Monthly Climatology of Thermospheric Neutral Winds Obtained from COSMIC Radio Occultation Measurements

Ludger Scherliess and Levan Lomidze

Center for Atmospheric and Space Sciences
Utah State University

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Trieste
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Basic Approach

Use a physics-based data assimilation model to determine the thermospheric neutral winds from COSMIC radio occultation data.

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GAIM-Full Physics
Low- and Mid-Latitude Ionosphere

--> GAIM-FP uses physics-based ionosphere-plasmasphere model (IPM)

Full Physics GAIM uses an **Ensemble Kalman Filter Technique**

Allows to **incorporate ionospheric physics** in data assimilation

Provides both specifications for the ionospheric plasma densities and drivers:

- Electric Field
- Neutral Wind
- Neutral Composition

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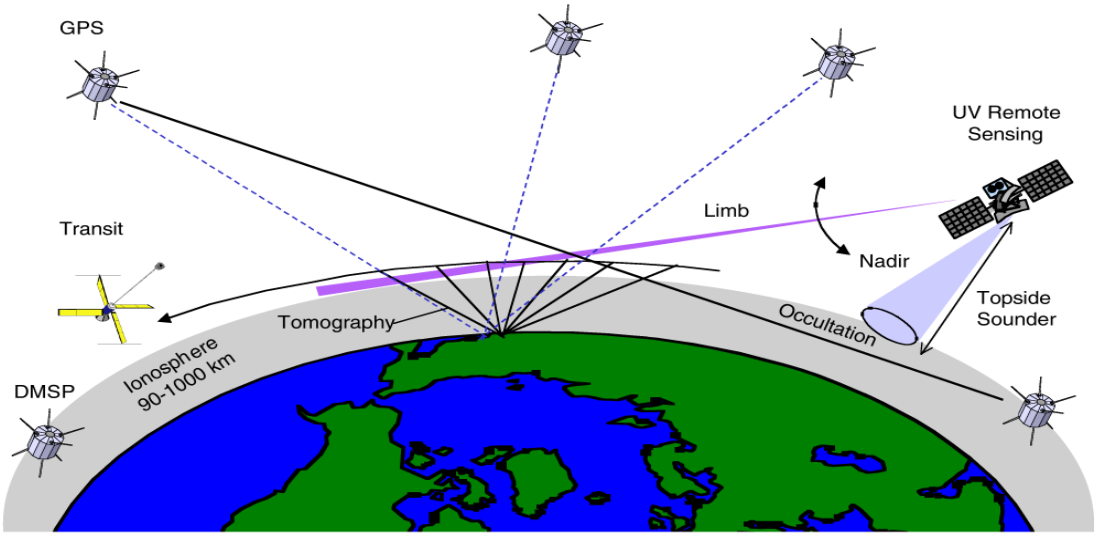
GAIM Assimilates Multiple Data Sources



- **Data Assimilated Exactly as They Are Measured**
  - **Bottomside N_e Profiles from Digisondes (30)**
  - **Slant TEC from more than 1000 Ground GPS Receivers**
  - **N_e Along Satellite Tracks (4 DMSP satellites)**
  - **Integrated UV Emissions (LORAAS, SSULI, SSUSI)**
  - **Occultation Data (CHAMP, IOX, SAC-C, COSMIC)**

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Typically the model is used to determine
ionospheric weather

Climate Mode:

Model is used to establish the
monthly/seasonal mean electron density distribution
as well as the self-consistent ionospheric drivers.

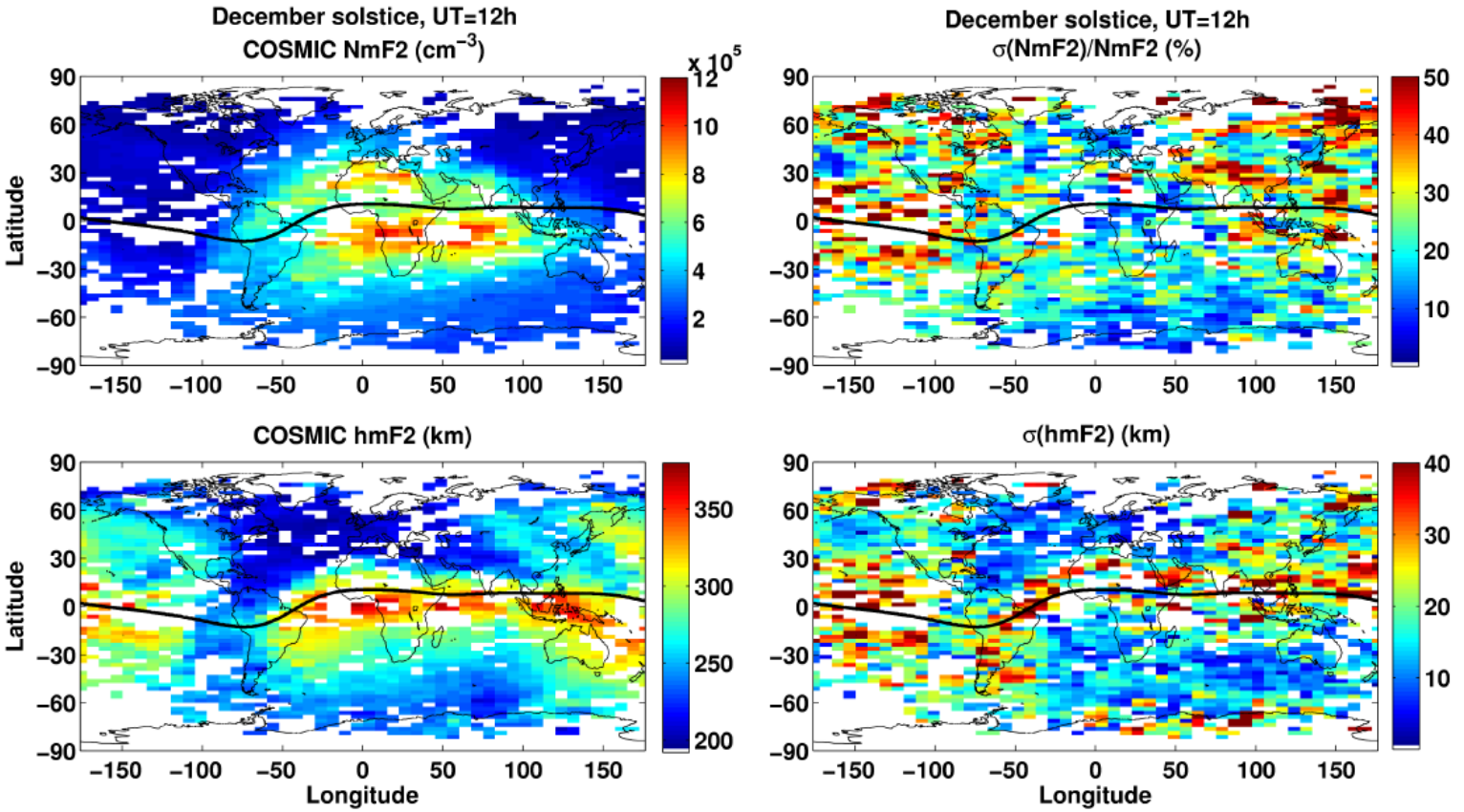
→ Assimilate Empirical Maps (NmF2, hmF2, …)

Assimilate Empirical Maps (NmF2, hmF2, …)

- ~190,000 COSMIC electron density profiles
- Half-hourly maps of peak density (NmF2) and peak height (hmF2)
- Grid size: 1.25^0 X 7.5^0 (Latitude x Longitude)
- Period: Nov, 2008 – Feb, 2009

