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Radar interferometry: Ionospheric Correction Models

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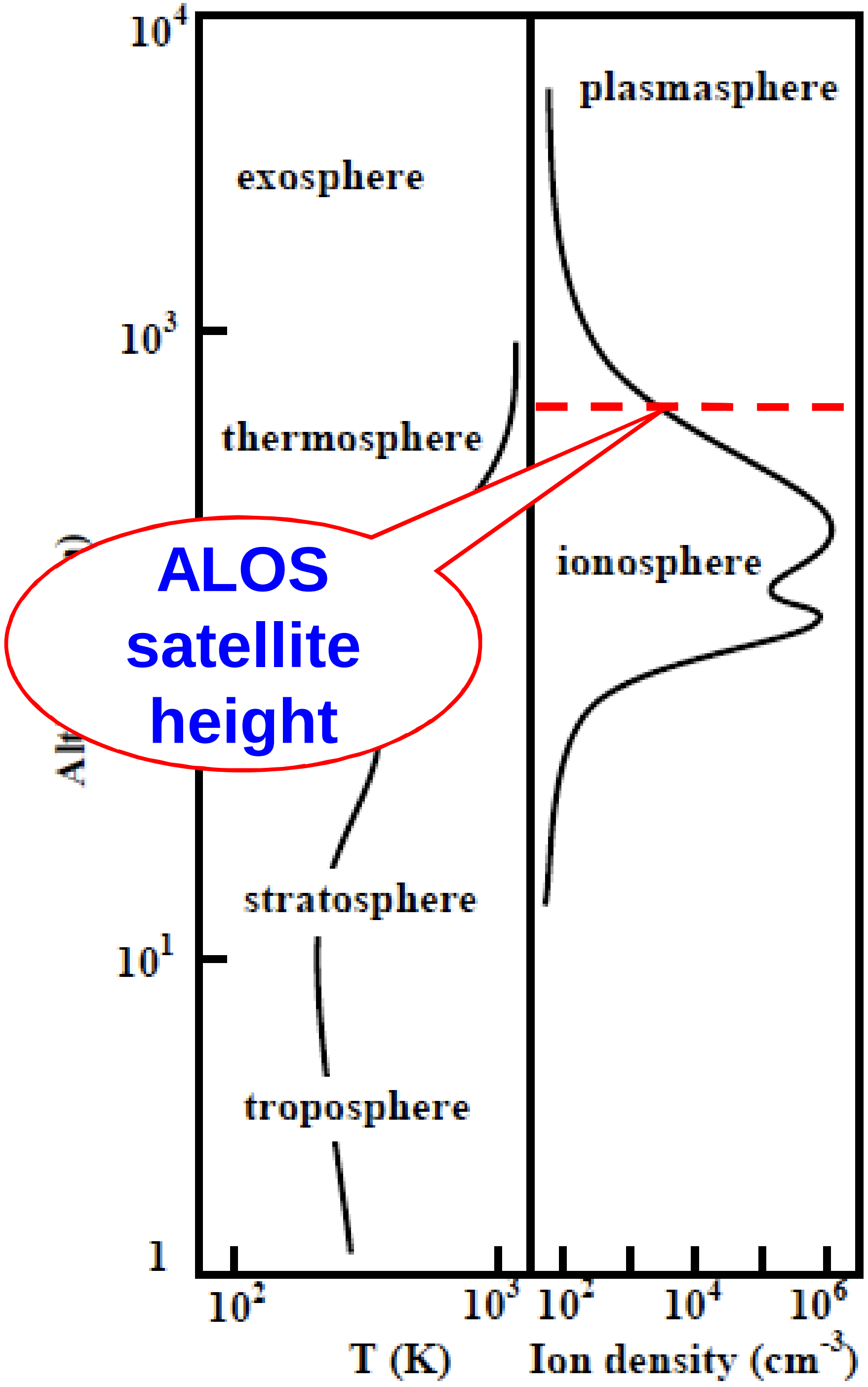

Schematic structure of the atmosphere

- Ionosphere extends from 50 km to 1500 km
- The ion density increases with altitude to a certain height and then decreases
- Radar signals travel through most of the ionosphere…

Main types of Ionospheric Effects

- **Total Electron Content (TEC)**

$$TEC = \int n_e ds$$

- **Phase advance (delay)**

$$\phi = -\frac{40.28}{f^2}\int_{\mathbf{r}_t}^{\mathbf{r}_r} n_e ds = -\frac{40.28}{f^2} STEC$$

Slant range
Total Electron Content
(STEC)

- Faraday Rotation (function of Earth's Magnetic Field, electron density, and frequency)

$$\Omega = \frac{K}{f^2}\int_{\mathbf{r}_t}^{\mathbf{r}_r} n_e B_0 \cos\theta ds$$

- Phase and Amplitude Scintillation (Random Fluctuations)

Note: For more details for the latter two, please refer to *(Pi et al., 2011, JGR)* & *(Meyer et al., Fringe workshop 2007)*

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GPS for mapping TEC

- **Phase observation equations:**

$$\rho = \lambda_1\varphi_1 + N_1\lambda_1 + \delta_{ion} = \lambda_1\varphi_1 + N_1\lambda_1 + 40.28 \cdot f_1^{-2} \cdot TEC$$

$$\rho = \lambda_2\varphi_2 + N_2\lambda_2 + \delta_{ion} = \lambda_2\varphi_2 + N_2\lambda_2 + 40.28 \cdot f_2^{-2} \cdot TEC$$

