a part of the WaferSat team of the Space Systems Laboratory, involved in designing a miniature wafer satellite using MEMS technology. She also worked on state space modelling of multiple-input-multiple-output (MIMO) systems along with a few machine learning projects. Currently, she is pursuing master's in aerospace engineering sciences at University of Colorado, Boulder. She is actively involved with the Chu Research Group, working on Fe Boltzmann Lidar and Na Doppler Lidar. Her current research involves identification and analysis of polar mesospheric clouds (PMCs) in the MLT region with the data from the group's Antarctica Lidar Campaigns.

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WHERE DO ALL UNANSWERED QUESTIONS GO TO?

THE IONOSPHERE.

> **“EVERYONE IS A GENIUS. BUT IF YOU JUDGE A FISH BY ITS ABILITY TO CLIMB A TREE, IT WILL LIVE ITS WHOLE LIFE BELIEVING THAT IT IS STUPID"**
>
> *- Albert Einstein*

STUDENT DAY SUMMARIES

The student day talks were recorded this year and can be found at this link:
https://www.youtube.com/watch?v=roRStwDhTkQ
Start times indicated in the talk titles

HIGH LATITUDE AND POLAR PROCESSES (00:36:50)

EFFECT OF GEOMAGNETIC STORMS ON THE THERMOSPHERE IONSPHERE SYSTEM (01:34:00)

INTRODUCTION TO GRAVITY WAVES (02:25:00)

ATMOSPHERIC TIDES, PLANETARY WAVES, AND VERTICAL COUPLING (03:12:00)

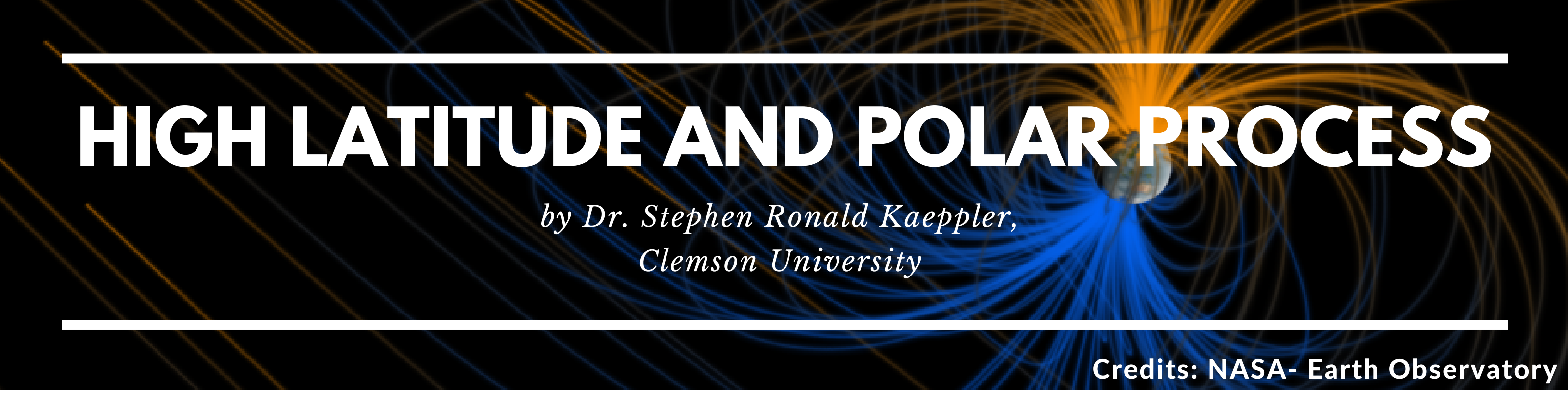
STATUS AND FUTURE OF DATA ASSIMILATION FOR SPACE SCIENCE (04:15:00)

LIVING WITH A STAR IN THE AGE OF DATA SCIENCE: TOOLS, TECHNOLOGIES AND MINDSETS FOR THE MODERN SPACE ENVIRONMENT (05:00:00)

DISTRIBUTED INSTRUMENTS: OPPORTUNITIES FOR NEXT GENERATION CEDAR SCIENCE (05:45:00)

THE IONOSPHERIC CONNECTION EXPLORER: MISSION AND FIRST DATA (06:28:00)

#FROMSTUDENTSFORSTUDENTS



HIGH LATITUDE AND POLAR PROCESS

by Dr. Stephen Ronald Kaeppler,
Clemson University

Credits: NASA- Earth Observatory

Summary written by
Robert Irvin

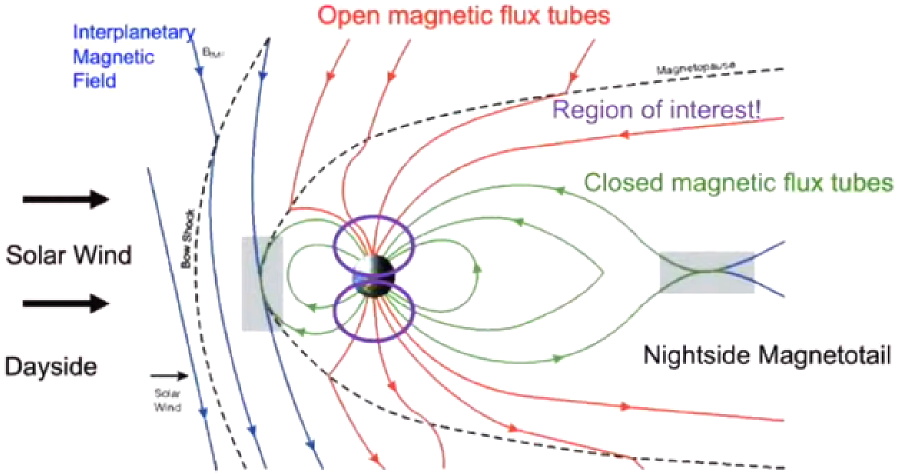
This talk covered basic principles, big questions, and future directions of High latitude and Polar processes of the Ionosphere-Thermosphere (IT) system. The ionosphere is defined as the weakly ionized portion of the atmosphere, above 50km or so, where free electrons exist in sufficient quantities to affect the propagation of radio waves (relevant to GPS, satellite communications, etc.). The primary source of this region is solar photoionization of the neutral atmosphere in the X-ray and Extreme Ultraviolet bands. The nomenclature of our field segments the ionosphere into stratified layers (D-region, E-region, F-region, Topside) defined by their varying electron densities, atomic and molecular ion compositions and concentrations, and ion-neutral chemistry and transport. The thermosphere describes the overlapping neutral portion of the atmosphere between roughly E-region altitudes and 500 km, which, to first order, contains molecular and atomic neutral species that exponentially decay independently at rates dependent on their mass and temperature. The magnetosphere then describes the extension of the ionosphere to higher altitudes where neutral densities are very low and Earth's geomagnetic field (dipolar to first order), with its interaction and response to the solar wind, is the dominant ion and electron forcing mechanism.

Why do we study high latitudes?

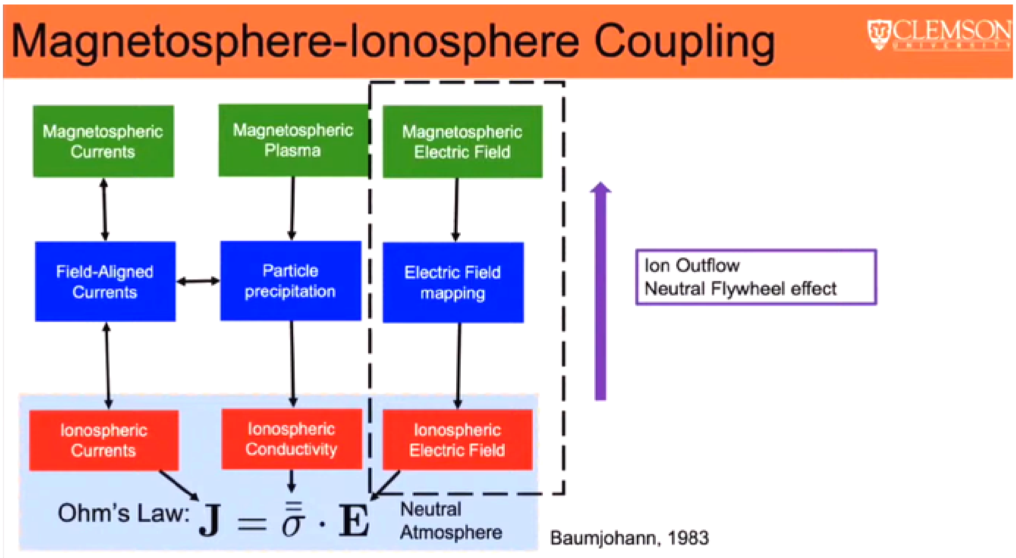
The magnetic field lines anchored to high latitudes exhibit greater 'non-dipolarness', to use such a phrase, because they can be more 'squished' and 'stretched' in the case of the dayside magnetopause and nightside magnetotail or they can exist as open field-lines directly tied to the solar wind in the case of the cusp region. Since, generally speaking, charged particles more easily travel along magnetic field lines than across them, the high latitude IT is tied to the input of particles and energy from the more active and dynamic regions of the magnetosphere, which can take the form of, for example, precipitating plasmasheet electrons as the source distribution of the auroral zone. So simply put, at high latitudes we can't understand what's going on in the IT unless we understand the driving mechanisms from the magnetosphere.

MI Coupling

Bostrom (1964) proposed an early model of MI configuration through current systems that connect these regions. We can use Ohm's law as a framework for studying MI coupling (Buamjohann, 1983) as ionospheric currents, conductivities, and electric fields couple to magnetospheric currents, plasma, and fields



Magnetosphere-Ionosphere coupling.



Magnetosphere-Ionosphere Coupling

Magnetospheric Currents
Magnetospheric Plasma
Magnetospheric Electric Field
Field-Aligned Currents
Particle precipitation
Electric Field mapping
Ion Outflow
Neutral Flywheel effect
Ionospheric Currents
Ionospheric Conductivity
Ionospheric Electric Field
Ohm's Law: $\mathbf{J} = \bar{\bar{\sigma}} \cdot \mathbf{E}$
Neutral Atmosphere
Baumjohann, 1983

Credits: Dr. Kaeppler Slide- Charts, CEDAR 2020

through field-aligned currents (FAC), particle precipitation, and field mapping.

> "The Ionosphere-Thermosphere basically forms the resistor to the magnetosphere."
> -Dr. Kaeppler

The Fields

We can think of the high latitude convective electric fields as being consistent with the motion of 'frozen-in' (conserved magnetic flux through highly conducting plasma) high latitude plasma anchored to magnetic flux tubes which are dragged along by the solar wind. This pattern is dependent on the orientation of the interplanetary magnetic field (the magnetic field carried by the solar wind), with southward orientation more nearly giving the idealized two-cell convection pattern but northward orientation resulting in a fragmentation of convection cells.

Particle Precipitation

Discrete/Diffuse Aurora and airglow patches are the visible trace resulting from particle precipitation. Why this matters? Enhanced electron densities in the ionosphere can result at lower altitudes from particle precipitation associated with aurora which changes the conductivity. Downward precipitating electrons correspond to upward FAC regions. Soft precipitation (<1 kev electrons/ions) in the polar cap/cusp regions tends to enhance F-region electron densities while hard precipitation enhances the E-region. Heating caused by soft particle precipitation is thought to be a mechanism of neutral upwelling in the polar cap.

Current Systems

In the 70s the picture of averaged, large scale FAC systems emerged as existing in pairs, corresponding to upward and downward currents. The real picture is more complicated, magnetometer data from the Active Magnetosphere and Planetary Electrodynamics Response Experiment (AMPERE) constellation is used to derive FAC patterns which we see exist on a variety of scales. Closure of large-scale field aligned currents in the IT, due to increasing neutral densities at lower altitudes, causes energy dissipation or Joule Heating.

Thermosphere Response

The Thermosphere winds are motivated by a different set of forces (pressure gradient, ion drag, Coriolis, etc.) than the ionosphere. Changes in neutral composition in the thermosphere can affect Joule Heating, upwelling, and hence ion composition changes. A note that, though this talk has been mostly covering forcing of the IT by the magnetosphere, the Lower atmosphere forcing can be just as significant a driver.

Feedback Mechanism

We have been talking mostly in terms of the IT response to the magnetosphere, but one important mechanism of influence in the reverse direction is ion outflow. Observations have been made of O+ deep in the magnetosphere which must have its origin in the ionosphere and this process has been found to vary with geomagnetic activity and with substorms. This is an active field of research which covered in the Cold Plasma Populations CEDAR Session.

Outlook/Future Directions

Future directions in the field, which parallel the ever improving available and affordable computational power, are directly assimilating data, improving model resolution, and incorporating machine learning techniques. Observationally, we need to move toward 3D and 4D measurements through satellite constellations (like the Geospace Dynamics Constellation) and combining ground and space observations (THEMIS).

SPEAKER BIOGRAPHY:

Dr. Kaeppler earned his Ph.D. in Physics from the University of Iowa in 2013. He was a postdoctoral fellow at SRI International from 2013-2015 and later a Research Engineer from 2015-2017. In 2018, Dr. Kaeppler joined the faculty at Clemson University. Dr. Kaeppler's research interests are in magnetosphere-ionosphere- thermosphere coupling at high latitudes, auroral electrodynamics, and bottomside ionospheric physics. Dr. Kaeppler is the PI of the NASA Ion Neutral Coupling during Active Aurora (INCAA) sounding rocket mission.

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EFFECT OF GEOMAGNETIC STORMS ON IONOSPHERE THERMOSPHERE SYSTEMS

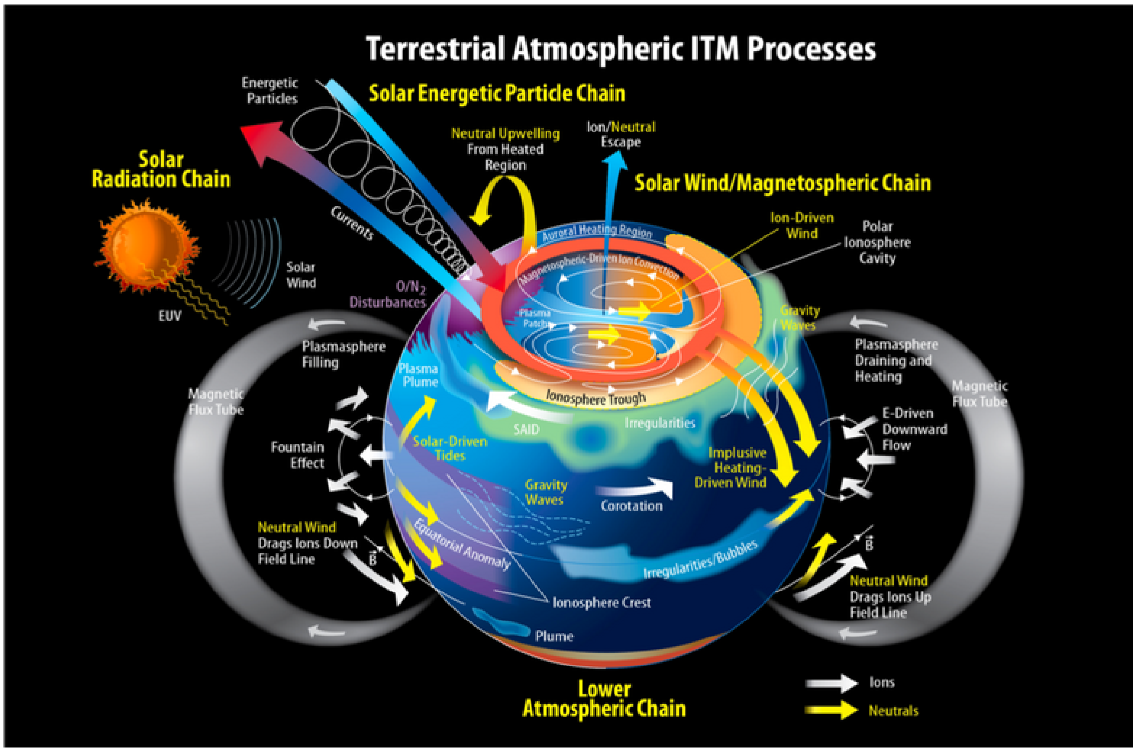
by Dr. Shasha Zou,
University of Michigan

Summary written by
Edith Macotela and Matthew Grawe

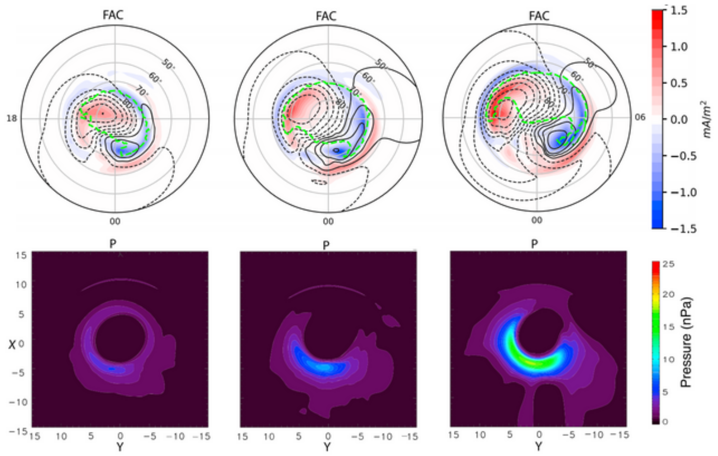
Understanding the effects of geomagnetic storms on the ionosphere-thermosphere system (IT system) has improved significantly in recent decades thanks to advances in monitoring, computational power, and modeling. During her tutorial presentation, Dr. Shasha Zou explored this in addition to discussing several geomagnetic storm effects. Special focus was given to plasma content in the ionosphere, thermospheric winds, thermospheric composition, and electric field changes. These discussion foci were supplemented with relevant data and modeling results.

