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Thermosphere-Ionosphere Integration at NRL

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NRL Thermosphere-Ionosphere (T/I) Coupling

- NRL has developed a thermosphere-ionosphere prediction capability, the Highly Integrated Thermosphere and Ionosphere Demonstration System (Navy-HITIDES), utilizing standardization and regridding tools of the Earth System Modeling Framework (ESMF).
- Navy-HITIDES is built on the physics and numerical algorithms of the NRL SAMI3 model. SAMI3 is a state-of-the-art, physics-based ionosphere model.
- Presently, Navy-HITIDES is coupled to the extended version of the Whole Atmosphere Community Climate Model (WACCM-X) with the day-to-day variation of weather provided by atmospheric specifications from the Navy Global Environmental Model (NAVGEM).
  - Integrated into this coupled model are the effects of drivers from atmospheric weather, the Sun, and the changing high altitude composition.

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Current Status and Plans

- One way coupling (thermosphere ➔ ionosphere) is completed (summer 2016)
- Short-term goals (few months):
  - Two-way coupling (thermosphere ➔ ➔ ionosphere) is under-way:
    - Mapping of scalar (electron temperature and O^+) and vector (ion-drift velocities) fields from the geo-magnetic to the WACCM grid
    - Use electron heating and ion drag from existing code in WACCM-X with HITIDES inputs
- Extended time frame goals (12 months):
  - Data assimilation: Kalman-filter to assimilate ion drift velocities (NASA/CINDI)
  - Code modernization and possibly inclusion of NRL D-region model (OASIS)
  - Nesting of regional high-resolution ionosphere in the global ionosphere

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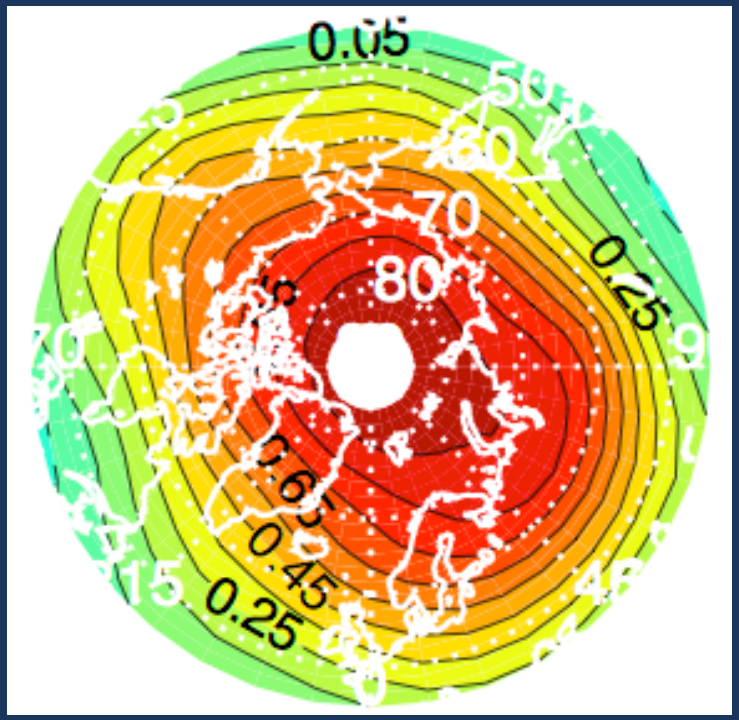
HITIDES + SD-WACCM-X

- **Nudging vertical domain: 50 km vs. 90 km**
  - ✓ SD-WACCM-X: Atmospheric specifications from NOGAPS-ALPHA
  - ✓ MLT behavior around the SSW of 2009
- **Nudging with different atmospheric specifications**
  - ✓ HITIDES + SD-WACCMX-X: NOGAPS-ALPHA (3DVAR) vs. HA-NAVGEM (hybrid-4DVAR)
- **Nudging strength: 10 h vs. 0.5 h**
  - ✓ HITIDES + SD-WACCM-X: Atmospheric specifications from High Altitude NAVGEM
  - ✓ Ionospheric response