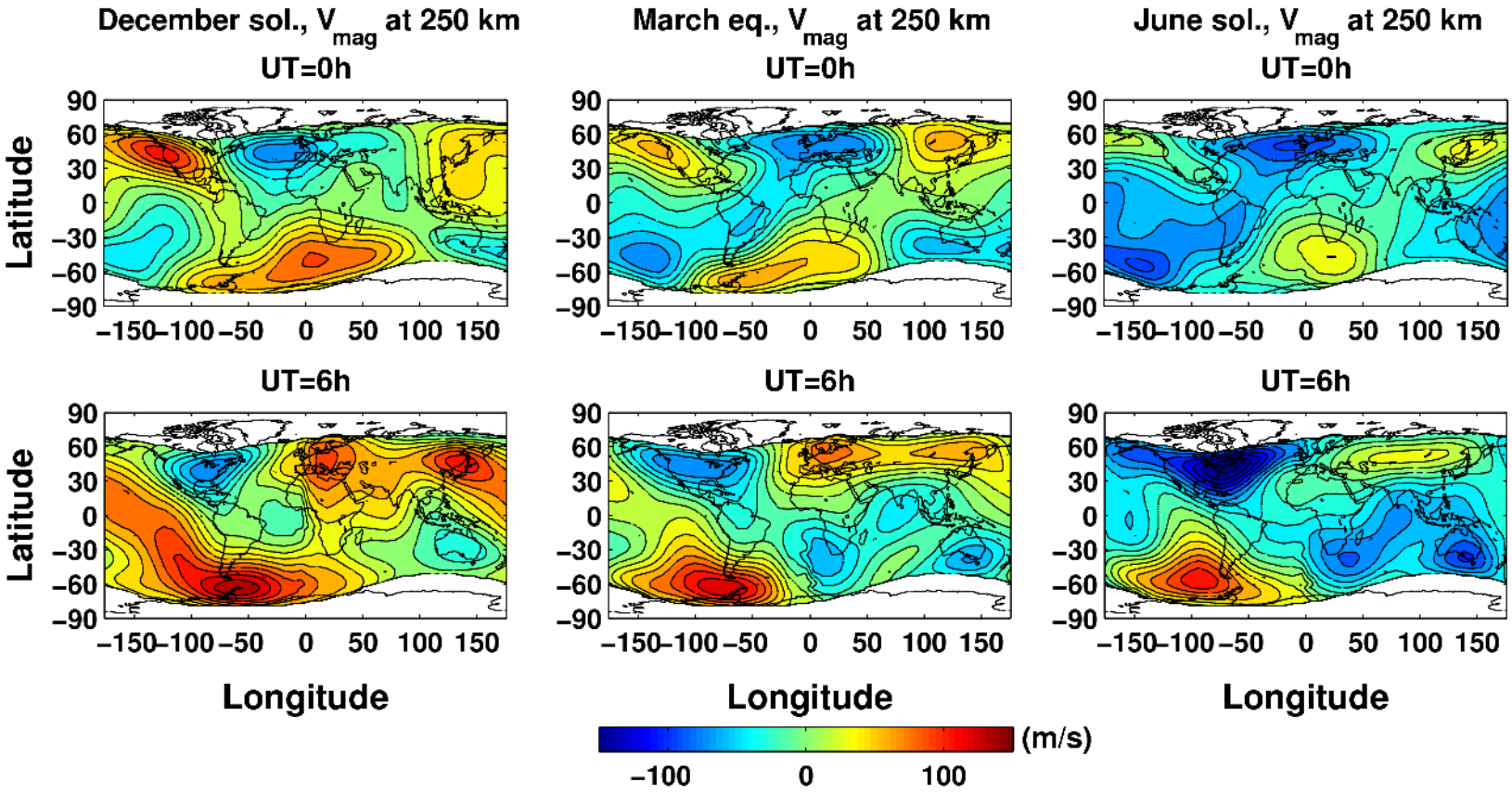
COSMIC electron density data

- NmF2 and hmF2 data were binned into 30-minute intervals and global maps were produced.



Global maps of NmF2 and hmF2 with their 1-σ errors at UT=12:00.

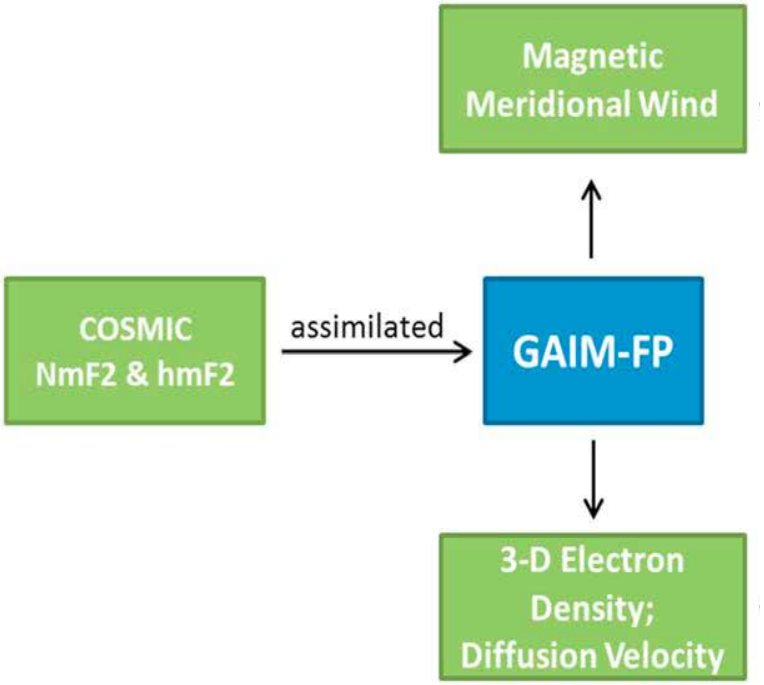
Derived Global magnetic meridional winds from COSMIC



The obtained wind pattern agrees well with its well-established characteristics:

- **Equatorward wind at night**
- **Poleward winds during day**
- **Predominantly summer-to-winter flow during solstices**
- **Symmetric pattern about the geographic equator during equinox**

Thermospheric Wind Assimilation Model (TWAM)



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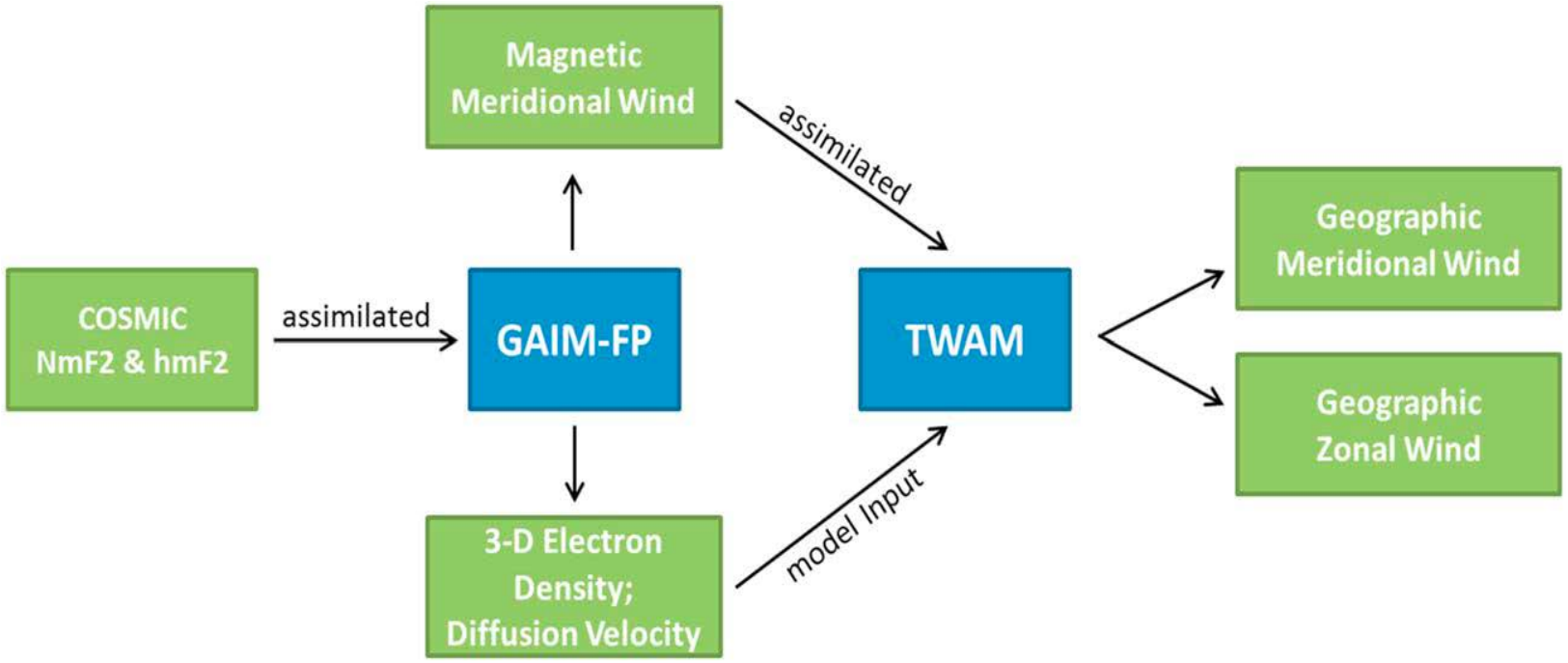

