Physical Interpretation of the Thermosphere-Ionosphere Response to Geomagnetic Storms

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Outline

- Research Goal and Approach
- Theory
- Numerical experiment using CTIPe physical model
- Results
- Summary

Research Goal and Approach

- Identify, separate and quantify the relative importance of physical mechanisms (thermospheric winds, thermal expansion, magnetospheric and disturbance dynamo electric fields, plasmaspheric depletion and refilling, interhemispheric flow, composition changes, etc.) in the ionosphere-thermosphere response to magnetic storms.

- Global, three-dimensional, time-dependent, non-linear coupled model of the thermosphere, ionosphere, plasmasphere, and electrodynamics (CTIPe) physical model.

- Observational data from ground and space, such as ionosonde, GPS-TEC provided by the Space Weather Prediction Center (SWPC) data assimilation model in its global configuration (MAGIC), GUVI O/N2 ratio and CHAMP neutral density are used to compare and support results provided by the physical model.

Research Goal and Approach

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F2 peak height changes at mid-latitudes during geomagnetic storms

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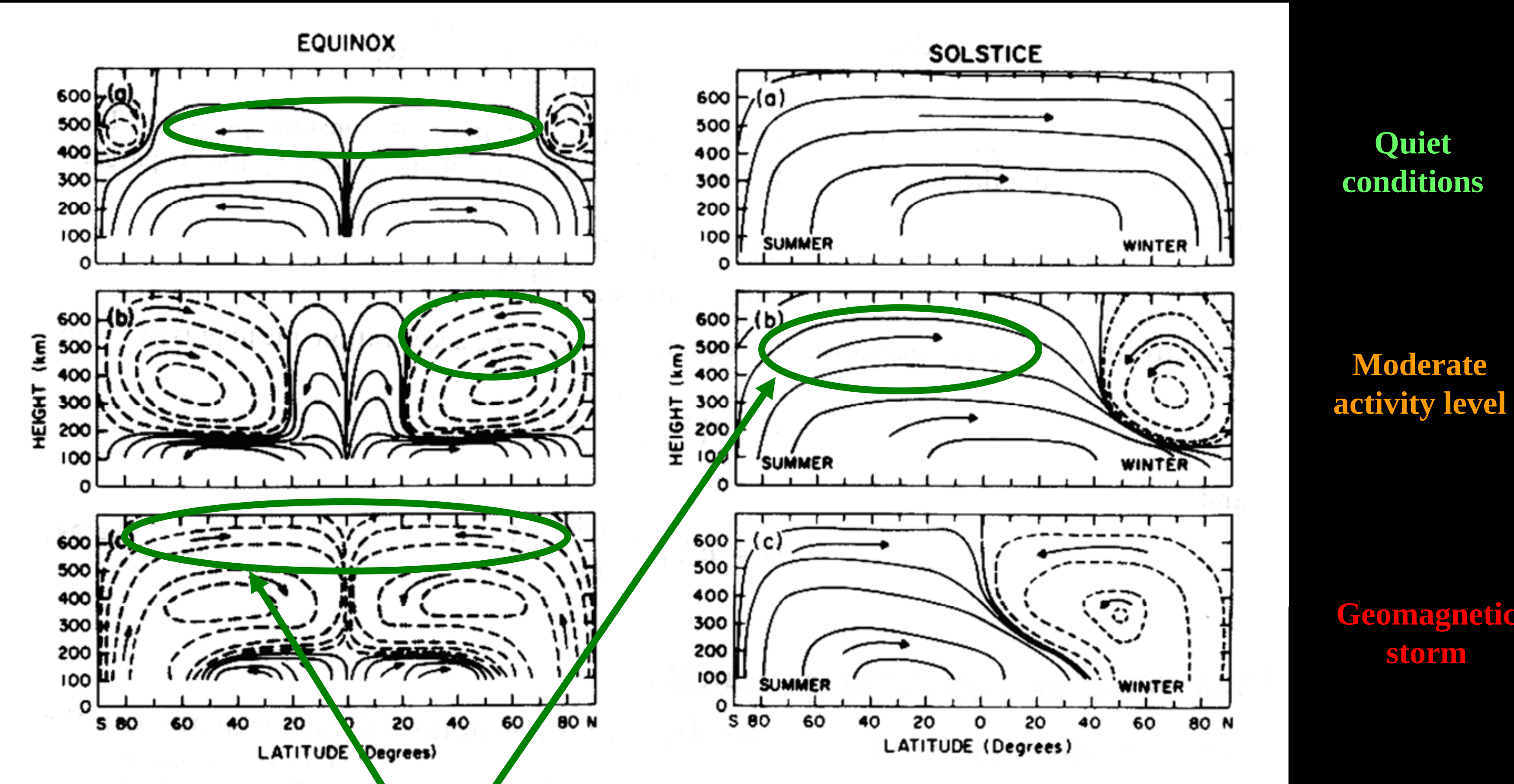
Physical mechanisms: - thermospheric wind
- thermal expansion

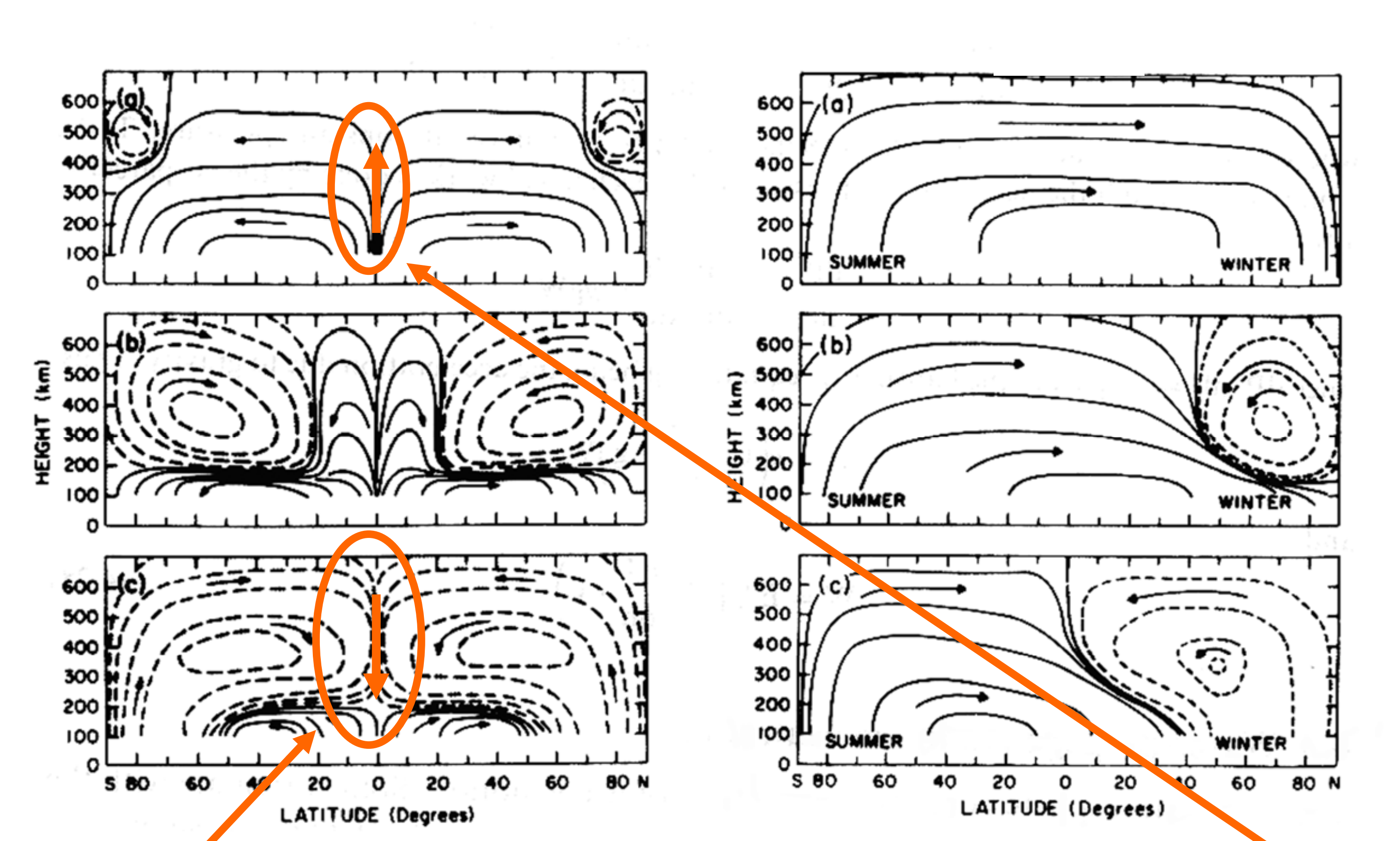
Thermospheric Winds



R.G. Roble, *The Upper Atmosphere and Magnetosphere.* National Academy of Science, Washington DC, 1977.

Horizontal wind: driven by the pressure inequalities due to temperature differences between polar and equatorial regions

Thermospheric Winds (cont'd)



R.G. Roble, *The Upper Atmosphere and Magnetosphere*. National Academy of Science, Washington DC, 1977.