Nudging Vertical Domain: 90 km vs. 50 km

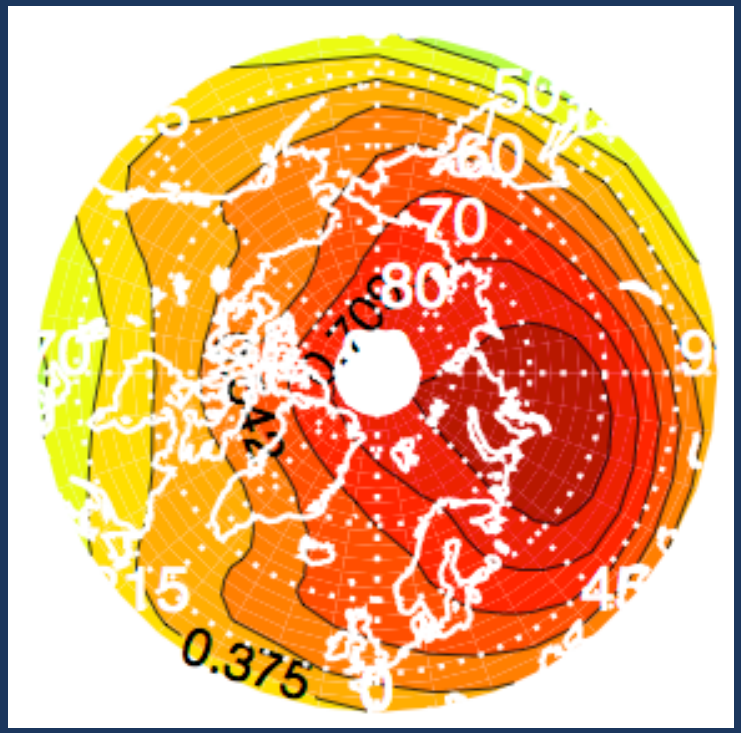
Nudging Domain: EOF1 – 90 km

Z=89 km – Perc Variance = 39%



Nudging up to 90 km

Z=89 km – Perc Variance = 41%



Nudging up to 50 km

Structure of the polar vortex in the MLT is visibly different:
Meridional gradients
Polar centric

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SSW Behavior: MLT Response

20 Dec 2008

20 Feb 2009

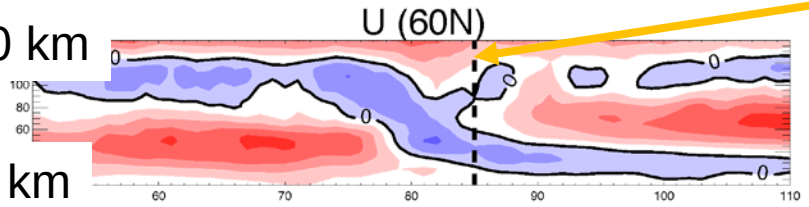
SSW 2009

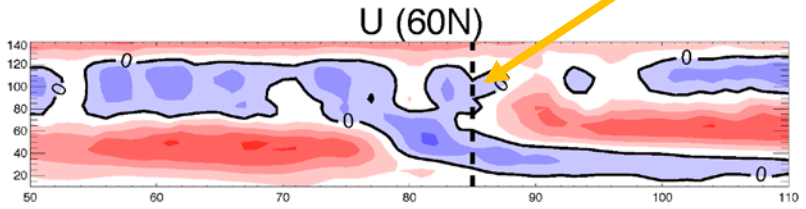
Nudging up to 90 km

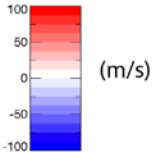
Nudging up to 50 km

150 km

10 km







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(1) Conclusions: Vertical Domain

- Simulations of the MLT are unambiguously different around a SSW.
  - MLT polar vortex and meridional gradients
  - Cold anomaly and MLT precursors of the SSW
  - Stratopause recovery
  - Wave structure

Nudging with Different Atmospheric Specification

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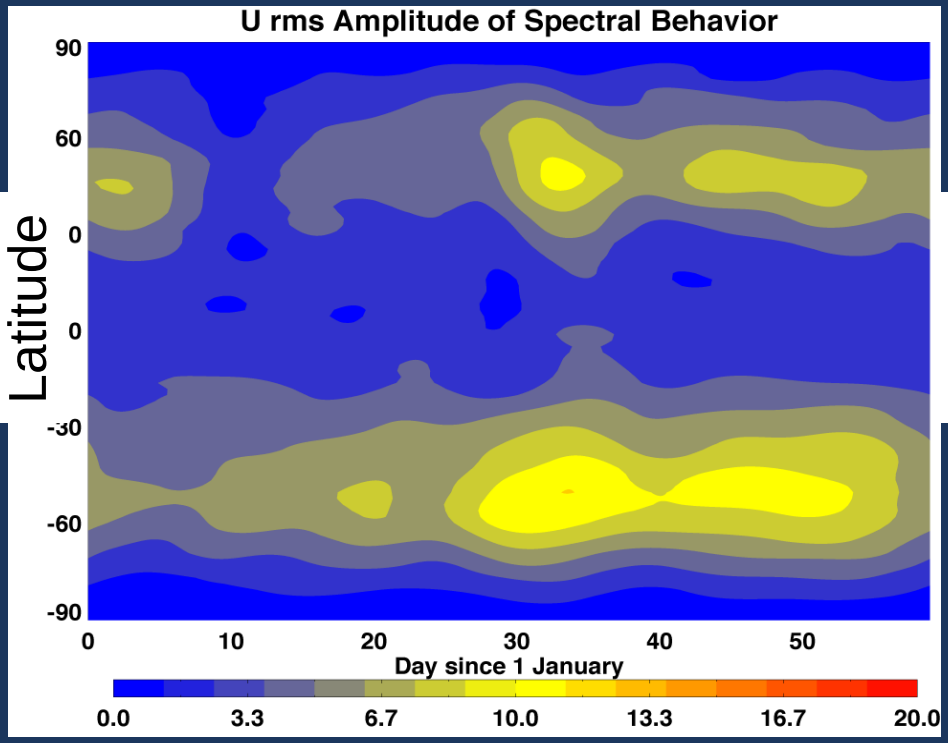
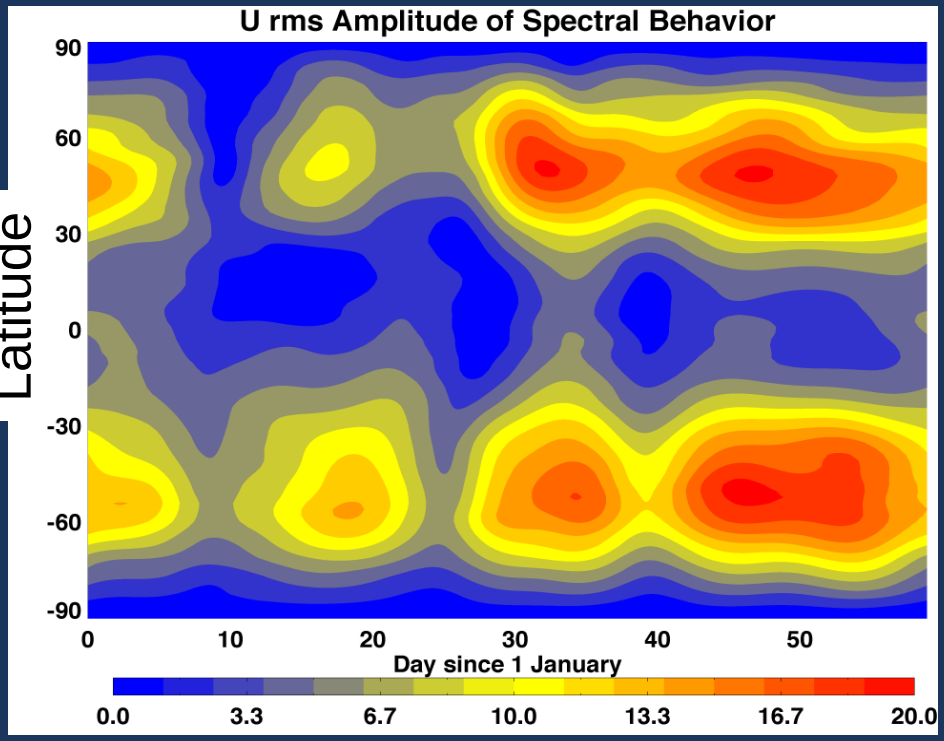
Semi-Diurnal Tide (SW2)