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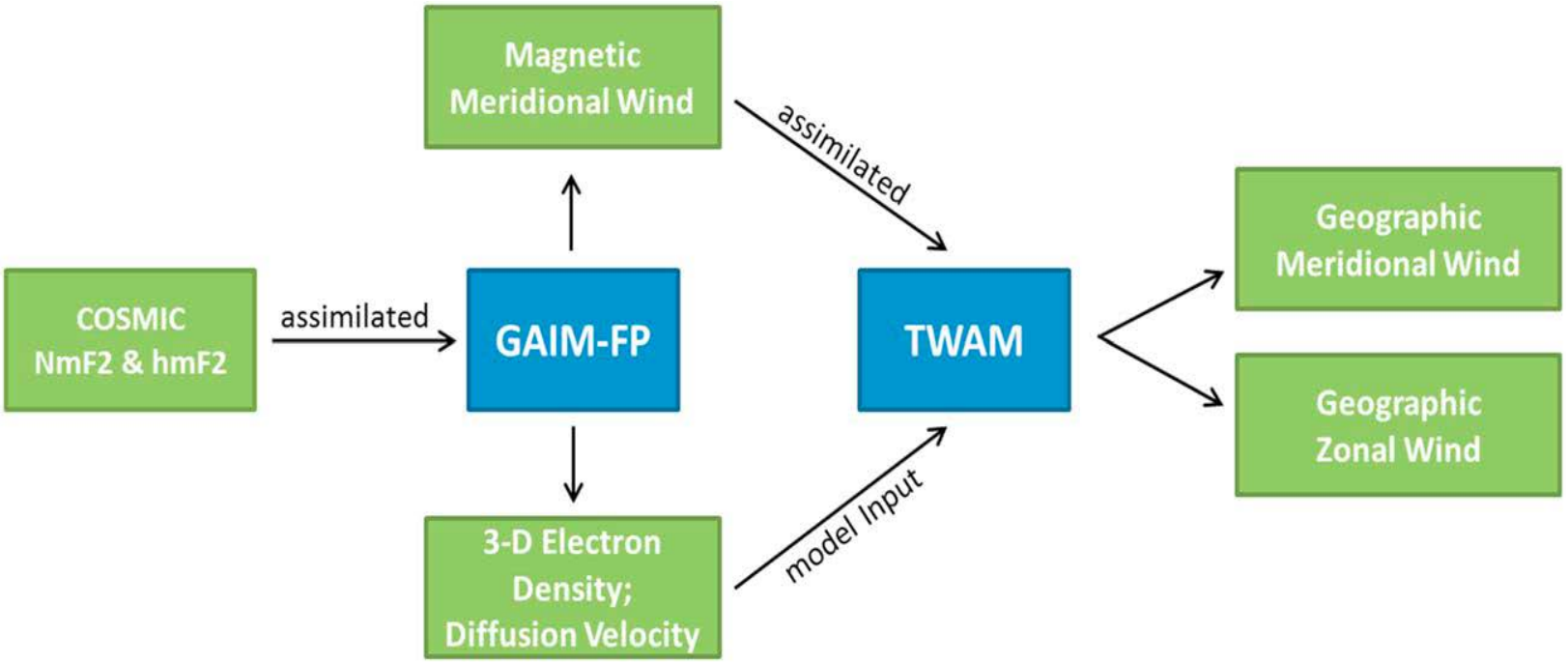


TWAM is based on a first-principles data assimilation model for the thermospheric wind.

Data are assimilated using an implicit Kalman filter technique.

→ Data are the magnetic meridional winds form GAIM-FP

Lomidze and Scherliess, 2015

Global TWAM Wind Pattern

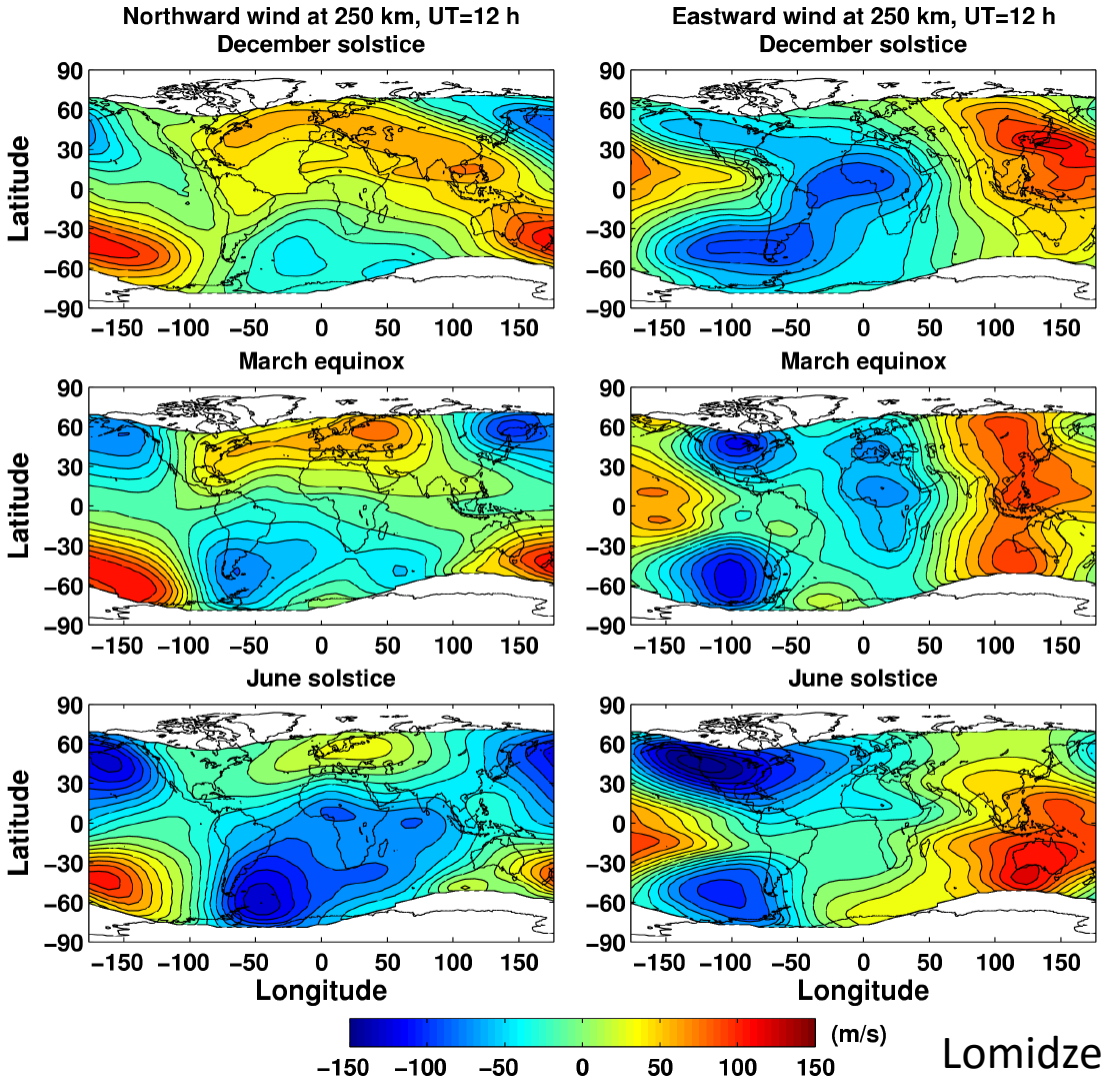
Good agreement with our current understanding of thermospheric dynamics.

Meridional **Zonal**

December Solstice

March Equinox

June Solstice



Lomidze and Scherliess, 2015

Comparison of TWAM with independent ground-based optical (FPI) data

Millstone Hill **Arecibo** **Arequipa**

Dec.

