COE CST Third Annual Technical Meeting:

Mitigating threats through space environment modeling/prediction

PI: Tim Fuller-Rowell

University of Colorado
Boulder

Center of Excellence for Commercial Space Transportation

October 29th, 2013

Overview

- Team Members
- Purpose of Task
- Research Methodology
- Results
- Conclusions and Next Steps
- Contact Information

Team Members

University of Colorado Boulder

CIRES

Timothy Fuller-Rowell, Tomoko Matsuo, Houjun Wang, Fei Wu

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, Jun Wang

NOAA Space Weather Prediction Center, Boulder, CO

and Environmental Modeling Center, Camp Springs, MD

Jeffrey Forbes

Aerospace Engineering Sciences, University of Colorado, Boulder

NOAA — National Oceanic and Atmospheric Administration, U.S. Department of Commerce

SWPC Space Weather Prediction Center

Purpose of Task

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 weather conditions (winds, turbulence, storms, lightning, etc.),

3. Plasma density, total electron content, ionospheric irregularities, and radiation conditions for communications, navigation, and safety in flight

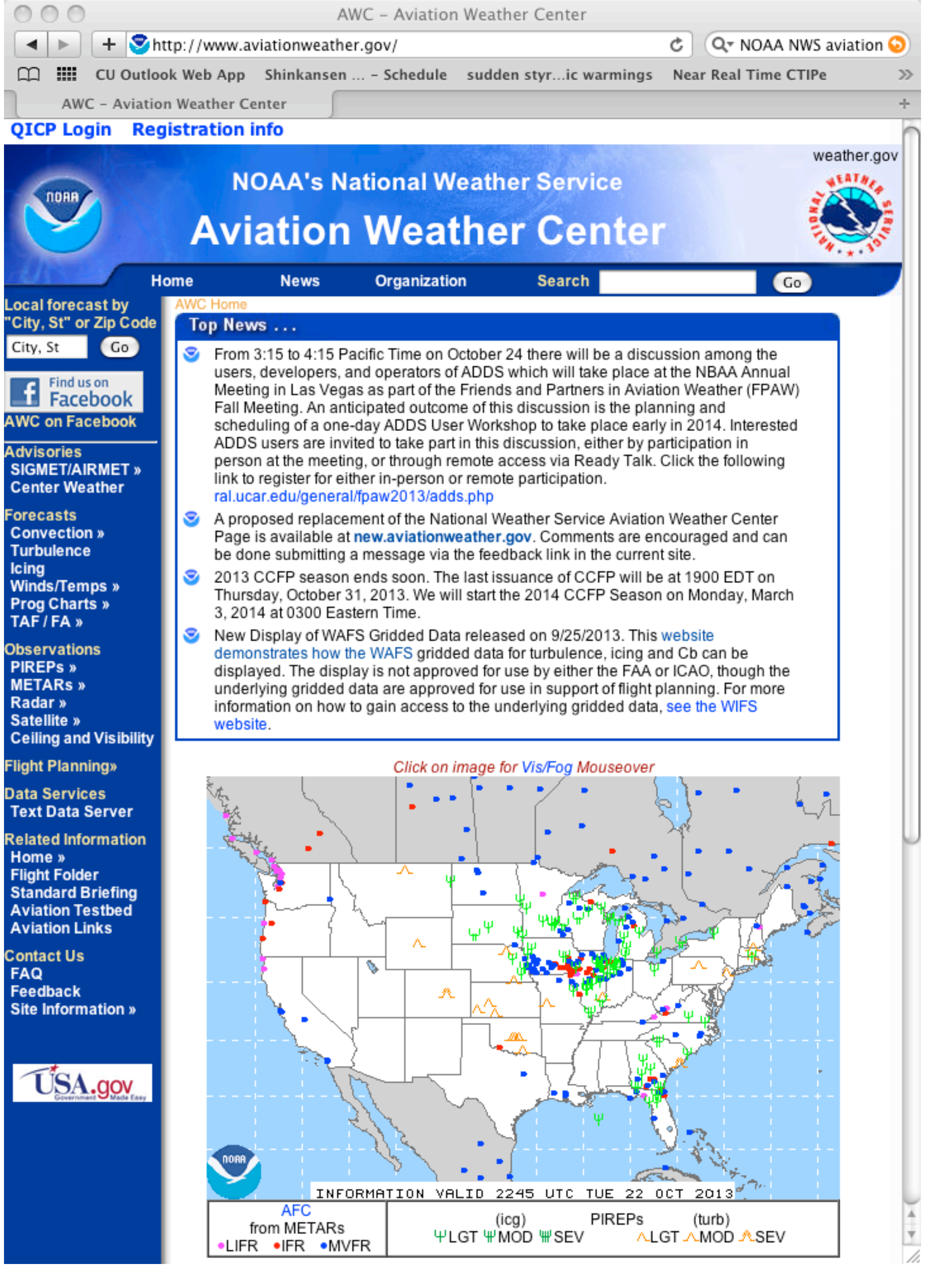
Objectives: *Develop a "weather" (terrestrial weather and space weather) prediction model extending from Earth's surface to the edge of space*