Dr. Zou summarized that, during geomagnetic storms, hundreds of gigawatts (GW) flow into the IT system in the form of electromagnetic energy (Poynting flux) and particle precipitation, leading to global and complex ionosphere-thermosphere system responses. Meanwhile, during quiet conditions, the high-latitude IT system and low-latitude IT system do not interact strongly between each other. She also explained that the response time difference between ions and neutrals, where for neutrals is much longer than that for ions, leads to many interesting responses (e.g., the “neutral flywheel” effect). Furthermore, she clarified that the ring current evolution modulates the convection and field aligned current (FAC) patterns at high latitudes (Figure 1). She also added that nitric oxide (NO) increases by an order of magnitude in auroral and sub-auroral regions due to solar and high auroral activity, and that meridional winds transport excess NO to mid- and -low latitudes.

Dr. Zou’s tutorial ended with a brief introduction to the Geospace Dynamics Constellation (GDC), which is a mission that will employ a multi-satellite architecture to understand how the high latitude ionosphere-thermosphere system responds to variable solar wind/magnetosphere forcing.



Ionospheric Thermospheric interaction among ions and neutrals. Credits: NASA



Credits: Wang et al, (2019)

In the figure above, we can observe the results of storm-time expansion of ionospheric convection. Dayside reconnection enhances after strong IMF southward turning during storm and efficiently transfers energies into the magnetosphere. High-latitude ionospheric convection and FACs expand to lower altitudes (top panel). Ring current evolution modulates the connection and FAC patterns (bottom panel).

SPEAKER BIOGRAPHY:

Dr. Shasha Zou is an Associate Professor at the Department of Climate and Space Sciences and Engineering, University of Michigan. Her research focuses on the dynamic coupling between the Earth's magnetosphere, ionosphere, and thermosphere during geomagnetic disturbances, such as storms and substorms. She has extensive experience in analyzing, interpreting, and modeling observations obtained by various ground- and space-based instruments.

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INTRODUCTION TO GRAVITY WAVES

by Dr. Christopher Heale,
Embry-Riddle Aeronautical University

Credits: NASA- Visible Earth

Summary written by
Komal Kumari and Aidan Montare

Gravity waves (GWs) are basically irregularities /wiggles in the upper atmosphere that are generated by perturbation in a stably-stratified atmosphere. The gravity acts downward as a buoyancy/restoring force when an air parcel is lifted up, which causes oscillatory motion in the air parcel, thus, gravity waves. The energy can then be carried out in wave-like motion in the atmosphere at both regional and local scales. The buoyancy frequency (N) limits the maximum possible high frequency GWs up to ~5 minutes. The buoyancy frequency is also important to understand the stability of the atmosphere.

Navier stokes equations for GW-like perturbations, i.e., Newton's second law $F = ma$ equations for the perturbed air parcel for both horizontal and vertical directions, with wave-like solutions provides Taylor-Goldstein (TG) equation and the dispersion relation. The TG equation provides information about the GW vertical wind velocity and vertical wavenumber (m) and the dispersion relationship explains the relation between GW oscillation in different atmospheric parameters (m, k (horizontal wavenumber), N, mean wind). The intrinsic frequency, phase and group velocity of the wave can indicate the energy and wave propagation direction. The GW phase velocity and the GW group velocity propagate vertically in opposite directions and the intrinsic frequency (wave frequency relative to mean horizontal wind) is important to understand the GW oscillation with respect to local horizontal mean wind. Gravity wave spectra vary at different atmospheric layers due to variation in background winds. Note that the amplitude increases exponentially with height due to conservation to energy.

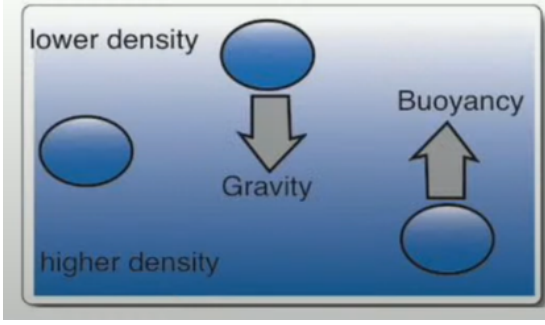
Polarization relation helps to determine the amplitude and phase relationship between wind, temperature, pressure and density gravity like oscillations which also depends on the horizontal and vertical wave scales of the wave. Gravity waves are highly dispersive and thus it is not easy to trace a single wave packet. Model simulations show a single gravity wave packet in 100 seconds can disperse to 100 kms. GWs in our atmosphere can span to horizontal wavelengths 10-1000 kms, vertical wavelengths 5-40 kms, period min-hours.

What causes gravity waves?

The main sources of gravity waves are present all over the globe such as topography e.g. mountains; convective processes e.g., thunderstorms, tornadoes, hurricanes; geostrophic adjustments e.g. jet streams; the natural hazards e.g., Tsunami's, volcanoes; Man made sources e.g. bombs, rockets

Physical mechanisms underlying gravity wave generation

Chris briefly discussed the life cycle of mountain waves. When the air is vertically lifted along the mountain, gravity waves are generated. He mentioned that the mean wind is important to propagate mountain gravity waves. The waves then move to the mesosphere with constant phases.



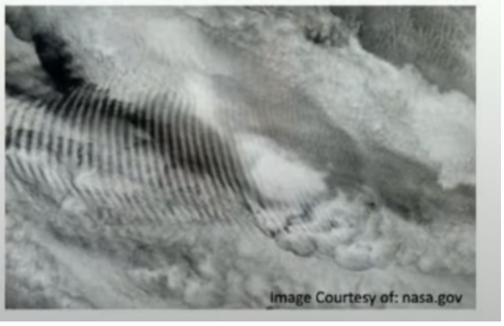
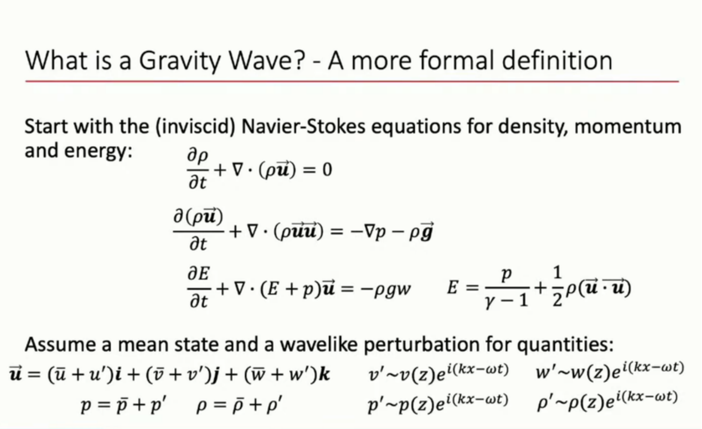


Image Courtesy of: nasa.gov



What is a Gravity Wave? - A more formal definition

Start with the (inviscid) Navier-Stokes equations for density, momentum and energy:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{\boldsymbol{u}}) = 0$$

$$\frac{\partial (\rho \vec{\boldsymbol{u}})}{\partial t} + \nabla \cdot (\rho \vec{\boldsymbol{u}} \vec{\boldsymbol{u}}) = -\nabla p - \rho \vec{\boldsymbol{g}}$$

$$\frac{\partial E}{\partial t} + \nabla \cdot (E + p)\vec{\boldsymbol{u}} = -\rho g w \qquad E = \frac{p}{\gamma - 1} + \frac{1}{2}\rho(\vec{\boldsymbol{u}} \cdot \vec{\boldsymbol{u}})$$

Assume a mean state and a wavelike perturbation for quantities:

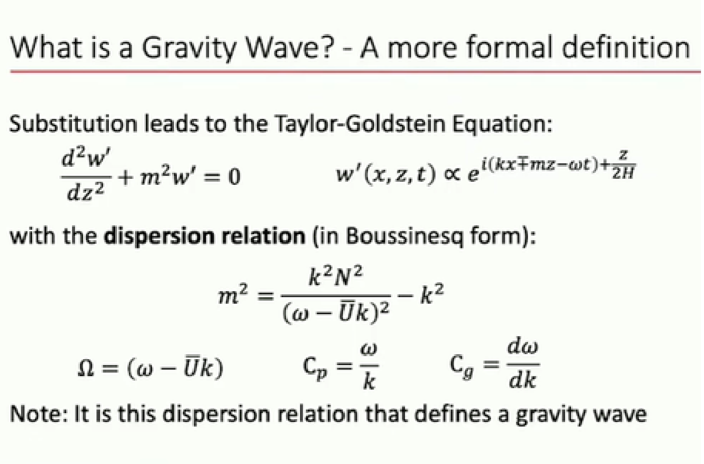
$$\vec{\boldsymbol{u}} = (\bar{u} + u')\boldsymbol{i} + (\bar{v} + v')\boldsymbol{j} + (\bar{w} + w')\boldsymbol{k} \qquad v' \sim v(z)e^{i(kx-\omega t)} \qquad w' \sim w(z)e^{i(kx-\omega t)}$$

$$p = \bar{p} + p' \qquad \rho = \bar{\rho} + \rho' \qquad p' \sim p(z)e^{i(kx-\omega t)} \qquad \rho' \sim \rho(z)e^{i(kx-\omega t)}$$

Latent heat release, obstacle effect, mechanical oscillator are other mechanisms which generate the gravity waves in convective processes. Chris showed how these waves propagate into the upper atmosphere carrying the momentum flux and energy. Secondary wave generation subsequently makes the process more complex.

Why are Gravity waves important?

Gravity waves can carry momentum and energy away from source in lower atmosphere and redistribute to different upper atmospheric layers through dissipation, wave breaking, momentum flux and mixing the transport constituents. When a gravity dissipates, it deposits energy and momentum into background flow and decelerates/accelerates the mean flow locally. Diffusion and viscous damping dissipative forces can result in local heating and cooling and thus change in temperature structure also. Some global implications are found in the Quasi Biennial Oscillation (a 2-year periodic zonal wind motion in the stratosphere) due to directly forced by GWs at equator, and in mean circulations such as cold-summer mesopause caused by GW forcings. Fundamentally, GWs are especially very important for weather-climate accurate prediction and are parametrized in GCM models. Gravity waves cannot be resolved in GCM models. Chris mentions that the parametrization is simplified and constrain gravity waves to be instantaneously generated at the source and propagation with no consideration of nonlinearity. The parametrization related to GW sources is tuned to make the results consistent with the observations and does not represent underlying GW-related physical mechanisms.



What is a Gravity Wave? - A more formal definition

Substitution leads to the Taylor-Goldstein Equation:

$$\frac{d^2 w'}{dz^2} + m^2 w' = 0 \qquad w'(x,z,t) \propto e^{i(kx \mp mz - \omega t) + \frac{z}{2H}}$$

with the **dispersion relation** (in Boussinesq form):

$$m^2 = \frac{k^2 N^2}{(\omega - \bar{U}k)^2} - k^2$$

$$\Omega = (\omega - \bar{U}k) \qquad C_p = \frac{\omega}{k} \qquad C_g = \frac{d\omega}{dk}$$

Note: It is this dispersion relation that defines a gravity wave

How do we measure Gravity waves?

The GWs can be observed using in situ measurement such as aircraft, balloons, rockets, ground based measurement such as imagers, lidar and radar to obtain altitude-time profile of GWs in the stratosphere-mesosphere-ionosphere and remote sensing such as satellites and GPS/GNSS networks. Modeling capabilities include local models i.e. Direct Numerical simulation with high resolution runs upto turbulence scale, Numerical Weather Prediction regional/global extended upto stratosphere, GCM models with much lower resolution (1-degree) with parameterized gravity waves. As mentioned above, the GW propagation from source to demise is instantaneous at the model grids and the nonlinearity is excluded in the parametrization.

How do winds and temperature vary along the gravity wave path?

If the background wind and temperature varies with altitude then the vertical wavelength of GW changes with altitude. This can be attributed to three main effects of the atmosphere on the gravity waves:

Refraction: Both the wind and the temperature act to refract the wave. If the wind or N increases (decreases) with altitude, then the vertical wavenumber decreases (increases) and waves travel more horizontally (vertically).

Reflection: If the intrinsic frequency shifts to N buoyancy frequency at an altitude, then waves go evanescent above that altitude and waves cannot travel further above and have to get reflected back. This is called a turning point.

***Ducting*:** If there are two turning points such that waves travel bouncing these two turning point layers, that is called ducting. The duct is leaky so energy does get dissipated subsequently. Short period waves can travel large horizontal distances away from their source regions due to ducting mechanisms.

Death of Gravity waves

If the vertical wavelength propagating vertical wavelength increases/decreases due to refraction and reflection, it has implications on propagation direction. Intrinsic frequency determines whether the waves reflect in the atmosphere or get absorbed. The gravity wave death can occur via critical level filtering (intrinsic frequency = 0) when the horizontal phase speed of the wave is equal to mean zonal flow velocity. The wave will be critically filtered and eventually absorbed in the mean flow. Overturning of GWs also occurs when intrinsic frequency matches the horizontal mean flow. Viscous dissipation is important for diffusivity of gravity waves. It is significant above 100 km altitude where smaller vertical wavelength rapidly dissipates. Larger vertical wavelengths travel farther to the upper atmosphere. All waves die from viscous dissipation eventually. Dissipation is fundamentally caused by momentum and heat flux divergence. Secondary gravity waves are likely to generate in each scenario.

Current challenges

Chris identified several current challenges in gravity wave research:

- How can we describe statistically the sources of gravity waves?
- How are momentum and energy distributed vertically in gravity waves?
- How can we model the nonlinear aspects of gravity waves?
- How can we relate gravity waves to effects in the ionosphere?
- And the big question: How can we improve the modeling of gravity waves in general circulation models?

SPEAKER BIOGRAPHY:

Dr. Christopher Heale is a Research Associate at the Embry-Riddle Aeronautical University. Christopher earned a Ph.D in 2015 from Embry-Riddle Aeronautical University, where he continued as a post-doc and then Research Associate. He predominantly studies the generation, propagation, and dissipation of gravity waves in the Earth's atmosphere using high-resolution large eddy simulations. In particular, his current interests include convective wave generation from large Mesoscale Convective Systems (MCS) over the mid-west U.S. and their effects on the upper atmosphere and ionosphere, as well as secondary wave generation from mountain wave breaking.