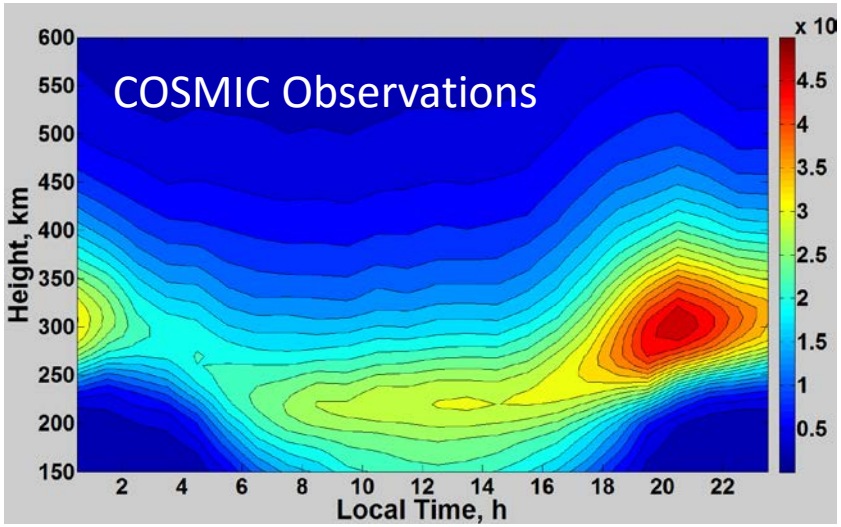
March

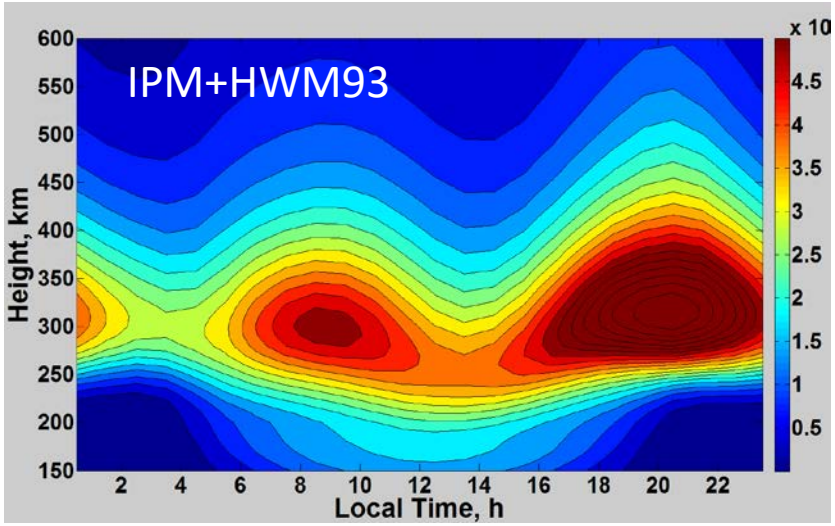
June

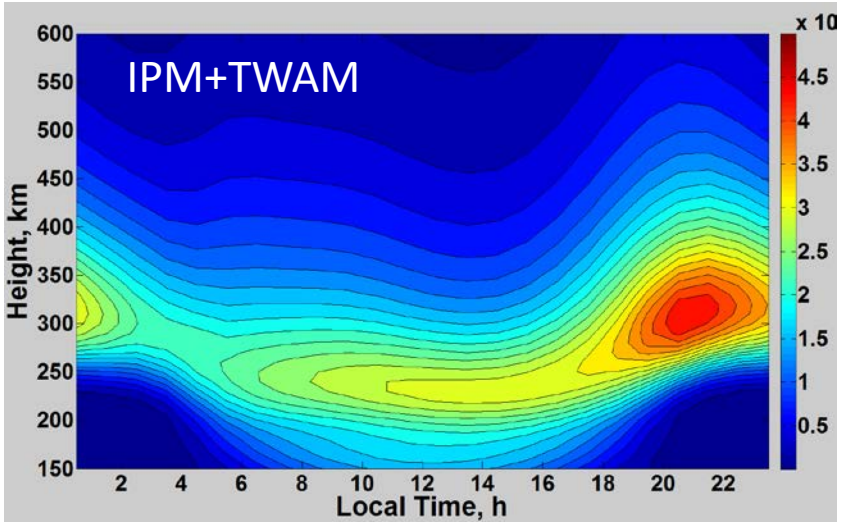
Lomidze and Scherliess, 2015

Effect of TWAM Winds on Ionosphere

Electron Density: December Solstice (60°S, 90°W)

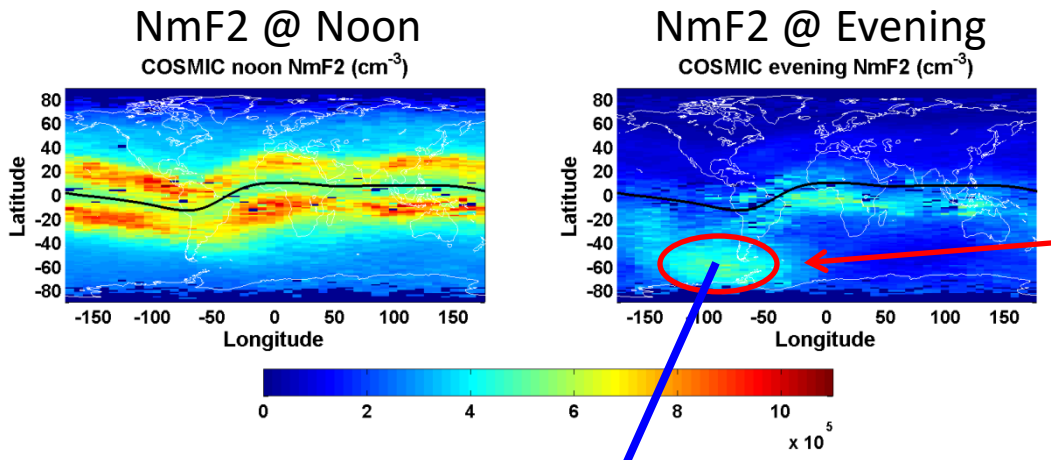




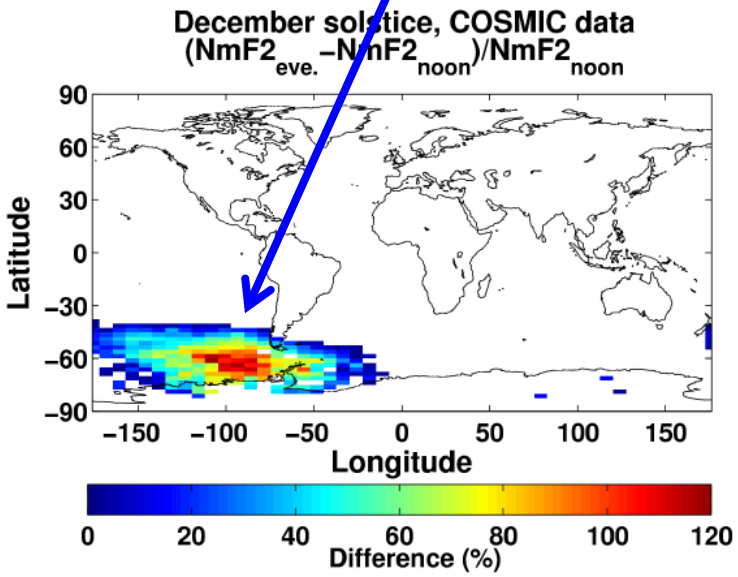


The Weddell Sea Anomaly

Electron density is larger at evening/night than during the day



Electron Density Enhancement



Relative difference between evening and noon NmF2.

The Weddell Sea Anomaly

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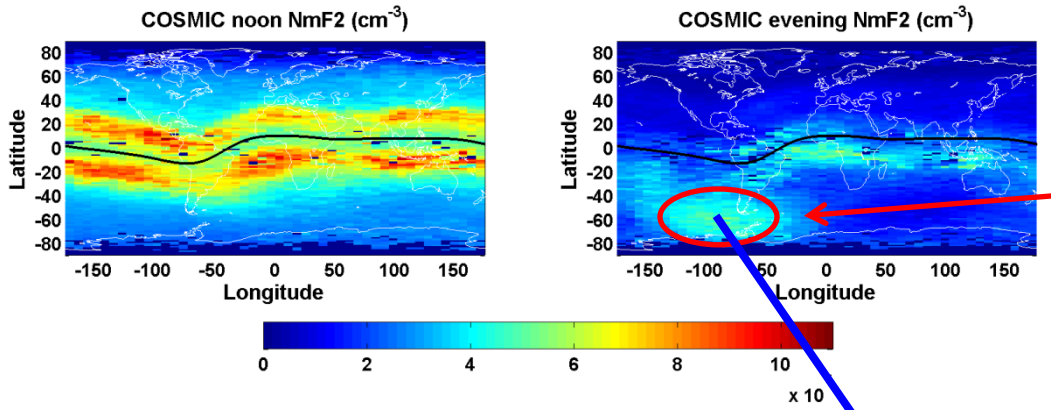

