WAM-IPE Review

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Outline:
- SWPC and its models
- What is WAM+IPE = IDEA?
- Why do we need it?
- Status current activities
- Deliverables and milestones
- Issues and challenges

* NESII = NOAA Environmental Software Infrastructure and Interoperability Group

Space Weather Prediction Center

established 1949

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

Research and Development – Space Weather Prediction Testbed

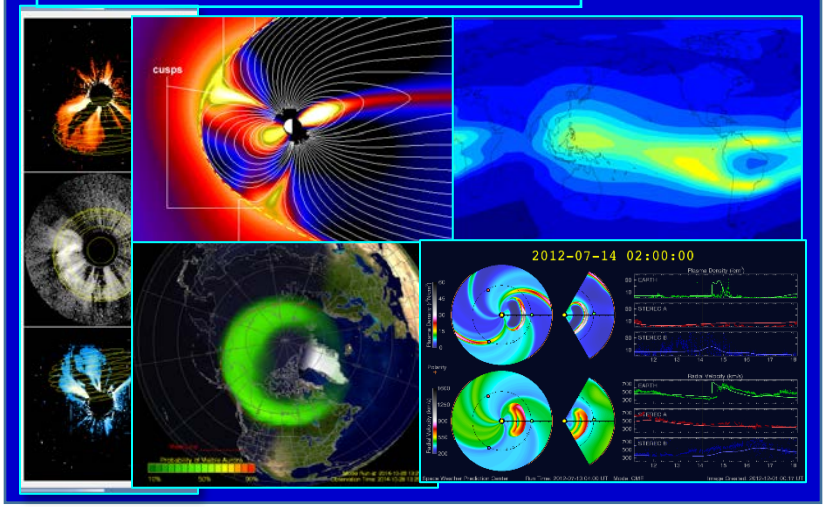
Transitioning models into operations

R2O

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

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

