Ionospheric Models at the NOAA Space Weather Prediction Center

Rodney Viereck

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Space Weather Prediction Testbed

1. And Univ. Colorado CIRES

Outline:
Specification
Forecasts
Ensemble Modeling and Data Assimilation

Space Weather Prediction Center

Operations – Space Weather Forecast Office

Putting out daily forecast since 1965.

Specifications; Current conditions

Forecast; Conditions tomorrow

Watches; Conditions are favorable for storm

Warnings; Storm is imminent with high probability

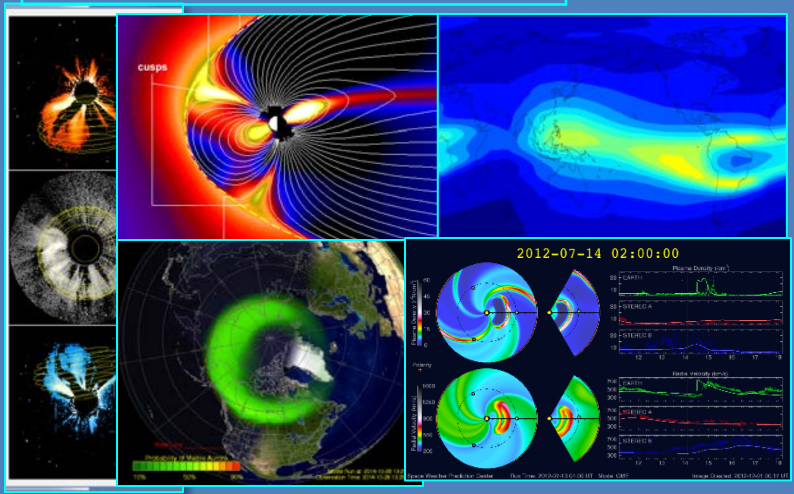
Alerts; observed conditions meeting or exceeding storm thresholds

R & D – Space Weather Prediction Testbed

Improving Products and Services

Research-to-Operations
- Applied Research
- Model Development
- Model Test/Evaluation
- Model Transition
- Operations Support

Operations-to-Research
- Customer Requirements
- Observation Requirements
- Research Requirements



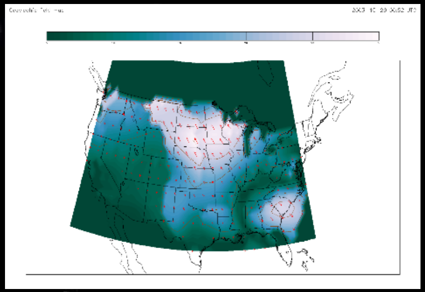
SWPC Models

- Solar
  - Wang Sheeley Arge (USAF)
- Heliosphere
  - Enlil (George Masson U.)
- Magnetosphere
  - Space Weather Modeling Framework (U. Mich.)
  - OVATION Prime 2013 (JHU APL)
- Ionosphere
  - D-RAP: D-Region Absorption Product
  - US-TEC: US Total Electron Content
  - CTIPe: Coupled Thermosphere Ionosphere Plasmasphere with electrodynamics
  - GIP: CTIPe ionosphere only
  - IPE: Ionosphere-Plasmasphere-Electrodynamics Model (3D-FLIP)
- Thermosphere/Atmosphere
  - Whole Atmosphere Model (WAM)