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

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

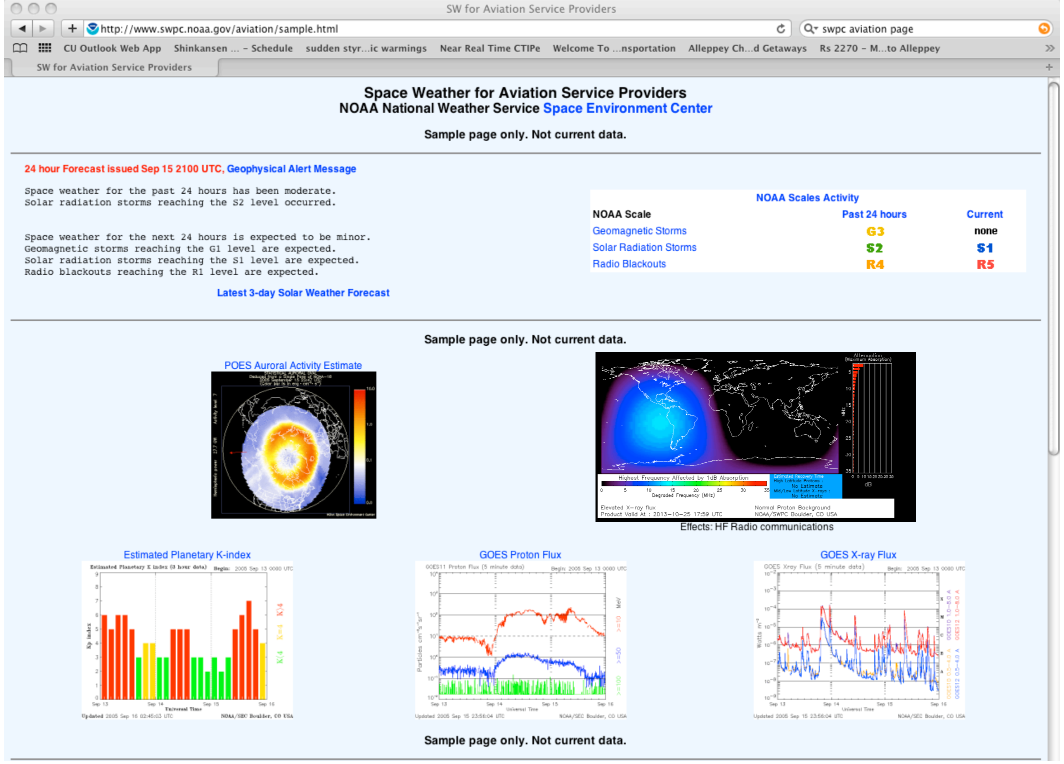
- Winds and temperature
- Turbulence
- Icing
- Analysis and Forecasts

