The Whole Atmosphere Model (WAM) Application of NOAA's Unified Forecast System (UFS)

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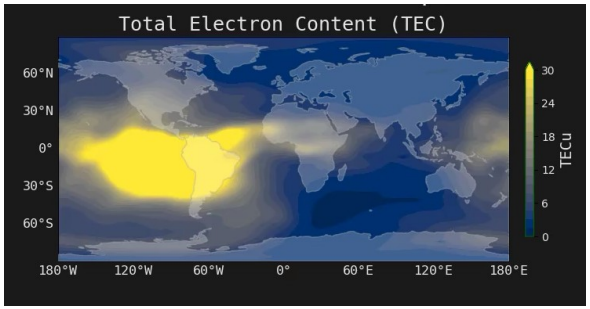
Solar and Geomagnetic Activities

(solar radiation, high-latitude ***E,*** *aurora, joule heating)*



Lower Atmospheric Perturbations

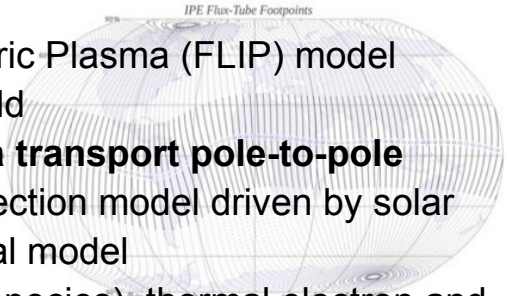
(thermospheric tides, planetary waves, gravity waves)

Whole Atmosphere Model (WAM)

- **0-600 km**, 0.25 scale height, 2°x 2° lat/long, T62, hydrostatic, 150 levels, 10-fold extension of **Global Forecasting System** (GFS) US weather model.
- O3 chemistry and transport, cloud physics and hydrology
- Radiative heating and cooling
- Sea surface temperature field and surface exchange processes
- Orographic and non orographic gravity waves parameterization
- **WAM Data Assimilation Scheme (WDAS)**
- Diffusive separation, ion drag, Joule heating, etc.

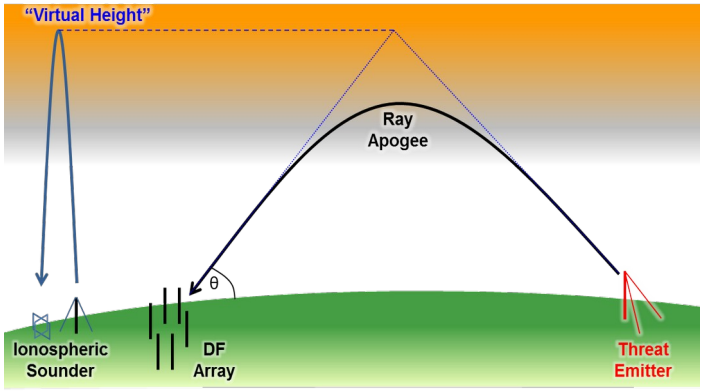
Ionosphere Plasmasphere Electrodynamics (IPE)

- Time-dependent, global 3D model **from 90 km to several Earth radii**
- **IGRF** coordinate system, accurately represents Earth's magnetic field
- Includes Field Line Interhemispheric Plasma (FLIP) model
- ExB transport across magnetic field
- **Seamless perpendicular plasma transport pole-to-pole**
- Weimer/Heelis empirical ion convection model driven by solar wind data, TIROS auroral empirical model
- Provides plasma densities (9 ion species), thermal electron and ion temperatures, and ionosphere and plasmasphere velocities
- ESMF 3D-regridding WAM→IPE information

