Imaging Ionospheric Fine Structures Using Polarimetric SAR and GPS

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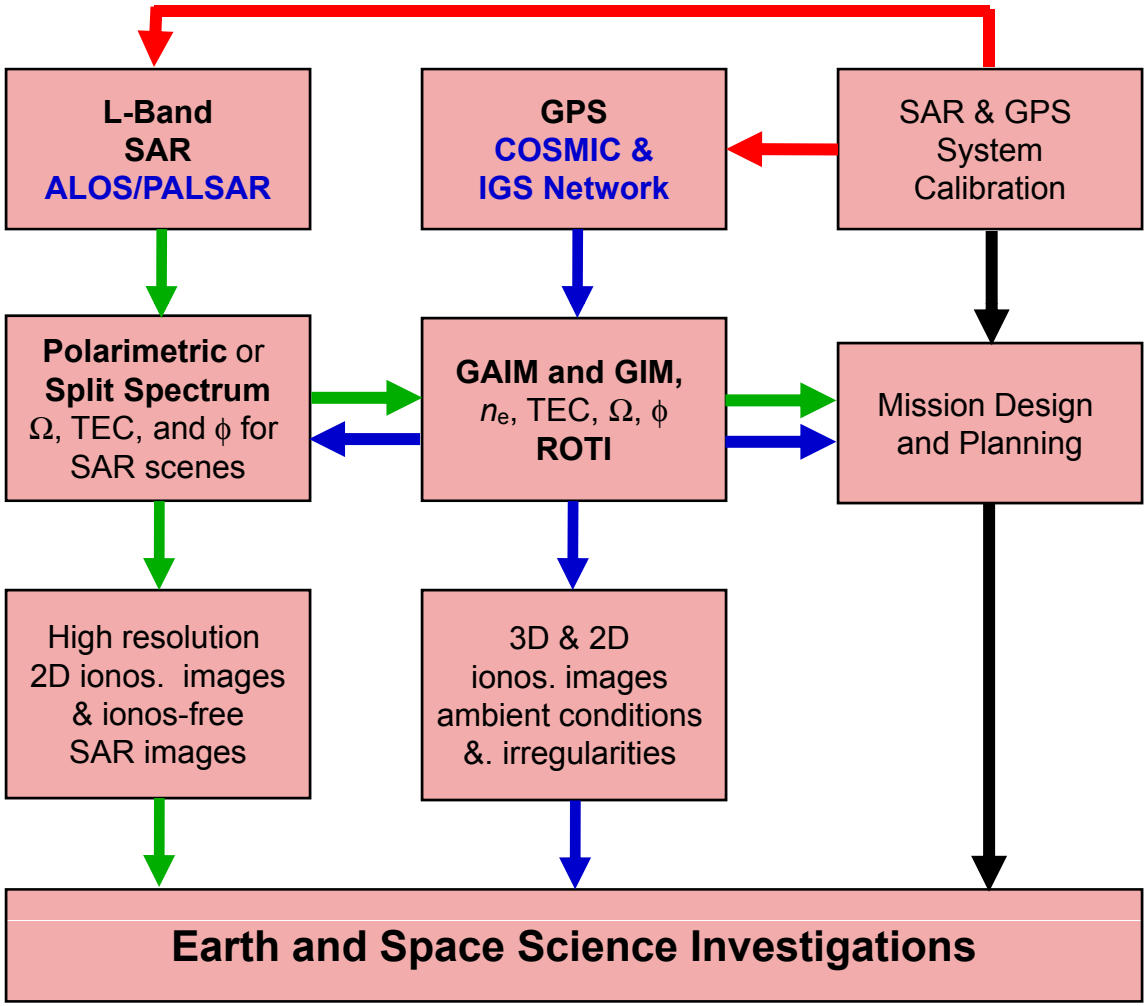
Introduction to ISSG

Ionospheric Specifications using SAR & GPS



Retrieving Faradar Rotation from Polarimetric SAR

Faraday Rotation:

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

n_e — electron density
B_0 — ambien mag. field
θ — angle between **k** and $\mathbf{B_0}$
K = 2.365×10^4 (in MKS units)

