The Abdus Salam International Centre for Theoretical Physics

United Nations Educational, Scientific and Cultural Organization

IAEA International Atomic Energy Agency

2025-26

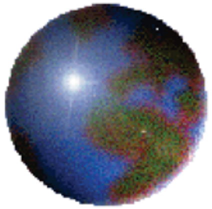
Satellite Navigation Science and Technology for Africa

23 March - 9 April, 2009

The Ionosphere and Effects on GNSS

Doherty Patricia

Institute for Scientific Research Boston College
St. Clement's Hall, 140 Commonwealth Avenue
CHESTNUT HILL MA 02467-3862
Massachusetts
U.S.A.



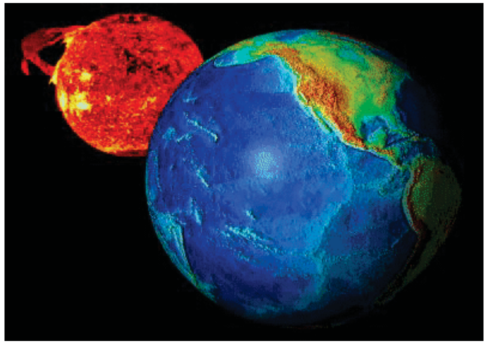
Ionospheric Effects on GNSS

Patricia H. Doherty
Boston College

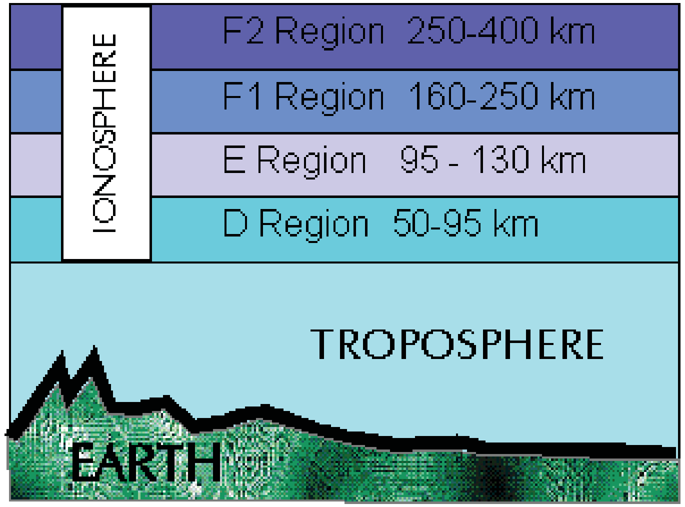
Prepared for the Satellite Navigation Science and Technology for Africa Workshop April 6, 2009 ICTP, Trieste, Italy

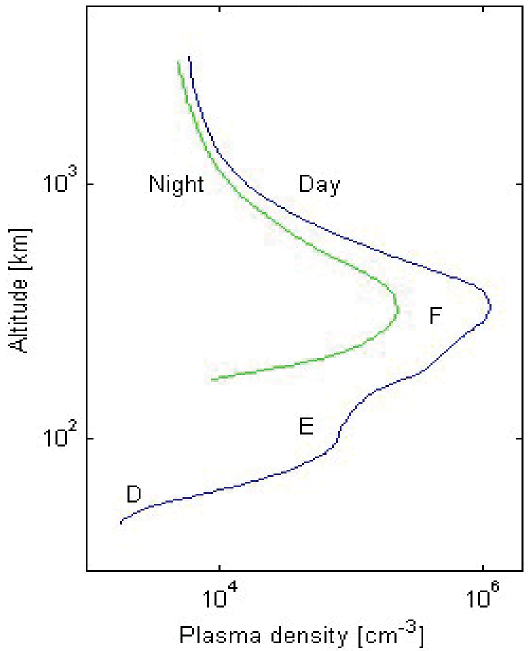
Outline

- What is the Ionosphere?
- Worldwide Ionosphere Characteristics
- Ionospheric Effects on Radio Waves
  - Range Delay
  - Amplitude and Phase Scintillation
- Mitigation of Ionospheric Effects
- Summary



What is the Ionosphere?





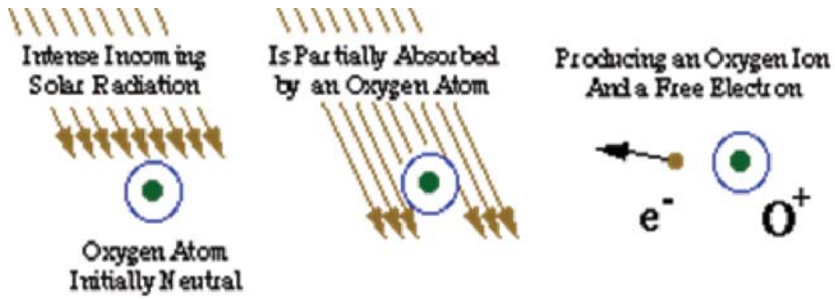
F Layer is most dense and highly variable.

The region of the atmosphere in which free electrons exist in sufficient quantities to affect the propagation of radio waves.

•Begins at about 50km and extends into space

•Produced by UV radiation from the Sun

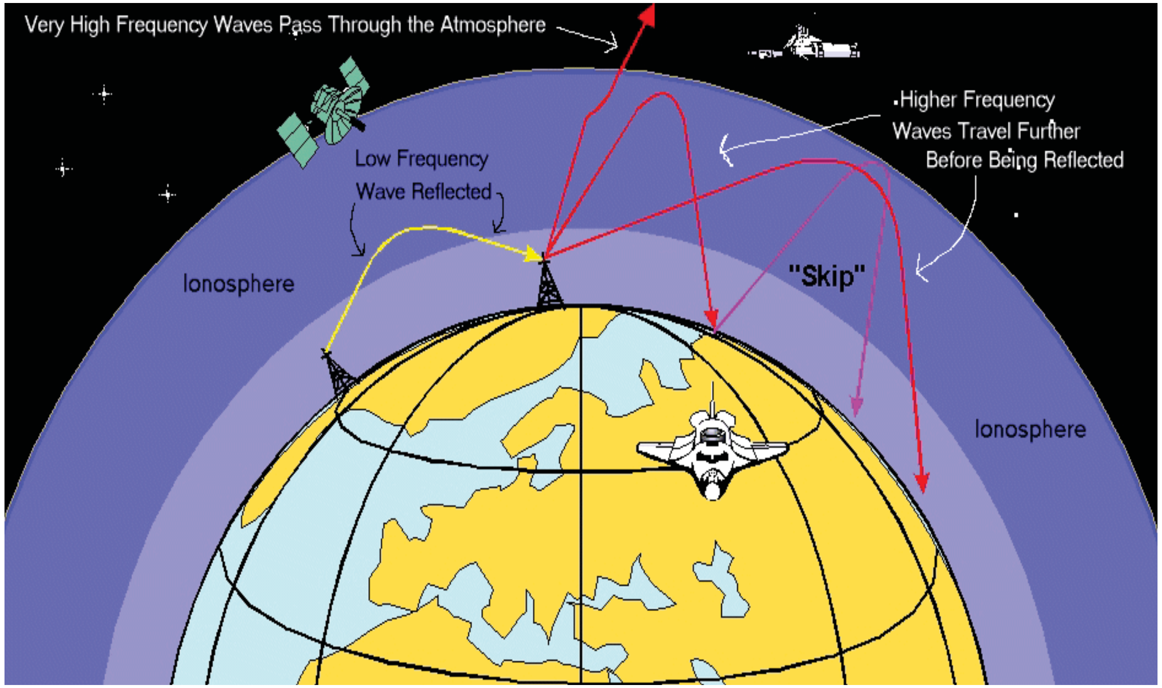
Photoionization



•Reverse process is ***Recombination***

•Controlled by chemical composition and transport by neutral winds

Ionospheric Effects on Radio Waves



• **On frequencies below~30MHz, the ionosphere bends path traveled by the radio wave back toward earth, allowing long distance communication.**

• **At much higher frequencies, radio waves passes right through the ionosphere.**

•**The speed of the signal is dependent on the density of electrons in the ionosphere.**

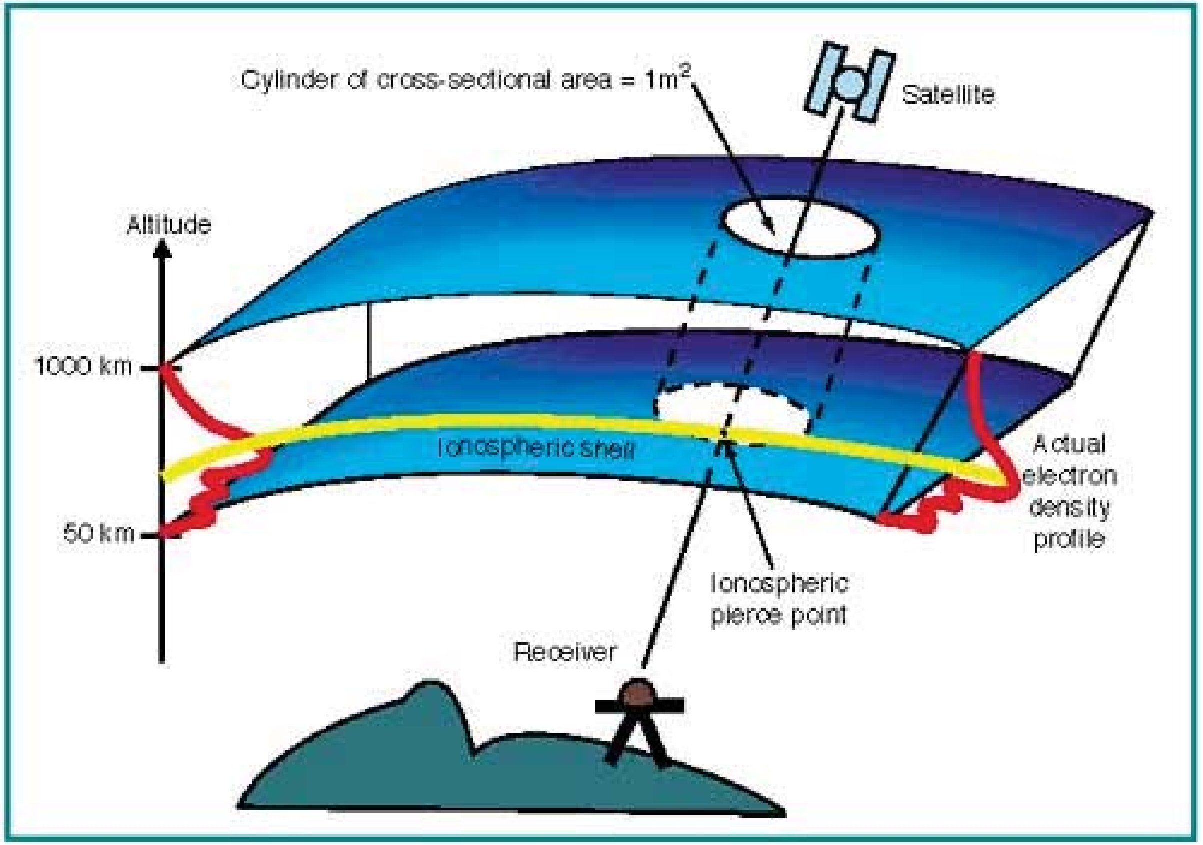
Ionospheric Effects on GPS

- Major ionospheric effects on GPS
  - Range Error
    - Due to a change in the speed of the signal
    - Mainly due to Total Electron Content (TEC)
    - Directly proportional to TEC

$$\text{Range Error} = \pm 40.3\ \text{TEC/f2 (in meters)}$$

    - Measured as:
      - Group Delay of the signal modulation (absolute range error)
      - Carrier Phase advance (relative range error)
  - Scintillation
    - Due to rapid fluctuations in the signal amplitude and phase
    - May induce loss of lock

Total Electron Content (TEC)



(Figure Courtesy of R. Langley)

Ionospheric Corrections

- **Single Frequency GPS Ionospheric Correction Algorithm (ICA)**
  - **developed in mid 1970's (Klobuchar)**
  - **corrects of ~50% of the ionospheric range error (works best at mid latitudes)**

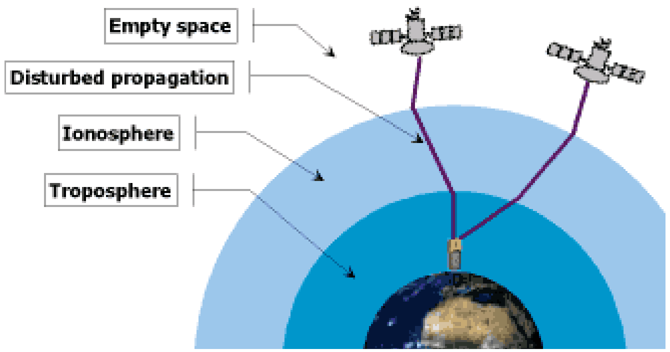
- **Dual Frequency GPS corrections yield absolute TEC calculations**

$TEC = 1/40.3 * (1/f1^2 - 1/f2^2)^{-1} * (P1-P2)$

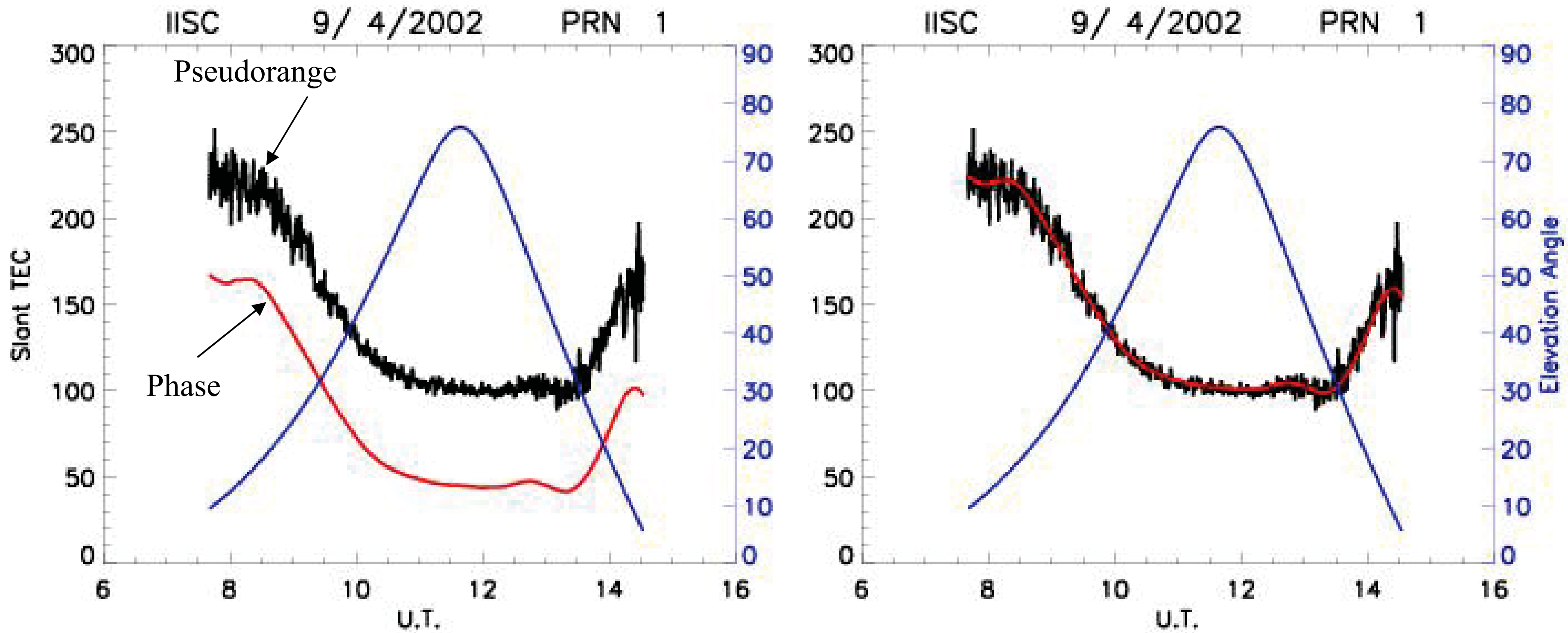
f1=1.575GHz

f2=1.227GHz

P1 and P2=pseudorange observables



Leveling Phase to Pseudorange

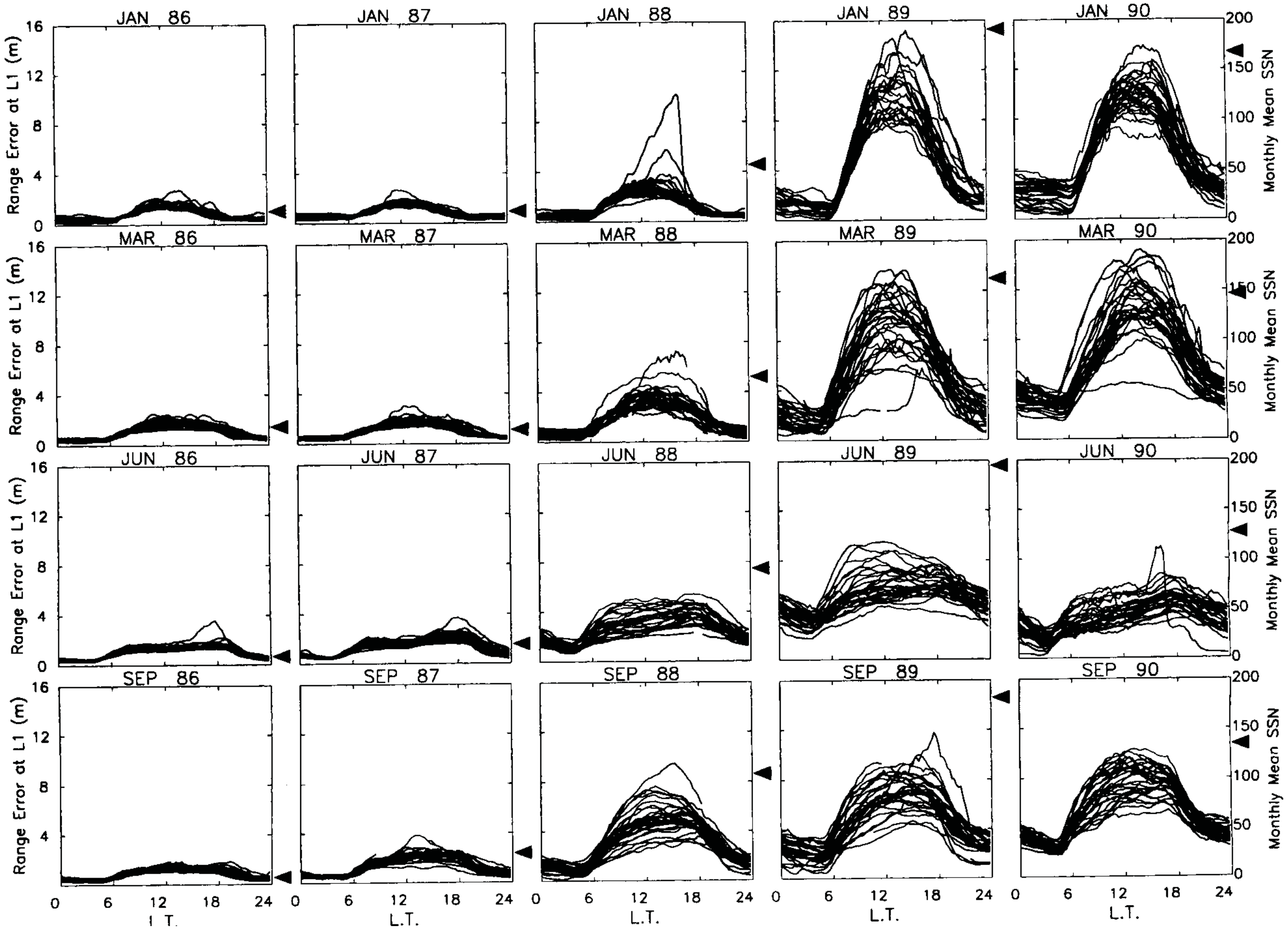


Pseudorange measurement is very noisy and susceptible to multipath – but it's an absolute measurement.

Phase measurement is very precise and not susceptible to multipath – but it's only a relative measurement.

Phase leveled to pseudorange with an arithmetic mean fit at elevation angles over 15 degrees.

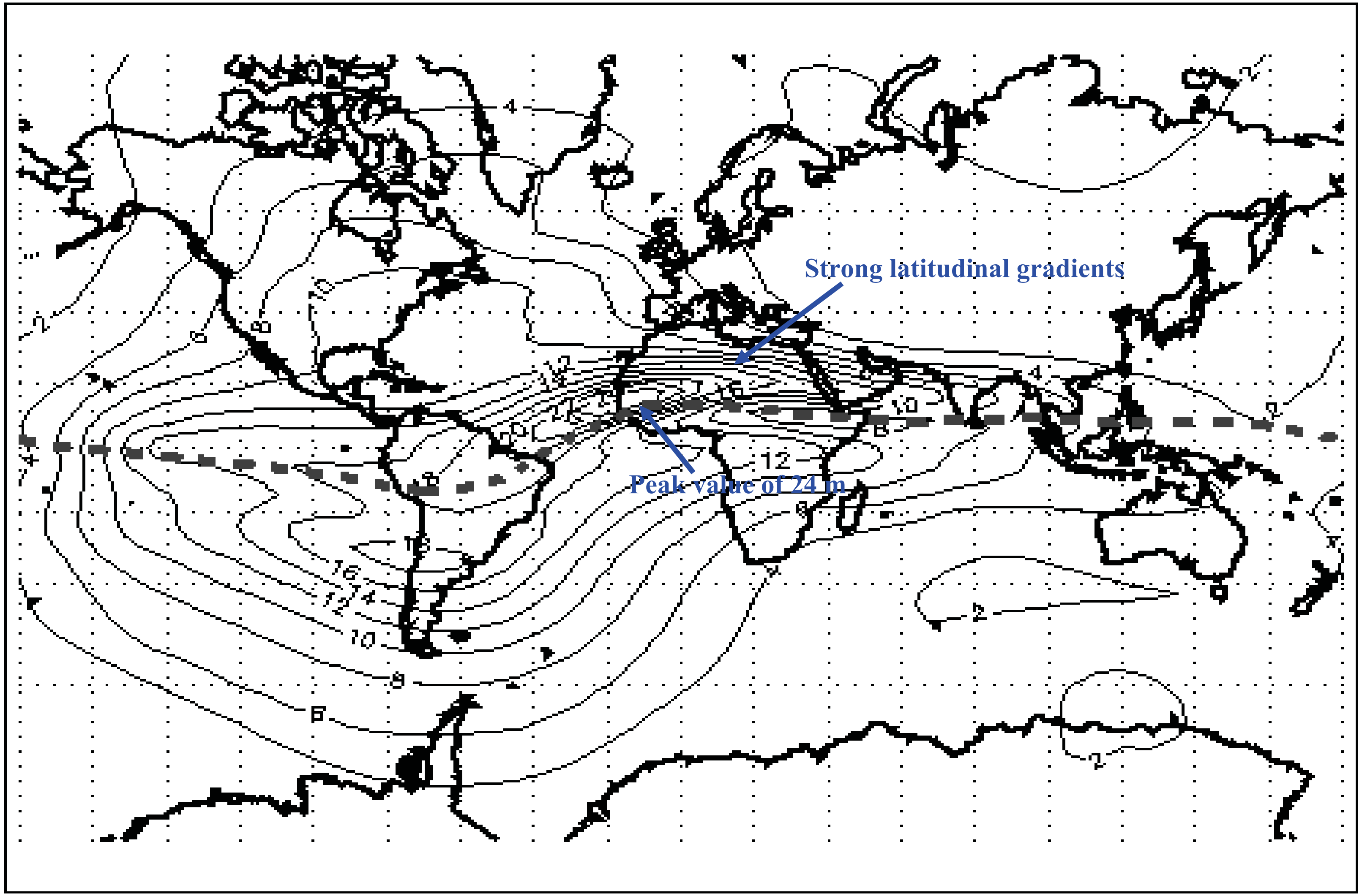
Ionospheric Variability and TEC



Ionospheric TEC varies with local time, solar activity, season, geomagnetic activity levels and geographic location.

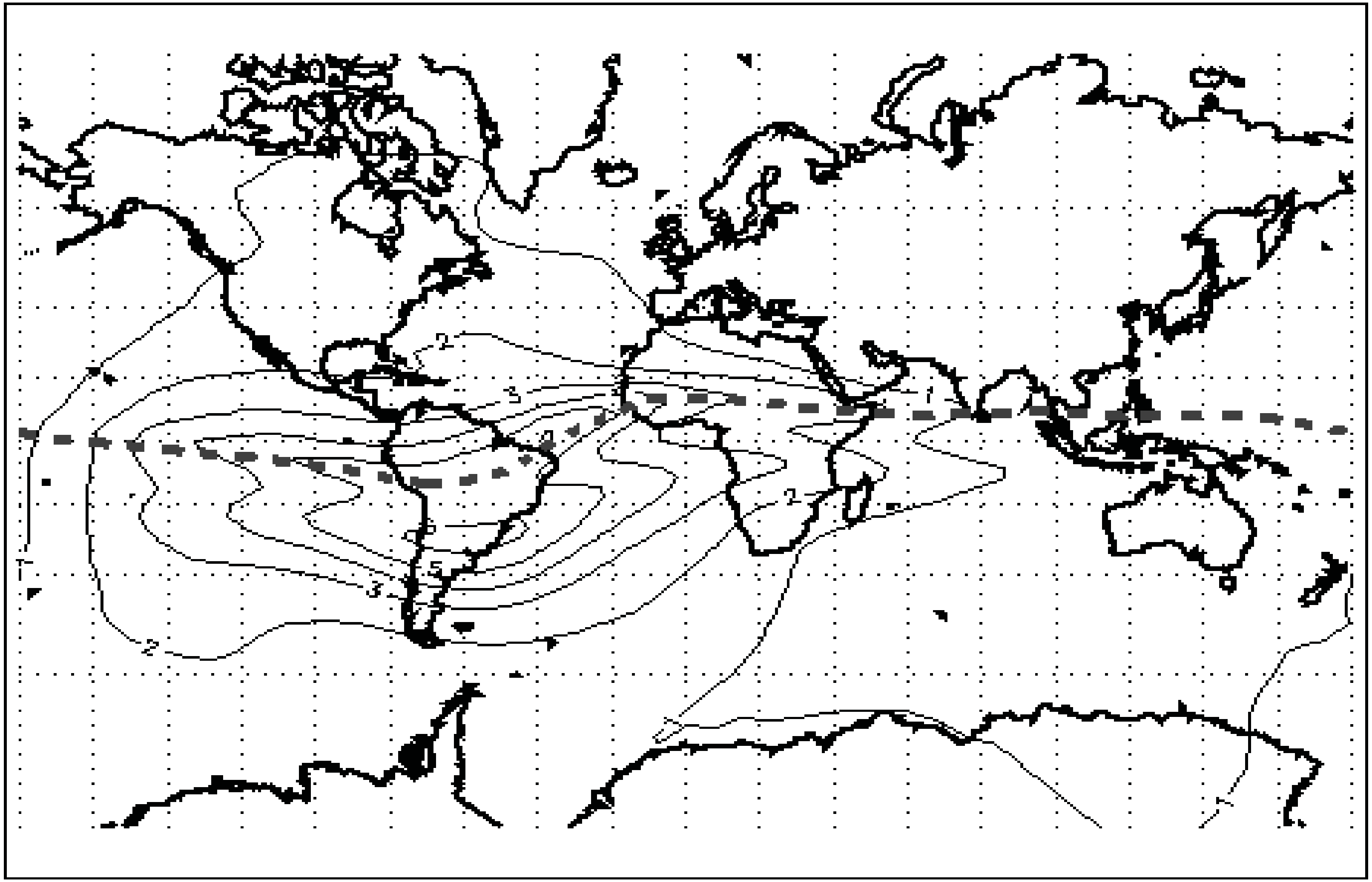
Range Error at L1 (m) - from PIM Model
Solar Maximum/January   Universal Time = 18 hrs

Solar Maximum



Range Error at L1 (m) - from PIM Model
Solar Minimum/January   Universal Time = 18 hrs

Solar Minimum



The Formation of the Equatorial Anomaly

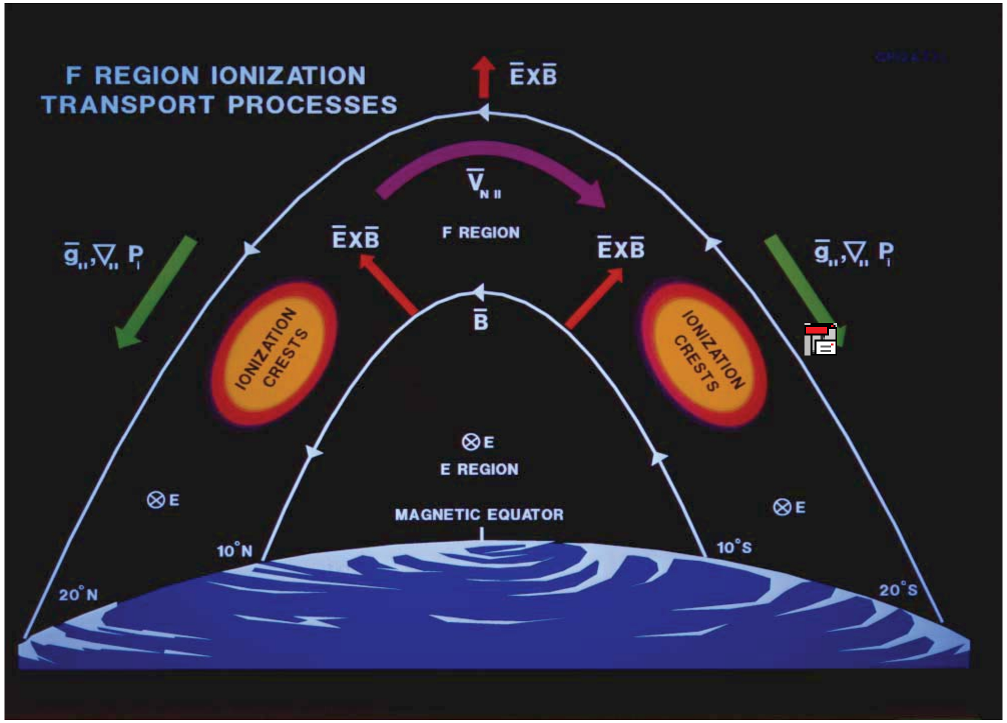


Figure Courtesy of Dave Anderson, NOAA

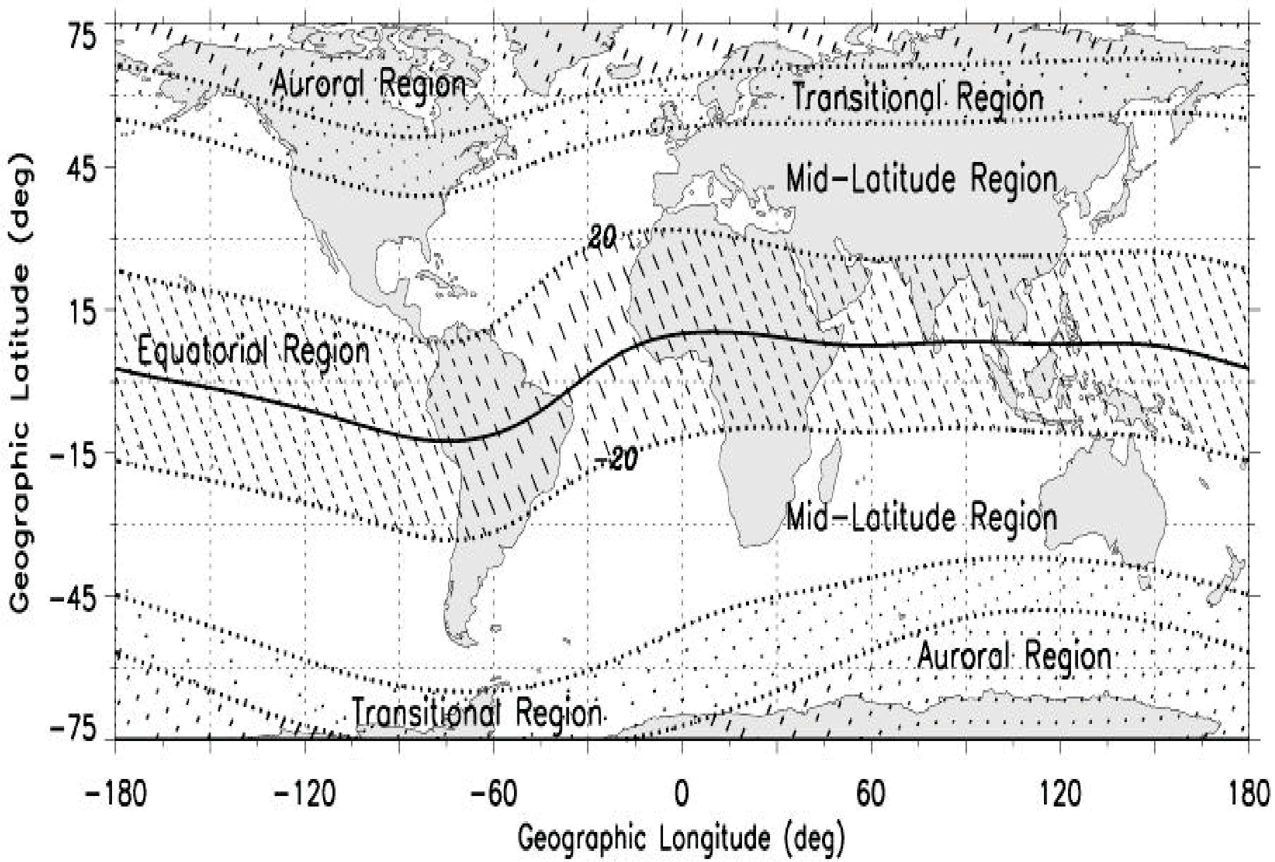
- Vertical drift velocities lift the F-region plasma to higher altitudes over the magnetic equator
- Pressure gradients and gravity force the heightened plasma downwards along magnetic field lines
- Strength of the drift velocities is highly variable