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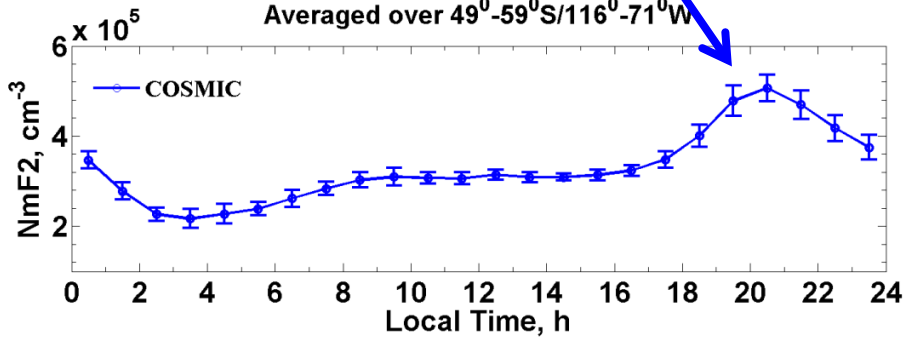
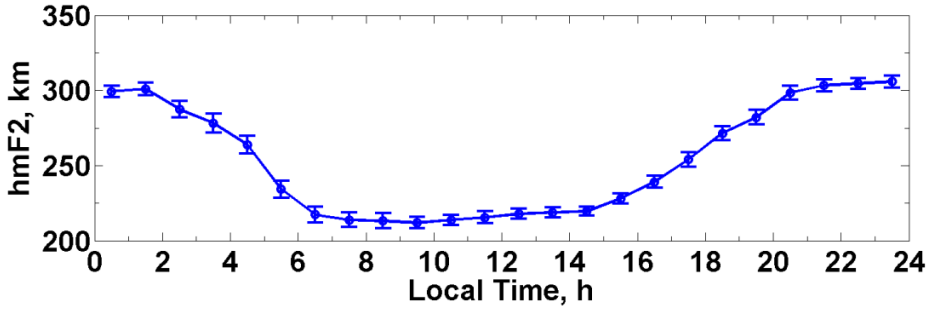


NmF2 from COSMIC

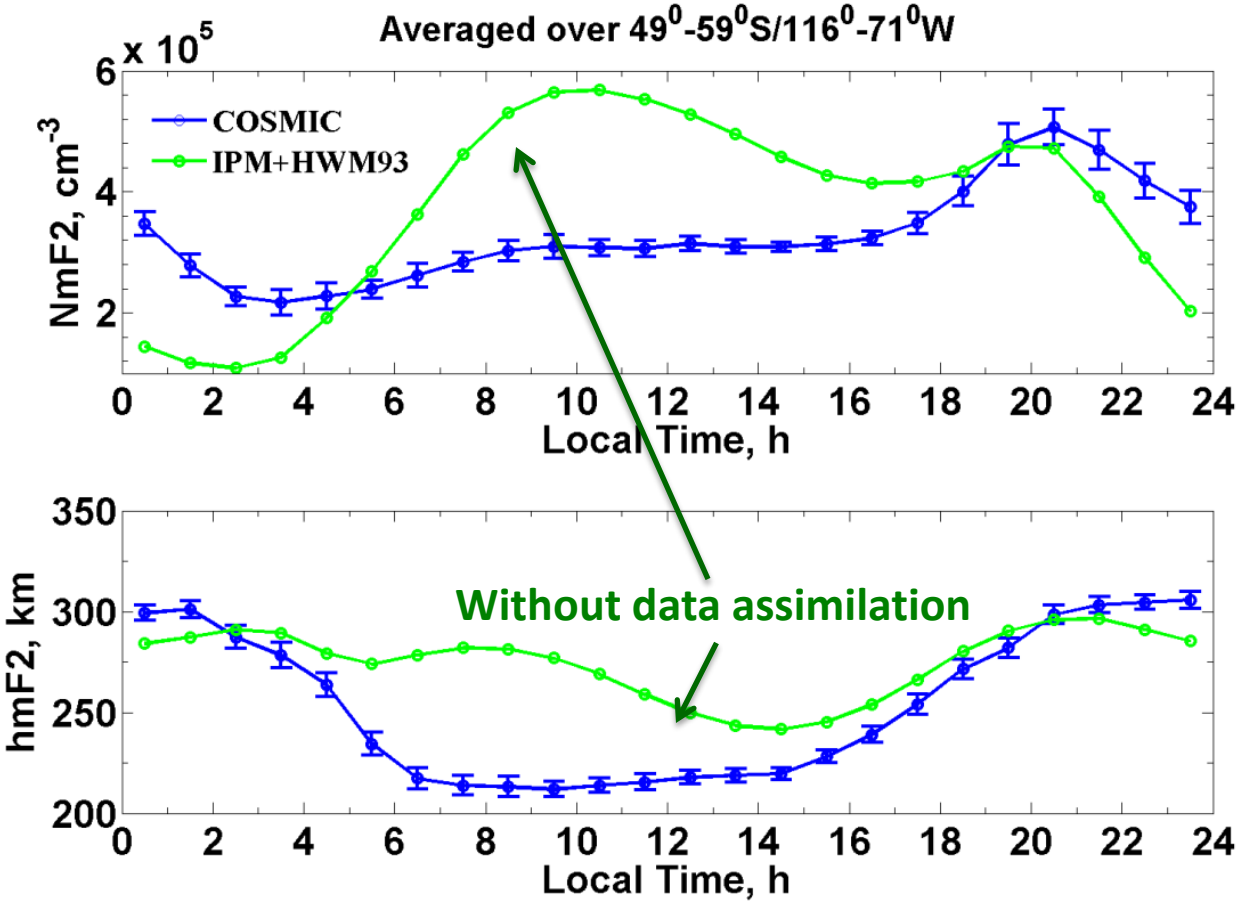


hmF2 from COSMIC

Lomidze et al., 2016

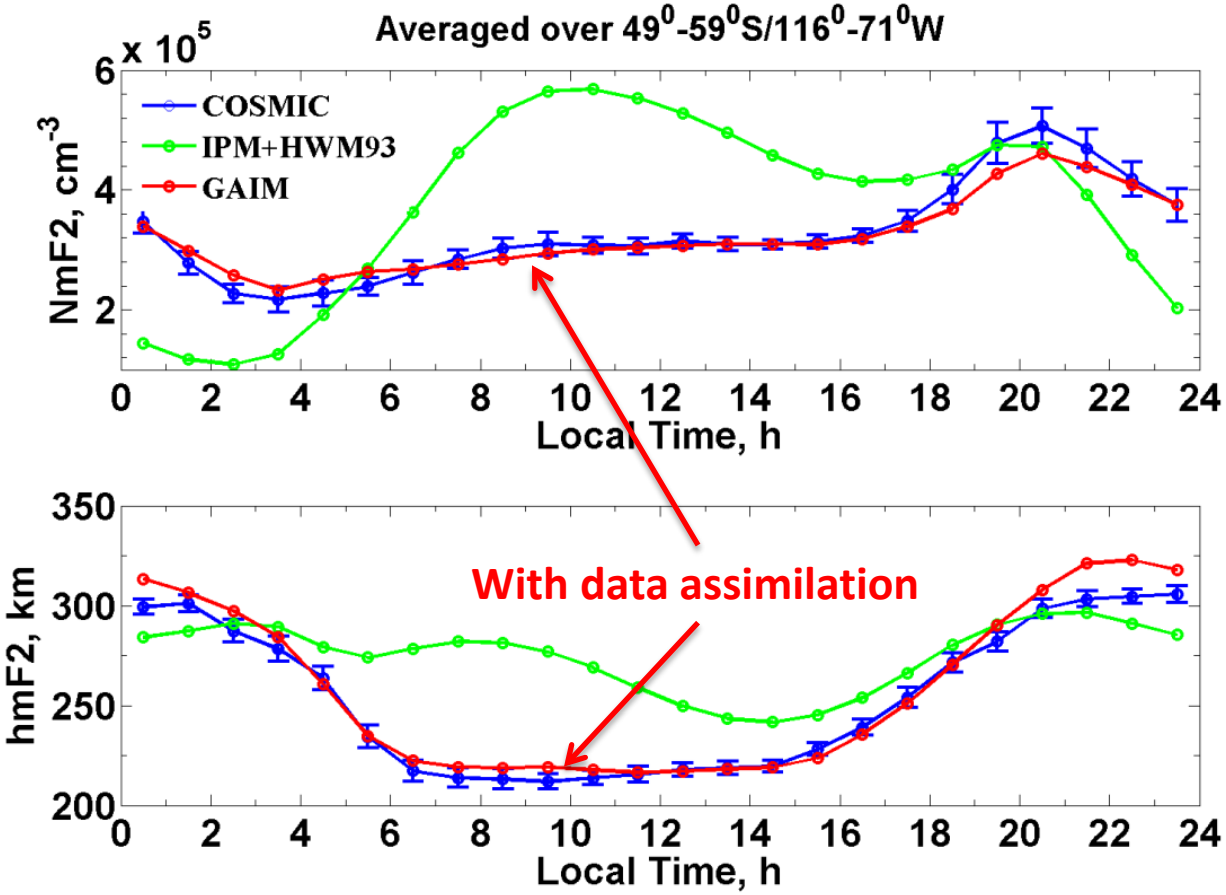
Modeling results without data assimilation (IPM model)