O2R

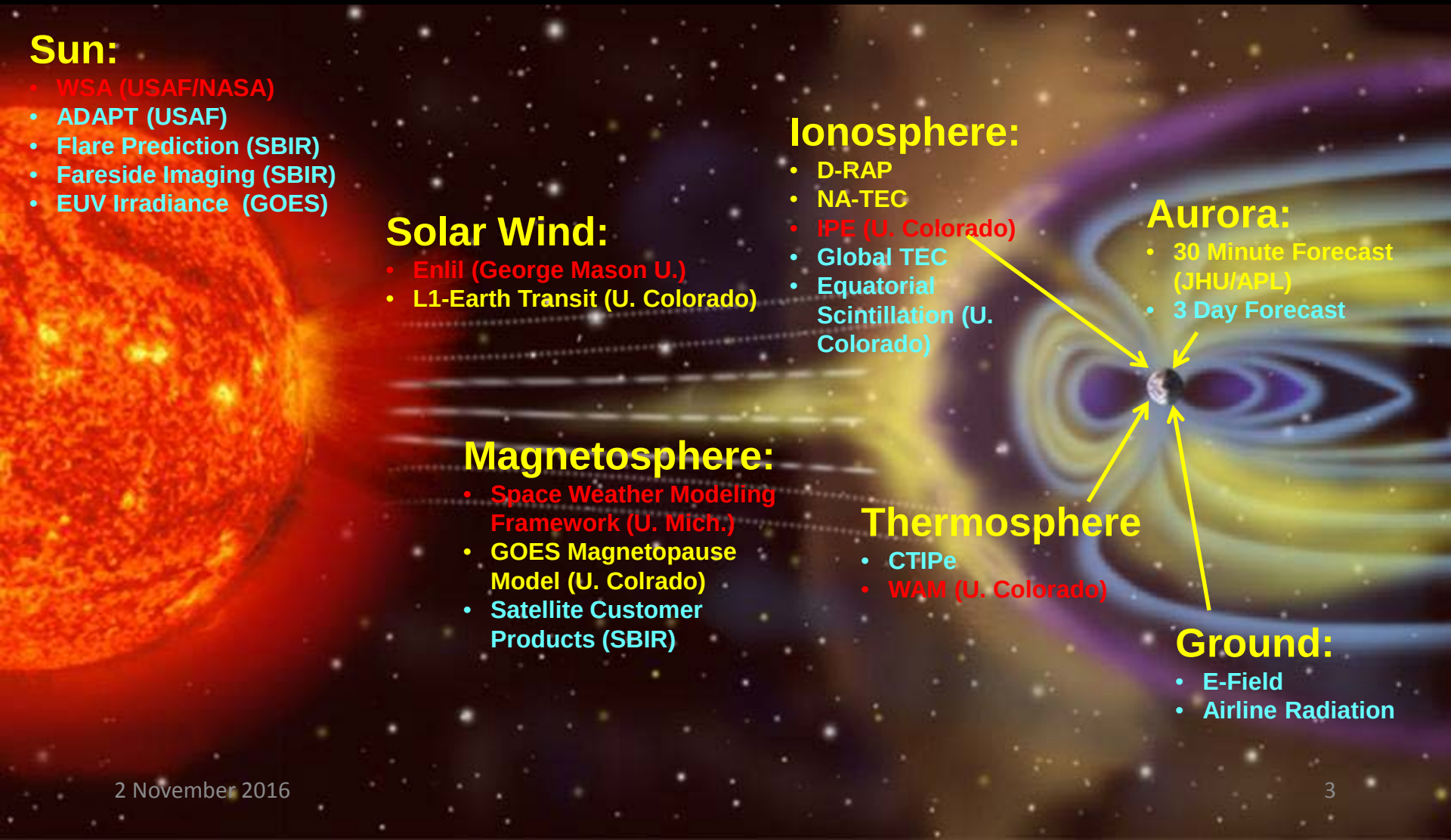


Space Weather Models

Operational

Under Development

Running on WCOSS



Sun:

- WSA (USAF/NASA)
- ADAPT (USAF)
- Flare Prediction (SBIR)
- Fareside Imaging (SBIR)
- EUV Irradiance (GOES)

Solar Wind:

- Enlil (George Mason U.)
- L1-Earth Transit (U. Colorado)

Ionosphere:

- D-RAP
- NA-TEC
- IPE (U. Colorado)
- Global TEC
- Equatorial Scintillation (U. Colorado)

Aurora:

- 30 Minute Forecast (JHU/APL)
- 3 Day Forecast

Magnetosphere:

- Space Weather Modeling Framework (U. Mich.)
- GOES Magnetopause Model (U. Colrado)
- Satellite Customer Products (SBIR)

Thermosphere

- CTIPe
- WAM (U. Colorado)

Ground:

