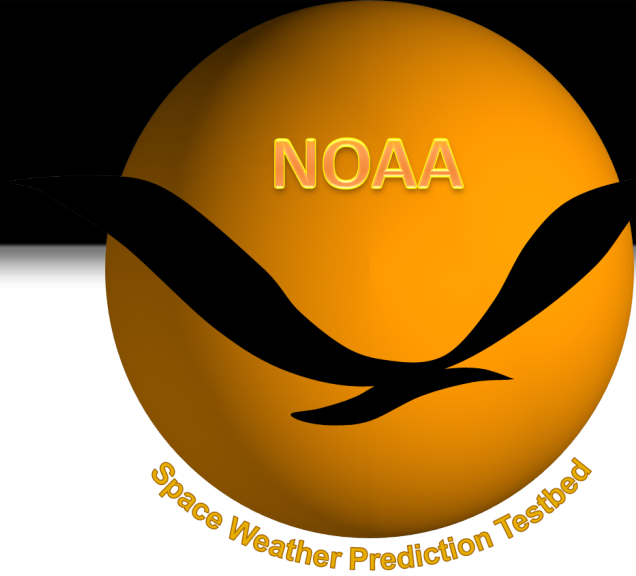


Space Weather Prediction Testbed

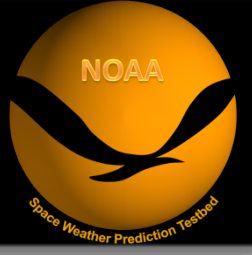
Rodney Viereck

Director, Space Weather Prediction Testbed

NWS/NCEP/Space Weather Prediction Center

Boulder Colorado

Outline



- Customer Growth
- Applied Research and Development Activities
  - Solar
  - Heliosphere (interplanetary space)
  - Magnetosphere
  - Ionosphere
  - Atmosphere
- Whole Atmosphere Modeling: Extending the GFS to 600km

Space Weather Services:
Critical to the World's Economy and Security

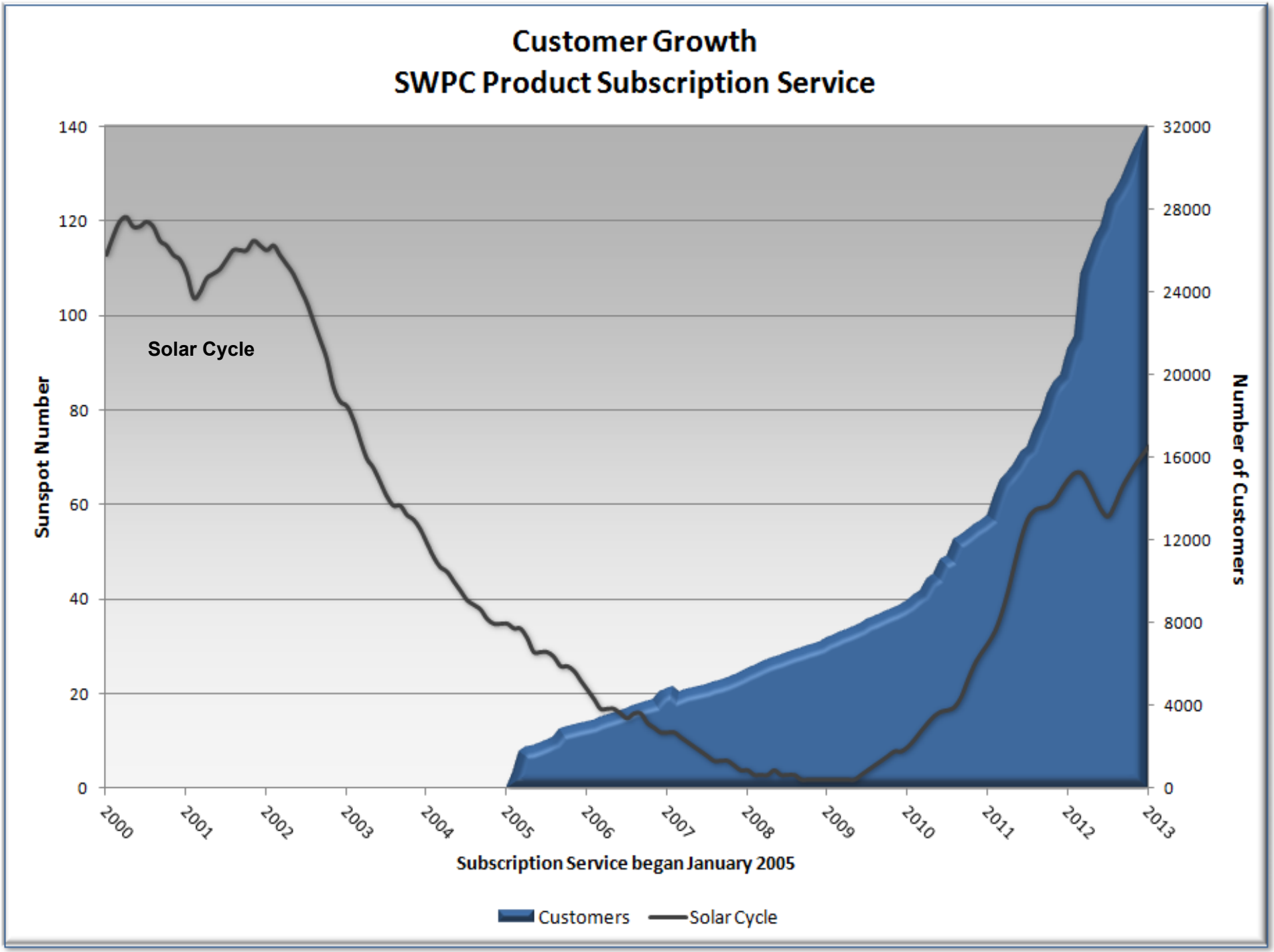
- **Aviation**
  - Polar route use – ~12,000 flights in 2012
  - Next Generation Air Transportation System – GPS based

- **Communication**
  - HF radio communication heavily relied upon by airlines, DOD, Emergency Managers, Search and Rescue, etc…

- **GPS**
  - Single biggest source of error is ionosphere
  - Strong growth in applications – surveying, drilling, precision agriculture, navigation, aviation

- **Electric Utilities**
  - Potential for significant disruption of service due to geomagnetic storm with major ($$$) consequences
  - FEMA addressing potential impacts related to space weather events through simulated exercise

- **Space Systems**
  - World satellite industry revenues in 2008: >$144 billion
  - Space weather support is critical for manned space flight and NASA robotic missions


Customer Growth
SWPC Product Subscription Service
Solar Cycle
Sunspot Number
Number of Customers
140
120
100
80
60
40
20
0
32000
28000
24000
20000
16000
12000
8000
4000
0
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
Subscription Service began January 2005
Customers
Solar Cycle

SWx Customers (A Sample)