IPM using empirical wind model (HWM93)



Data Assimilation Results (IPM + TWAM)

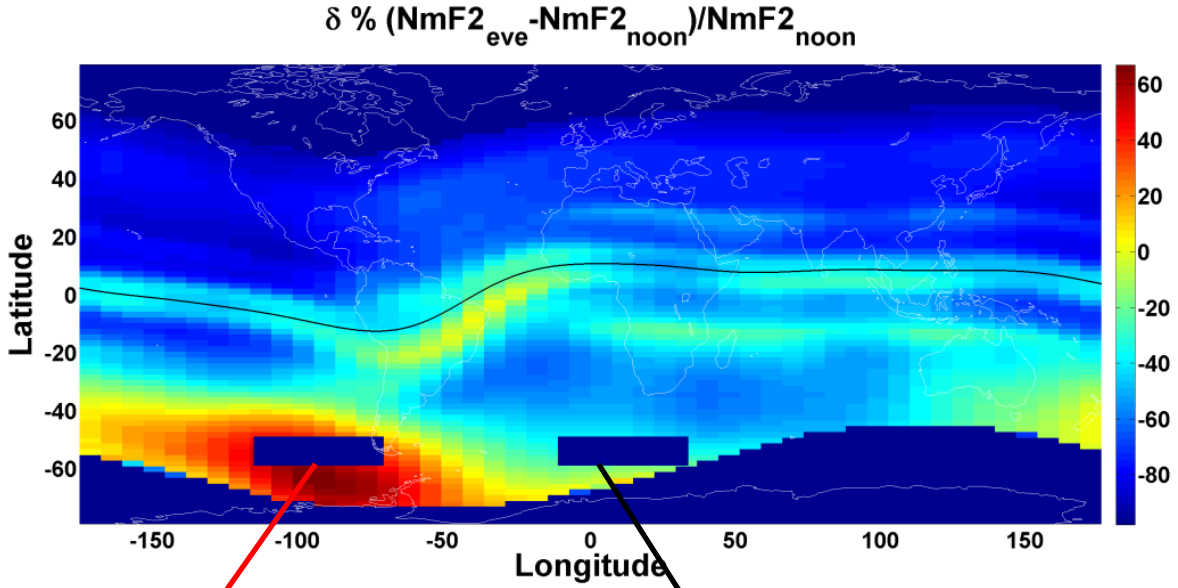
IPM using TWAM winds



TWAM Winds greatly improved the model to data comparison!

Compare terms over the anomaly and outside the anomaly

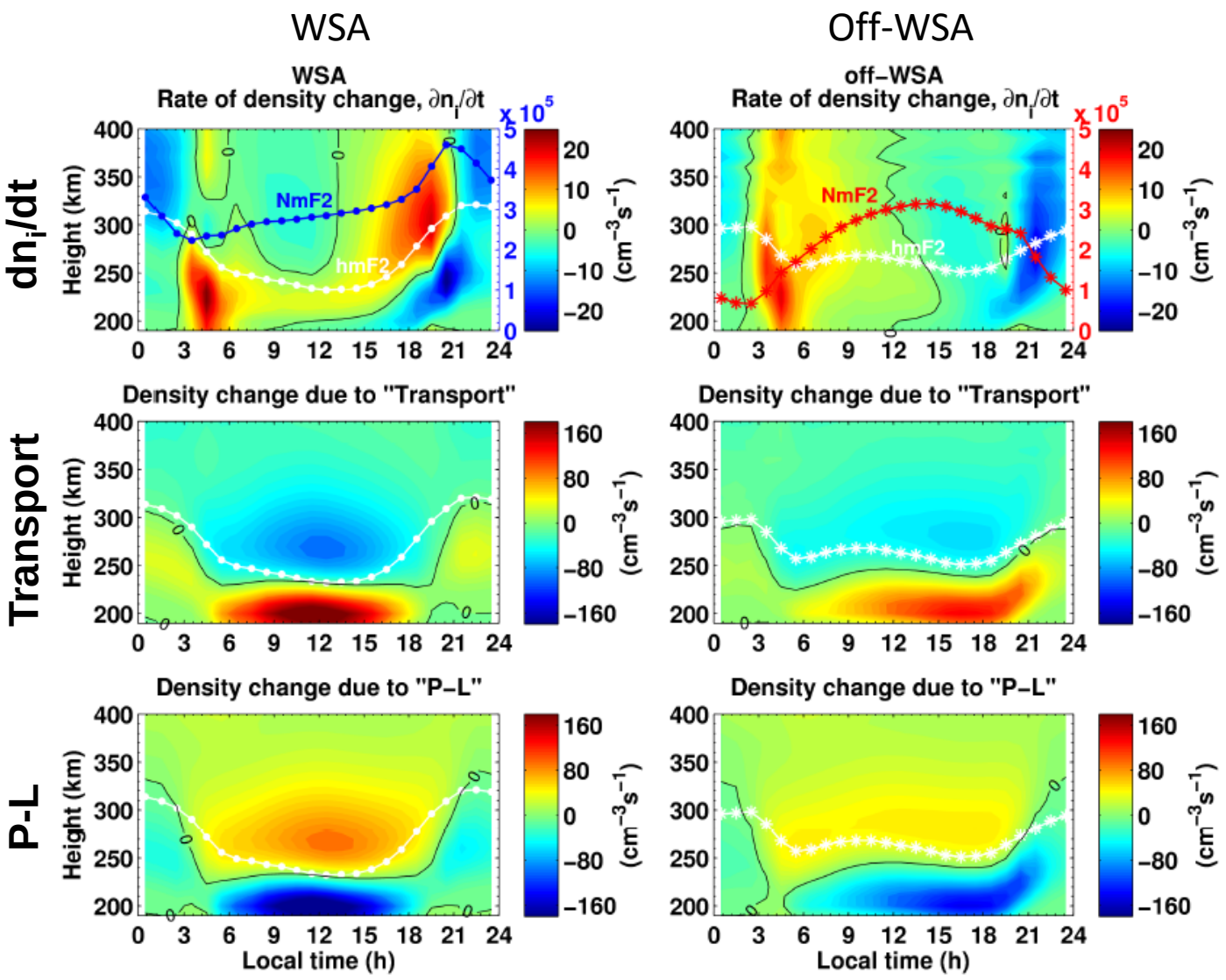
WSA *vs* off WSA



WSA
(49^0-59^0 S, 116W^0-71^0 W)
Incl= -56^0
decl= +25^0

Off WSA
(49^0-59^0 S, 11W^0-34^0 E)
Incl= -61^0
decl= -28^0

Comparison of parameters over “WSA” and “off-WSA”: Plasma transport, production and loss



- Large positive rate of density change over the WSA during evening.
- At hmF2 and above the density is reduced due to the transport over both sites.
- Solar production dominates over chemical recombination for most of the day.