- E-Field
- Airline Radiation

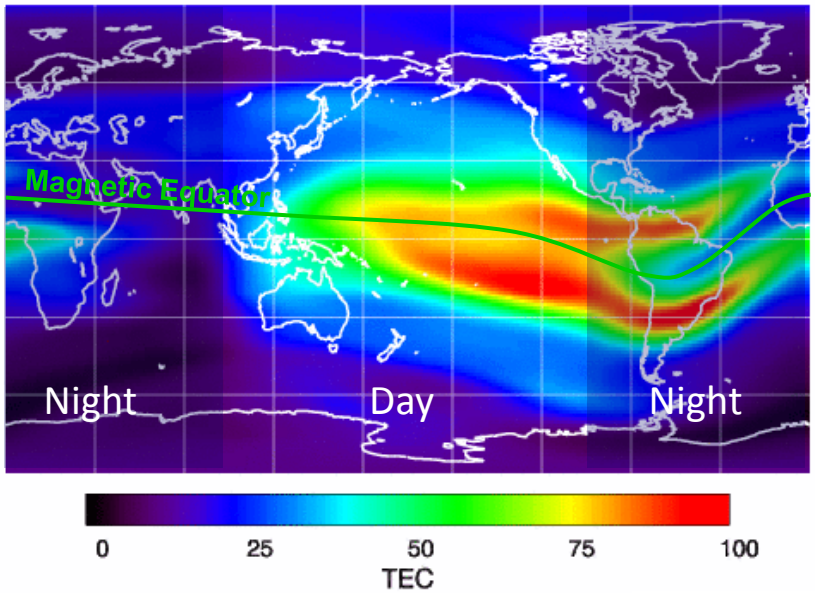
Customer Requirements

- Customer require better forecasts of ionosphere and thermosphere impacts on systems.
  - **GPS/GNSS** systems are affected by small and medium scale structures in the ionosphere that are not captured in current ionosphere models.
  - **HF Communication** is affected by large, medium, and small scale structures in the lower ionosphere that are not captured in current ionosphere models
  - **Satellite Communication** (Ground to space) is affected by small and medium scale structures
  - **Satellite drag** is affected by medium and large scale structures and winds in the thermosphere (neutral atmosphere) that are not currently modeled.

- Ionosphere is controlled by space weather (solar EUV and geomagnetic storms) and by terrestrial weather (tides, planetary and gravity waves).
  - The Ionosphere is a “driven” system responding primarily to external drivers.
  - There are no forecast models that capture all of the external drivers

Variable Ionosphere

Total Electron Content (Height Integrated Electron Density)



Model of the Ionosphere Without Lower Atmosphere Inputs:

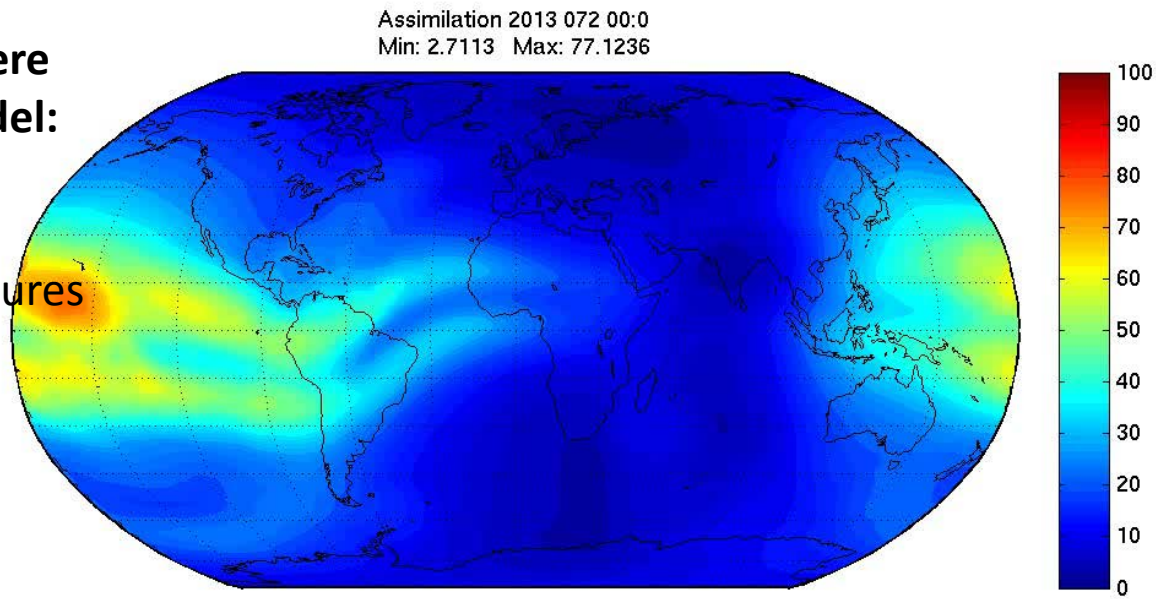
- Captures diurnal and large scale lat/lon structures

Observations of the Ionosphere Assimilative Ionospheric Model:

- COSMIC Radio Occultation
- Ground GPS Observations

Captures medium scale structures driven from below

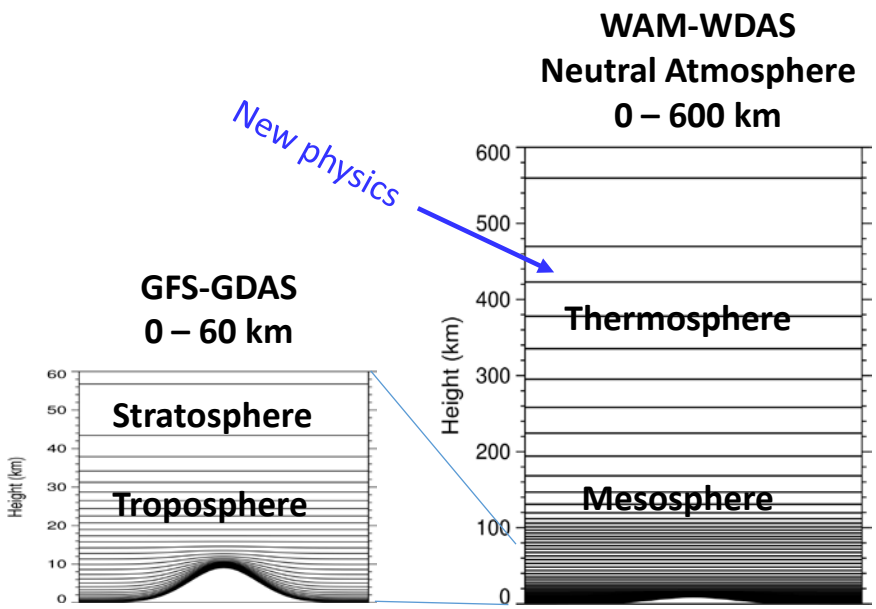
- Tides
- Planetary waves
- Gravity waves

