COE CST Fourth Annual Technical Meeting:

Mitigating threats through space environment modeling/prediction

PI: Tim Fuller-Rowell
Student: Catalin Negrea

University of Colorado
Boulder

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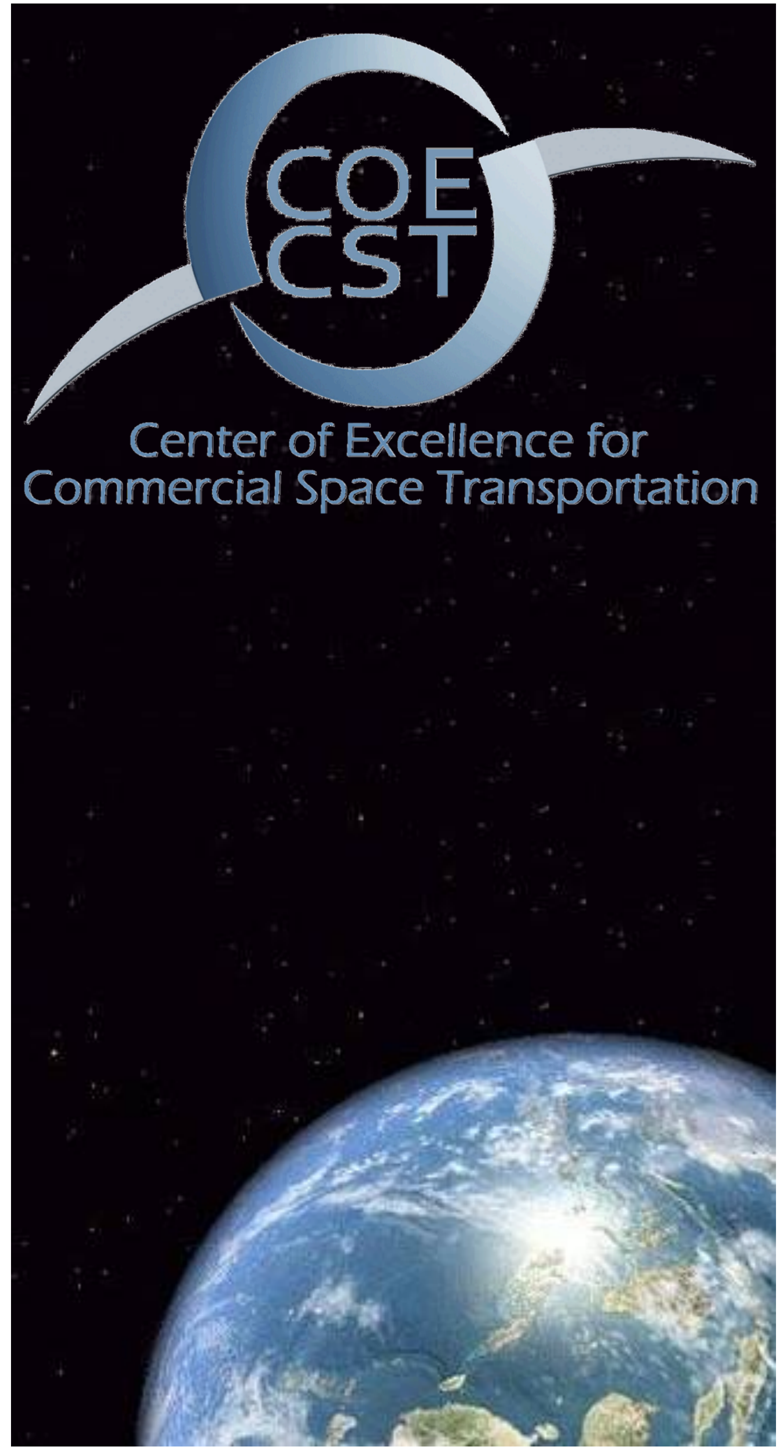
Washington, DC



Overview

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Team Members

Tim Fuller-Rowell, Tomoko Matsuo, Houjun Wang, Tzu-Wei Fang

Cooperative Institute for Research in Environmental Sciences (CIRES)