Major Findings

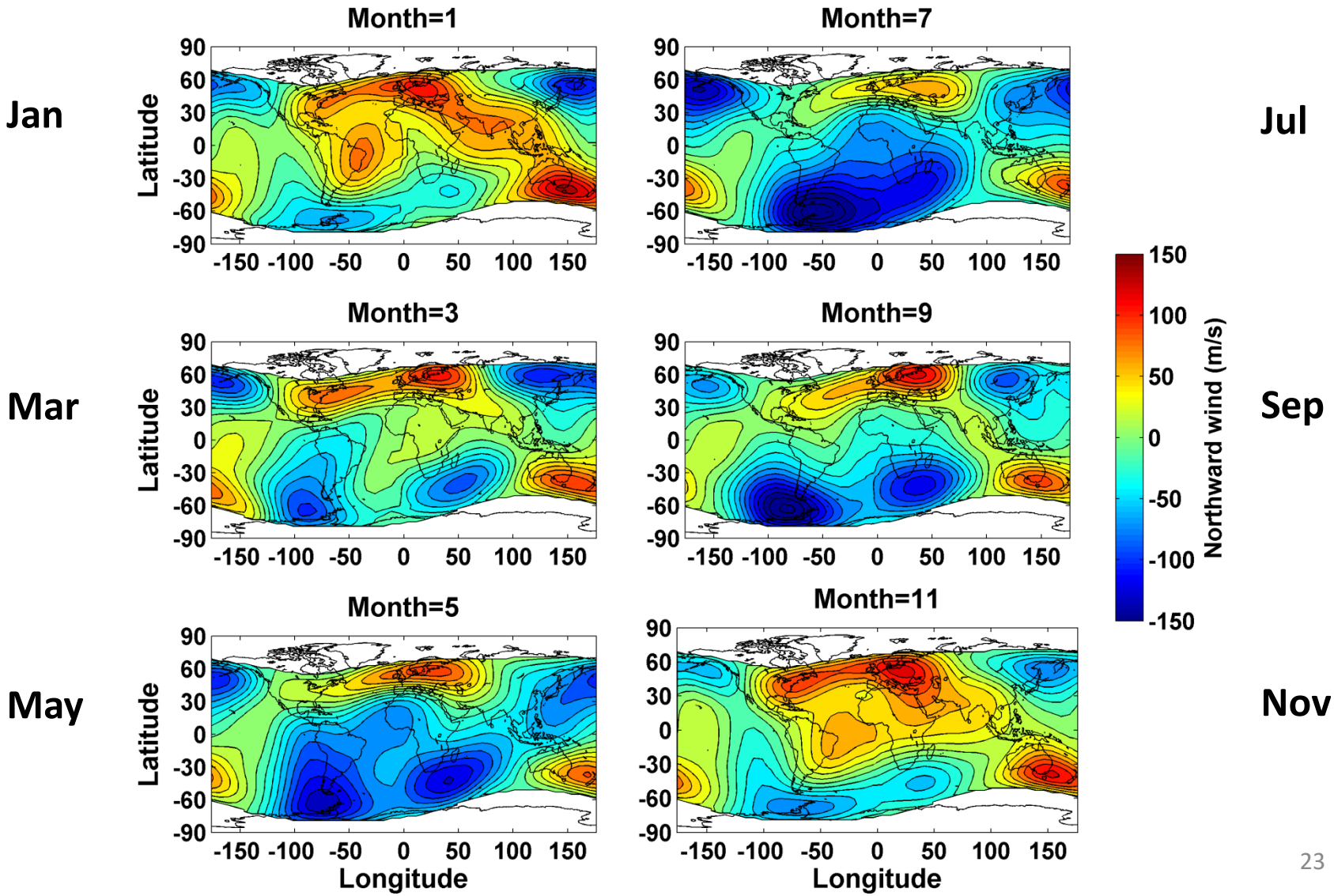
- ✓ Thermospheric neutral winds obtained from GAIM-FP and TWAM closely reproduce both, NmF2 and hmF2 over the evening anomaly sites.
- ✓ The neutral wind drives the anomalies.
- ✓ The density increase is due to solar production which is not balanced by chemical loss and transport.
- ✓ The reduced rate of loss **by transport** further contributes to the density enhancement.

→All of these results were based on Radio Occultation Measurements

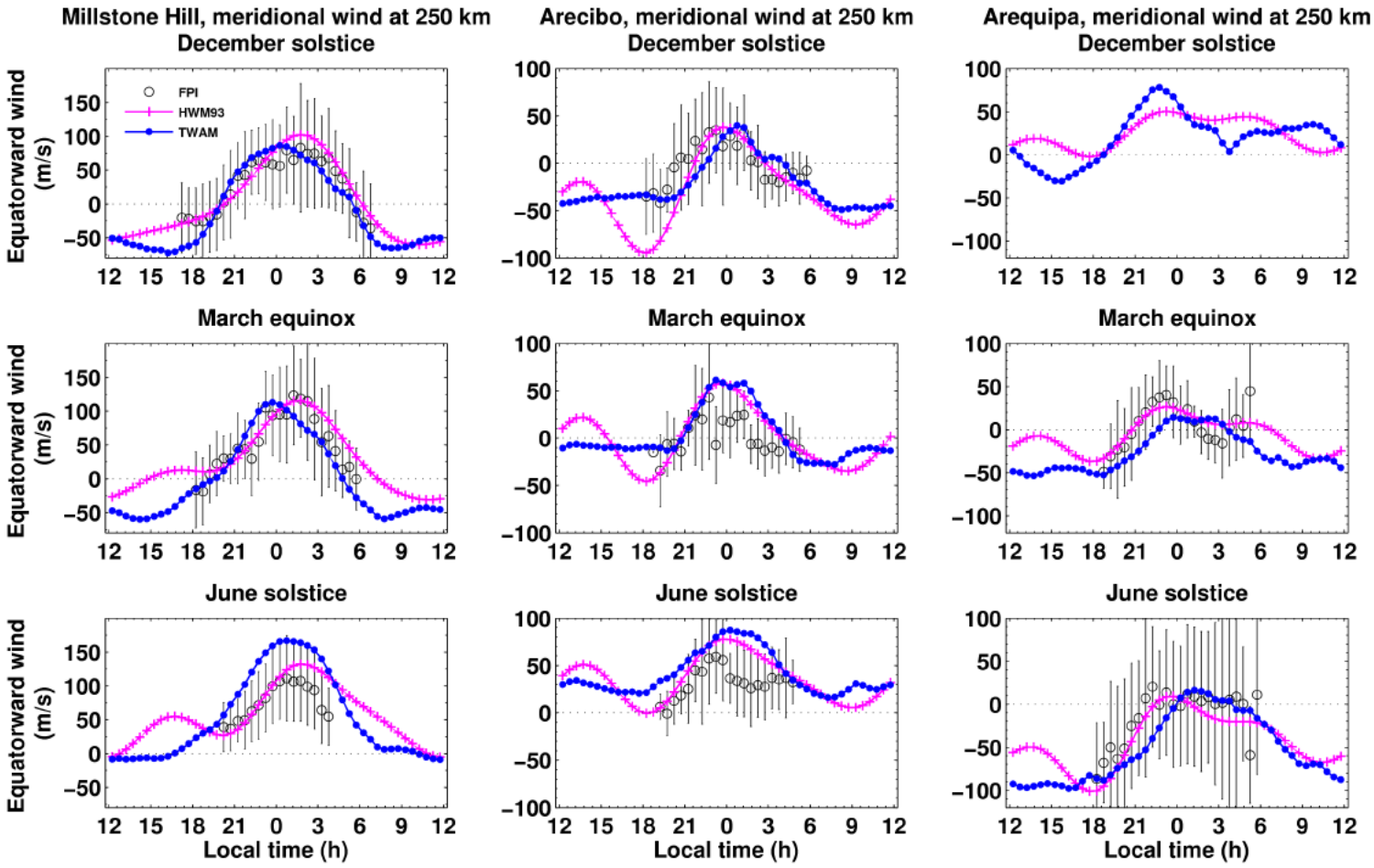
Monthly Variation of Thermospheric Winds