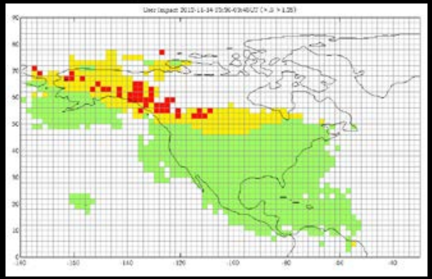
Ionospheric Models and Products

Development

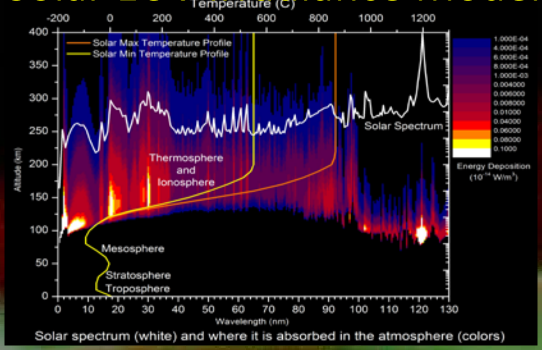
Electric Field Model



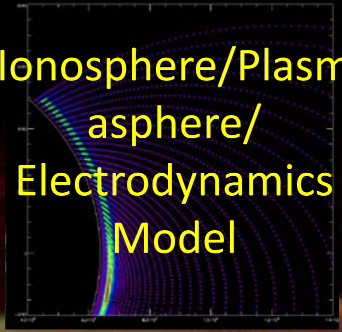
ROTI GPS Product



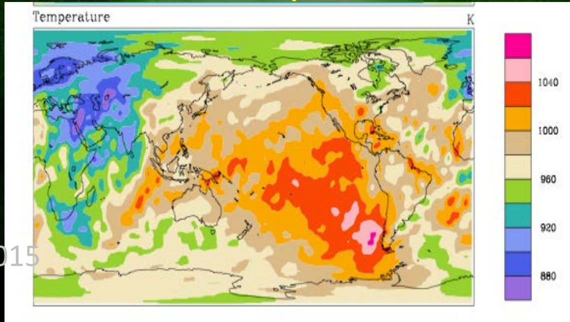
Solar EUV Irradiance Model



Ionosphere/Plasmasphere/Electrodynamics Model



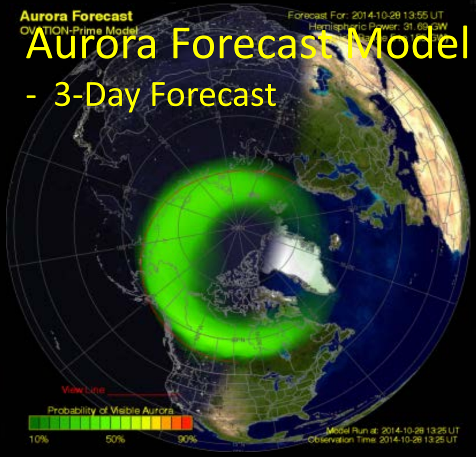
Whole Atmosphere Model



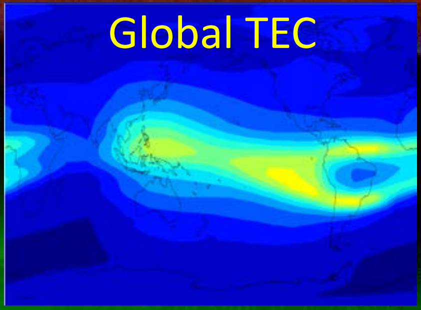
Prototype

Aurora Forecast Model

- 3-Day Forecast

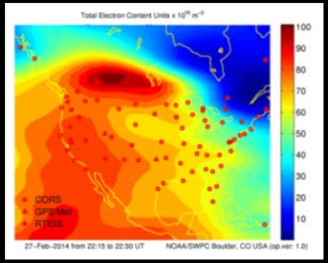


Global TEC

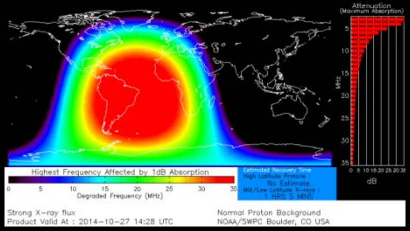


Operations

US-TEC

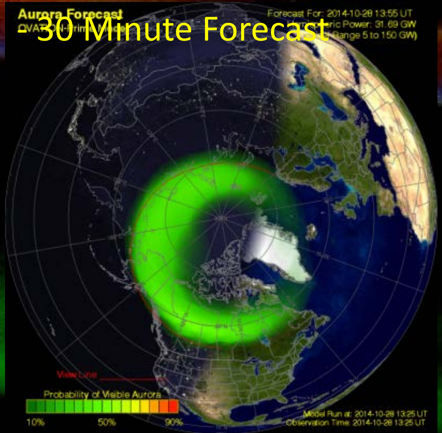


HF Com Absorption

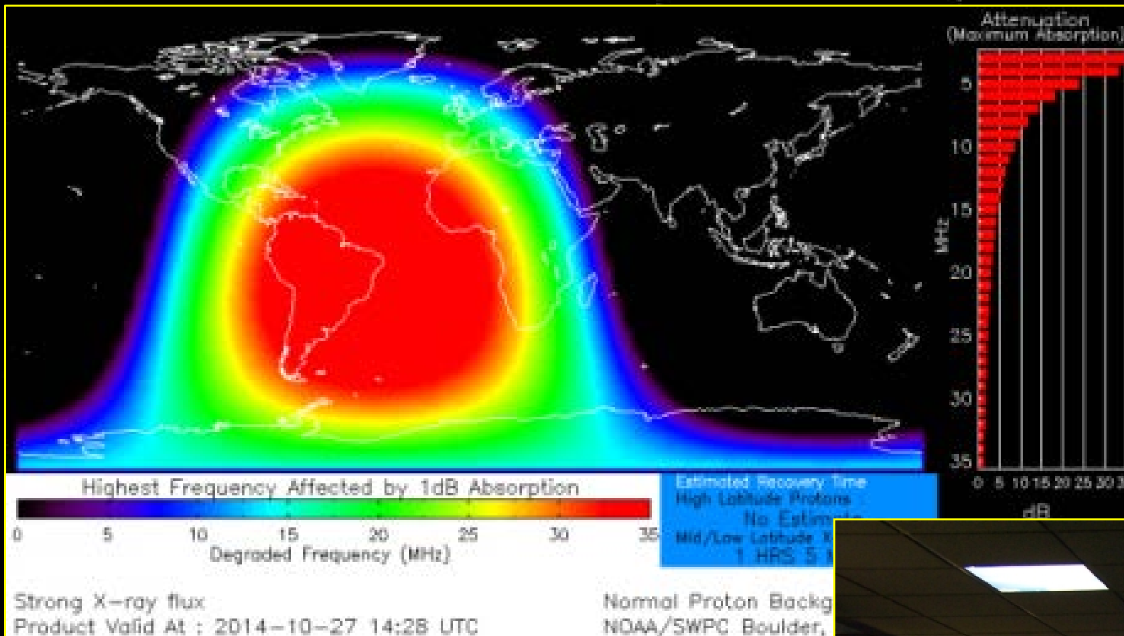


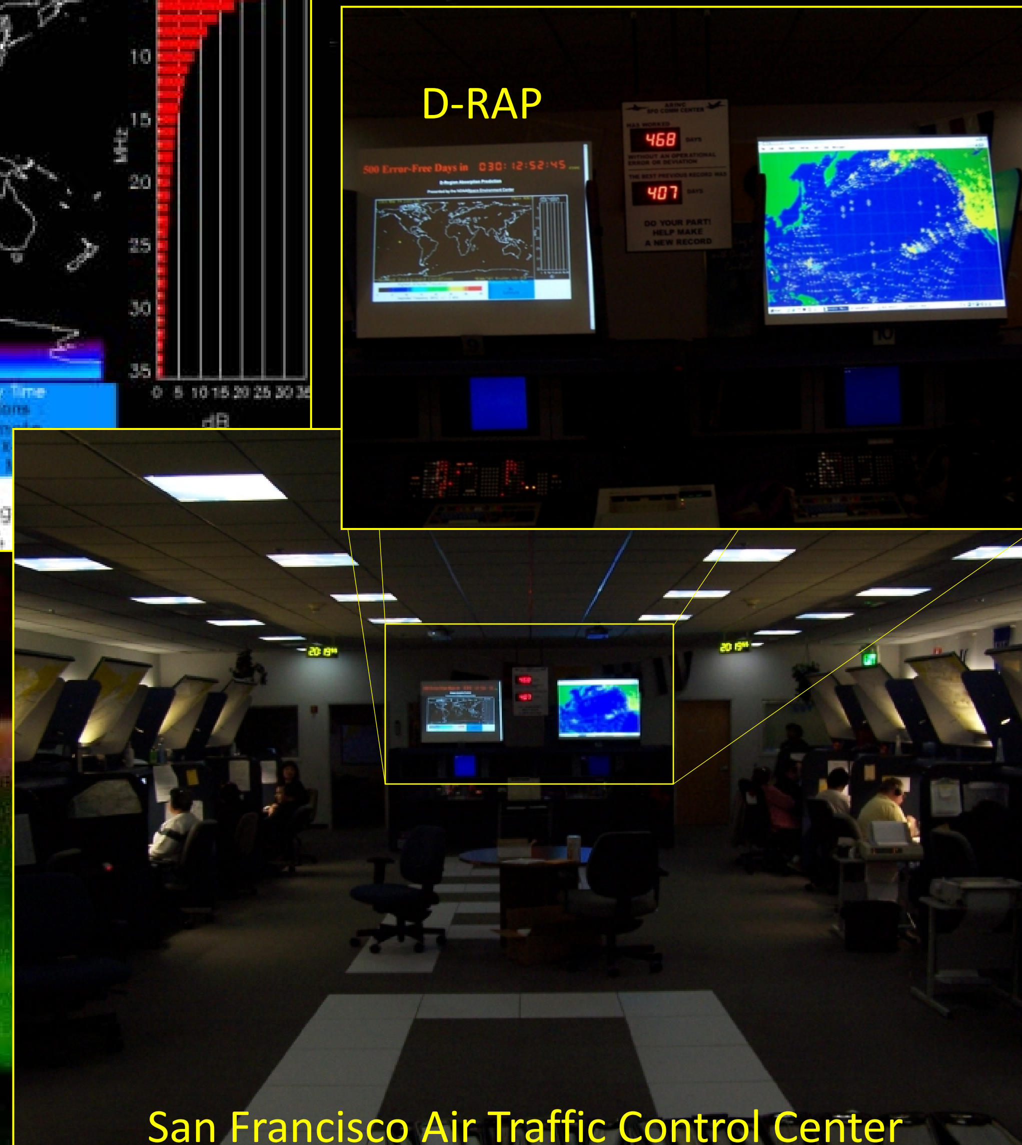
Aurora Forecast Model

- 30 Minute Forecast



D-Region Absorption Product (D-RAP) and HF Com



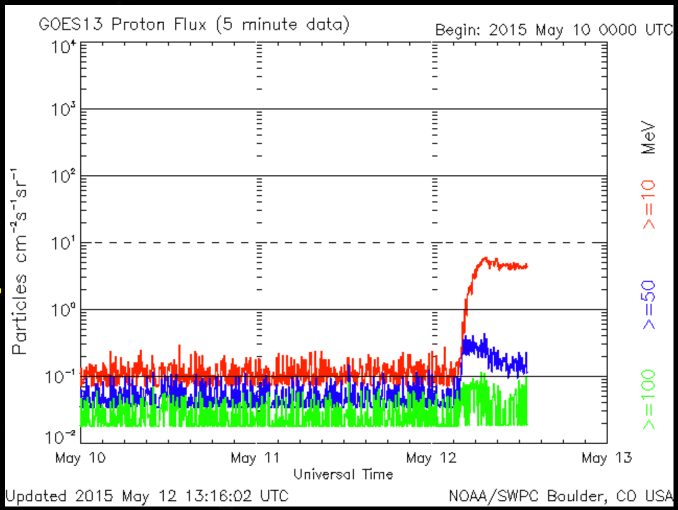


- Global D-Region Specification for HF Com.
- Inputs: Solar X-ray, Energetic Protons, Kp
- Customers: Airlines, Maritime, DHS, DOD, Ham

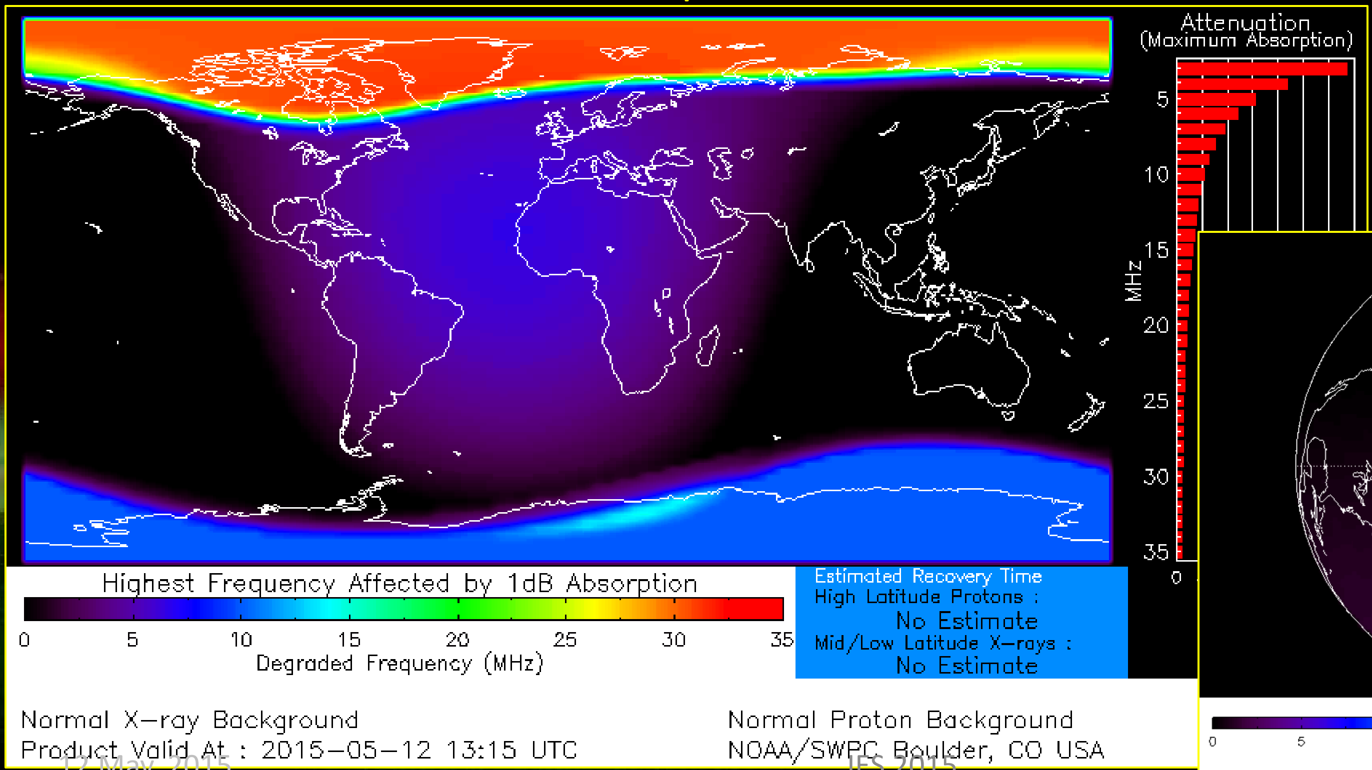
D-Rap: Current HF

Minor proton event 5/12/2015

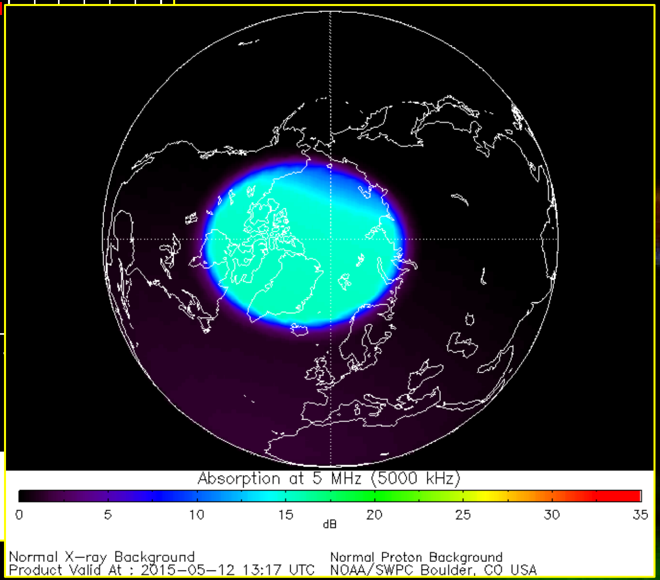
http://www.swpc.noaa.gov/products/d-region-absorption-predictions-d-rap