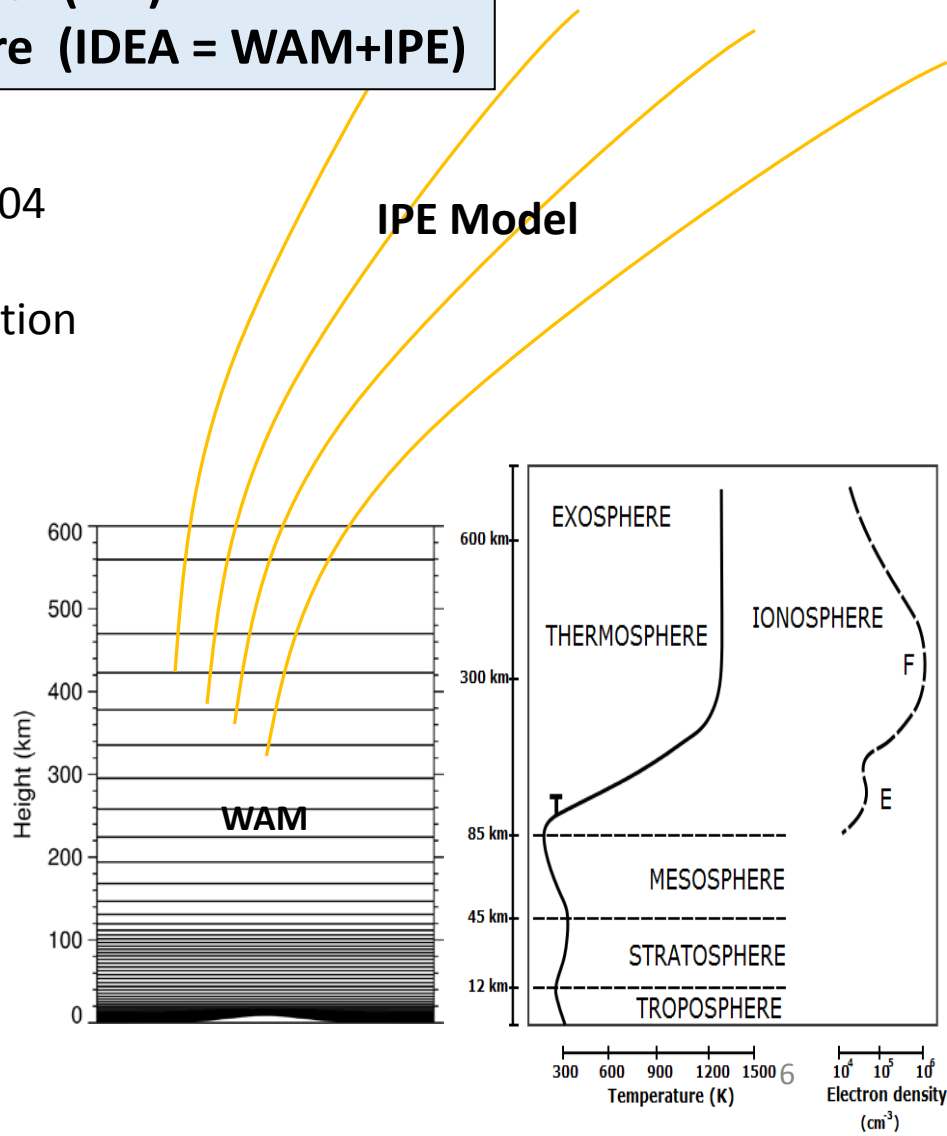


Integrated Dynamics in Earth's Atmosphere (IDEA)

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

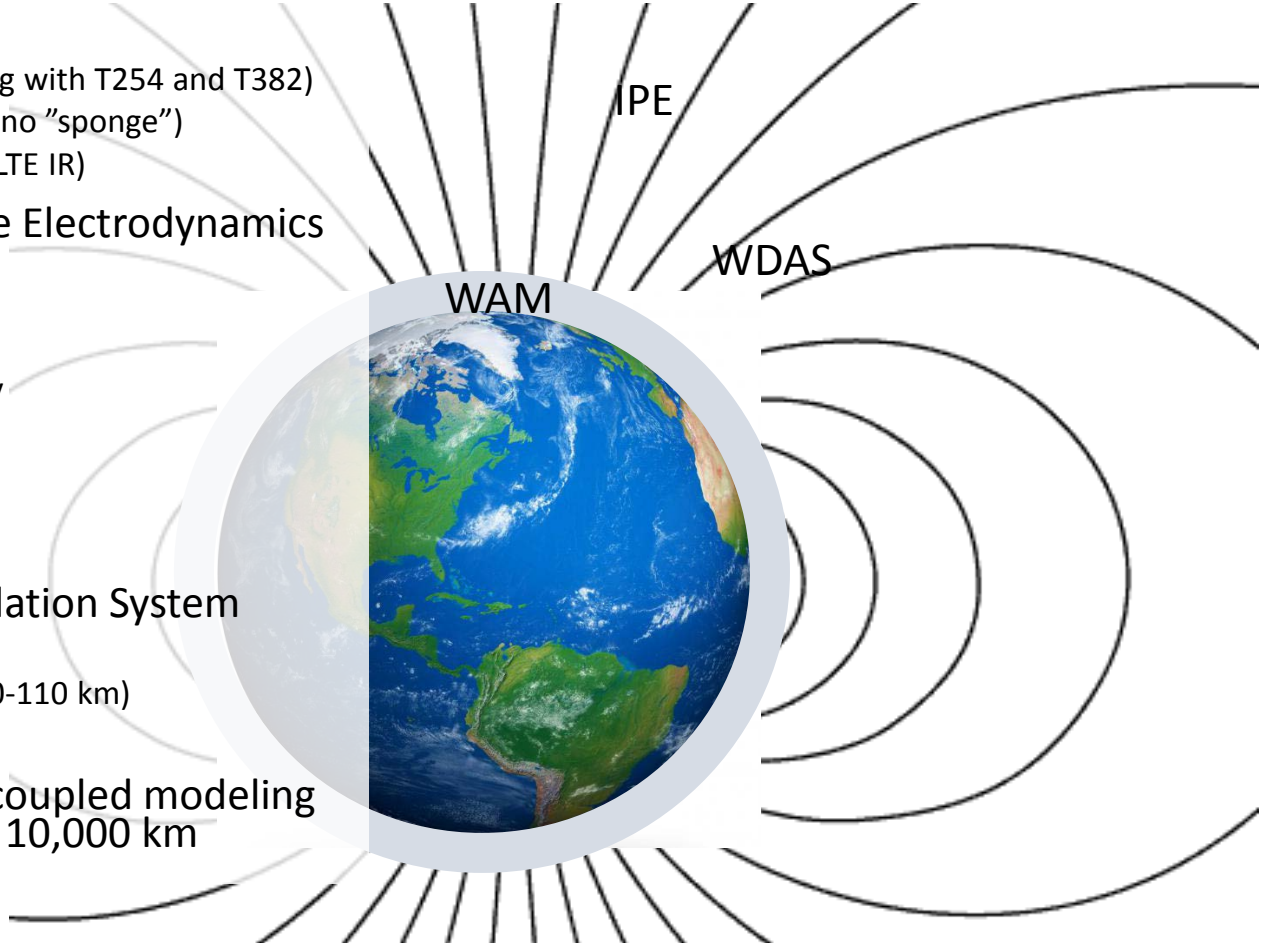
- History:
  - Research and development started in 2004 with NASA, NSF, DOD funding.
  - Focus shifted to operational implementation (and NOAA funding) in 2011