WACCM-X w/ NOGAPS-ALPHA
6-hourly cadence
Zonal Wind SW2 Amplitude at 110 km



WACCM-X w/ HA-NAVGEM
3-hourly cadence
Zonal Wind SW2 Amplitude at 110 km



- The 3-hour product can better capture the semi-diurnal tide
- SW2 is twice as strong in WACCM-X with HA-NAVGEM forcing

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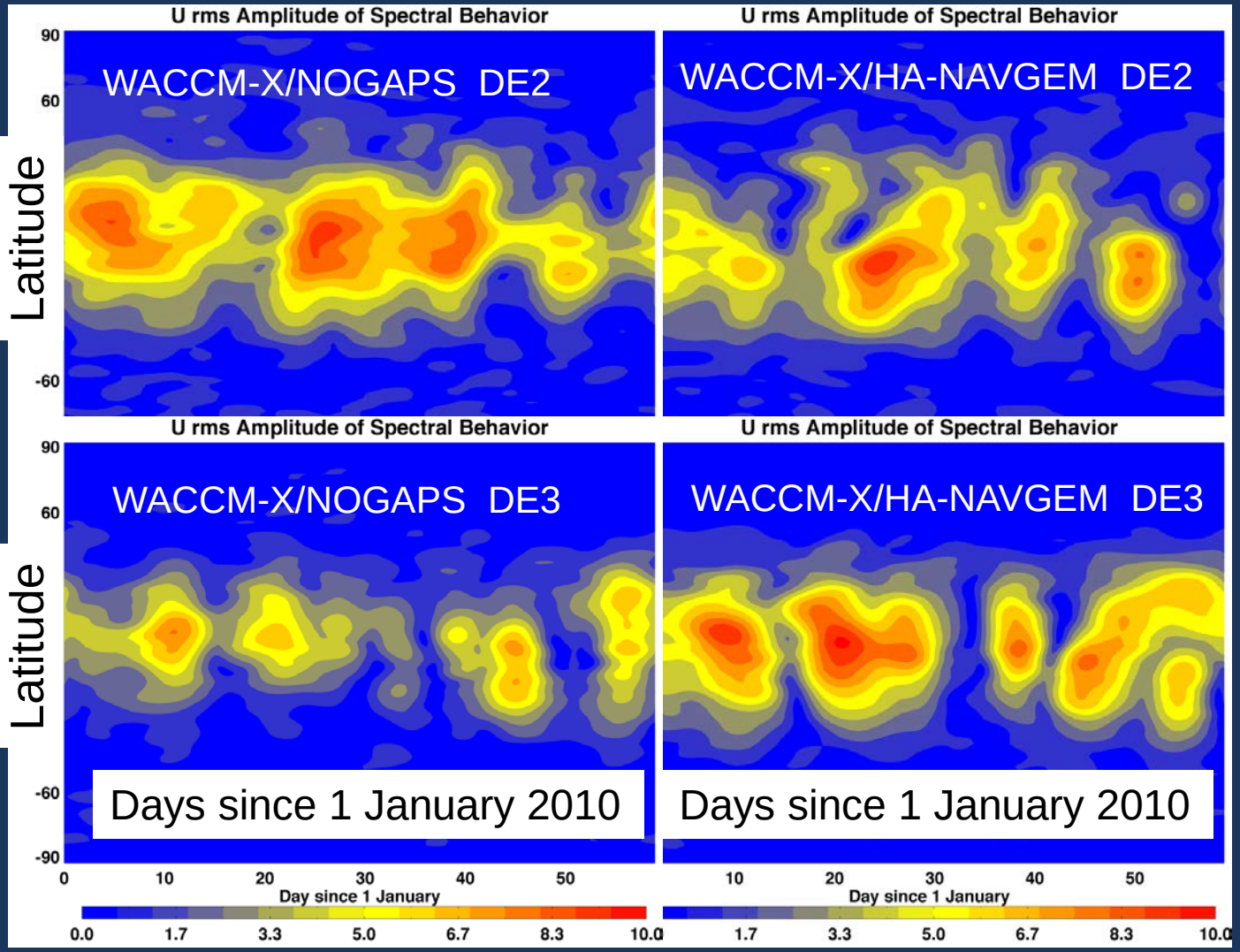
Non-Migrating Tides (DE2 & SE3)