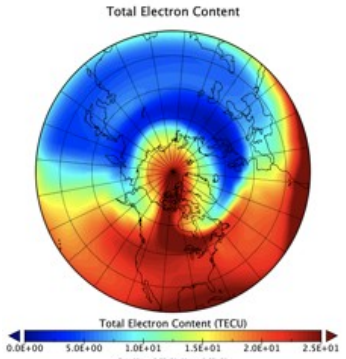


WAM-IPE Products/Concerns

- **For HF communication:**
  - Changes in the Minimum Usable Frequency (LUF) due to D-region absorption (D-RAP)
  - Changes in the Maximum Usable Frequency (MUF) due to the peak plasma density (NmF2) and height of peak (hmF2)
  - Undulations in bottom-side F-region



- **For positioning, navigation, timing, and other communication:**
  - Mesoscale structure and gradients in plasma density (diffract radio signals and cause amplitude or phase fluctuation in GNSS signals)
  - Delay in navigation signal due to line of sight electron content (position error)
  - Small-scale ionospheric irregularities causing scintillations/fluctuation or complete loss of signal

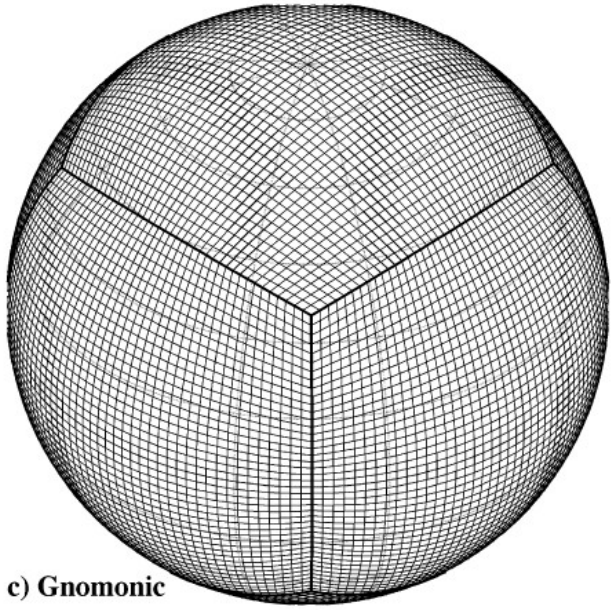


What are the goals of upgrading?

- Non-hydrostatic effects
- Deep Atmosphere effects
- Much Higher resolution (25km)
- Unification with other NOAA models under the UFS umbrella (FV3 dynamical core, Common Community Physics Package)