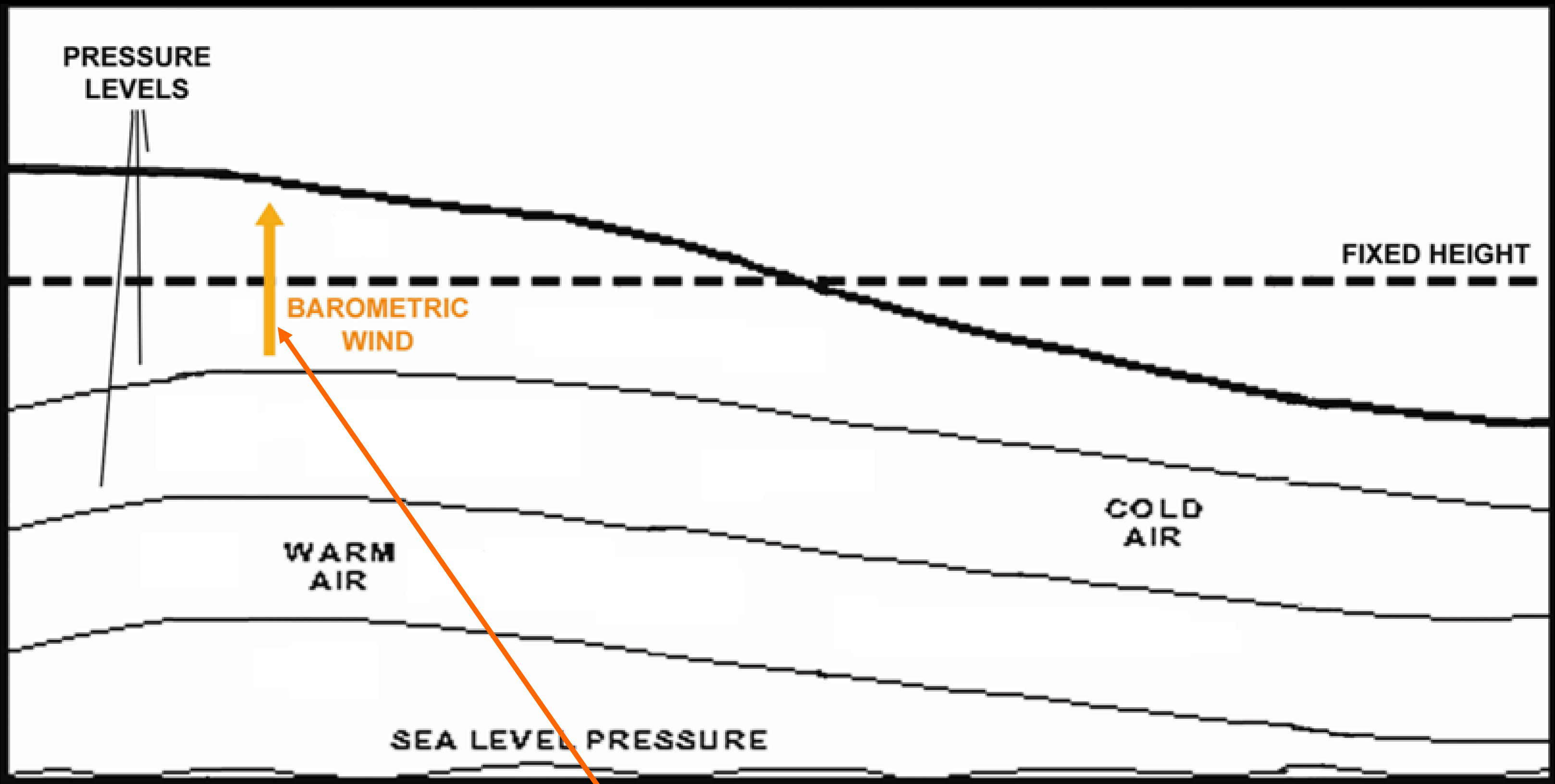
Quiet conditions

Moderate activity level

Geomagnetic storm

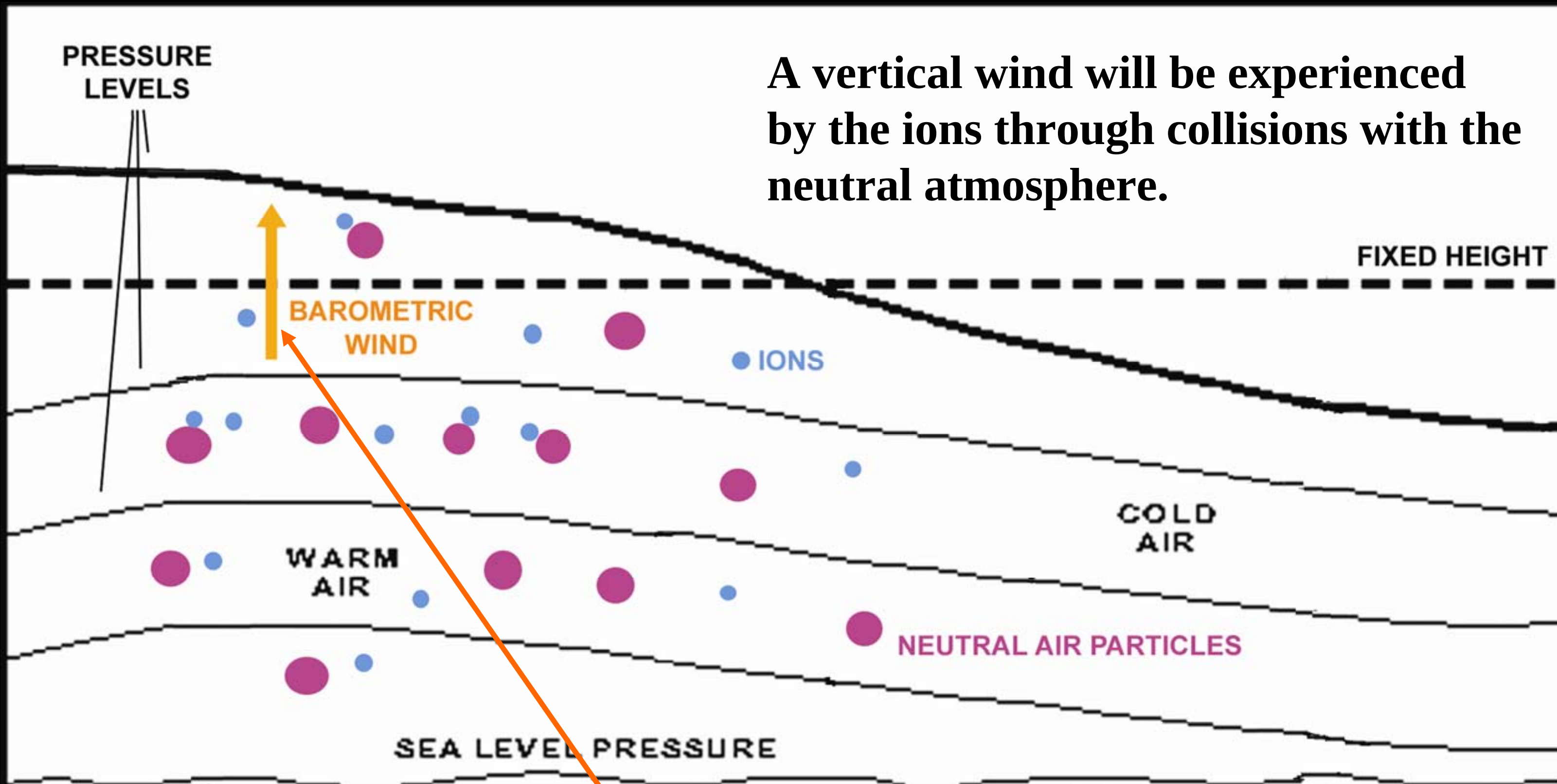
Vertical wind -> divergence component: arises from the divergence (or convergence) in horizontal winds, and represents the flow "across" the pressure levels

Thermospheric Winds (cont'd)



Vertical wind -> barometric component: represents the rise and fall of constant pressure levels due to **thermal expansion** or **contraction**

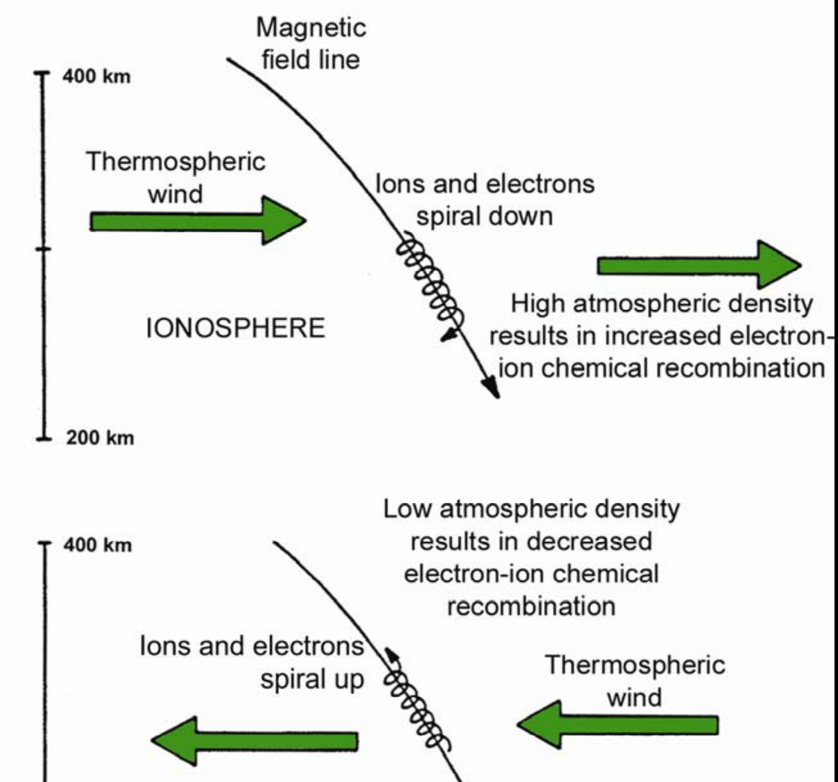
Thermospheric Winds (cont'd)