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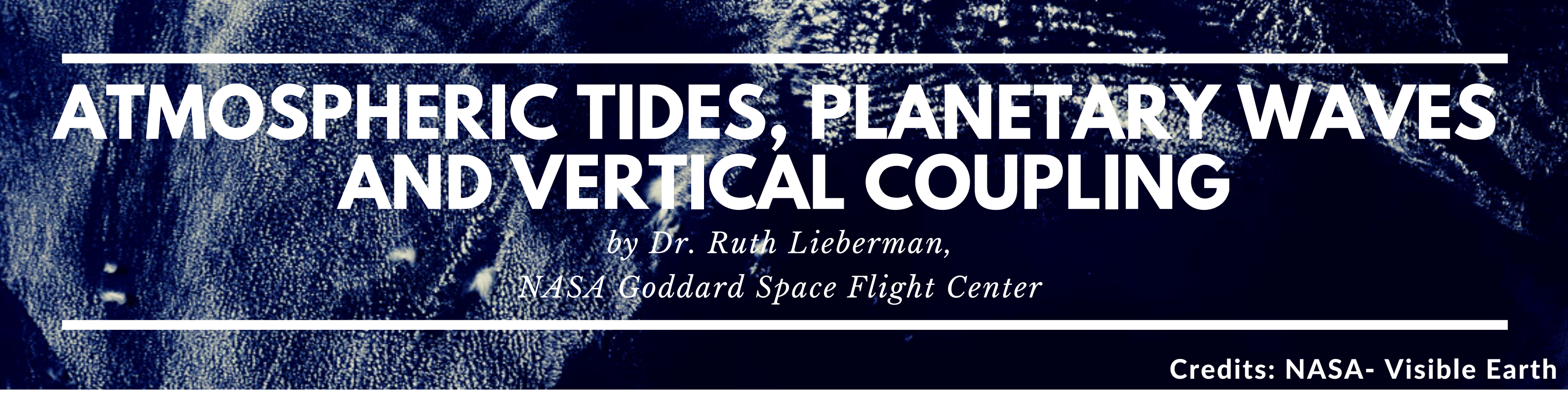


ATMOSPHERIC TIDES, PLANETARY WAVES AND VERTICAL COUPLING

by Dr. Ruth Lieberman,
NASA Goddard Space Flight Center

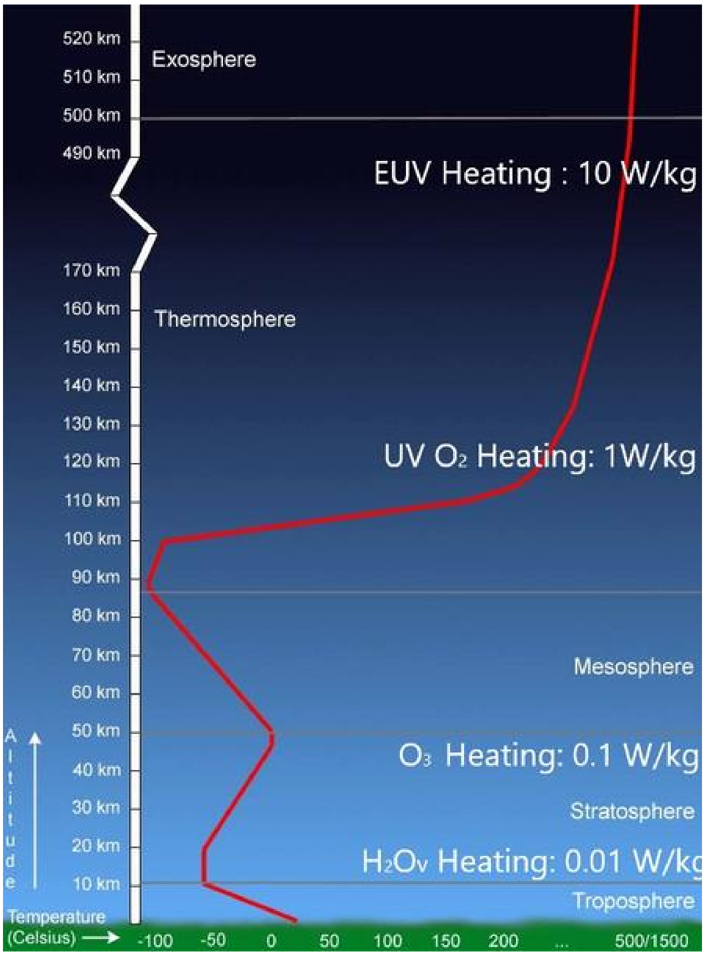
Credits: NASA- Visible Earth

Summary written by
Deepthi Ayyagari

Observational studies over the past two decades clearly show that the quiet time ionosphere is influenced by large-scale motions below 100 km of Earth's atmosphere. These large-scale motions mentioned here refer to Tides and Planetary waves. Studies implicate that Tides propagate into ionosphere unlike planetary waves which vertically propagate don't reach the atmosphere directly! In order to understand the vertical coupling process of these tides and waves the basic understanding required is to study the behavior of each of these components which drive these motions!

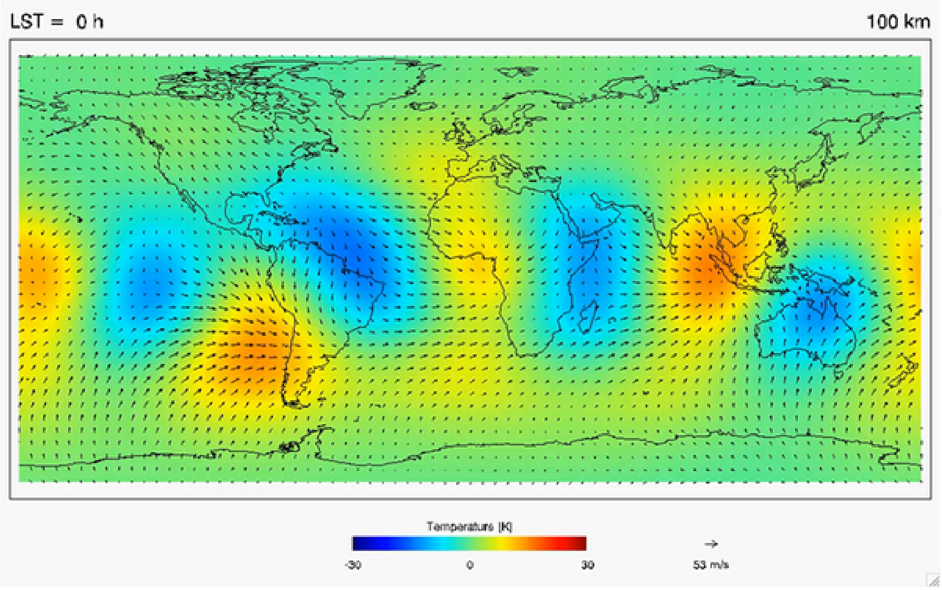
Let's start with Thermal tides: A regular diurnal (daily) cycle in heating generates thermal tides that have periods related to the solar day. The largest amplitude thermal tides are caused by the periodic heating of the atmosphere by the Sun – the atmosphere is heated during the day and not heated at night. This set of tendency occurs because the solar heating of the atmosphere occurs in an approximate square wave profile hence rich in harmonics. In general, this diurnal heating would give rise to tides with a period of 24 hours, corresponding to the heating's periodicity. However, observations reveal that large amplitude tides are generated with periods of 24 and 12 hours.

Understanding Atmospheric Tides and Planetary Waves
Assume a waves on a sphere in a frictionless atmosphere with a resting background state. In short to study the generation of inertia-gravity waves we first need to set the scene by laying down the fundamentals of geophysical fluid dynamics, the most important aspects of which are rotation and stratification and the effect of the earth's rotation on large scale motion is to deflect the flow's direction which is termed as the Coriolis effect.



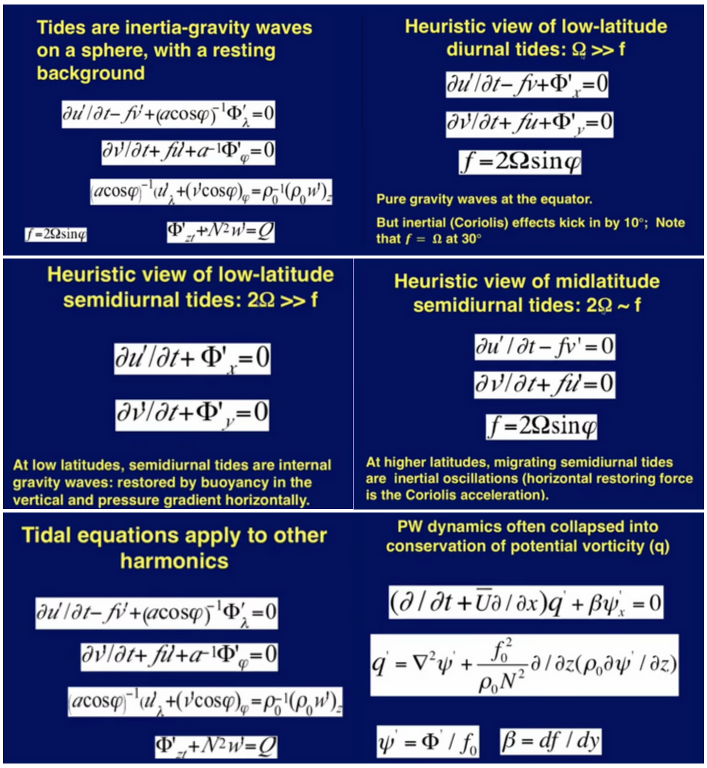
Credits: Dr. Lieberman Slide- Charts, CEDAR 2020

At the equator the earth's rotation vector is parallel to the earth's surface and is therefore applying a force which is perpendicular to the earth's surface. This force is directly opposed by the gravitational force and so there is no net motion. In contrast, when not at the equator, the gravitational force and the force perpendicular to the earth's rotation axis are no longer in opposing directions, but an angle has formed between them. This change in angle between the forces gives rise to the variation, across different latitudes, of the Coriolis force. Similarly when we are trying to understand the vertical propagation of these waves the amplitude increases exponentially with altitude till stratopause then further to linear, breaking and finally decays! Diurnal tides propagate



Observed tidal perturbations at 100 km altitude
https://upload.wikimedia.org/wikipedia/commons/thumb/f/fb/Timed100kmsabertidisep2005.gif

between 30 North and South whereas semi-diurnal tides propagate vertically at all latitudes! Another class of atmospheric waves that are very important for circulation are propagating buoyancy waves (also called internal gravity waves), which correspond to oscillations primarily in the vertical plane when the square of the Brunt–Väisälä frequency exceeds zero.



Tides are inertia-gravity waves on a sphere, with a resting background

$$\partial u'/\partial t - fv' + (a\cos\varphi)^{-1}\Phi'_\lambda = 0$$

$$\partial v'/\partial t + fu' + a^{-1}\Phi'_\varphi = 0$$

$$(a\cos\varphi)^{-1}(u'_\lambda + (v'\cos\varphi)_\varphi = \rho_0^{-1}(\rho_0 w')_z$$

$$f = 2\Omega\sin\varphi \qquad \Phi'_{zt} + N^2 w' = Q$$

Heuristic view of low-latitude diurnal tides: Ω >> f

$$\partial u'/\partial t - fv + \Phi'_x = 0$$

$$\partial v'/\partial t + fu + \Phi'_y = 0$$

$$f = 2\Omega\sin\varphi$$

Pure gravity waves at the equator.

But inertial (Coriolis) effects kick in by 10°; Note that $f = \Omega$ at 30°

Heuristic view of low-latitude semidiurnal tides: 2Ω >> f

$$\partial u'/\partial t + \Phi'_x = 0$$

$$\partial v'/\partial t + \Phi'_y = 0$$

At low latitudes, semidiurnal tides are internal gravity waves: restored by buoyancy in the vertical and pressure gradient horizontally.

Heuristic view of midlatitude semidiurnal tides: 2Ω ~ f

$$\partial u'/\partial t - fv' = 0$$

$$\partial v'/\partial t + fu' = 0$$

$$f = 2\Omega\sin\varphi$$

At higher latitudes, migrating semidiurnal tides are inertial oscillations (horizontal restoring force is the Coriolis acceleration).

Tidal equations apply to other harmonics

$$\partial u'/\partial t - fv' + (a\cos\varphi)^{-1}\Phi'_\lambda = 0$$

$$\partial v'/\partial t + fu' + a^{-1}\Phi'_\varphi = 0$$

$$(a\cos\varphi)^{-1}(u'_\lambda + (v'\cos\varphi)_\varphi = \rho_0^{-1}(\rho_0 w')_z$$

$$\Phi'_{zt} + N^2 w' = Q$$

PW dynamics often collapsed into conservation of potential vorticity (q)

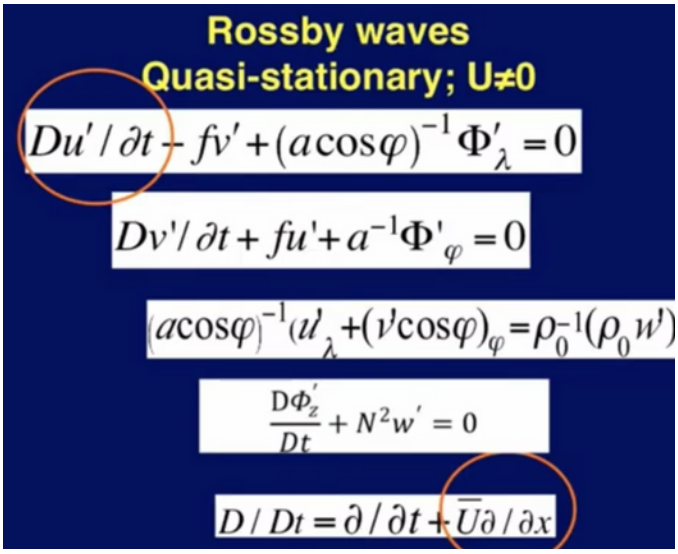
$$(\partial/\partial t + \bar{U}\partial/\partial x)q' + \beta\psi'_x = 0$$

$$q' = \nabla^2\psi' + \frac{f_0^2}{\rho_0 N^2}\partial/\partial z(\rho_0\partial\psi'/\partial z)$$

$$\psi' = \Phi'/f_0 \qquad \beta = df/dy$$

Credits: Dr. Lieberman Slide- Charts, CEDAR 2020

In case of planetary waves, they're governed by same equations as explained in earlier case of Tides and Gravity waves but like the name suggests they have a longer period. The dynamics of these waves are governed by conservation of quasi geostrophic potential vorticity.



Rossby waves
Quasi-stationary; U≠0

$$Du'/\partial t - fv' + (a\cos\varphi)^{-1}\Phi'_\lambda = 0$$

$$Dv'/\partial t + fu' + a^{-1}\Phi'_\varphi = 0$$

$$(a\cos\varphi)^{-1}(u'_\lambda + (v'\cos\varphi)_\varphi = \rho_0^{-1}(\rho_0 w')$$

$$\frac{D\Phi'_z}{Dt} + N^2 w' = 0$$

$$D/Dt = \partial/\partial t + \bar{U}\partial/\partial x$$

Credits: Dr. Lieberman Slide- Charts, CEDAR 2020

They propagate upward, equatorward and westward relative to mean wind. For example, during ENSO events in the Pacific, the extraordinarily warm sea-surface temperature can excite waves in the atmosphere passing above. Yet it is found that the wave pattern generated is sensitive to the location (east and west) of the forcing region. Another interesting aspect is the SSW and Vortex spinning phenomena observed in 2009, analysis of wave activity in the extra tropical troposphere revealed that two Rossby wave trains propagated eastward to the North Atlantic several days prior to the vortex splitting. The first wave train propagated from the subtropics and mid-latitudes of the eastern Pacific Ocean over North America and the second one propagated from the northern Pacific Ocean. These wave trains contributed to an intensification of the tropospheric anticyclone

Europe and to the splitting of the stratospheric polar vortex.