University of Colorado, Boulder and NOAA Space Weather Prediction Center

Catalin Negrea

Student, Electrical, Computer, and Energy Engineering, University of Colorado

Mihail Codrescu, Rodney Viereck, Mark Iredell

NOAA Space Weather Prediction Center, Boulder, CO

and Environmental Modeling Center, Camp Springs, MD

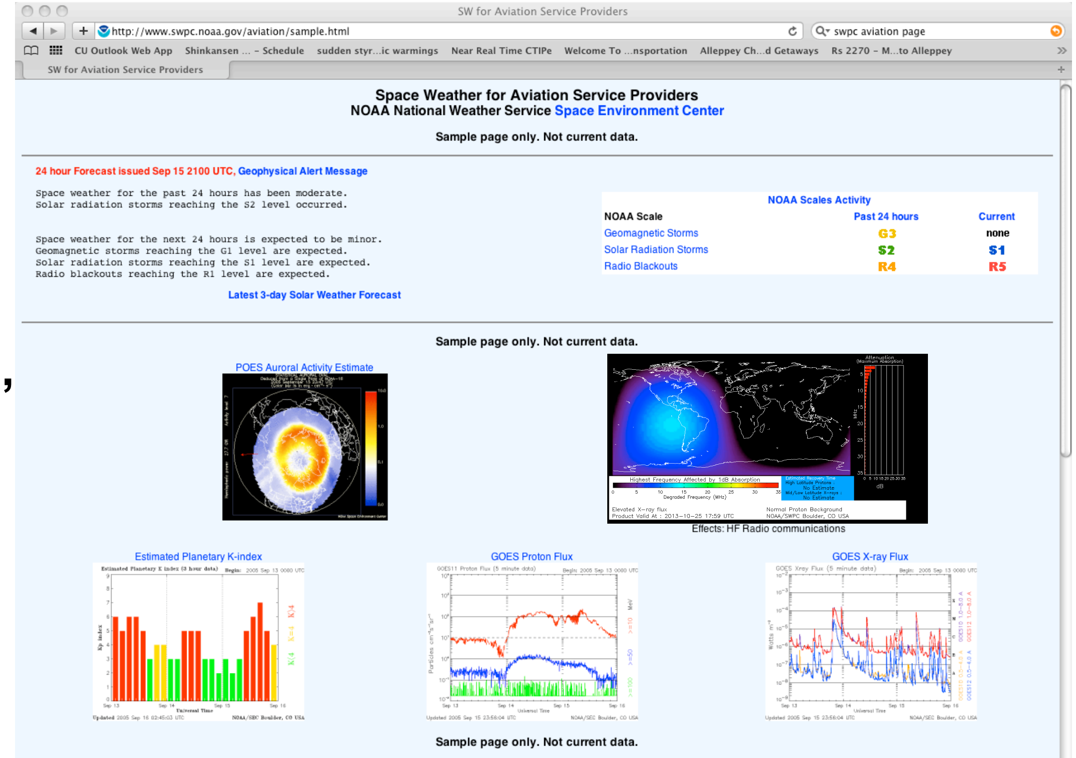
Jeffrey Forbes

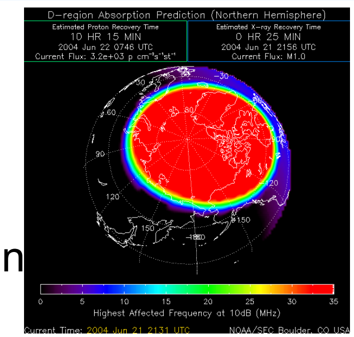
Aerospace Engineering Sciences, University of Colorado, Boulder

Current: Aviation Space Weather Support

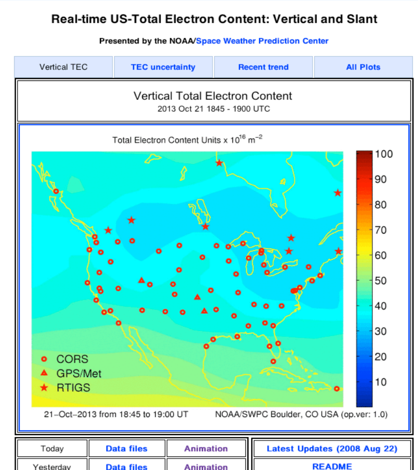
: conditions above ~80 km from NOAA Space Weather Prediction Center impacting communications, navigation, and radiation hazard

- Solar flare prediction: D-region absorption, HF radio blackout
- Solar proton events: polar cap absorption, radiation hazard
- Coronal mass ejections: geomagnetic activity forecast, ionospheric disturbances
- Empirical neutral density model for orbit prediction (Jacchia-Bowman 2008)





Polar cap absorption and radiation hazard

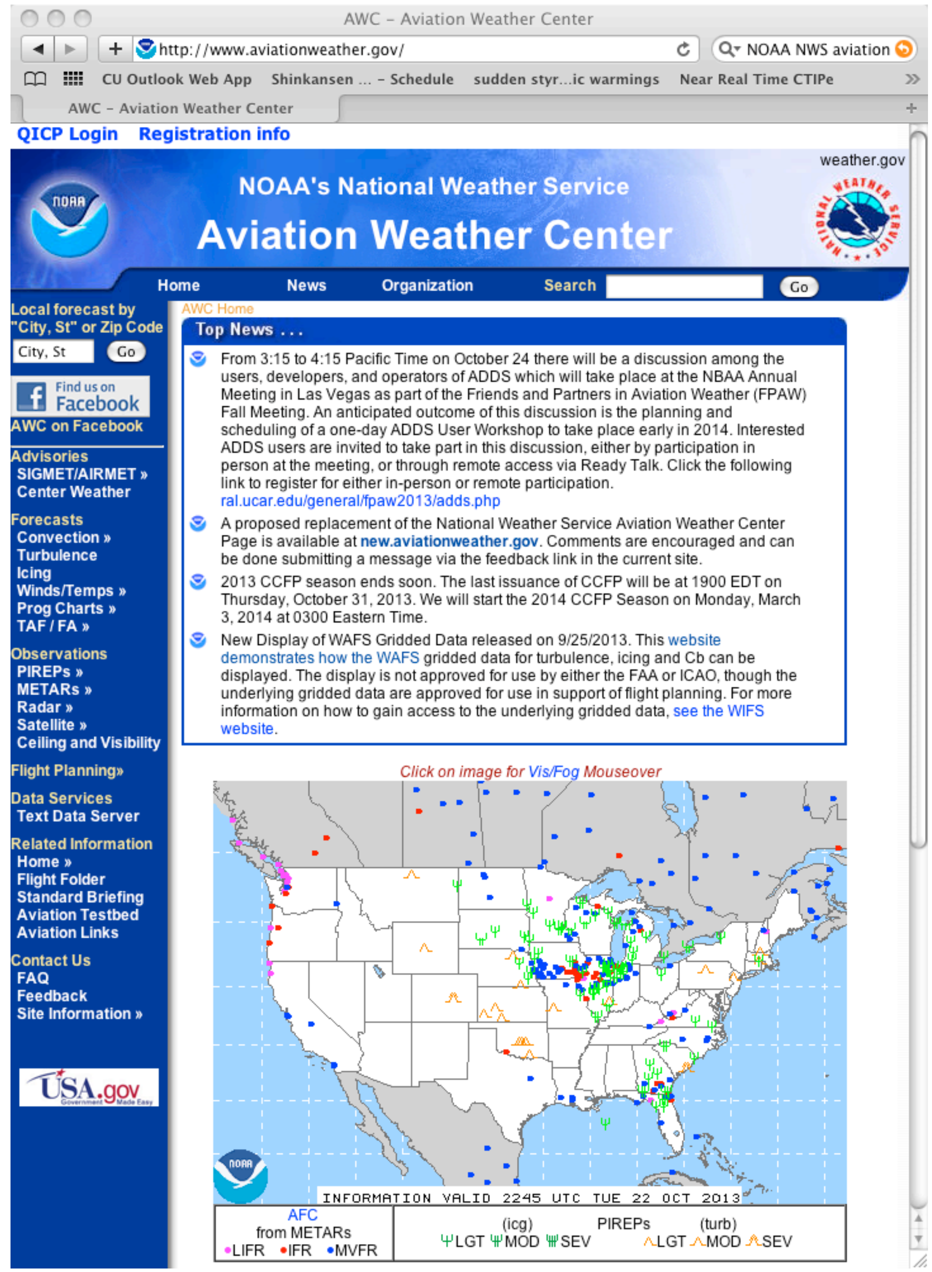


US-TEC for GPS positioning correction

Current:
Aviation Weather Support

: conditions below 50 km from National Weather Service Global Forecast System (GFS) model and Gridpoint Statistical Interpolation (GSI) data assimilation system