Airlines	Surveying and Mapping	Electric Power	Satellites
Aer Lingus	AE & E Trucking, Etc., LLC	Allegheny Power	Lucent Technologies
Air Canada	AEI-CASE Engineering	Ameren Corporation	AeroMap U.S.
Air China	Airmag Surveys	Bechtel Nevada	Aerospace Corporation
Air Europa	Associated Engineers, Inc	Bonnevill Power Administration	Alcatel Space
Air Line Pilots Association	Athens Group (oil & gas)	Central Maine Power	American Space Culture Foundat
Air New Zealand	Baker Hughes (drilling)	Cleco Power LLC	AMSAT-France
AirMed Inc.	Banks		
Airservices Australia	Barr E		erospace
Alaska airlines	Benne		g
Allied Pilots Association	Black		dian Space Agency
ALPA Japan	Carver		a Space Surveillance Centre
American Airlines	Christ		Globe
American Eagle airlines	Clarida		tar
American Trans Air	Consu		n Reconnaissance Systems
Boeing / Flight Test	DGR		al Dynamics C4S
British Airways	Diamo		sat
Bushmail	Earth		at
Cathay Pacific Airway	Easter		pace Systems Division
Continental Airlines	Excel		Aerospace Exploration Agency
Emirates	Geoco		ommunications
FedEx	GeoLo		eed Martin
German ALPA	Global		Skynet
Icelandic ALPA	GRW		hay Satellite Corporation
Irish Aviation Authority	Halcyo		Space Science Systems, Inc.
Jet Aviation Business Jets	J. D. E		AT Info
korean air	Johns		Skies Satellites
Lufthansa	Jones		pace Technology
Lufthansa Cargo	marine R/D Survey	Puget Sound Energy	North Star Data
Northwest Airlines	NC Geodetic Survey	Soreq NRC	Northrop Grumman
Oslo Lufthavn AS	Nexen Inc. (oil)	Swedish Geological Survey	Oceaneering Space Systems
Qantas Airways	NOVA Engineering & Consulting, Int'l.	Texas-New Mexico Power	Omnistar, Inc.
Raytheon Aircraft Co.	NYS Professional Engineer	Transpower NZ Ltd	ORBCOMM
SCTA	Old Dominion Freight Lines	US NRC	Orbital Sciences Corp
SkyWest Airlines	Olson Trucking	We Energies	PT Asia Cellular Satelitte
Sun Country airlines	Oxy (oil & gas)	Western Area Power Admin.	Raytheon
Sundt air (Norway)	Pape-Dawson Engineering		Rockwell Collins, Inc.
Swales Aerospace	PGS Onshore		SES Americom
United Airlines	Planning Consultants, Inc.		SES ASTRA
APLA, Argentina	Portland Natural Gas Transmission		Sirius Satellite Radio
ATA Airlines	Raymac Surveys		Skyway, Inc.
NetJets	Schlumberger Drilling & Measurements		Space Engineering Development
North American Airlines	Seelye		Space Imaging

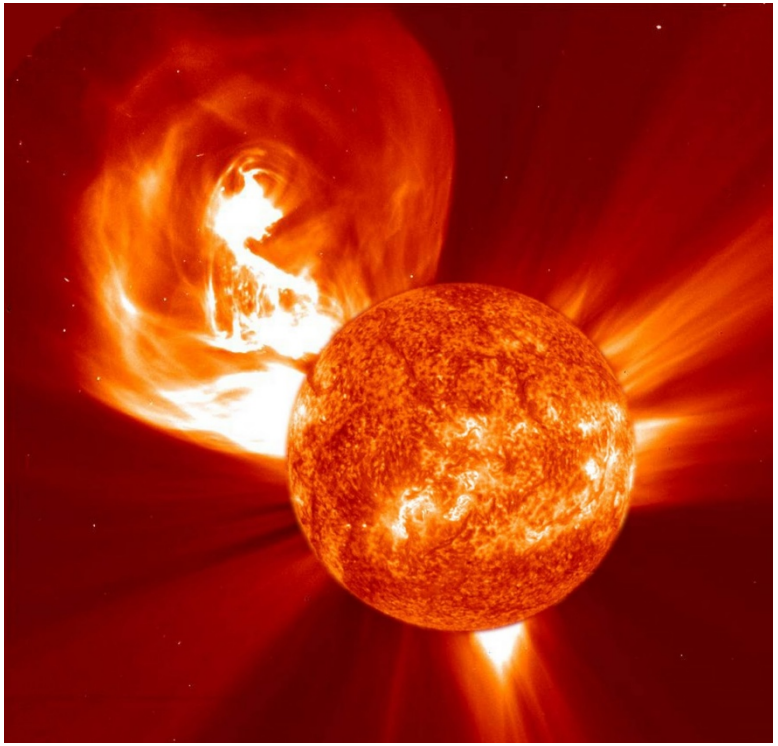
- **Every Major Airline (world wide)**
- **Every Major US Power Company**
- **Every Major Satellite Company (world wide)**
- **US Federal Agencies**
  - **Department of Defense.**
  - **NASA**
  - **Department of Energy**
  - **Department of Homeland Security**
  - **Federal Aviation Administration**

- **32,000 Specific Customers**
- **15 – 20 Million Web Hits a day**

SWPT Activities: Solar

Requirement: Improve the forecast of major space weather events and of HF communication outages.

- **Improve skill of flare and CME forecasts**
  - **Solar flare forecasting SBIR**
  - **Improving CME characterization**
  - **Automating solar feature recognition**
  - **Improving drivers for solar wind models (with US Air Force Research Lab)**

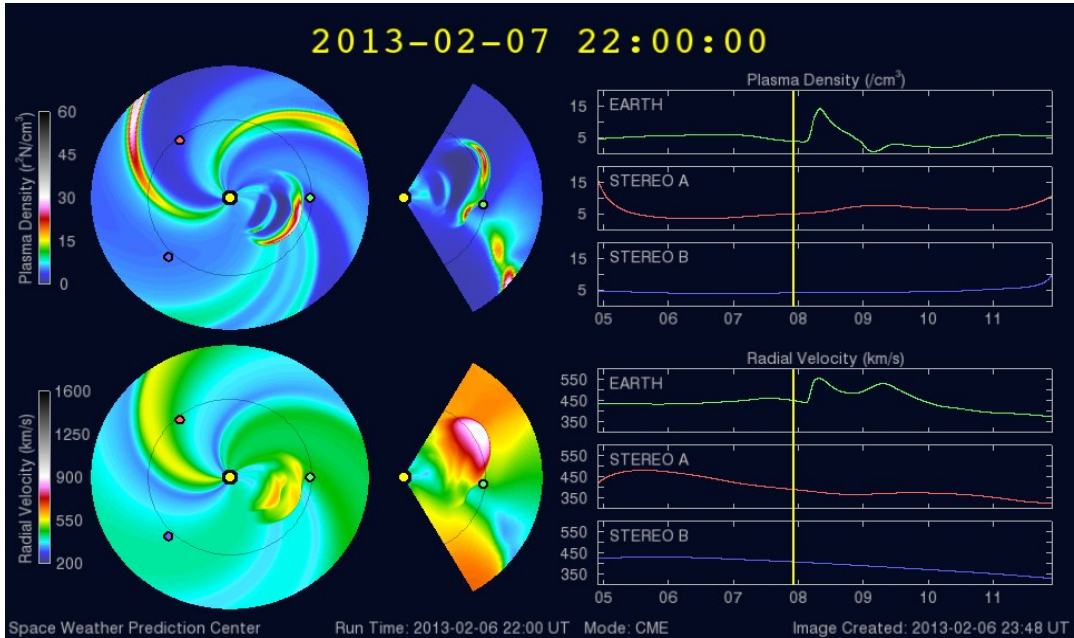


SWPT Activities: Heliosphere

(Sun to Earth)

Requirements: Propagate the solar events through the background solar wind to Earth to increase forecast accuracy and lead time.