Observational challenges

The measurement techniques between 100-200 kms are sensitive to only day-time emissions.

Temporal measurements for longitudinal structures is ambiguous.

Identification and tracking of sources of Ionospheric variability through neutral atmosphere

ICONic Opportunities

The Ionosphere Connection Explorer (ICON) was launched in October 2019 and addresses these observations challenges at low latitudes. Global, low latitude thermospheric neutral winds and ion velocities along common magnetic field lines and the direct observations connecting electric fields in lower thermosphere to the ion velocities at the spacecraft altitude (~575km).

SPEAKER BIOGRAPHY:

Dr. Lieberman earned a Ph.D. in Atmospheric Sciences from the University of Washington. She was a postdoctoral researcher with the Upper Atmosphere research Satellite (UARS) mission at the University of Michigan. In 1997 Ruth joined Northwest Research Associates, Inc. in Boulder, CO, and migrated with their dynamics group to GATS-Inc. in 2012. From 2016-2018 she was the Aeronomy Program director at National Science Foundation. Since August 2018 she has been a Research Scientist in the Heliophysics division at Goddard Space Flight Center. Ruth's work focuses on observations, and observation-driven modeling of tidal and planetary wave dynamics.

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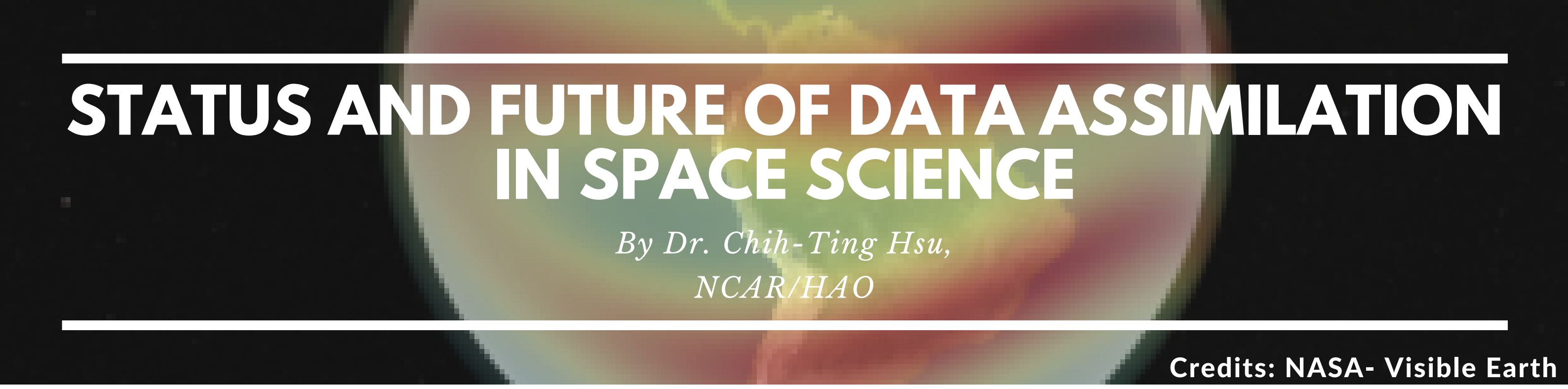

STATUS AND FUTURE OF DATA ASSIMILATION IN SPACE SCIENCE

By Dr. Chih-Ting Hsu,
NCAR/HAO

Credits: NASA- Visible Earth

Summary written by
Robert Irvin

What is data assimilation/why we need data assimilation?

Data assimilation (DA) combines observations with a prior state, or background knowledge, given by a numerical or empirical model. This is done because models and observations both have limitations. Observations have error, bias, noise, data gaps and can contain space-time ambiguity. For example, data assimilation can be used to fill in TEC (Total Electron Content) data gaps that exist over the oceans. Numerical models are very sensitive to minor changes in initial conditions, so data assimilation can help solve the initial value problem.

Introduction to data assimilation method

The basic idea of data assimilation can be explained by Bayes theorem where the posterior probability is proportional to the prior probability, given by model, and the likelihood, given by observation which results in a reduced uncertainty of the posterior. Variance minimum and Maximum likelihood methods are two ways to solve this problem.

4D variational method

3D in space plus 1D in time. The idea behind 4D var is to find a new initial condition that can minimize difference between observations and model and also the prior and posterior initial conditions. This is done by optimizing a cost function which is weighted by these two factors, where the model states need to be converted to observation space by the use of an observation specific forward operator.

Ensemble Kalman Filtering

In Ensemble Kalman filtering (EnKF), we consider a set of initial conditions to represent the prior probability. Assuming the likelihood that related to observation error is known, the posterior states can be computed using the Kalman gain that given by prior probability and likelihood in the analysis step. The updated posterior states are used for model forecasting. The analysis and forecast steps are alternately carried on in data assimilation cycles.

> “The purpose of data assimilation is to combine the observation information with the background knowledge optimally to reduce observation error, fill up the gap of observation, and get a better estimate of the initial condition."
>
> - Dr. Hsu

Application of data assimilation to space science and its challenge

Some important applications to space science include upper atmospheric weather forecasting, characterizing the relative impact of observing systems, and reanalysis of data.

Upper atmosphere Weather Forecasting

Because of the many drivers of the upper atmosphere, specification of model initial state and time dependent forcing are important. In the example shown, Chen et al. (2016) applied DA techniques to geomagnetic storms. The authors tested the predictability of data assimilation at different time-steps using GPS TEC observations, TIE-GCM (Thermosphere Ionosphere Electrodynamics General Circulation Model) and Ensemble Adjustment Kalman Filter with KP and F10.7 values specified for each ensemble member which will drive TIE-GCM.

Techniques which can aid in the generation of time dependent forcing pertinent to this study, and upper atmosphere forecasting more generally, are machine learning, which might give time variation of KP, and a Coupled systems approach tying the ionosphere with the magnetosphere or lower atmosphere.

Impact of Observing System
Impacts of different observing system for the same observation variable are different, because of observation error, location, data volume, etc. For example, the electron density profile ionosonde resulting from GNSS (satellite orbit) and ionosonde (fixed location) systems will be different. A DA experiment can be done by combining a model with either real or synthetic observations. The authors in Hsu et al. (2018) used synthetic observations to compare the impact on ionospheric specification in mid/low latitudes by satellite constellations designed for radio occultation.

Reanalysis of Data
Data assimilation can be used to obtain a better specification of a region of interest which can be compared with some other independent observations to potentially uncover some missing physics. In the example shown, authors in Chen et al. (2017) used data assimilation to improve the TIE-GCM electric field and hence plasma drifts which were then compared with independent observations at Jicamarca Radio Observatory data.

Some science topics which could be helped by the use of data ssimilation include phenomena that can be observed by more than one type of observation or observing system, phenomena which do not have enough observations where DA can be used to fill in the gaps, or the phenomena is in a hidden state or difficult to observe such as the case of the global electric field mentioned above.

SPEAKER BIOGRAPHY:

Dr. Hsu is a postdoctoral fellow at High Altitude Observatory National Center for Atmospheric Research, Boulder. Her work focuses specifically on coupled upper atmosphere data assimilation. Her research interests include inquiring the predictability of the ionospheric and upper atmospheric weather, assessing remote sensing data impacts on the predictability of the T-I interaction region, and ensemble analysis of the coupling of the ionosphere and the neutral atmosphere.

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LIVING WITH A STAR IN THE AGE OF DATA SCIENCE: TOOLS, TECHNOLOGY, AND MINDSETS FOR THE MODERN SPACE ENVIRONMENT

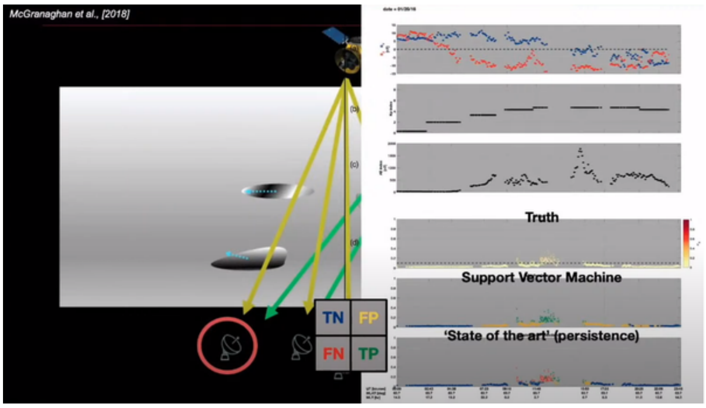
By Dr. Ryan McGranahan
ASTRA LLC

Credits: NASA

Summary written by
Matthew Grawe

What tools are necessary to predict variations in the space environment?
Dr. Ryan Mcgranaghan (ASTRA LLC) provided some key insights towards answering this question during his discussion entitled "Living with a star in the age of data science: tools, technology, and mindsets for the modern space environment", given as part of the student workshop at the 2020 CEDAR Virtual Meeting. Ryan outlined several overarching considerations that, together, could lead to a paradigm shift in the way data is utilized in the space science community.

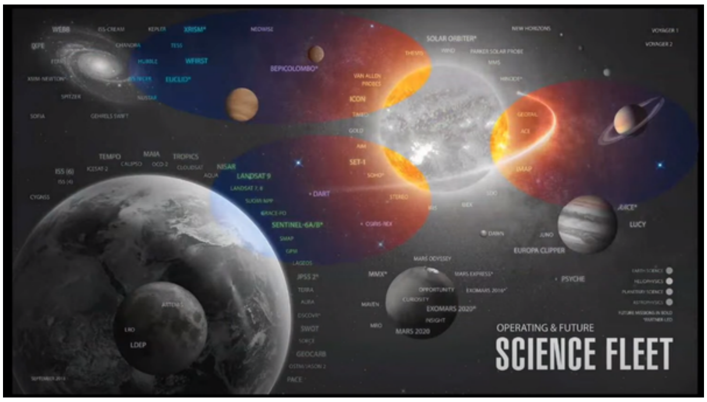
Firstly, to quote Ryan directly, “We don’t have a data problem, we really have an information problem”. The currently existing space science fleet generates vast quantities of data; the Solar Dynamics Observatory (SDO) and the Daniel K. Inouye Solar Telescope (DKIST), for example, generate terabyte-level data volumes each day. Ryan discussed mindsets (and gave examples of useful tools) that can help our community not only tackle the growing amount of data in our field, but also help us combine datasets, understand data uncertainty, and provide low-latency observations (especially for prediction). All of these discussion points are encompassed by the “Four Vs of Big Data”: Volume, Variety, Veracity, and Velocity.



A case example was the use of a support vector machine to make predictions of GNSS scintillation.

> "We don't have a data problem, we really have an information problem."
>
> -Dr. Mcgranahan.

In addition to the information problem, Ryan explained the need for new approaches to predictive modeling; the complexity of space weather and the near-Earth environment demands that we explore models capable of capturing systems that evolve nonlinearly. Many techniques exist (some of which are more easily explainable than others) and it is important to let the science dictate what is needed. Two case examples were provided as part of the discussion: prediction of GNSS scintillation using a support vector machine (SVM) and reconstruction of 3-dimensional relativistic (MeV) electron fluxes in the magnetosphere. Ryan also raised the important point that similar looking data may arise from very different-looking phenomena (try Googling “muffin or chihuahua”!), and it is important to develop methods for understanding and interrogating these models, so uncertainties are correctly reported.



The importance of being antidisciplinary and taking a systems perspective. Looking at the areas between fields can often lead to fruitful discoveries.

Lastly, Ryan stressed the importance of being interdisciplinary (or antidisciplinary, a term he often uses) in our research, and that progress demands a systems perspective. Ryan advised us that “there is a lot of value to be generated from the from the progress that’s been made in sister disciplines”. Focusing on the coupling between different research fields often leads to important breakthroughs.

Ryan’s talk can be viewed on YouTube as part of the full workshop.

SPEAKER BIOGRAPHY:

Dr. Mcgranahan Principal Data Scientist /Aerospace Engineering Scientist, ASTRA, LLC. At ASTRA, Ryan leads data science and machine learning efforts to improve our understanding of the Earth’s space environment. Ryan began this role after completing a Jack Eddy Living With a Star Postdoctoral Fellowship at the NASA Jet Propulsion Laboratory, during which he studied the Earth’s and solar system planets’ interactions with the Sun. Ryan was selected as a National Science Foundation Fellow to complete his Ph.D. research at the University of Colorado Boulder, and completed his degree in Aerospace Engineering Sciences in the Fall of 2016. He also holds a Master’s Degree in Aerospace Engineering Sciences from CU Boulder and a Bachelor’s Degree in Aerospace Engineering from the University of Tennessee.

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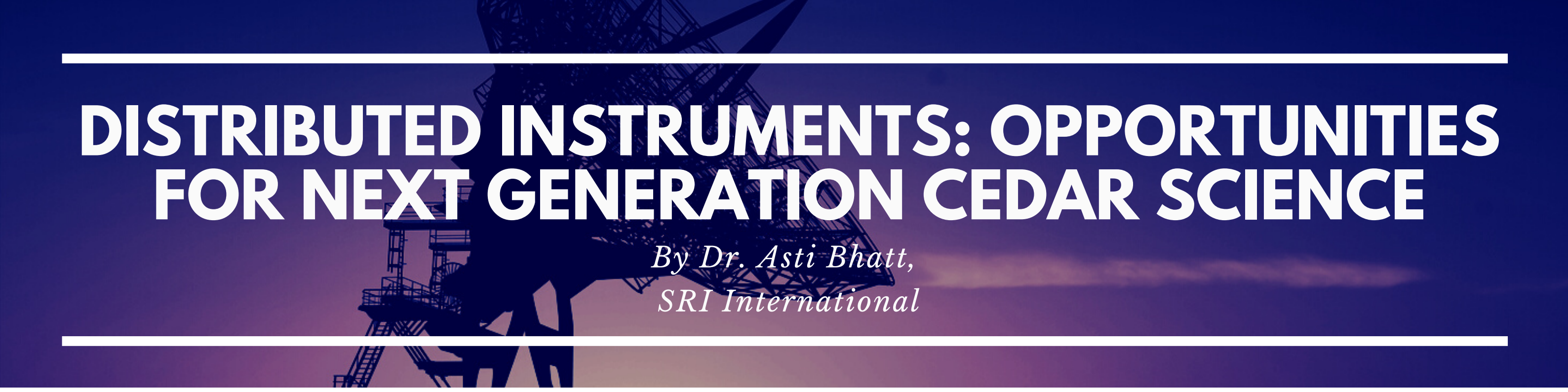

DISTRIBUTED INSTRUMENTS: OPPORTUNITIES FOR NEXT GENERATION CEDAR SCIENCE

By Dr. Asti Bhatt,
SRI International

Summary written by
Meghan LeMay

Given the abundance of data available to the CEDAR community, Dr. Asti Bhatt (SRI) provided an extensive overview of what types of data are useful to CEDAR scientists. A distributed array of small instruments (DASI) provides spatial and temporal resolution using small instruments with the capability of collecting a variety of data. These instruments are spaced far apart with the goal of collecting a variety of data everywhere and at all times. The Ionosonde network, SuperDARN, THEMIS optical imaging network, GNSS receivers, and the Low-latitude Ionospheric Sensor Network (LISN) are all classic DASI networks that provide data products scientists build ionospheric profiles from. DASI networks originated from the need to have relatively cheap, global coverage to provide the modeling community with data to assimilate and evaluate ionospheric models with. Instruments such as incoherent scatter radars (ISR) provide highly accurate and detailed measurements but are resource intensive especially in terms of cost making them infeasible for global coverage. This makes the less accurate DASI networks highly effective for large-scale M-I-T study. The National Academy of Scientists has identified science drivers that require distributed measurements to achieve them using various spatial and temporal scales. These drivers include but are not limited to topics such as plasma redistribution, particle energization, and particle precipitation which are fundamental to the understanding of M-I-T coupling. Some current DASI efforts that are in various stages of implementation are the HamSCI Personal Space Weather Station (PSWS), the Zephyr multiple-input multiple-output (MIMO) Meteor Radar Network, MagStar, Space Weather Underground (SWUG), ScintPi, and MANGO-NATION. The PSWS is a multi-instrument ground-based device that uses software defined radio, a magnetometer, and GNSS to collect space weather measurements. These individual devices can be operated in a user’s backyard and are part of a larger distributed network. Zephyr is a distributed network that aims to measure mesospheric and lower thermospheric winds and will be built in the Rocky Mountain region. MagStar is an array of six high-quality, real-time magnetometers collecting 1 Hz geomagnetic data. SWUG is a collaboration between the University of New Hampshire and high school students deploying magnetometers across New England to study ionospheric current systems. ScintPi is a low-cost, open source Raspberry Pi based GPS scintillation monitor. MANGO-NATION combines optical techniques using astronomy cameras and Fabry-Perot interferometers that can be installed on any rooftop to image the F-region and neutral winds. Students interested in getting involved with DASI projects can do so both on the hardware and the data side. If interested in building and deploying instruments contact the scientists involved. On the data side, students should think about how to combine data from multiple DASI sources along with highly accurate ISR, satellite, and rocket data.