Vertical wind -> barometric component: represents the rise and fall of constant pressure levels due to **thermal expansion** or **contraction**

Thermospheric Wind Effect on the Ionosphere

Horizontal wind

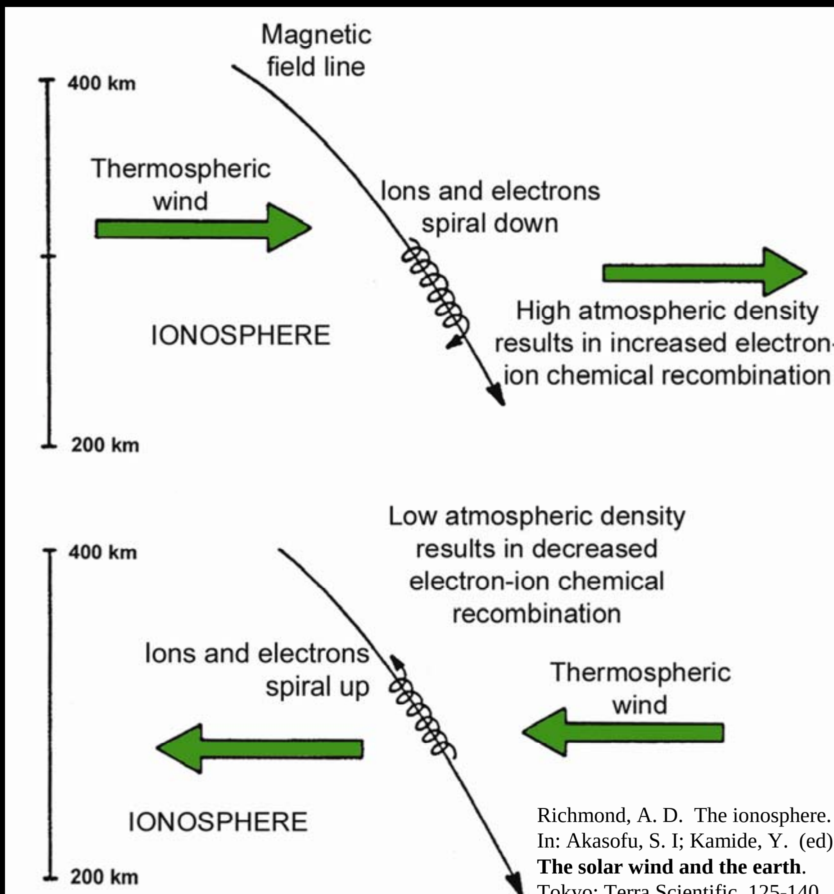


Richmond, A. D. The ionosphere. In: Akasofu, S. I; Kamide, Y. (ed). **The solar wind and the earth**. Tokyo: Terra Scientific, 125-140, 1987.

Poleward wind lowers the F2 layer while equatorward wind raises F2 layer beyond the normal diurnal variation from production, recombination, and diffusion (Miller et al., JGR, 1986). The same applies to storm-time winds.

Thermospheric Wind Effect on the Ionosphere (cont'd)

Horizontal wind



Richmond, A. D. The ionosphere. In: Akasofu, S. I; Kamide, Y. (ed). **The solar wind and the earth**. Tokyo: Terra Scientific, 125-140, 1987.

Method of determining meridional winds from measurements of F2 layer height (Rishbeth et al., 1978; Miller et al., 1986; Richards, 1991; Codrescu et al., 1992)

$$hmF2 = hmF2_0 + \alpha\, V_{mag}$$

$hmF2_0$ = F2 layer peak when the horizontal component meridional wind is zero

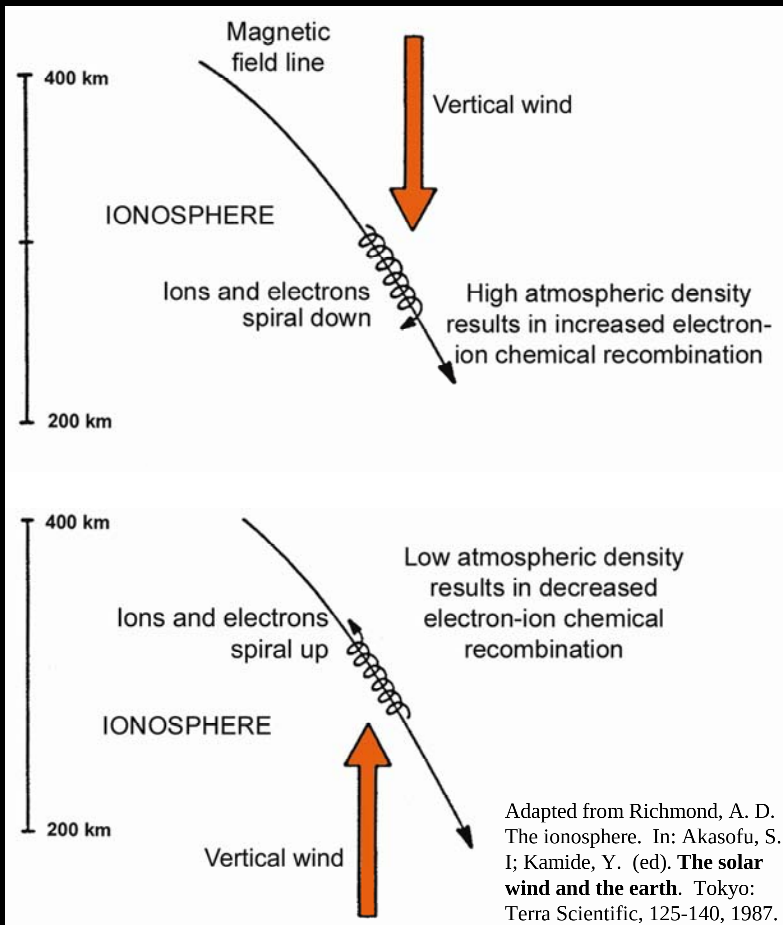
V_{mag} = horizontal component of the neutral wind along the magnetic meridian

$$\alpha = 2 \times \left[1 + 0.25 \cos \frac{2\pi}{24}(LT - 14)\right] \sin I \cos I$$

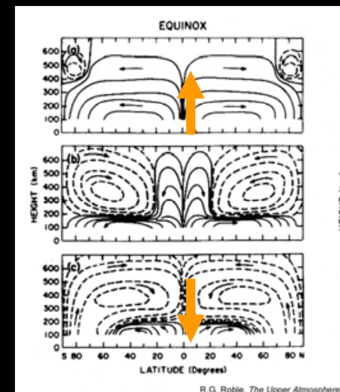
LT: Local time; I: Magnetic dip angle

Thermospheric Wind Effect on the Ionosphere (cont'd)

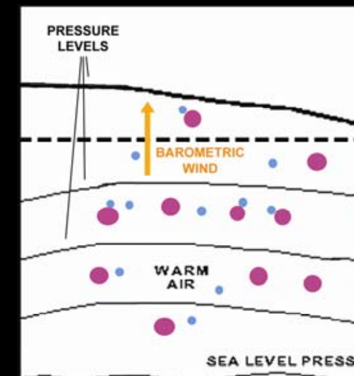
Vertical wind = Divergence + Barometric



Adapted from Richmond, A. D. The ionosphere. In: Akasofu, S. I; Kamide, Y. (ed). **The solar wind and the earth**. Tokyo: Terra Scientific, 125-140, 1987.



Small effect -> plasma pushed out of equilibrium with its surroundings

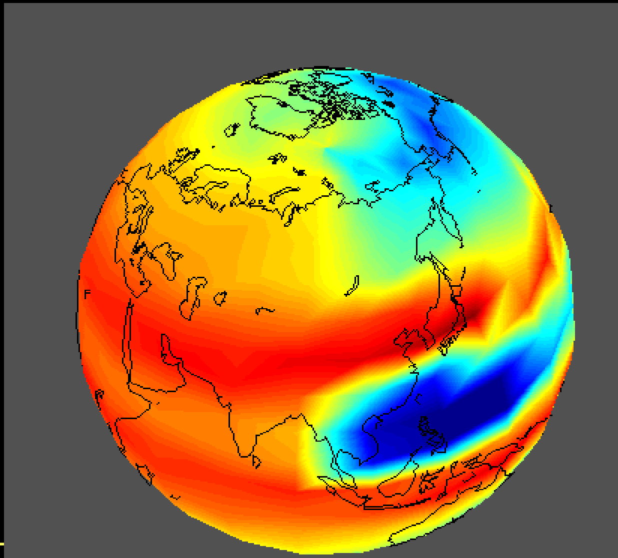


Integrated effect-> plasma moving with thermal expansion remains in equilibrium with its surroundings

Numerical experiment to demonstrate the height change experienced by the ionosphere during geomagnetic storms using CTIPe physical model.