WAM-IPE Details

- WAM = Whole Atmosphere Model (Extended GFS)
  - 0 – 600 km (p_t = 1.5x10^{-7} Pa)
  - ~ 2° x 2° T62L150 (experimenting with T254 and T382)
  - Horizontal and vertical diffusion (no "sponge")
  - Radiative heating (EUV, UV, Non-LTE IR)
- IPE = Ionosphere Plasmasphere Electrodynamics Model
  - 100 – 10,000 km
  - Grid follows magnetic field lines
  - Drivers: Solar wind and Solar EUV
- Coupling:
  - One way (WAM to IPE)
  - Two way
- WDAS = WAM-IPE Data Assimilation System
  - Lower Atm. GSI DA (0-60 km)
  - Middle Atm. Extended GSI DA (50-110 km)
  - Upper Atm. DA (120 – 600 km)
- IDEA = WAM + IPE + WDAS A coupled modeling system spanning from the 0 to 10,000 km



Only a coupled atmosphere-ionosphere model will provide adequate forecasts of space weather impacts on communication and navigation systems.

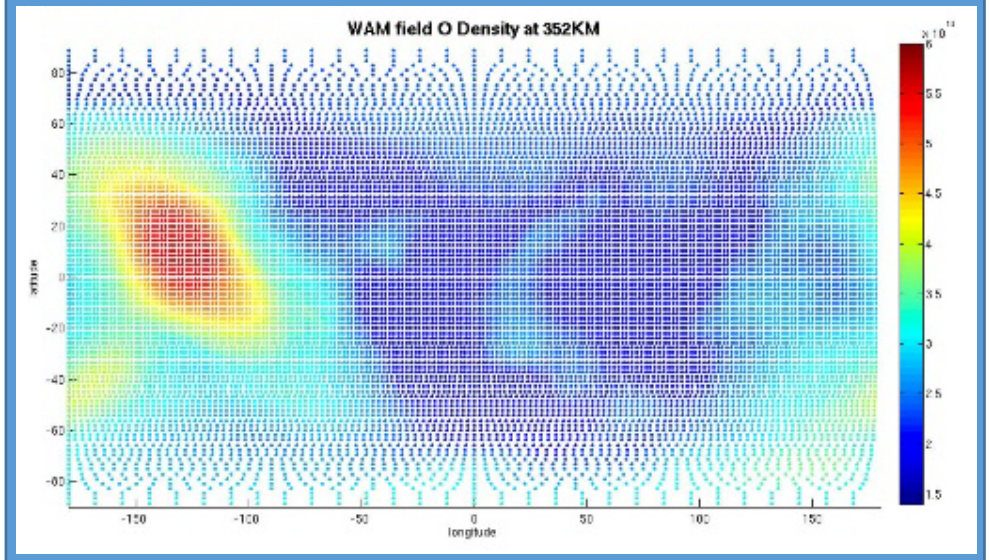
WAM and IPE Status

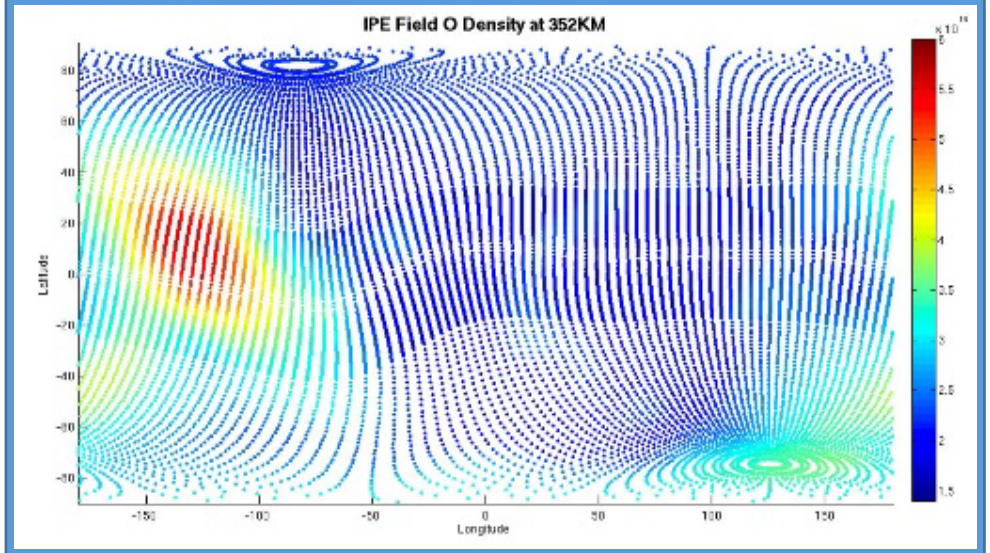
- WAM:
  - Real-time WAM has been running on WCOSS-dev and Theia for over a year
  - New WAM (Updated physics and SWx drivers) is implemented and tested on Theia.
  - Real-time New WAM on WCOSS-Dev in cycling mode with data assimilation was unstable during Q1-Q2 of 2016.
    - SWPC and EMC are working to identify the problem and fix it.
    - Anticipate stable real-time New-WAM performance after debugging and additional tests on Theia with Parallel Analysis-Forecast cycling of NCEP/EMC under workflows 2 and 3.
- IPE:
  - IPE validation ongoing (on Theia)
  - Porting IPE to WCOSS-Dev
  - Adding Scalable Modeling System (SMS) to WCOSS
    - SMS is a parallelization tool that translates Fortran code into a parallel version that runs efficiently on both shared and distributed memory systems. This software has been used successfully at NOAA ESRL since 1993 to parallelize and run many oceanic and atmospheric models.
  - Establishing IPE real-time runs

WAM-IPE Coupling
(NESII Support)

- FY16 One-way coupling scheme (WAM to IPE) established
- FY17 One-way coupling scheme is being implemented and tested.
- FY17 Two-way coupling scheme will be established
- FY18 Two-way coupling scheme will be implemented

Validation of WAM-IPE Coupling Scheme





WDAS Status:

- WDAS (Lower atmosphere) is fully operational and is used to drive WAM-real-time
- Middle Atmosphere Data Assimilation (50-120 km) is under development
  - Funding from NOAA R2O Testbeds/NGGPS
  - Should be implemented in WAM in FY17-18
- Upper Atmosphere/Ionosphere Data Assimilation (200-600 km)
  - Research project (NASA funded)
  - Ready in FY19? (NOAA funded?)