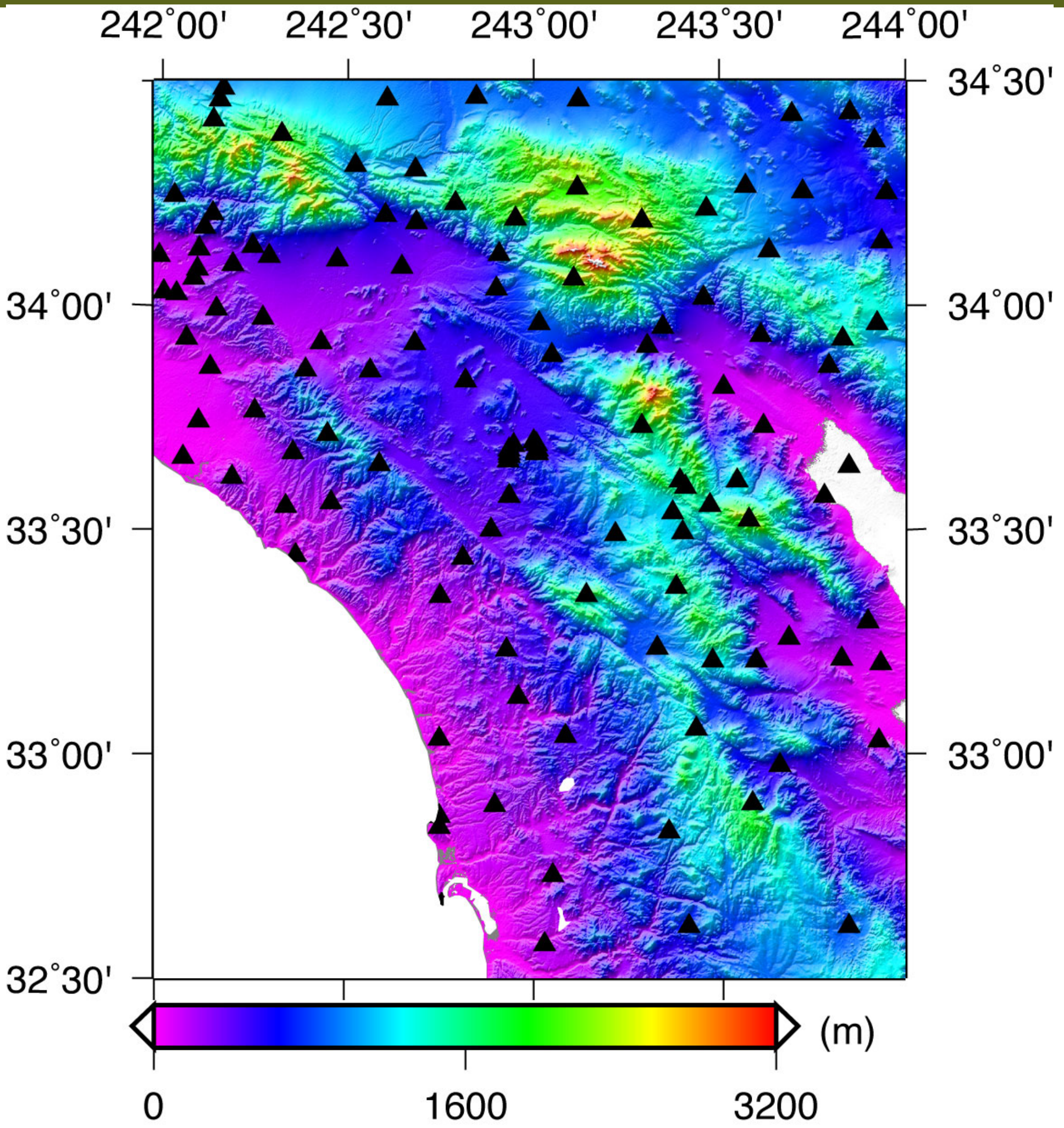
- **Differencing, we can rearrange for TEC:**

$$TEC = 9.52437(\textcolor{blue}{\lambda_1}(\textcolor{blue}{\varphi_1} + \textcolor{red}{N_1}) - \textcolor{blue}{\lambda_2}(\textcolor{blue}{\varphi_2} + \textcolor{red}{N_2}))$$