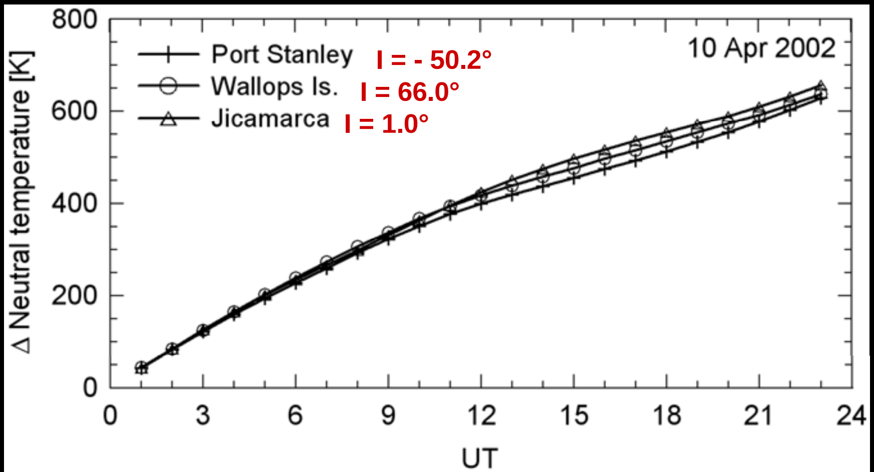
Coupled Thermosphere Ionosphere Plasmasphere Model with self-consistent Electrodynamics (CTIPe)

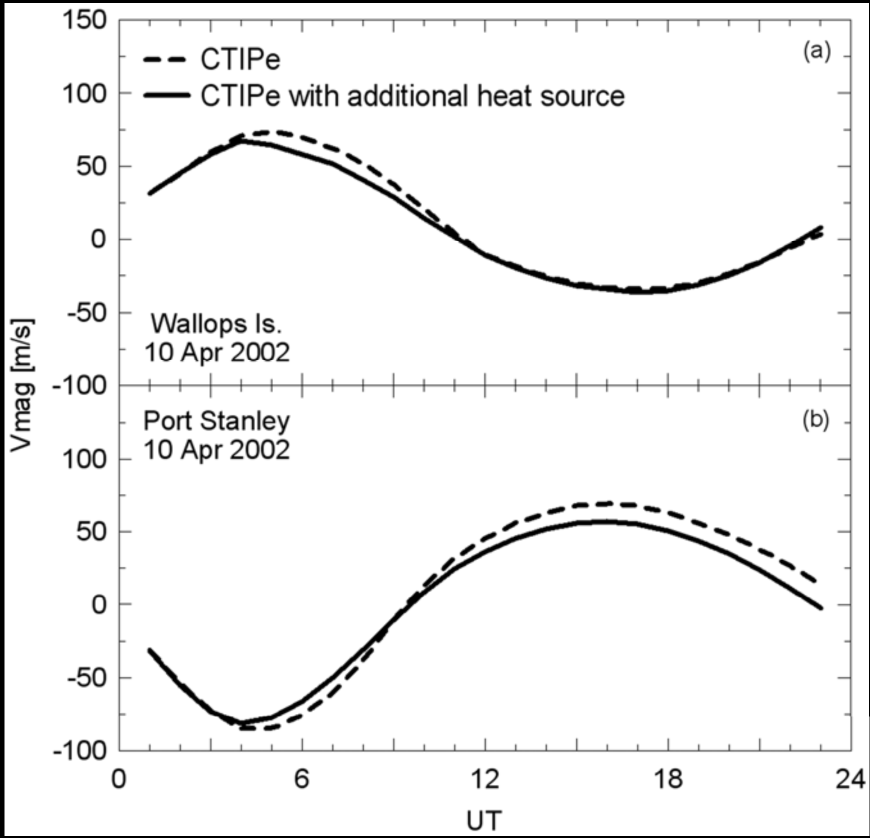
- Global thermosphere 80 - 500 km, solves momentum, energy, composition, etc. V_x, V_y, V_z, T_n, O, O_2, N_2, ….
- High latitude ionosphere 80 -10,000 km, solves continuity, momentum, energy, etc. O^+, H^+, O_2^+, NO^+, N_2^+, N^+, V_i, T_i, ….
- Plasmasphere, and mid and low latitude ionosphere
- Self-consistent electrodynamics
- Forcing: solar UV and EUV, Weimer electric field, TIROS/NOAA auroral precipitation, tidal forcing



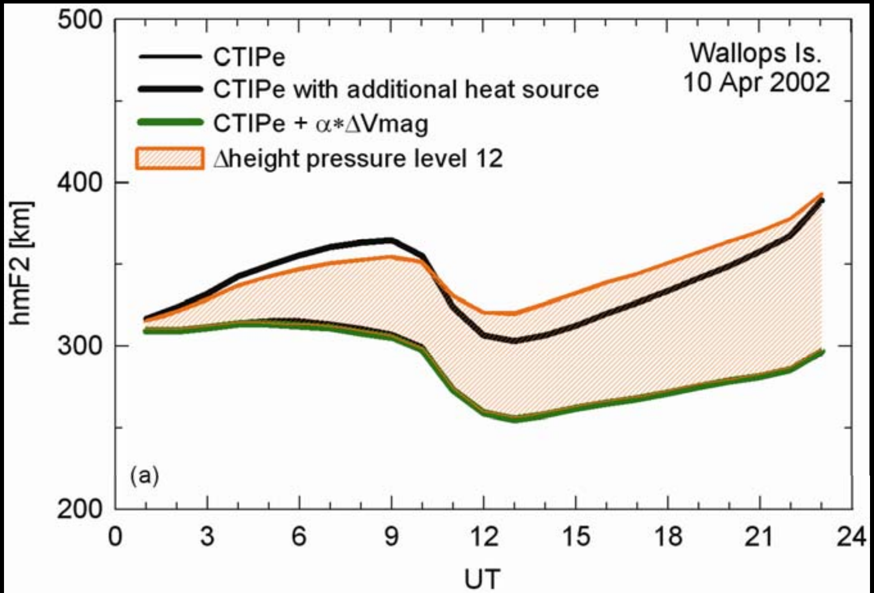
Numerical Experiment: Impact of the Thermal Expansion on Changes in the F2 Peak Height

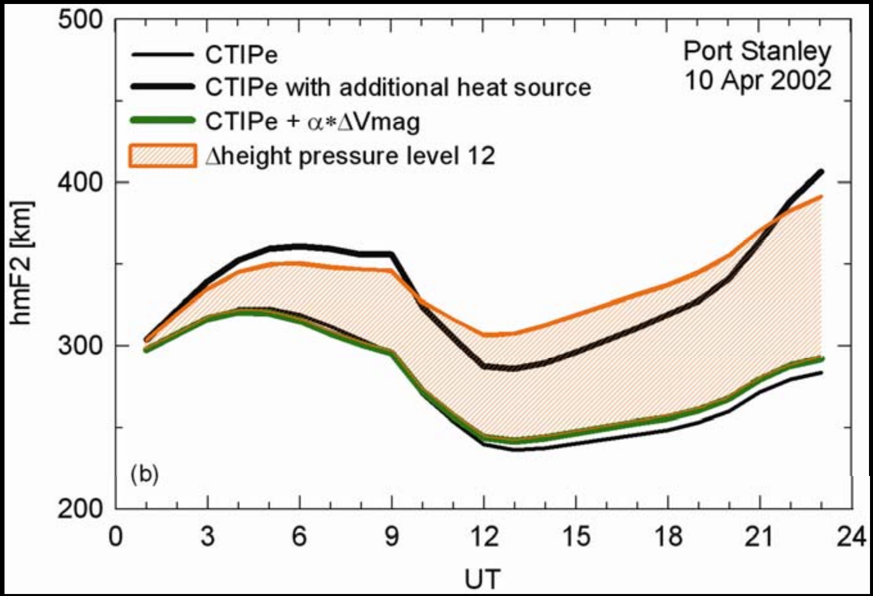
In order to isolate the effect of thermal expansion on F-region height from other mechanisms, a fixed amount of heat was added to all CTIPe grid points -> simulates the thermospheric heating without creating a change in the global wind pattern.