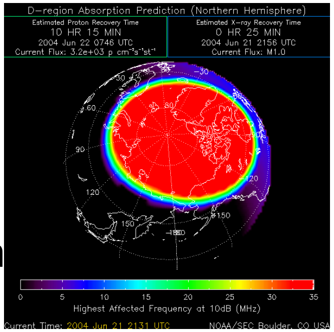


Current: Aviation Space Weather Support

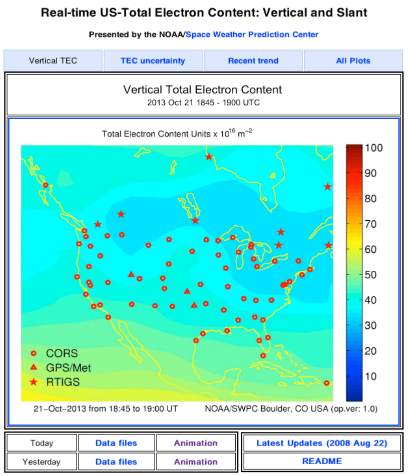
: conditions above 100 km from Space Weather Prediction Center impacting communications, navigation, and radiation hazard

- Solar flare prediction: D-region absorption, HF radio blackout
- Solar proton events: polar cap absorption, radiation hazard
- Coronal mass ejections: geomagnetic activity forecast, GPS/GNSS positioning error, etc.
- Empirical neutral density model for orbit prediction (Jacchia-Bowman 2008)





Polar cap absorption and radiation hazard



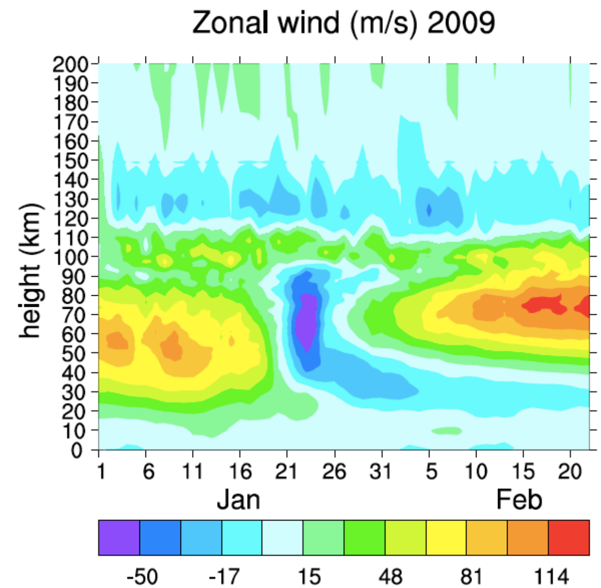
US-TEC for GPS positioning correction

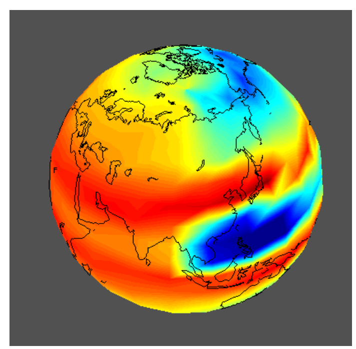
Research Methodology

- CST requires an integration of 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, and satellite drag
- Ionospheric space weather forecast for plasma density and ionospheric irregularity conditions
- Radiation hazard (e.g., NAIRAS potential new start)