SPEAKER BIOGRAPHY:

Dr. Bhatt is a space physicist with over 10 years of experience. Her specific research pertains to studying continent-scale processes in the earth's upper atmosphere using a large network of optical imagers, and small-scale transient processes in the earth's ionosphere-magnetosphere, in response to geomagnetic storms, using a variety of radio and optical instruments. She builds, installs and develops data analysis systems, for optical imagers she uses in her research. She also leads a cyberinfrastructure project called the Integrated Geoscience Observatory to provide a collaborative software platform to geospace scientists, designed to generate reproducible research results.

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THE IONOSPHERIC CONNECTION EXPLORER (ICON)

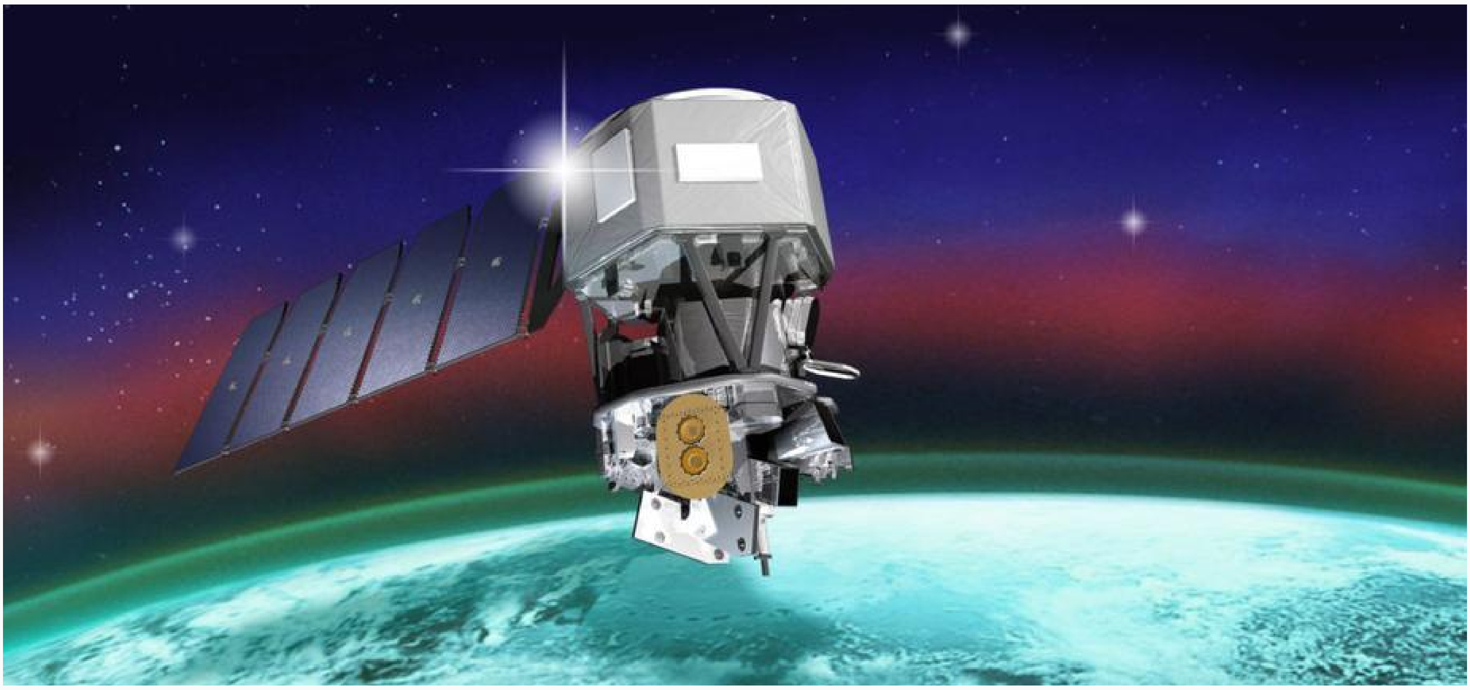
By Dr. Scott England and Dr. Colin Triplett,
Virginia Tech. University / University of California Berkeley

Summary written by
Komal Kumari and Matthew Grawe

The student workshop was concluded with a useful discussion from Dr. Scott England (Virginia Tech) and Dr. Colin Triplett (UC Berkeley) concerning the recently launched Ionospheric Connection Explorer (ICON). ICON was launched in October 2019 and its first observational data were presented during the 2020 CEDAR Meeting. The ICON mission is focused on the low latitude ionosphere-thermosphere region, with the goal to better understand the coupling between the ionosphere and thermosphere. ICON orbits at an altitude of approximately 600 km and houses several instruments that measure various atmospheric and ionospheric parameters.

Three of the onboard instruments (MIGHTI, EUV, and FUV) use limb airglow observations to provide measurements of neutral winds /temperatures, daytime ion parameters, and nighttime ion parameters (respectively). The fourth onboard instrument (the IVM) provides in-situ measurements of ion velocity and ion density. Currently, ICON looks to the north and swaths the whole planet from 12°S to 40°N in one month. The data is categorized into four levels: Level 1 {Brightness, Intensity} ; Level 2 {Winds, Temperature, Composition ([O]/[N2], Night/Daytime O+, height of F2-layer (HmF2) and number density in the F2 layer (NmF2)}; Level 3 {Data summaries / regularly gridded data}; and Level 4 {Model outputs run with the instrument observations}.

At low latitudes, the plasma is dense due to high on production during the day, and there is plasma upwelling due to the presence of eastward electric and horizontal magnetic fields. The winds blowing in the E-region move ions and produce currents, and gradients in the E-region wind field/conductivity build up electrostatic fields which map to the F-region along equipotential lines. This process supplies the electric field needed to create a plasma upwelling, leading to increased plasma production and lifetime (making the F-region plasma even more dense). The lifted plasma diffuses down the magnetic field lines and settles, creating two dense bands of ions north and south of the magnetic equator.



ICON artist design. Credits: NASA - ICON website

Day-to-day variation of the ExB drift (even at solar minimum and low magnetic activity) at the equator often deviates from overall climatological behavior, and the reasons why are not well understood.

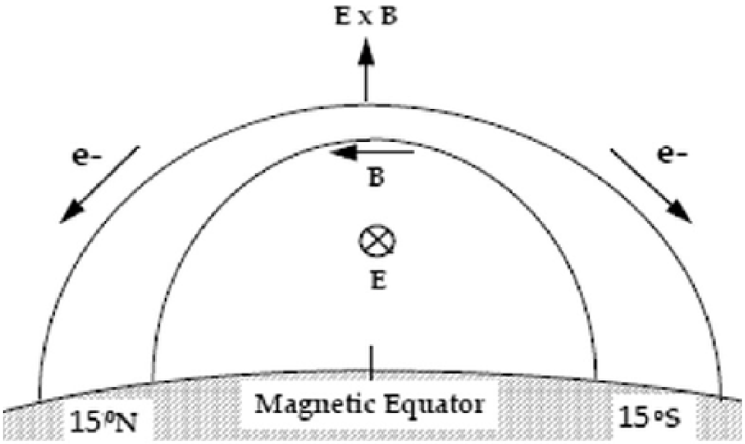
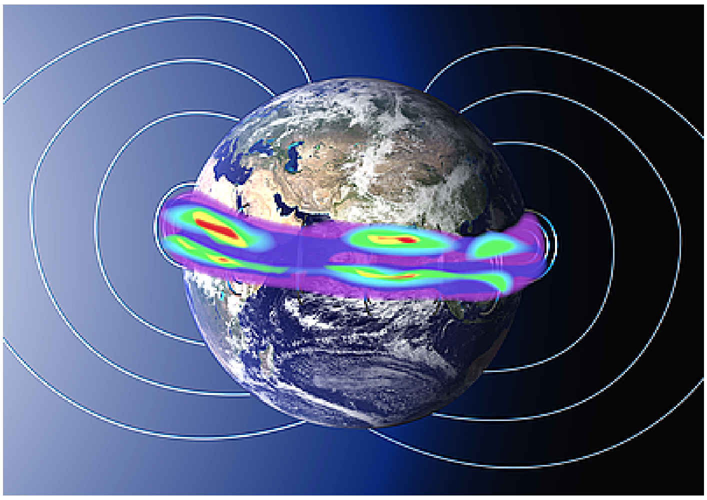


Illustration of the equatorial fountain effect which gives rise to the equatorial anomaly. E and B represent the electric and magnetic field vectors respectively. Credits: DOI: 10.1016/j.asr.2015.05.037

ICON observations will capture the medium-to-large scale characteristics of both spatial and temporal variability in the low-latitude ionosphere (extending down to the E-region) in hopes to elucidate these deviations. The variability observed is theorized to originate from neutral drivers below the ionosphere. For example, atmospheric waves propagating upwards from below the ionosphere might be responsible for the spatial and temporal features in the day-to-day variability observed in the low-latitude ionosphere. The Level-1 and Level-2 data will be publicly available in July. Get the data at https://icon.ssl.berkeley.edu/Data.



Ionospheric region to be observed by ICON. Credits: NASA

SPEAKERS BIOGRAPHY:

Dr. England did his PhD at the University of Leicester, UK, studying coupling of energy and momentum between different regions of the atmosphere via atmospheric waves. He spent 12 years at the Space Sciences Laboratory at the University of California, Berkeley, where his studies focused on the interaction between atmospheric waves and charged particles in the near-Earth space environment. He came to Virginia Tech in 2016, and currently focuses on using remote sensing instruments to study the upper atmosphere and near-earth space environment. He is the Project Scientist for the NASA ICON spacecraft, a Co-Investigator on the NASA GOLD spaceflight mission, and a Participating Scientist on the NASA MAVEN mission to Mars.

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Dr. Triplett received his Ph.D. from the University of Alaska, Fairbanks in Atmospheric Sciences. His research focuses on dynamics of the middle and upper atmosphere and how different scale waves interact and drive the atmospheric system. He has used both model simulations as well as sounding rocket/lidar data to study multiple scales from turbulence to atmospheric tides. Dr. Colin is currently working with the Ionospheric Connection Explorer (ICON), NASA's explorer mission to study the interaction of the neutral atmosphere and the ionosphere.

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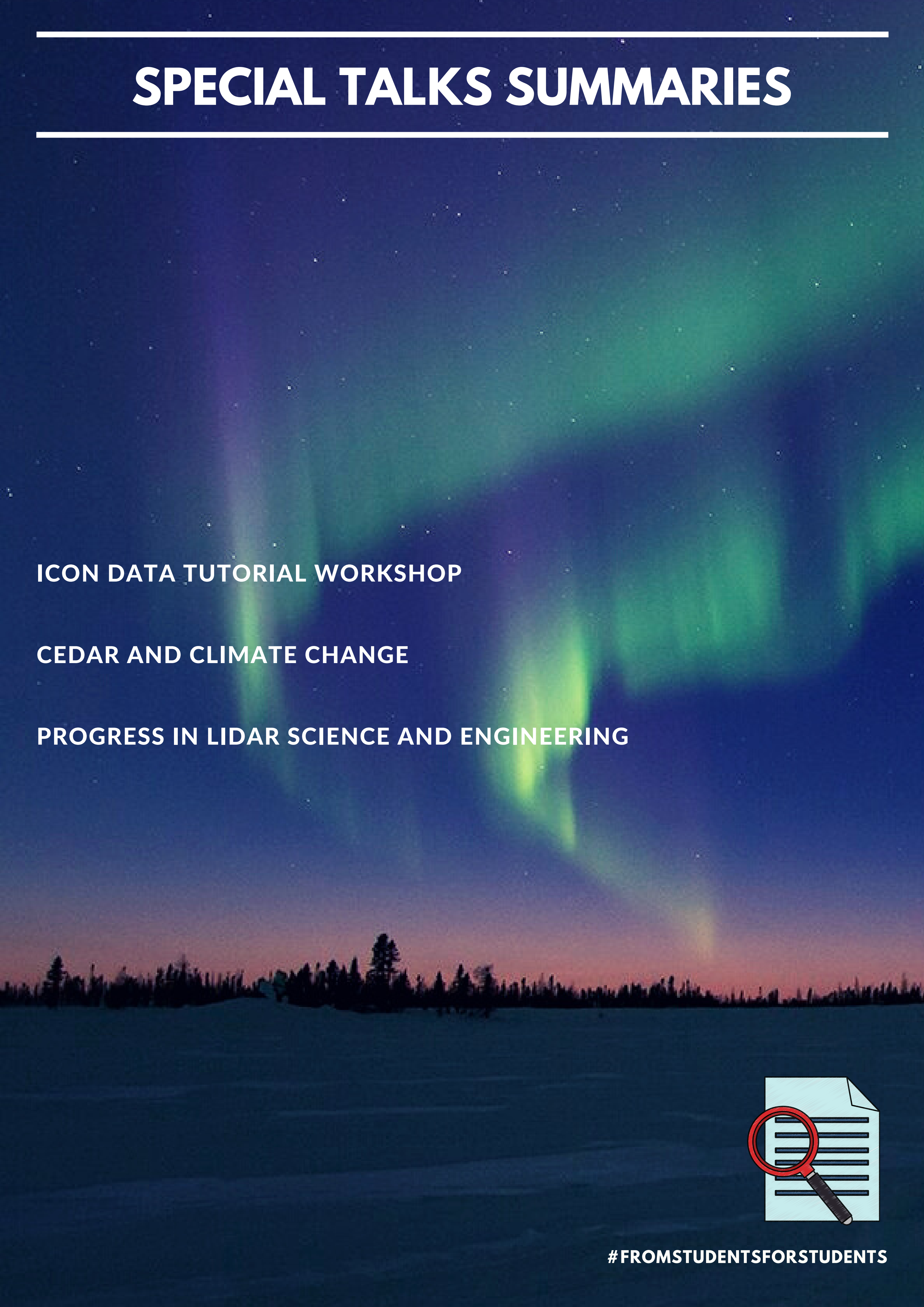


SPECIAL TALKS SUMMARIES

ICON DATA TUTORIAL WORKSHOP

CEDAR AND CLIMATE CHANGE

PROGRESS IN LIDAR SCIENCE AND ENGINEERING

#FROMSTUDENTSFORSTUDENTS

ICON DATA TUTORIAL WORKSHOP

Credits: NASA-ICON website

Summary written by

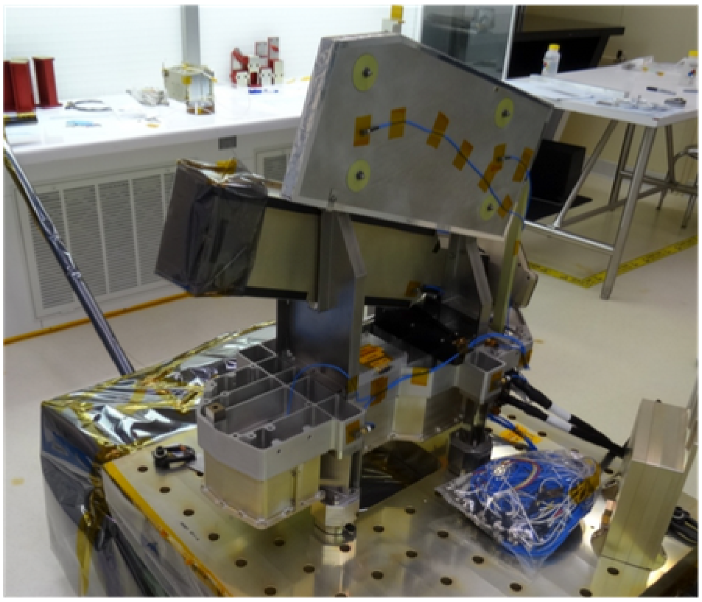
Gonzalo Cucho-Padin

In this workshop, the speakers provided useful information regarding the instruments, post-processing algorithms, and data products from the recently launched NASA's Ionospheric Connection Explorer (ICON) mission. The slides are available at:
http://cedarweb.vsp.ucar.edu/wiki/index.php/2020_Workshop:ICON_data_tutorial

Dr. Scott England (Virginia Polytechnic Institute and State University) introduces the instruments onboard ICON which include the Michelson Interferometer for Global High-resolution Thermospheric Imaging (MIGHTI) for wind and temperature measurements, the Extreme and Far Ultraviolet (EUV & FUV) spectrographs to determine thermospheric ionospheric composition and ion density, and the Ion Velocity Meter (IVM) to investigate both ion velocity and ion density. As stated by Dr. England, the ICON mission has been developed to primarily understand the dynamics in the magnetic equatorial thermospheric ionospheric region and, for this reason, its orbit covers the +/- 30 magnetic latitude range with a perigee of 575 km, and a revisiting period of 97 minutes. Current data products in netCDF format and daily cadence are publicly available on the main ICON website for research purposes.