Zonal Wind Amplitudes at 110 km
Latitude vs. Day of Year



➔ Contributes to wave-3 pattern of ionospheric maps at a fixed LT

➔ Contributes to wave-4 pattern of ionospheric maps at a fixed LT

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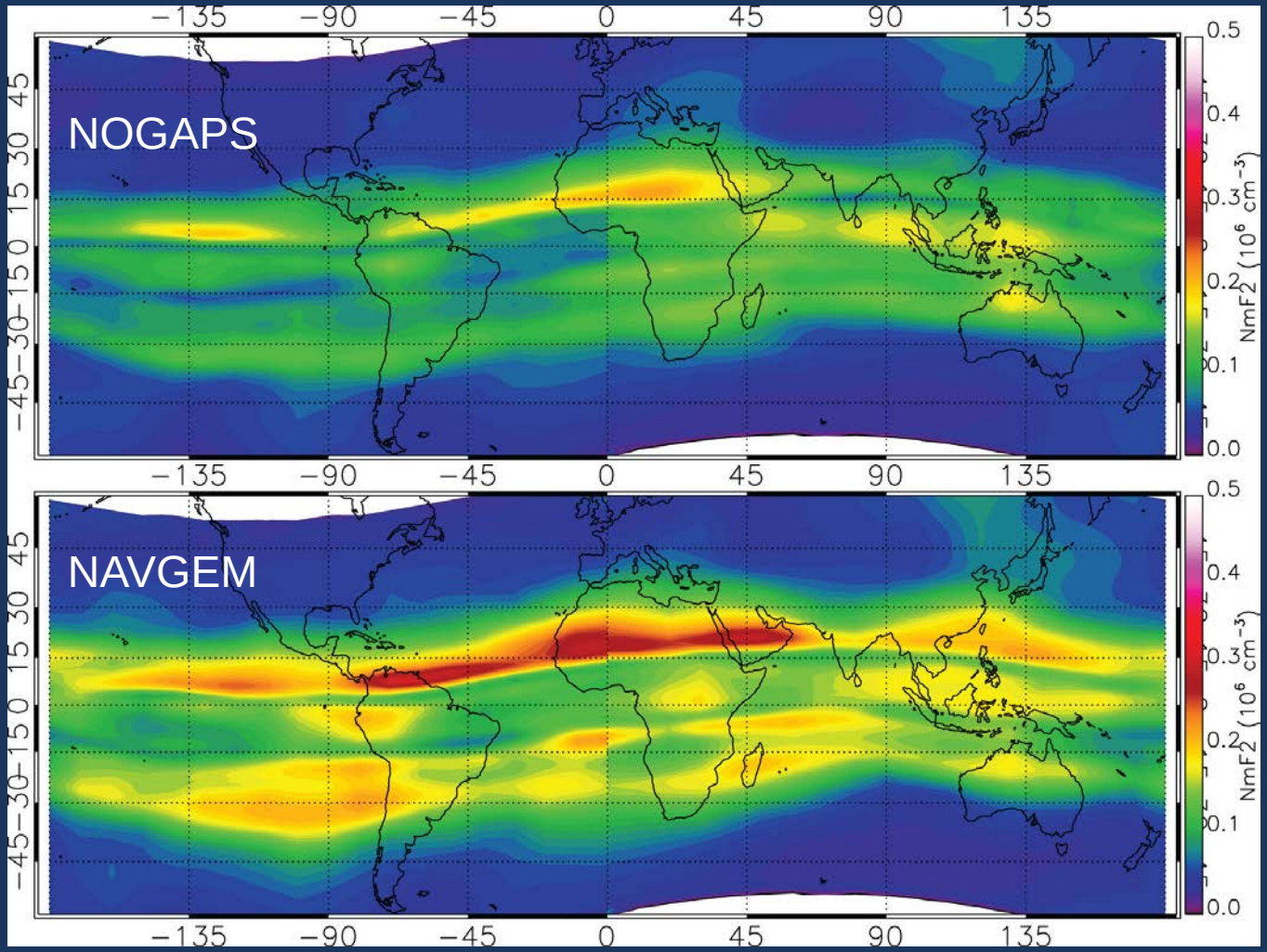
Day-to-Day Variability of NmF2

Navy-HITIDES/WACCM-X Variation in NmF2 during January 2010
1-σ Standard Deviation of NmF2 at 13:00 LT



Simulations with NAVGEM forcing capture more day-to-day variability in the ionosphere

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(2) Conclusions: Different Atmospheric Specifications