Numerical Experiment: Impact of the Thermal Expansion on Changes in the F2 Peak Height (cont'd)



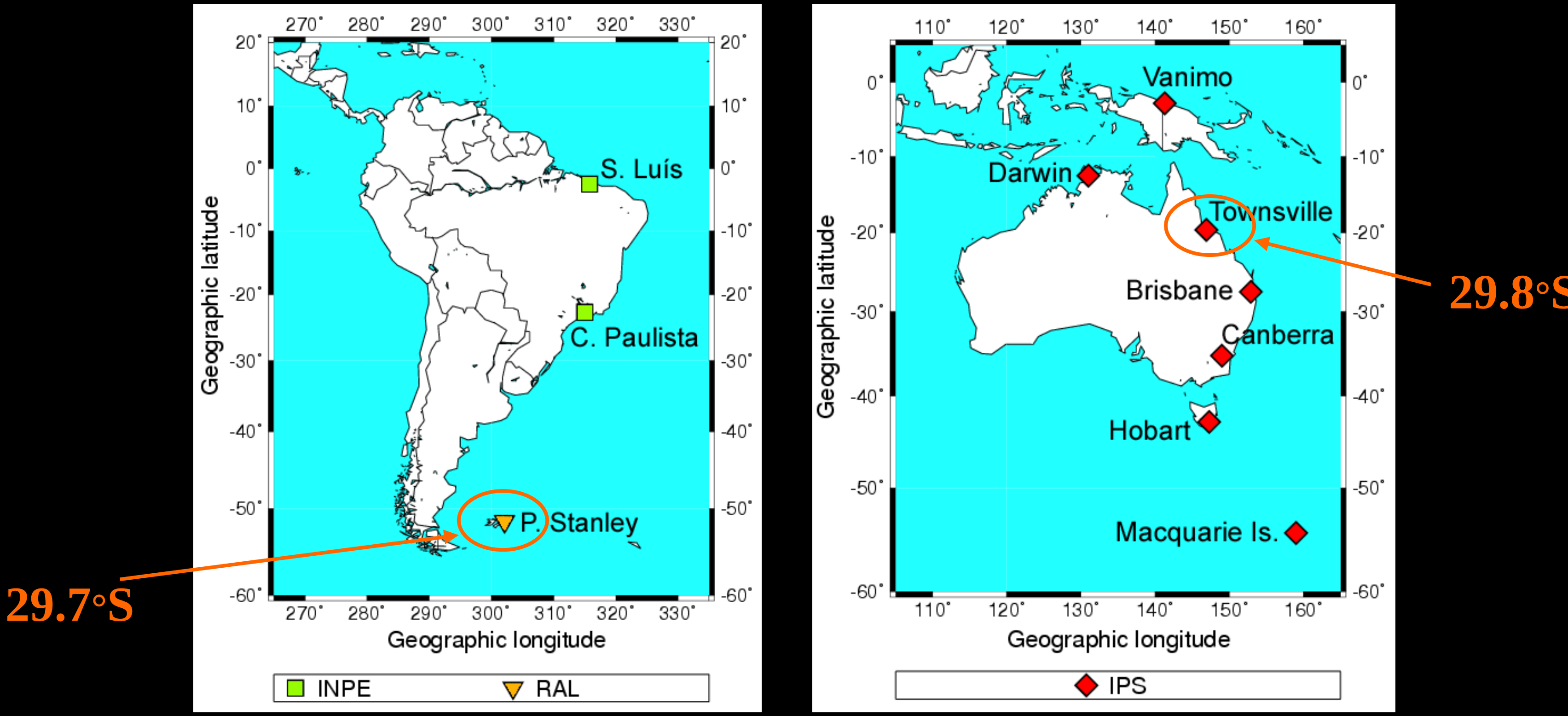


Height changes in the neutral atmosphere from thermal expansion are clearly reflected in the changes of hmF2.

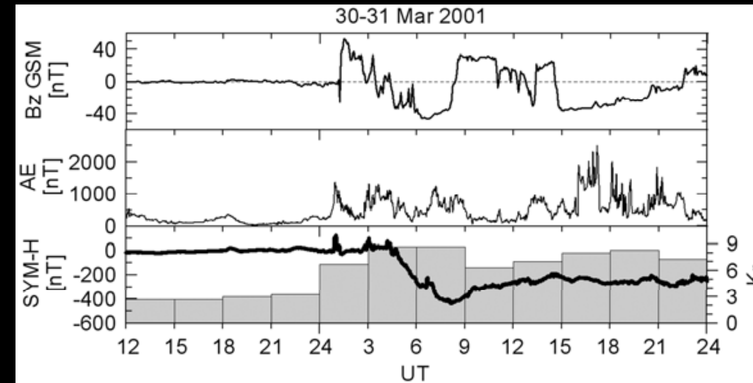
Fedrizzi et al., AGU Monograph on Mid-Latitude Ionospheric Dynamics and Disturbances, *accepted*, 2008.

Relative Contribution of Horizontal Winds and Thermal Expansion in the Mid-latitude Ionospheric-Thermospheric Response to the March 31, 2001 Magnetic Storm

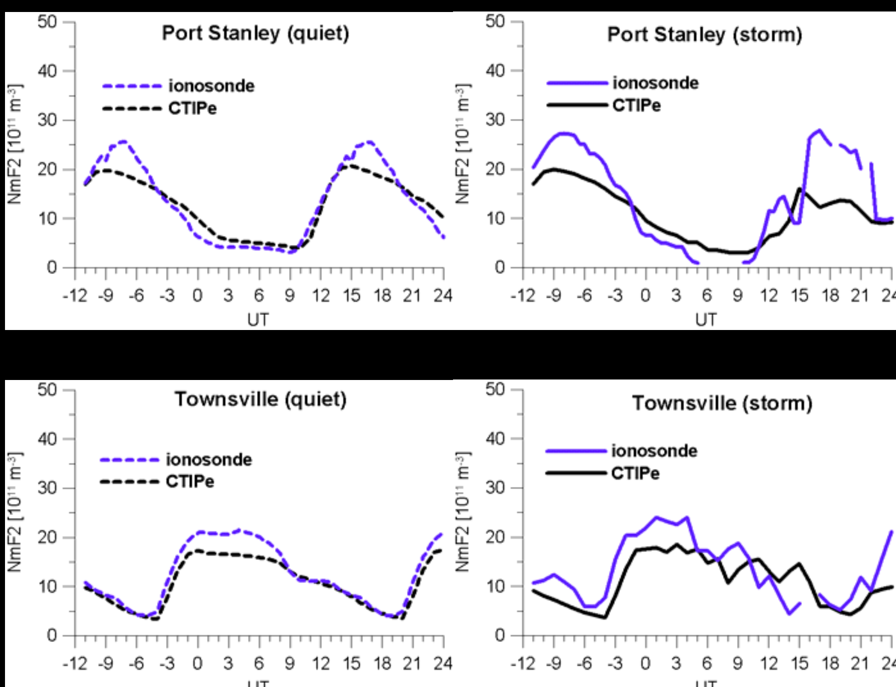
Ionosonde Stations



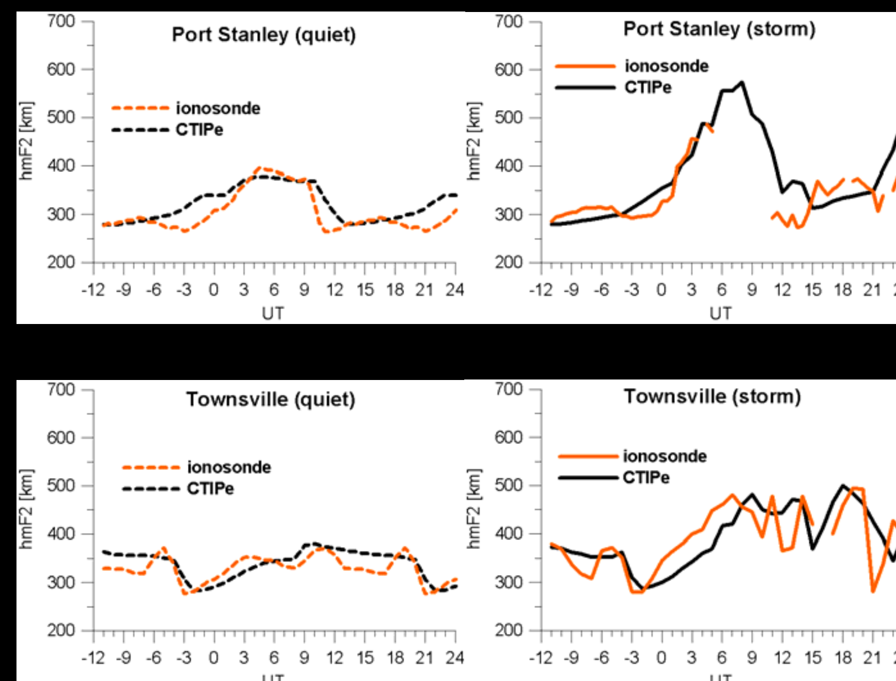
Ionosonde x CTIPe
(March 31, 2001 Magnetic Storm)