- **Improving the WSA-Enlil Model**
  - **First full year of operations running on the NCEP computers**
  - **Improving input and propagation of CMEs**
  - **Collaborating with international partners to develop ensemble forecasts with Enlil**
    - **UK Met Office**
    - **Korean Radio Research Agency**
    - **Australian Radio Propagation Services Agency**
    - **Belgium Royal Observatory**

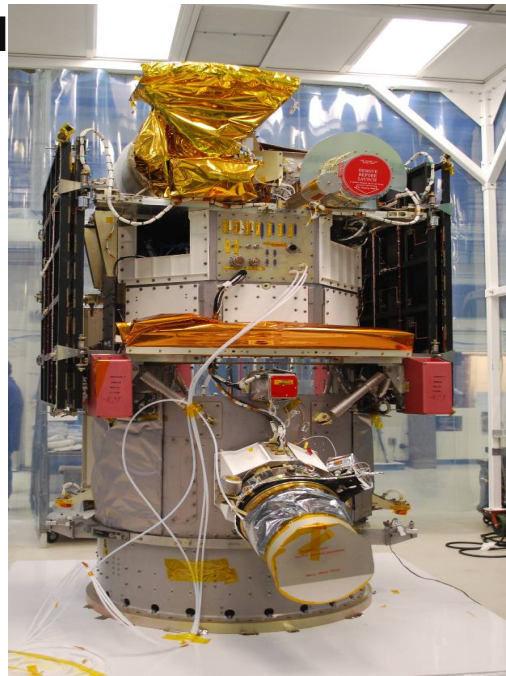


SWPT Activities: Heliosphere

(Sun to Earth)

Requirements: Improve forecast lead time and forecast accuracy for geomagnetic storms

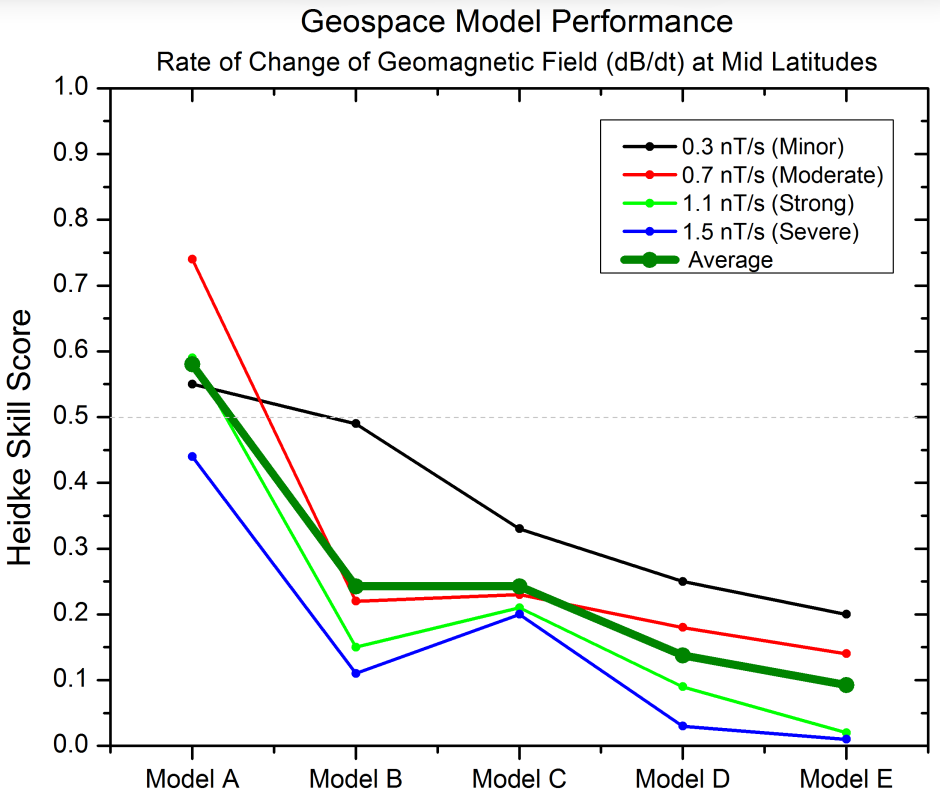
- Replace the 15 year old ACE spacecraft at L1.
- NOAA, NASA, DOD have teamed up to fly DSCOVR
  - Space Weather Forecast Center defines the data and product requirements
  - SWPT will develop the real-time satellite downlink and data collection system
  - SWPT will develop the data processing and product generation algorithms
- DSCOVR Launch in 2015



SWPT Activities: Magnetosphere

Requirements: Provide regional information on the impacts of geomagnetic storms for improved electric power reliability

- **Collaborating with NASA Community Coordinated Modeling Center to evaluate Geospace models**
- **Collaborating with USGS to improve ground conductivity models**
- **Developing regional products for now-casting of impacts.**

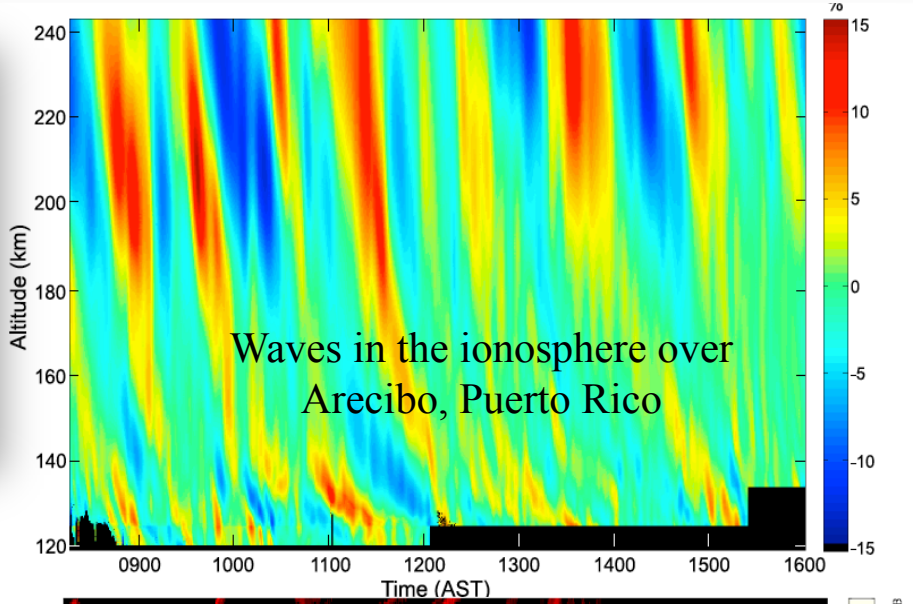


SWPT Activities: Thermosphere - Ionosphere

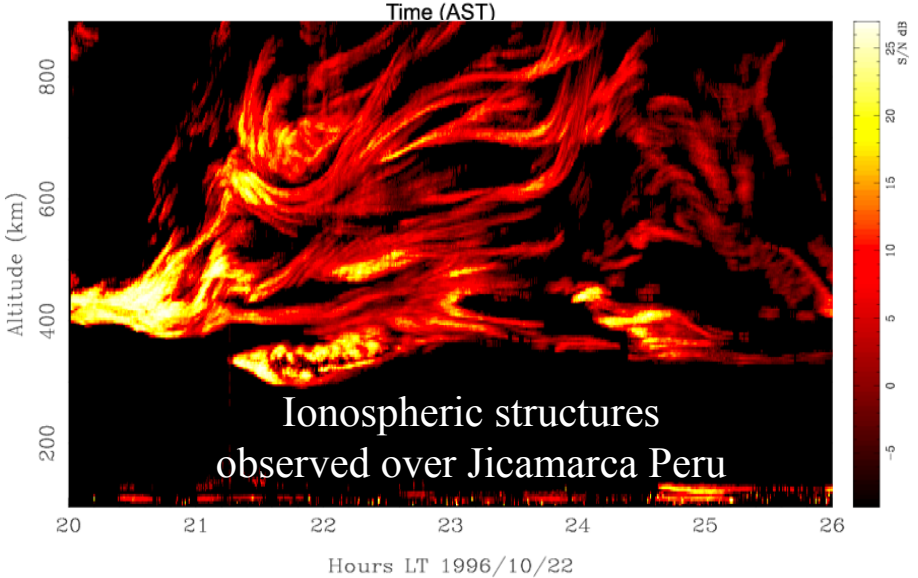
Requirements:
Improve the reliability and accuracy of GPS/GNSS systems.

Improve forecast for communication and navigation outages.