- Navy-HITIDES has been one-way coupled to WACCM-X
- Simulated January 2010 using forcing from:
  - **NOGAPS-ALPHA (6-hour)**
  - **HA-NAVGEM (3-hour)**
- 3-hour HA-NAVGEM forcing results in better resolution of SW2 in SD-WACCM-X
- Navy-HITIDES/WACCM-X with NAVGEM improves ionospheric specification
  - **Better day-to-day and longitudinal variability**
  - **Closer match to observations**

Nudging Strength: 10 h vs. 0.5 h

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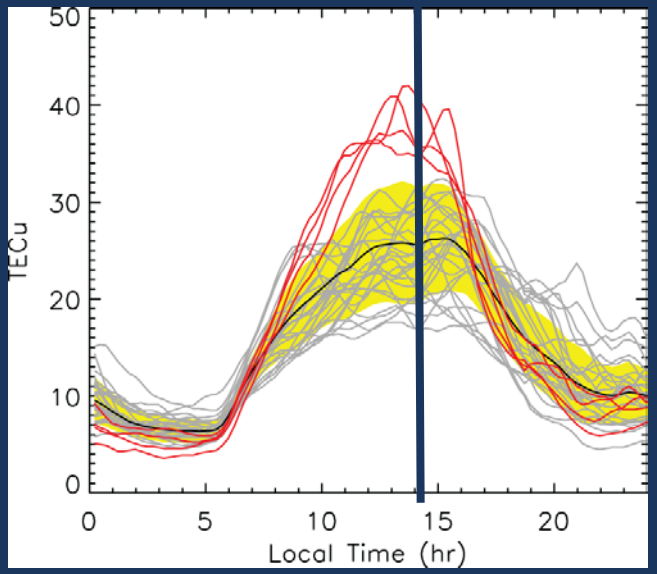
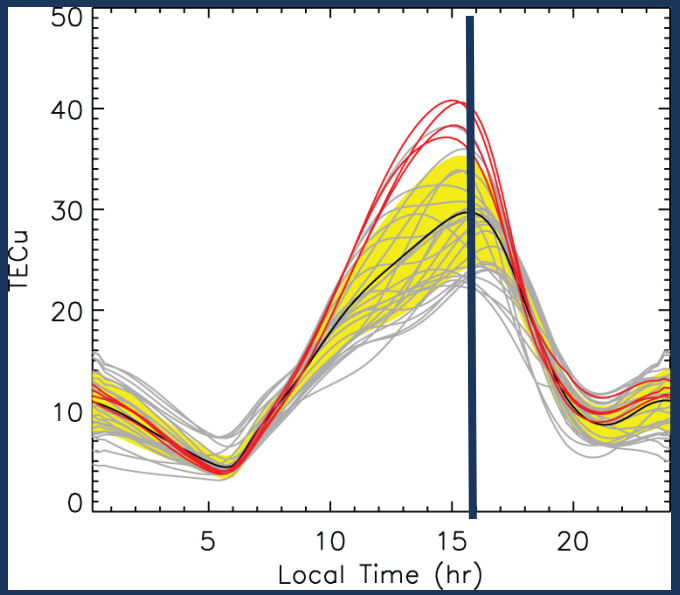
TEC: 2 – 31 January 2010

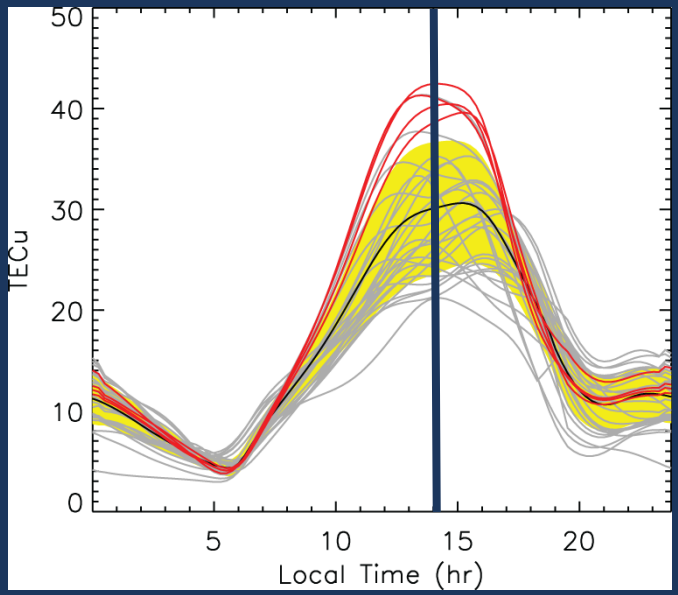
JPL GIM



10-hour nudging



0.5-hour nudging



Gray : Daily TEC
Black : January average
Yellow : 1-standard deviation
Red : 17,19-21 January 2010

