Transitioning a Coupled Whole Atmosphere Model (WAM) and Ionosphere-Plasmasphere-Electrodynamics (IPE) Model into Operations at NOAA

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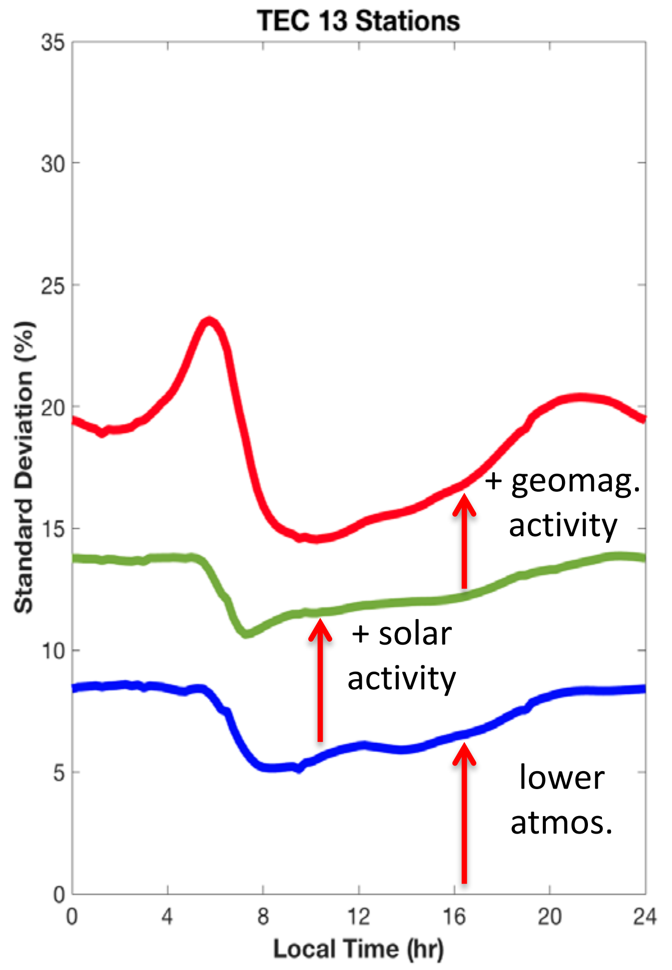
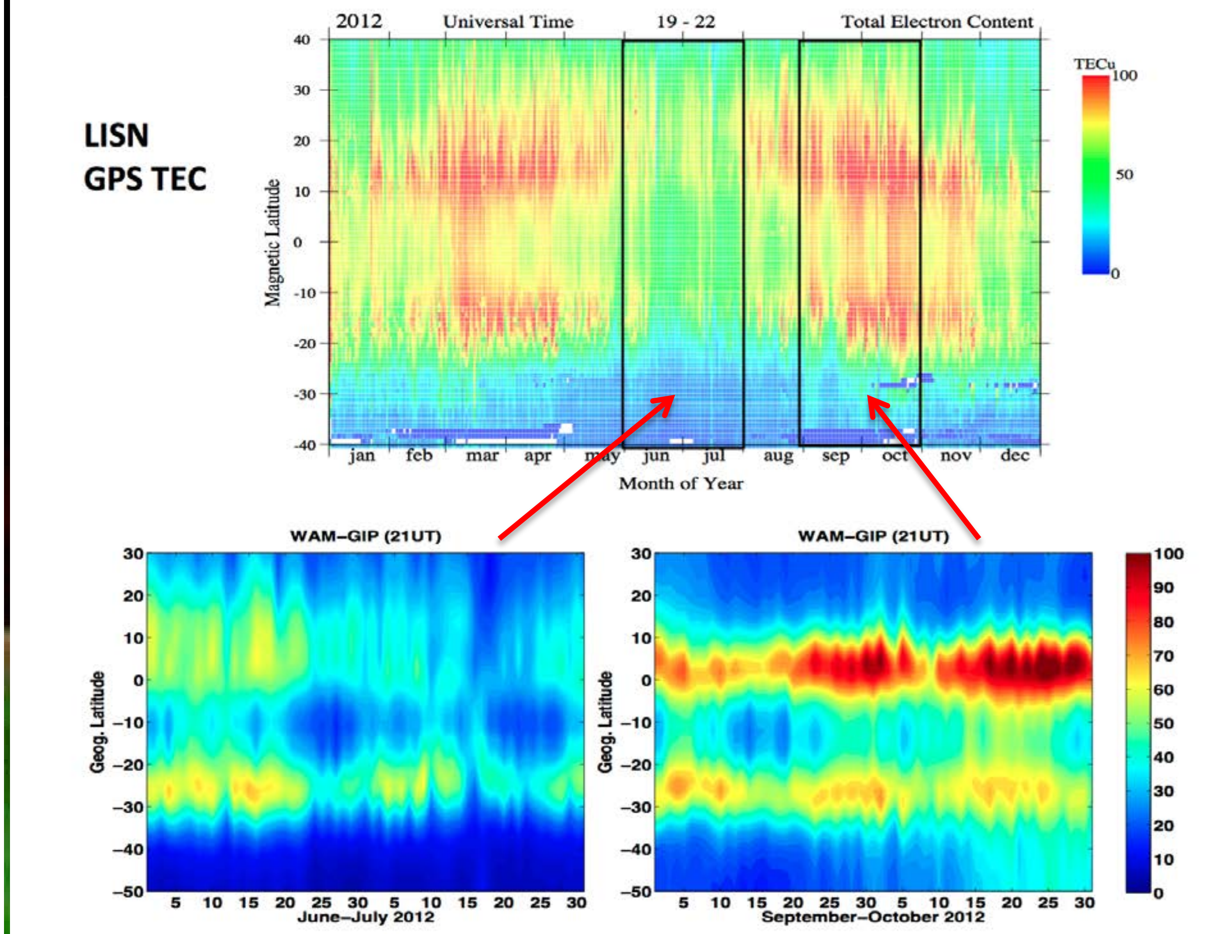
NOAA Operational Models

- WSA-ENLIL and the Michigan Geospace physical models have been transitioned to NOAA operations and are now providing real-time space weather products
- National Weather Service is committed to raising the lid of the US weather model to improve long-range seasonal and sub-seasonal terrestrial weather forecasts
- Presents an opportunity to include an operational thermosphere ionosphere physical model - specifying and forecasting space weather in the upper atmosphere

Ionospheric Variability (TEC) and Sources in American Sector

(Model: Tzu-Wei Fang, SAIR project; GPS TEC data: Cesar Valadares, LISN)





Thermosphere-Ionosphere Model Requirements

- A physical model capable of responding to the three major drivers: solar activity (EUV and UV radiation for heating, ionization, and dissociation), geomagnetic activity (magnetospheric convection, auroral ionization for Joule heating and ion drag), and forcing from the lower atmosphere (tidal winds, gravity waves, etc.)
- The forcing from the lower atmosphere has directed the use of a whole atmosphere model (WAM), which is an extension of the National Weather Service (NWS) operation Global Forecast System (GFS) terrestrial weather model for the US weather forecasting