- Winds and temperature
- Turbulence
- Icing
- Analysis and Forecasts

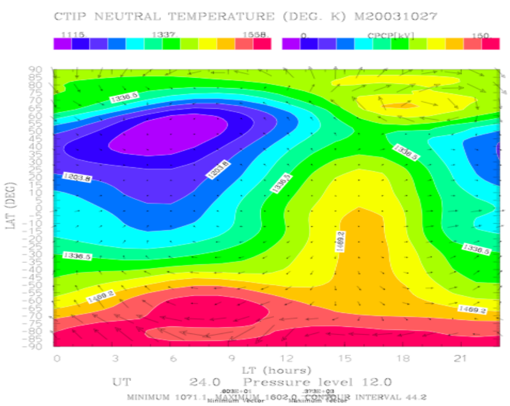


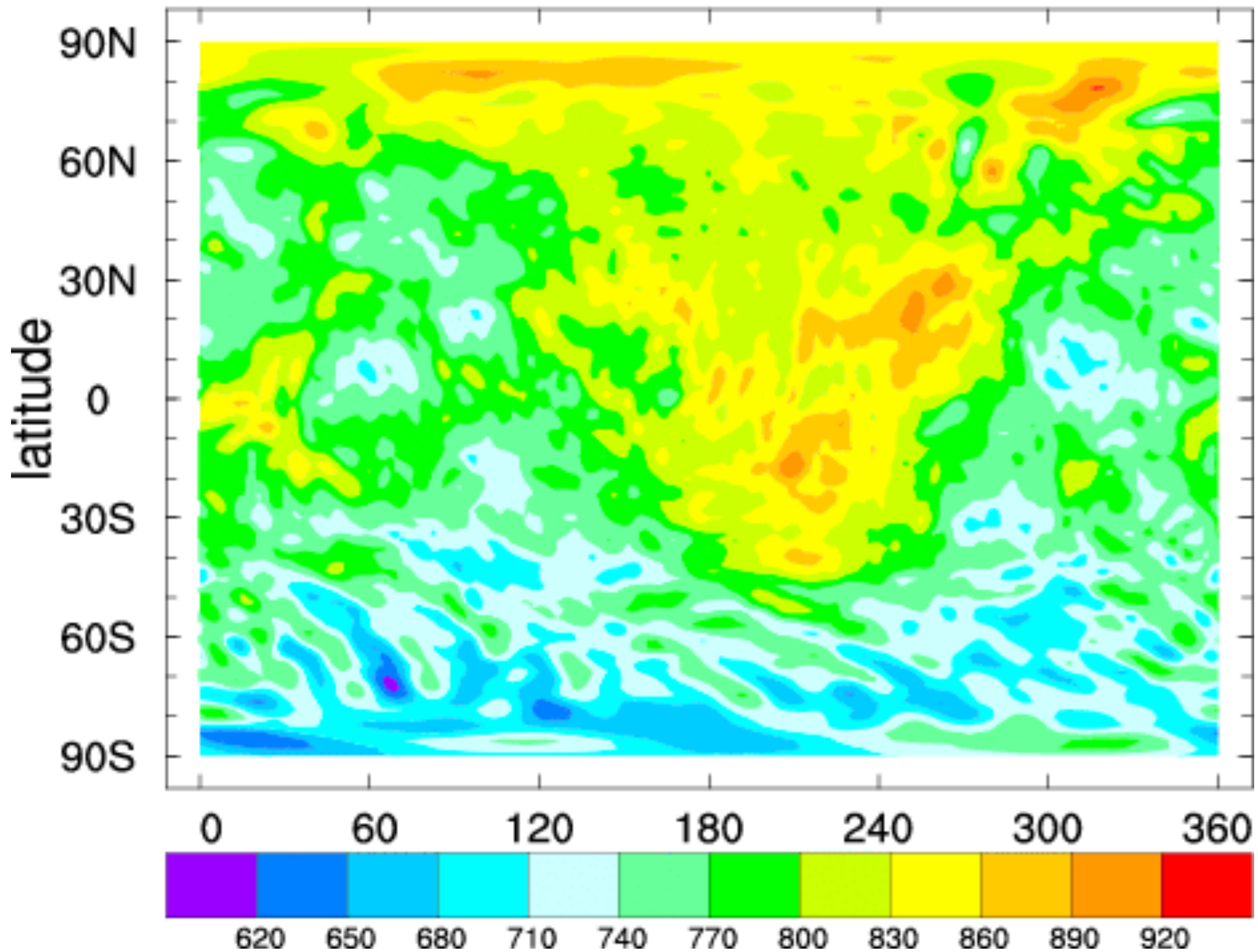
Temperature 200 km altitude

Sep 03 UT00:00 200km WAM T

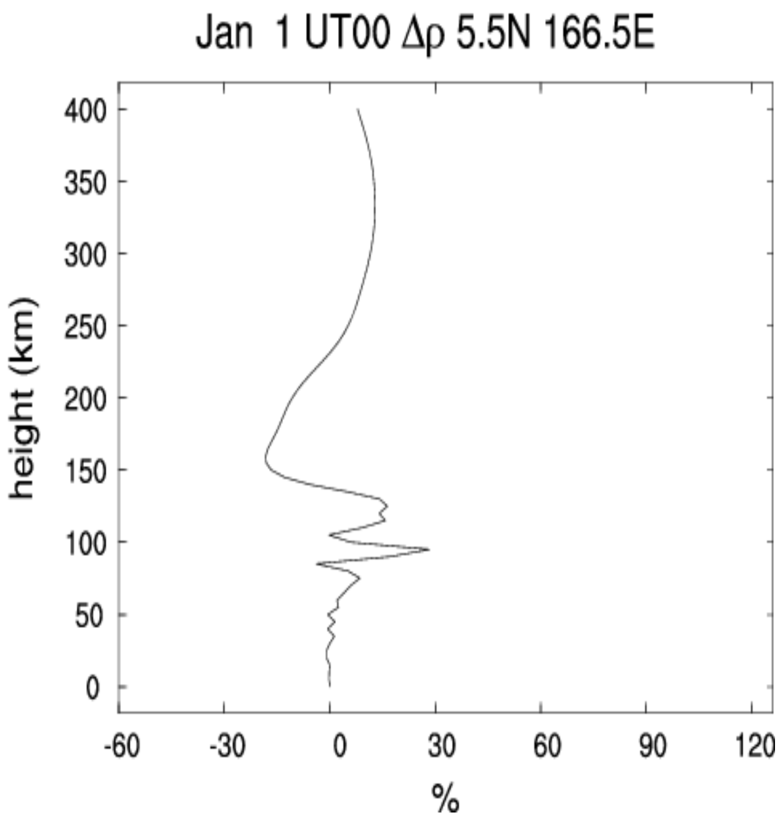
....or is this reality?

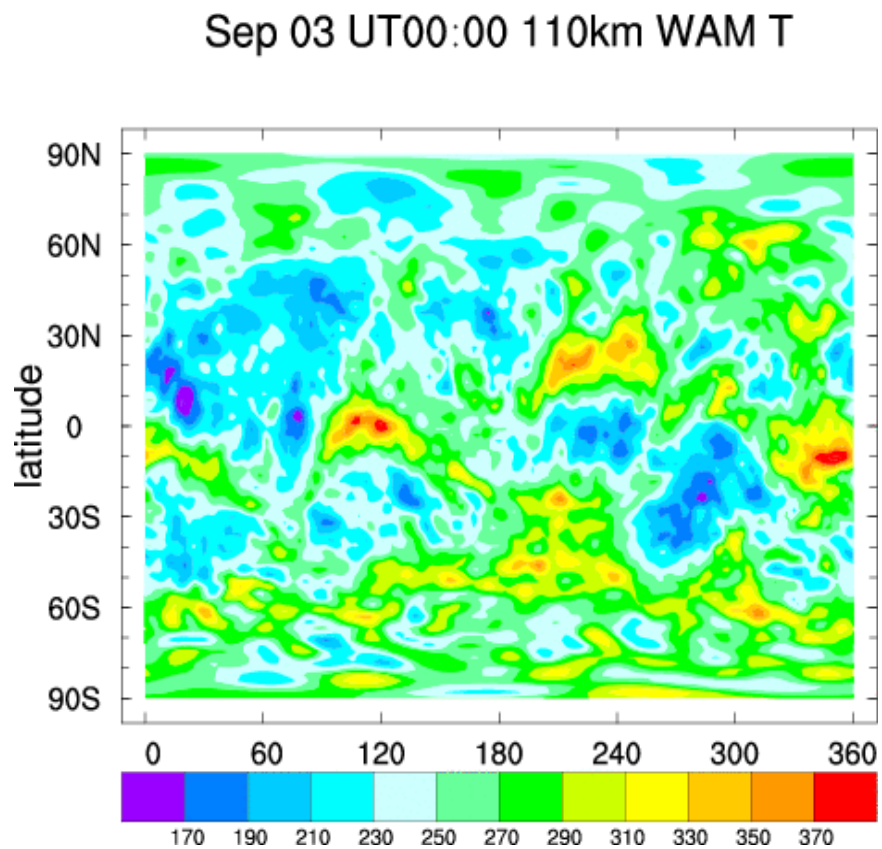
Is this reality in the upper atmosphere?