WDAS Data List
(WDAS = WAM-IPE Data Assimilation System)

- Lower Atmosphere: All of the data that goes into GFS
- Middle Atmosphere (Stratosphere, Mesosphere, Lower Thermosphere)
  - Additional channels to SSMIS to ~80-100 km altitude for temperature (historical only)
  - Extend use of AIRS, IASI, CRIS, AMSUA for temperature.
  - Microwave Limb Sounders for ozone, H2O, and temperature to 85 km
  - OMPS ozone profiles (20-70 km)
  - SABER-TIMED temperature, ozone, O, and H2O profiles
- Upper Thermosphere and Ionosphere
  - Ionospheric radio occultation e.g., COSMIC-II (LOS TEC, S4, σ_Φ)
  - Ground-based dual frequency GPS receivers
  - Ground-based magnetometers
  - UV satellite imager (GOLD) for O/N2 and/or high latitude and vertical drift at low latitude
  - IRIDIUM-AMPERE
  - SuperDARN
  - Satellite accelerometer data for neutral density e.g., GOCE, GRACE, SWARM
  - Global network of Ionosondes/Dynasondes
  - Incoherent Scatter Radars (MH, Arecibo, Jicamarca, AMISR, etc.)
- DSCOVR solar wind data at L1
- Solar flux, F10.7 cm, GOES-EUV

WAM and the FV3 Dynamical Core

Improvements to WAM Physics and Chemistry with FV3 Implementation

- Improvements to Model Improvements to Forecast
- Improved Gravity Wave Representation (resolution-aware)
- Vertical Eddy Diffusion of WAM tracers (major species)

WAM Physics Must be Coupled to the New FV3 Dynamical Core

- Horizontal molecular diffusion of tracers, momentum and heat
- Thermodynamics equation solved for enthalpy enthalpy, as a replacement of the potential
- temperature of FV3 (trial version can be started with PT and variable Cp)
- Deep atmosphere
  - Height dependent gravity: g(z) ~ 1/r2
  - Terms 1/r and 1/r2 in all evolution equations: r = rE + z
- Gas Tracers
  - GFS: Dry Air, H2O, O3*
  - WAM: N2, O*, O2*, H2O, O3*
  - FV3WAM: N2, O*, O2*, H2O, O3*, He, H2O*, NO*

    * Includes associated photochemistry
- Numerical Specifics
  - High Magnitudes of Tem-re and Winds with strong Diurnal Variations
  - Strong and fast variations (orders) during geomagnetic storms and Sudden Strat. Warming.
    - T = 2000 K and U = 1000 m/s,

WAM Physics and FV3 Coupling in NEMS

- Working Group Established
  - EMC-SWPC/CIRES-GFDL (FY16)

- First Implementation with Enthalpy and transport of Major Species (O, O2, N2)
  - Use experience of WACCM-CESM with the Potential Temp-re in FV2. (FY17) in hydrostatic NEMS-WAM.

- Validate Diurnal Cycles in the Middle Atmosphere and Thermosphere (Tides and Tracer Transport, FY17-18) in hydrostatic FV3 of NEMS-WAM.

- Performance and validation of the non-hydrostatic FV3 of NEMS-WAM (FY18-19). Tune-up of WAM physics.

Deliverables and Milestones

Blue indicates FV3 activities

FY 17

Q1 WAM-Real-time with SWx drivers running in realtime on WCOSS-dev
Q1 IPE-Real-time on WCOSS-Dev
Q1 Perform Initial coupling WAM-Physics & FV3 for Potential Temp-re and WAM major tracers.
Q2 Complete implementation and testing of 1-way coupling
Q3 Establish the techniques and methodologies for running WAM at a 1-hour rapid refresh cycling in upgraded WDAS-GSI
Q3 Develop and evaluate WAM-Physics and FV3 for Enthalpy
Q4 WAM-IPE output available at SWPC for product generation.
Q4 WAM – IPE with 1-way coupling running on WCOSS-Dev

FY18

Q1 Initial set of ionospheric products developed.
- Global Total Electron Content (TEC) maps to specify single frequency GPS errors.
- Global maps of Rate of TEC Index (ROTI) to specify errors and availability of dual frequency (precision GPS).

Q2 Tune WAM-Physics and FV3 and validate
Q3 Complete implementation and testing of 2-way coupling
Q4 WAM-FV3 for hydrostatic dynamical core and initial cycling
Q4 WAM-IPE with 2-way coupling running on WCOSS-Dev

Questions: