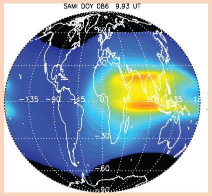
Modeling the Daily Variability of the Midlatitude Ionosphere with SAMI3/SD-WACCM-X

K. A. Zawdie[1], D. P. Drob[1], S. E. McDonald[1], F. Sassi[1], C. E. Coker[1], D. Siskind[1], I. Azeem[2]
[1]SpaceScience Division, US Naval Research Laboratory, Washington, DC
[2]Atmospheric & Space Technology Research Associates (ASTRA), Boulder, CO

Model Setup

NRLSSI Solar Irradiance Model



SAMI3

Physics based model of the ionosphere
Models dynamics and chemistry of
7 ion species from 85 km to 8 R_E

Thermospheric Composition
Neutral Winds
Temperature

Hourly

WACCM Whole Atmosphere Community Climate Model

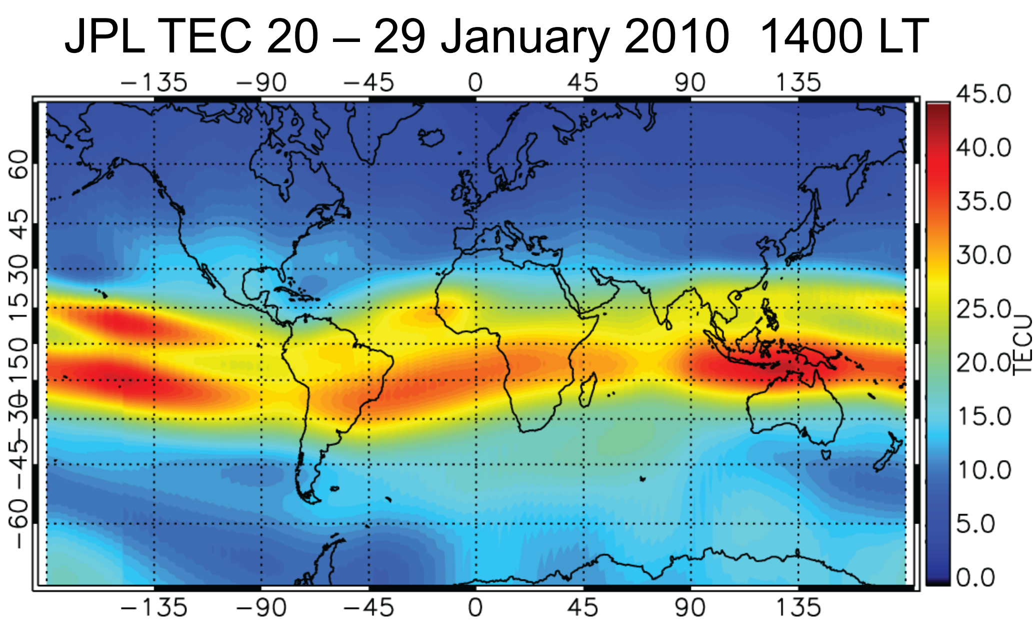
Global climate-chemistry model
Solves dynamics, physics and chemistry
globally from ground to ~500 km

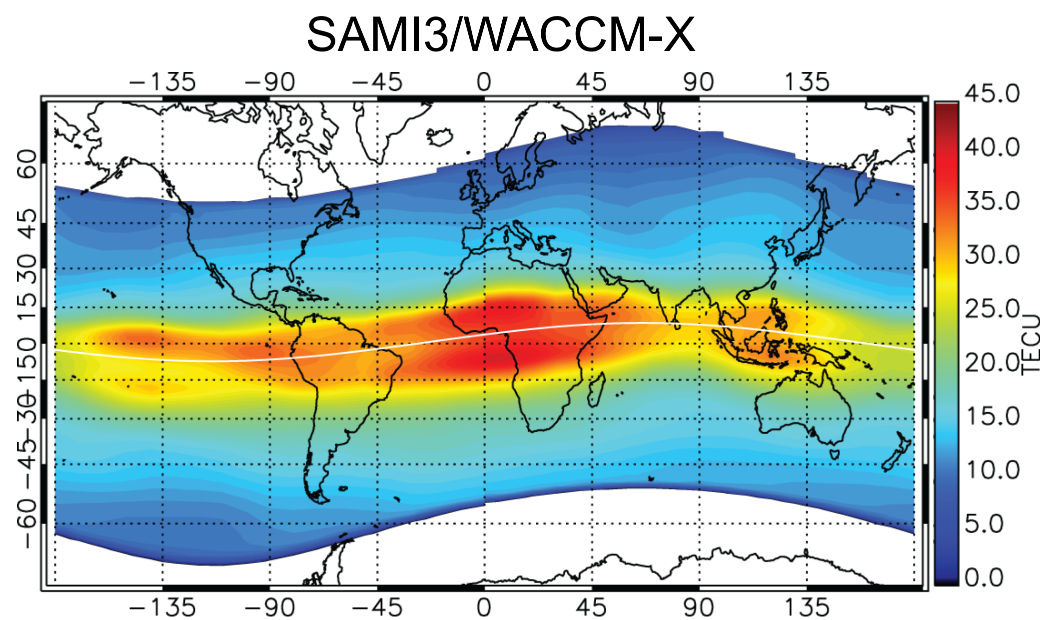
Every 3 hours

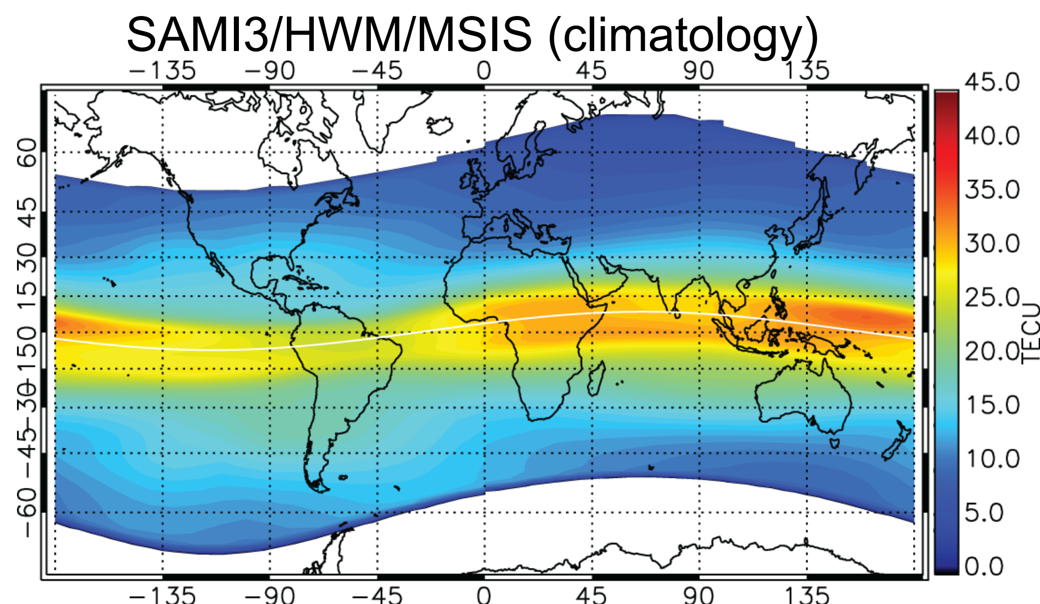
SD-WACCM-X

NAVGEM: Operational Navy Analysis (ground to ~92 km)
4DVAR data assimilation products

14LT: TEC map



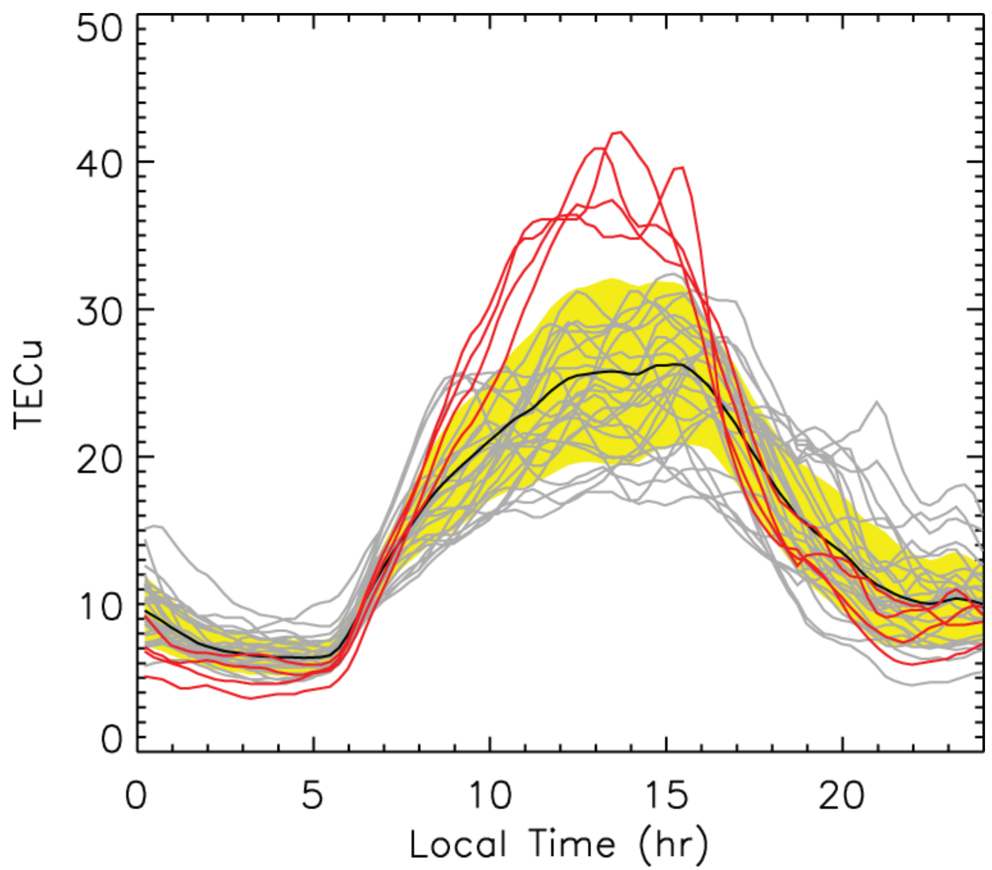




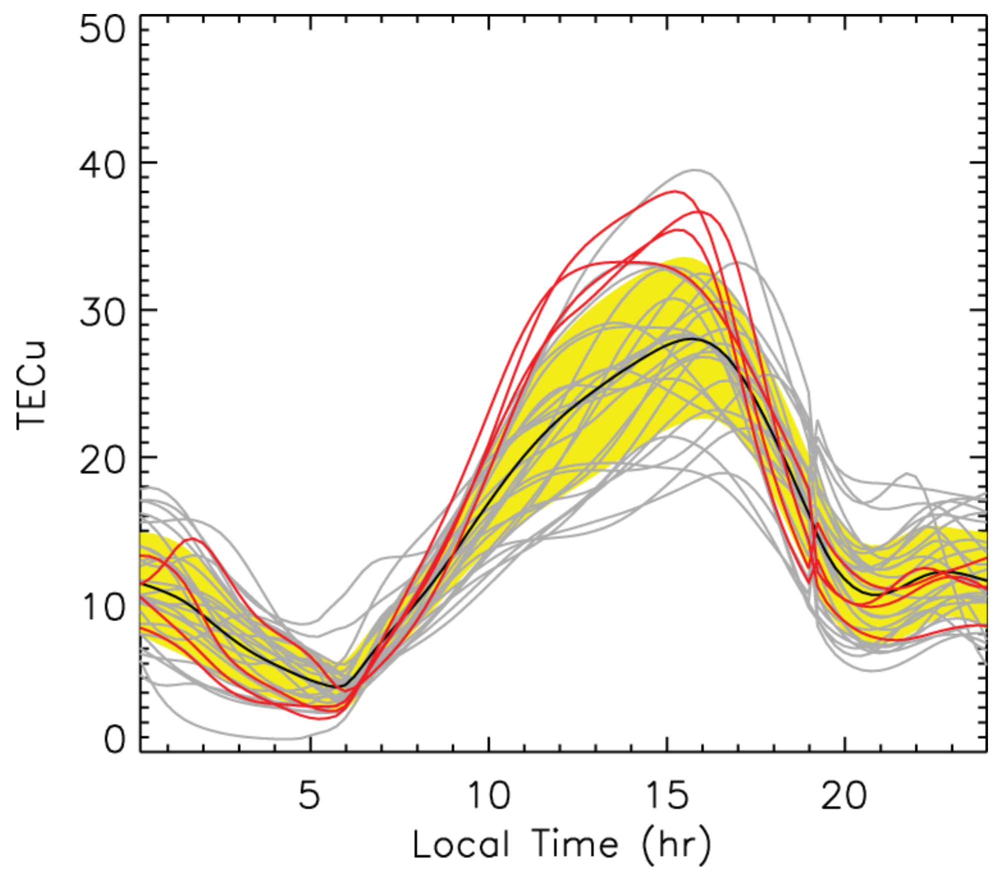
- SAMI3 TEC reduced by a factor of .70 to better match the magnitude of JPL TEC

Daily TEC variation

JPL TEC January 2-31, 2010

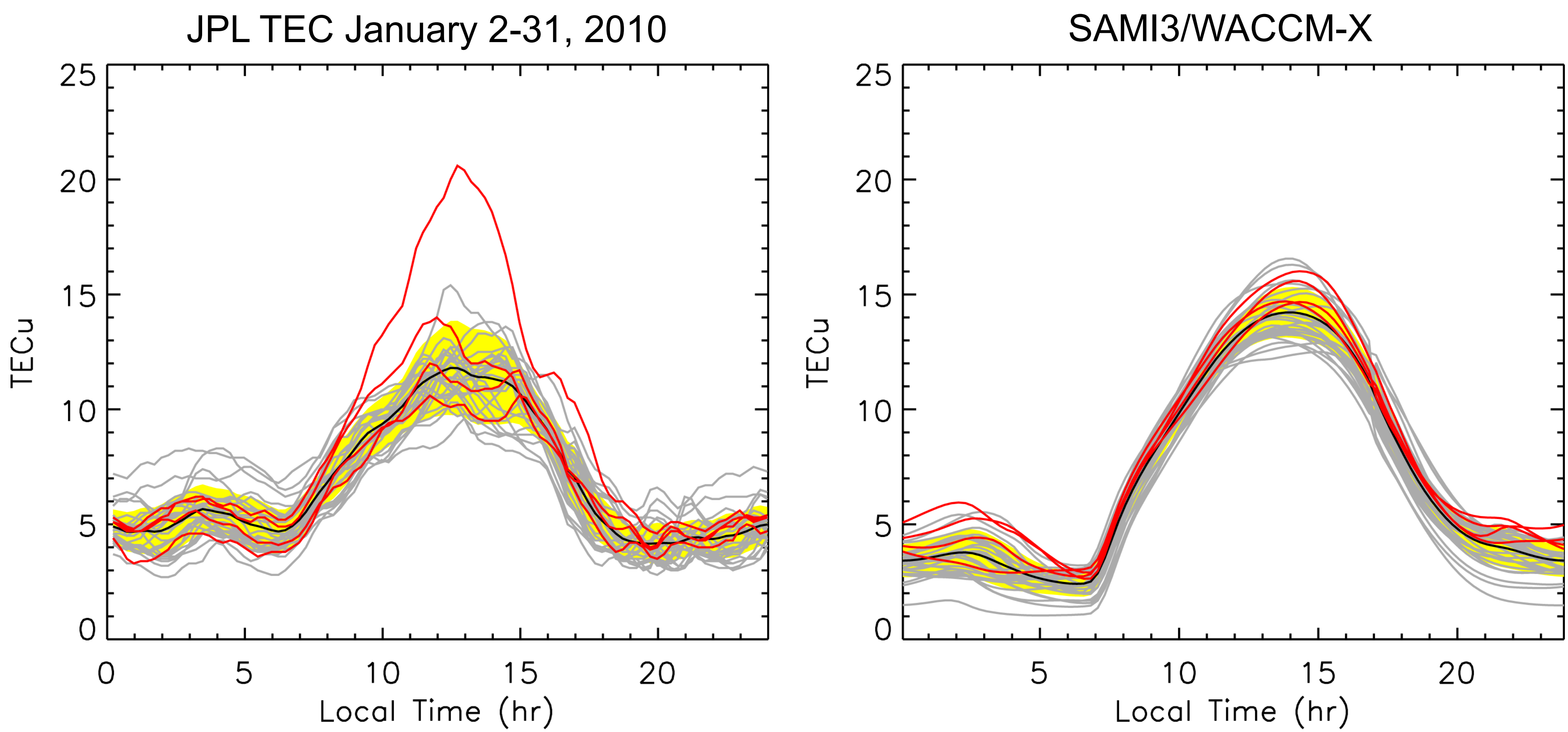


SAMI3/WACCM-X

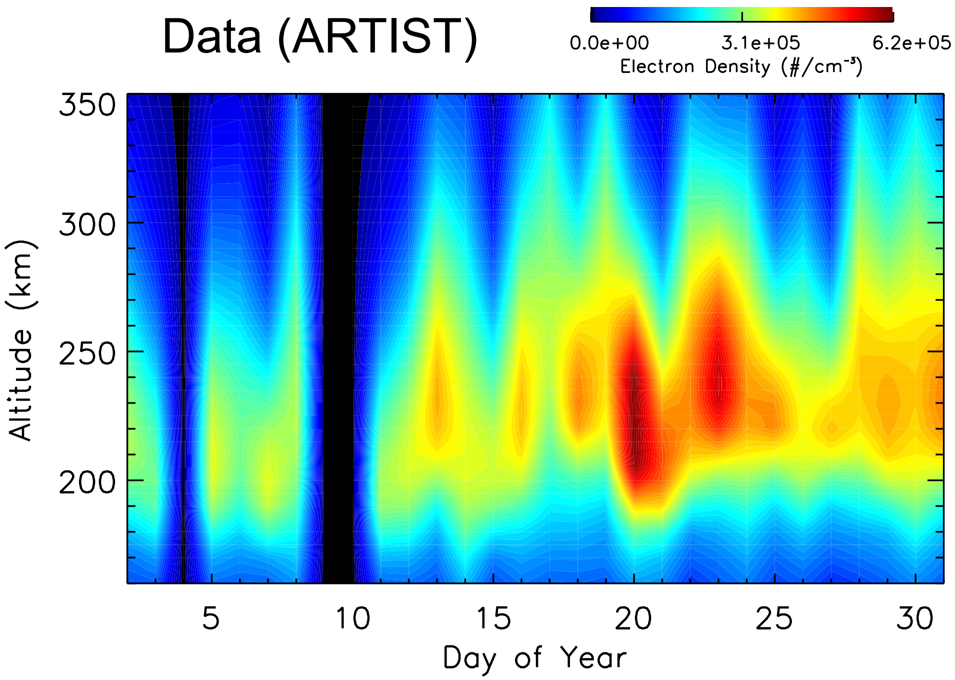


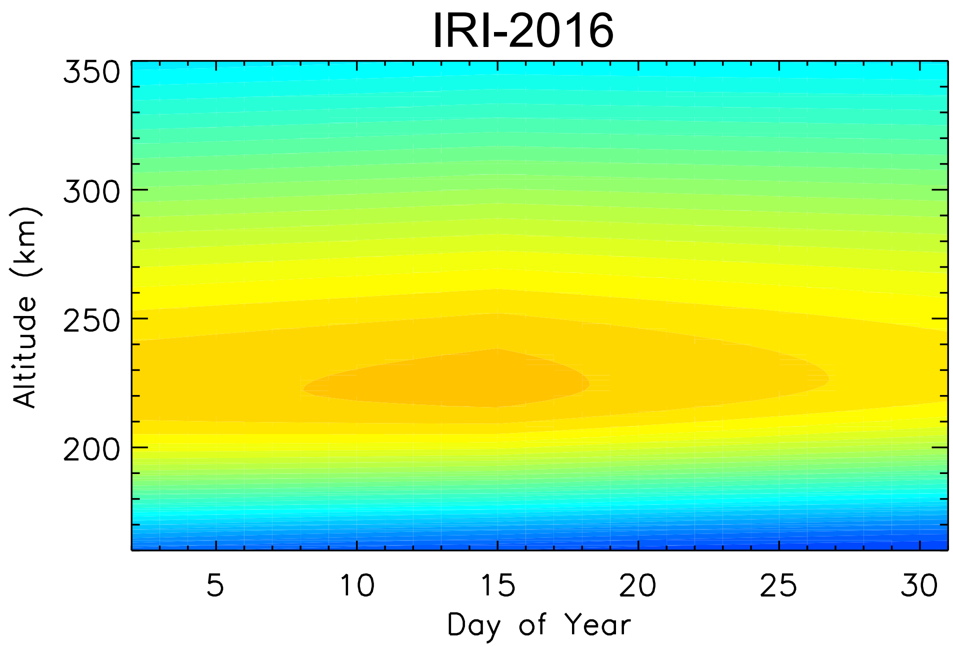
At the geographic equator, 285° longitude