Ionospheric Regions of the World

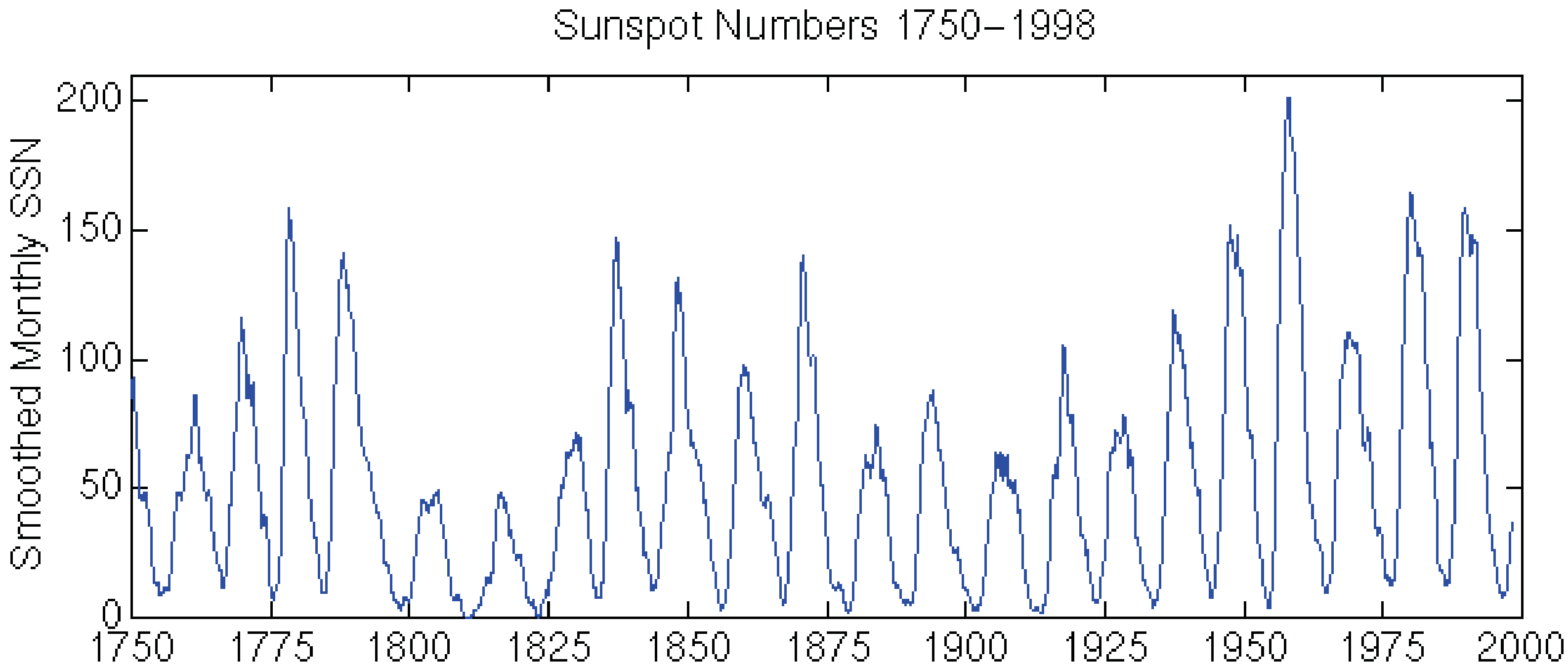
Equatorial latitudes: strongest effects, scintillation and bubbles limited to post-sunset and pre-midnight, scintillation seasonally dependent, not correlated with magnetic activity

Mid-Latitudes: rare scintillation, only during extreme levels of geomagnetic activity

Auroral latitudes: scintilation related to geomagnetic activity, less intense than low latitude effects

