COE CST First Annual Technical Meeting:

Mitigating threats through space environment modeling/prediction

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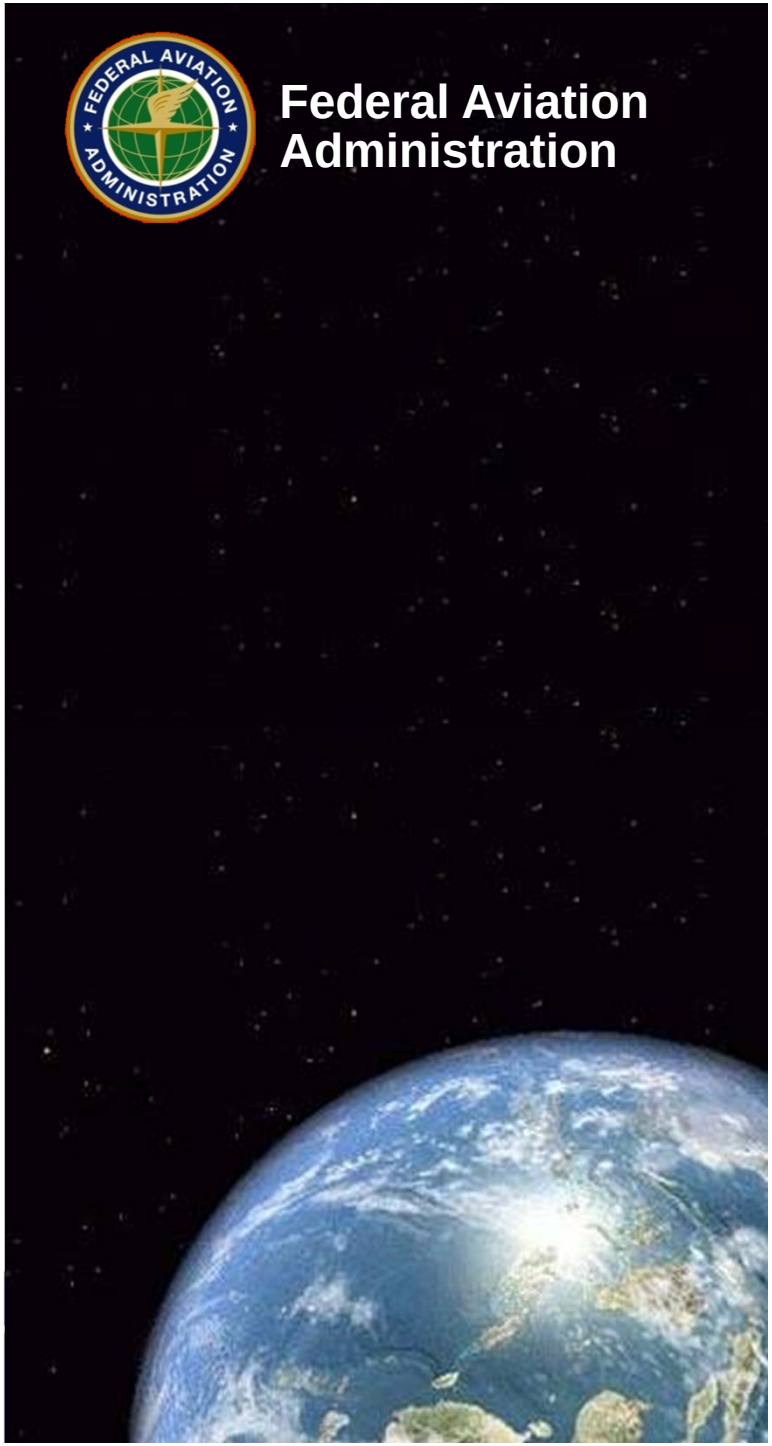
Presented by

Tomoko Matsuo

November 9th, 2011



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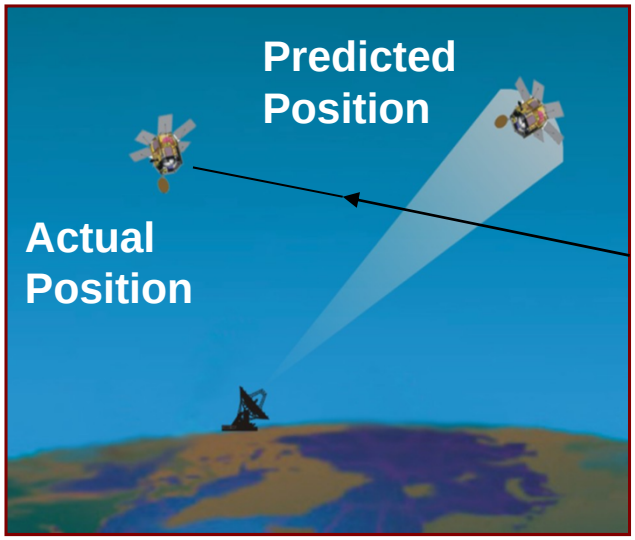
Purpose of Task

Purpose: *An integrated air and space traffic management system requires seamless and real-time access to density predictions for on-orbit collision avoidance and atmospheric re-entry, and near-surface weather prediction*

Objectives: *Develop a "weather" (terrestrial weather and space weather) prediction model extending from Earth's surface to the edge of space*

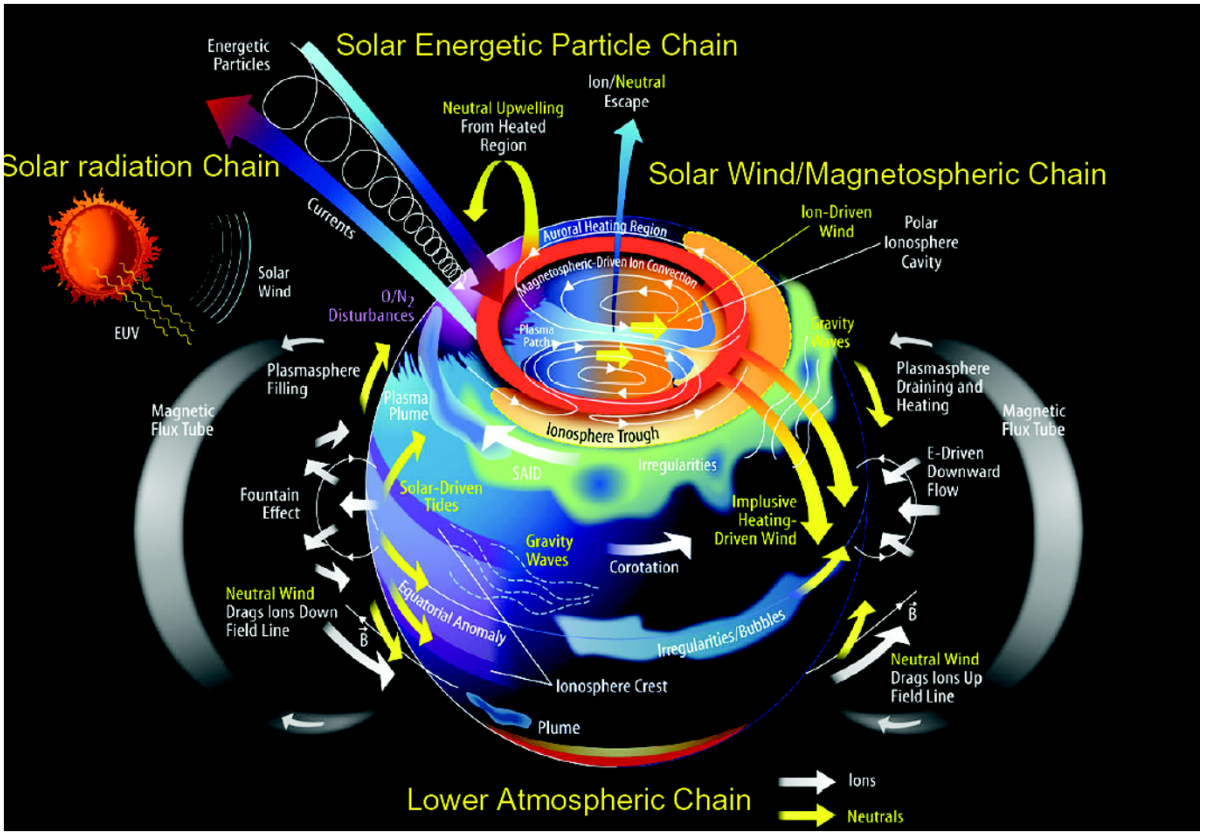
Goals: *Predict the environmental conditions needed for safe orbital, sub-orbital, re-entry, descent, and landing*

Drivers of the density variability



Satellite drag and orbit prediction has traditionally relied on understanding the response to **solar and geomagnetic forcing**

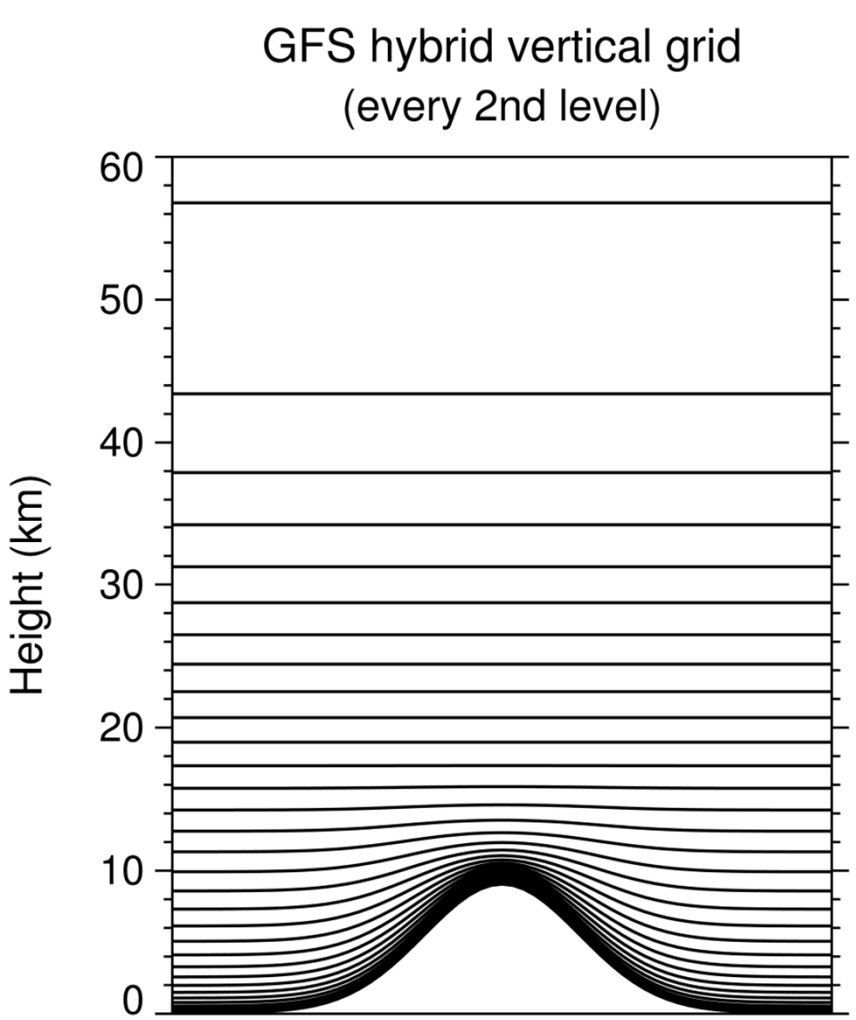
Understandable:
since 80% of the forcing above 200km comes from solar and geomagnetic activity

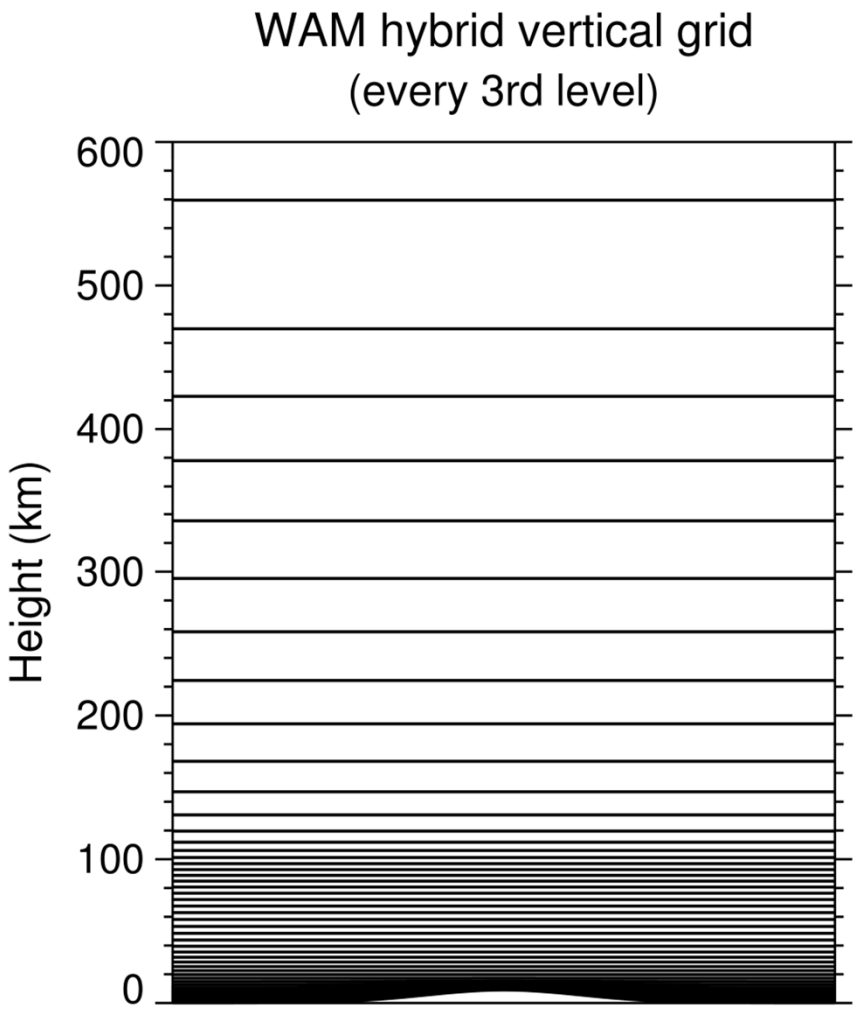


So why a Whole Atmosphere Model

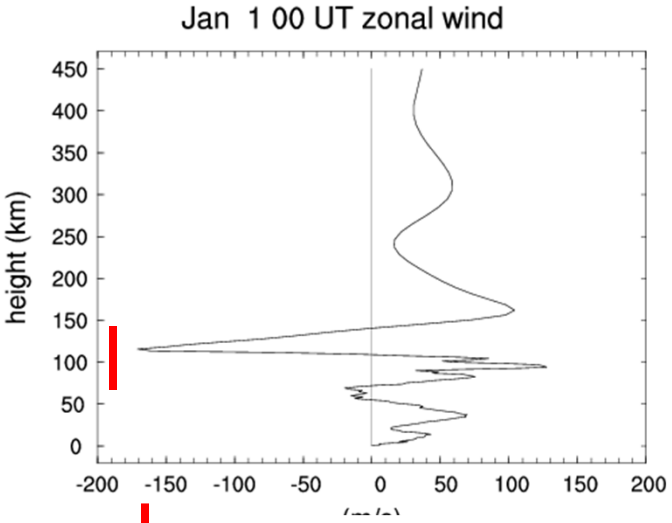
- **Re-entry** calculations have been notoriously bad at predicting place and time of impact
- With rise in Commercial Space Transportation increasing use of **sub-orbital** vehicles and need for controlled re-entry, decent and landing
- Altitude region of interest is impacted by both **“terrestrial or tropospheric weather”** and **“space weather”**
- Therefore need to characterize the atmospheric conditions seamlessly **from the ground to orbital altitudes**

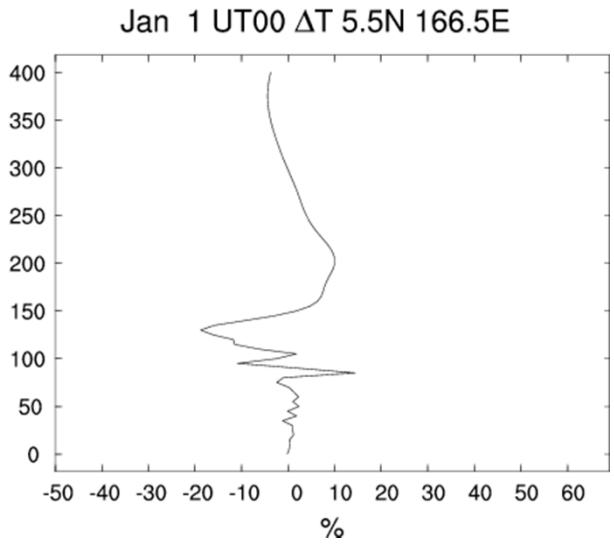
Whole Atmosphere Model (WAM)

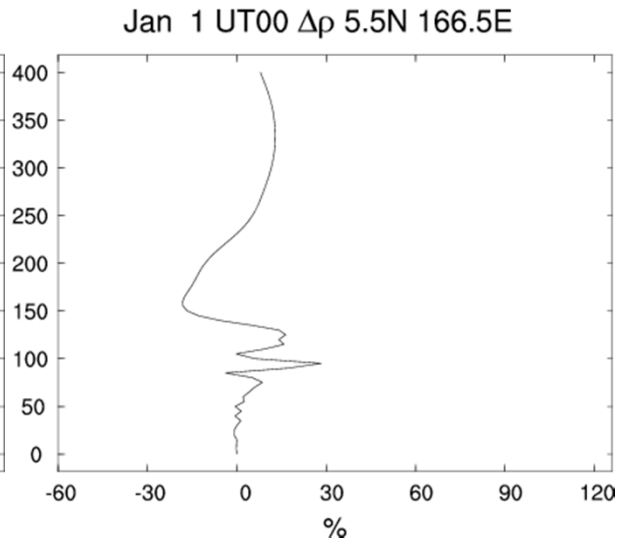


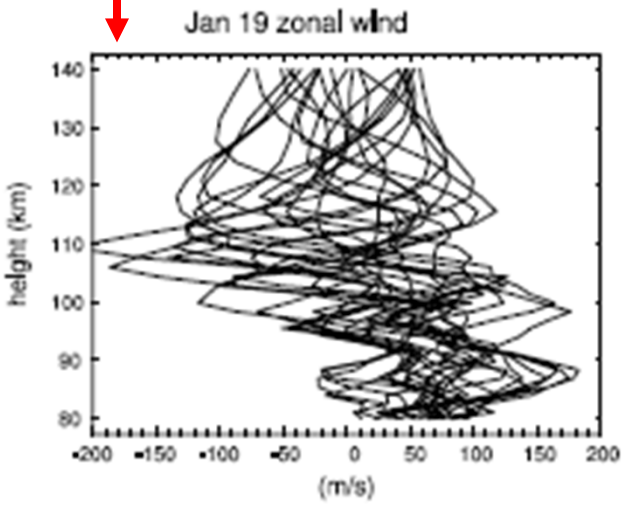


Strong Variability at Sub-orbital / Re-entry Altitudes

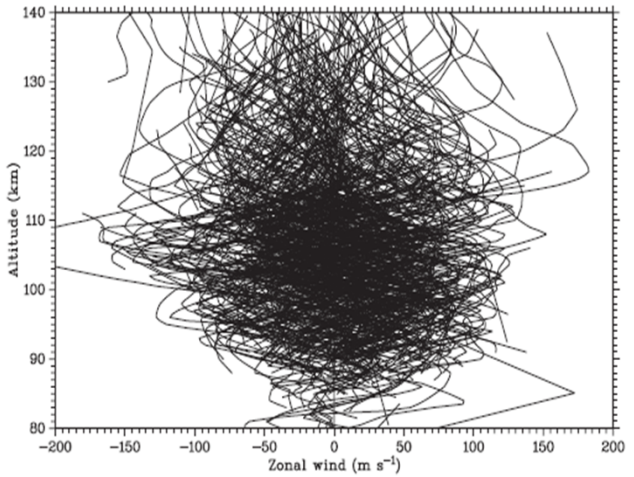








Observed Variability: zonal winds at mid/low latitudes from rocket-released chemical trails (Larsen, 2002)

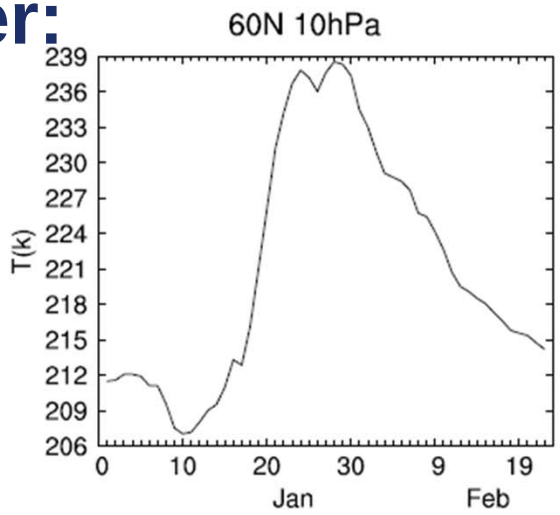


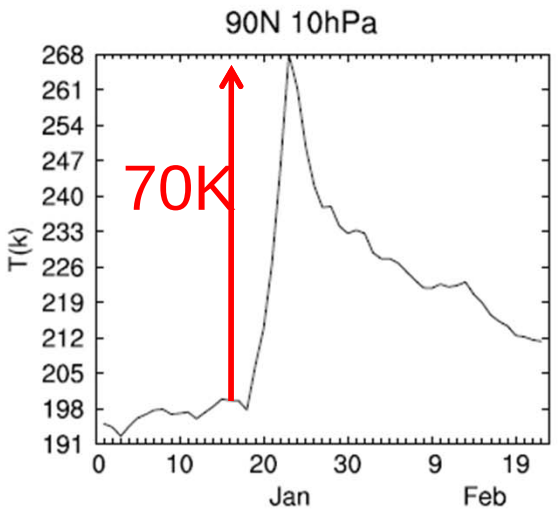
Data Assimilation

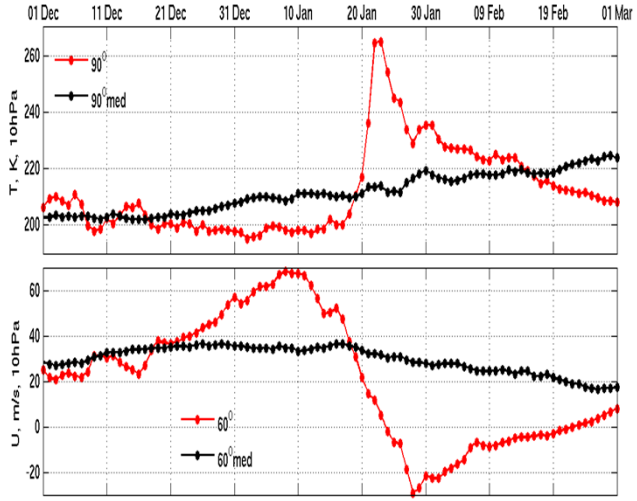
- **Gridpoint Statistical Interpolation (GSI)** is the NCEP operational analysis system for global and regional NWP
- Uses a 3-D variational **(3DVAR)** analysis technique
- Replace GFS with WAM
- Analysis system was modified to use **incremental analysis updates (IAU)** to avoid use of digital filter, which excessively damps tidal propagation to the thermosphere
- Simulate January 2009 and 2010 periods during large **sudden stratospheric warmings**

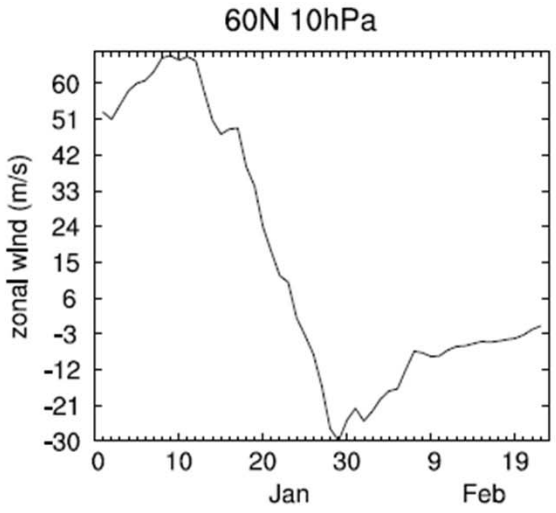
Terrestrial Weather: Jan 2009 SSW

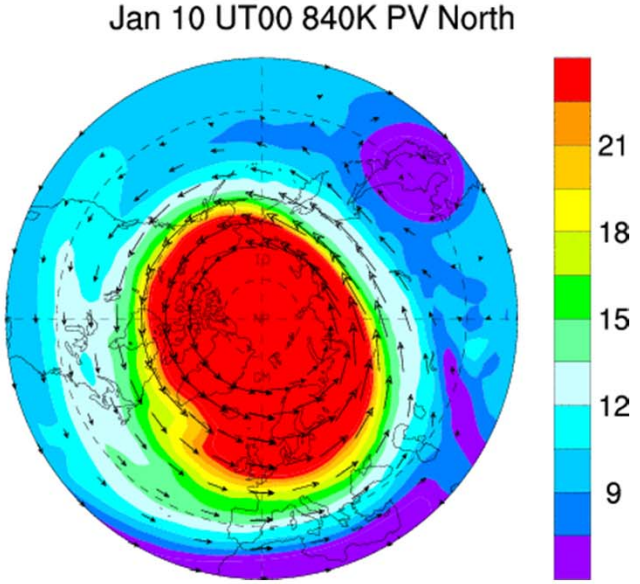
Comparison with European Centre for Medium Range Weather Forecasting (ECMWF)











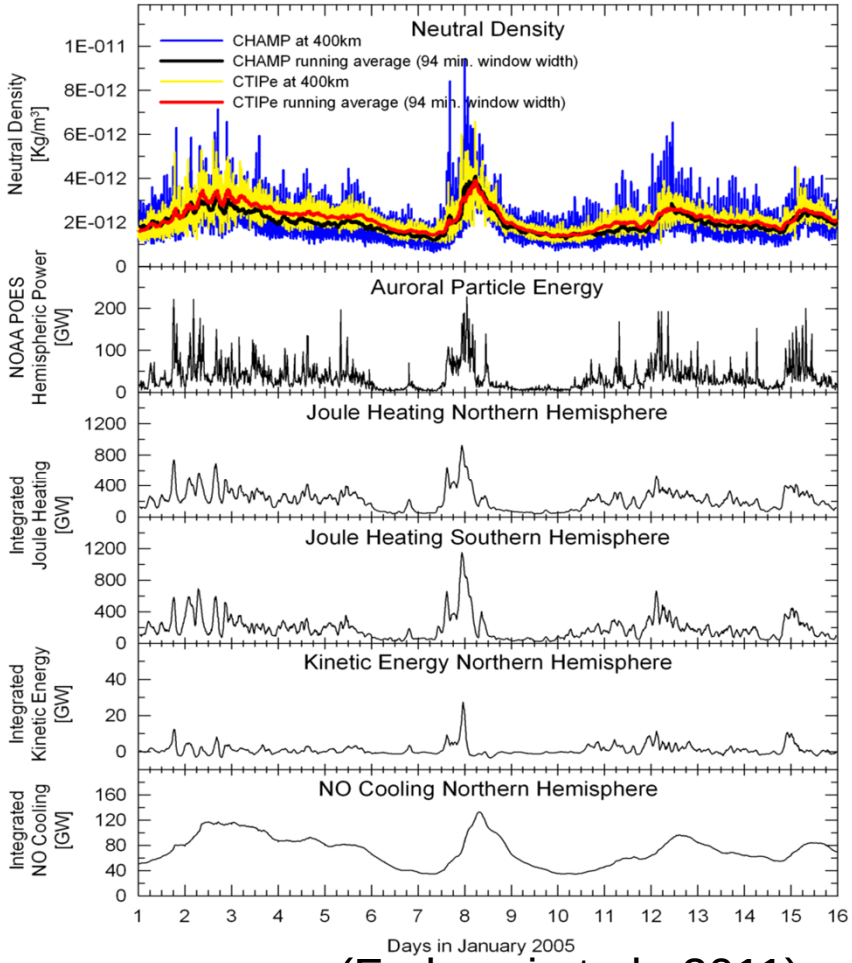
Space Weather Modeling: Coupled Thermosphere-Ionosphere-Plasmasphere (CTIPe) Model

- **Global thermosphere** 80 - 500 km, solves momentum, energy, composition, etc., O, O_2, N_2 (Fuller-Rowell et al., 1996)

- **Global ionosphere** 80 - 10,000 km, solves plasma continuity, momentum, energy, electrodynamics etc., O^+, H^+, O_2^+, NO^+, N_2^+, N^+(Millward et al., 1996)

- **Solar and geomagnetic forcing** solar UV and EUV, Weimer electric field, TIROS/NOAA auroral precipitation

Coupling with WAM



(Fedrezzi et al., 2011)

Summary

- **WAM** is designed to forecast the **environmental conditions from the ground to 600km**
- **WAM** will cover the **orbital, sub-orbital, re-entry, descent, and landing requirements for atmospheric density**
- **WAM** will simulate the internal atmospheric sources of variability (gravity waves, tides, planetary waves, midnight density maximum, wave 4 structure, sudden stratospheric warmings, etc.)
- **Coupled to an ionosphere module, WAM** will also be able to respond to space weather forcing (solar flares, geomagnetic storms, solar proton events) to address not only density requirements, but also **communications and navigation needs**
- **WAM** will follow, and forecast several days ahead, the whole atmosphere dynamical response to atmospheric processes using a modified version of the **NCEP GSI operational data assimilation system**
- **WAM** will also provide environment conditions for micrometeoroid and orbital debris detection / avoidance (Sigrid Close) and collision probability for space situational awareness (Dan Scheeres)

Next Steps

- **Extend WAM data assimilation** into the lower thermosphere (SABER, MLS temperatures, etc.)
- Test **higher resolution WAM T382** (35 km resolution) to resolve wave field penetrating to the thermosphere and test semi-annual variation in density
- Full **coupling of the ionosphere** (e.g., Ionosphere-Plasmasphere-Electrodynamcis (IPE) model, CTIPe) to respond to **solar and magnetospheric forcing**
- Explore **assimilation of ionospheric data** for density prediction
- Whole atmosphere/ionosphere data assimilation at high resolution

- **Transition** at NOAA

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