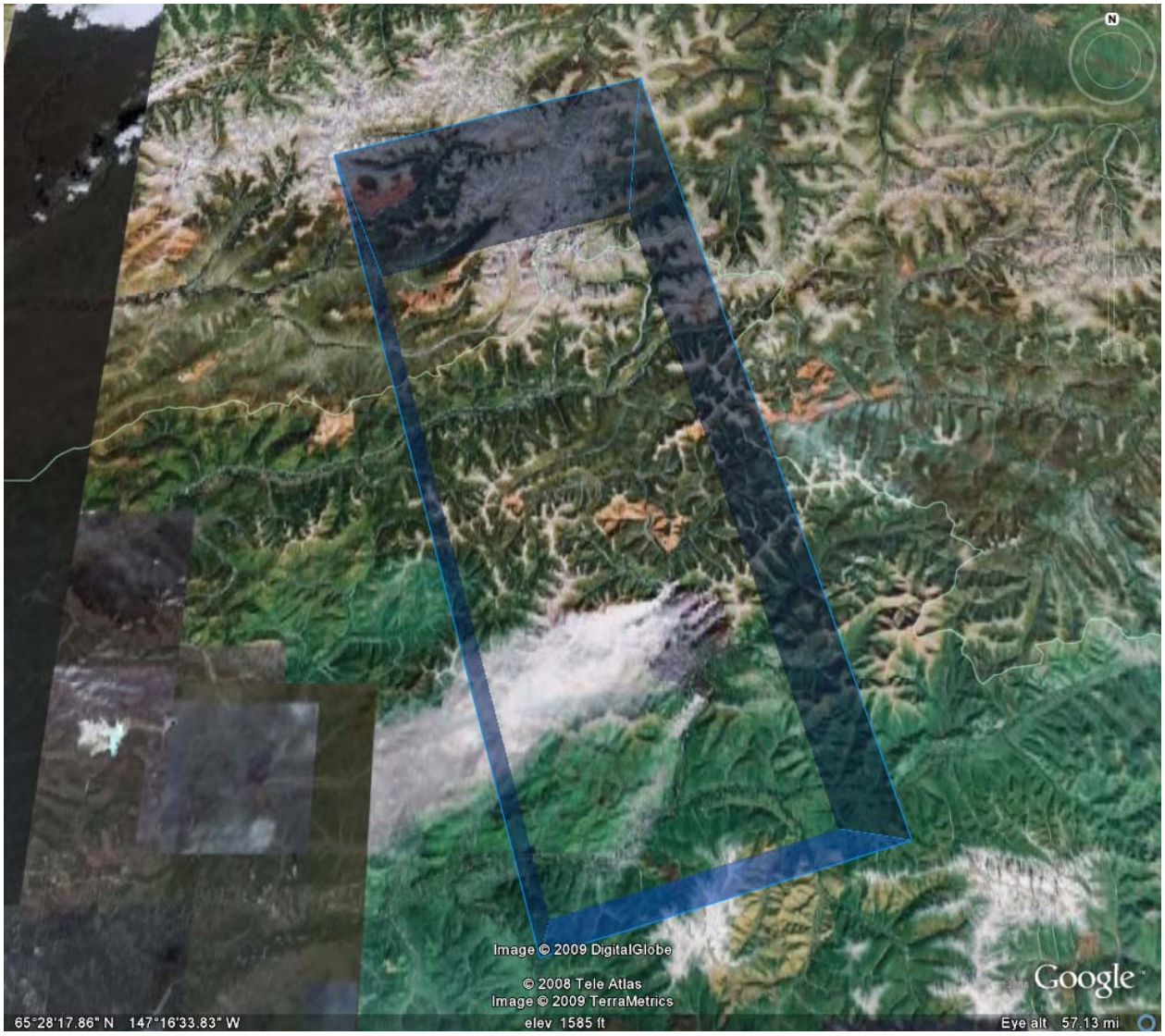
- **Polarimetric measurements (scattering matrix):**

$$\mathbf{M} = Ae^{j\phi}\mathbf{R}^{\mathrm{T}}\mathbf{R}_{\mathbf{F}}\mathbf{S}\mathbf{R}_{\mathbf{F}}\mathbf{T} + \mathbf{N}$$

- **System calibration [Freeman et al., 2008]:**
  - Calibration without or with Faraday rotation