1 dB Absorption

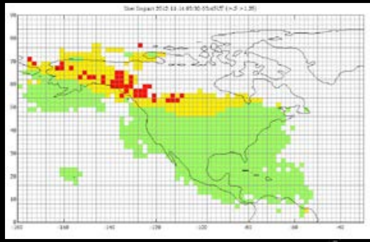


Absorption at 5 MHz



US – Total Electron Content

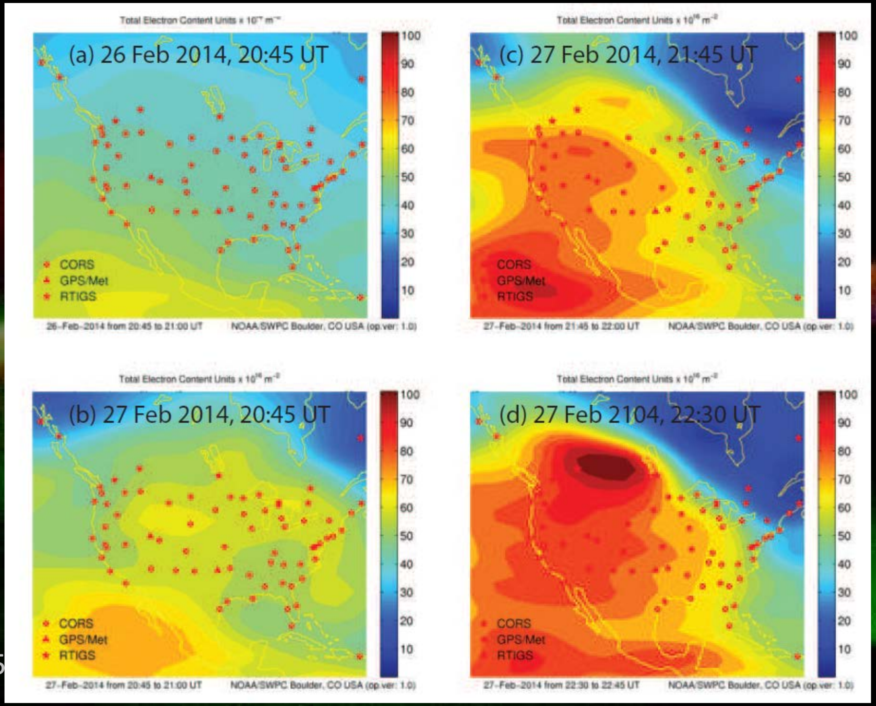
- Assimilative product creating TEC maps from ground GPS receivers
- Customers: GPS/GNSS Users (Airlines, FAA, Transportation, etc…)
- Future:
  - Expand to all of North America
  - Input from COSMIC II Radio Occultation
  - ROTI product for precision GPS customers

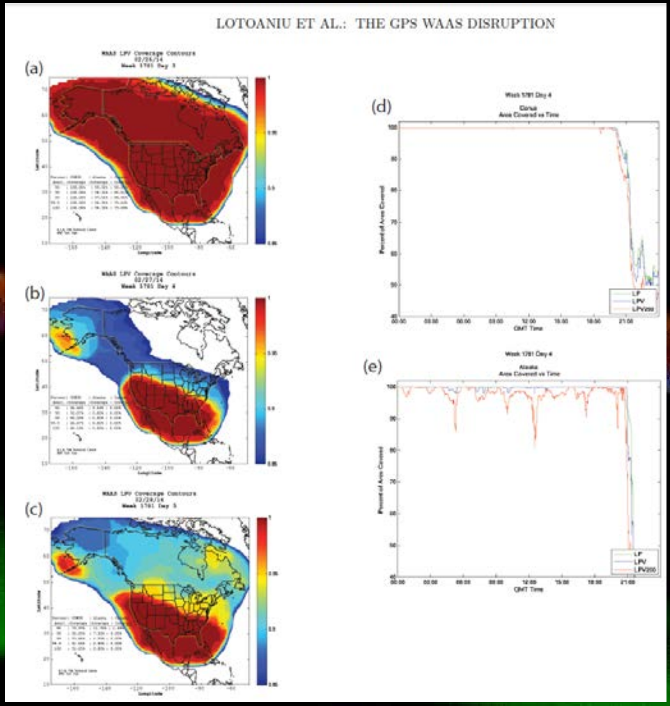


ROTI product by Propagation Research Ass. And JPL

USTEC captures the TEC enhancement during a moderate storm(Kp<6)

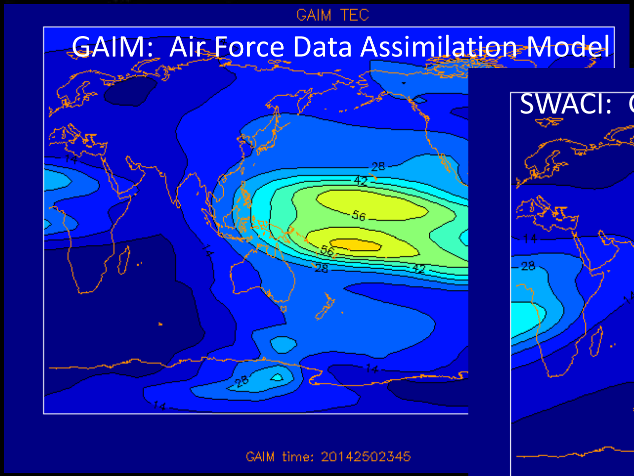
Storm produced day-side ionospheric structures that impacted the FAA WAAS