Benefits of WAM

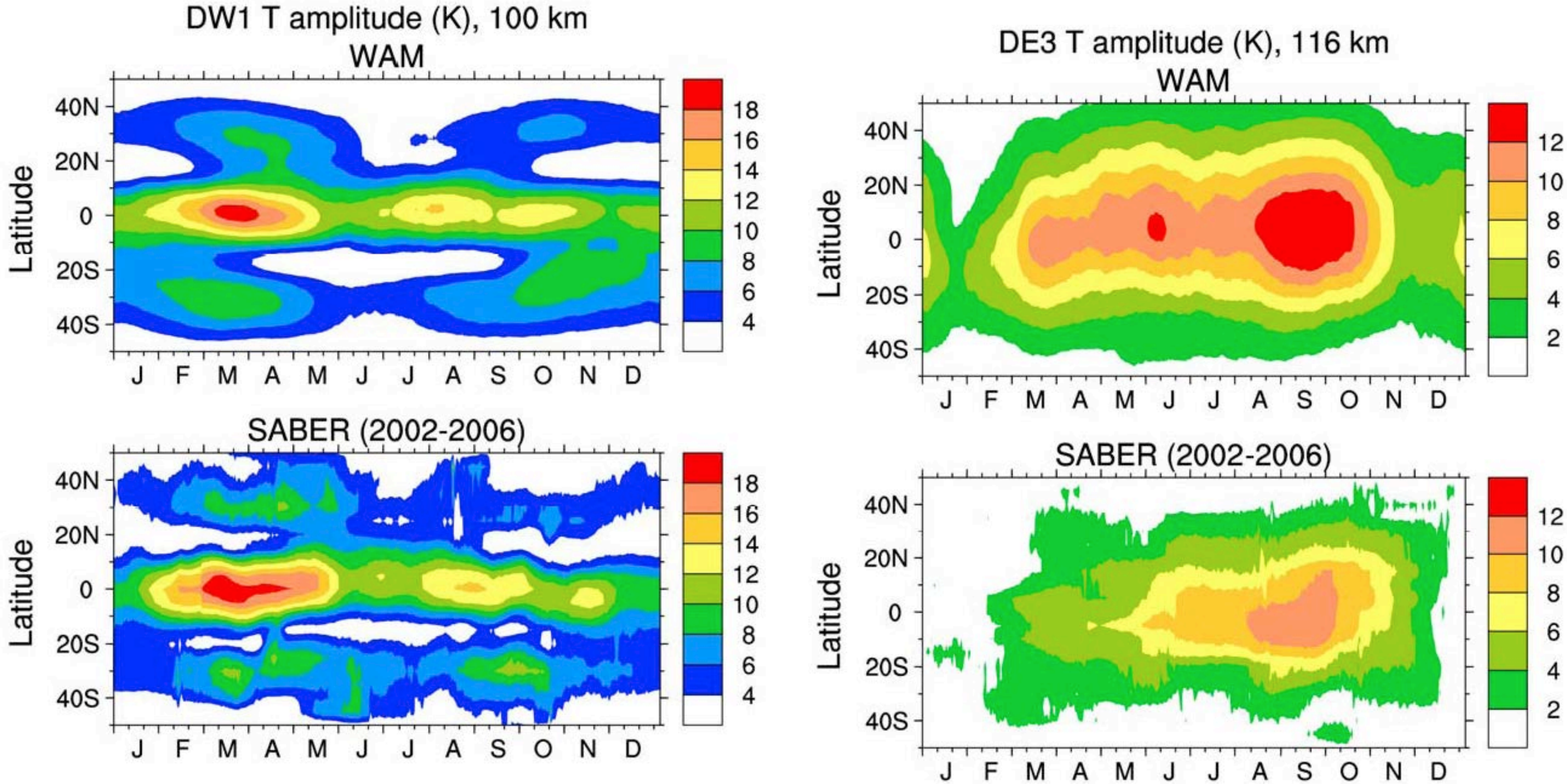
- Compatible with the US weather model already running operationally
- Can implement the operational Gridpoint Statistical Interpolation (GSI) data assimilation system, utilizing the lower atmosphere data
- Able to follow real lower atmosphere weather events and their impact on the upper atmosphere and ionosphere (such as hurricanes, tornados, planetary waves, sudden stratospheric warming, tropical convection, longitude structure in migrating and non-migrating tides)

Future Benefits of WAM

- Benefit from gradual improvements in the lower atmosphere physics and all the expertise at the Environmental Modeling Center (EMC)
- Benefit from improvement in the dynamical core – plan to replace the spectral dynamical core in GFS with FV3 from GFDL for the NOAA weather model, which includes non-hydrostatic processes

WAM agrees well with the diurnal migrating tide DW1 and the famous DE3

WAM model top: Akmaev et al. 2008



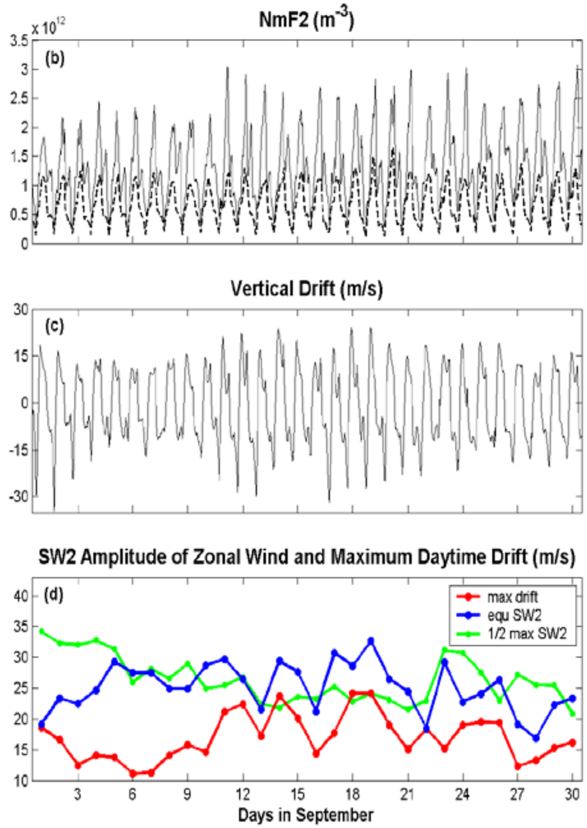
DW1

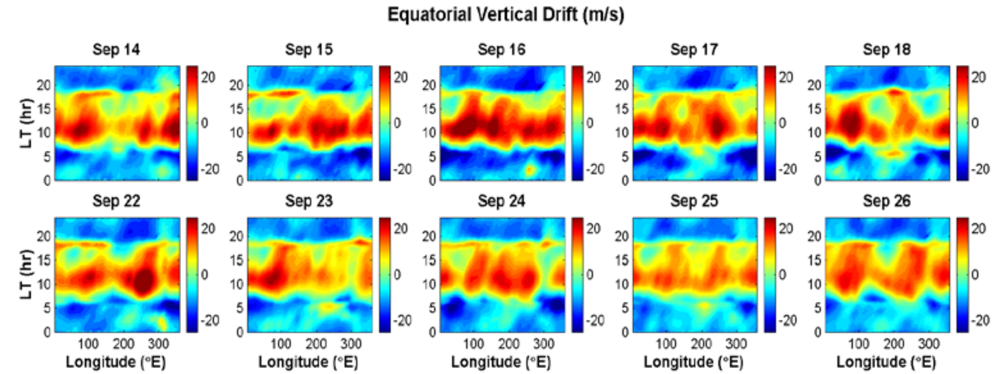
SABER observations below: Forbes et al. 2008