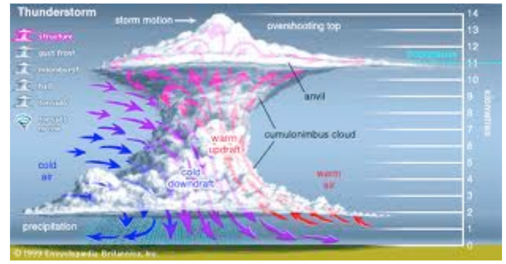


Structure and variability between 80 and 120 km altitude



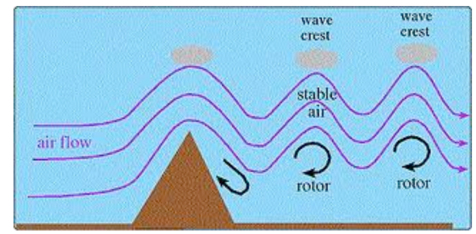


Many Lower Atmosphere Sources of Waves



- Tropical convection
- Hurricanes, tornados, thunderstorms
- Wind shear, frontal systems
- Large-scale ocean swell

- Orographic effects such as airflow over mountains



- Jet stream, polar stratospheric vortex

- Equatorial Kelvin waves
- Ozone and water vapor absorption of solar radiation
- etc., etc., …………………………

Task Description

Purpose: *An integrated air and space traffic management system requires real-time access to:*

1. Knowledge of the environmental conditions and their impact on flight conditions from the ground to 600 km, including forecast of:

2. Neutral density variability and structure for on-orbit collision avoidance and atmospheric re-entry, and forecast of near-surface and space weather conditions (winds, wind shear, temperature, variability and turbulence, storms, lightning, etc.),

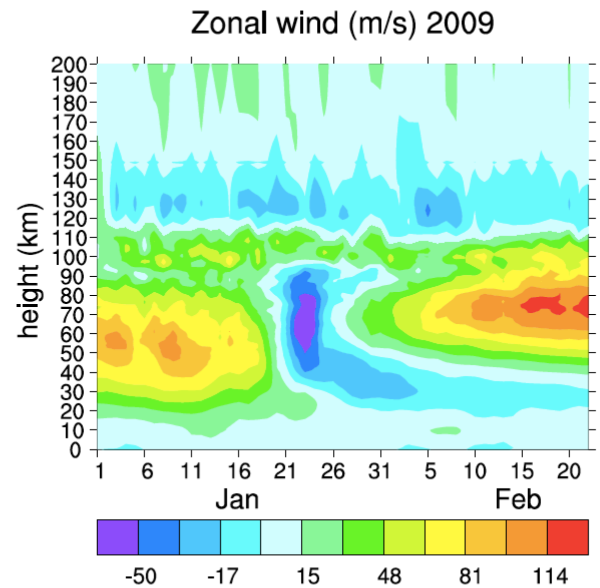
3. Plasma density, D-region absorption, total electron content, ionospheric structure and irregularities, and radiation conditions, for communications, navigation, and safety in flight

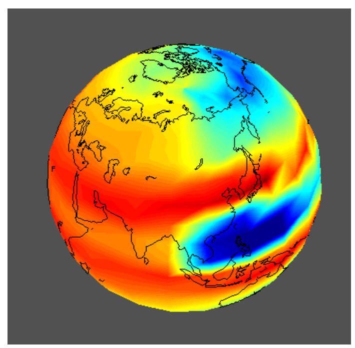
Objectives: *Fill the gap between terrestrial and space weather forecasts and develop a "weather" prediction model extending from Earth's surface to the top of the atmosphere*

Goals: *Predict <u>the environmental conditions</u> needed for safe orbital, sub-orbital, re-entry, descent, and landing*

Research Methodology

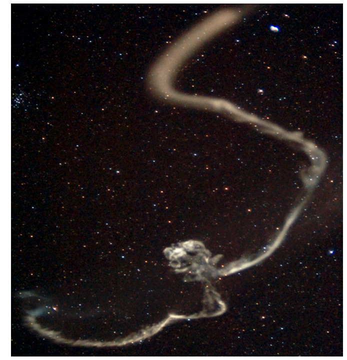
- Global seamless neutral whole atmosphere model (WAM) 0-600 km, 0.25 scale height, 2° x 2° lat/long, hydrostatic, 10-fold extension of Global Forecasting System (GFS) US weather model.
- O_3 chemistry and transport
- Radiative heating and cooling
- Cloud physics and hydrology
- Sea surface temperature field and surface exchange processes
- Orographic gravity wave parameterization
- Eddy mixing and convection
- Diffusive separation of species
- Composition dependent C_p
- Height dependent g(z)
- EUV, UV, and non-LTE IR
- Ion drag and Joule heating





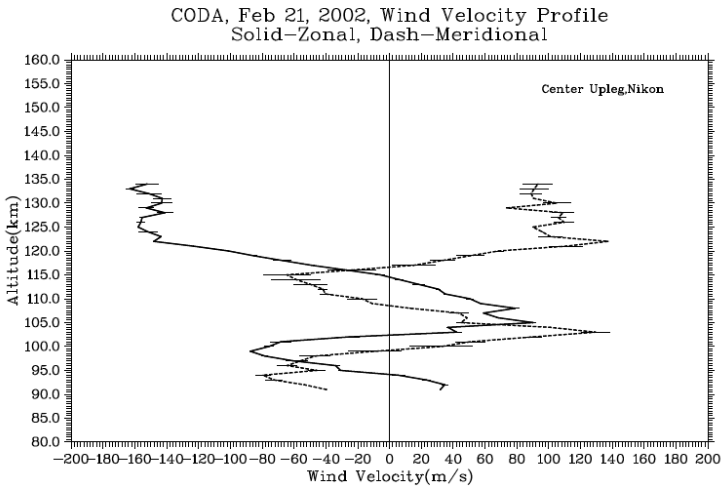
Coupled to a global ionosphere, plasmasphere, electrodynamics module (GIP) for plasma parameters