Dr. Christoph Englert (Naval Research Laboratory Washington DC) provided a thorough explanation about the MIGHTI instrument. It aims to measure the bulk motion of the atmosphere, or winds, between ~90 to to 300 km by observing the red (630 nm) and green (557 nm) emissions from oxygen on the Earth's horizon (limb). The instrument comprises two identical sensors MIGHTI A and MIGHTI B, that look 90 degrees from each other. The sensors look 45 and 135 degrees from the spacecraft velocity direction, respectively, to get both the wind velocity and direction.

The Michelson interferometers are capable of determining the wavelength of incoming light by forming a fringe pattern. When the emitting source moves, the estimated wavelength varies based on the Doppler shift theory. A CCD camera identifies the small movements in the fringes to retrieve the wind profiles. Additionally, this camera detects the molecular oxygen A-band emission (~759-771 nm), whose shape is a function of temperature. A posterior analysis is conducted to retrieve the temperature of the observed target.



MIGHTI instrument. Credits: NASA-ICON website

Dr. Brian Harding (University of California Berkeley) explained the Level 2 wind data, which is obtained from the MIGHTI instrument. Both Zonal Wind (East-West) and Meridional Wind (North-South) are provided in two separate altitude ranges: ~150 to 300 km and ~90 to 200 km that were estimated using the oxygen red and green lines, respectively. During the day time, there is continuous coverage (~90 to 300km). There are data gaps during night time due to the absence of airglow at ~109 to ~210 km. For altitudes >210km, red emission is dimmer near the magnetic equator, especially after pre-reversal enhancement, penetration electric fields, or during ionospheric depletions.

Additionally, the acquisition is halted when the satellite passes through the South Atlantic Anomaly. Dr. Harding recommended the use of numerous quality flags available within the data to perform research.

Dr. Michael Stevens (U.S. Naval Research Laboratory) explained the retrieval of upper atmospheric temperatures using the MIGHTI observations of infrared emission for molecular oxygen O2 A-band (~759-771 nm). Three filter channels with center lines at ~760 nm, ~763 nm, and ~765 nm and bandwidth of ~2 nm were utilized to obtain this band's information. The ratio of the signal between filters determines temperature. Also, Dr. Stevens provided a comparison study between retrieved MIGHTI temperatures and MSIS at 95 km. A high correlation was shown with slight overestimation from MSIS. Dr. Stevens pointed out that MIGHTI has a 12 K systematic uncertainty due to uncertainty in filter center wavelengths and should be considered in research studies.

Dr. Robert Meier (George Mason University) described the ratio of thermospheric O/N2 that is obtained from the FUV instrument when measuring the Earth's disk. Dr. Meier highlighted the importance of this ratio as it is responsive to thermospheric dynamics as well as proportional to electron densities. Also, he indicated that ICON disk O/N2 data quality is excellent, O/N2 is typically lower than NRLMSIS by 20%, and there is excellent agreement with (Global UV imager) GUVI O/N2 at solar minimum conditions.

Dr. Farzad Kamalabadi (University of Illinois at Urbana-Champaign) described the inversion algorithm utilized to estimate electron density from nighttime UV emission at 135.6 nm. First, Dr. Kamalabadi showed the production mechanisms of oxygen line (135.6 nm) and presented an equation that relates the volume emissivity ratio (VER) of this emission with electron density, ion oxygen density, and atomic oxygen density. Second, Dr. Kamalabadi stated an inverse problem where the unknown is the source volume emissivity vector, which is estimated using the 135.6 nm measurements as well as the geometry of the acquisition (i.e., line of sight direction, satellite position, grid size among others). The resulting VER is then used with the above-mentioned equation to calculate the electron density.

> "The Ionospheric Connection Explorer will study the frontier of space: the dynamic zone high in our atmosphere where terrestrial weather from below meets space weather above."
>
> -NASA

Dr. Andrew Stephan (U.S. Naval Research Laboratory) described the usage of the EUV instrument. EUV radiation from the sun is absorbed by O atoms in the upper atmosphere at ~200km. This radiation ionizes atomic O atoms forming O+. Some of them are in an excited state and emit light at 61.7 nm and 83.4 nm wavelengths detected by ICON/EUV instrument. A comparison of these two emissions enables the measurement of the O+ density between 200km altitude and the spacecraft location. Dr. Stephan mentioned that the available data includes O+ density profiles vs. altitude, HmF2 and NmF2, geolocation data, and quality flags.

Dr. Russel Stoneback (University of Texas at Dallas) presented the Ion Velocity Meter (IVM) instrument and its data products. The IVM is comprised of two sensors Retarding Potential Analyzer and the Ion Drift Meter. Together the sensors provide major thermal plasma constituent densities, thermal plasma temperature, thermal plasma drift perpendicular, and parallel to the magnetic field. Instrument processing tools have been developed using open-source software, specifically the Python Satellite Data Analysis Toolkit (pysat). Data is available as a time series per day.

Finally, **Dr. Yen-Jung Joanner Wu** and **Dr. Colin Triplett** (University of California, Berkeley) provided an informative tutorial on working with ICON data products. They have developed a set of software packages in Python and IDL languages are publicly available.

CEDAR AND CLIMATE CHANGE

Credits: NASA-TIMED website

Summary written by

Aurora López Rubio

The emissions gap report of 2019 from the United Nations Environment programme (UNEP) says that we are on the brink of missing the global warming target of 1.5°C, with the consequence of serious climate change impacts. In this workshop this topic was discussed, as well as how the CEDAR science can contribute to addressing this problem.

Dr. John Emmert (U.S. Naval Research Laboratory) talked about how NRLMSIS ® 2.0 (US Naval Research Laboratory Mass Spectrometer and Incoherent Scatter Radar) is relevant to climate studies. NRLMSIS ® 2.0 is an empirical model that describes the average behavior of the atmosphere given some observations and physical constraints. The model helps to detect better climate changes, for example, it gives a distilled view of a historical record of observations and it can also be used for a baseline for attributing long term trends.

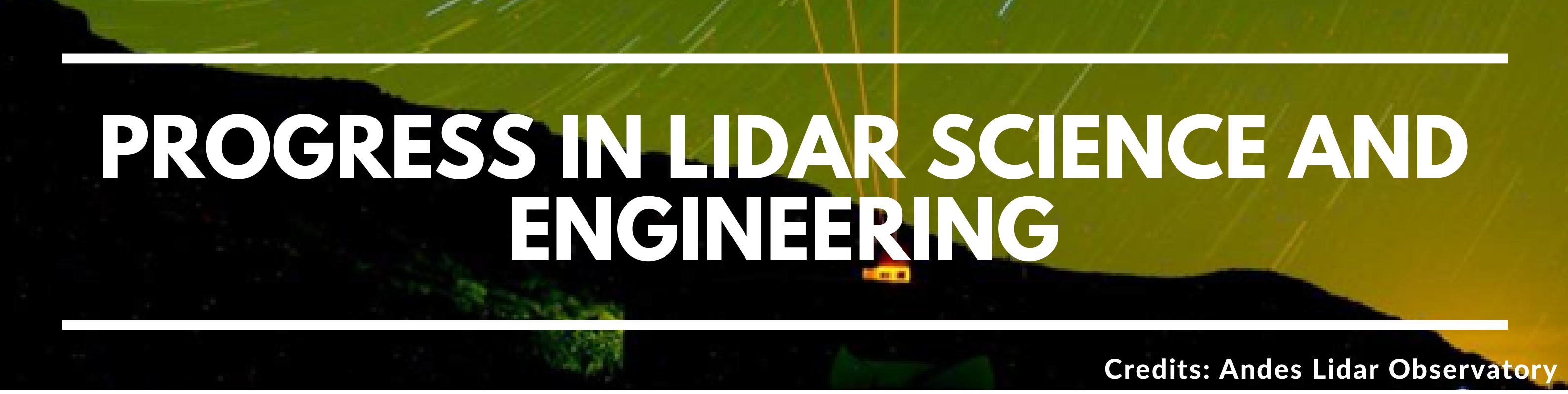
Then, **Dr. Martin Mlynczak** (NASA's Langley Research Center) gave an update on the Thermosphere Climate Index, that indicates the thermosphere response to solar activity. This index is a linear combination of the F10.7 solar index and the Ap geomagnetic index generated by looking at 15 years of data. As of the day of the workshop, the solar minimum of this cycle was reached, but we do not know yet the thermosphere temperature will decrease even more in the current cycle. But how is this index relevant to climate studies? The natural variability needs to be removed when looking at long term changes, and this index represents the natural variability of the solar cycle in the thermosphere.

Dr. Stan Solomon (National Center for Atmospheric Research) gave an overview of global climate changes simulations, specifically using the WACCM-X model. It describes how the thermosphere and middle atmosphere behave under idealized conditions, but it can be set up to include both lower, middle atmosphere and thermosphere-ionosphere interaction and a dependence on solar activity. It was shown that the upper atmosphere is indeed cooling, basically due to the increase in CO2. These types of simulations help us to understand the changes on the atmosphere and its drivers.

> "Every fraction of additional warming beyond 1.5°C will result in increasingly severe and expensive impacts."
>
> -UNEP

Dr. Hanli Liu (National Center for Atmospheric Research) described SIMA (System for Integrated Modeling of the Atmosphere). It is an effort to unify different atmosphere models: weather (e.g. WRF, MPAS), climate (e.g. CAM), chemistry (e.g. WRF-CHEM) and geospace (e.g.TIE-GCM/CMIT) models. SIMA aims to integrate all these different components to complement and extend all the existing applications. SIMA addresses the study of the climate change as it expands the reach and capabilities of the atmosphere modeling, like prediction capabilities.

Finally, **Dr. Jia Jia Yue** (Catholic University of America) continued talking about modeling using historical data. He mentioned that to study a trend, especially in the 20th century, it must be considered the ozone cooling during the end of this century, that changes the dynamic of the atmosphere. He showed how the temperature has changed on the last 30 years combining two satellite data and how the trends can be quantified more accurately, and how this helps to understand better the climate study.



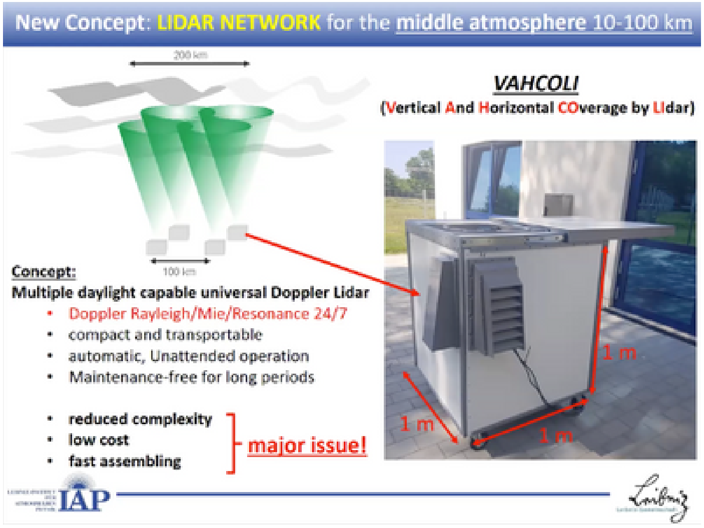
PROGRESS IN LIDAR SCIENCE AND ENGINEERING

Credits: Andes Lidar Observatory

Summary written by
Arunima Prakash and Fan Yang

The first talk of the session was given by **Dr. Josef Höffner** (Leibniz-Institut Fur Atmospharen Physik) on VAHCOLI: A network for the middle atmosphere of general-purpose Doppler Rayleigh/Mie/Resonance Lidar. He introduced the idea of having a network of general Lidars. The first approach towards a better system started with Na lidar and the systems evolved over time to incorporate Alexandrite lasers efficient enough for taking temperature measurements. The next big step is a network of Lidar utilizing a multiple daylight capable universal Doppler Lidar. The features of this system are that it is an autonomous maintenance free system which is small enough to be easily transported. With low cost and fast assembly with reduced complexity, these lidars can be deployed at various locations to get simultaneous wind and temperature measurements. The housing, telescope and the optical system was 3D printed, assembled and developed at IAP. A Diode pumped Alexandrite ring laser was used. The system is sealed and does not require water cooling, making it more efficient and compact for transport. Rayleigh, Doppler Me, Doppler Resonance, all were demonstrated for Potassium measurements using the above system. The next step for the team is to generate power equivalent to that of the flash lamp pumped ring laser, to move on to enhancing to double pump power in future.

Dr. Bernd Kaifler (German Aerospace Center) spoke next on the airborne lidar project ALIMA: measuring temperature and wind in the middle atmosphere from an aircraft. The aircraft was deployed to Rio Grande – covering several mountain ranges, the Southern Ocean and the Antarctic Peninsula, with the main objective to observe gravity waves. The need to use airborne lidar for detecting gravity waves is due to the lack of spatial resolution available in ground-based setup. Multi beam lidar systems and networks offer sparse horizontal sampling and often offer aliasing problems. Taking a flight run as an example, it was observed that once you cross the Antarctic Peninsula, highly perturbed thermal structures were seen. On decomposing, the wave field 4 different wave modes were observed. These were found to be small horizontal scale wave carrying most of the gravity wave momentum – small scale waves are not resolved by ground-based instruments. The team designed an airborne lidar system capable of resolving most of the gravity wave spectrum – ALIMA. It consists of a high spectral resolution temperature and Doppler wind lidar (operating at 532nm), a Fe fluorescence temperature and wind lidar (operating at 372nm) as well as 1.5m broadband OH airglow imager. Two fibers are used for each channel to allow reconfiguration depending on nighttime or daytime measurements.



New Concept: LIDAR NETWORK for the middle atmosphere 10-100 km

VAHCOLI
(Vertical And Horizontal COverage by LIdar)

Concept:
Multiple daylight capable universal Doppler Lidar
- Doppler Rayleigh/Mie/Resonance 24/7
- compact and transportable
- automatic, Unattended operation
- Maintenance-free for long periods

- reduced complexity
- low cost
- fast assembling

major issue!

The next talk was by **Fan Yang** (Embry-Riddle Aeronautical University) on Relationship between Turbulence and Atmospheric Stabilities Revealed by Na Lidar Measurements at Andes Lidar Observatory. Turbulence in the atmosphere are due to wind shear caused by gravity waves and convective and dynamic instabilities in the atmosphere.