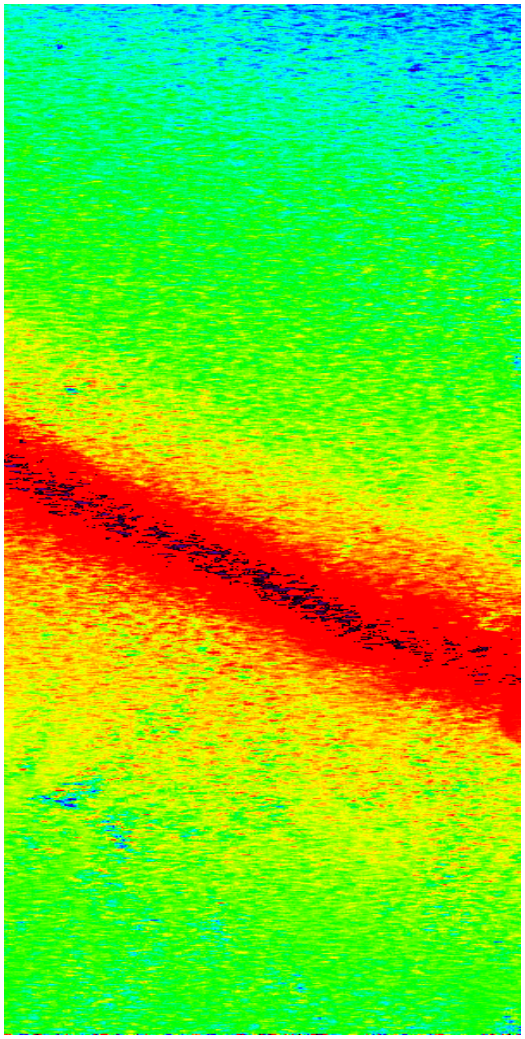
- **Deriving Faraday rotation image using Bickel and Bates' approach [1965]**

ALOS Scene over Alaska

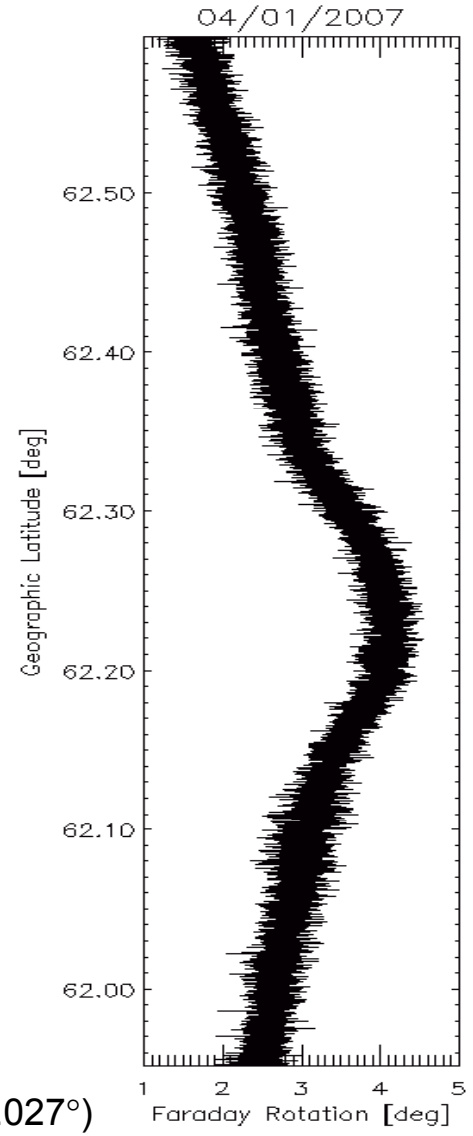


Faraday Rotation Image Measured Using Polarimetric SAR

- Faraday rotation is derived from polarimetric measurements made using **ALOS L-band PALSAR** over Alaska at 07:28 UT on 4/1/2007
- The size of the Image scene is about ~28 x 62 km^2
- **1D FR in the azimuth dir**: mean FR in the range dimension is shown as a function of latitude. Noise of about 0.5 degrees is seen in the data *before smoothing*.
- **2D image**: Features at scales < 110 x 197 m^2 are smoothed or removed to reduce noise.
- The **tilted strip** seems aligned with the ambient **magnetic inclination contour**
- The FR image shows not only **ionospheric gradient but also curvature within the radar scene** in both azimuth and range directions.