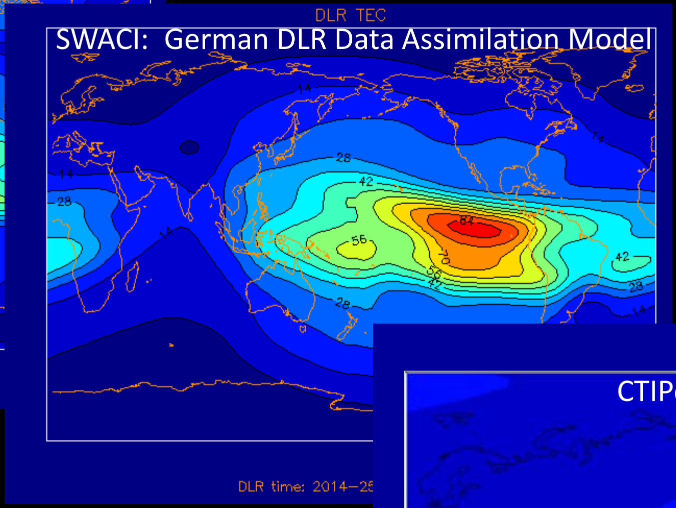


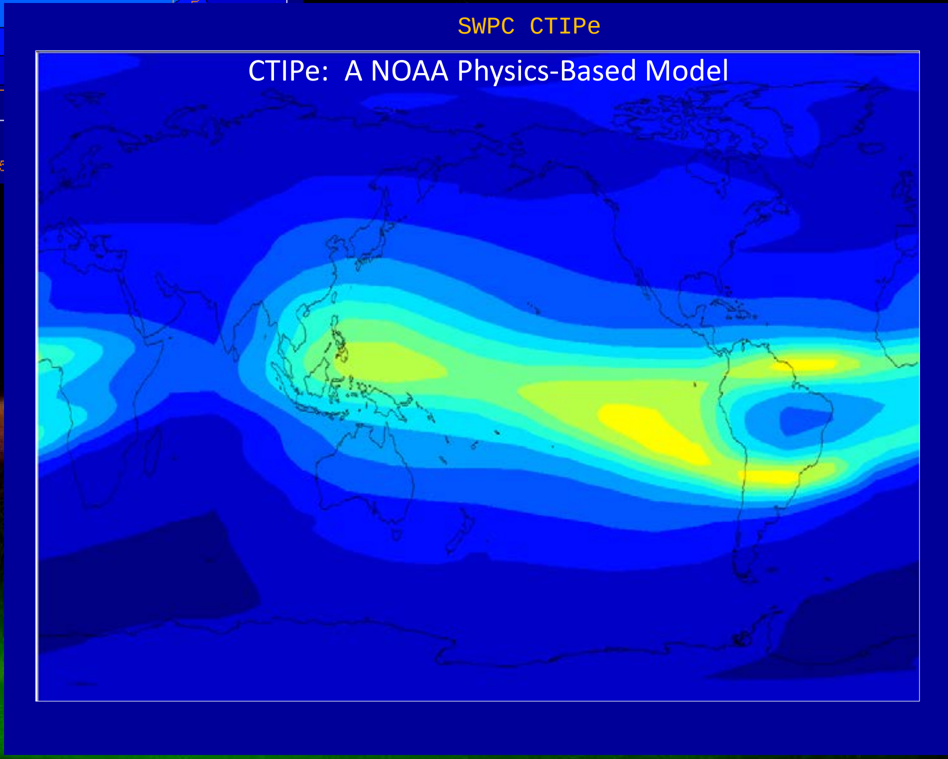


Comparing Empirical and Physics-Based Models

Real-time Global TEC Specification



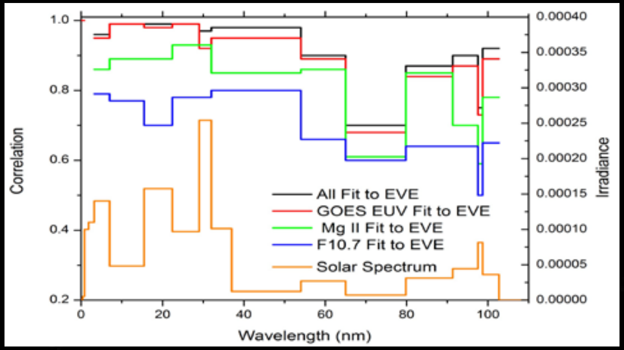




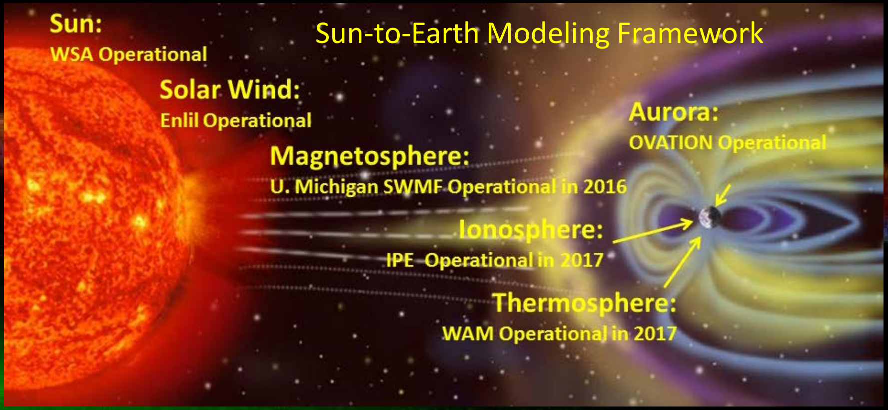
- **NOAA is testing global TEC specification models:**
  - **Air Force GAIM**
  - **DLR SWACI**
  - **NOAA CTIPe (physics-based)**
- **Each model has its strengths and weaknesses.**

Requirement: Multi-Day Forecasts of the Ionosphere

- Requires multi-day forecasts of all three drivers
  - Solar EUV and X-ray irradiance
    - GOES real time EUV irradiance
    - AFRL ADAPT forecast (1-7 days)
  - Geomagnetic Storms
    - WSA – Enlil – SWMF – I/T models
    - 1-7 day geomag forecast.
    - 1-3 day storm forecast
      - Still missing Bz
  - Forcing from the lower atmosphere (tides and waves)

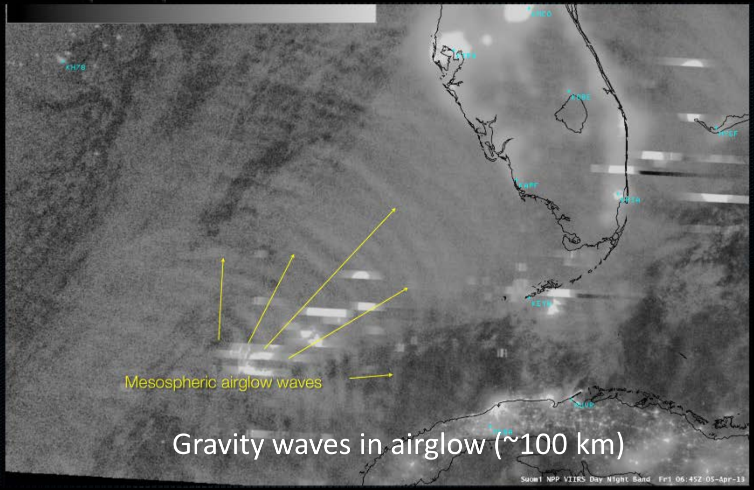


Broadband Parameterization based on Solomon and Qian (2005)



Why Couple to the Lower Atmosphere?

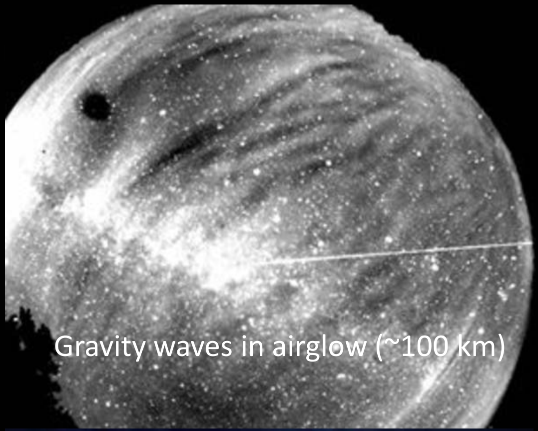
Gravity Waves



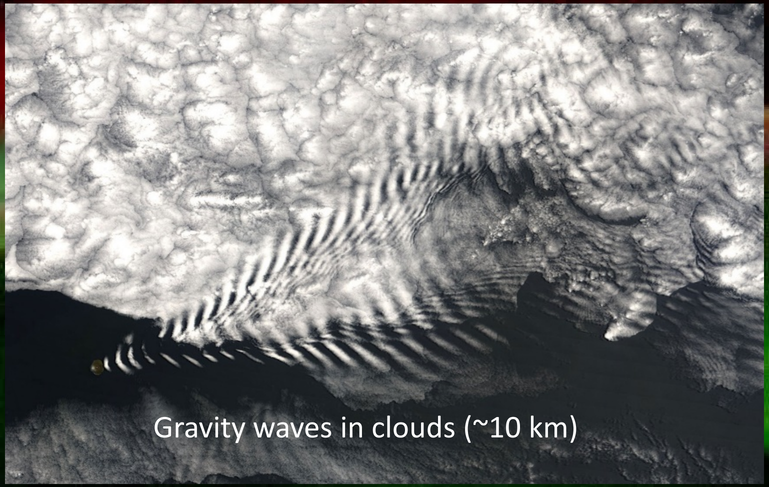
Gravity waves in airglow (~100 km)

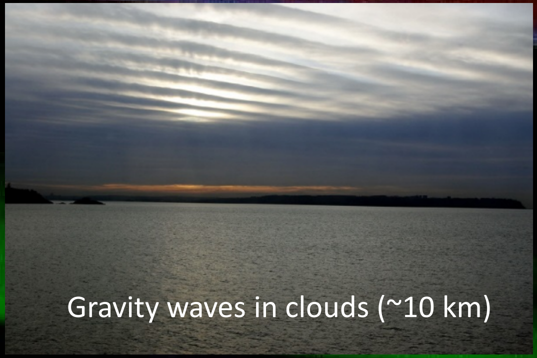
Gravity waves

- Propagate upward
- Grow in amplitude as they go up.
- Often break at some altitude
- When the break, they deposit energy (both **thermal** and **momentum**)


Gravity waves in airglow (~100 km)

Gravity waves in clouds (~80 km)


Gravity waves in clouds (~10 km)


Gravity waves in clouds (~10 km)

Why Couple to the Lower Atmosphere?

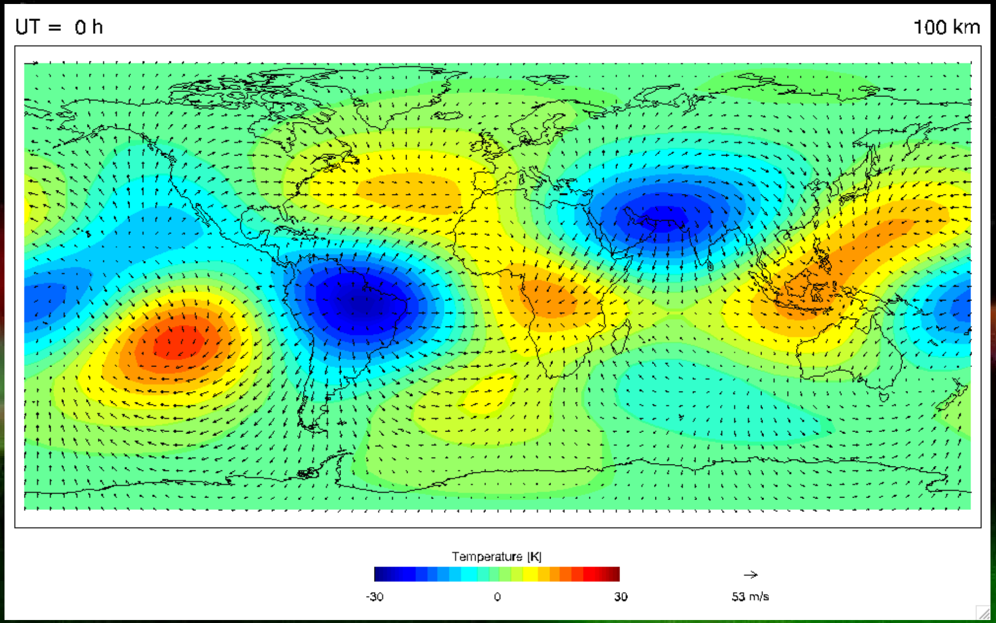
Atmospheric Tides

The four peaks in diurnal temperature amplitude result from superposition of

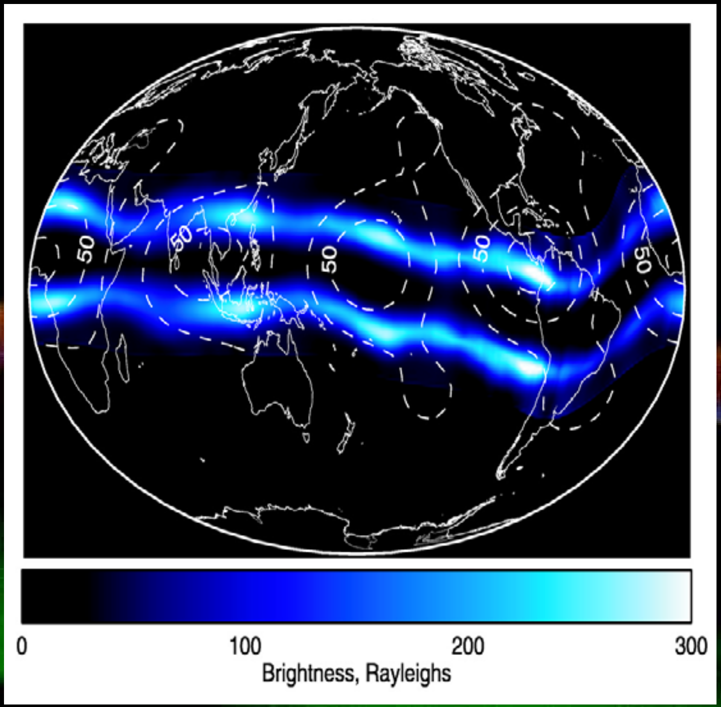
- The migrating (to the west) tide (DW1)
- Non-migrating eastward mode with zonal wavenumber 3 (DE3).