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

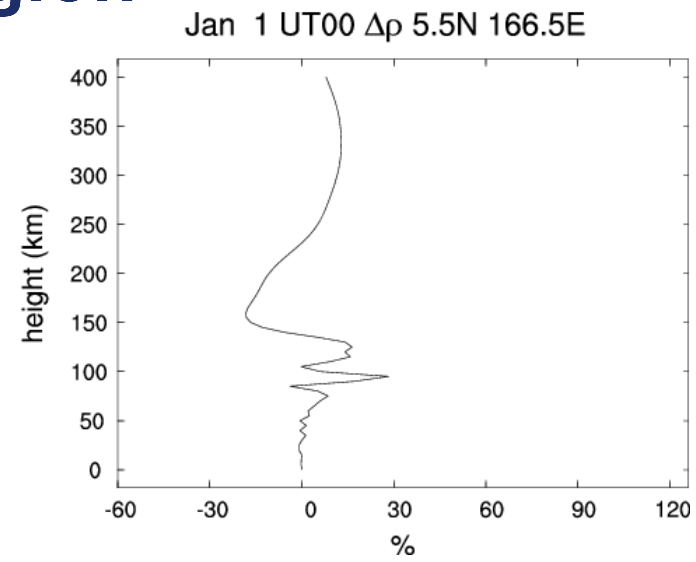


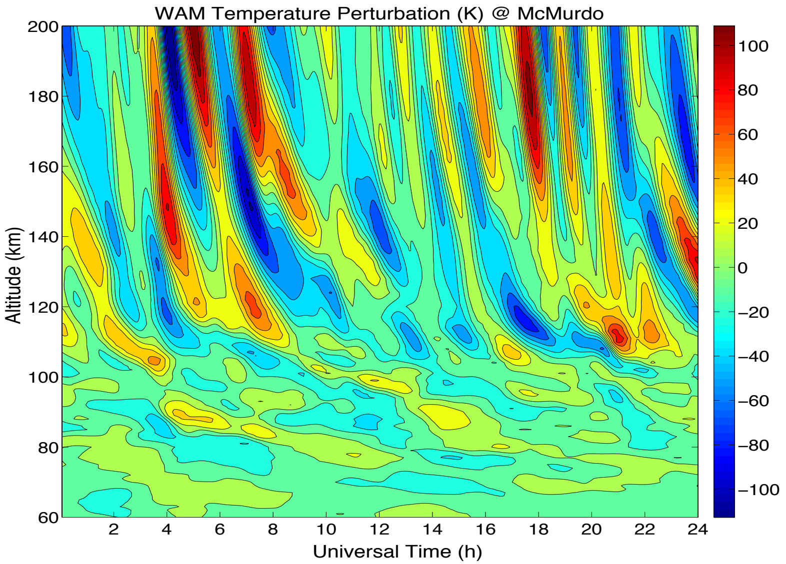


Coupled to a global ionosphere, plasmasphere, electrodynamics module (GIP) for plasma parameters

Variability in the re-entry region

- Tropospheric weather drives localized and steep density gradients in the sub-orbital and re-entry region (80 to 150 km altitude).
- The whole atmosphere model (WAM) is able to simulate and hopefully predict this structure for situational awareness
- Efforts are under way to validate the WAM structure by comparing with ground-based LIDAR observations in the mesosphere and lower thermosphere, in collaboration with colleagues at CU (Xinzhao Chu and Xian Lu).