Daily TEC variation at Boulder, CO

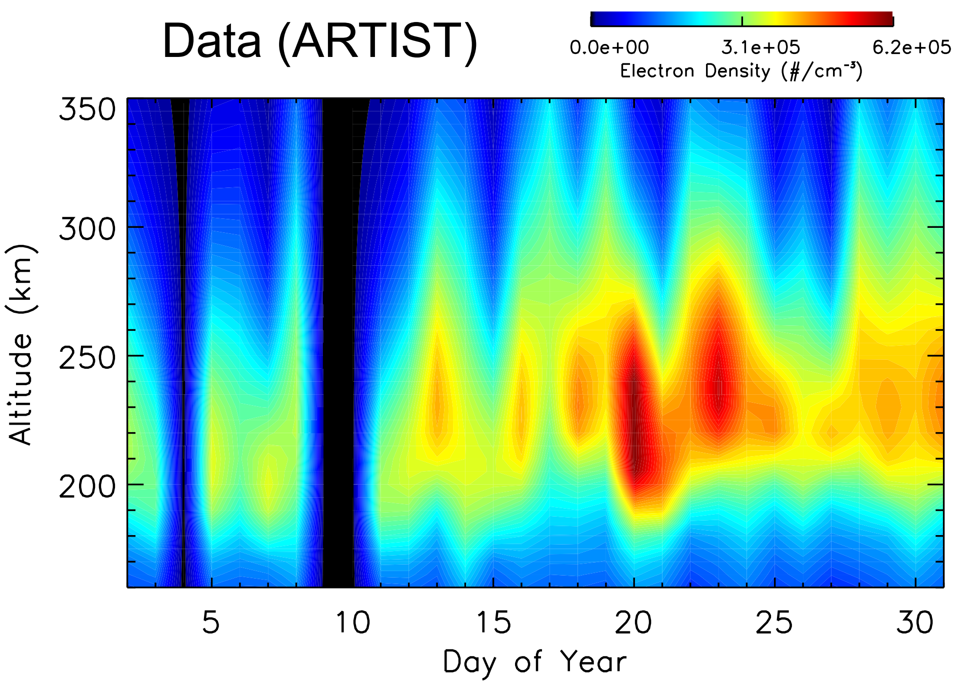


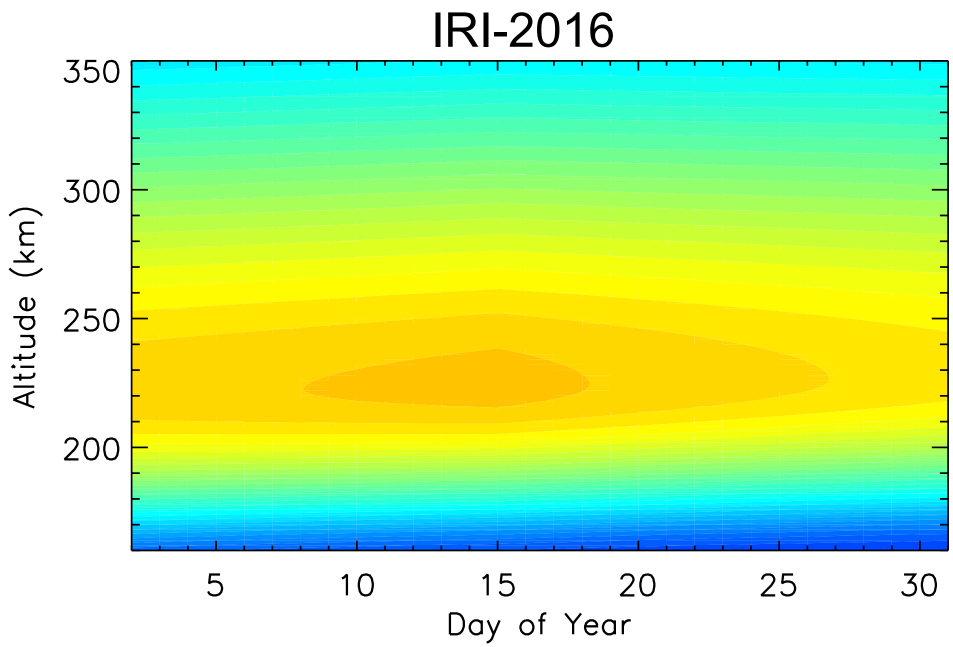
15LT: Electron Density Profiles

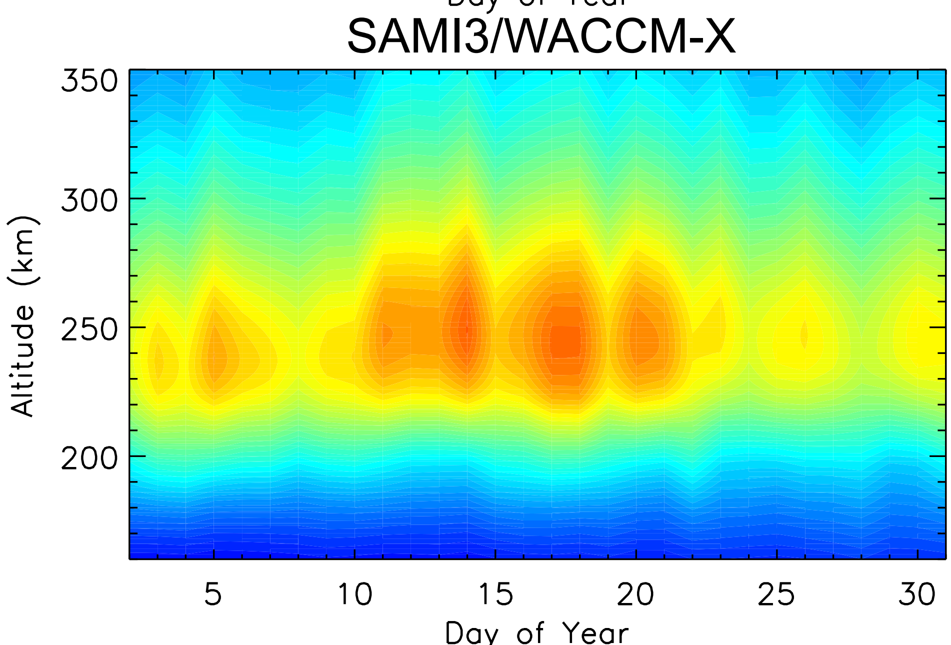




15LT: Electron Density Profiles

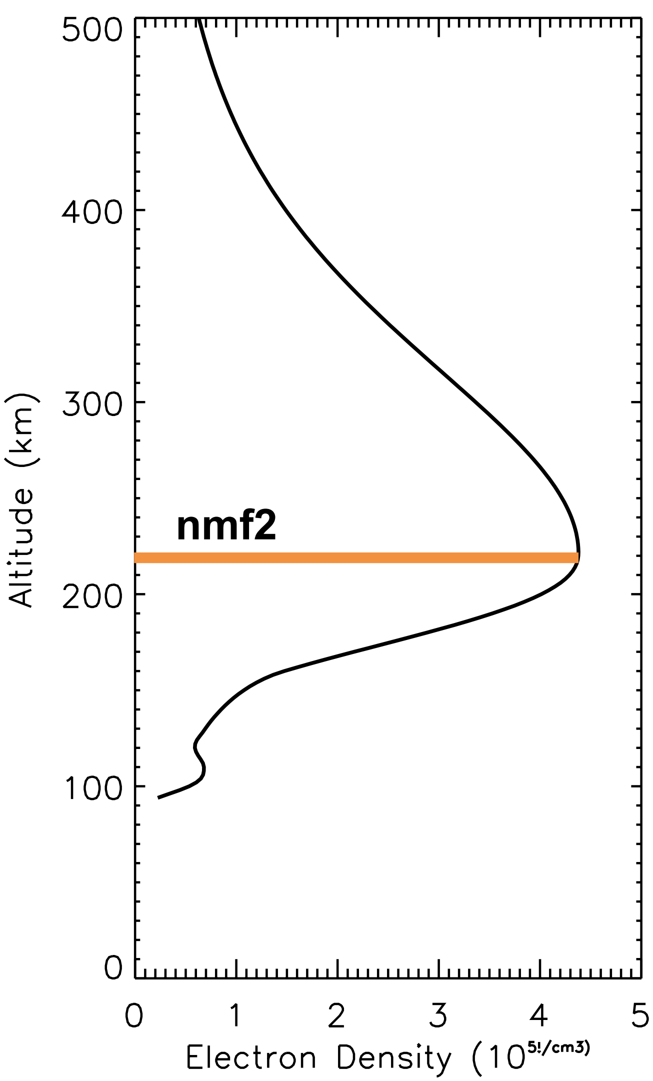


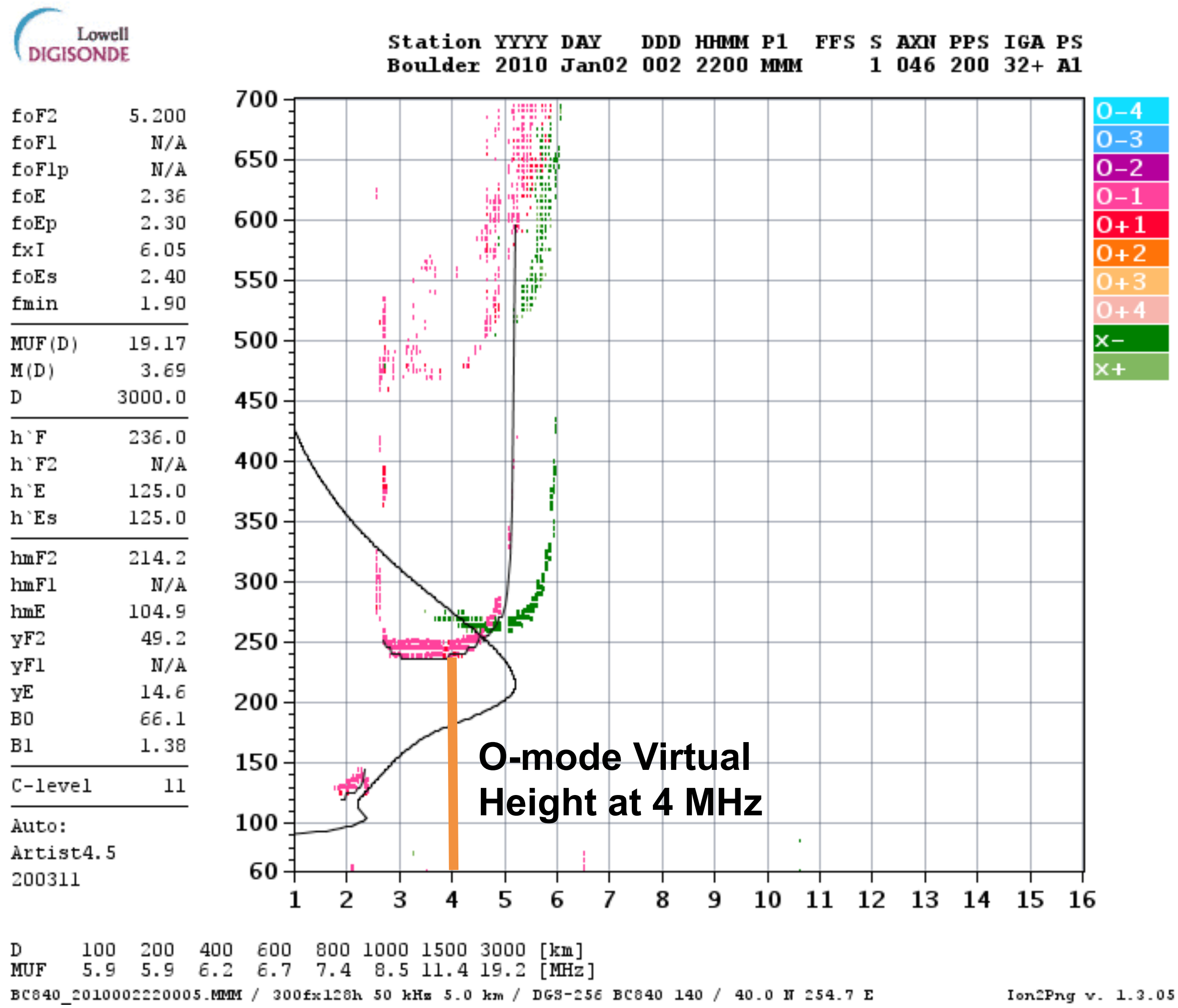




- SAMI3/WACCM-X scaled by a factor of .57
- Capturing some daily variation

Ionospheric Parameters

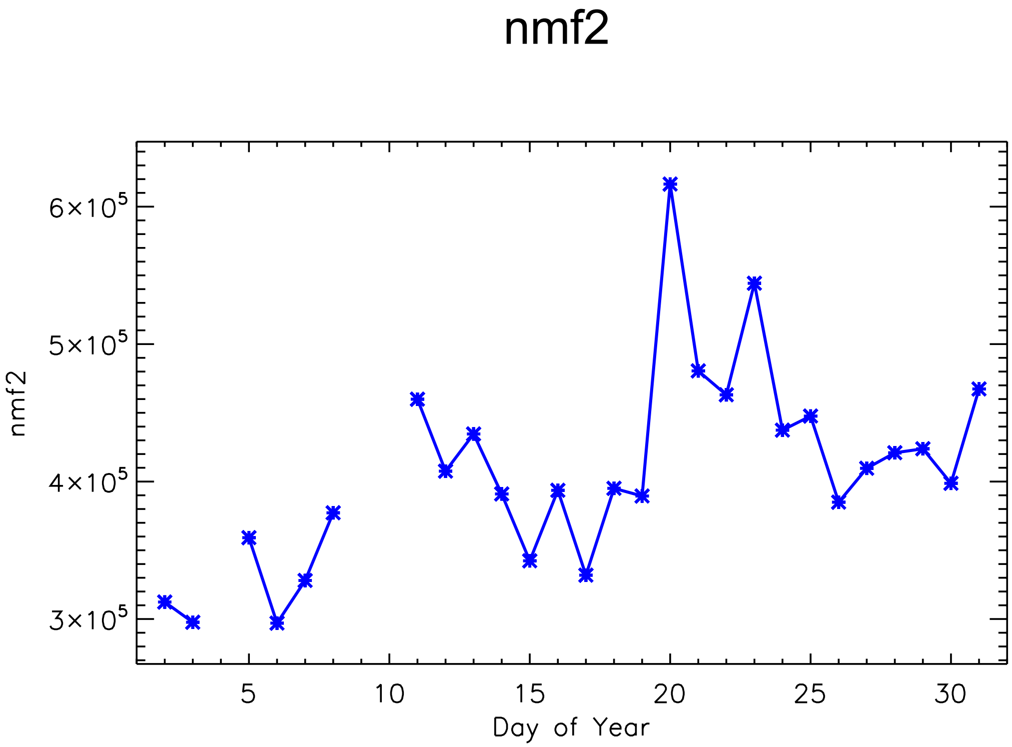


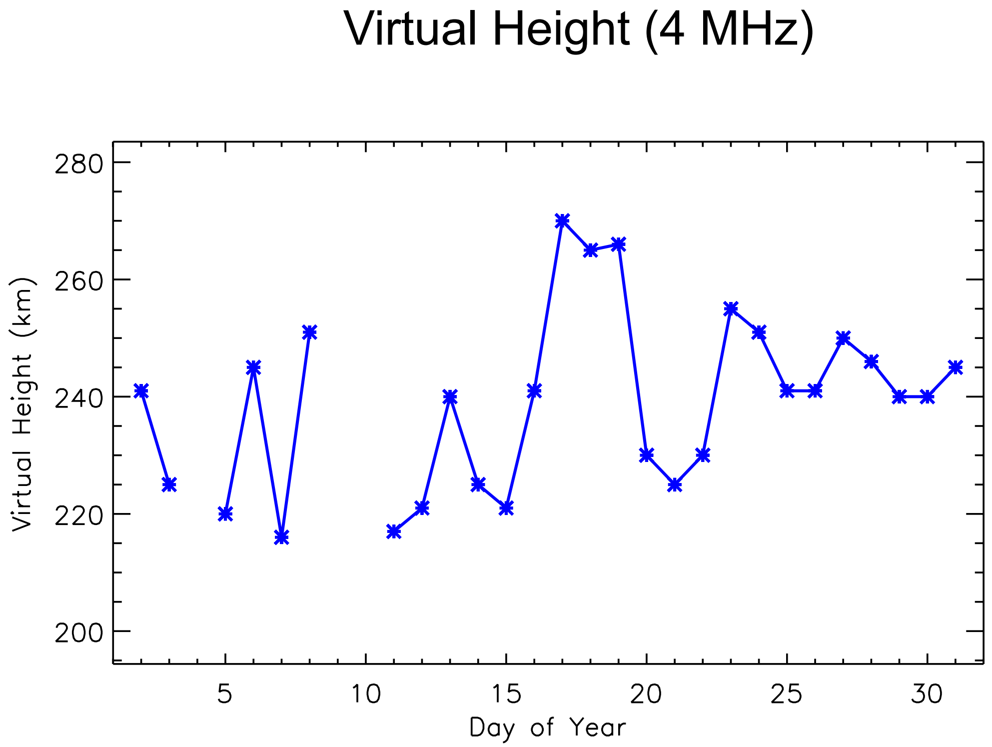


NRL HF Propagation model (MoJo-15) is utilized to calculate the O-mode virtual height for the model ionospheres

Daily Variability at 15LT

Data

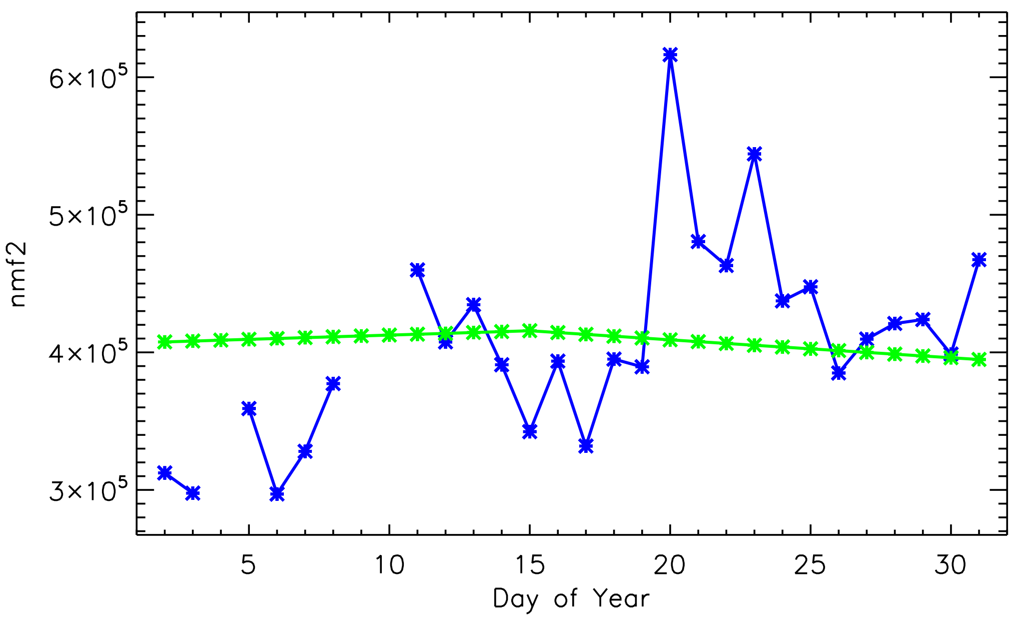




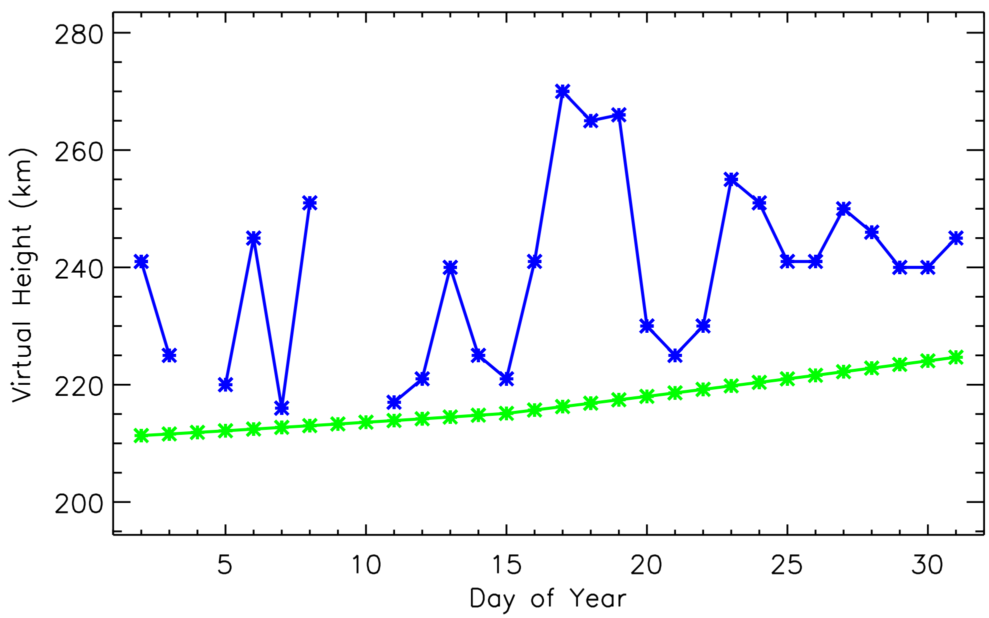
Daily Variability at 15LT

Data
IRI-2016

nmf2

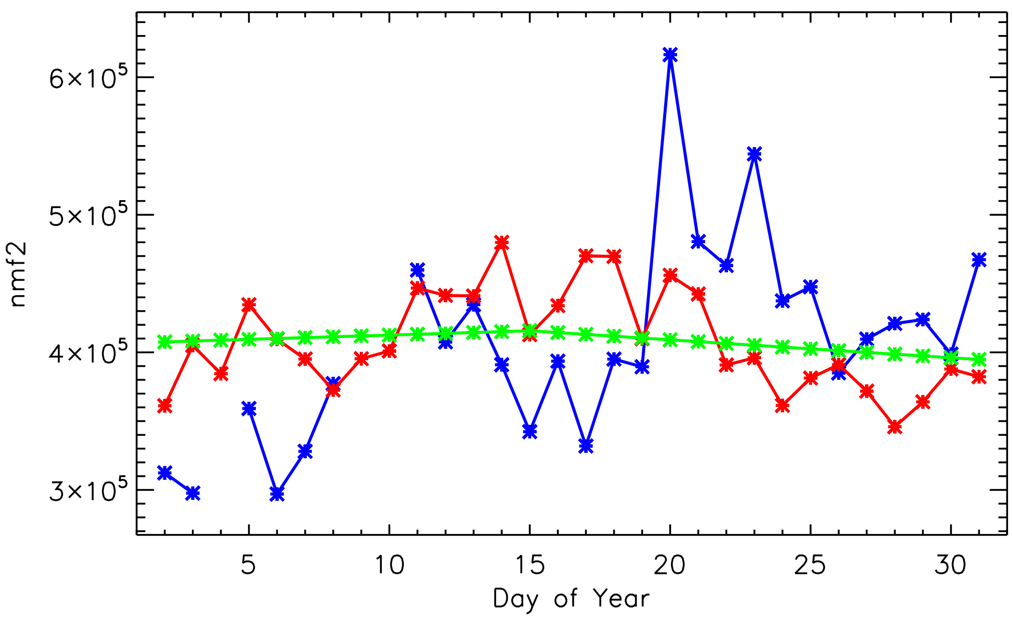


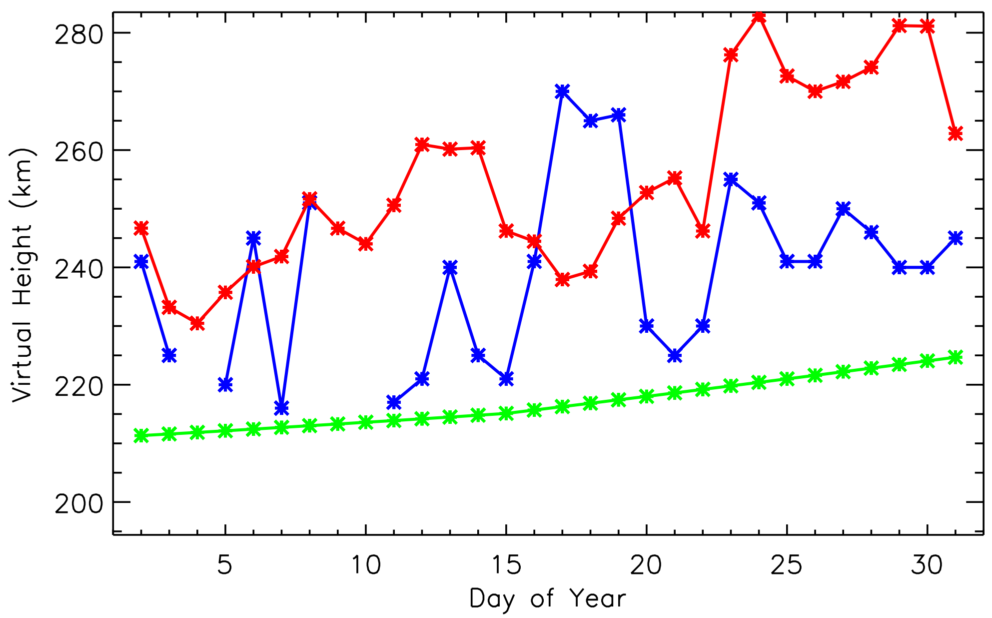
Virtual Height (4 MHz)



Daily Variability at 15LT

Data
IRI-2016
SAMI3/WACCM-X



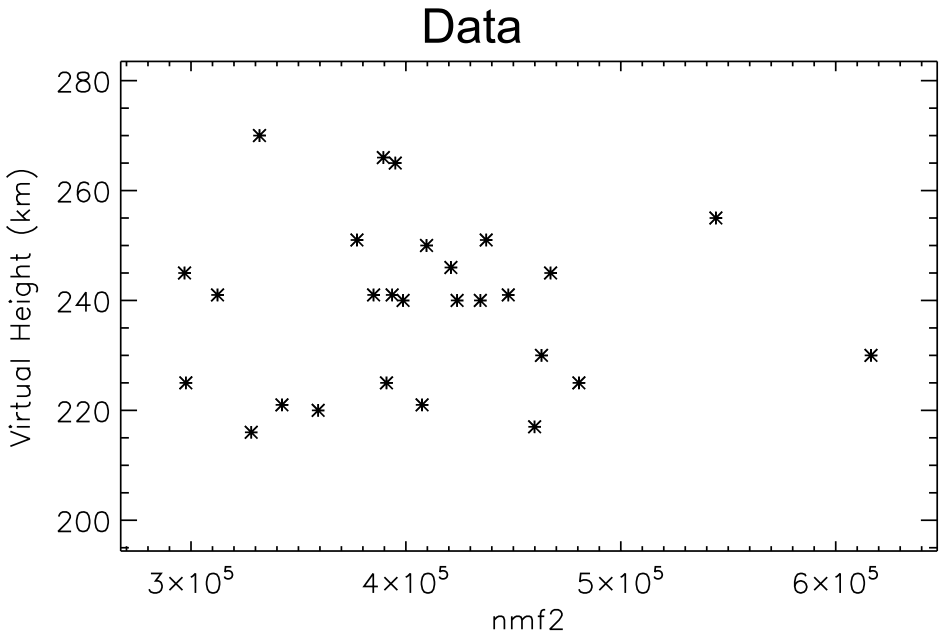


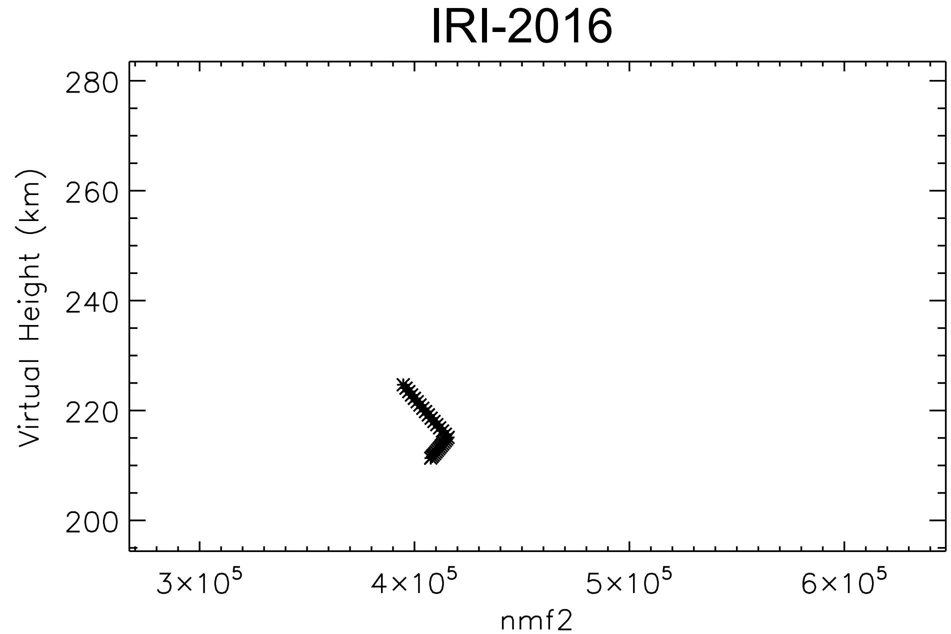
Data	7.2e4
IRI	6e3
SAMI/WACCM-X	3.6e4

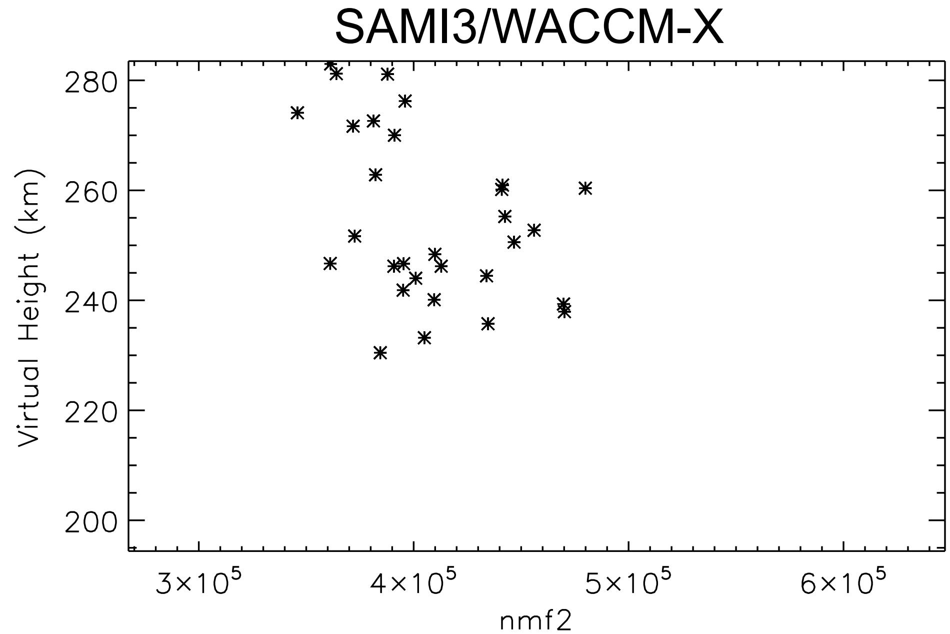
Standard Deviation

Data	15
IRI	4
SAMI/WACCM-X	15

Another Perspective (15LT)

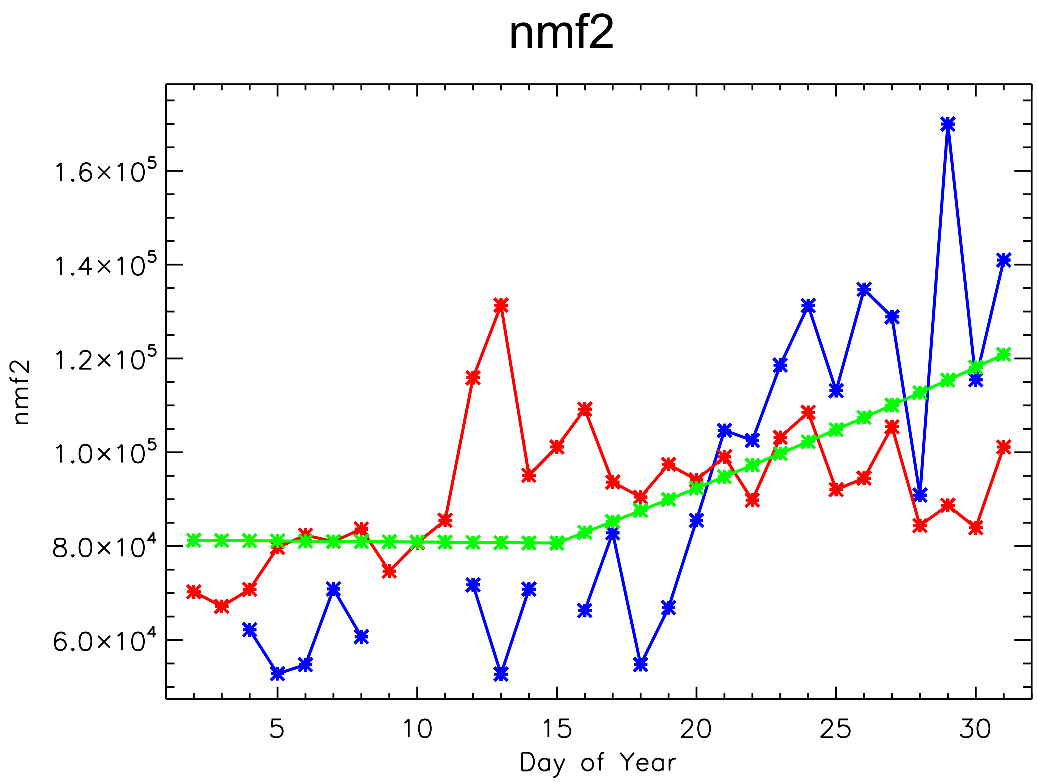


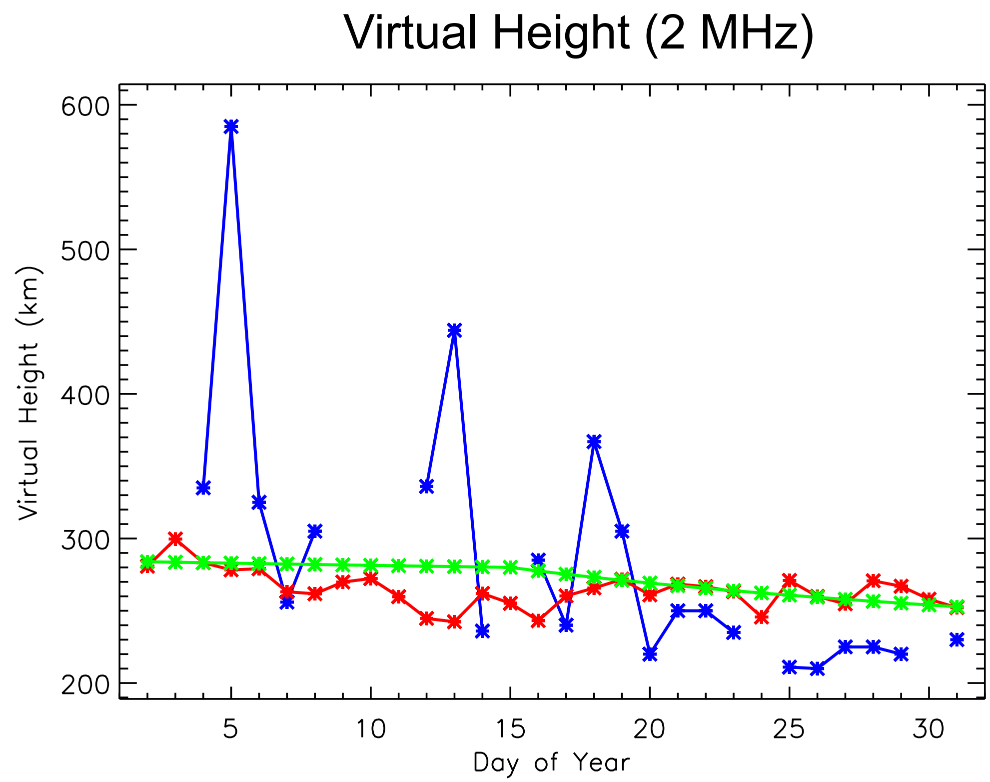




Daily Variability at 19LT

Data
IRI-2016
SAMI3/WACCM-X



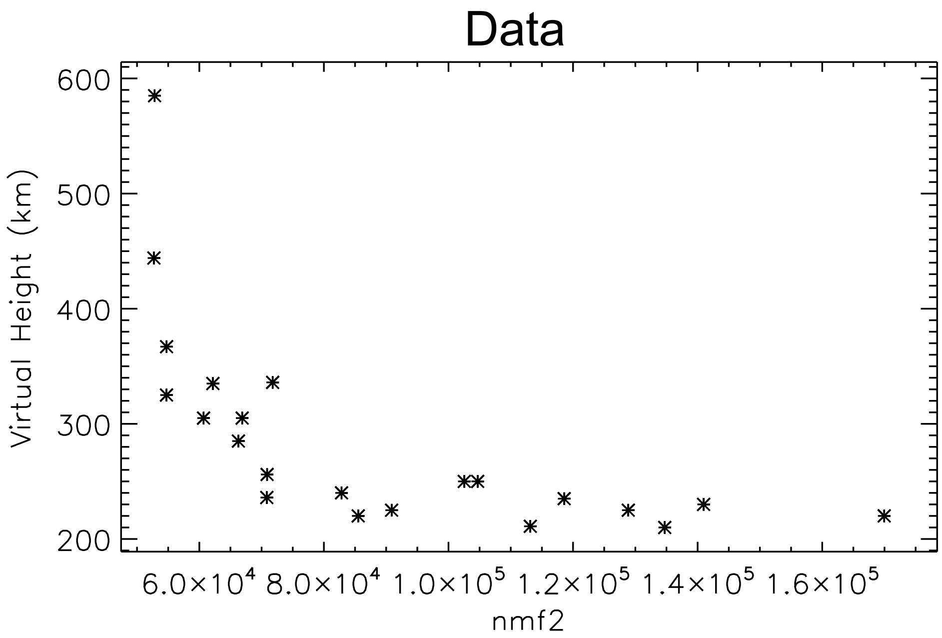


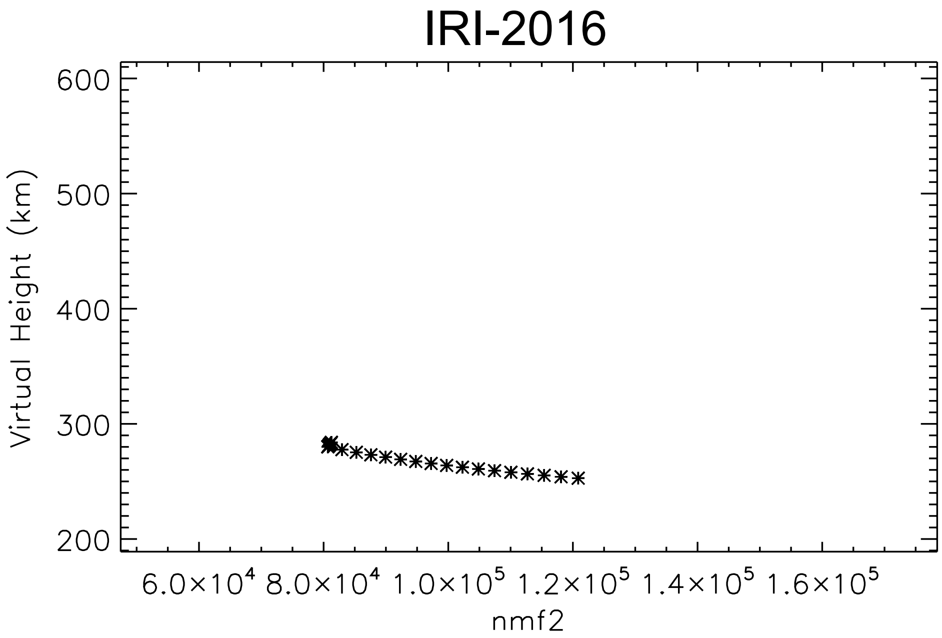
Data	3.3e4
IRI	1.3e4
SAMI/WACCM-X	1.4e4

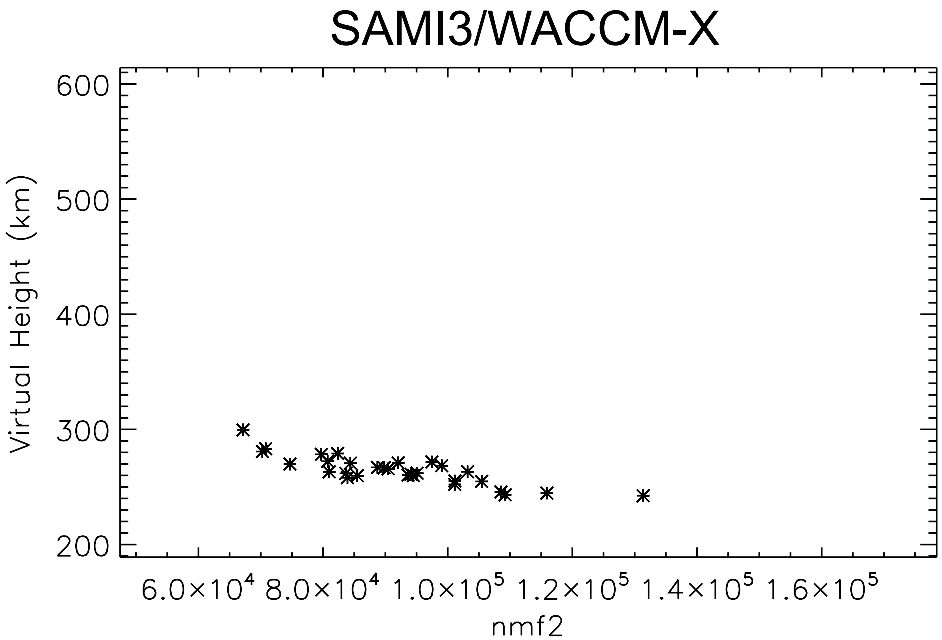
Standard Deviation

Data	90
IRI	11
SAMI/WACCM-X	13

Another Perspective (19LT)

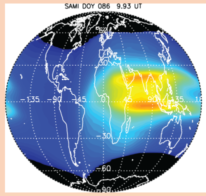






Recent History

NRLSSI Solar Irradiance Model



SAMI3

Physics based model of the ionosphere
Models dynamics and chemistry of
7 ion species from 85 km to 8 R_E

~~Thermospheric Composition~~
Neutral Winds
~~Temperature~~

Hourly

SD-WACCM-X

WACCM
Whole Atmosphere Community Climate Model

Global climate-chemistry model
Solves dynamics, physics and chemistry
globally from ground to ~500 km

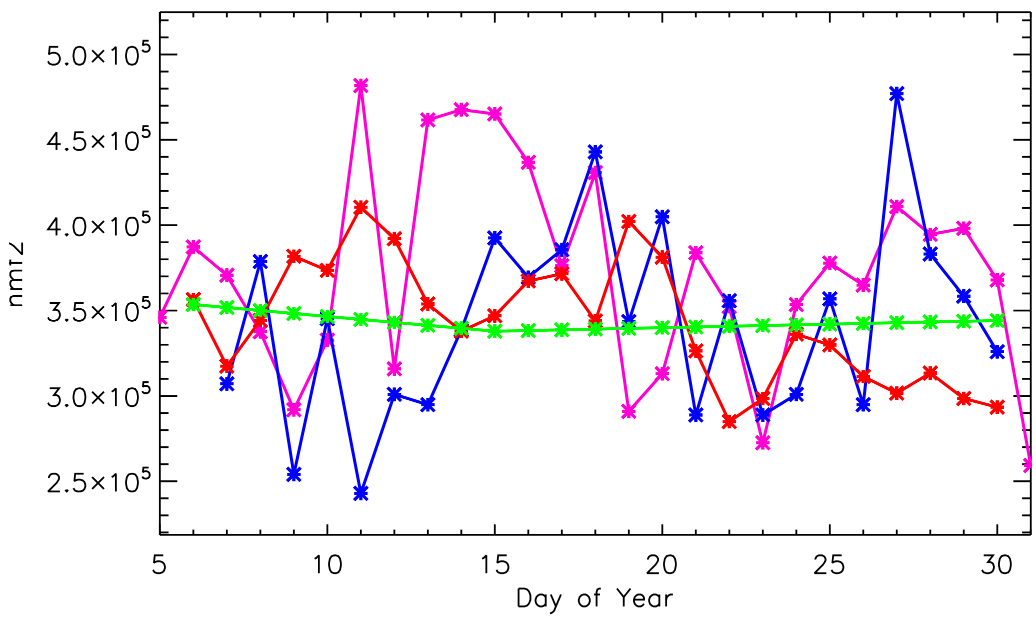
Every ~~3~~ 6 hours

NOGAPS-Alpha merged with MERRA data:
(ground to ~92 km) 3DVAR data assimilation
products

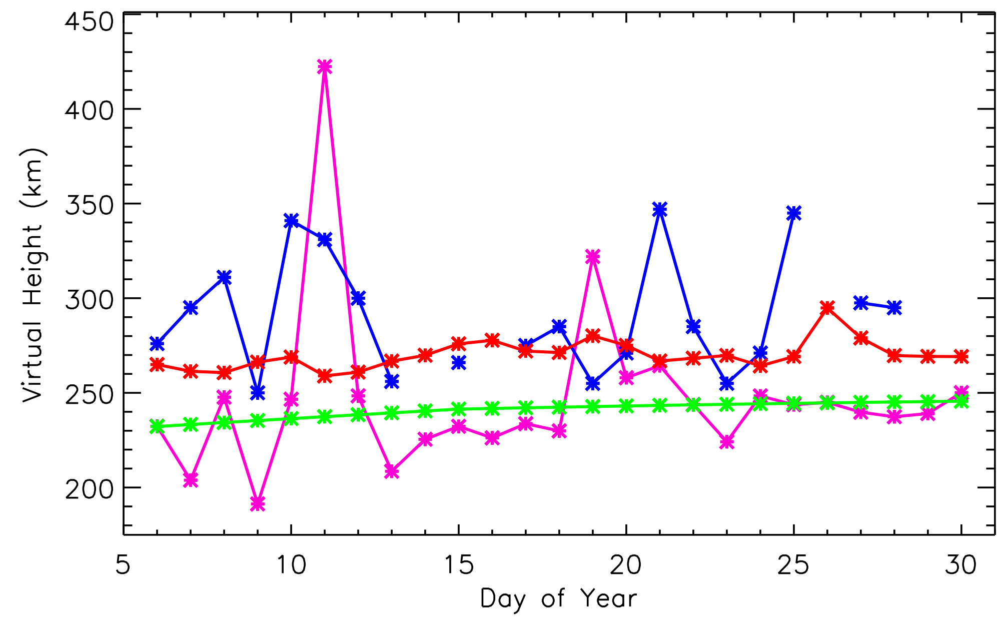
Daily Variability at 12LT

Data
IRI-2016
SAMI3/WACCM-X winds only
IDA-4D

nmf2



Virtual Height (4 MHz)



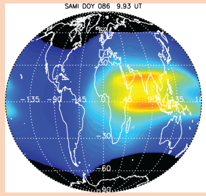
Data	5.7e4
IRI	4.2e3
SAMI/WACCM-X	3.6e4
IDA-4D	5.8e4

Standard Deviation

Data	30
IRI	4
SAMI/WACCM-X	8
IDA-4D	44

Coming soon…

NRLSSI Solar Irradiance Model



SAMI3

Physics based model of the ionosphere
Models dynamics and chemistry of
7 ion species from 85 km to 8 R_E

Thermospheric Composition
Neutral Winds
Temperature

Hourly → Every 5 min

SD-WACCM-X

WACCM