🔵 Known parameters / observations

🔴 Can be precisely estimated

Continuous GPS stations



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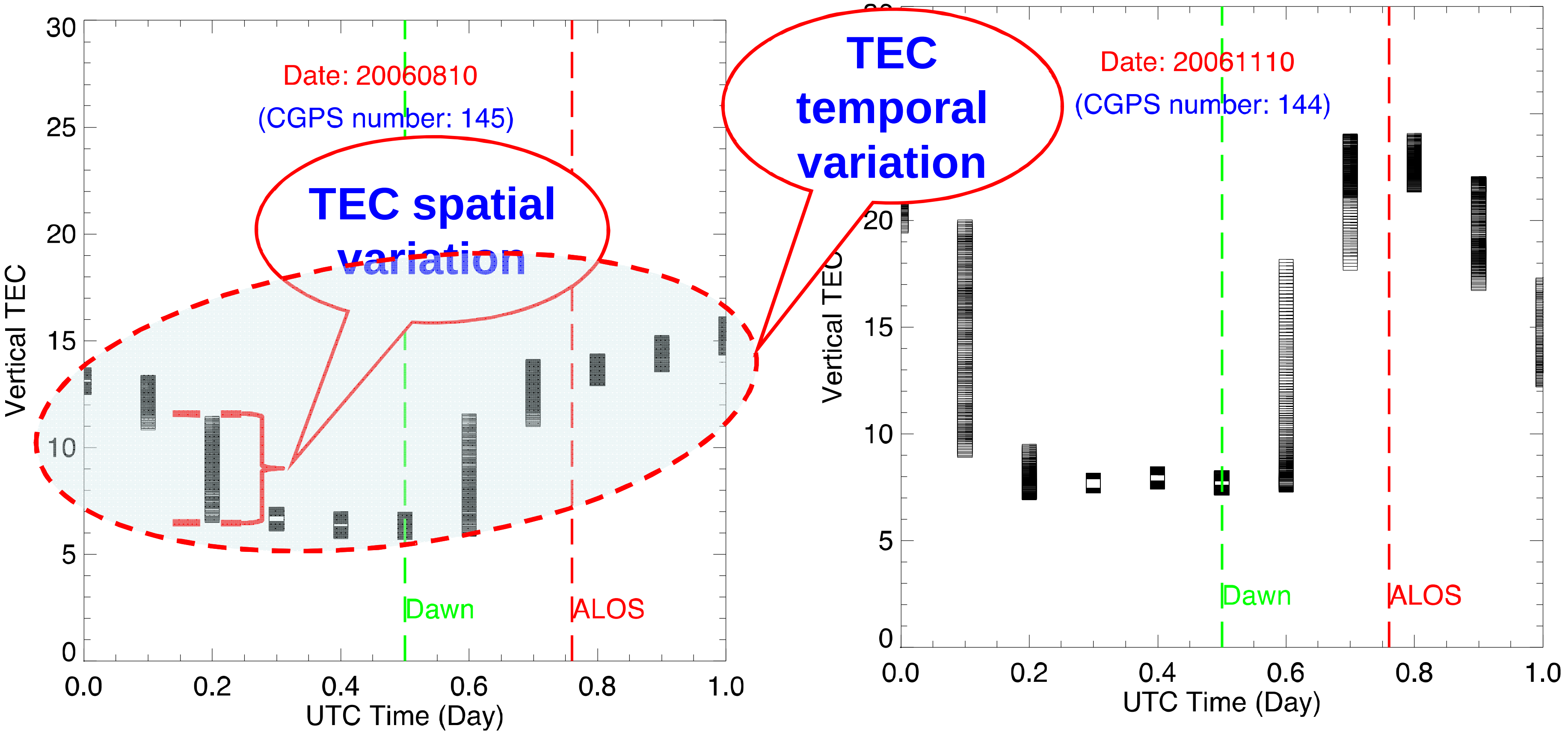
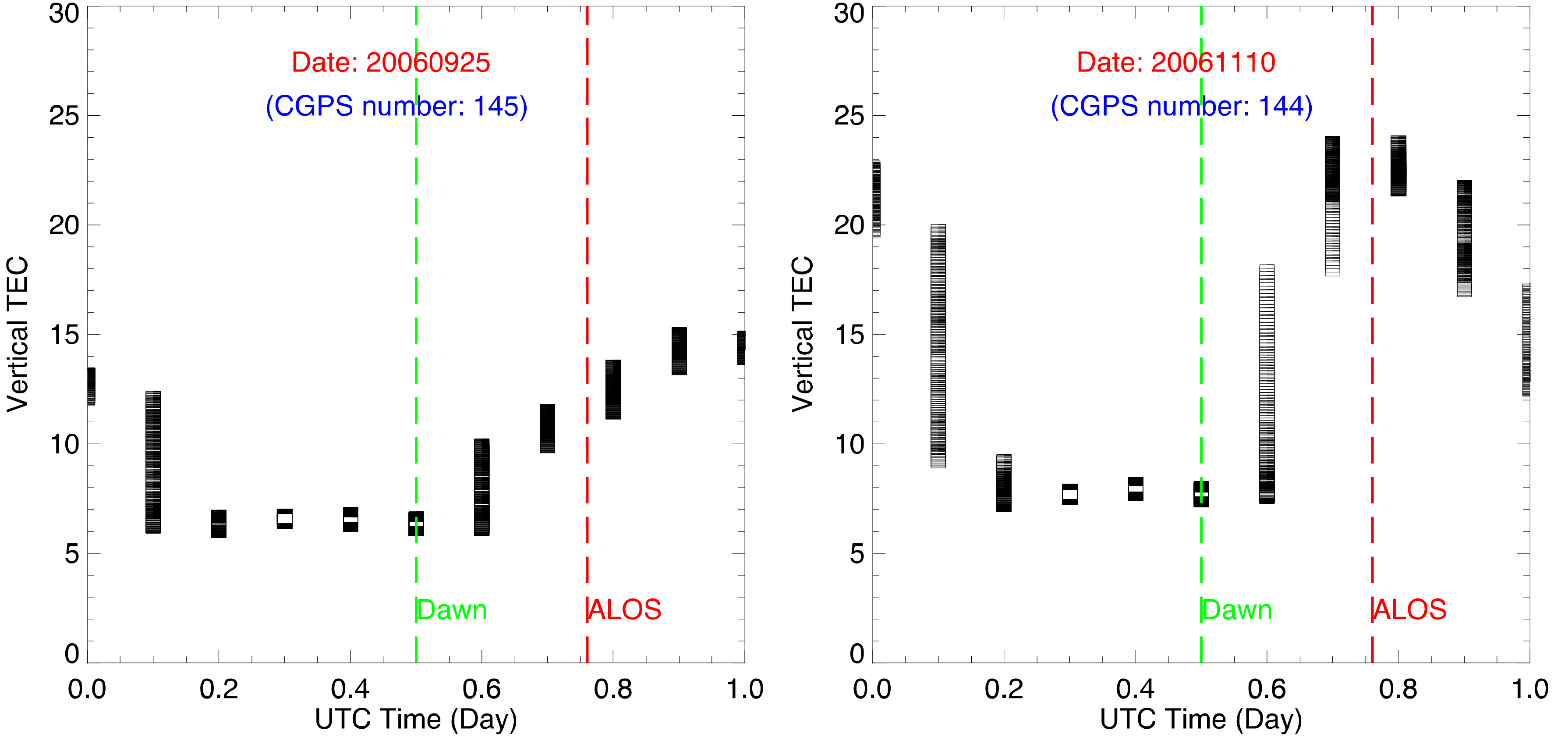
TEC daily spatio-temporal variations



N.B. Both show that TEC spatial and temporal variations are minimised at DAWN.

TEC daily spatio-temporal variations



N.B. Both show that TEC spatial and temporal variations are minimised at DAWN.

Properties of the Ionosphere

- Plasma irregularities scale lengths cover a wide range:
  (1 m – 1000 km)
- Particularly cause problems for GNSS applications.

Small scale (<10 km)	**Medium scale (~ 100 km)**	**Large scale (~1000 km)**
< 1 TECU	≈ 1 TECU	≈ 10 TECU

Meyer *et al.*, 2005

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Effects of Total Electron Content (TEC)

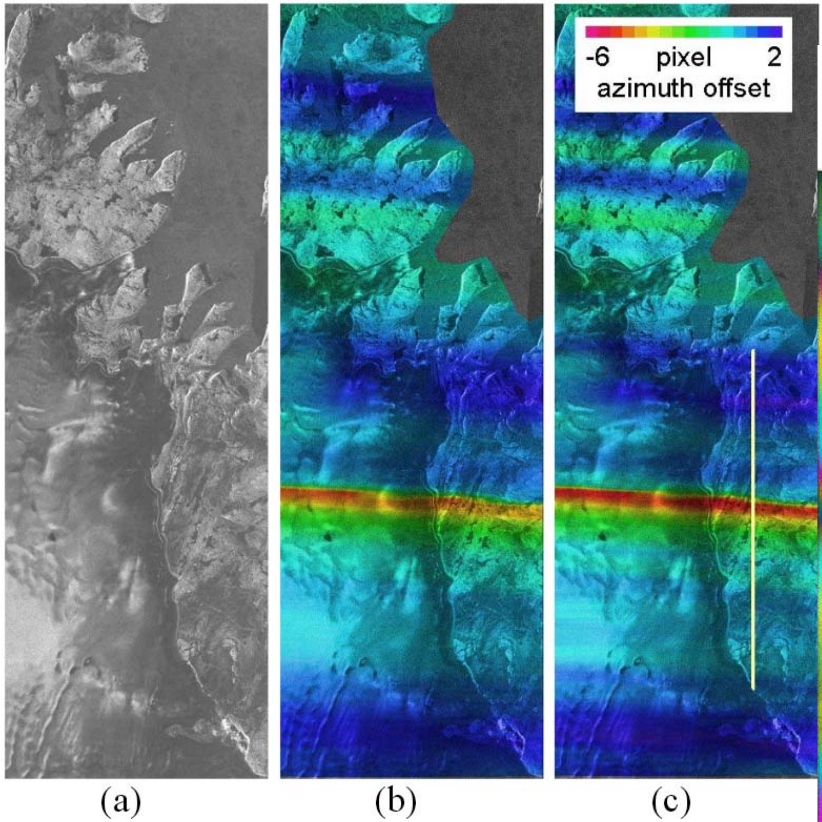
1 TECU (= 10^{16} electrons/m^2) corresponds to (one way)

λ (m)	***LOS range change* (m)**
C-band: 0.06	0.014
L-band: 0.24	0.250

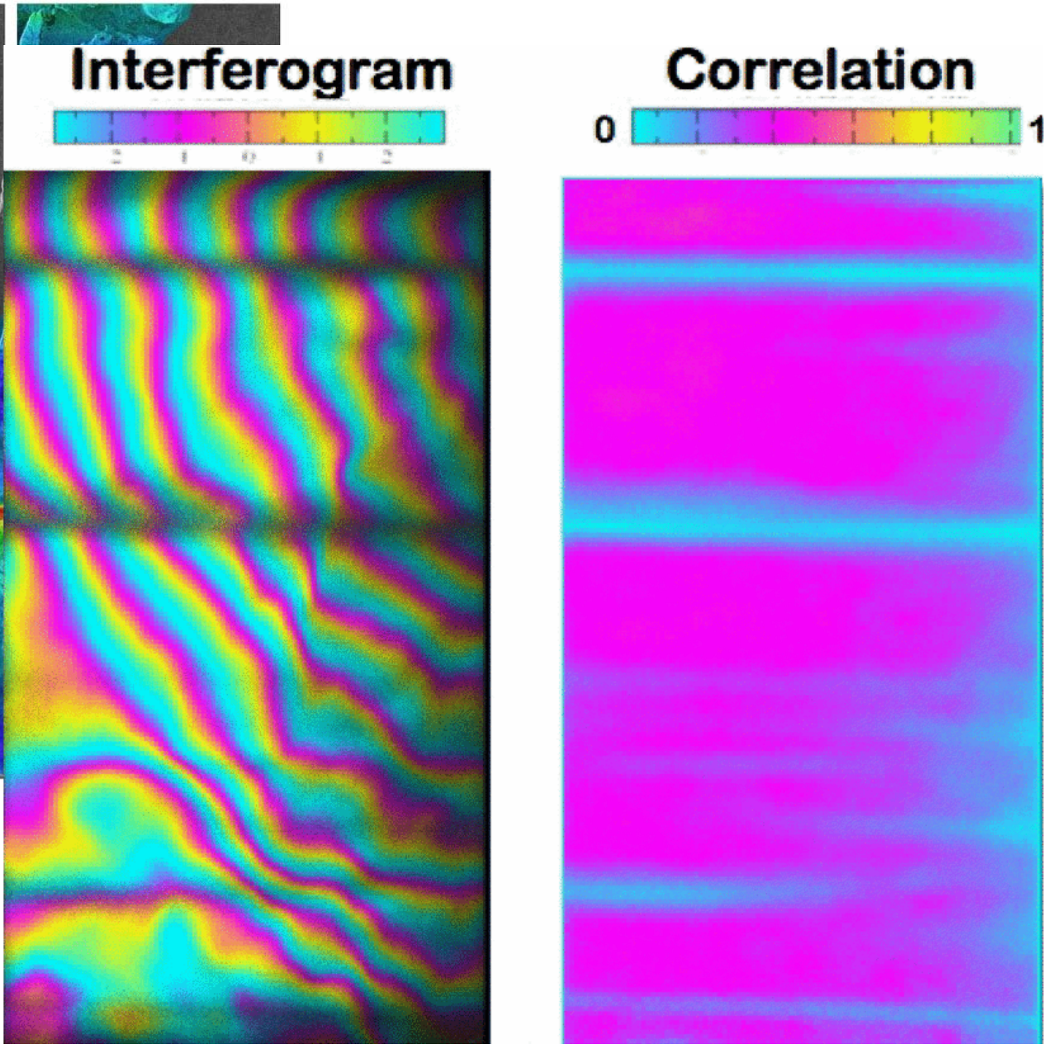
- L-band data is sensitive to ionospheric effects
  - 17 times greater than C-band
  - Effects between near and far range can be up to 2~25m range change in the satellite line of sight (Pi, 2006, JPL)

- Typical daytime TEC can reach 20 to ~100 TECU

Ionospheric effects on interferograms

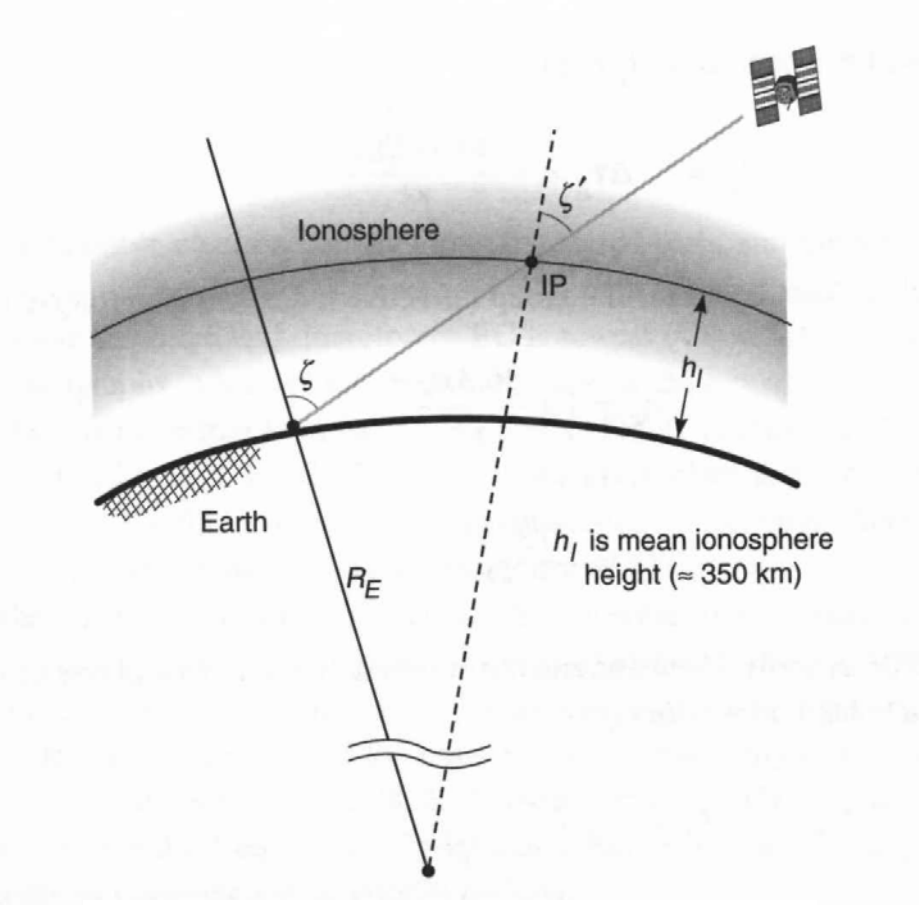


Wegmuller *et al.*, 2006



Rosen *et al.*, 2010

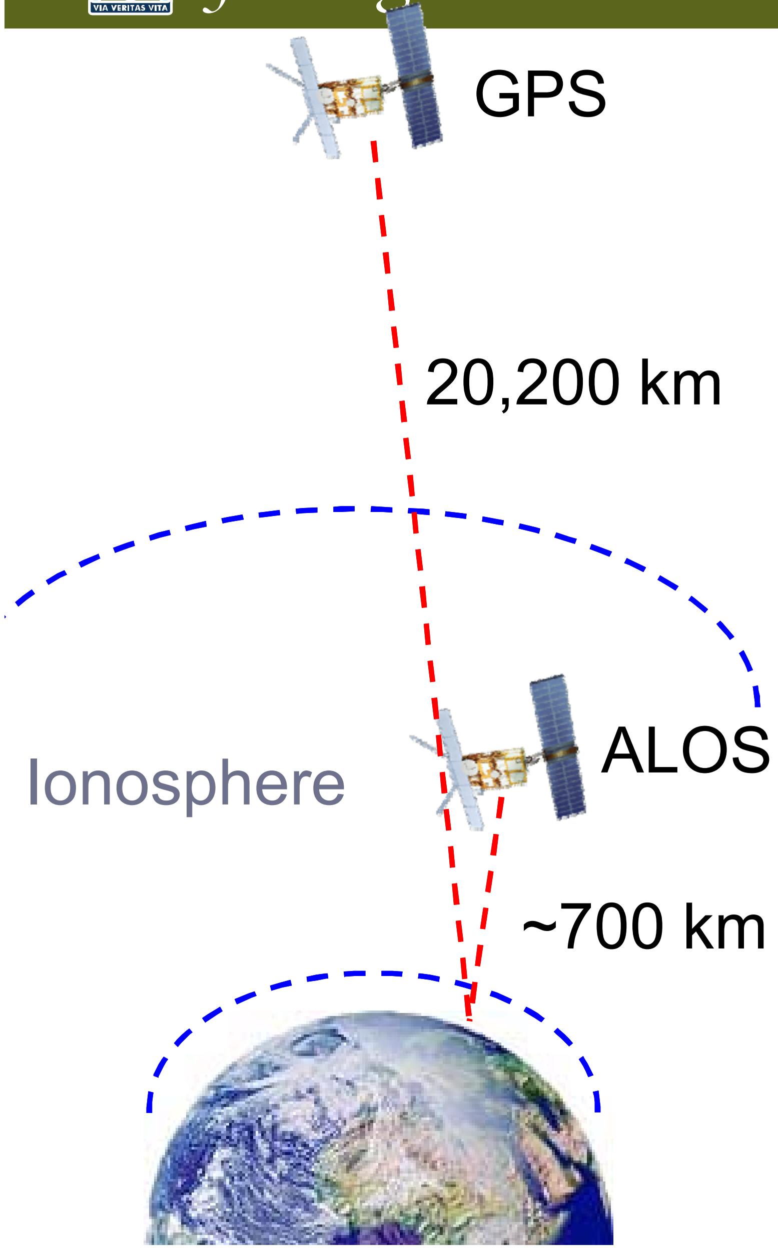
InSAR Correction? Troposphere vs Ionosphere



(from *Misra and Enge [2001]*)

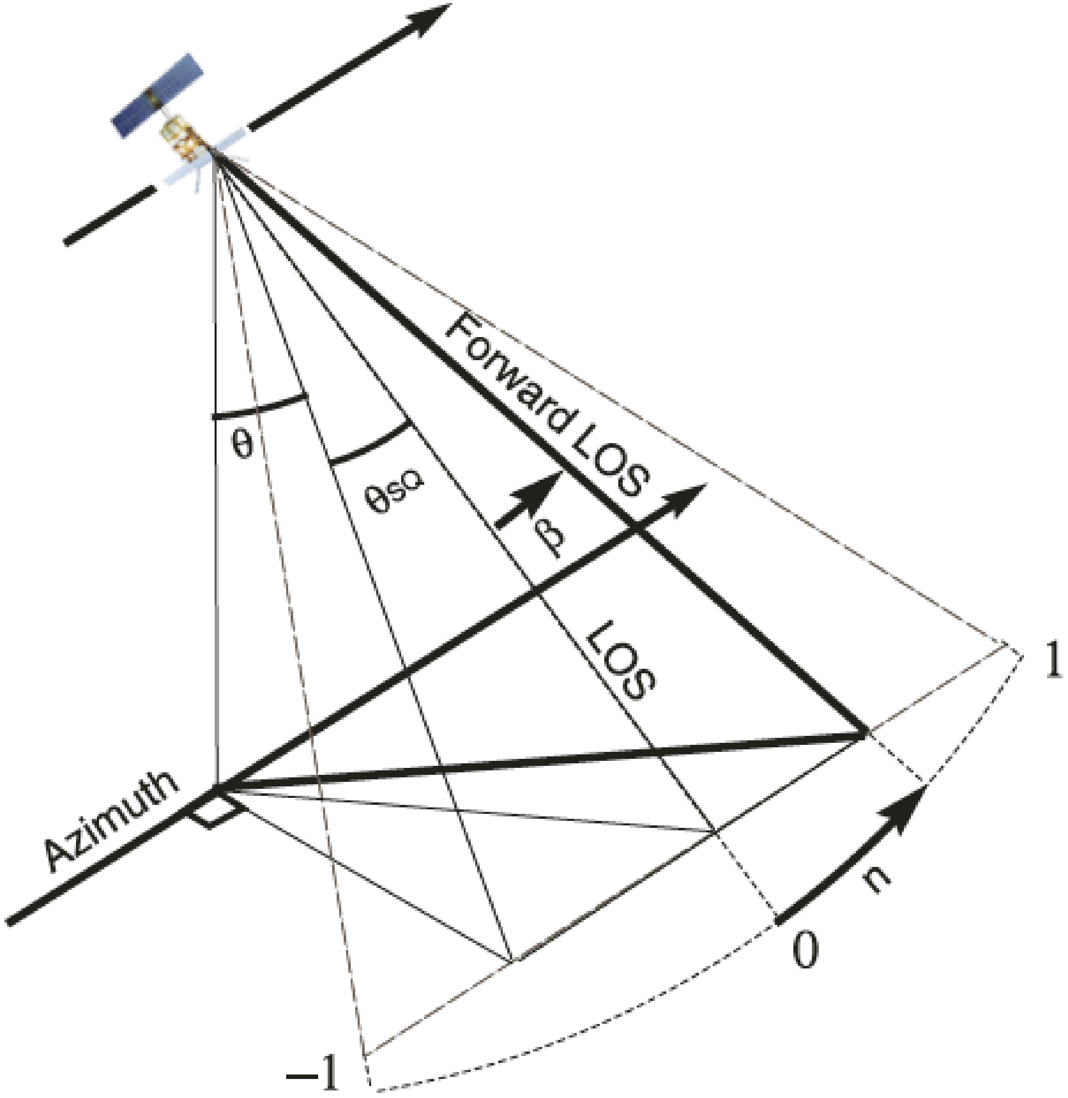
- Ionosphere is **thicker** than Troposphere – Mapping Functions **usable?**
- Frequency should be taken into account for Ionospheric correction
- No topography-dependent signals for Ionospheric correction

Geometry: GPS vs ALOS



	GPS	**ALOS**	**InSAR correction**
Iono delays	One way	Two ways	OK
Satellite height	20200 km	~700 km	Introduce a scale factor?
Line of sight	Vertical	Off-vertical	Mapping Function
Spatial resolution	A few km	10-20 m	?

Split-Spectral InSAR



Split-Spectral InSAR for mapping TEC

- **Phase observation equations:**

$$\begin{cases} \frac{\lambda_1}{4\pi}\phi_1 = D - 2 \times \frac{40.28}{f_1^2} \times TEC = D - 2 \times S_1 \times TEC \\ \frac{\lambda_2}{4\pi}\phi_2 = D - 2 \times \frac{40.28}{f_2^2} \times TEC = D - 2 \times S_2 \times TEC \end{cases}$$

- **Differencing, we can rearrange for TEC:**

$$\frac{\lambda_2}{4\pi}\phi_2 - \frac{\lambda_1}{4\pi}\phi_1 = -2 \times S_2 \times TEC + 2 \times S_1 \times TEC$$

$$TEC = \frac{\lambda_2}{4\pi \times 2 \times (S_1 - S_2)}\left(\phi_2 - \frac{\lambda_1}{\lambda_2}\phi_1\right)$$

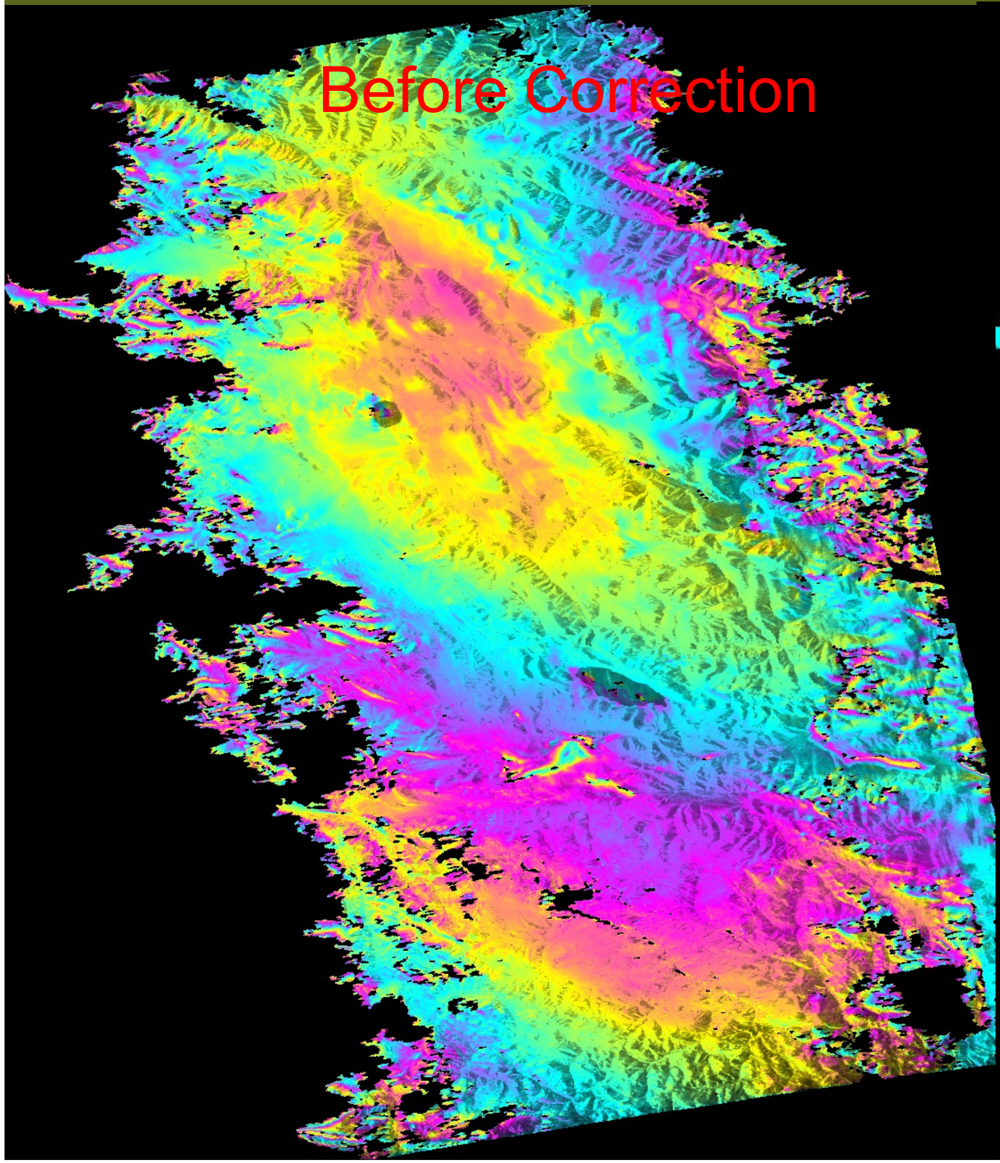
Estimation Issues

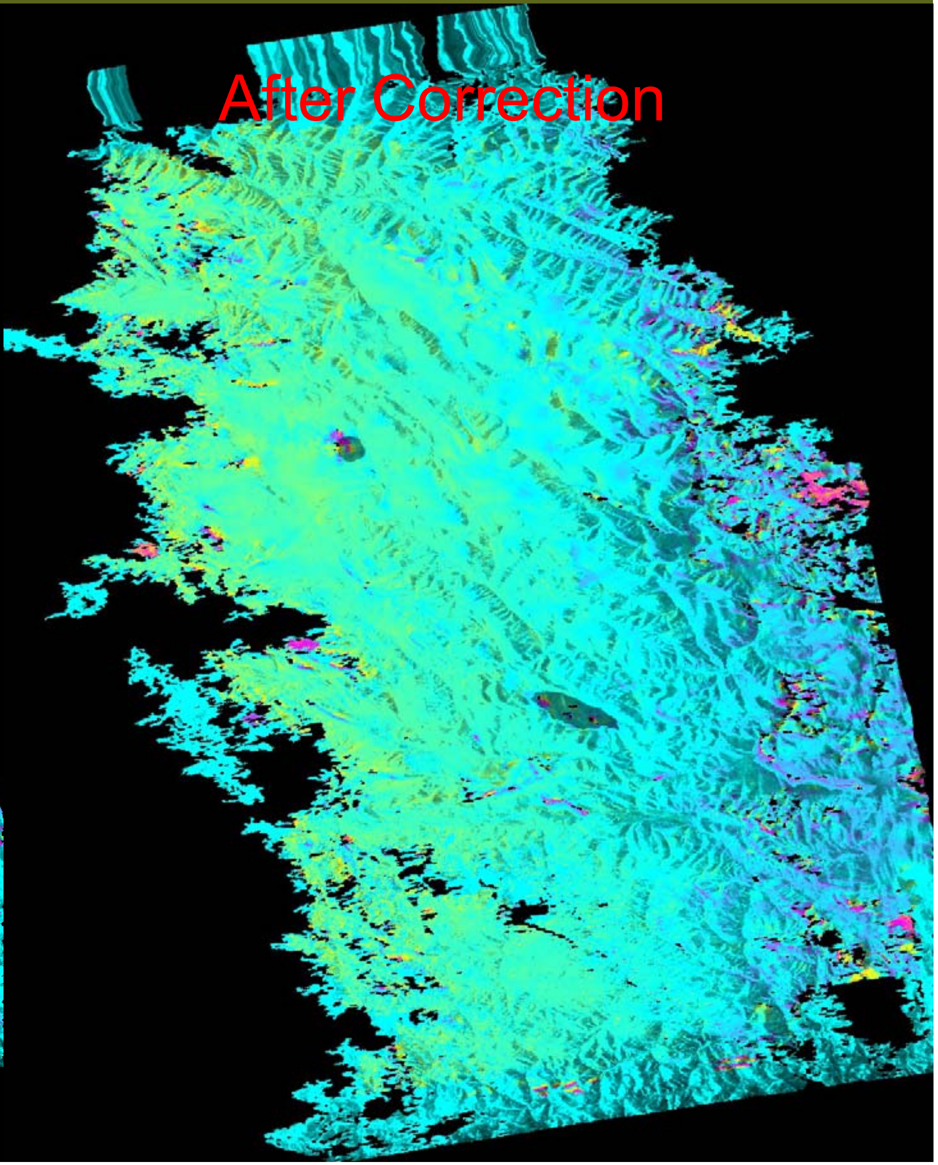
	ALOS	**Envisat**	**TerraSAR-X**
Centre frequency:	1.270 GHz	5.331 GHz	9.65 GHz
Chirp bandwidth	28 MHz	16 MHz	Up to 150 MHz
PRF	1500 – 2500 Hz	~ 1800 Hz	2000 – 6500 Hz

- Fringe variability should be sufficiently low, and the interferogram coherence should be sufficiently high (due to phase unwrapping requirements).

- The denominator involve differences of numbers that are nearly equal, so the phase differences are scaled up by a large factor amplifying the noise. Considerable smoothing is required to recover a usable signal.

Split-Spectral InSAR: case study


Before Correction


After Correction