These disturbances play an important role in diffusion of mass, energy and momentum in the MLT region. The turbulent scale fluctuation is derived by SPM invented by Gardner and Liu 2014. A method invented by Gardner and Liu were used to eliminate photon noise biases in computing second order statistics of Lidar measurements, which is also been used by Dr.Chu's group. The turbulence in the atmosphere can be evaluated by studying turbulence heat flux. They found that convectively unstable regions had a significantly larger turbulence heat flux than the averaged heat flux. The turbulence heat flux in this region also cools the atmosphere above 92km and below 87km. The turbulence in the dynamically unstable region was less than that of the convectively unstable region.

Na Doppler and Fe Boltzmann lidars running at Arrival Heights under Antarctic skies in June 2019. Credits: Danny Hampton, Ian Geraghty, and Zimu Li

Next in line was **Dr. Xinzhao Chu** (University of Colorado Boulder), who spoke about exploring the Antarctic atmosphere and space with simultaneous Na and Fe Lidar measurements of 10 years. The team installed two Lidars in Arrival Heights Lidar Observatory at Antarctica – Fe Boltzmann Lidar in 2010 and Na Doppler Lidar in 2018. The four major features studied by the group are – Composition of Fe, Na, PMC, PSC and smoke, thermal structure, dynamics of various waves, fluxes and variances as well as chemistry of metals including neutral and ion chemistry. The group observed QBO signals in the stratospheric gravity wave EPM at Antarctica. Dr. Chu, then talked about a technique; an interleaved method to eliminate photon noise biases in computing second order statistics of Lidar temperature, wind and species measurements. Next she spoke about the results of the high resolution of Na Lidar data, which lead to Lidar observations of vertical wind and SSW (Sudden stratospheric warming) in Antarctica. They found that the mean vertical winds show consistent patterns with the residual circulations but much larger magnitudes.

> "Total heat transport in the unstable region was found to be much smaller than the total heat transport."
>
> -Yang.

> "Earth's space and atmosphere is a strongly coupled system undergoing complex processes and interacting with the Sun, cosmic dust with various origins."
>
> - Dr.Chu

Diego Janches and his colleague, Tony Yu, are advancing the world's first spaceborne sodium lidar for mesospheric studies. Credits: NASA- Goddard

From NASA we had **Dr. D. Janches** (NASA/GSFC), who spoke about the progress made on Na lidar technology at the GSFC for space applications. He introduced the ACaDAMe project that is proposed to deploy from ISS. It uses the Sum frequency generation technology in order to generate high power for small scale dynamics.

Next he introduced the B-SoLiTARe project which would be deployed on a balloon. It is a low cost project utilizing Self Raman technology – Raman Crystal resonator using a Nd:YVO4 laser. The balloon would fly from Matt Boudreau, measuring tides around the Antarctic region. Since the balloon is slower than ISS, the resolution here is higher and the integration time is longer that can be met with lower power requirements as well.

Dr. Titus Yuan (Utah State University) talked about long lasting large vertical wind perturbations near turbopause and its relation to Na layer extension into thermosphere. His team updated USU Na lidar with 4 1.25m diameter mirrors. The mirrors were originally used as the receiver for USU Rayleigh Lidar. They extended the Na lidar observation range to lower thermosphere (120 km). The utilization of large mirror also increased the SNR for temperature and wind measurement in mesopause. The team also measured the Na density. The Na density is highly correlated with plasma density from VIPIR ionosonde. The vertical wind perturbations in lower thermosphere are larger than those in the upper mesosphere and show no wave features. More work needed to reduce the background noise in measurements in the lower thermosphere.

Dr. Tao Li (University of Science and Technology of China) reported 8 years observations of mesopause region by Na lidar over Hefei, China. They used 3 frequencies in their Lidar system. They have three 1m diameter telescopes directing toward zenith, 15 degree off zenith toward east and west. These telescopes ensure the USTC Lidar system capable to measuring the momentum flux. This system is located in the city, so the city light introduced many noise to the system, which makes their resolution limited to 2km and 5min. His team compared the USTC sodium lidar observation result with WACCM simulation and satellite observation. They found heat flux is mostly downward with maximum mean value of 0.4K m/s mostly induced by short-period GWs and sodium flux is downward mostly induced by long-period waves. The zonal momentum flux is westward and anti-correlated with zonal wind in fall and winter.

> "Hourly vertical wind measurements demonstrate long lasting perturbations near and above turbopause"
>
> -Dr. Yuan.

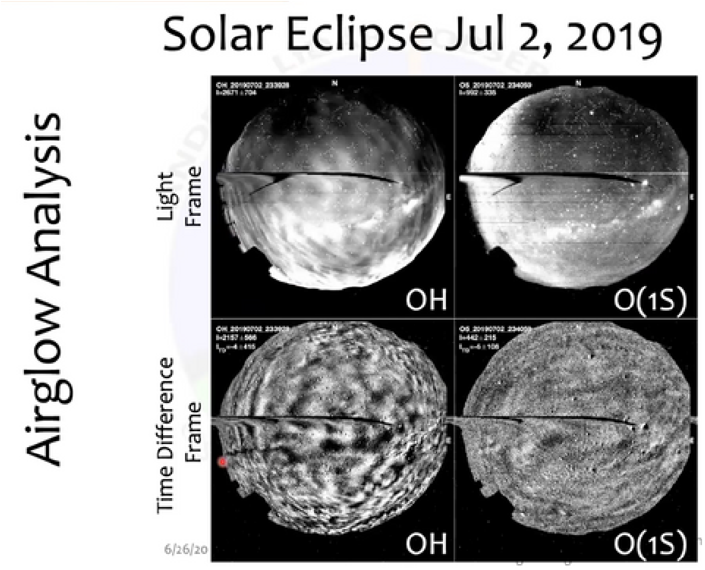
> "Ca+ is the only ion can be observed from ground, so it’s a proxy for all metal ions."
>
> - Dr.Raizada

Dr. Bifford P. Williams (GATS and University of Alaska Fairbanks) presented recent progress with the sodium resonance wind-temperature lidar, Rayleigh lidar, and meteor radar at Poker Flat Research Range (PFRR). The PFRR ground based instrumentation includes Poker Flat Meteor Wind Radar, Poker Flat Incoherent Scatter Radar, Digisonde, All-sky Imagers, Spectrogragh, Poker Flat Scanning Doppler Interferometer, Poker Flat Metal Resonance Density Lidar, Poker Flat Rayleigh Density Temperature Lidar, Na Resonance Wind Temperature Lidar, Volume Imaging Na Lidar and rocket launch pad. In 2017, the team replace some frequency seed for Na Lidar. Their team focused their campaigns on PMC’s and SSW’s elements unique to polar sites. SRWTL can resolve full GW spectrum with new telescope. Continues zenith and horizontal measurements are available because the team split the beam into 2 or 3 beams with separate receivers. Meteor radar plus day/night SRWTL capability allows them to measure long-period waves.

Dr. Shikha Raizada (University of Central Florida) talked about significance of Calcium ion observations using resonance Lidar at Arecibo. Ca+ is the only ion can be observed from ground, so it’s a proxy for all metal ions. In 2015, the team upgrade their receiver system by installing a new high quantum efficiency PMT. The presentation includes 3 night observation about Ca+, neutral particle distributions and electron column abundances. Metal Ions (Ca+) in F-region were observed only during pre-dawn hours and were not present during pre-midnight. Neutral metals were not present at thermospheric altitude in these observation. They suggested that neutral winds were conducive for DLs generation. And Ca+ above 150km were observed during the presenting of strong downward drifting suggesting the role of electronic field.

Dr. Fabio Vargas (University of Illinois at Urbana-Champaign) reported result of solar eclipse effects in measurements near the Andes Lidar Observatory (ALO) on July 02, 2019. The totality path is right above ALO. A month before this event, the team updated ALO Lidar system by installing a daytime filter, so Lidar can work not just at night. They presented many results from different instruments. One week before the eclipse, the team finished installing a new meteor Radar.

The meteor Radar observed the horizontal wind change due to the eclipse. Ionosonde from their collaborator at the University of La Serena observed F layer density enhances prior the event. Airglow imager shows the airglow layers perturbation (see figure below). Lidar observed the cooling of the mesopause region after sunset. Meteor radar observed the zonal wind decreases in amplitude. Ionosonde showed some shift of the E and F layers peak to higher altitudes. GPS data need more analysis.



Airglow evolution during Solar Elipse on July 2th, 2019. Credits: Fabio Vargas

The complete session recording can be found at: https://alaska.zoom.us/rec/share/1PdEAeng_GBLbafy4UHgeqccHLnIT6a81CRP_vAOyh3VVn7OzNv6pLxw0L11c8Ga

QUESTIONS AND ANSWERS

HIGH LATITUDE AND POLAR PROCESSES

INTRODUCTION TO GRAVITY WAVES

ATMOSPHERIC TIDES, PLANETARY WAVES, AND VERTICAL COUPLING

LIVING WITH A STAR IN THE AGE OF DATA SCIENCE: TOOLS, TECHNOLOGIES AND MINDSETS FOR THE MODERN SPACE ENVIRONMENT

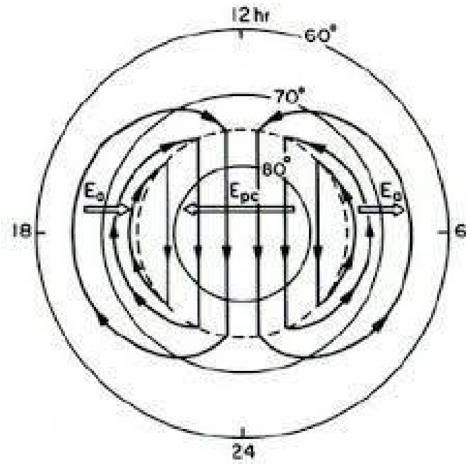
THE IONOSPHERIC CONNECTION EXPLORER: MISSION AND FIRST DATA

USEFUL LINKS

#FROMSTUDENTSFORSTUDENTS

HIGH LATITUDE AND POLAR PROCESSES

by Dr. Stephen Kaeppler



I wish to thank the students for some very insightful questions!

1. Is the thermosphere strictly the neutrals in the atmosphere?

Yes. The neutrals are the thermosphere, and the plasma/ionized portion of the earth's upper atmosphere is the ionosphere.

2. Does the thermosphere span the same 'height' as the ionosphere?

For all intents and purposes yes. However, it is important to consider that the neutral atmosphere is extended out into space and that region is called the exosphere. The ionized portion starts to merge into the magnetosphere. Typically, the ionosphere/thermosphere is below 1000 km altitude.

3. Do convection patterns set up electric fields, or do electric fields set up convection patterns? What is the most causal explanation?

This is an interesting question and it depends on your perspective. I would encourage the student to read Section 2.6 out of Kelley 2009 textbook (*The Earth's Ionosphere: Plasma Physics and Electrodynamics*) and also to read the following: https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/2001GL013014

The short answer to the question is that, at least at high latitudes when discussing the convection pattern, the electric fields are caused by the Earth's magnetic flux tubes being moved due to the solar wind. However, in the ionosphere, the electric field generation can become more complicated (as noted by Kelley) where you can have dynamo effects in which the neutral wind actually generates the electric field.

Consider the diagram. First, if we agree/assume that flux tubes are moved across the polar cap from the dayside to the nightside, as the result of the solar wind, then an electric field in the polar cap, Epc, is set up due to $E = - V \times B$, where B points downward in the northern hemisphere. We also need to consider that electric fields diverge (converge) from positive (negative) charge, in which the electric field connects from a positive charge to a negative charge. Technically, it is a positive to negative potential drop across the polar cap, but we can think of these as static charges for simplicity. As a result of this over the cap electric field being set up, we can see that the dawn (dusk) cell corresponds to the positive (negative) charge. This means that we expect electric fields to be divergent (convergent) on the dawn (dusk) sector. The resulting electric fields due to this charge/potential set up electric fields which support the convection that is observed in the two cell "Dungey" cycle. You can see two of these electric fields, as E0, but keep in mind that those electric fields are not constrained simply to that magnetic latitude and local time. The electric field pattern also explains why flux tubes that move to the nightside/midnight sector get transported back to the dayside, moving westward (eastward) on the dusk (dawn) side.

4. Why are there two convection patterns?

I assume you mean "why is there a two cell convection pattern?" Please see the response to question #3.

5. **What is the causality? What physically is driving which electric field? They can cause each other, but what direction is the energy transferred?**

See the above response to question #3.

6. Can speaker talk about transition from stage 8 to stage 9 in details for magnetic field lines?

See the above response to question #3.

7. How do we differentiate between a diffuse aurora and airglow in auroral regions?

Airglow and diffuse aurora can produce deexcitation of oxygen which causes 557.7 nm emission. Airglow typically peaks at an altitude of 90 km, while diffuse aurora may have a much larger altitude extent. If we flew a particle detector through diffuse aurora, we would see that the energy spectrum looks completely different than airglow because diffuse aurora is the ‘rain’ caused by energetic particles being scattered into the loss cone in the geomagnetic equator of the magnetosphere. These particles typically have energies of the order of a few keV. Airglow can also occur at all latitudes, while diffuse aurora is restricted to high latitudes (except in unusually strong events).

8. Is there more or less Auroral activity during solar minimum (higher GCR). Can/have these patterns be seen in induced magnetosphere for other planets (e.g. Mars)?

In general, solar minimum does have less auroral activity, but that does not mean it ceases or that you cannot have an isolated solar storm. You will still have nightly aurora and substorms, at say Poker Flat, Alaska. I am unsure what the current state of the art is on other planets. I am also not sure what GCR means.

9. When you mention diffused and discreet auroras, can you give a brief description of auroral arcs? How can they be differentiated/ classified?

Arcs are typically described as sheets, rays, curtains or aurora that have an overall form. Diffuse aurora is usually more of an unstructured glow in the sky. Some of these morphological features are discussed in Kivelsen and Russells *Introduction to Space Physics* textbook. In general, discrete aurora is what you probably typically think of as aurora, the beautiful dancing structures across the sky. I recommend you watch some auroral videos on youtube.

10. What is the meaning of Joule dissipation in different frames of reference?

That is an excellent question. Again, I would refer to section 2.6 in Kelley, 2009. Additionally, please see the following papers:
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2004JA010615
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JA017302
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2011JA017302 (Appendix 1)

I will add that typically Joule dissipation is calculated in the frame of the atmospheric neutrals. Appendix 1 of Thayer and Semeter provide a justification as to why that is the case.

11. Can we have a global diffuse aurora on Earth?

In some cases, yes, I believe so.

12. Can polar wind and ion outflow cause long-term escape of ionosphere?

Yes. That is one of the reasons why it is an interesting and relevant topic to study.

13. How is the incoming energy from the magnetosphere to the polar cap distributed to the entire global system, let say to lower latitudes?

Typically, energy that is deposited in the polar regions can propagate to lower latitudes through gravity waves, and in particular, large scale traveling ionospheric disturbances. These are generated by heating caused by auroral processes. This is by no means the only process. In fact, a large part of CEDAR seeks to understand these connections.

. What are some current constellations or projects to collect data from for this research?

I do not know to what degree tidal w’ it affects the plasma drift. I have not seen any papers about this. The E x B effect (driven by tidal horizontal wind) is much more significant.

INTRODUCTION TO GRAVITY WAVES

by Dr. Christopher Heale

1. What distinguishes a gravity wave from a planetary wave?

The primary difference are the scales, forcing mechanisms, and restoring forces. Typically gravity waves have horizontal scales between 10-1000 km and min to a few hour periods, with gravity/buoyancy as the restoring forces. Planetary Waves have much larger scales (fractions of the planetary circumference) and much longer periods (fractions of days) and are heavily influenced by the Coriolis force, due to their long period. This is less of a concern for gravity waves (although it does influence longer period waves).

2. Would an N^2 < 0 or locally unstable case cause a Rayleigh-Taylor instability as opposed to a propagated gravity wave?

Yes, if N^2 is negative, the atmosphere is locally unstable and a convective instability forms.

3. If gravity waves are locally spaced, then how do we take global gravity wave observations?

The most common way to do this is through satellite observations. However, it is difficult to understand how a wave evolves in time from these observations as the current satellites that measure gravity waves typically only observe a given location twice a day.