Tilel structures modifies the Ionosphere/Thermosphere system

NASA TIMED SABER and TIDI



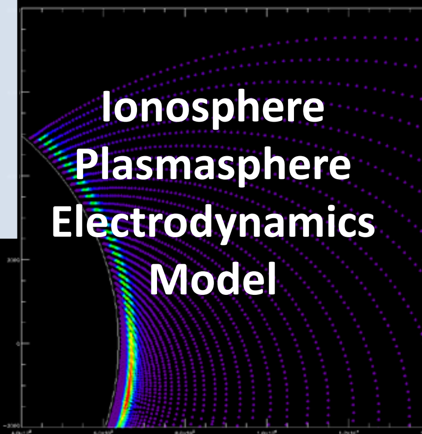
NASA IMAGE (Immel et al)



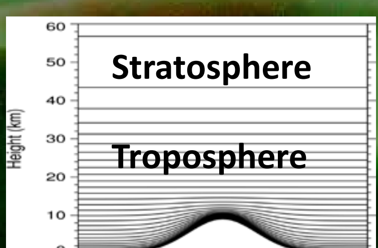
Forcing the Thermosphere from Below:
The Whole Atmosphere Model (WAM)

Global Forecast Systems (GFS = weather model)
Whole Atmosphere Model (WAM = Extended GFS)
Ionosphere Plasmasphere Electrodynamics (IPE)
Integrated Dynamics in Earth's Atmosphere (IDEA = WAM+IPE)

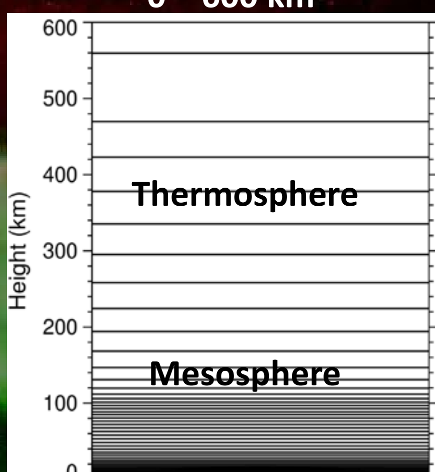
- FY15: Real-time WAM
- FY17: Real-time WAM driving IPE
- FY19: Fully Coupled WAM-IPE with data assimilation