- **Three Thermosphere Ionospheric Drivers**
  - **Solar EUV Irradiance**
  - **Geomagnetic Storms**
  - **Waves/Tides from below**



Waves in the ionosphere over Arecibo, Puerto Rico



Ionospheric structures observed over Jicamarca Peru

Whole Atmosphere Model
Extending the Global Forecast Systems Model

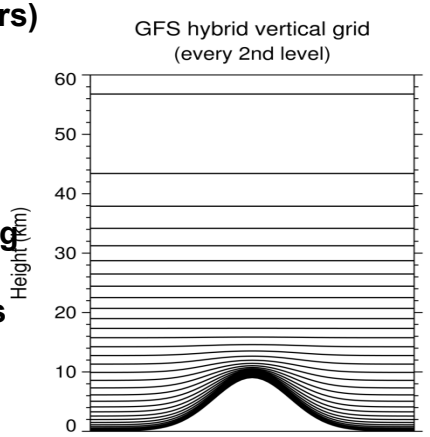
WAM models the neutral atmosphere up to 600 km altitude to include the mesosphere and thermosphere

Global Forecast System (GFS) model

- Operational weather model
- T382L64 (~0-60 km Res.)
- 4 forecasts daily
- Global ensemble (14 members) forecasts up to 16 days

Physics

- O3 chemistry & transport
- Radiative heating and cooling
- Cloud physics & hydrology
- Surface exchange processes
- Orographic gravity waves
- Eddy mixing and convection

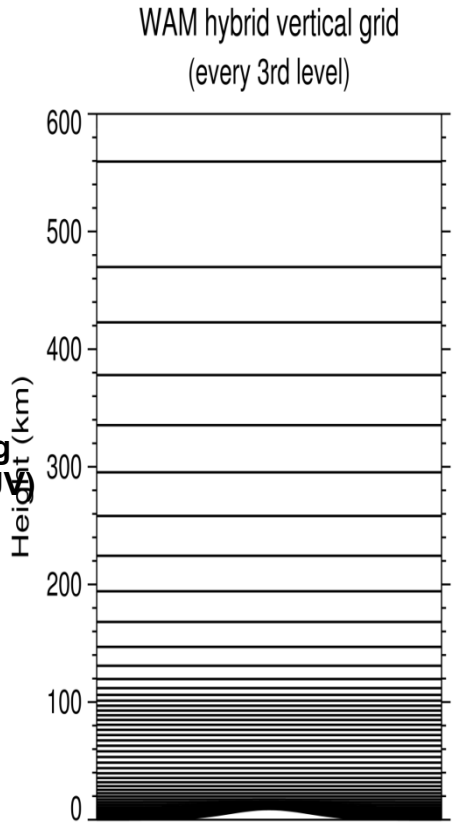


Whole Atmosphere Model (WAM)

- T62L150 (0 – 600 km Res.)
- Variable Composition ? thermodynamics
- Timing ~ 1 Day requires 8 min/day on 32 nodes

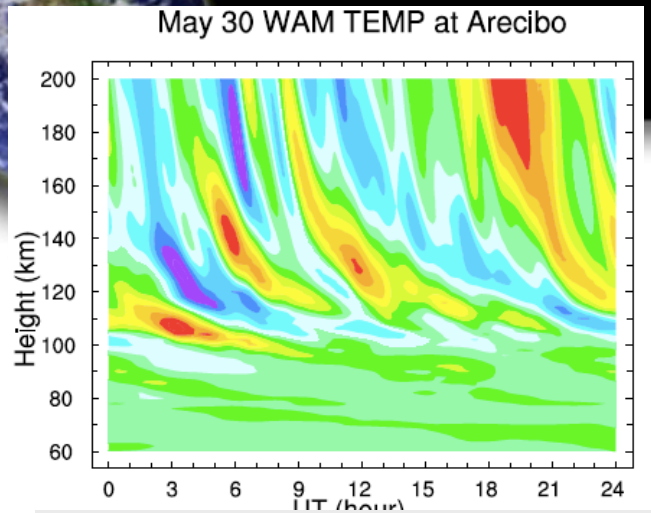
Physics

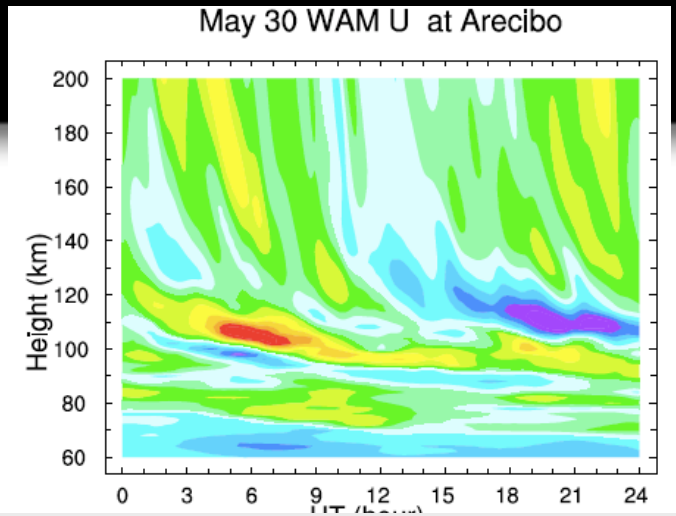
- Horizontal & vertical mixing
- Radiative heating (EUV & UV) and cooling (non-LTE)
- Ion drag & Joule heating
- Major species composition
- Non-orographic gravity waves
- Eddy mixing



Waves in WAM

temp

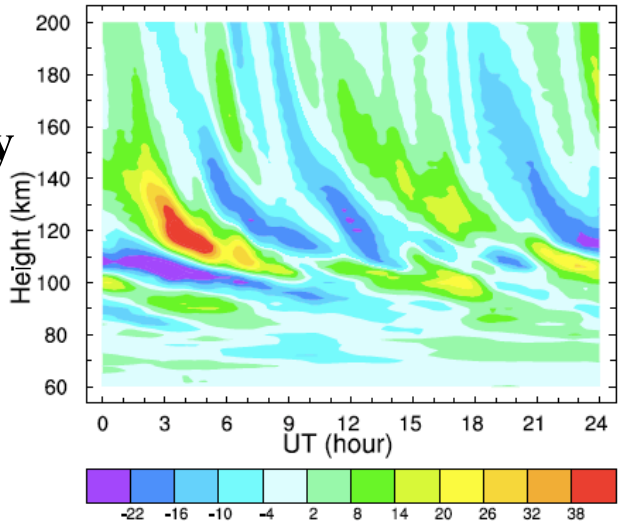


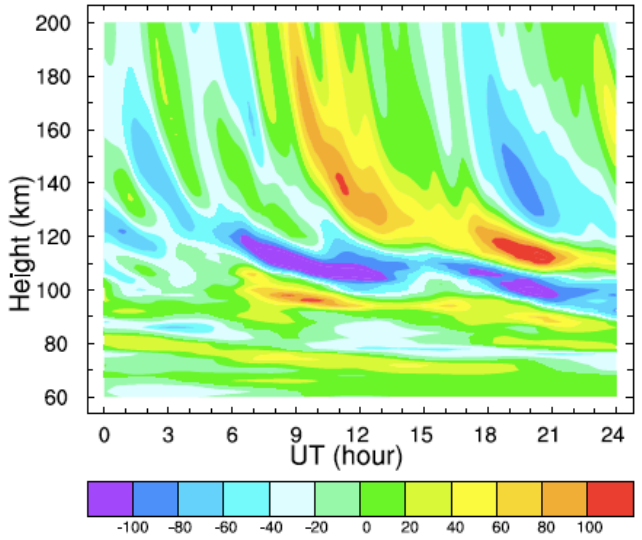


zonal wind

Question: Are the neutral atmosphere waves in WAM similar to the waves observed in the ionosphere?

density

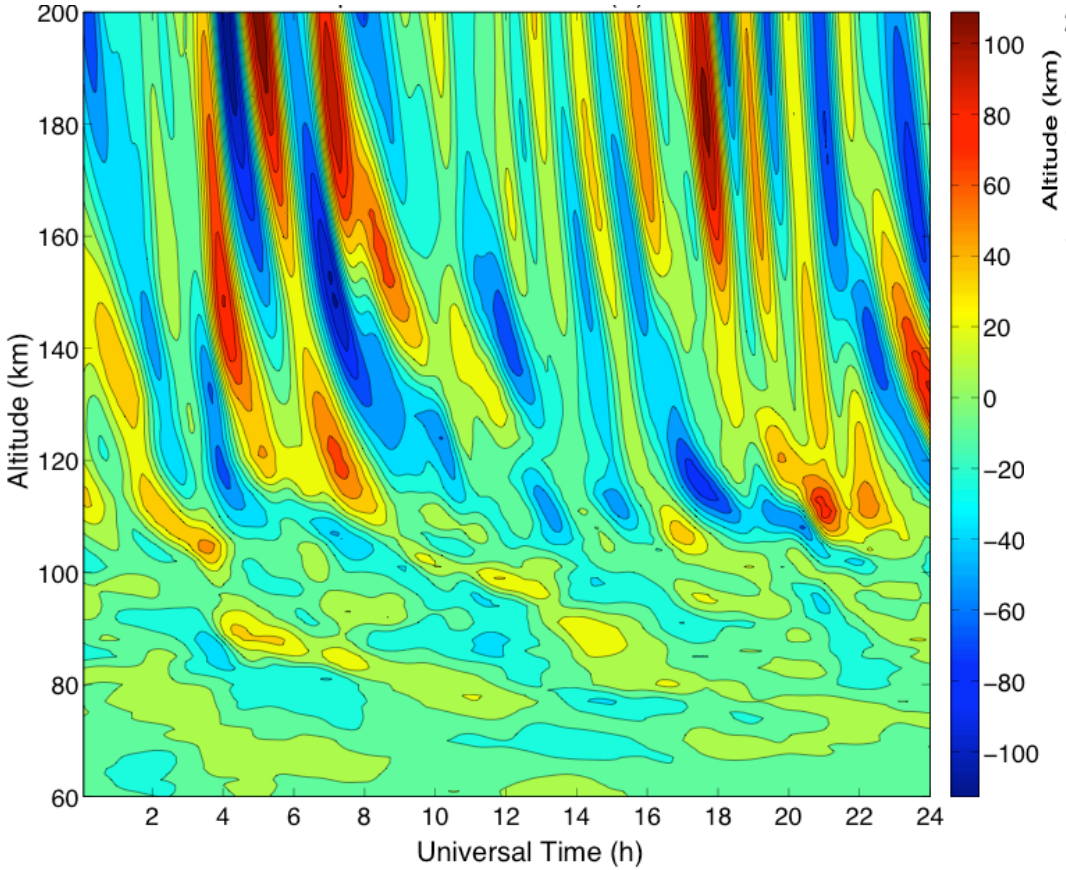


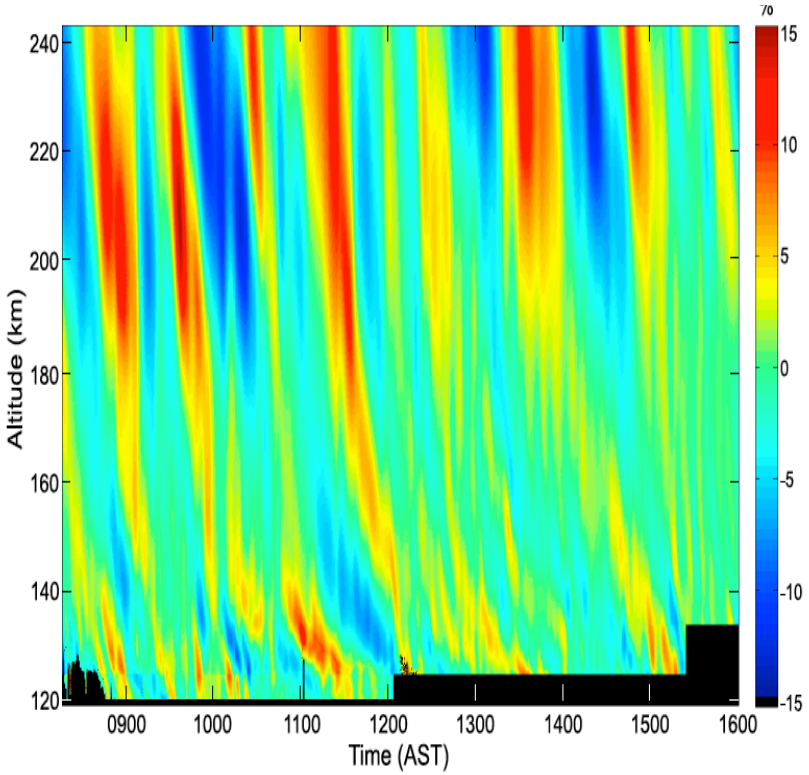


meridional wind

WAM waves compared to Radar

Waves in WAM

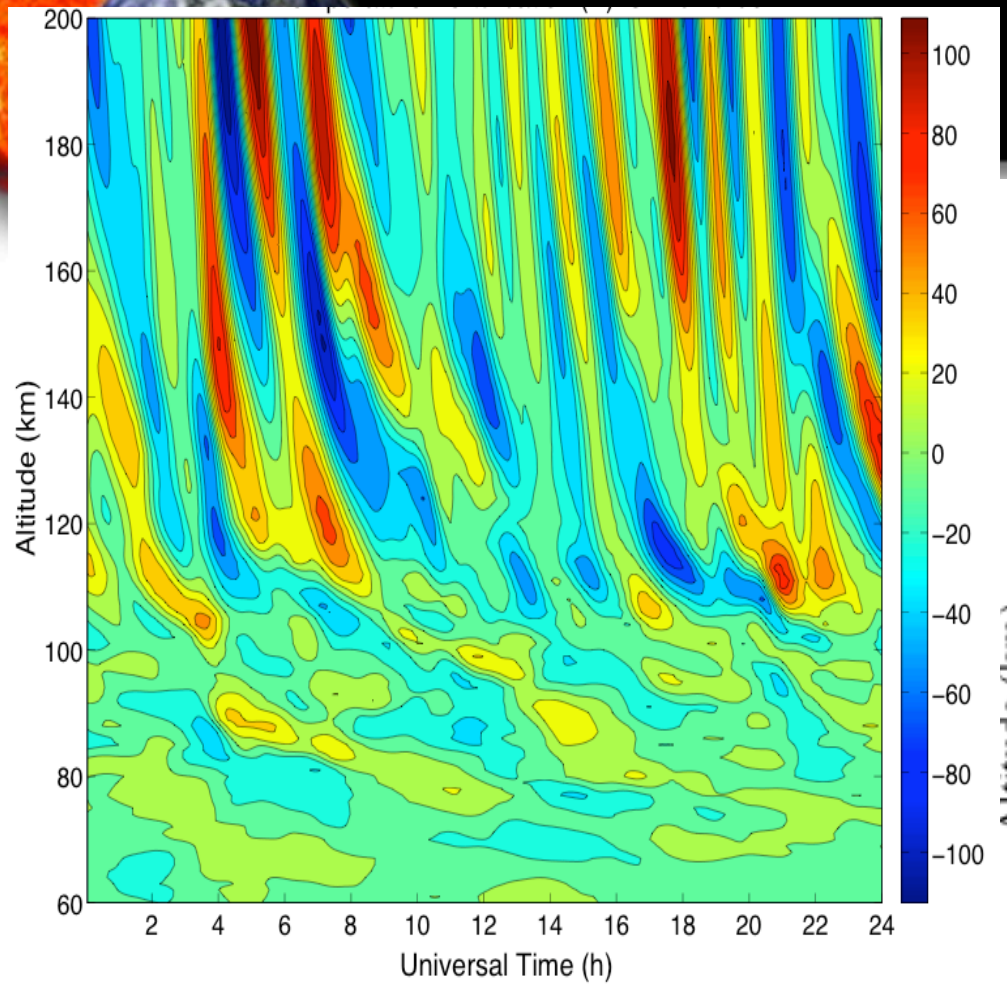




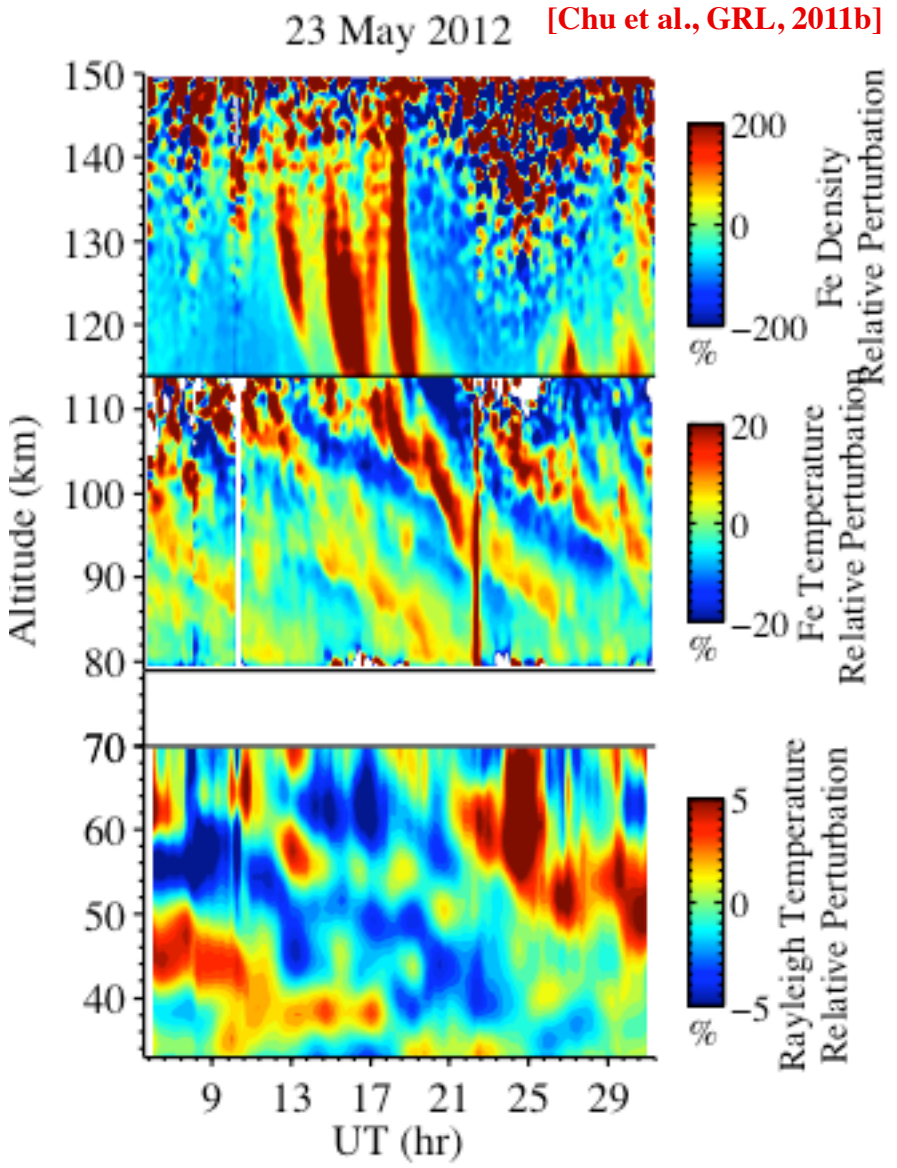
Waves in the ionosphere at Arecibo

[Djuth et al., JGR, 2010]

WAM Compared to Lidar



[Chu et al., GRL, 2011b]



WAM Development Activites

- Porting WAM to Zues
- Continued Validation and Testing
- Extending the data assimilation scheme up to the middle and upper atmosphere
- Finding data to assimilate in the middle and upper atmosphere
- Coupling to the ionosphere model

Extended GSI: Data Assimilation Issues

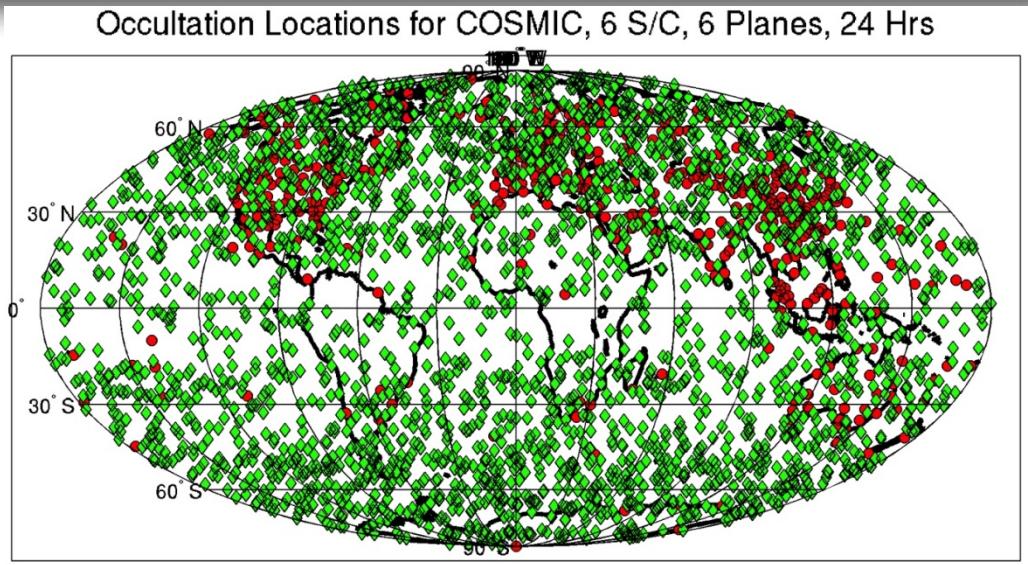
- Run WAM-GSI-IAU in real-time mode.
- Run GSI with a data assimilation window of 1 hour rather than 6 hours.
  - At 6 hours, we loose some of the amplitude of the 6, 8, and 12 hour tides, which start to dominate in the lower thermosphere.
  - At some point we would need to go to ~15 mins to deal with ionospheric effects
  - Requires some sort of hybrid data assimilation scheme
- Need to validate the forward models, some of which are in the CRTM radiation codes.
- Test and validate the extended modeling and a hybrid data assimilation system
  - Deal with biases etc.
- Extend the ozone chemistry and stratospheric dynamics to higher altitudes.
  - NRL has been working on
    - Extended version of ozone chemistry,
    - Improving the diurnal variation etc.
- Assimilate stratospheric data