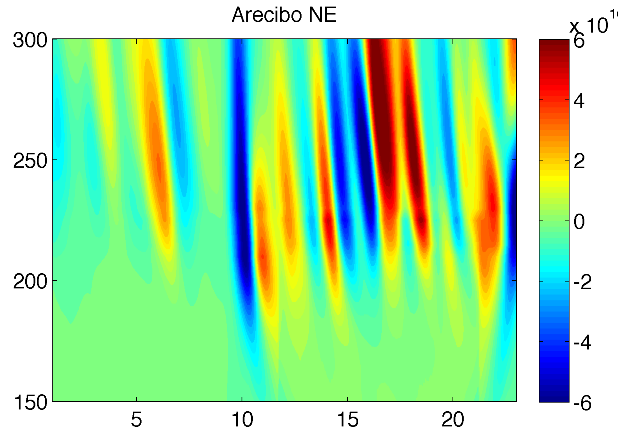




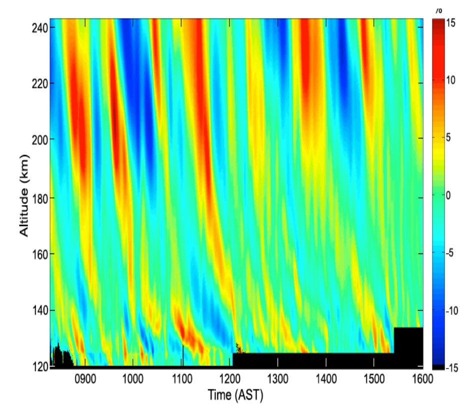
Validation: ionosphere and Fe LIDAR

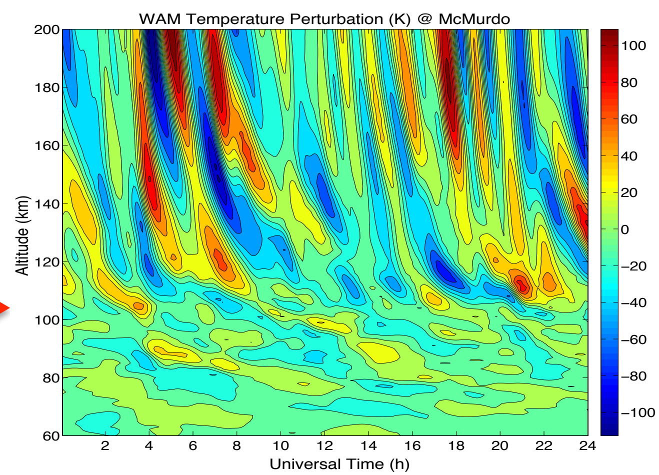
- WAM fields drive ionospheric structure in good agreement with observations from incoherent scatter radar (ISR)
- WAM structure also agrees well with ground-based LIDAR observations in the mesosphere and lower thermosphere