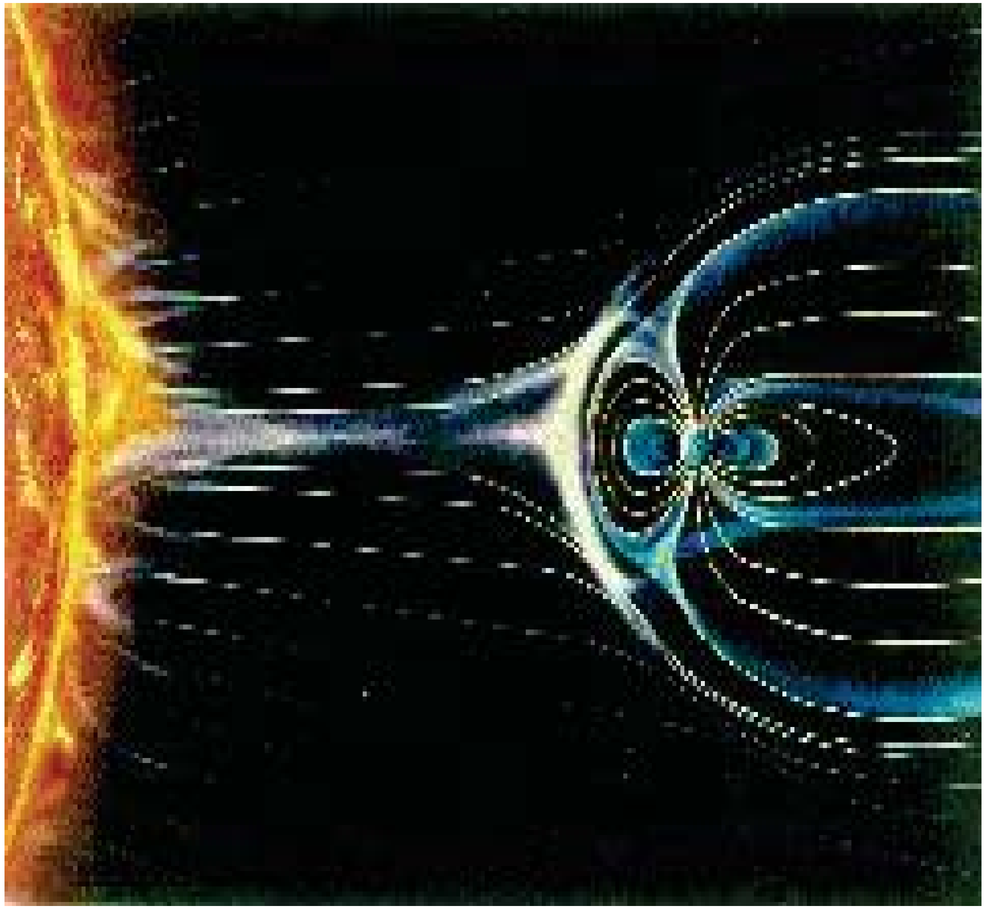


The Solar Cycle



Increase in geomagnetic storms during declining solar cycle

Magnetic Storm Effects



Auroral regions expands poleward and equatorward

Storms may induce strong spatial gradients in TEC

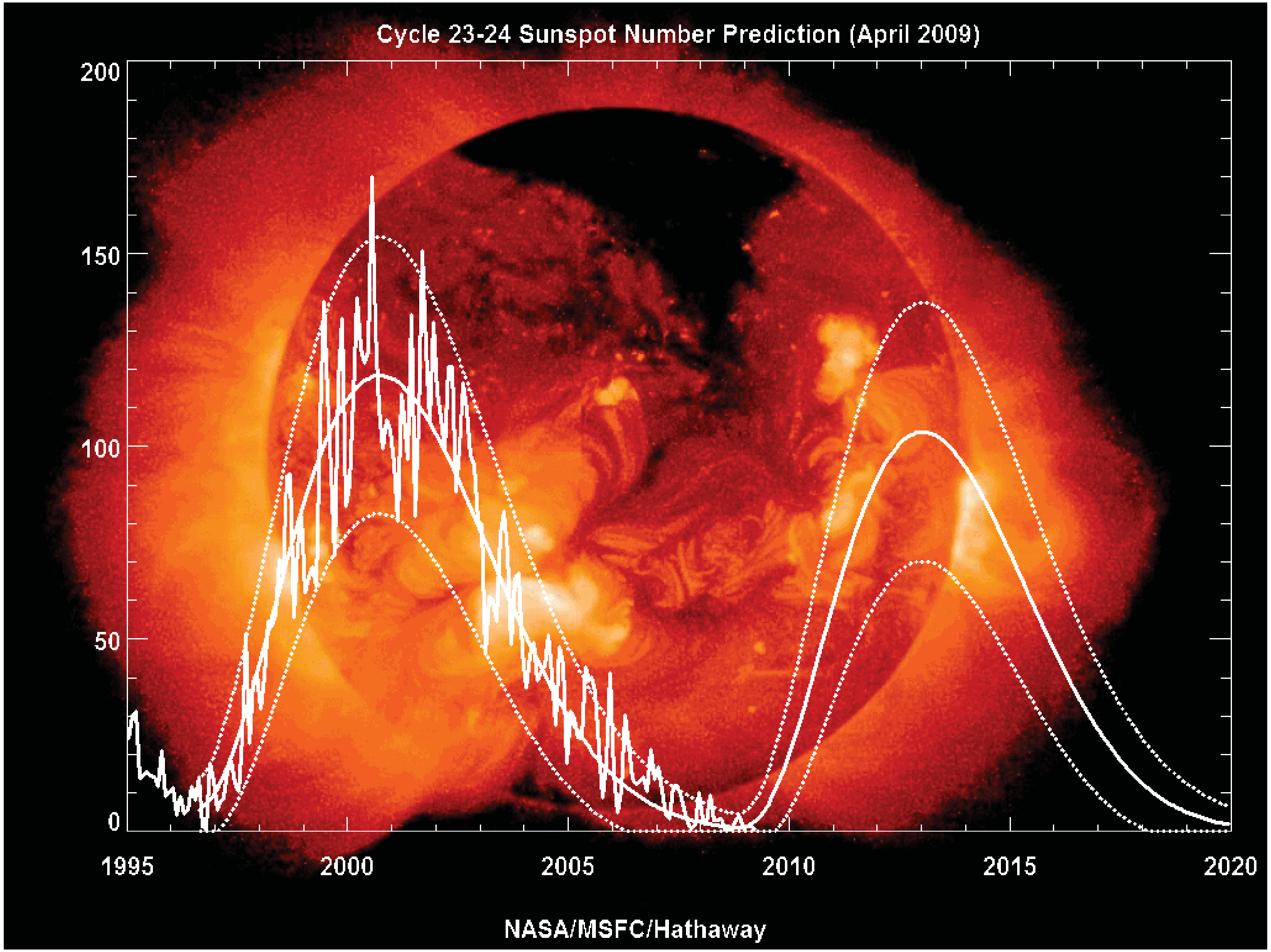
Storms may induce rapid fluctuations in the carrier phase and in the amplitude of the signals

Results in poor positioning capability

Summary

- Ionosphere can be a great source of error for GPS positioning
- Ionosphere varies by local time, season, geographic location, magnetic and solar activity
- Major effects on GPS are Range Error and Scintillation
- Range Error is best mitigated with a 2 frequency receiver
- Low latitude regions and magnetic storm periods are most problematic

Solar Cycle 24 – A Slow Start



Useful Numbers for GPS

Current GPS frequencies are L2 = 1.22760 GHz and L1 = 1.57542 GHz

GPS modernization efforts call for two new civil signals: a C/A-coded signal on L2 and a third civil signal on L5 at 1.17645 GHz. The civil signal on L1 will remain unchanged.

GPS data can be expressed as:

TEC units (1 TEC unit = 1 x 10^{16} el/m^2)
meters at L1
nanoseconds at L1
differential nanoseconds (L1-L2) or (L2-L1)

1 TEC unit:
= .351 nanoseconds of differential delay
= .542 nanoseconds of delay at L1
= .163 meters of range error at L1
= .853 cycles of phase advance at L1

1 nanosecond of differential code delay:
= 2.852 TEC units
= 1.546 nanoseconds of delay at L1
= 0.464 meters of range error at L1

1 nanosecond of delay, measured at L1:
= 1.8476 TEC units
= 0.300 meters of range error at L1

1 meter of range error:
= 6.15 TEC units (measured at L1)
= 3.73 TEC units (measured at L2)

(Courtesy of J. Klobuchar)