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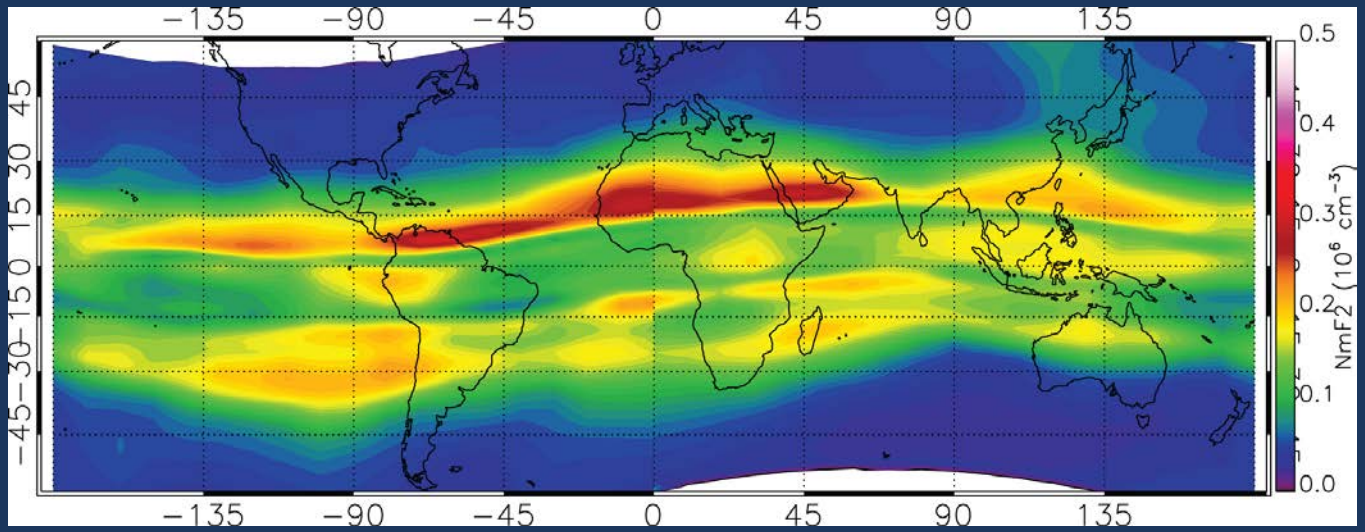
NmF2 Variability: Standard Deviation January 2010

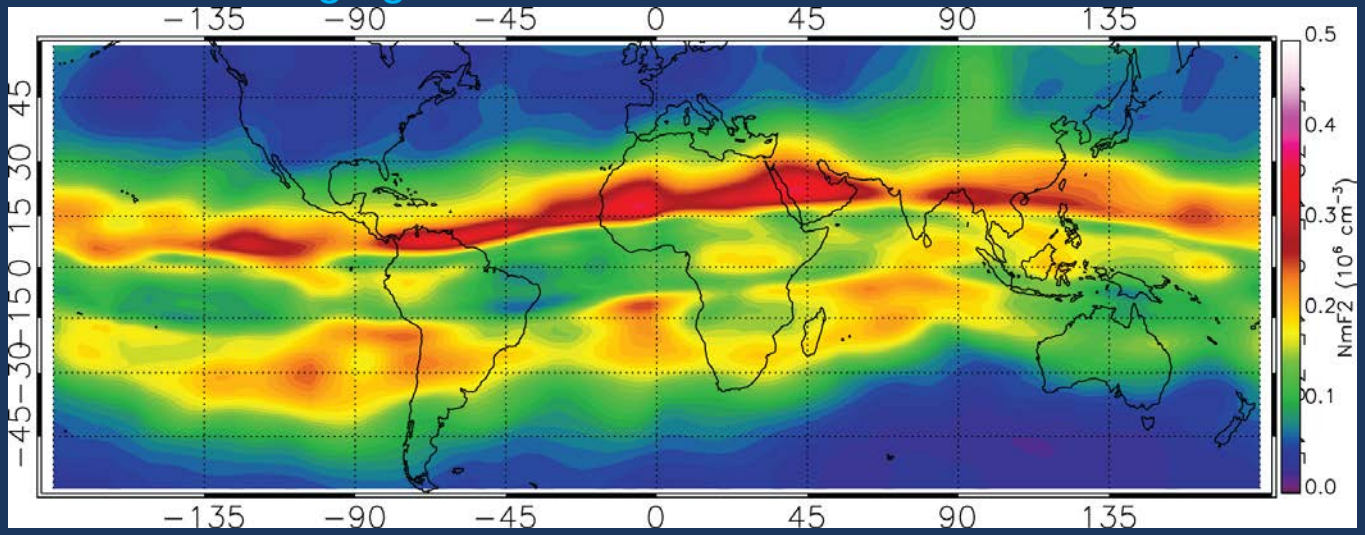
10-hour nudging

13:00 LT



0.5-hour nudging

13:00 LT



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(3) Conclusion: Nudging Strength

- Nudging strength (10 h vs. 0.5 h) has important consequences for the ionospheric variability (NmF2)
- Modest changes appear in the TEC
- Results obtained obtained with a weaker nudging strength (50 h) show a significantly decreases ionospheric variability.