Whole Atmosphere Community Climate Model

Global climate-chemistry model
Solves dynamics, physics and chemistry
globally from ground to ~500 km

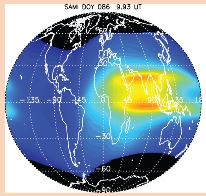
Every 3 hours → Hourly

NAVGEM
Navy Global Environmental Model

NAVGEM: Operational Navy Analysis (ground to ~92 km)
4DVAR data assimilation products

Under Development

NRLSSI Solar Irradiance Model



SAMI3

Physics based model of the ionosphere
Models dynamics and chemistry of
7 ion species from 85 km to 8 R_E

Thermospheric Composition
Neutral Winds
Temperature

Ion and electron density,
temperature, velocity

WACCM Whole Atmosphere Community Climate Model

Global climate-chemistry model
Solves dynamics, physics and chemistry
globally from ground to ~500 km

NAVGEM Navy Global Environmental Model

NAVGEM: Operational Navy Analysis (ground to ~92 km)
4DVAR data assimilation products

SD-WACCM-X

Conclusions

- Virtual height is a good independent measure of the bottomside variability as long as the frequency is not in the cusp region
- Upgrades to SAMI3/WACCM-X have resulted in better modeling of bottomside daily variability
- SAMI3/WACCM-X shows significantly more daily variability than IRI-2016 during the day, but less than the data
- SAMI3/WACCM-X captures some daily variability just after sunset, but doesn't capture the cusp feature seen in the virtual height data
- Future work: examine more times and locations

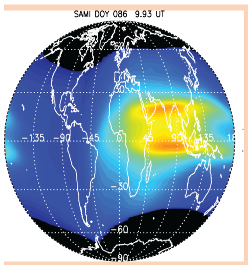
Acknowlegements

This work was supported by the Chief of Naval Research (CNR) under the NRL 6.1 Base Program.