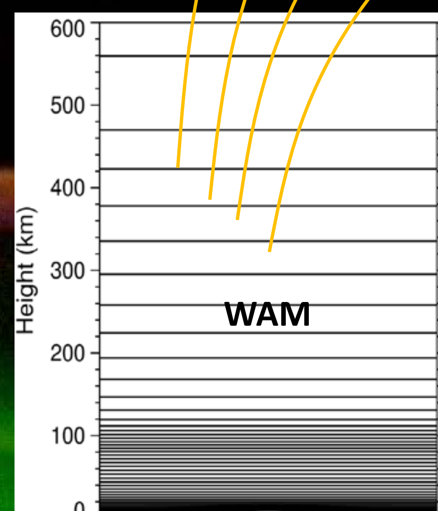


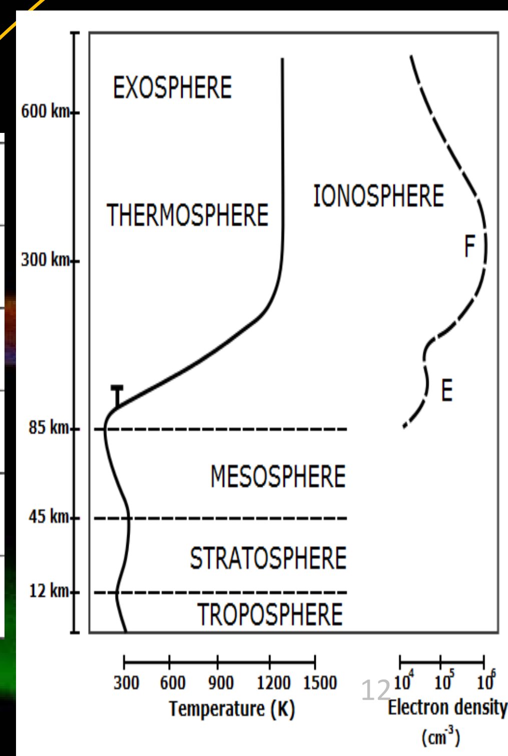
GFS
0 – 60 km



WAM
Neutral Atmosphere
0 – 600 km

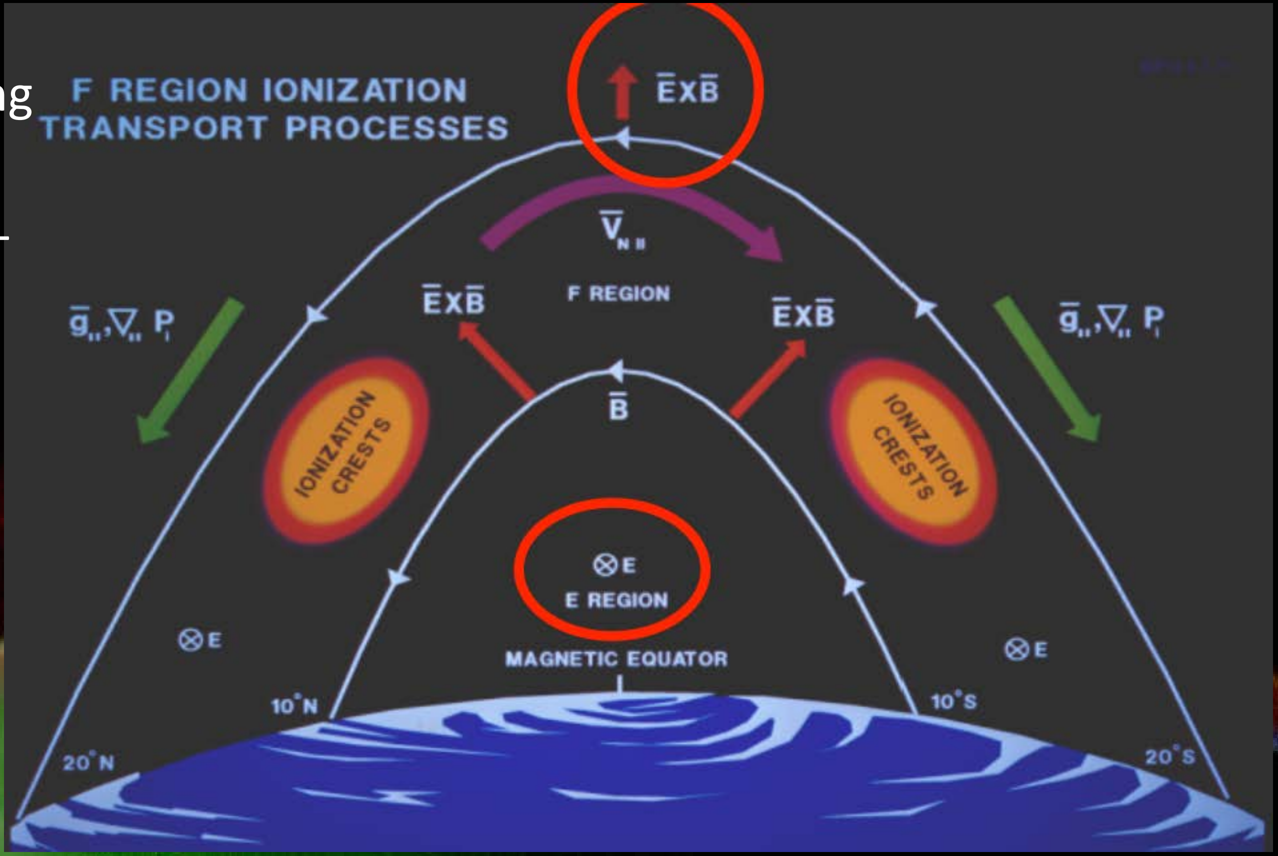




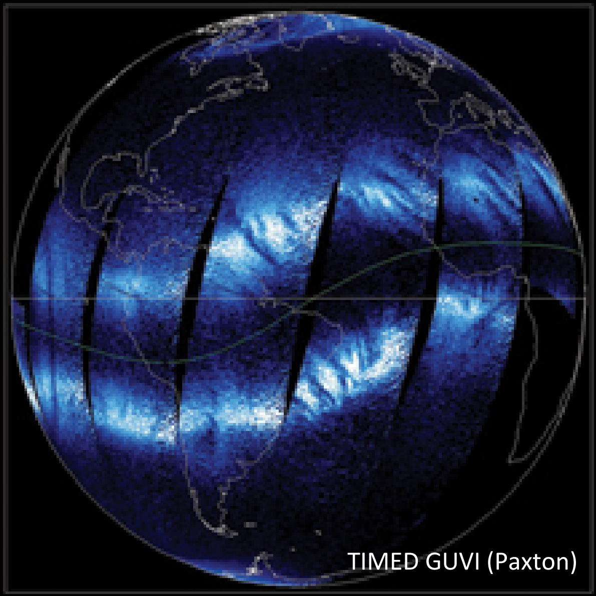


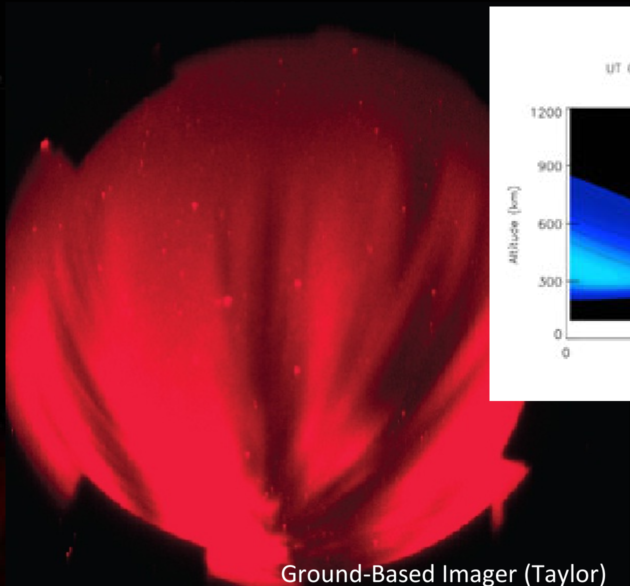
Forecasting Equatorial Ionosphere

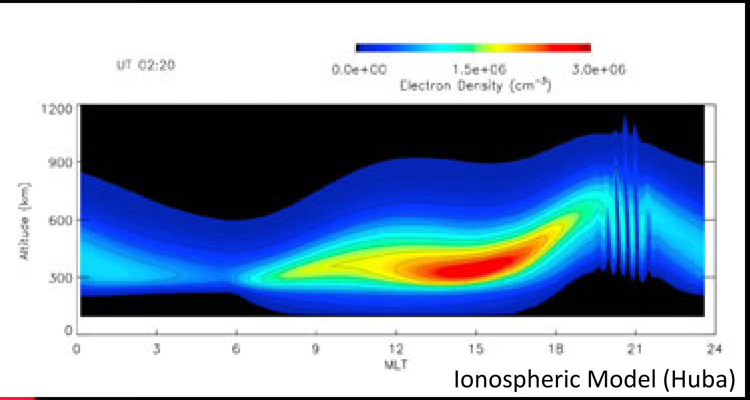
- One of the key challenges is forecasting equatorial scintillation
- Can the coupled WAM-IPE model forecast conditions that lead to equatorial ionospheric structures (ExB)?



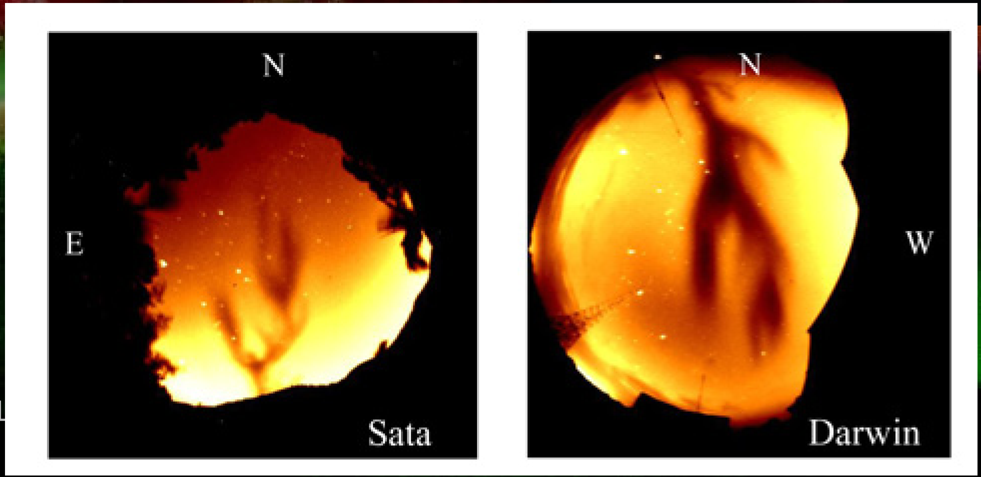
ExB Drift Leads to Plasma Bubbles
Plasma Bubbles Lead to Dropped GPS Signals

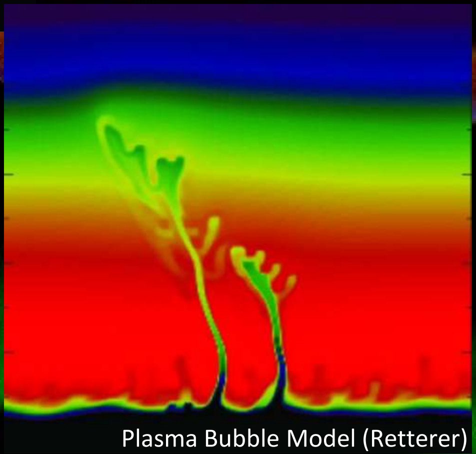

TIMED GUVI (Paxton)


Ground-Based Imager (Taylor)



Ionospheric Model (Huba)




Plasma Bubble Model (Retterer)

Midnight Temperature Maximum (MTM)

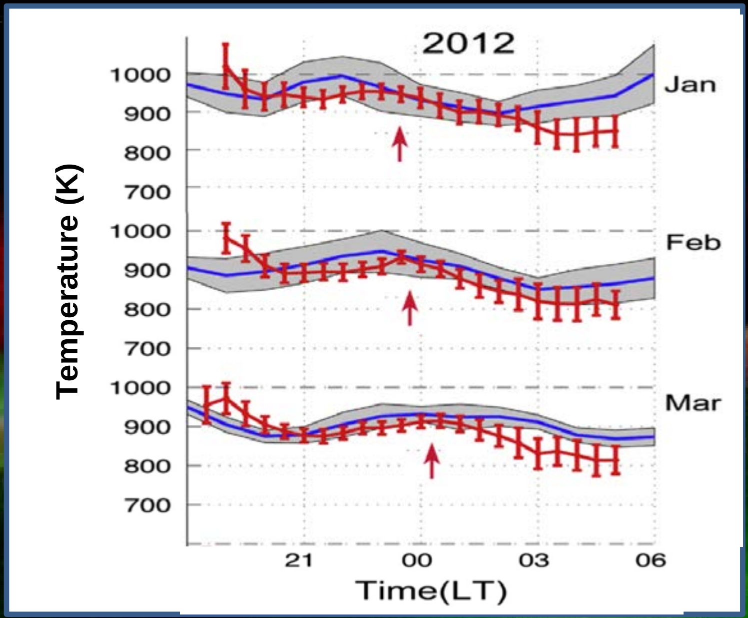
Fang et al 2014

WAM reproduces the MTM:

- WAM is the first comprehensive model to internally generate an MTM of a realistic magnitude.
- WAM simulation show robust feature of MTM and the associated midnight density maximum (MDM).

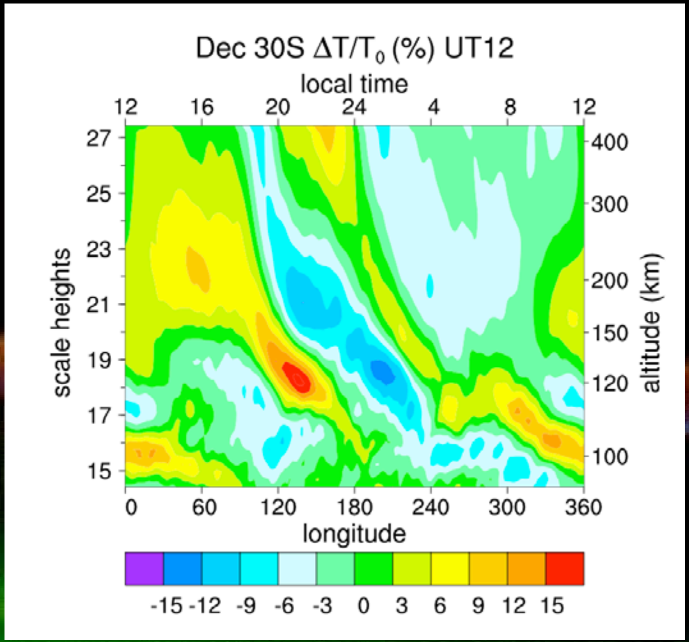
MTM is the Result of Tides in the Lower Atmosphere:

- MTM can be traced down to the lower thermosphere, where it is manifested primarily in the form of an upward propagating terdiurnal tides.
- Tides with higher-order zonal wavenumbers and frequencies modify the MTM amplitude.



Meriwether et al. (2013)

Comparisons of WAM MTM (blue) with FPI measurements at Brazil (red) from Sep 2009 to Aug 2012.



Akmaev et al. (2009)

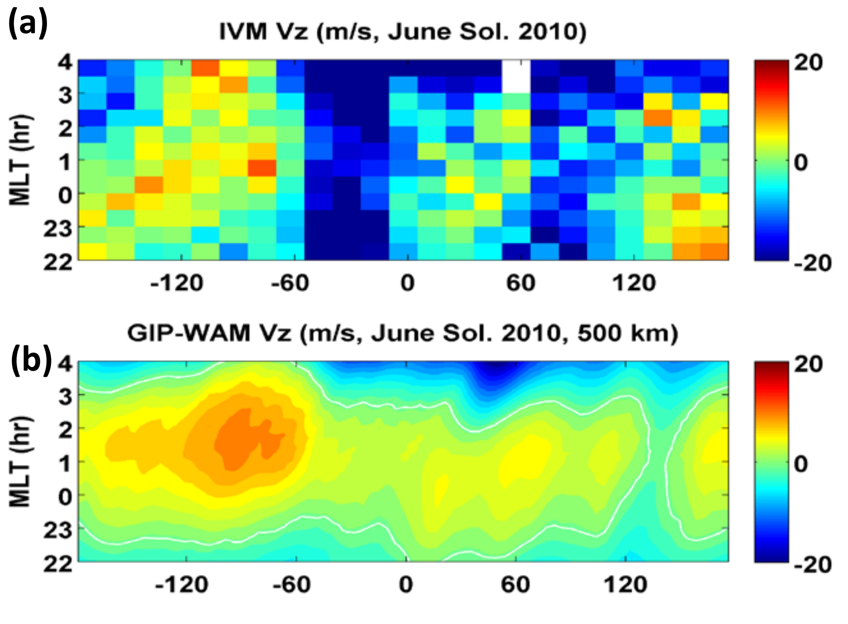
WAM simulation of relative temperature deviation as a function of height and longitude (local time)

Vertical Ion Drifts from Models and Observation

Fang et al 2014

MTM Produces ExB Drift

- Driving an ionosphere model (GIP) with WAM wave fields reproduces the magnitude and longitudinal distribution of nighttime upward drift observed by C/NOFS IVM.
- The nighttime upward drift is more pronounced in June-July season.