NmF2

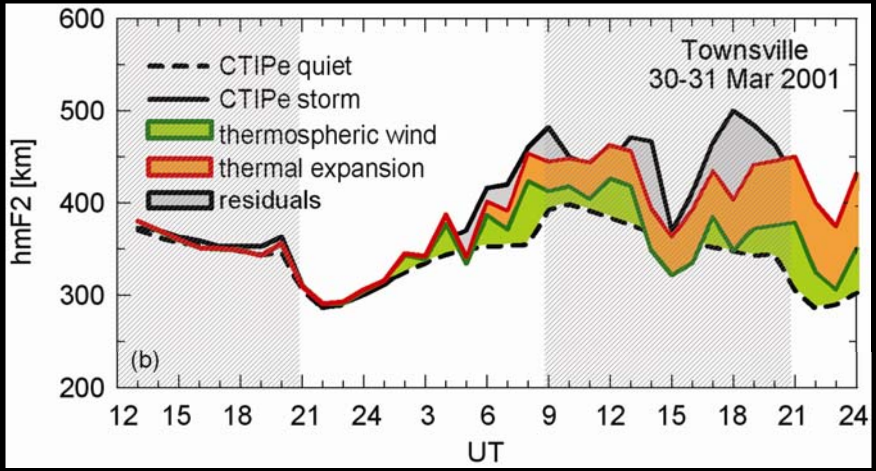


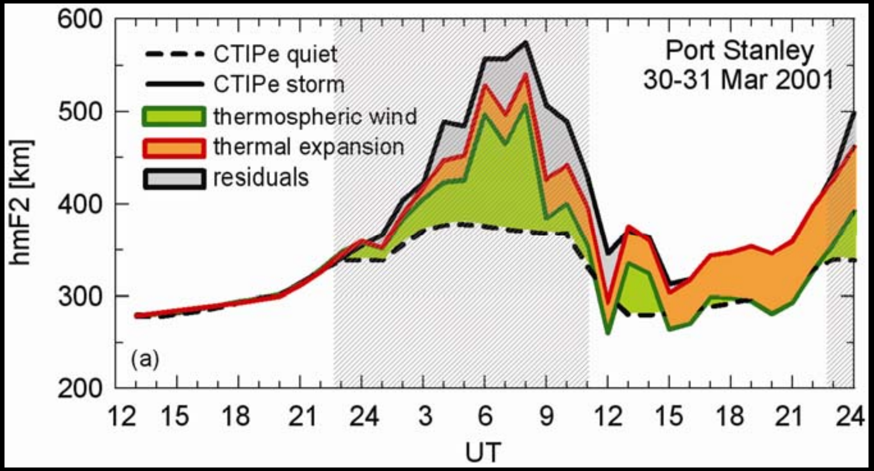
hmF2

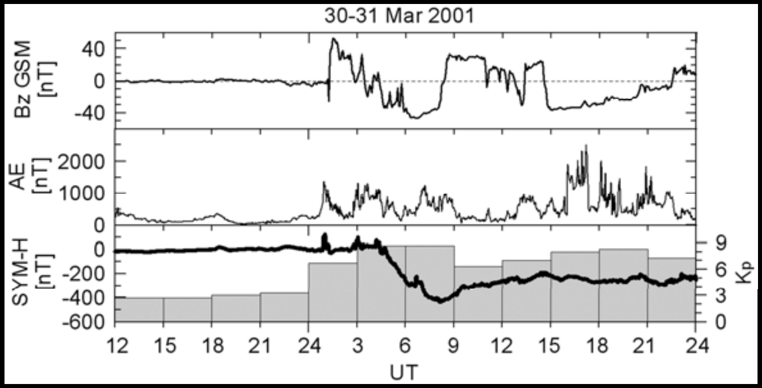


Relative Contribution of Horizontal Winds and Thermal Expansion

(March 31, 2001 Magnetic Storm)

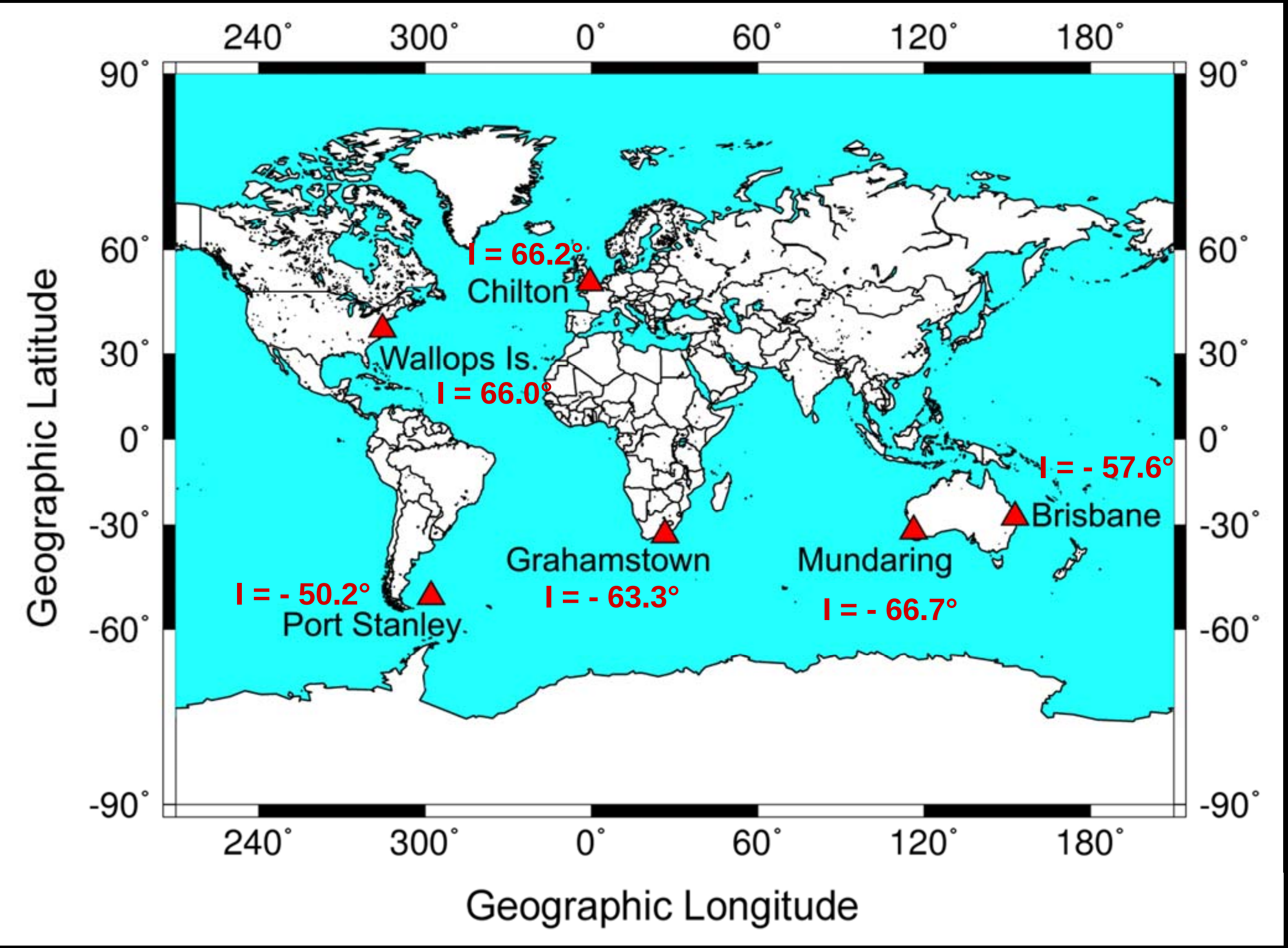






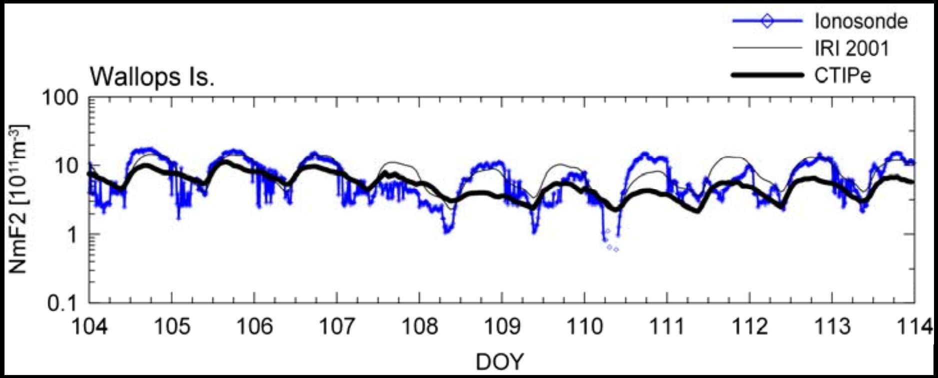
Relative Contribution of Horizontal Winds and Thermal Expansion in the Midlatitude Ionospheric-Thermospheric Response to the April 17, 2002 Magnetic Storm