WAM-IPE Data Sources

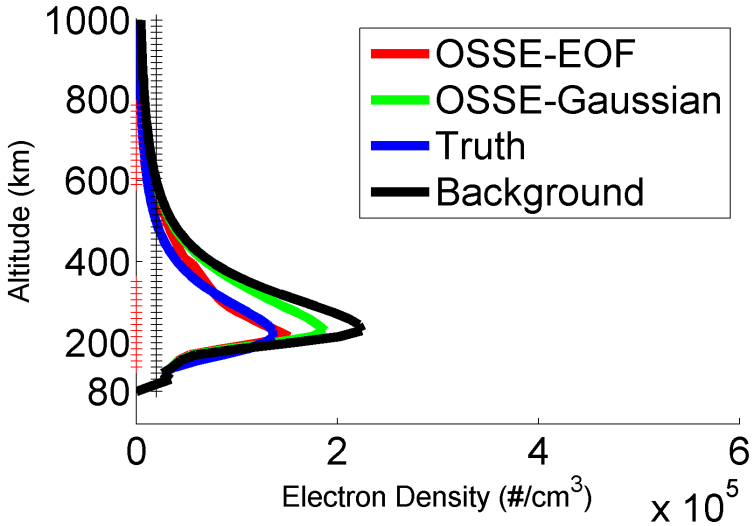
- **Stratosphere/mesosphere/lower thermosphere:**
  - Add analysis of additional channels to SSMIS to 100 km altitude for temperature.
  - Extend use of AIRS, IASI, CRIS, AMSUA for stratospheric temperatures.
  - MLS for ozone and temperature to 120 km
- **Upper thermosphere and ionosphere:**
  - Ionospheric radio occultation e.g., COSMIC-II (LOS TEC, S4, σΦ)
  - Ground-based dual frequency GPS receivers
  - Ground-based magnetometers
  - IRIDIUM-AMPERE Satellite Data
  - SuperDARN Radar Data
  - UV satellite imager for O/N2 and/or temperature (e.g., GOLD)
  - Accelerometer data for neutral density e.g. GOCE, GRACE, SWARM
  - Global network of Ionosondes/Dynasondes
  - Incoherent Scatter Radars (MH, Arecibo, Jicamarca, AMISR, etc.)
  - Solar Extreme UltraViolet Irradiance, GOES-EUV, SDO-EVE

Cosmic II
Ionospheric Data Assimilation

- **Need to prepare models for COSMIC II data**
  - **COSMIC I Latency is too long (1-2 hours) for operational use.**
  - **Vast improvement in global coverage over ground-based systems**
- **Development and Testing using COSMIC I data**
  - **Using the current US-TEC Assimilation Model (CONUS Only) to test and develop assimilation schemes**
  - **Vast improvement in reproduction of ionospheric height profiles.**

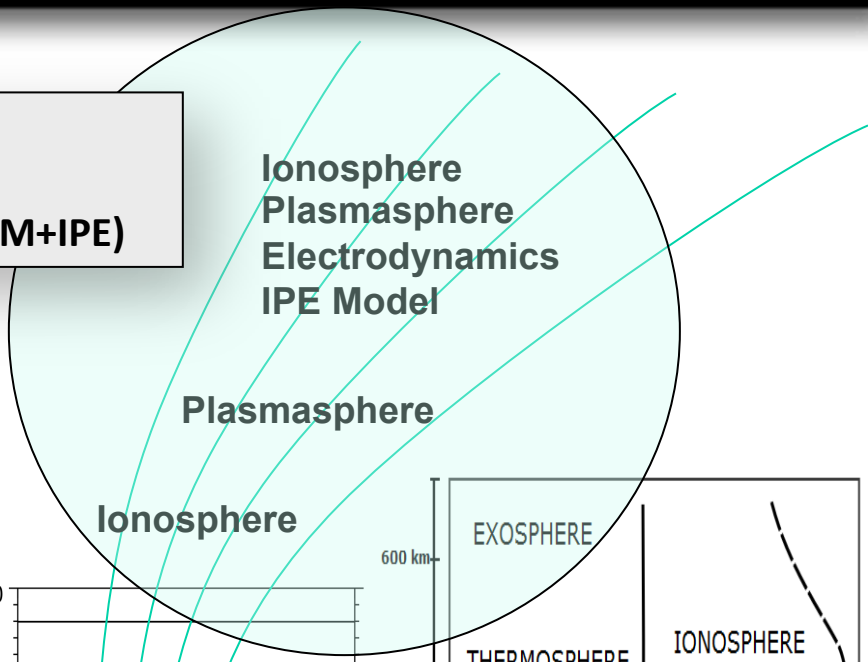


OSSE result by using GPS & F-3/C data at Lon:-104° & Lat:38°

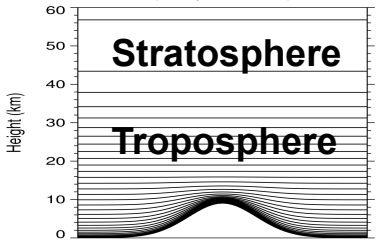


IPE: Adding the Ionosphere

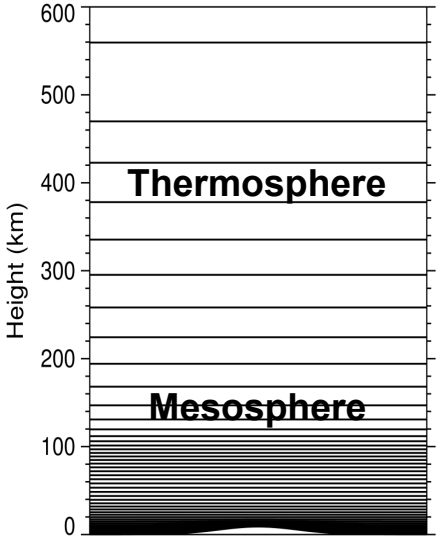
Whole Atmosphere Model (WAM = Extended GFS)
Ionosphere Plasmasphere Electrodynamics (IPE)
Integrated Dynamics in Earth's Atmosphere (IDEA = WAM+IPE)

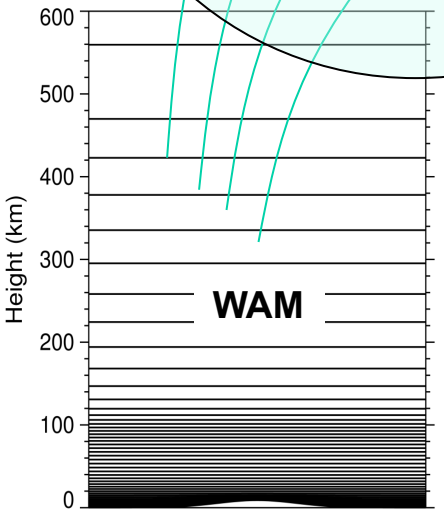


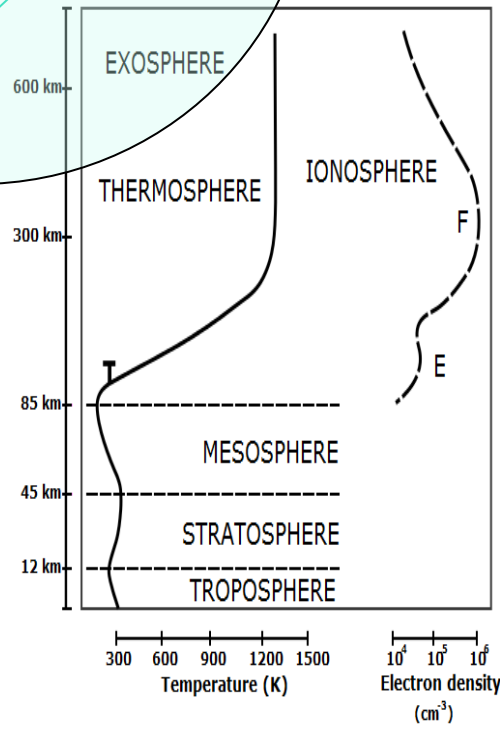
GFS
0 – 60 km



WAM
Neutral
Atmosphere
0 – 600 km







Many People Involved

Space Weather Prediction Testbed

NOAA NWS Space Weather Prediction Center and
CIRES University of Colorado

Tim Fuller-Rowell, Rashid Akmaev, Fei Wu,
Houjun Wang, Tzu-Wei Fang, Naomi Maruyama, and Catalin Negrea

NOAA OAR ESRL GSD and CIRES University of Colroado

Mark Govett, Jacques Middlecoff

NOAA NCEP Environmental Modeling Center:

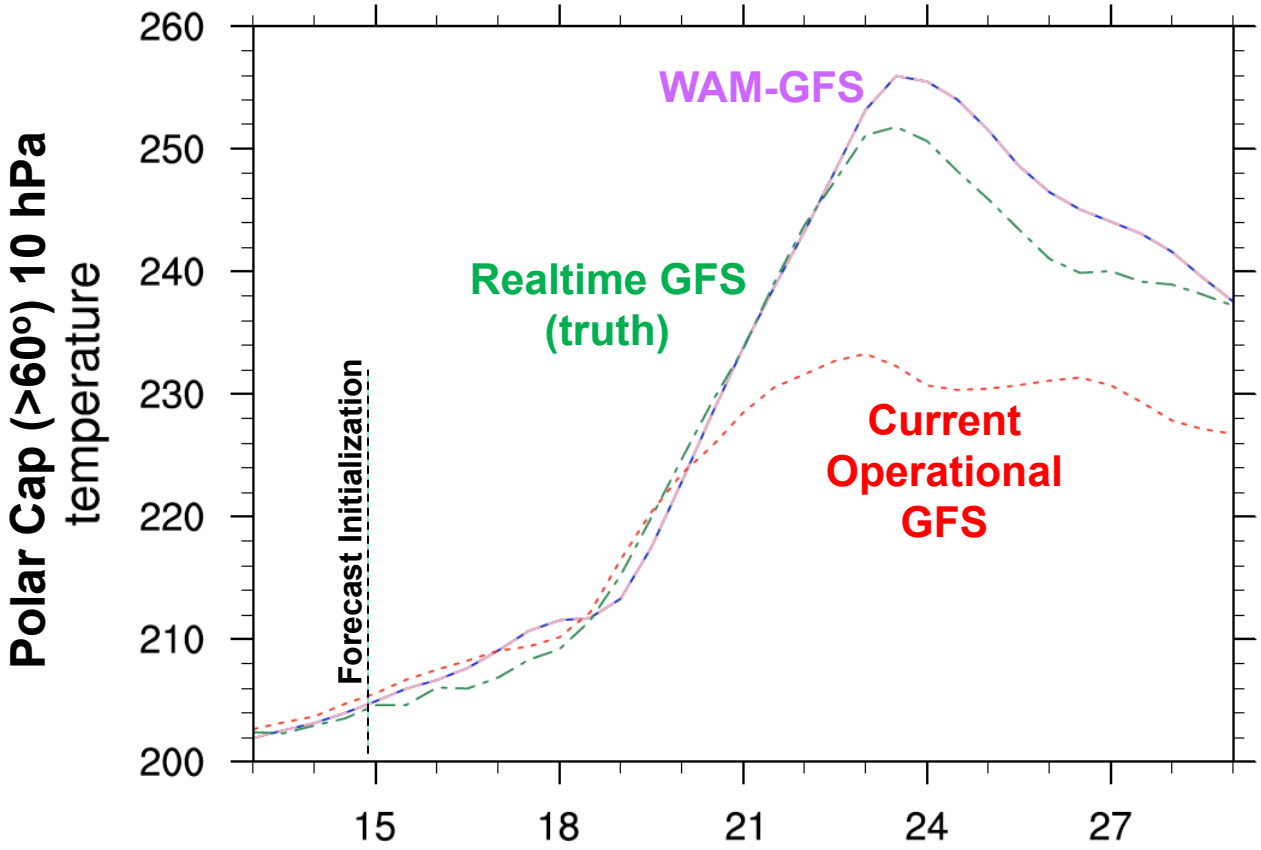
Mark Iredell, Moorthi Shrinivas, Henry Juang,
Jun Wang, and Misha Rancic

NCAR and Other Academic Institutions:

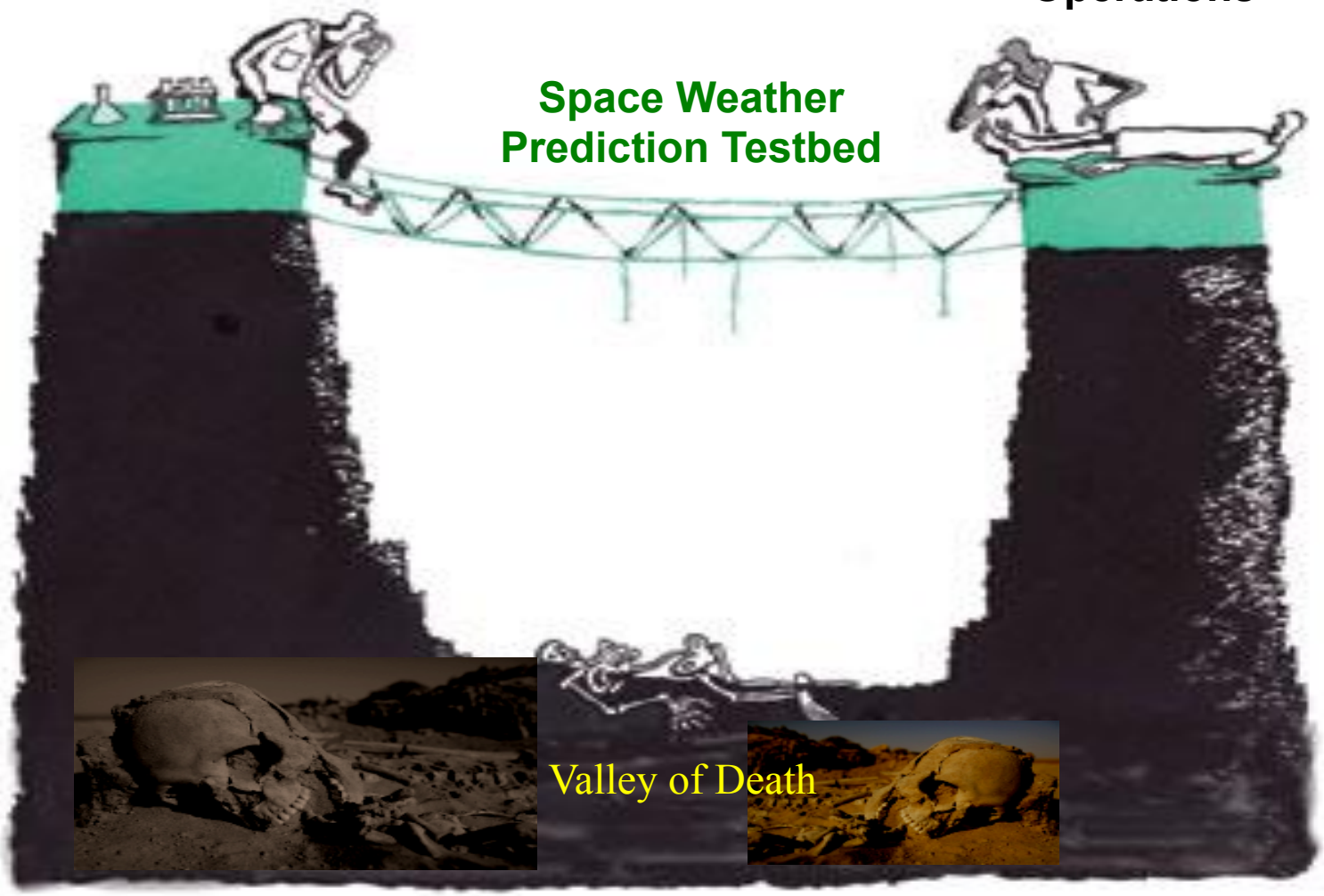
Art Richmond, Astrid Maute, Xinzhao Chu, Xian Lu,
Koki Chau, Larisa Goncharenko, John Retterer, Vivien Matthius, Peter Hoffman, Klemens Hocke, Simone Studer, and Roland Tsunoda

WAM-GFS Improves Long-Range Weather Forecasts

- **WAM-GFS is able to forecast the Jan 2009 SSW much better than Current GFS**
  - **WAM forecast provided 1-2 days additional lead time for SSW**



Questions?


Research
Operations
Space Weather
Prediction Testbed
Valley of Death