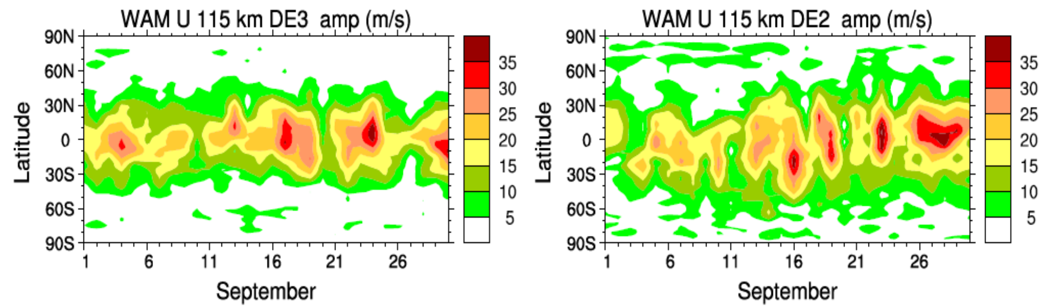
DE3

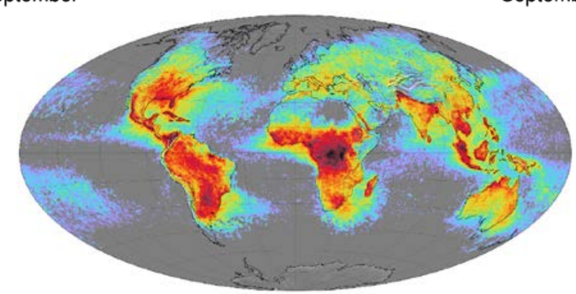
Example of impact of tidal variability

Tzu-Wei Fang et al. 2013 from WAM-GIP model simulation







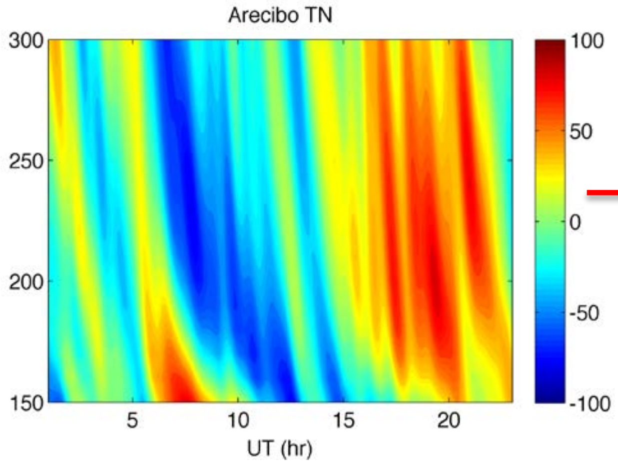


Modulation of semi-diurnal tide SW2 correlates with increases in peak vertical plasma drift and N_mF2

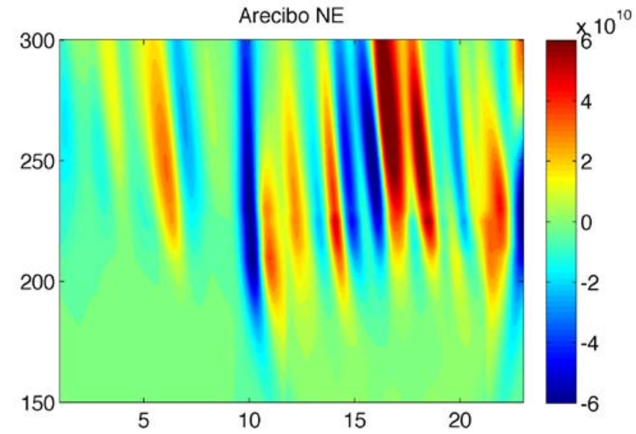
Modulation of DE3 and DE2 tidal amplitudes correlates with number of peaks in longitude structure of vertical plasma drift

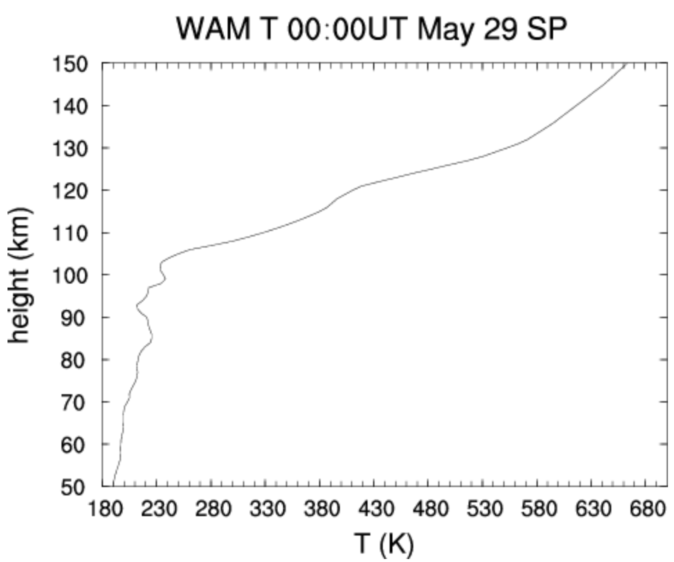
Arecibo de-trended temperature and plasma density