Ionosonde Stations

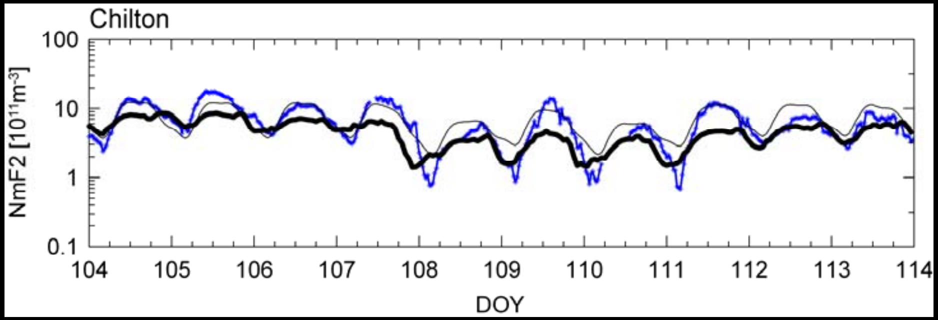


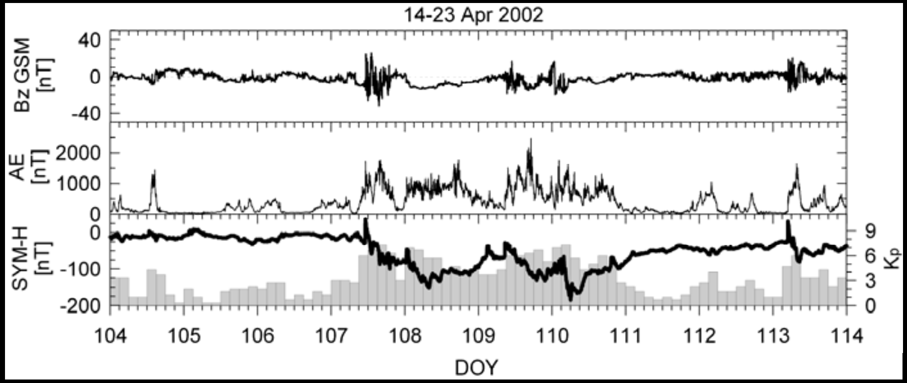
Ionosonde NmF2 x CTIPe NmF2
(April 17, 2002 Magnetic Storm)

American Sector

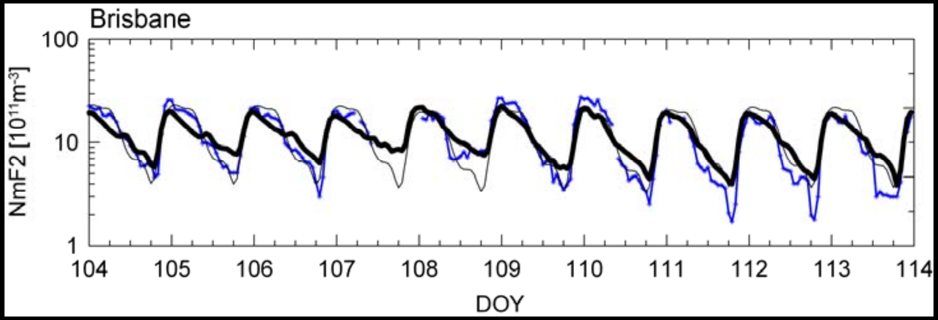


European Sector





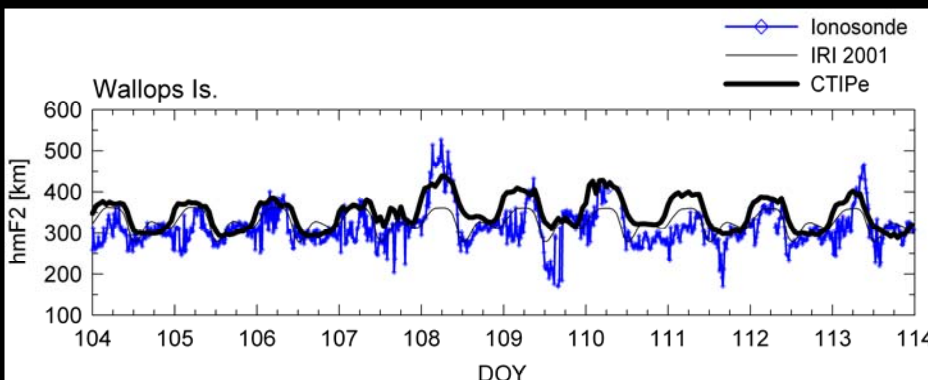
Australian Sector



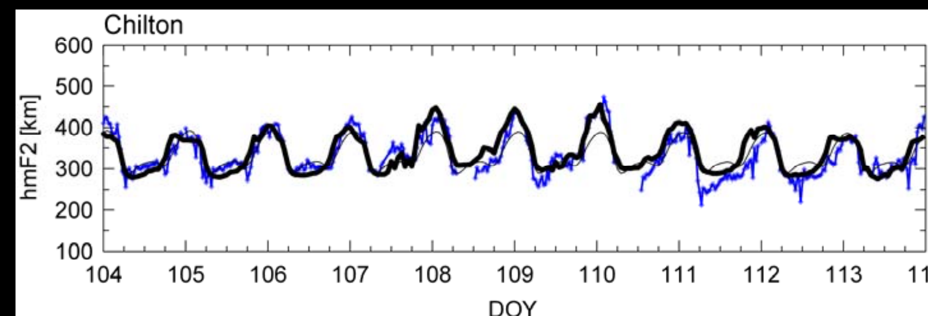
Ionosonde hmF2 x CTIPe hmF2

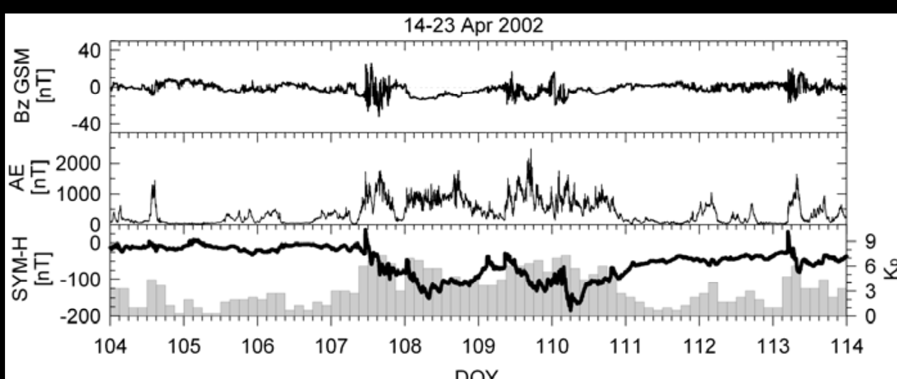
(April 17, 2002 Magnetic Storm)