Backup Slides

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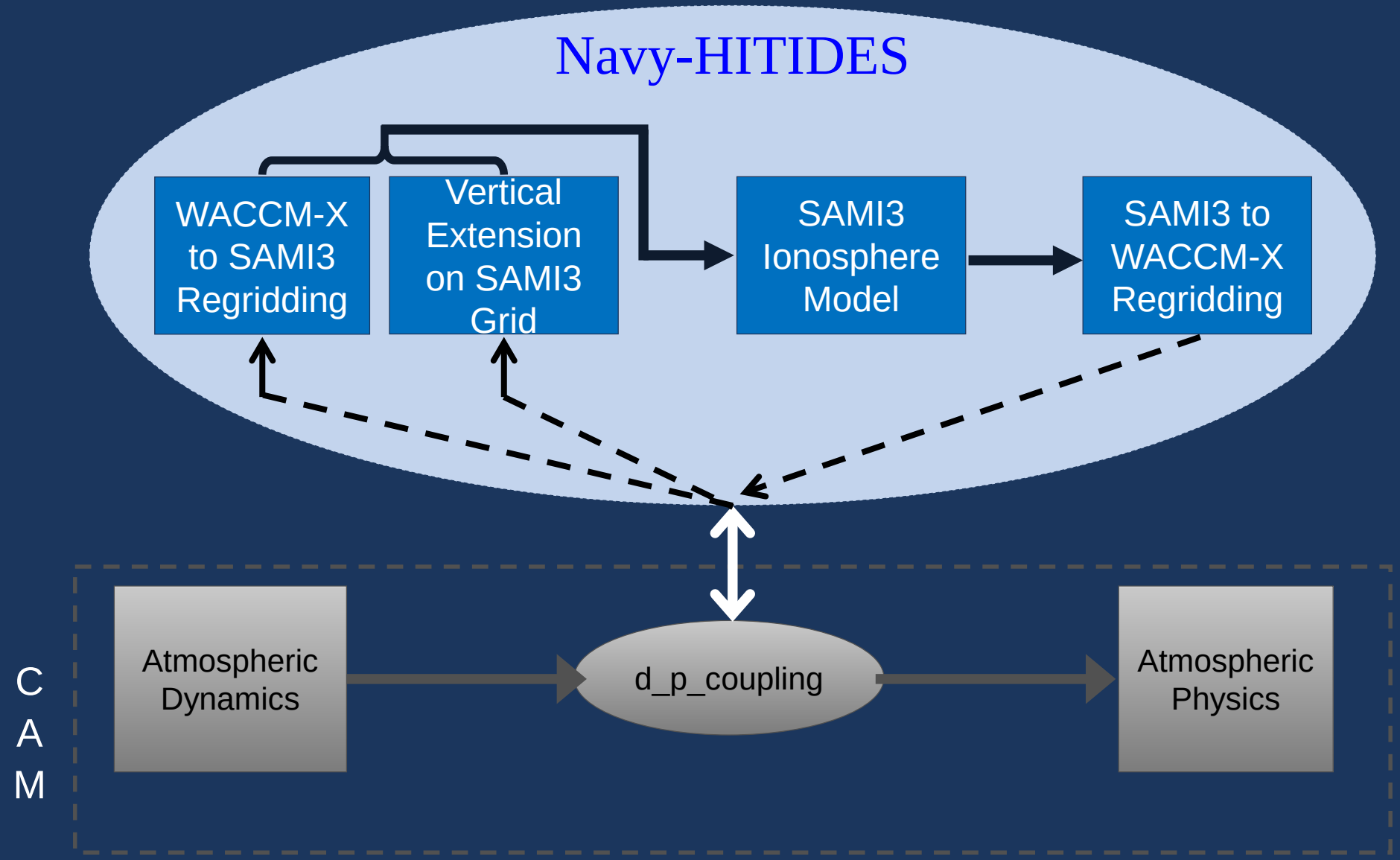
T/I Coupling Overview



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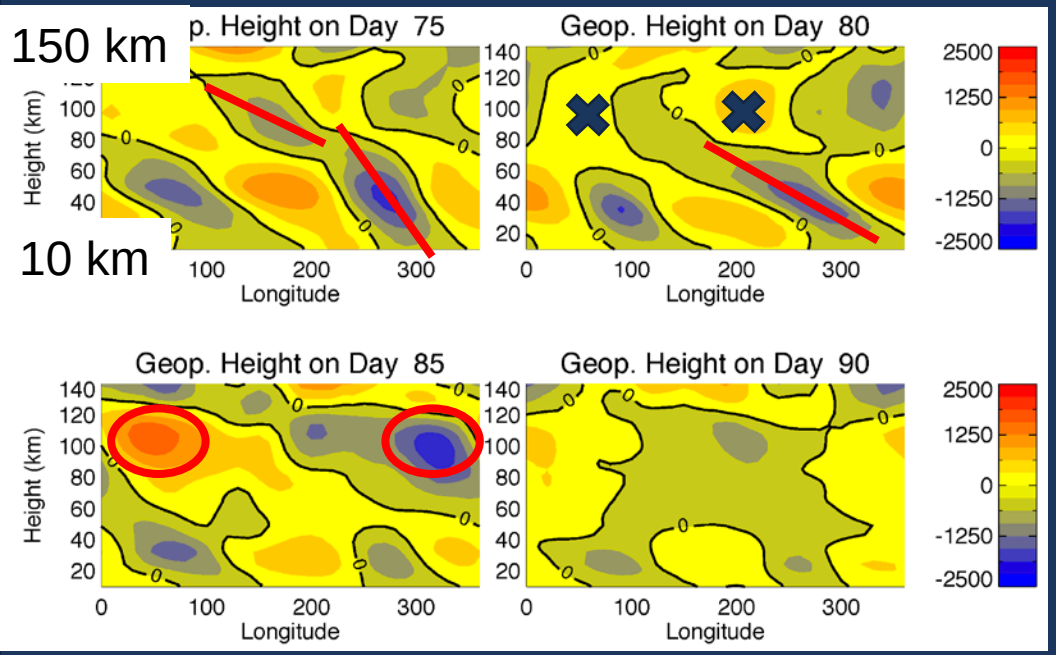
Wave Structure