UT=13h

Meridional Wind

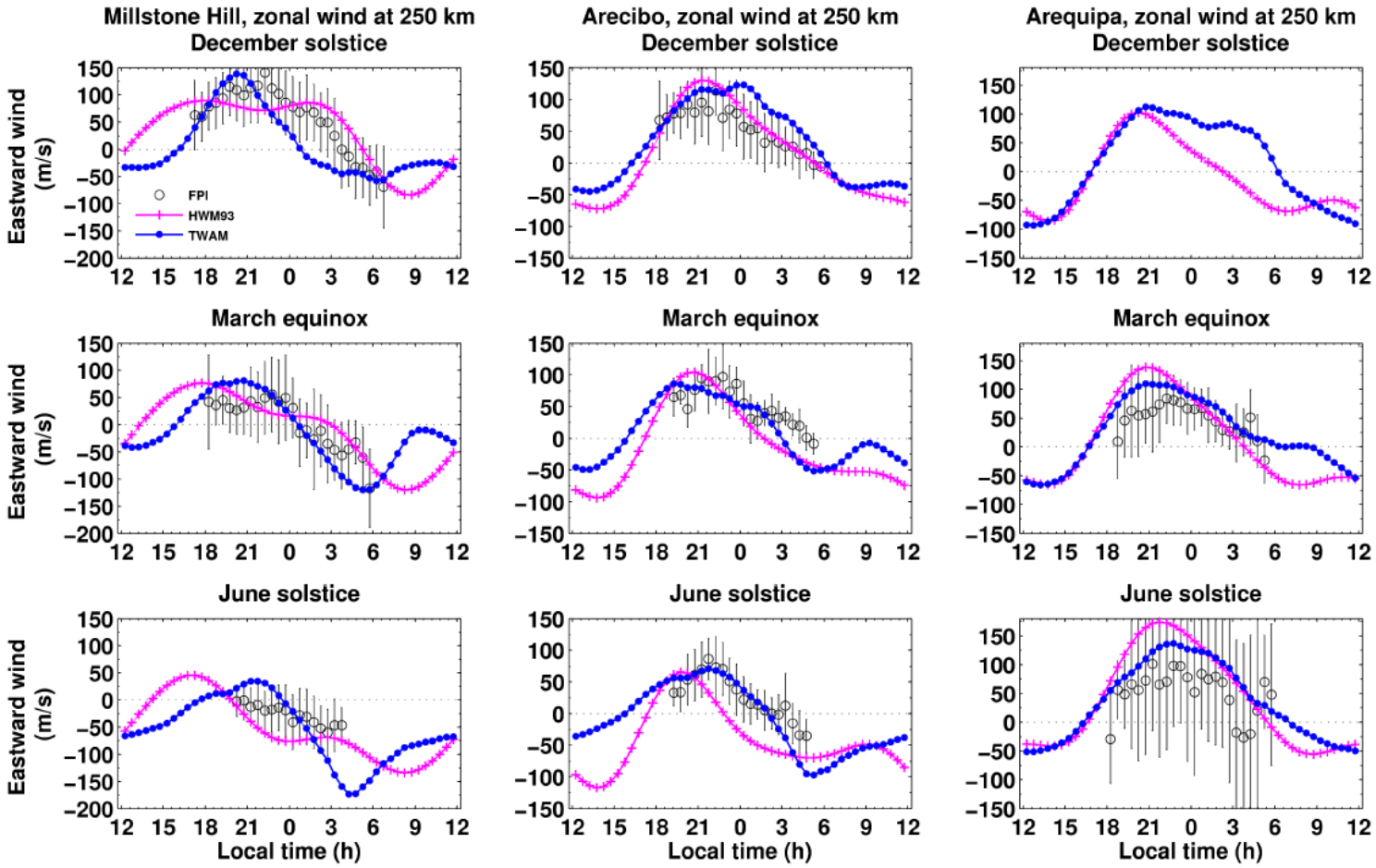


Comparison of TWAM geographic meridional winds with FPI and HWM93 data



LT variations of seasonal geographic meridional winds from FPI observations, HWM93 and TWAM. (Positive - equatorward).

Comparison of TWAM geographic zonal winds with FPI and HWM93 data



LT variations of seasonal geographic zonal winds from FPI observations, HWM93 and TWAM. (Positive - eastward).

Global Assimilation of Ionospheric Measurements (GAIM) Full Physics-Based Model

- Uses Physics Based Ionosphere-Plasmasphere Model (IPM)
  - Global 3-D electron densities
  - Includes all major physical and chemical processes
  - 6 ionic species (NO^+, O_2^+, N_2^+, O^+, H^+, He^+)
  - 90 – 20,000 km height range
- Ensemble Kalman Filter technique
- Estimates physical drivers (wind, E-field, composition)

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For more details see *Scherliess et al., Radio Sci., 44, 2009*

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Determination of Ionospheric Drivers Using The Full Physics-Based GAIM Model

- Ionospheric **Sensitivities to Drivers** are embedded in the **Covariances** and are automatically and at each Time Step calculated.

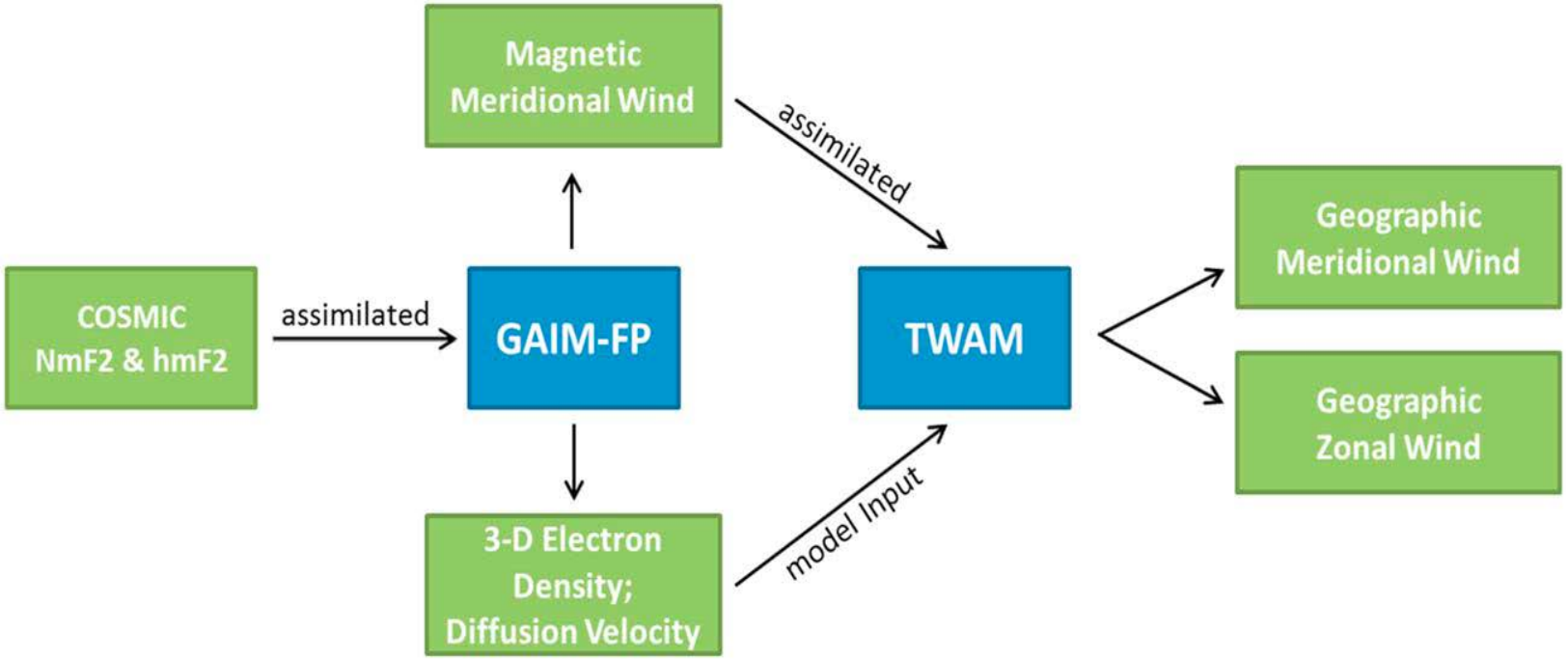
- Drivers include:

  - Electric Fields
  - Neutral Wind
  - Composition
  - …

Thermospheric Wind Assimilation Model (TWAM)

Data are assimilated using an implicit Kalman filter technique.

→ Data are the magnetic meridional winds form GAIM-FP



TWAM provides the 3-D thermospheric wind

Lomidze and Scherliess, 2015

Thermospheric Wind Assimilation Model (TWAM)

TWAM is based on a first-principles data assimilation model for the thermospheric wind.

Physics-based Model:

The equation of motion of the neutral air

$$\frac{\partial u}{\partial t} + (\mathbf{u} \cdot \nabla)\, u = 2\Omega v \sin\theta - \frac{1}{\rho}\frac{\partial p}{\partial x} + \frac{\mu}{\rho}\frac{\partial^2 u}{\partial z^2} - \nu_{ni}\,(u - u_i)$$

$$\frac{\partial v}{\partial t} + (\mathbf{u} \cdot \nabla)\, v = -2\Omega u \sin\theta - \frac{1}{\rho}\frac{\partial p}{\partial y} + \frac{\mu}{\rho}\frac{\partial^2 v}{\partial z^2} - \nu_{ni}\,(v - v_i)$$

Lomidze and Scherliess, 2015