American Sector

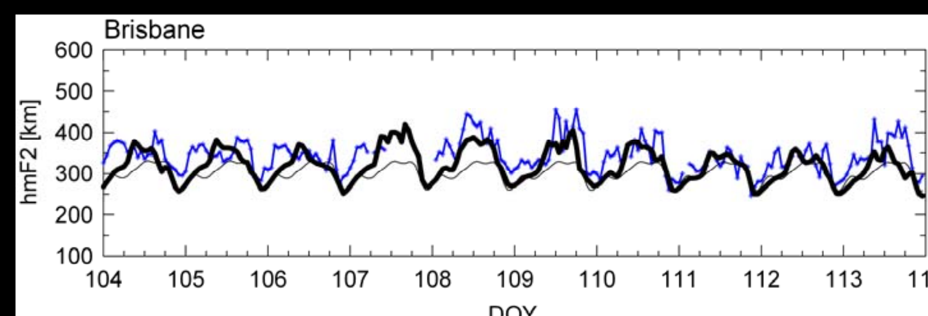


European Sector



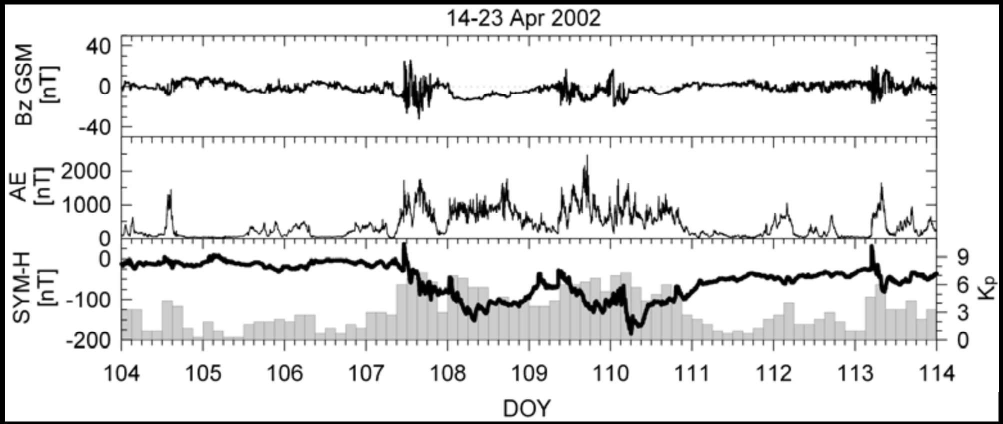


Australian Sector

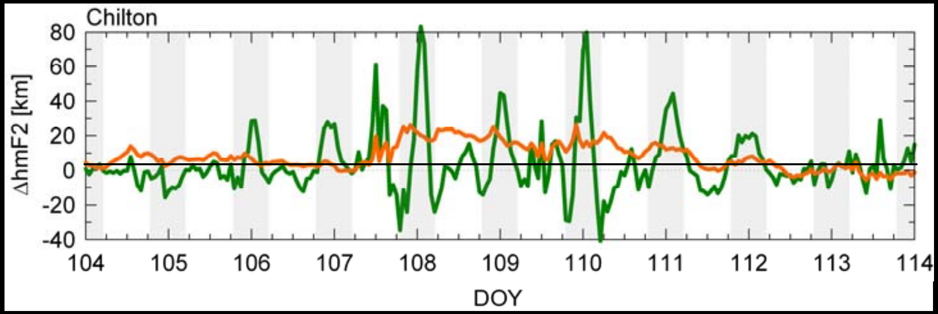


Changes in hmF2 due to Horizontal Winds and Thermal Expansion

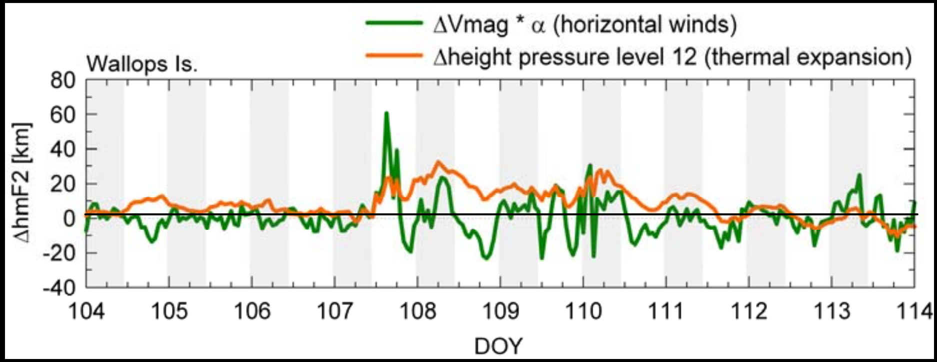
(April 17, 2002 Magnetic Storm)



European Sector



American Sector



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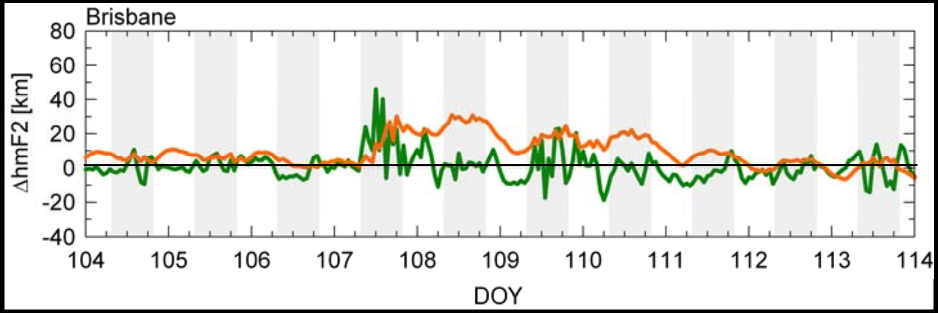
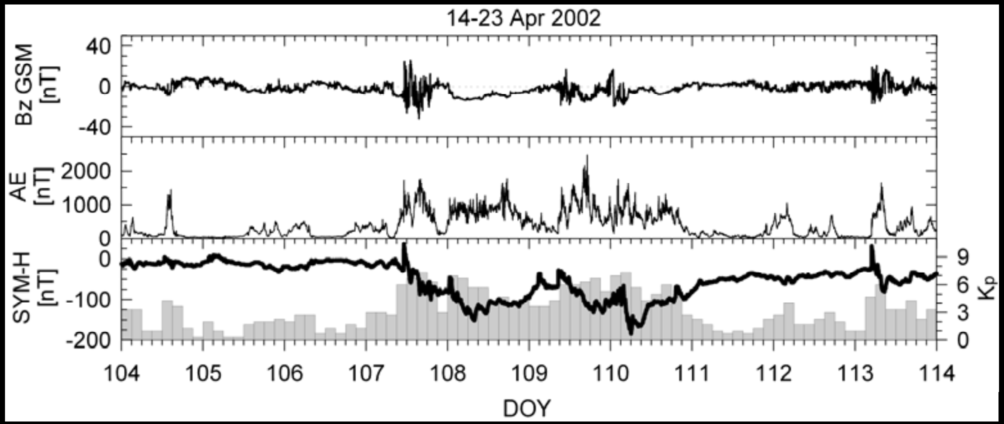
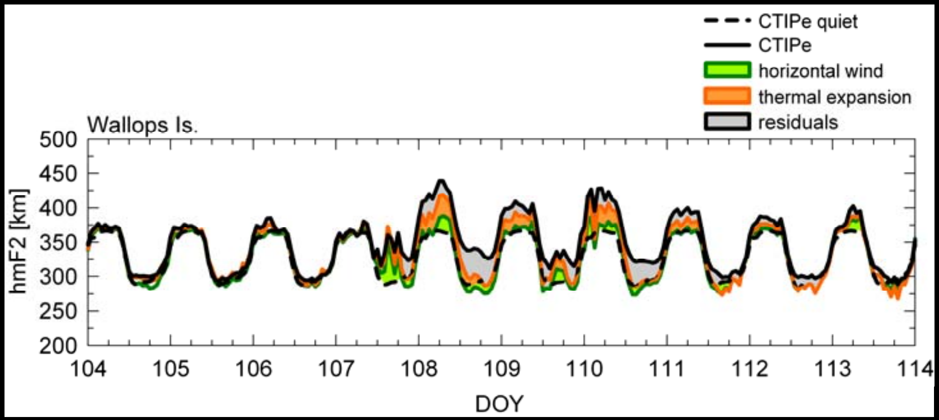


Relative Contribution of Horizontal Winds and Thermal Expansion

(April 17, 2002 Magnetic Storm)



American Sector



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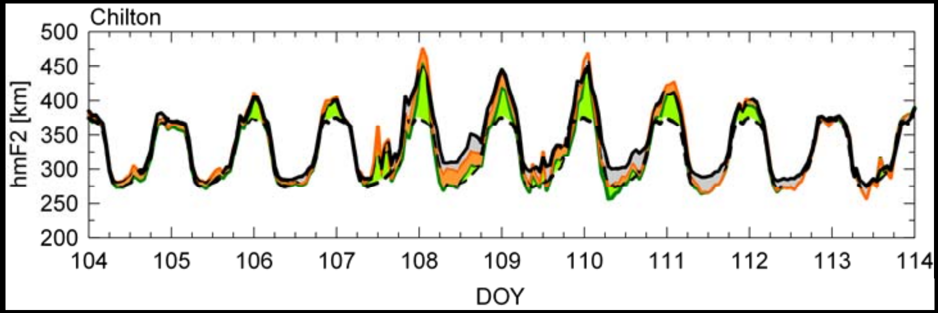
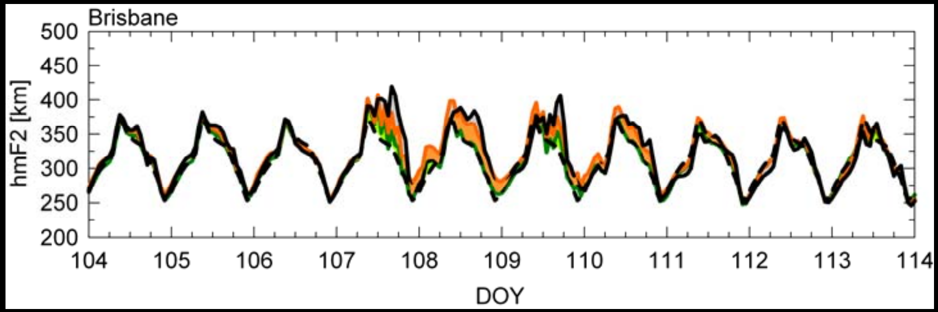


Australian Sector



Summary

- Horizontal winds and thermal expansion account for most of the F2 peak height changes at mid-latitudes during geomagnetic storms.

  Other mechanisms:

  - disturbance dynamo and prompt penetration e-fields
  - divergence winds
  - upwelling and downwelling modifying the O/N2 ratio
  - interhemispheric flow
  - plasmaspheric flux tube refilling

  Uncertainties:

  - CTIPe neutral winds
  - constant of proportionality (α) computation

Summary (cont'd)

- Horizontal wind surge: plasma is pushed out of equilibrium, so continually attempts to return to its original height after the wind has abated.

- Thermal expansion effects: integrate over the duration of heating and cooling events.

- Both horizontal wind and thermal expansion processes contribute significantly to the F-region height changes during geomagnetic storms. Their relative importance will depend on the local time at the storm commencement, the spatial distribution of the energy at high latitudes, the storm intensity, development and recovery duration.

Acknowledgements

- UMLCAR DIDBase - ***Ionosonde data***
- IPS Radio and Space Services - ***Ionosonde data***
- NOAA NGDC Solar Terrestrial Physics Division - ***Ionosonde and Kp data***
- Scripps Orbit and Permanent Array Center (SOPAC***)*** - ***GPS data***
- Continuous Brazilian Monitoring Network ***(RBMC) -*** ***GPS data***
- The Johns Hopkins University Applied Physics Laboratory - ***GUVI data***
- GeoForschungsZentrum (GFZ) - ***CHAMP data***
- Dept. Aerospace Engin. Sciences (Univ. Colorado) - ***CHAMP data***
- World Data Center for Geomagnetism, Kyoto - ***SYM-H data***
- CDAWeb - ***IMF data***
- NASA/GSFC/SPDF/Modelweb - ***IRI 2001***

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