(a) C/NOFS IVM climatology in 2010 June solstice

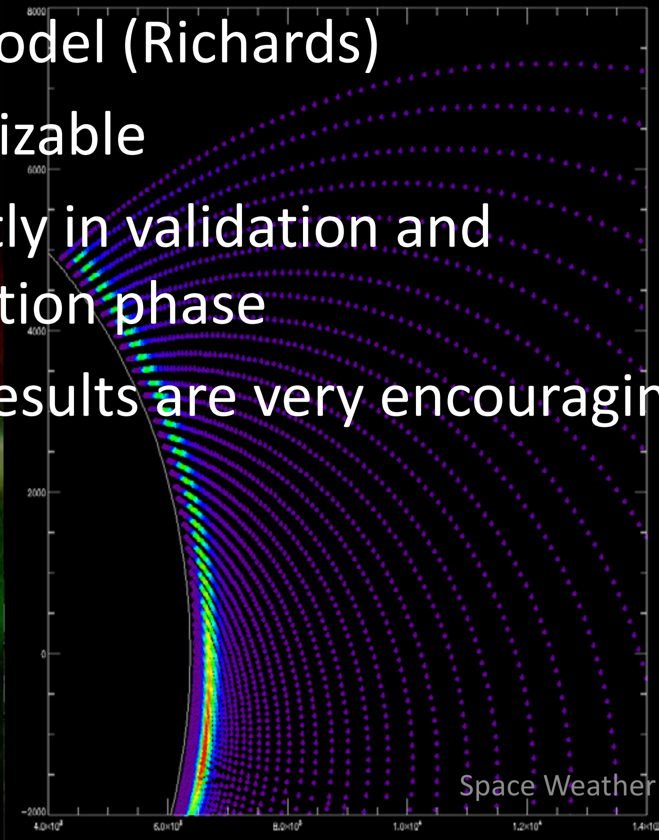
(b) WAM-GIP climatology of June and July 2010

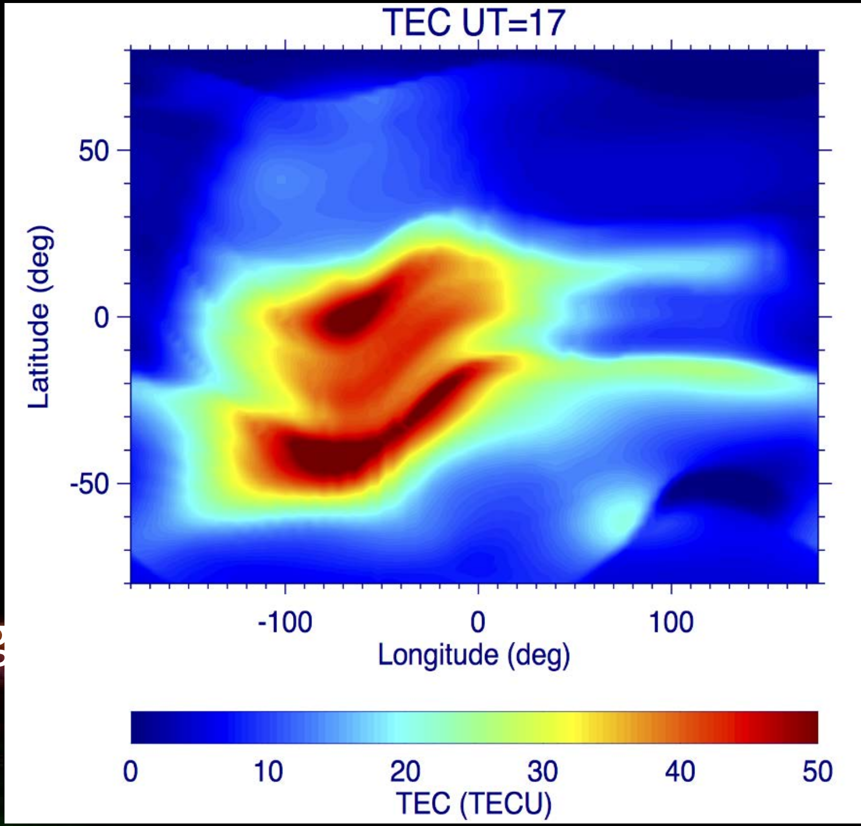
WAM + GIP produces the conditions necessary for post sunset plasma bubbles to form

Replacing GIP with IPE

(Ionosphere Plasmasphere Electrodynamics)

- GIP is a science code… not well suited for operations
- IPE is a 3D version of the FLIP flux tube model (Richards)
- Parallelizable
- Currently in validation and verification phase
- Initial results are very encouraging





Improving Forecasts

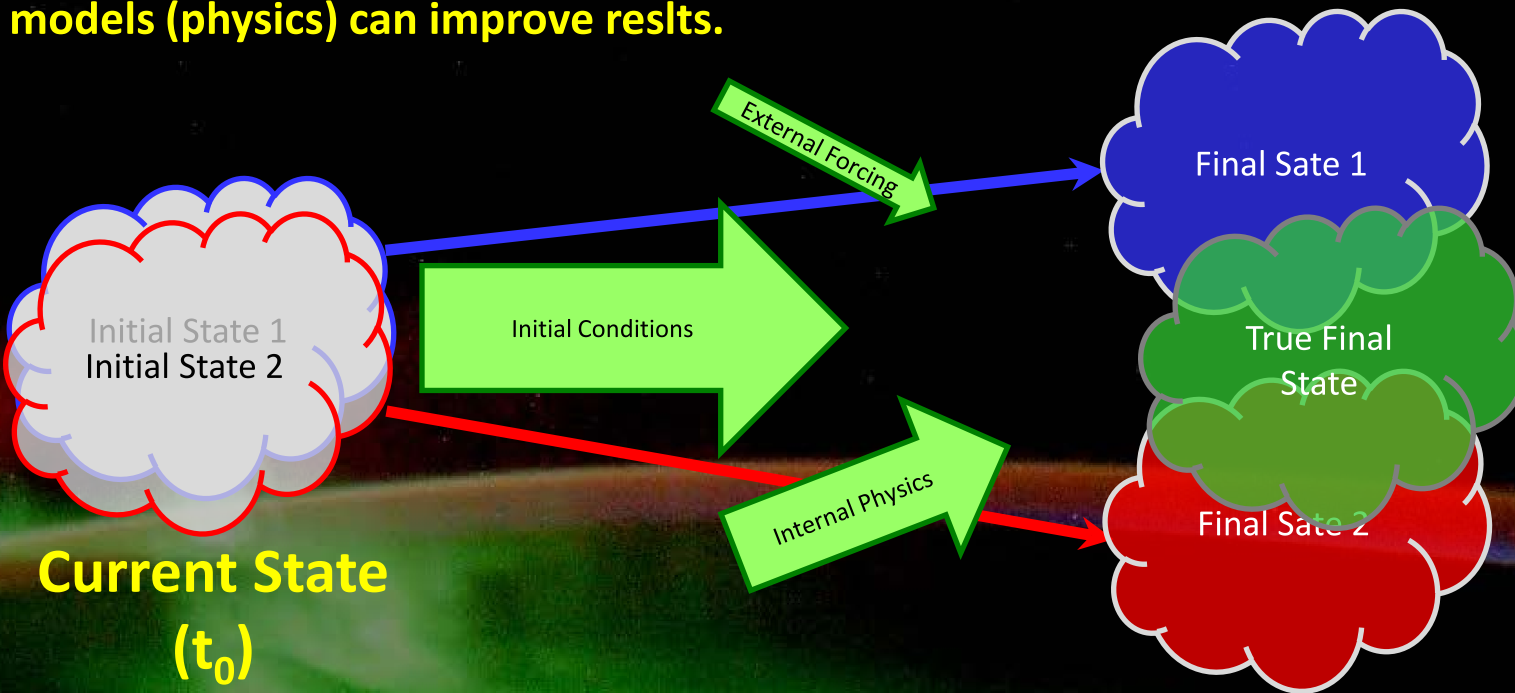
- Data Assimilation: Improving the forecast by providing a better estimate of the initial or intermediate state

- Ensemble Modeling: Improving the forecast by varying key parameters to estimate the range of solutions

Data Assimilation

Chaotic System (Weather)

- Assimilating data reduces errors in the initial state which has a big impact on the final solution
- Ensembles based on different starting conditions or different models (physics) can improve reslts.