WAM temperature at Arecibo

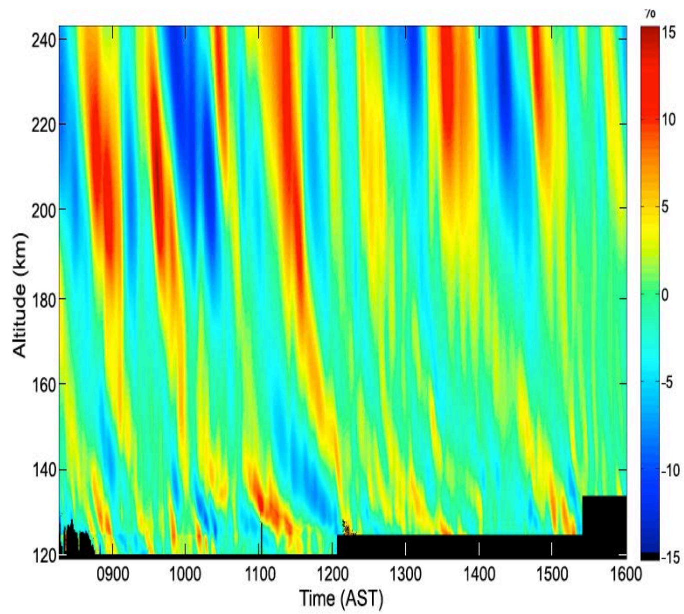


WAM-GIP plasma density at Arecibo



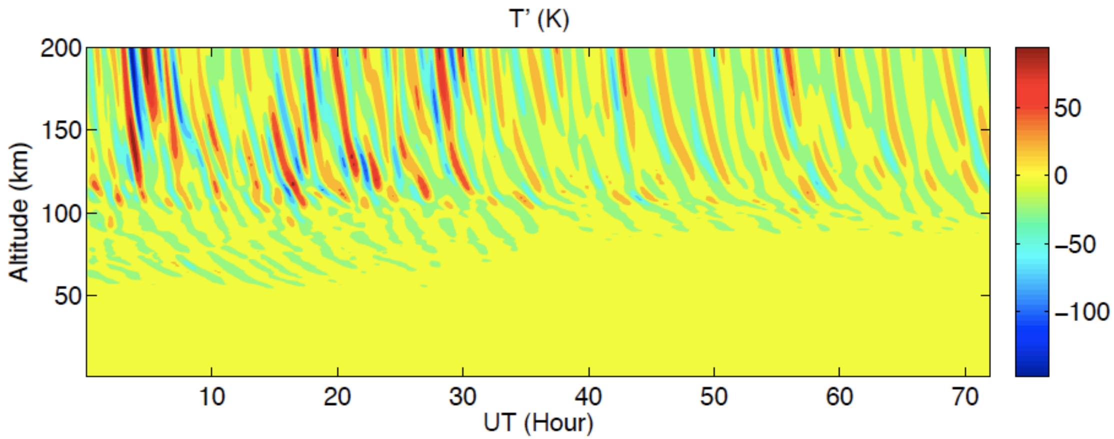


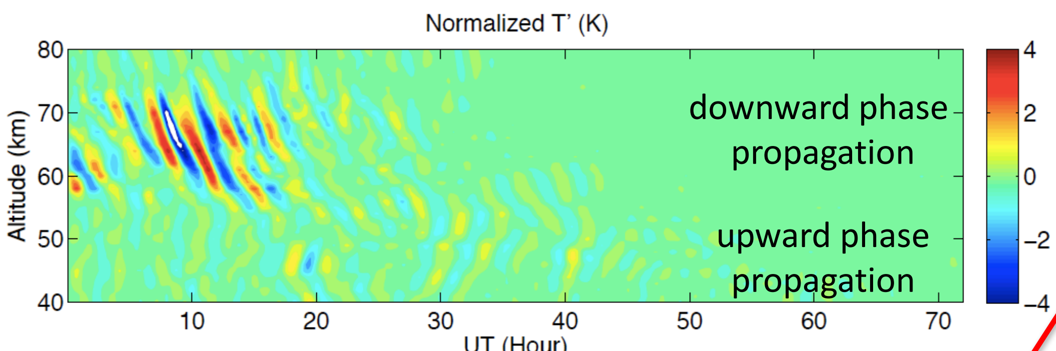
WAM-GIP model



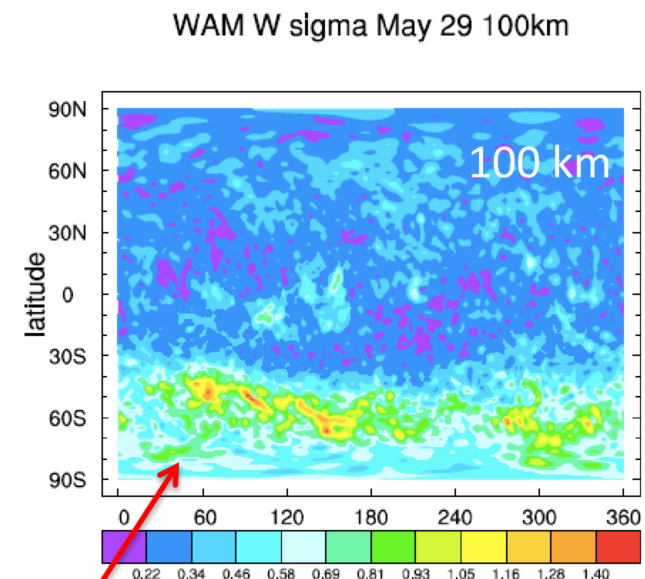
ISR observations of N_e perturbations, Djuth et al.

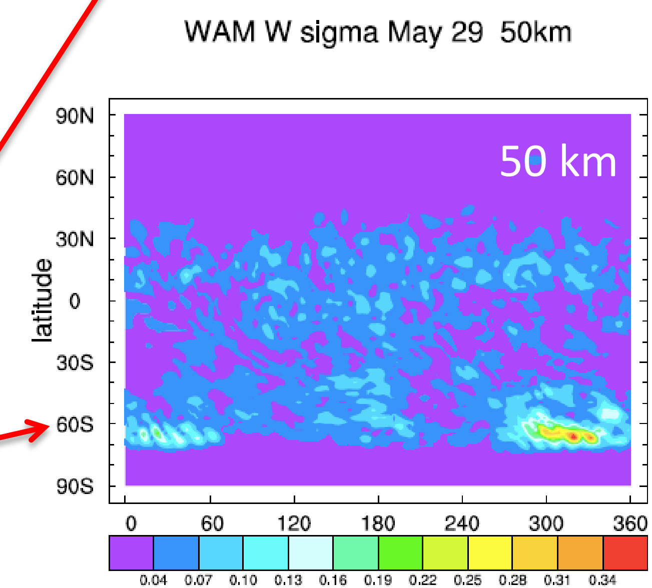
Source of waves –
unbalance flow of stratospheric jets





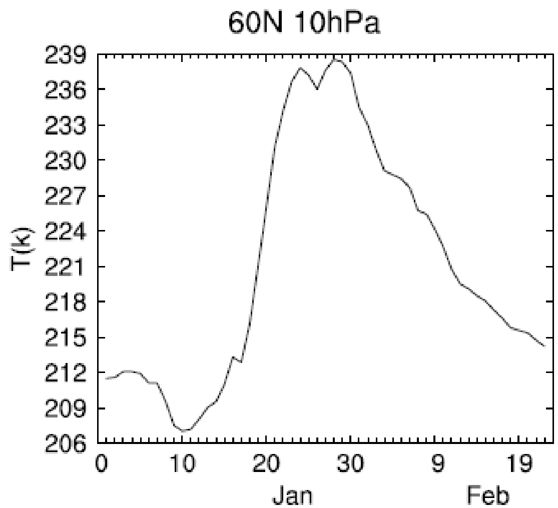
Scaled in altitude by exp(-(z-40)/2H)

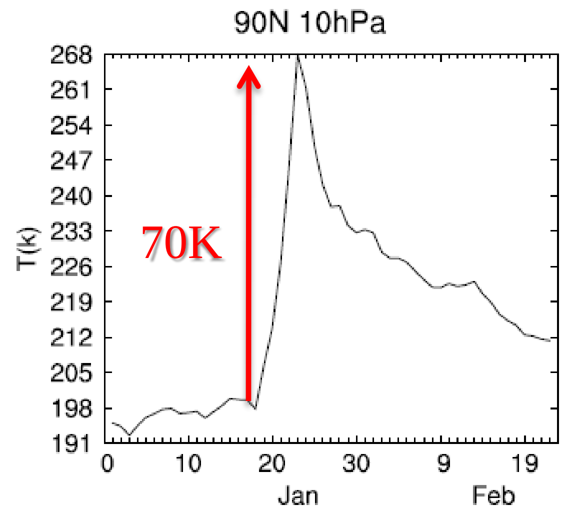


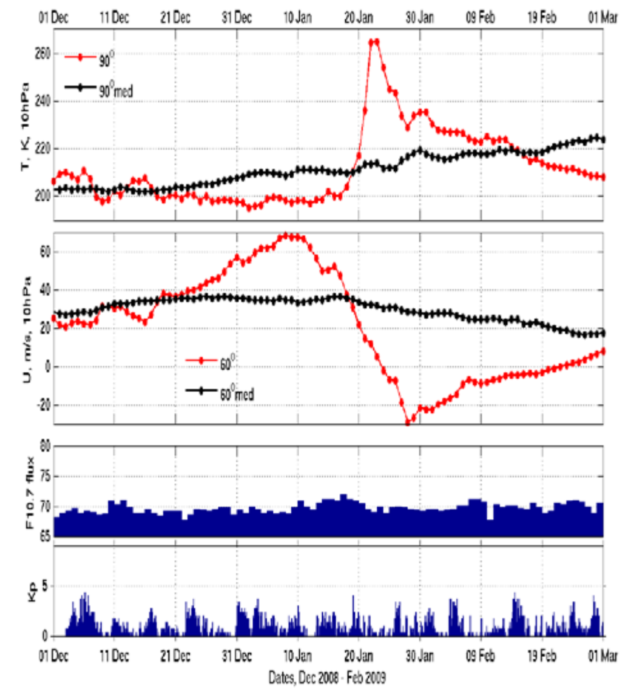


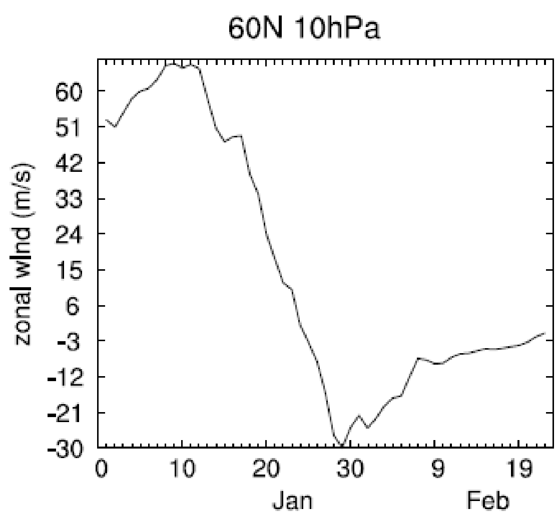
Instabilities in strong stratospheric jets in winter high latitudes at 50 km growing in amplitude into the lower thermosphere (100 km)