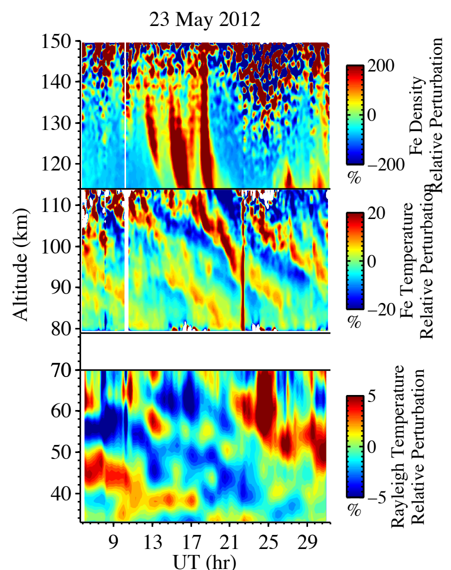
WAM-GIP



ISR

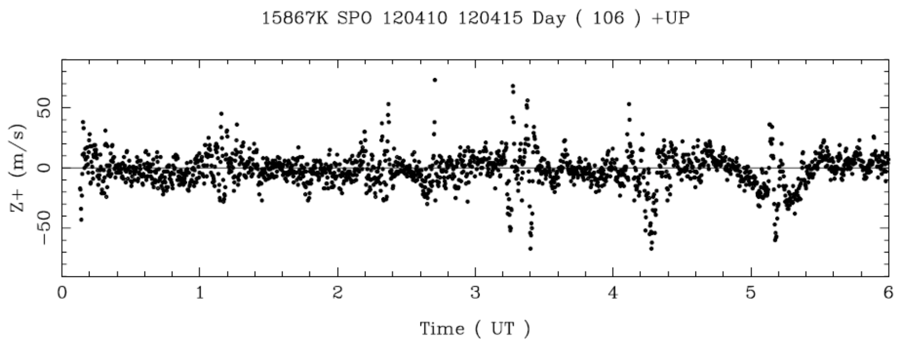


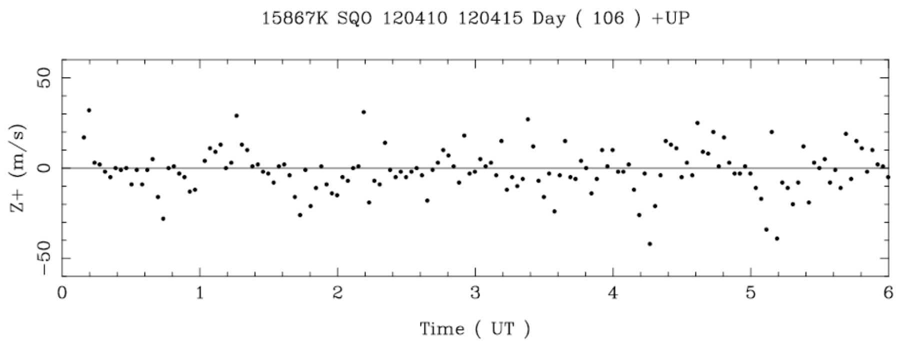


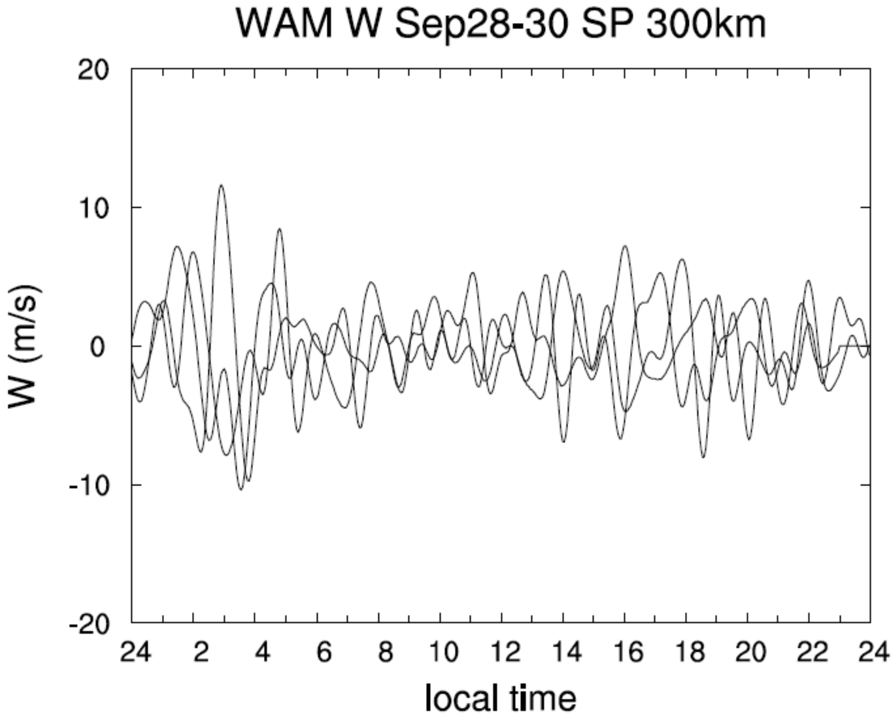


LIDAR

WAM Validation: Fabry-Perot tri-static south pole vertical winds (Gonzalez Hernandez)