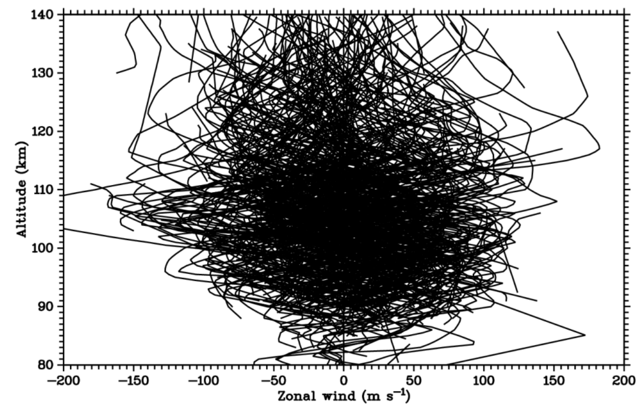
Chemical trails show steep horizontal wind shear



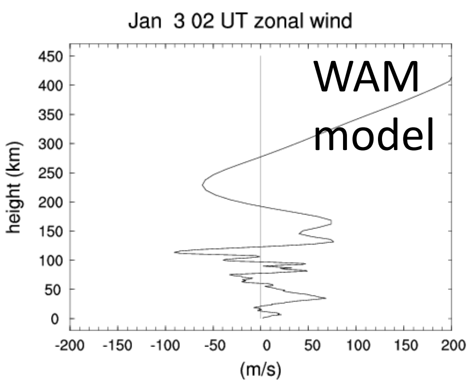
Four decades of wind measurements in lower thermosphere Larsen, 2002