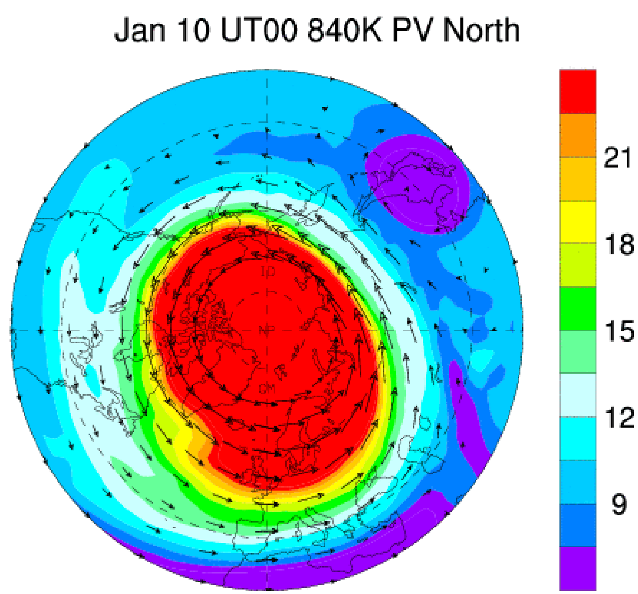
WAM simulations of the January 2009 sudden stratospheric warming











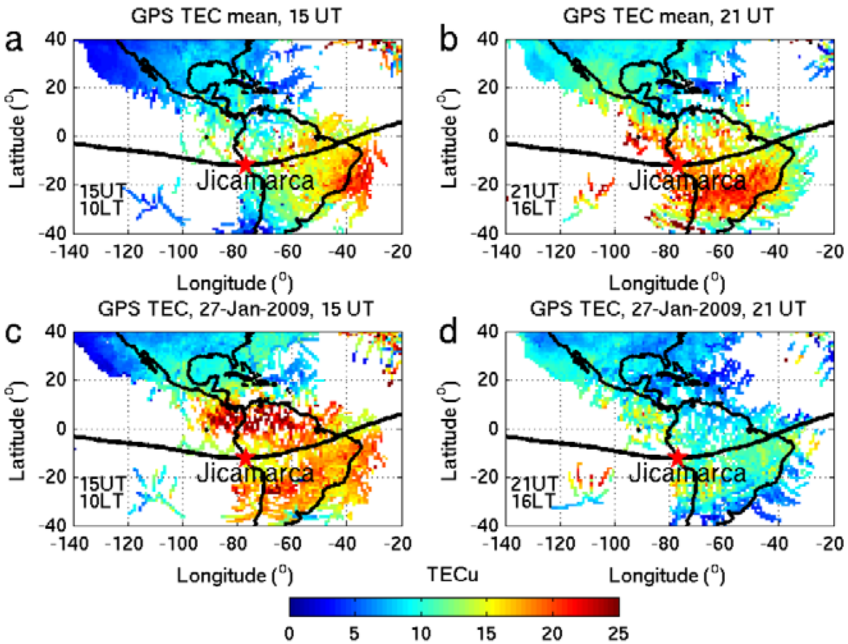
Same as ECMWF

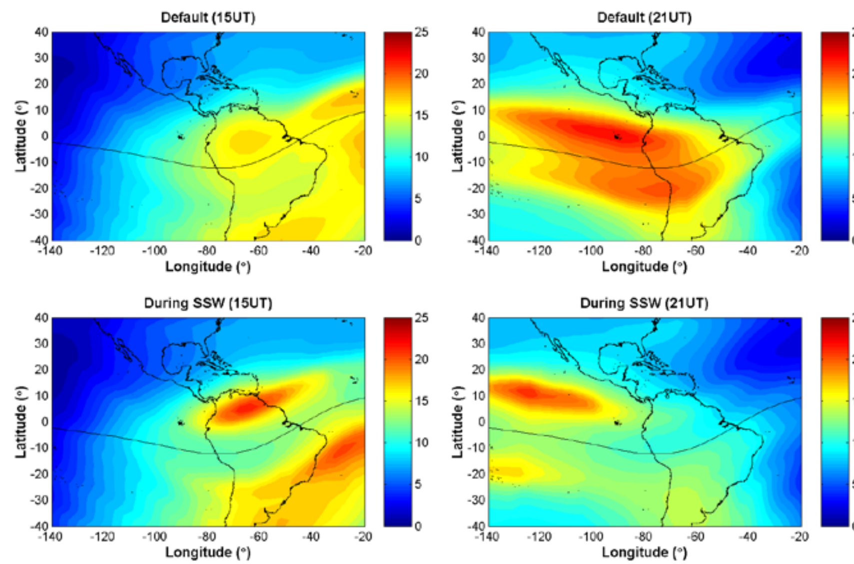
"validation"

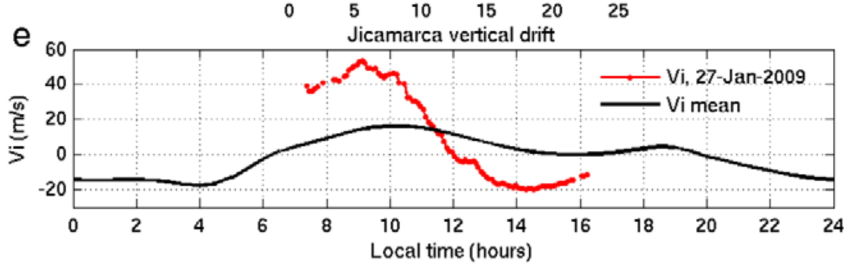
January 2009 Stratospheric Warming impact on EIA