FV3

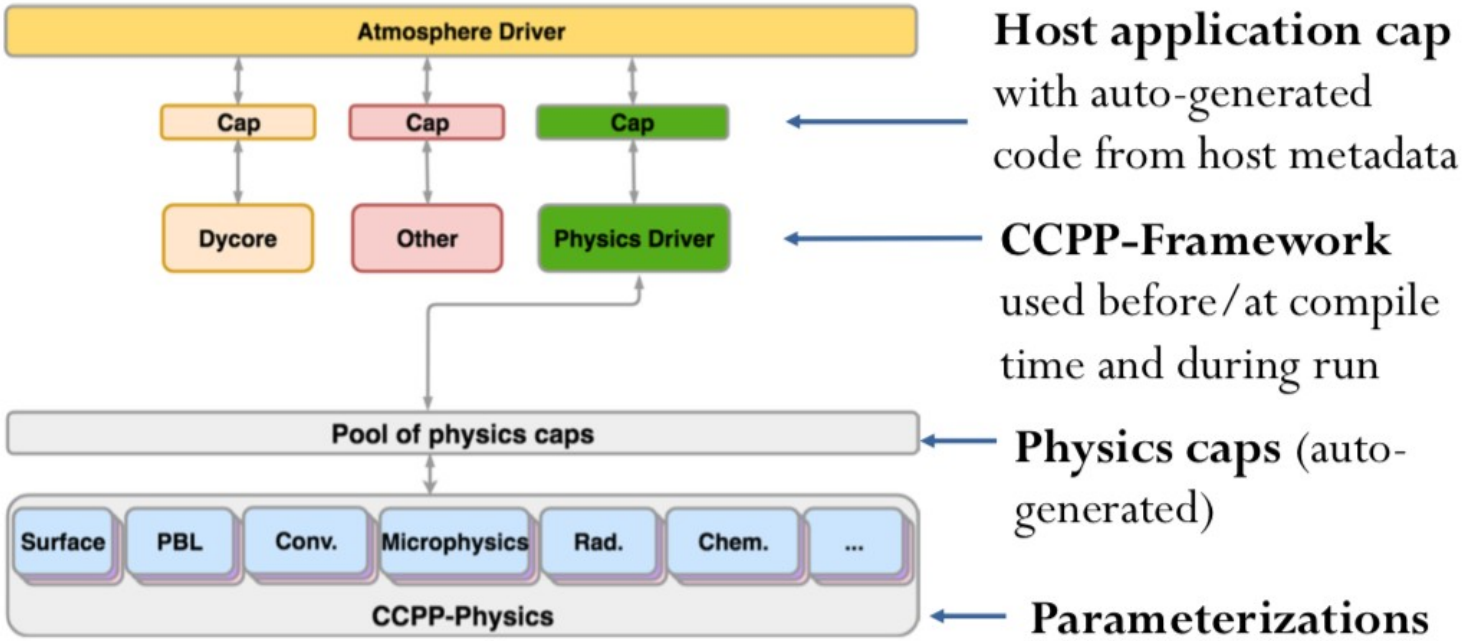
- Finite Volume on cubed sphere
- Non-hydrostatic
- Lin-Rood 2D FV advection
- Lagrangian vertical pressure coordinate
- Currently shallow atmosphere
- Forward in time split-explicit time stepping
- Semi-implicit solver for vertical sound and gravity waves



c) Gnomonic

CCPP

- Modular physics package
- Link any number of physics schemes to any dynamics fitted with the package through xml



Multi-gas Functionality

- Accounts for changes in atmospheric composition from }

- We have to be careful when converting between and T

WAM-physics

- The IDEA physics package from GSM-WAM is currently ported as a single scheme into CCPP

```
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    <scheme>wamphys</scheme>
    <scheme>wamphys_post</scheme>
    <scheme>GFS_surface_generic_pre</scheme>
    <scheme>GFS_surface_composites_pre</scheme>
    <scheme>dcyc2t3</scheme>
    <scheme>GFS_surface_composites_inter</scheme>
    <scheme>GFS_suite_interstitial_2</scheme>
  </subcycle>
```

Kappa Correction

- Red terms are typically neglected in shallow atmosphere models
- One way to compute this term is to add as an advected tracer whose value is reset at the start of each step by the changes in composition

Horizontal Molecular Diffusion in FV3

- These terms are treated explicitly
  - Coefficients are computed in the physics
  - Limiters are applied to the coefficients for stability
- Done in time-split fashion after dynamics
- May require implicit formulation or sub-cycling in the future

Vertical Molecular Viscosity on w in FV3

- Vertical velocity (w) is not a prognostic variable in the physics (vertical MD is applied in the physics)
- We must apply it fully implicitly to w in the vertical solver of the dycore

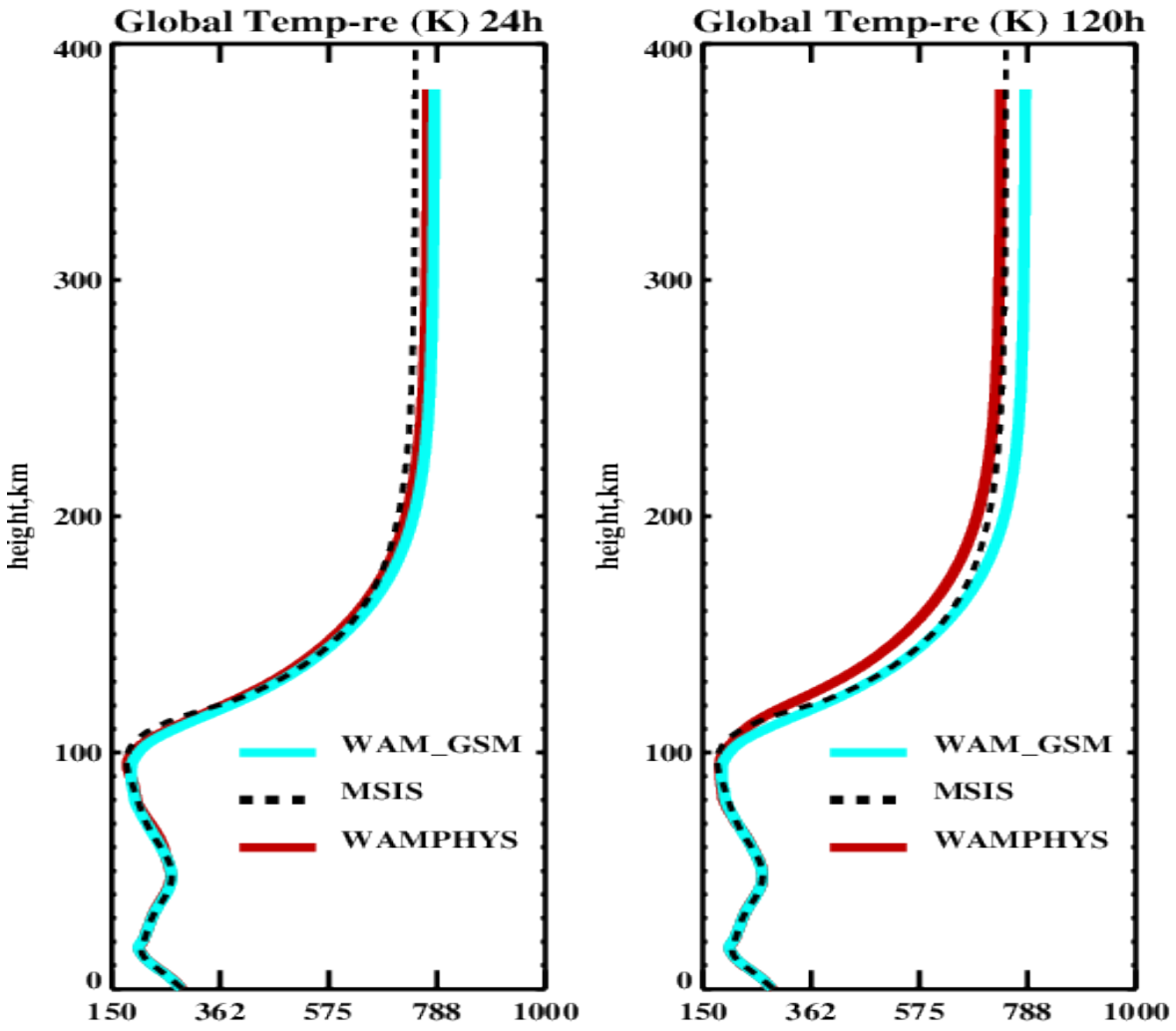
- Discretize fully implicitly and solve a tridiagonal system for w

Experiment Setup

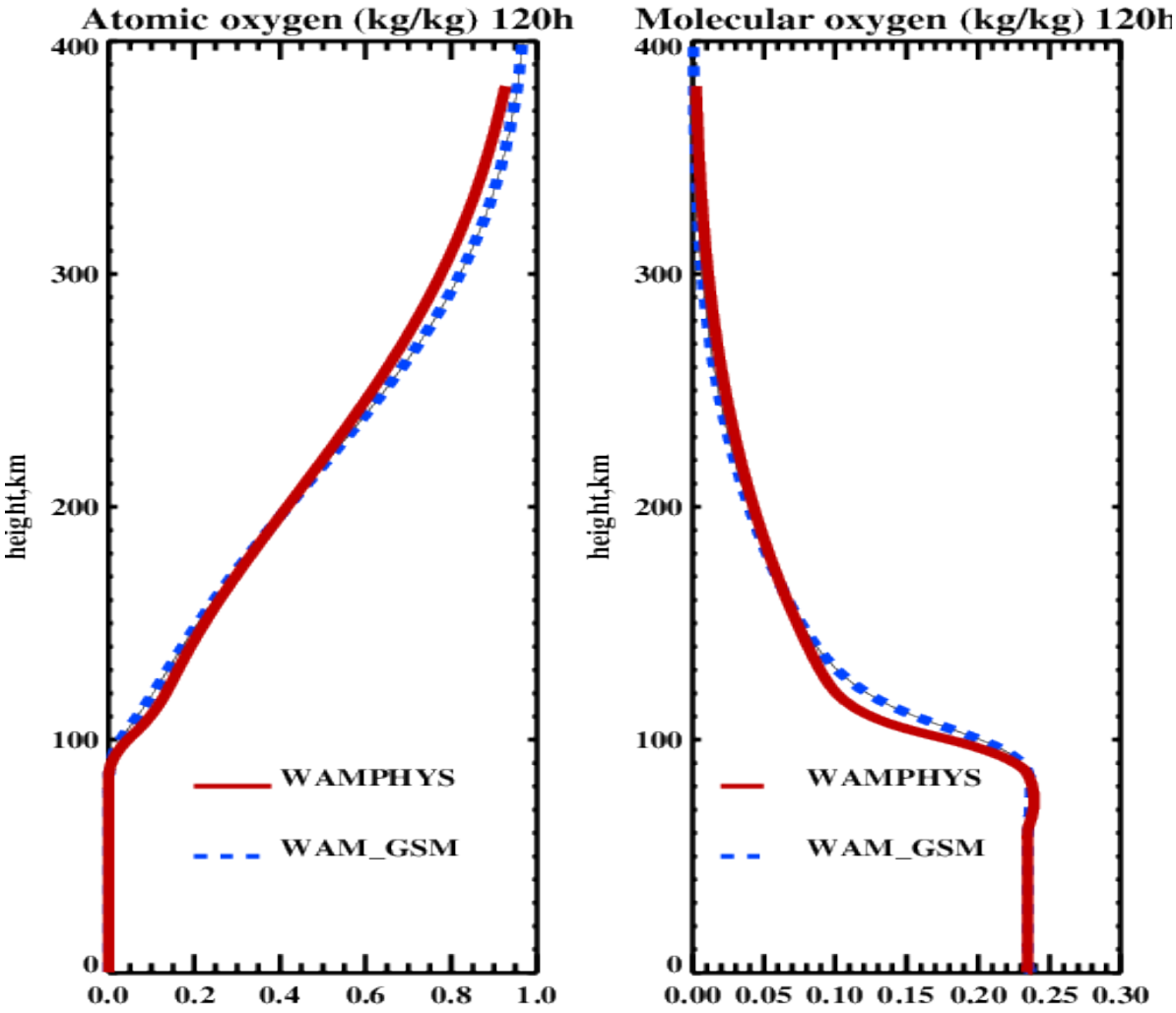
- C96 (~1 degree) grid spacing
- 150 levels up to ~500km
- Start a single 5 day forecast from remapped GSM-WAM initial conditions

- Examine global mean values for temperature and composition
- Compare with GSM-WAM and NRL MSIS
- *goal is to approximately match

Results: Global Mean Temperature Profiles



Results: Composition



Conclusions/Future Work

- We're able to approximately match the results of the neutral atmosphere GSM-WAM model with the new UFS-WAM application
- Need to begin testing at higher resolution to examine non-hydrostatic effects
- Deep atmosphere formulation (with full Coriolis and variable gravity)
- Fully implicit horizontal molecular diffusion
- Coupling to IPE through ESMF
- Development of new DA through JEDI