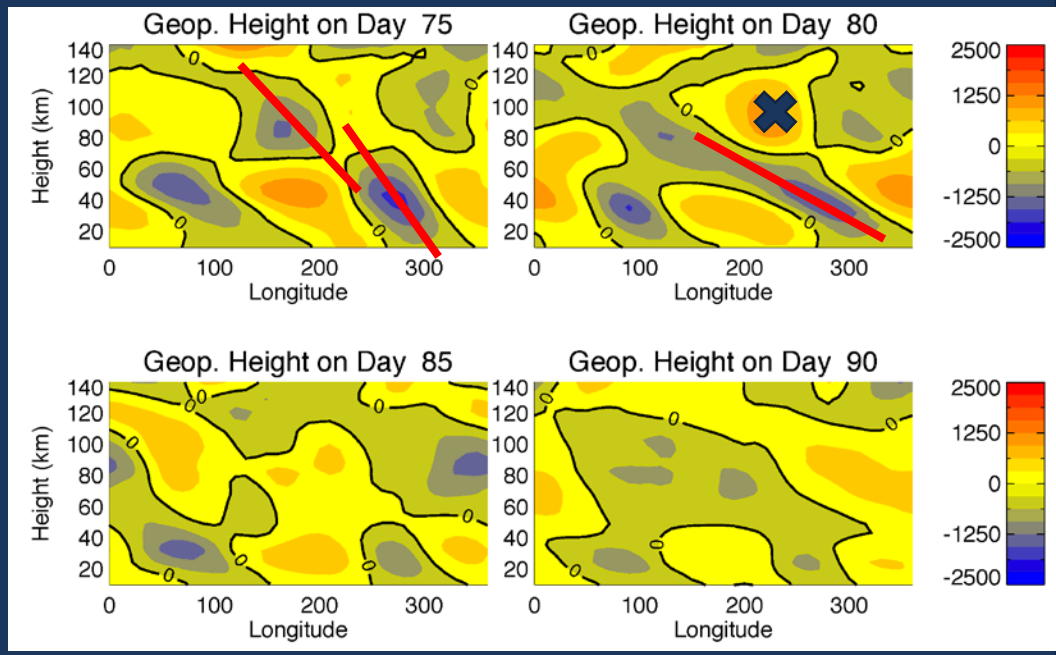
14 Jan 2009 19 Jan 2009



24 Jan 2009 29 Jan 2009

Nudging up to 90 km

14 Jan 2009 19 Jan 2009



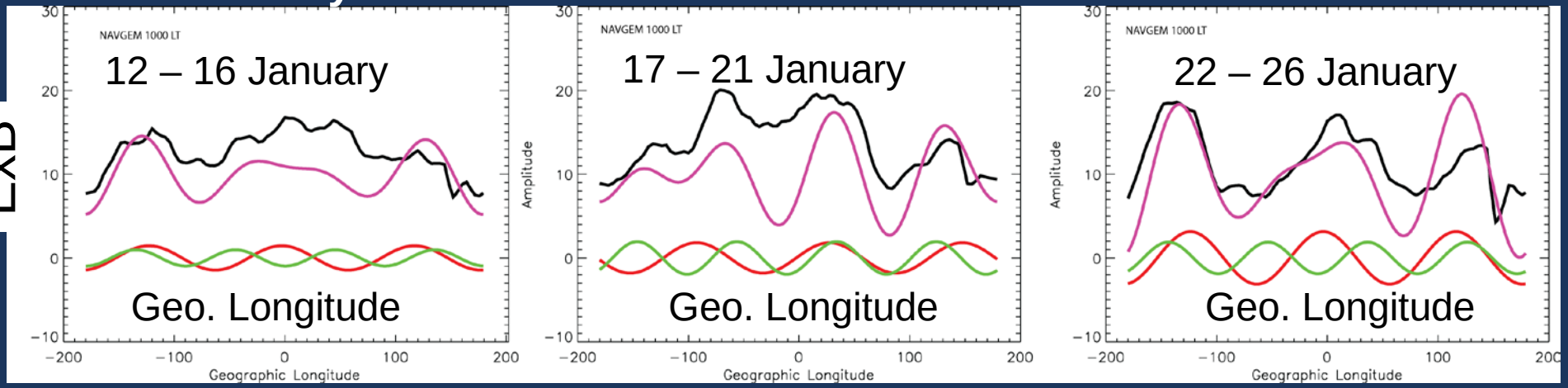
24 Jan 2009 29 Jan 2009

Nudging up to 50 km

Wave-3 and Wave-4 Amplitudes at 10:00 LT

Navy-HITIDES/WACCM-X w/ HA-NAVGEM Simulation

ExB



Vertical ExB drift at 10:00 LT

Wave-3 amplitude (**DW4**, **SPW3**, DE3, SW5)

Wave-4 amplitude (**DE3**, SPW4, SE2)

Wave-3 + Wave-4 amplitude (shifted and amplified to match ExB drift)

- Amplitudes of wave-3 and wave-4 are similar during each of the 5-day periods
- Appearance of 4 peaks during 17 – 21 January primarily due to shift in phase of wave-3