GPS-TEC observation
before and after SSW

WAM-GIP
before and after SSW





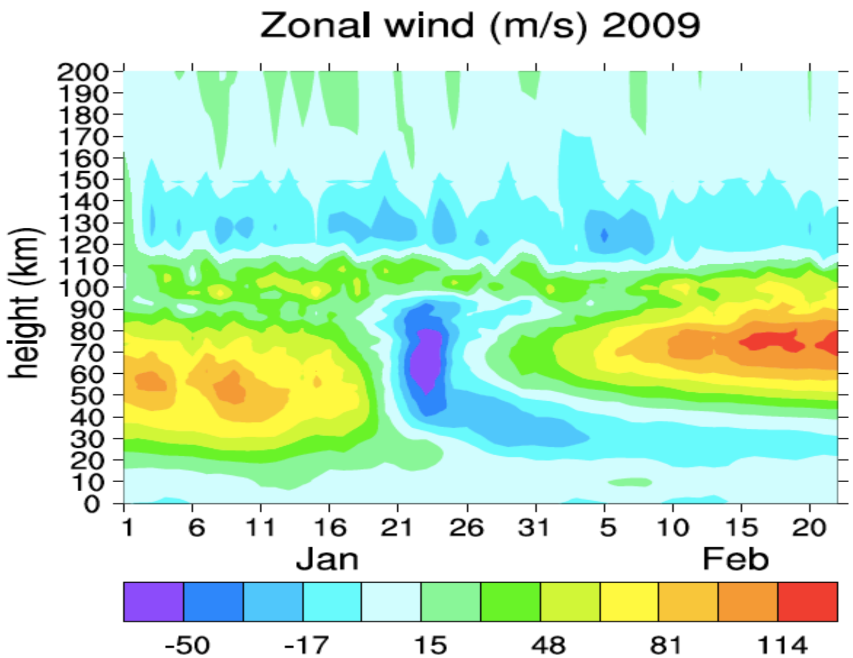


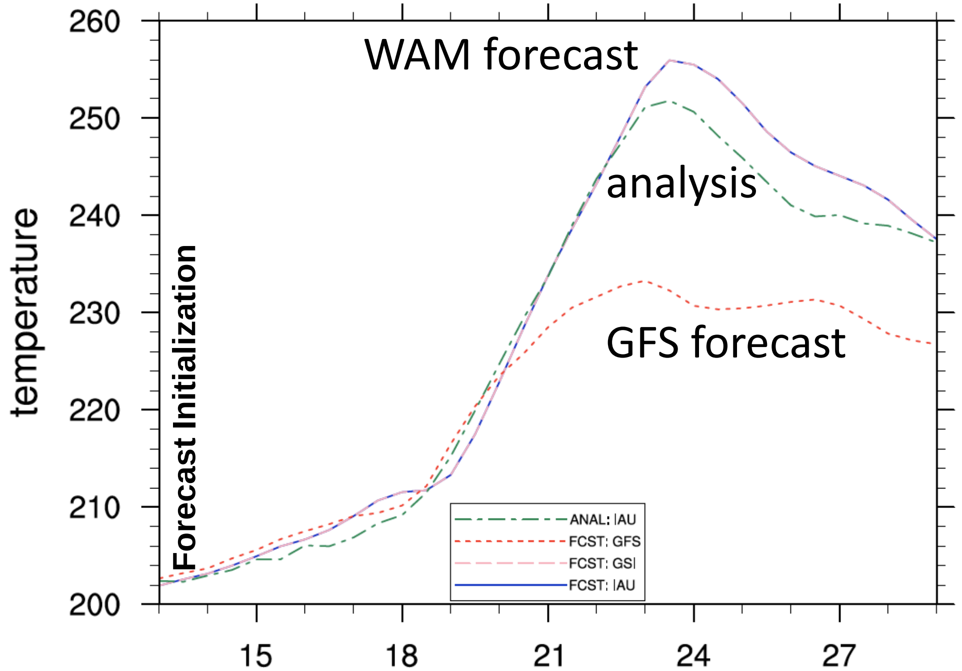
SSW vertical plasma drift
Jicamarca (Chau et al., 2010)

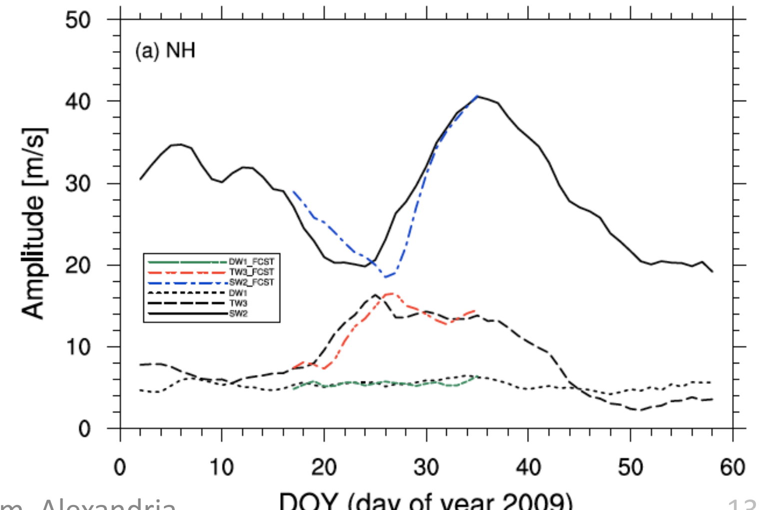
Good agreement between GIP and Goncharenko et al. (2010) on Jan 27th, 15 and 21 UT,
10 and 16 LT

Ionosphere, electrodynamic, and tidal response can be forecast at least a week ahead (Wang et al., 2011)

Initialized with analysis using operational data on Jan 13th, WAM is able to forecast the warming and tidal response several days in advance (Wang et al. 2011), farther ahead than the NWS GFS operational model







WAM also has potential to improve long-range tropospheric weather forecasting – so-called "downward control"

Ionospheric Component Requirements

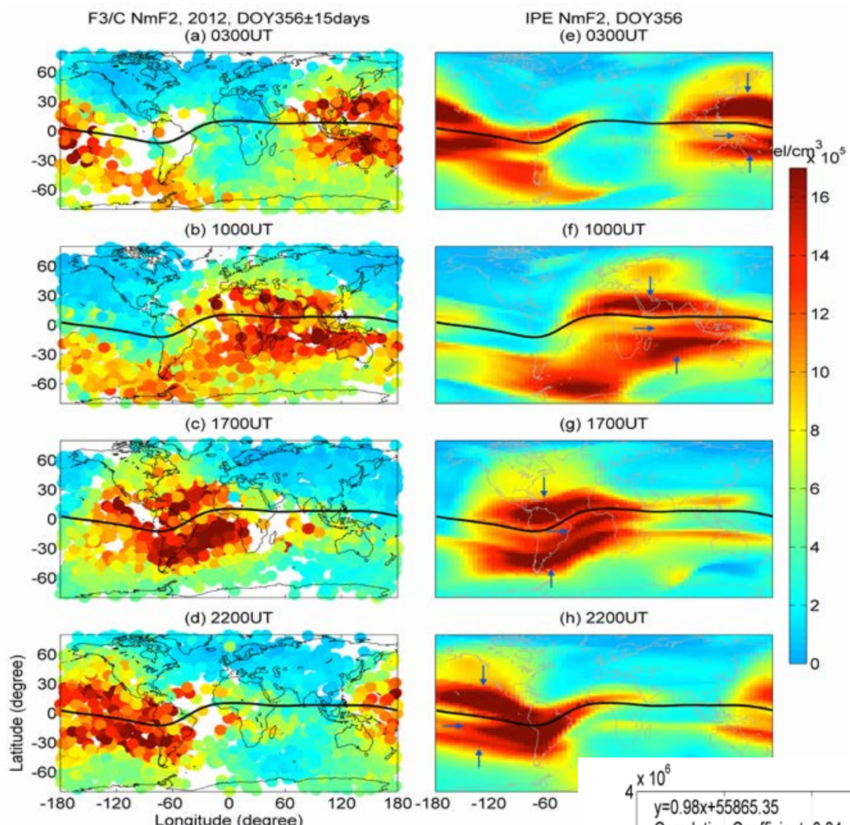
- Global, < 200 km resolution, to match T62 WAM spectral model resolution, and flexible for future applications
- Topside ionosphere for storm-time plasma storage and TEC, exchange between hemispheres at mid and low latitude (i.e., requires a plasmasphere)
- Self-consistent electrodynamics for quiet and storm-time dynamo
- IGRF and APEX coordinate system to follow shape of magnetic equator
- Earth System Modeling Framework (ESMF)-NUOPC layer compatible for 3D re-gridding and coupling to NWS weather model
- Dynamic plasmapause
- ~10x faster than real-time on ~100 processors
- Robust
- OpenSource – NWS has community model approach

- Initially will only be coupled one way with WAM – neutral horizontal and vertical winds, temperature, and composition driving the ionosphere
- Providing 3-day forecast every 6 hours