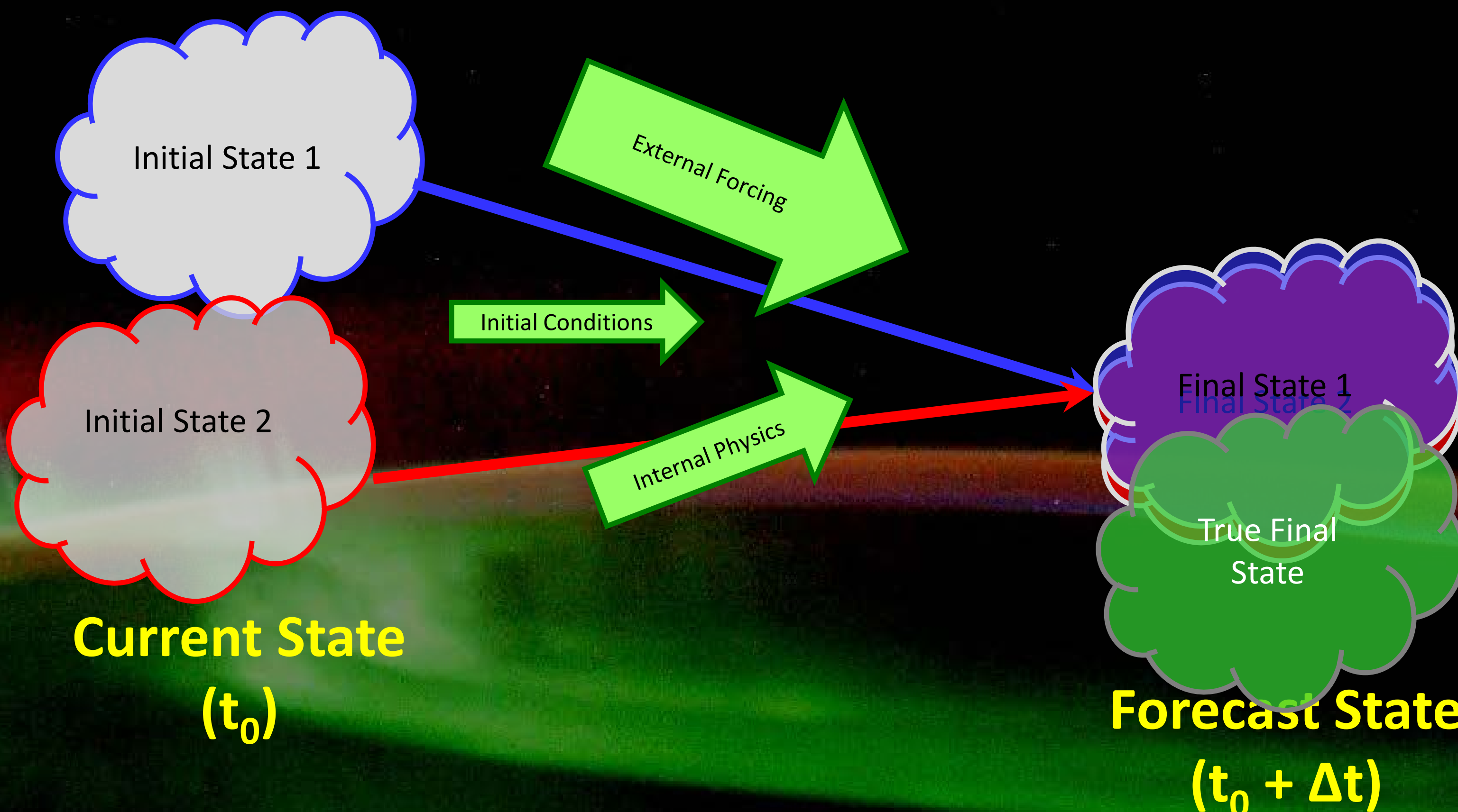
Current State (t_0)

Forecast State ($t_0 + \Delta t$)

Space Weather Data Assimilation

Driven System (Space Weather)

- Changes in the external forcing dominate. Initial state loses importance quickly over time
- Ensembles based on variations in external forcing or from different models (physics) can improve results.



Data Assimilation in the Ionsphere

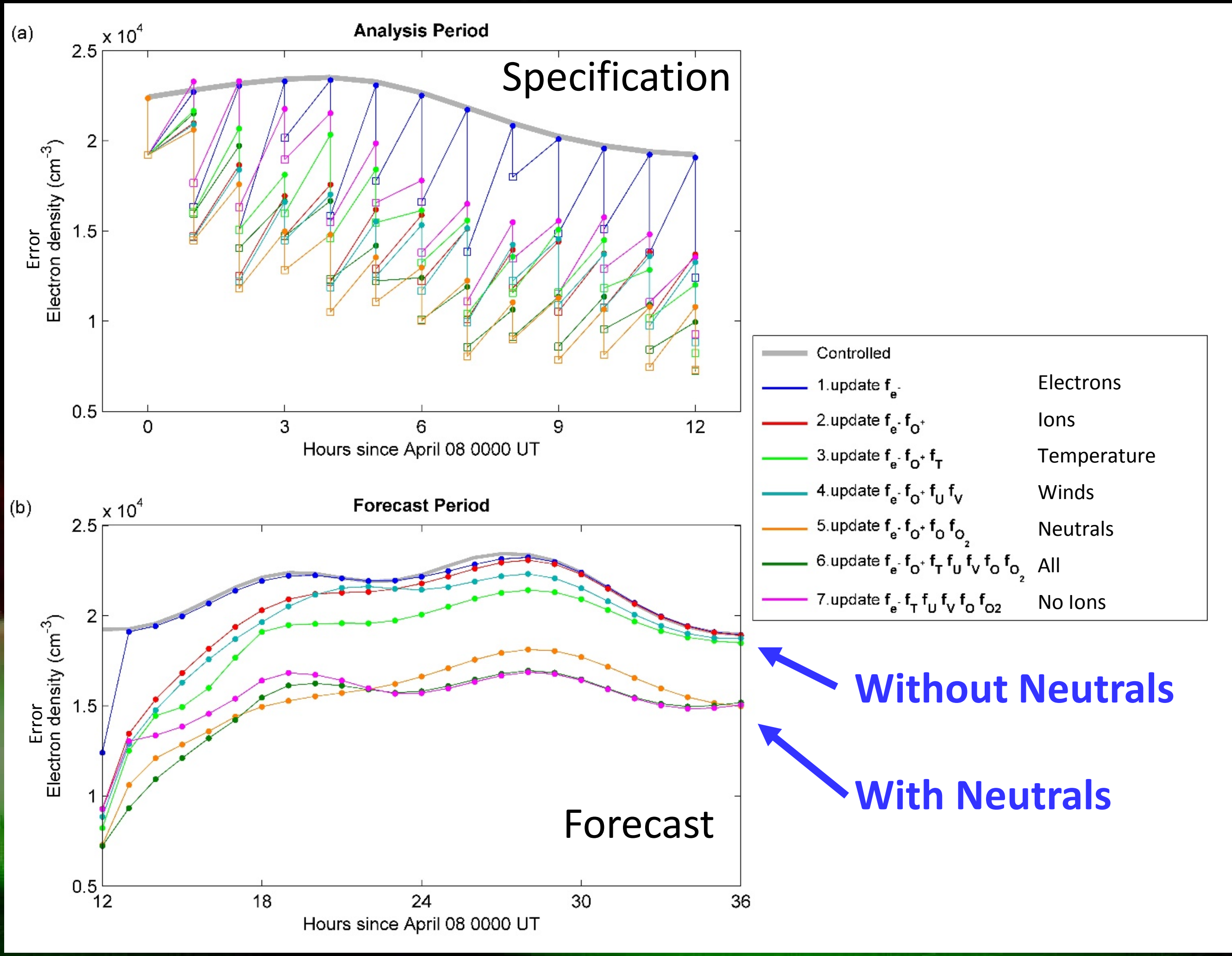
(Hsu, Matsuo, Wang, Liu, 2014)
Using TIEGCM

Question:

- Does Data Assimilation Work in the ionosphere?

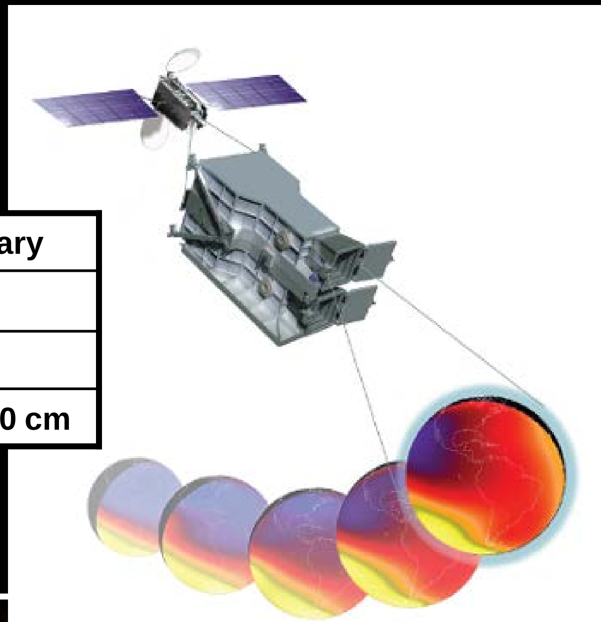
Answers:

- Assimilating only electron and ion data does not work very well
- Assimilating winds and temperatures helps a little
- **Neutral composition is the most important parameter for improving forecasts**



Global-scale Observations of the Limb and Disk (GOLD)

NASA Instrument of Opportunity



Instrument Summary	
Mass	34 kg
Power	61 W
Size	42 × 42 × 70 cm

Observations:

- Hemispheric maps of…
  - Neutral temperature
  - O/N_2 ratio (composition)
  - Electron density
- Limb scans of temperature

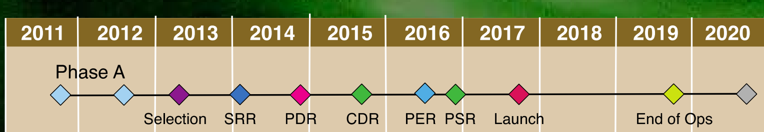
Imaging Spectrograph:

Two independent, identical channels

Wavelength range: 132 – 160 nm

Target Launch: October 2017

Hosted Payload on geostationary commercial satellite



Florida Space Institute (FSI) University of Central Florida

PI: Richard Eastes

Project Coordinator: Andrey Krywonos

Laboratory for Atmospheric and Space Physics (LASP)
University of Colorado

Deputy PI: William McClintock

Project Manager: Mark Lankton

NOAA SWPC

Collaborator: Mihail Codrescu

Summary

- Current NOAA operational models
  - Empirical specification models
- Near-term prototype models
  - Physics based specification models
- Future models (2-4 years)
  - Fully coupled physics based forecast models
    - WAM for thermosphere
    - IPE for ionosphere
    - Data assimilation (where applicable)

Questions?