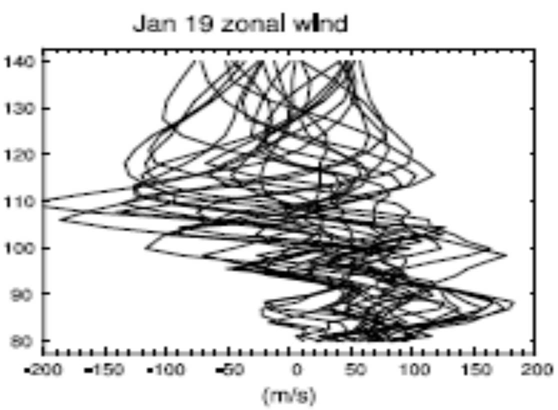
courtesy Miguel Larsen, Tianyu Zhan

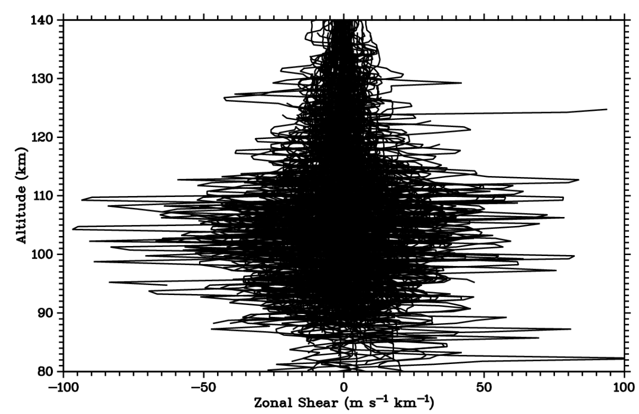




Typical peak zonal wind +/- 100 m/s



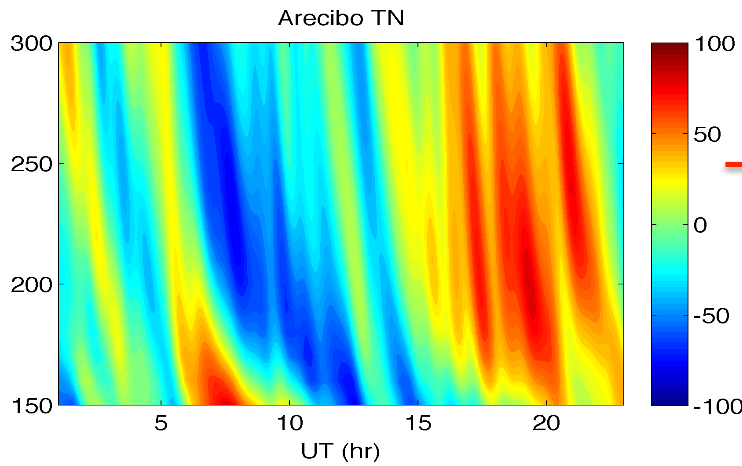


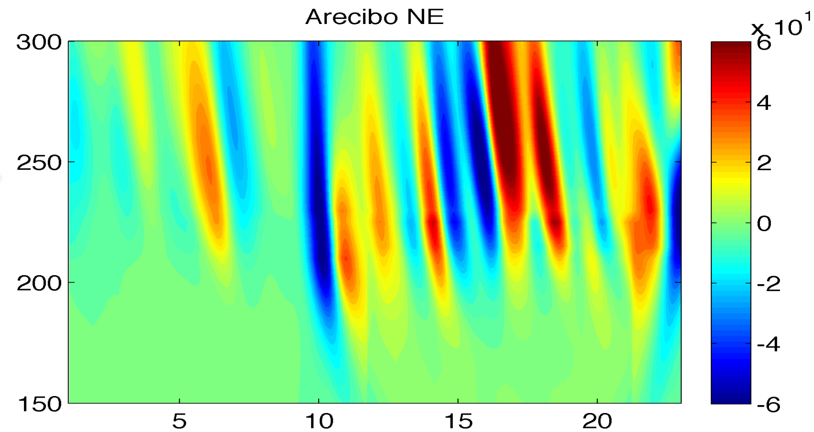


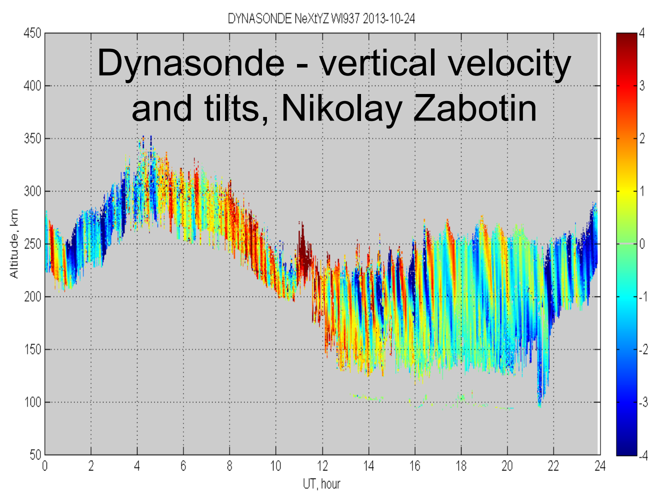
Vertical wind shear +/- 50 m/s per km

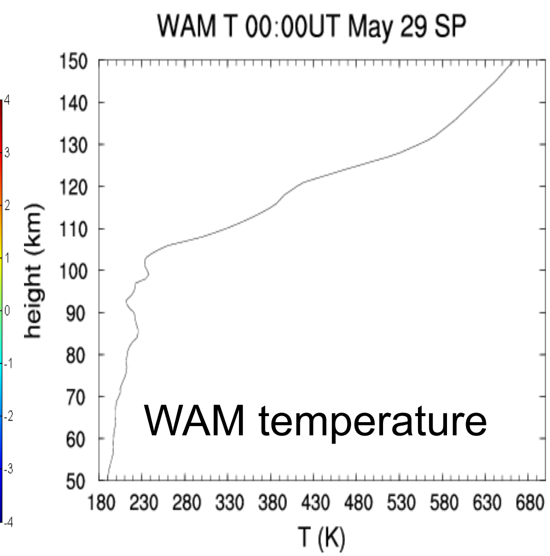
Use WAM winds, composition, density to drive plasma density
- agrees well with Arecibo ISR observations by Djuth et al. -

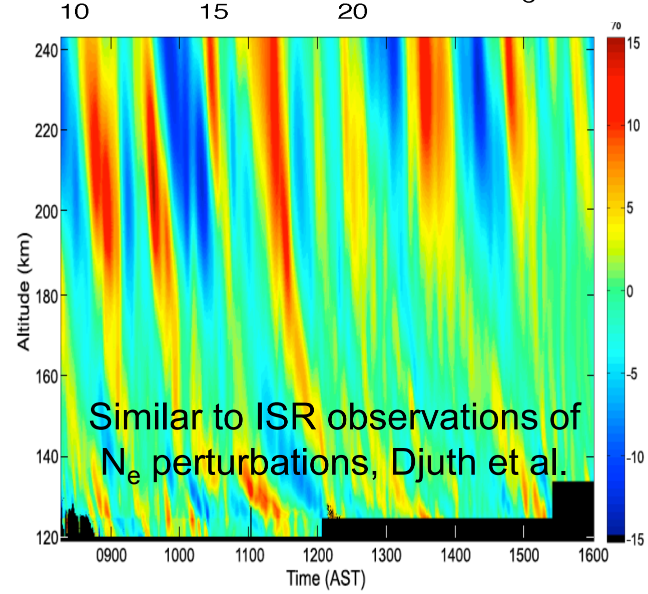
WAM wind and temperature perturbations drive 20% plasma density perturbations