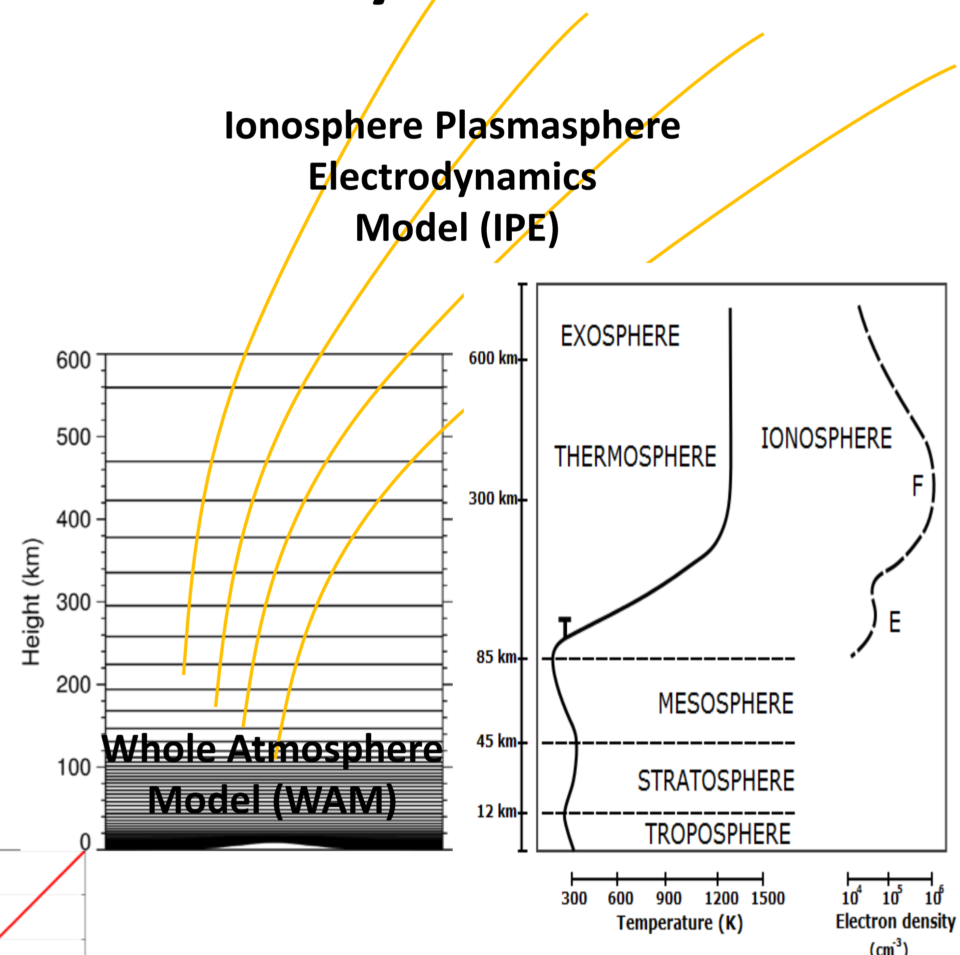
Ionosphere-Plasmasphere-Electrodynamics (IPE) Model

- Based on Phil Richards (GMU) FLIP flux-tube model (validated for > 20 years)
  - Solves for ion species (O^+, H^+, He^+, NO^+, N_2^+, O_2^+, N^+), electron and ion temperature
  - Solve for photoelectron production , transport, and loss – source of secondary ionization, plasma heating, conjugate effects
  - Comprehensive photochemistry
  - Stable flux-preserving numerical scheme
  - Comprehensive neutral gas heating rates – when fed back to WAM
- Global Ionosphere-Plasmasphere-Electrodynamics configuration - Naomi Maruyama (CIRES)
  - global seamless distribution of flux-tubes
  - perpendicular semi-Lagrangian ExB transport
  - flexible resolution
  - International Geomagnetic Reference Atmosphere and APEX coordinate system [Richmond 1995]
  - Variable time-dependent polar cap boundary for plasma outflow and refilling
- Self-consistent global dynamo electrodynamics module on same grid, merged with magnetospheric electric fields - Art Richmond/Astrid Maute (NCAR/HAO)
- ESMF 3-D re-gridding: Information exchange between WAM and IPE through interpolation across very different 3-D grid structures (lat, long, pressure vs flux tubes)
- SMS/MPI parallel processing
- Forcing – initially
  - Weimer empirical magnetospheric electric field driven by DSCOVER IMF and solar wind observations
  - TIROS/NOAA empirical auroral precipitation
  - Penetration electric field
  - WAM fields
- Forcing – future
  - Geospace fields
  - Improve penetration E-field

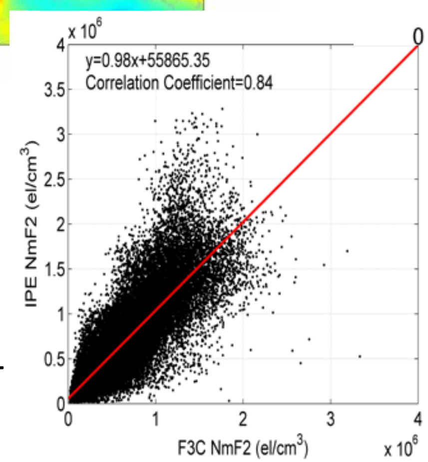
Ionospheric Plasmasphere Electrodynamics (IPE) Model Developed by Naomi Maruyama



Ionosphere Plasmasphere Electrodynamics Model (IPE)

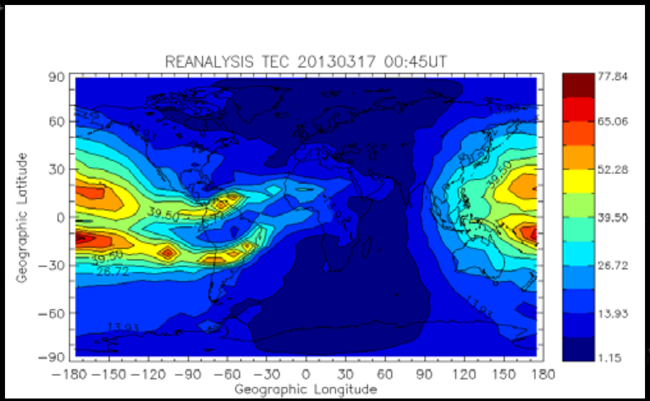


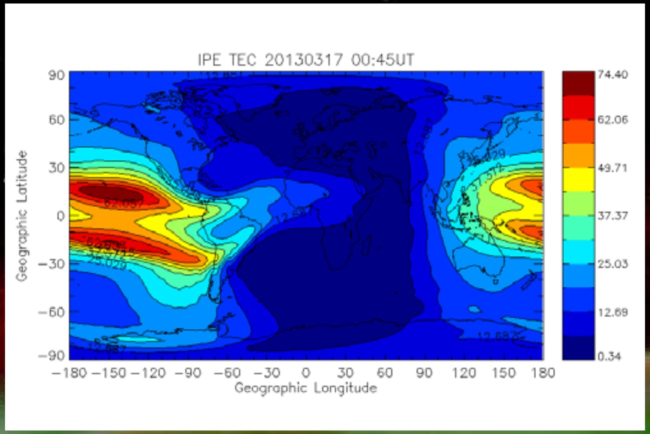
IPE validation shows excellent agreement with ionospheric climatology from COSMIC radio occultation (Maruyama et al., 2015) correlation coefficient 0.84

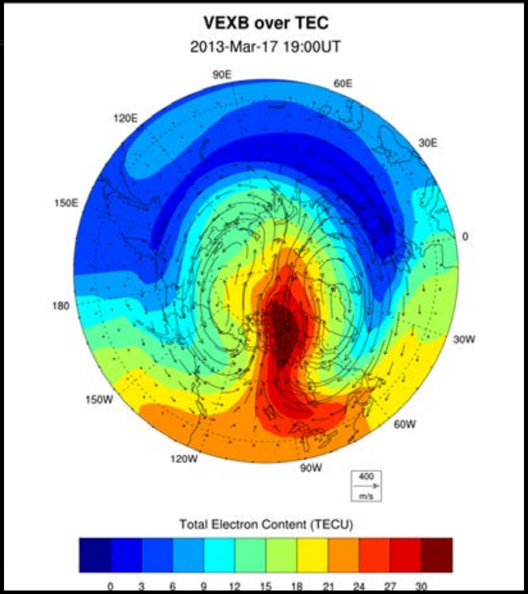


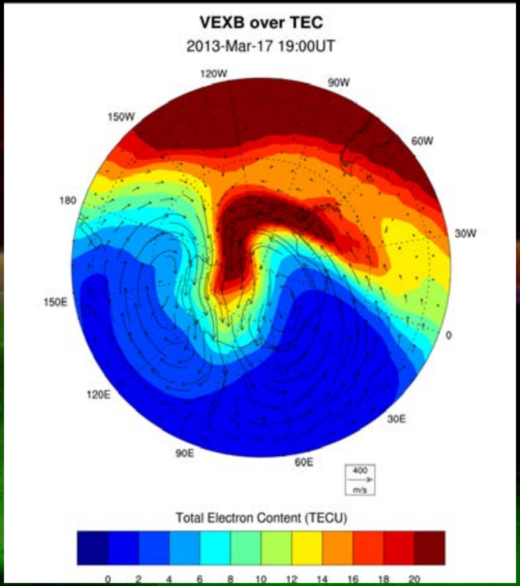
The Ionosphere-Plasmasphere-Electrodynamics (IPE) model is being coupled to WAM using the Earth System Modeling Framework. WAM-IPE is scheduled to be transitioned into operations at NOAA National Weather Service in 2017/18