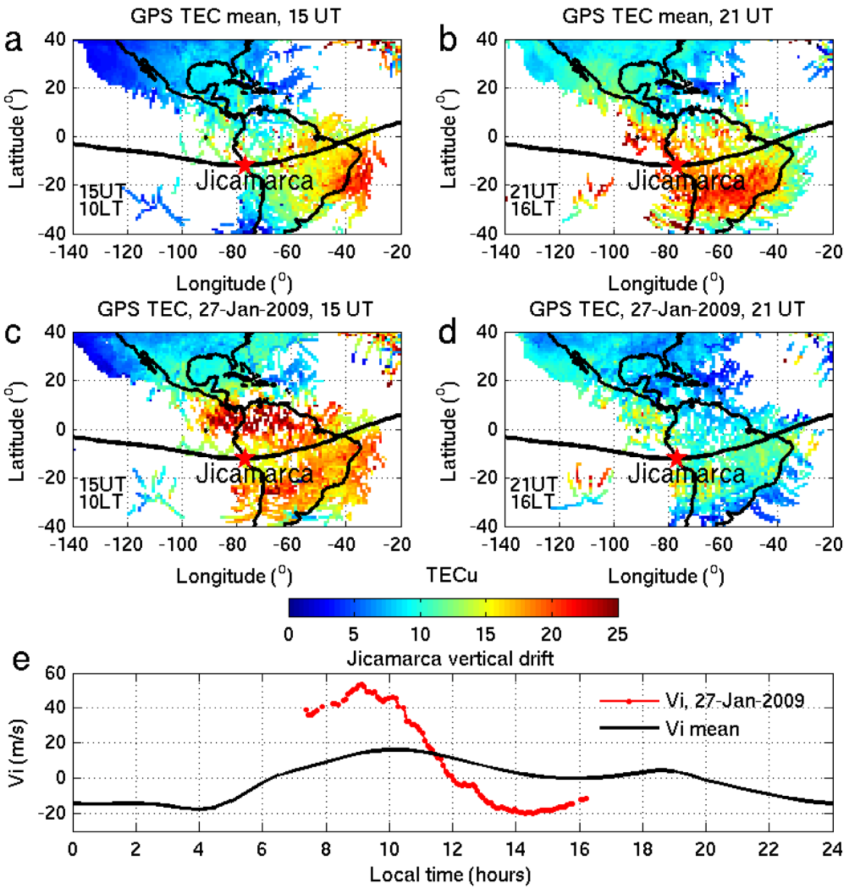




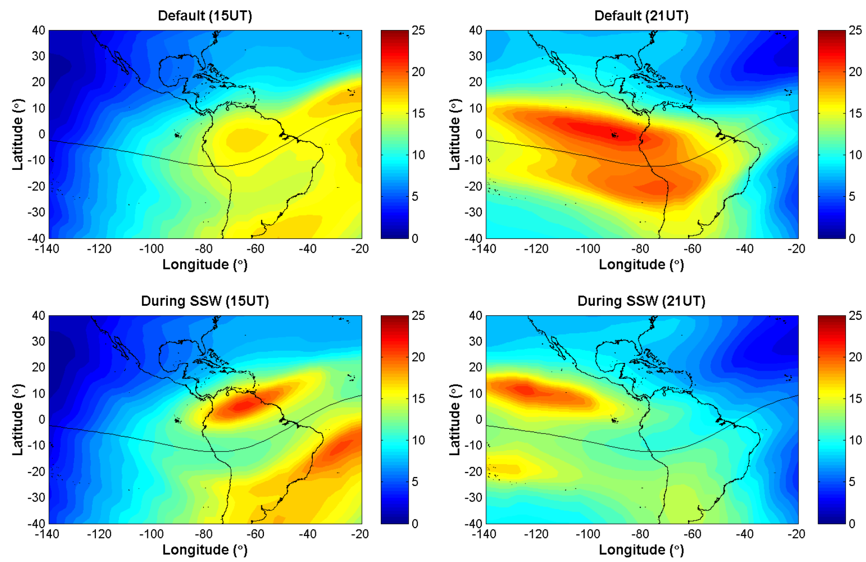


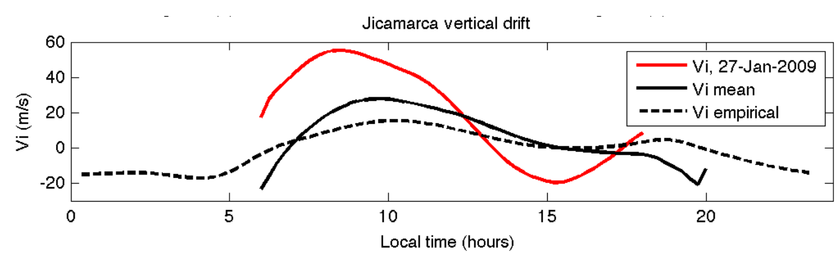
Simulation of January 2009 dynamics and impact on EIA

GPS-TEC and Jicamarca vertical plasma drift before and after SSW (Goncharenko/Chau



WAM-GIP before and after SSW





Reasonable agreement between GIP and observations on Jan 27th at 15 and 21 UT, equivalent to 10 and 16 LT over SA

Summary, Conclusions, and Next Steps:

- WAM and GIP 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 ~2015
- WAM predicts strong neutral density structure in the re-entry region ~50-100%
- WAM spectrum of variability agrees with ISR N_e, Fe LIDAR, and FPI winds

Next steps:

- **Continue to validate** WAM and GIP and explore impact on density, drag, and ionosphere structure
- Establish full **two-way coupling of WAM to the ionosphere** GIP 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 and ionosphere structure
- Explore **assimilation of ionospheric data** for density prediction
- 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