Backup Slides

Bottom-side Ionosphere Weather Modeling

How do environmental conditions (chemistry, solar drivers, and meteorology) affect radio-frequency wave propagation?



SAMI3

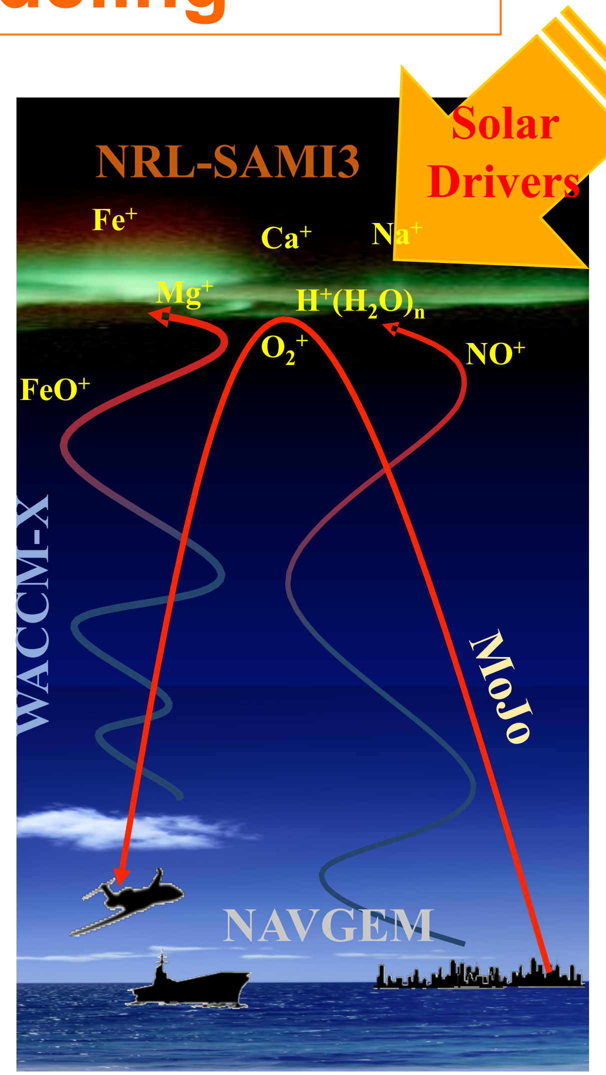
Physics-based model of the ionosphere.
Dynamics and chemistry of 7 ion species from 85 km to > 20,000 km

Full Coupling

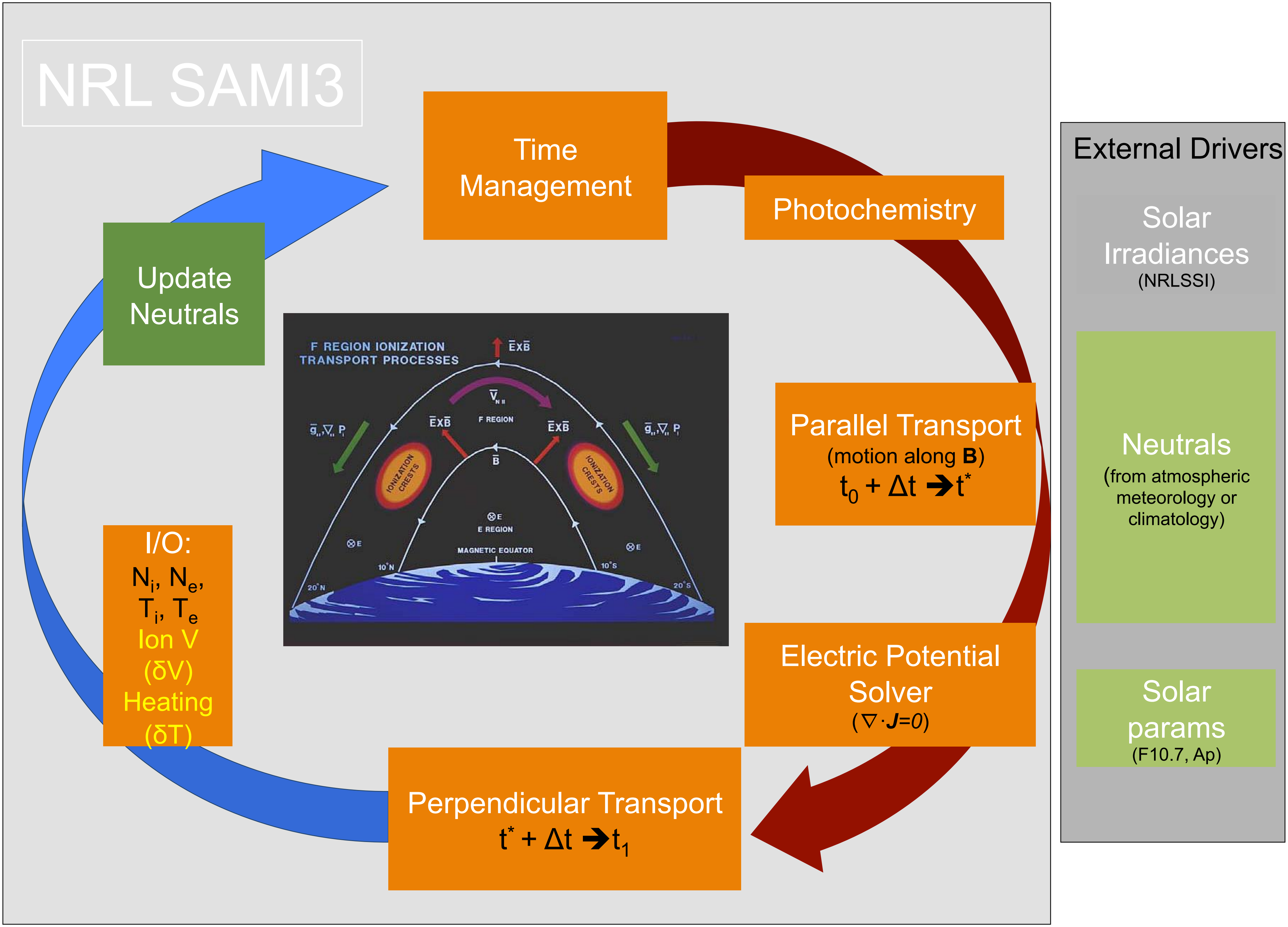
WACCM
Whole Atmosphere Community Climate Model

Global climate-chemistry model
Solves dynamics, physics and chemistry globally from ground to ~500 km

NAVGEM: Operational Navy Analysis (ground to ~92 km)
4DVAR Hourly data assimilation products



MoJo
Radio-wave propagation code.
Includes updated dispersion and attenuation.
Capable of using observations & model data.
Produces ionograms (WSBI) for verification.


NRL SAMI3
Time Management
Photochemistry
Update Neutrals
F REGION IONIZATION TRANSPORT PROCESSES
F REGION
E REGION
MAGNETIC EQUATOR
IONIZATION CRESTS
Parallel Transport
(motion along **B**)
$t_0 + \Delta t \rightarrow t^*$
I/O:
N_i, N_e,
T_i, T_e
Ion V
(δV)
Heating
(δT)
Electric Potential Solver
($\nabla \cdot \boldsymbol{J}=0$)
Perpendicular Transport
$t^* + \Delta t \rightarrow t_1$
External Drivers
Solar Irradiances
(NRLSSI)
Neutrals
(from atmospheric meteorology or climatology)
Solar params
(F10.7, Ap)

Atmospheric Tides

Migrating Tides (sun-synchronous)

• Due to periodic variations in the troposphere and stratosphere heating due to daily variations in the absorption of solar radiation

• Reach large amplitudes in lower thermosphere (100 – 150 km)

• Westward propagating

Nonmigrating Tides

• Due to longitudinal variations in heating rates, such as:

- Land-sea differences in latent heat release
- Nonlinear tide-tide interactions
- Tide-planetary wave interactions

• Eastward/westward propagating or stationary

Other Models

- **IRI**
  - Using both IRI-2012 and IRI-2016
  - Default parameters
- **IDA-4D**
  - Background model: IRI-2012
  - Boulder Ionosonde data not ingested
  - Assimilated Data:
    - GPS TEC
    - Occultation Measurements from GRACE and CHAMP
    - DORIS beacon TEC measurements
    - TEC from topside ionospheric sounders (GRACE-A, GRACE-B, SAC-C)

HF Propagation Model: MoJo-15

Integrates the Haselgrove raytrace equations in 3D spherical coordinates using a 4th order Runge-Kutta scheme, assuming the following for the index of refraction:

$$n^2 = 1 - 2X \frac{1 - iZ - X}{2(1 - iZ - X) - Y_T^2 \pm \sqrt{Y_T^4 + 4Y_L^2 (1 - iZ - X)^2}}$$

$$X = \frac{\omega_e^2}{\omega^2} \quad Y = \frac{\omega_{ecf}}{\omega} \quad Z = \frac{\nu_e}{\omega} \quad Y_T = Y \sin\psi \quad Y_L = Y \cos\psi$$

Ψ = angle between the wave normal and the earth's magnetic field

Includes iterative homing algorithm for eigenrays