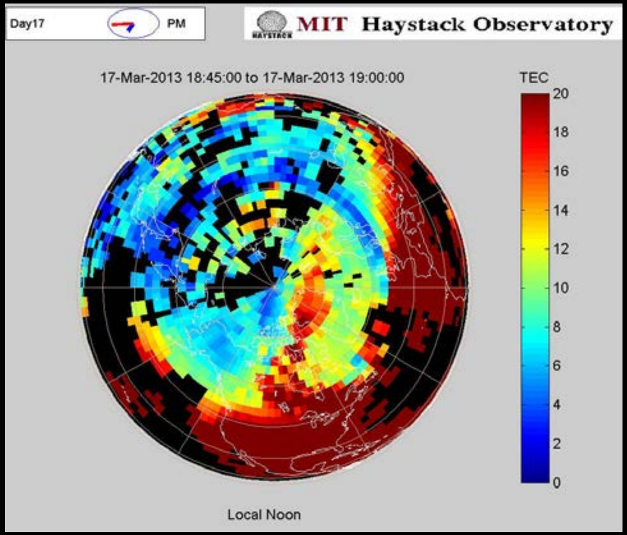
19UT March 17, 2013 North and South Hemisphere

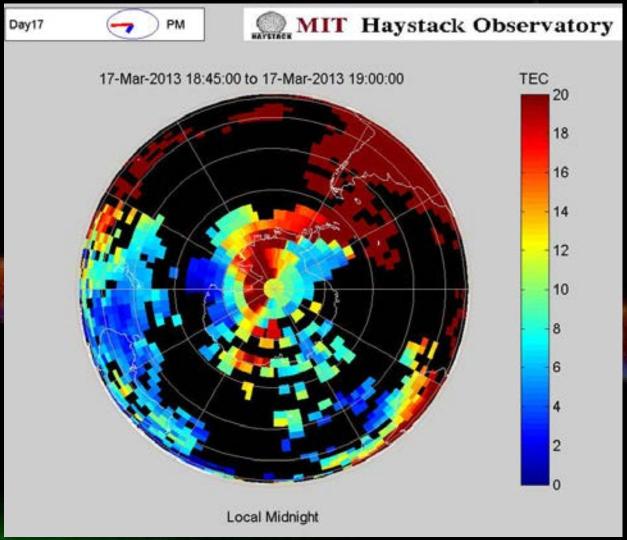












quiet initial conditions

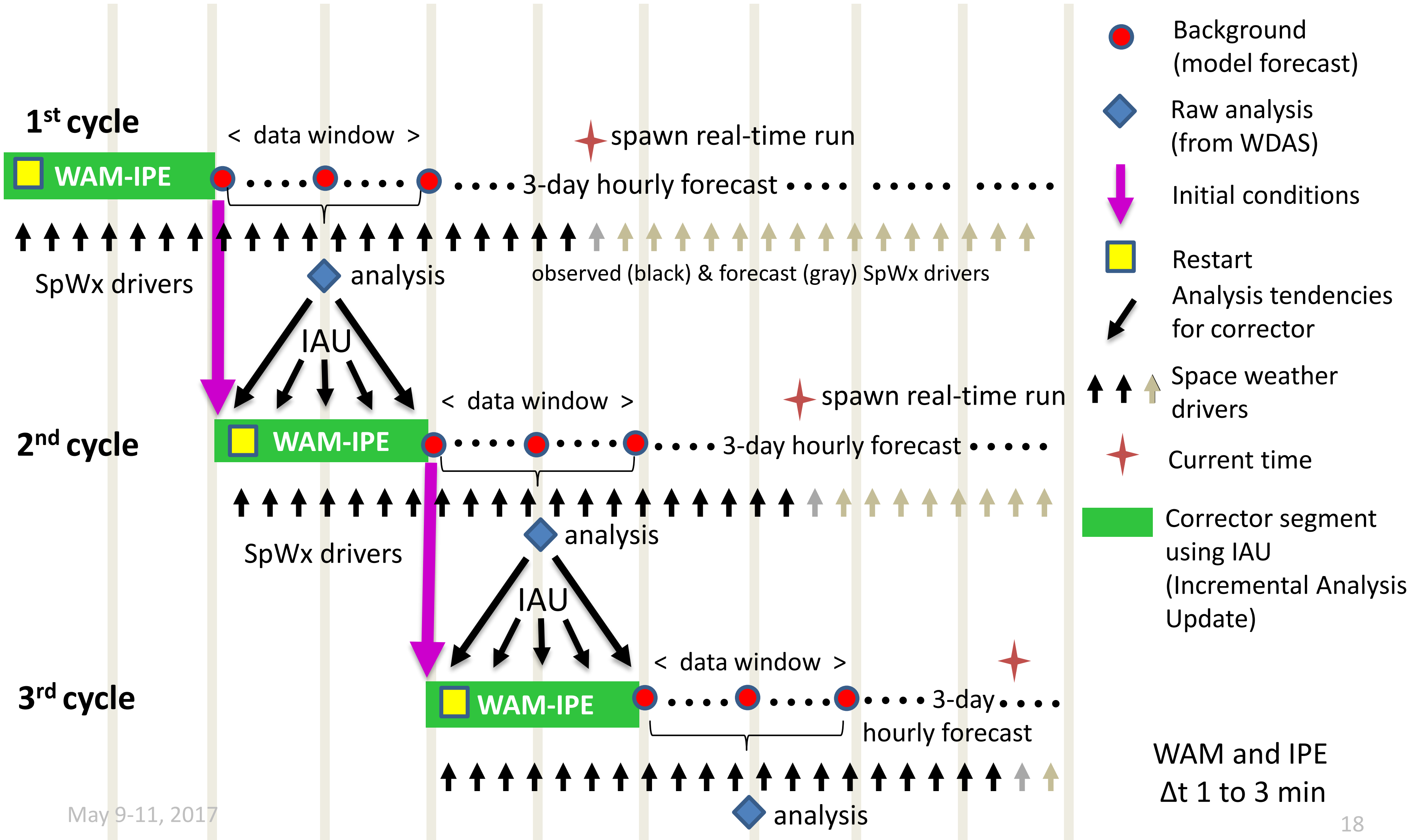
Re-analysis vs IPE

Anthea Coster

TEC maps MIT

WAM-IPE Operational CONOPS

Three-day forecast every six hours



Summary and Conclusions

- The initial WAM-IPE configuration to be tested in September 2017 is first step, initially one-way coupling WAM to IPE only

- It will include physics-based data assimilation in the lower atmosphere (below 60 km)

- The initial configuration will also be constrained by the NWS-NCEP 6-hour assimilation cycle, which will initially lag real time by a few hours.

- Penetration electric field model is preliminary – need for improved empirical penetration electric field model (e.g., Manoj algorithm with latitude structure), or coupled RCM, or coupling with operational Michigan Geospace model

- Potential to expand the GSI data assimilation to 100 km, and add thermosphere/ionosphere data assimilation in upper levels with GOLD and COSMIC-II, need for shorter more rapid assimilation update cycle, and launch of "real-time" run to follow space weather drivers in real-time

- Possibility to include irregularity model driven by WAM fields

- Possibility to upgrade to new non-hydrostatic dynamical core FV3 and improve resolution to capture more of the wave spectrum

- The configuration will be a community resource – new NWS paradigm. It is important to push for a NOAA grants program to enable proposals for improvements in all space weather operational models (WSA-ENLIL, Geospace, WAM-IE), whole-atmosphere data assimilation schemes, data sources, and products