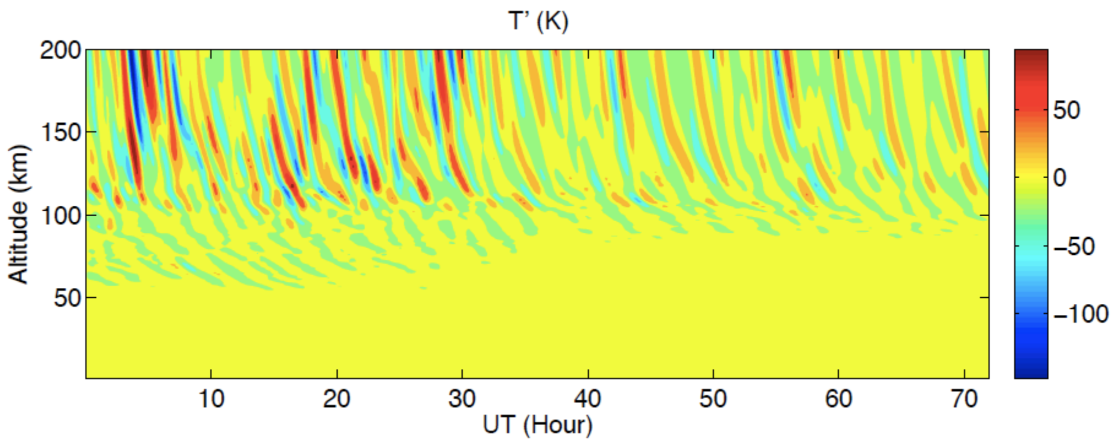


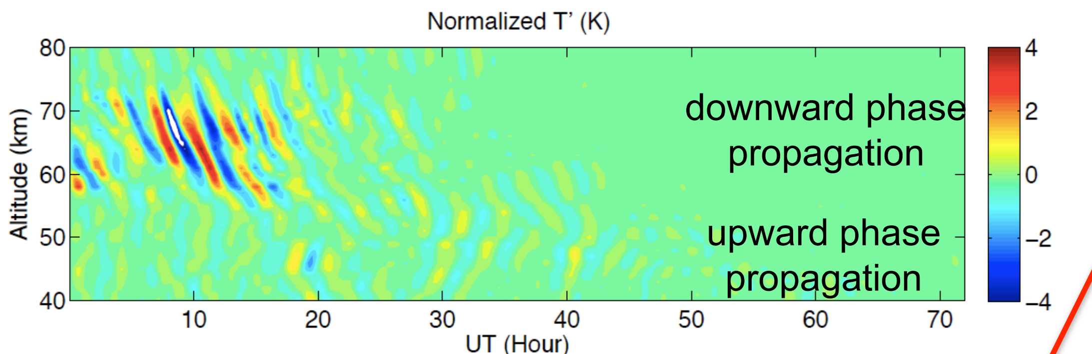


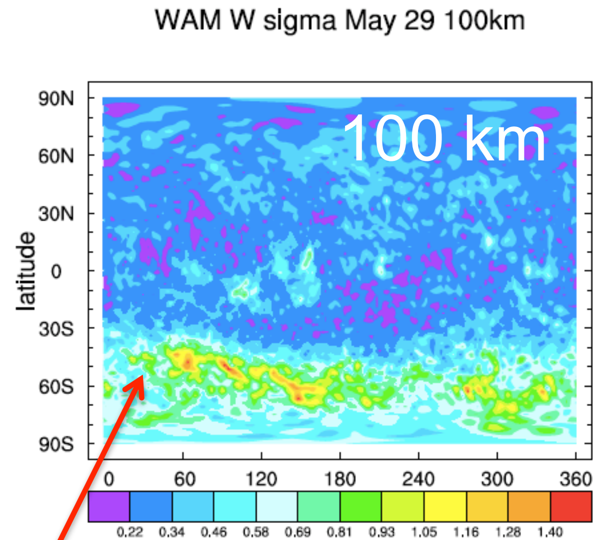


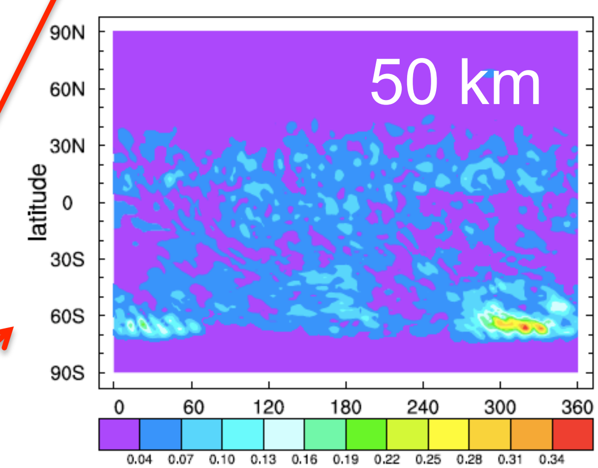


Tracing the origin of one of the many source of waves – unbalance flow of stratospheric polar jets –









Instabilities in strong polar stratospheric jets in winter high latitudes at 50 km growing in amplitude into the lower thermosphere (~100km)

Opportunity

- To define the weather and space weather products tailored to suborbital flights and commercial space transportation needs
- Integrate terrestrial and space weather conditions (from one coordinated source)
- Seamless model from the ground to 600 km altitude to fill gap between conventional weather and space weather for commercial space transportation
- Neutral atmosphere weather forecast for winds, temperature, density, turbulence, wind shears, deviations from average, and vehicle drag
- Ionospheric space weather forecast for plasma density and ionospheric structure and irregularity conditions
- Radiation hazard (e.g., NAIRAS potential new start)

Summary, Conclusions, and Next Steps:

- WAM and plasma model are developed and are being validated to combine terrestrial and space weather conditions through the whole atmosphere-ionosphere
- WAM is being integrated into the NOAA Environmental Modeling System (NEMS) to be transitioned into operations in ~2016
- WAM predicts strong neutral wind and density shear at sub-orbital apogee and re-entry region 80-120 km
- WAM spectrum of variability agrees with observations of ISR N_e, Fe LIDAR, and winds from rocket trails and Fabry-Perot

Next steps:

- **Continue to validate** WAM and ionospheric model and determine what is it about the environmental conditions that impacts CST
- Establish full **two-way coupling of WAM to the ionosphere** module to determine balance between lower atmosphere and solar/magnetospheric space weather forcing
- **Extend WAM data assimilation** into the lower thermosphere (SABER, MLS temperatures, etc.)
- Test **higher resolution WAM T382** (35 km resolution) to resolve small-scale wave field penetrating to the thermosphere and impacting density, wind shear, and ionosphere structure
- Explore **assimilation of ionospheric data**
- Whole atmosphere/ionosphere data assimilation at high resolution

Contact Information

- **Dr. Tim Fuller-Rowell,** Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Tim.Fuller-Rowell@noaa.gov

- **Dr. Tomoko Matsuo**, Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Tomoko.Matsuo@noaa.gov

- **Dr. Houjun Wang**, Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Houjun.Wang@noaa.gov

- **Dr. Fei Wu**, Physicist, Cooperative Institute for Research in Environmental Sciences, University of Colorado/Space Weather Prediction Center, Fei.Wu@noaa.gov

- **Catalin Negrea**, Student, CU Electrical, Computer, and Energy Engineering, Catalin.Negrea@noaa.gov

- **Dr. Mihail Codrescu**, Physicist, NOAA/Space Weather Prediction Center, Mihail.Codrescu@noaa.gov

- **Dr. Rodney Viereck**, Physicist, NOAA/Space Weather Prediction Center, Rodney.Viereck@noaa.gov

- **Dr. Jun Wang**, Physicist, NOAA/Environmental Modeling Center, Jun.Wang@noaa.gov

- **Professor Jeffrey M. Forbes**, Department Chair, Aerospace Engineering Sciences, University of Colorado, Forbes@Colorado.edu