4. At what altitude, gravity waves affect the upper atmosphere dynamics directly and indirectly?

They can influence the atmosphere at all altitudes from the troposphere to the thermosphere. The distribution of the energy and momentum deposition is still far from completely understood, but it is known that gravity waves dominate in the Mesosphere and Lower Thermosphere region.

5. What are the current challenges on the study of GWs in the mesosphere-thermosphere?

The current challenge is to be able to understand the global distribution of gravity waves, their spectral characteristics, evolution, and energy and momentum deposition. The limitation occurs because these waves are 'deeply propagating' and so instruments need to measure the whole depth of the atmosphere to fully quantify them. No single instrument can do this and so a suite of instruments are needed in order to fully capture the gravity wave lifecycle.

6. Could you provide any source for generating gravity waves from latent heat?

The most common sources of gravity wave generation by latent heat release are from precipitation in convective systems, such as thunderstorms etc.

7. If we are to simulate gravity waves in high-resolution GCMs, is increasing the horizontal resolution more essential or vertical?

At this stage, I believe that increasing the horizontal resolution would be more essential. This is because many physical processes are not resolved at all at the current horizontal resolution and this is why parameterizations are required. Increasing the horizontal resolution would decrease the dependence upon these parameterizations and their simplified physics.

8. What is the overall energy deposition into the upper atmosphere by gravity waves?

This is still, very much, an open question and will require significant measurement and modeling campaigns to ascertain.

9. How the energy momentum is affected when the wave is ducted within the mean flow velocity?

Linear theory suggests that because a wave is trapped, the upward and downward waves contribute equal and opposite energy and momentum so there is no net effect. However, in reality, waves are never perfectly ducted and leakage and tunneling can occur. So a gravity wave can deposit its energy and momentum far from the source region through this mechanism.

10. In the mesosphere, GWs are one of the main sources of Kelvin-Helmholtz instability. Where does that stand on the "death of a GW"? (critical or breaking)?

Kelvin-Helmholtz instabilities are considered a wave breaking mechanism.

11. What's the main mechanism that keeps GWs from penetrating the E- and F-regions?

Gravity Waves can penetrate into the E and F regions, but they are heavily damped by viscosity in this region (which increases exponentially with altitude). Gravity waves which reach these heights have large phase speeds and vertical wavelengths as viscosity acts more strongly on smaller vertical scales.

12. Does it mean gravity waves more than 300 km wavelength can't be generated in the tropospheric convection?

Convection can generate large scale waves (>300 km). The scales generated are dependent upon the scales of forcing and heating present within a convective system. This ranges from the size of an individual plume, to the scale of the whole storm system, which can be very large.

13. How to differentiate between large wave like structures and acoustic waves like in observational data?

Distinguishing between acoustic and gravity waves comes down to the speed of the wave. Acoustic waves have much shorter periods and travel much faster than gravity waves.

ATMOSPHERIC TIDES, PLANETARY WAVES AND VERTICAL COUPLING

by Dr. Ruth Lieberman

1. How does the low E-region shears relate to the upward propagation of tides and pws?

a. Tidal winds filter the transmission of GWS. See reply to question 6.
b. GWs help to shape the background winds, which can affect the Doppler-shifted tidal frequency. The tides propagate vertically more efficiently where their Doppler-shifted frequency is higher than the Coriolis frequency.

2. Semidiurnal "mode" or" component"? Can you expand on the nomenclature of tidal oscillations?

“Harmonic” or “component” would be the most suitable term. These refer to the period of the oscillation. “Mode” refers to the latitudinal structure.

3. What's the importance of the tides in the E and F region dynamics? ie., if were to remove the tides, how big of an effect in the dynamics in percent?

Many studies report longitudinal variations of ~40% associated with the eastward-propagating wavenumber 3 tide.

4. Very nice to hear from Dr. Ruth and very nice talk with potential topic. Are the tidal sources different in temperature and wind fields?

For all the models I am familiar with, no.

5. Does the vertical neutral motion caused by the tides around the equator interact with the fountain effect in the ionosphere?

I do not know to what degree tidal w’ it affects the plasma drift. I have not seen any papers about this. The E x B effect (driven by tidal horizontal wind) is much more significant.

6. Does the tide play any role in Gravity wave dynamics in middle atmosphere?

Yes. Because of the long zonal wavelengths the tides appear to the GWs as part of the background wind. This results in a diurnal cycle GW filtering. The filtered GWs deposit their momentum below the levels at which their phase speeds equal the tidal wind speeds. The result is a downward progression of the tide.

7. How strong are tides in the high latitude winter? How do tides get modulated by auroral activity?

At 95 km, the SAAMER radar (53.8°S, 57.8°W) has measured semidiurnal tides between 30-40 m s-1 in zonal wind, and 40-60 m s-1 in the meridional wind. Very similar values reported for meridional wind in January at Trondheim (63°N). The diurnal tides at SAAMER are 15 m s-1 in zonal wind, and about 10 m s-1 in meridional wind.

A good overview of theoretical tidal responses to geomagnetic activity is provided by Fesen (1997): Geomagnetic activity effects on thermospheric tides: a compendium of theoretical predictions, JASTP, 59, 785-803.

8. You mentioned 2- and 5 day waves are "free" modes of the upper atmosphere. What is a "free" oscillation, and why are 2 and 5 days special? Why not 3, 4, 6?

These are the natural frequencies that a frictionless atmosphere (with no background wind) “rings” at, without any external forcing. For zonal wavenumber one, free oscillations occur at 5, 10, and 16 days. For wavenumber 2, a free oscillation is reported at 4 days. A free oscillation of wavenumber 3 occurs at 2.1 days. In the presence of background winds, the longer periods can be altered. For example, the 5-day wave shifts to 6.5 days in a realistic background wind.

9. Could you throw more light on the sources of these atmospheric tides (Lunar, migrating, and non migrating).

The main sources are thermal, e.g., solar heating. There is also gravitational forcing of the atmosphere by the moon, that generates a lunar tide, but it is about an order of magnitude weaker than the solar tides. Migrating tides refer to tides whose amplitude and phase are uniform in longitude with respect to local time: this means that the hour of maximum of the tide is the same in local time at all longitudes. The main source of the migrating tide is solar heating, which has a very strong longitudinally uniform component in local time. One of my figures showed that this heating maximized almost everywhere at 12:00 noon. Nonmigrating tides have amplitudes and phases that are variable in local time. Their sources are longitudinally variable heating. I showed how the diurnal harmonic of latent heat release was strongly variable in longitude: It was strong over continents (where it maximized near local noon), and weak over the oceans (where it maximized after midnight).

10. I am currently looking at the methods of deriving atmospheric tides from meridional neutral winds. Which of these methods would recommend (Fourier transform and least square fit)?

For equispaced sampling I would recommend Fourier methods, otherwise, LSF methods.

11. What are the distinct differences between gravity wave and atmospheric tide at the midlatitude?

To be a GW, the wave must have a period that is shorter than the Coriolis period. The Coriolis period varies in latitude, from infinity at the equator to 12 hours at the pole. At 30° the Coriolis period is 24 hours. At 45° the Coriolis period is about 17 hours. If the wave has a period that is much shorter than the Coriolis period (like, under an hour) then it is probably close to a pure gravity wave, dominated by buoyancy and pressure gradient forces. If its period increases to several hours, and is getting close to the Coriolis period (also known as the inertial period), the waves are technically called “inertia-gravity” waves. Their dynamics are influenced by the Coriolis force, as well as the pressure and buoyancy forces.

LIVING WITH A STAR IN THE AGE OF DATA SCIENCE: TOOLS, TECHNOLOGY, AND MINDSETS FOR THE MODERN SPACE ENVIRONMENT

by Dr. Ryan McGranaghan

1. What role will feature engineering play in data science as the volume and complexity of data grows?

Feature engineering is extremely important. One of the central questions facing our (and all science) communities is the information content of our data. Feature engineering is the process of determining those data with the most rich information content and then to utilize those data more effectively. This is a process that resonates across all of CEDAR.

2. How do you decide the most suitable tool to use among so many available ones especially in machine learning aspect?

Experimentation and tools that facilitate quickly trying out new ideas and receiving clear feedback on those ideas is critical. Additionally, how do we more effectively transfer that knowledge to others to build on each other's work rather than reinventing it.

3. Can we download data from Helioviewer.org?

Yes! Please explore all of the functionality at the website and think about how this powerful example might be a guide for CEDAR.

4.How likely do you think that forecasting using machine learning will be automatic? Since models generated are normally applicable to very specific conditions.

We need to think about models that are more fluidly improved (e.g., continual ML training, adaptive models). Generalizability is an open topic in the ML community, so each of you will be the people to answer this question!

THE IONOSPHERIC CONNECTION EXPLORER: MISSION AND FIRST DATA

by Dr. Scott England

1. Several talks today have used the term "electric field mapping". Can you elaborate on what this is? Is it an approximation?

What is the 'theoretical basis' of equipotential magnetic field lines? How is it connected to electric field mapping? Will you please explain its origin? [6:37:22] The theoretical basis is that the conductivity parallel to the magnetic field line is high. The assumption is that it's quasi-infinite.

2. Are data from ICON free to access online?

Yes, go to icon.ssl.berkeley.edu/data

3. What are these summary data?

These Level 3 data have not yet been produced, but it's intended that these will be climatological averages, monthly averages etc.

4. Does ICON provide any sort of data regarding the irregularities in the ionosphere that could be used for scintillation studies?

Yes. These are clearly visible in situ in the IVM densities and drifts. The FUV nighttime O+ also reveals them as a reduction in O+.

5. How is the disk O/N2 retrieved? Could you elaborate further?

This comes from the ratio of Far UV airglow associated with these 2 species, both of which are excited by photoelectron impacts in the middle thermosphere. Details are here: Stephan, A.W., Meier, R.R., England, S.L., Mende, S.B., Frey, H.U. and Immel, T.J., 2018. Daytime O/N2 Retrieval Algorithm for the Ionospheric Connection Explorer (ICON). Space Science Reviews, 214:42 (17pp.). Public access. DOI: 10.1007/s11214-018-0477-6

6. Why are there such large gaps in Zonal Wind data?

There are gaps when the spacecraft is in the South Atlantic Anomaly. A future release of the data will reduce these gaps, but there will always be data outages associated with the SAA, as for most LEO missions.

7. Are the ICON and SABER temperatures compared at around the mesopause region? If so, what is the accuracy?

Yes, conjunctions are seen. At some altitudes the agreement is extremely good, but the SABER data do not cover all the altitudes of the ICON data.

8. Can the ICON provide information concerning vertical drift velocities of the plasma?

Yes, this is the primary data product of the IVM instrument.

9. Can the ICON system measure both night and daytime thermospheric winds continuously?

ICON can measure thermospheric winds during both day and night, but there are differences. In the day, winds are available form 90 - 300 km. There are gaps when the spacecraft is in the SAA, and at the terminators, when there are sharp gradients in the airglow. At night, winds are available from 90-105 km, and in the 200 - 300 km range. The higher altitude data have some outages in the pre-dawn region where no airglow is seen during current solar conditions.

USEFUL LINKS

CEDAR 2020 student day recorded talks link:
https://www.youtube.com/watch?v=roRStwDhTkQ

Virtual CEDAR bookshelf (courtsey Dr. Delores Knipp)
https://doi.org/10.5281/zenodo.3974613)
http://cedarweb.vsp.ucar.edu/wiki/images/f/f1/2020CEDAR_Knipp_Book_shelf_titles.pdf

CEDARWiki:
cedarweb.vsp.ucar.edu

2020 Workshop: presentations - CEDARWiki:
http://cedarweb.vsp.ucar.edu/wiki/index.php/2020_Workshop:presentations

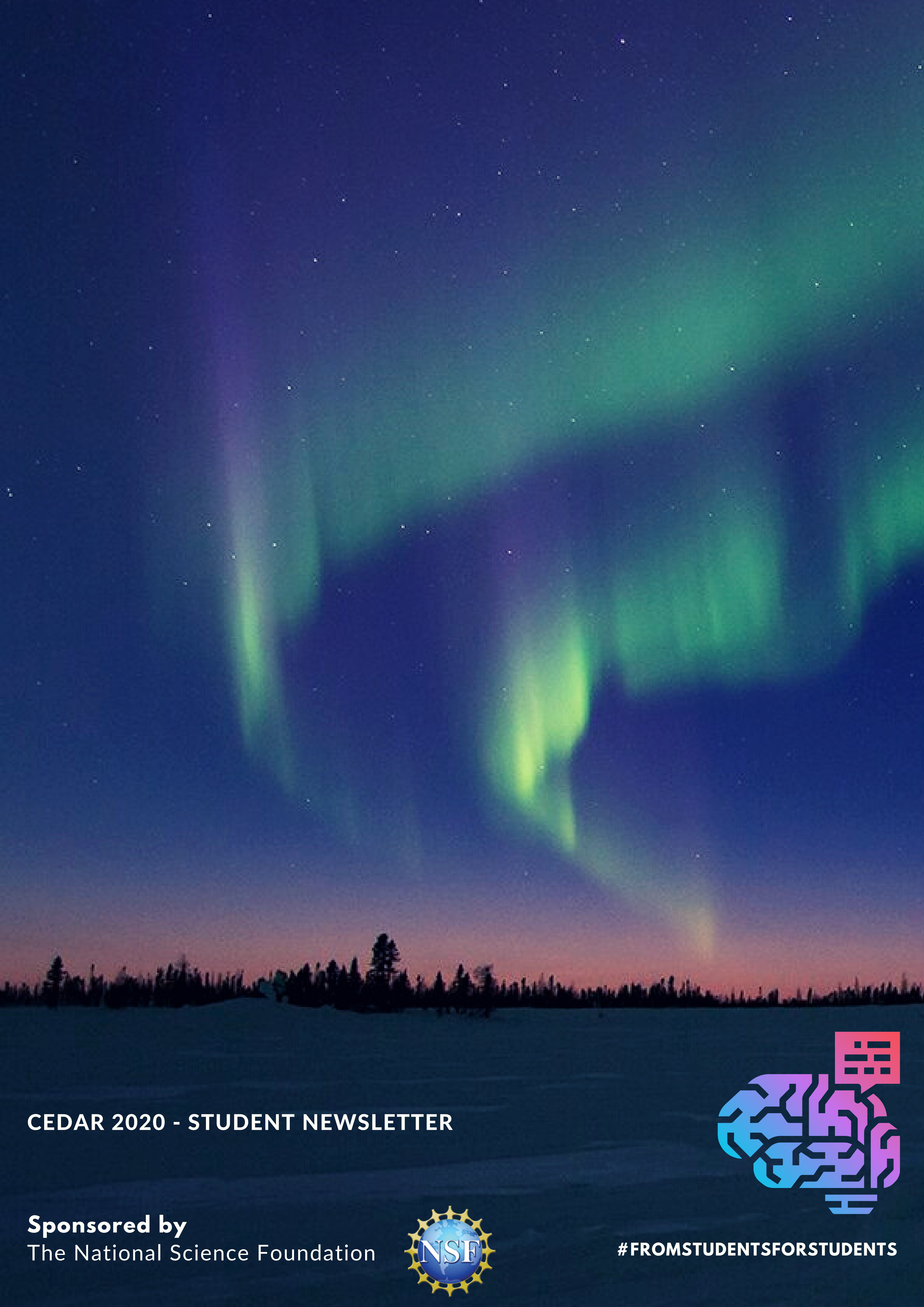
Main ICON website:
https://icon.ssl.berkeley.edu/

Python products to handle ICON data:
https://github.com/YJWu-SSL/ICON_Data_Demo.

UNEP 2019 emissions gap report:
https://www.unenvironment.org/interactive/emissionsgapreport/2019/

CEDAR Workshop 2020: Progress in Lidar Science and Engineering

https://alaska.zoom.us/rec/share/1PdEAeng_GBLbafy4UHgeqccHLnIT6a81CRP_vAOyh3VVn7OzNv6pLxw0L11c8Ga



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