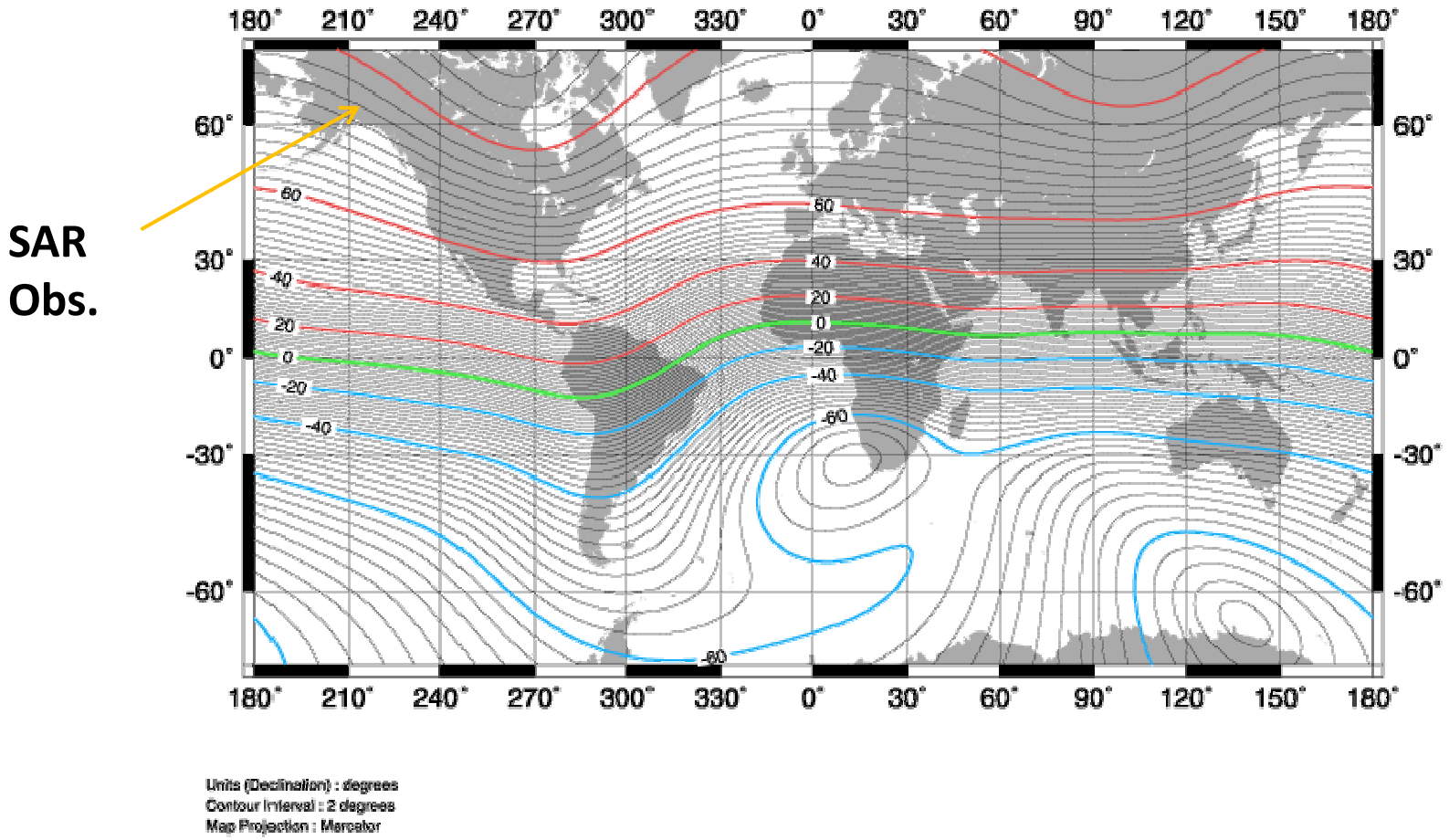


(220.243°, 61.959°)



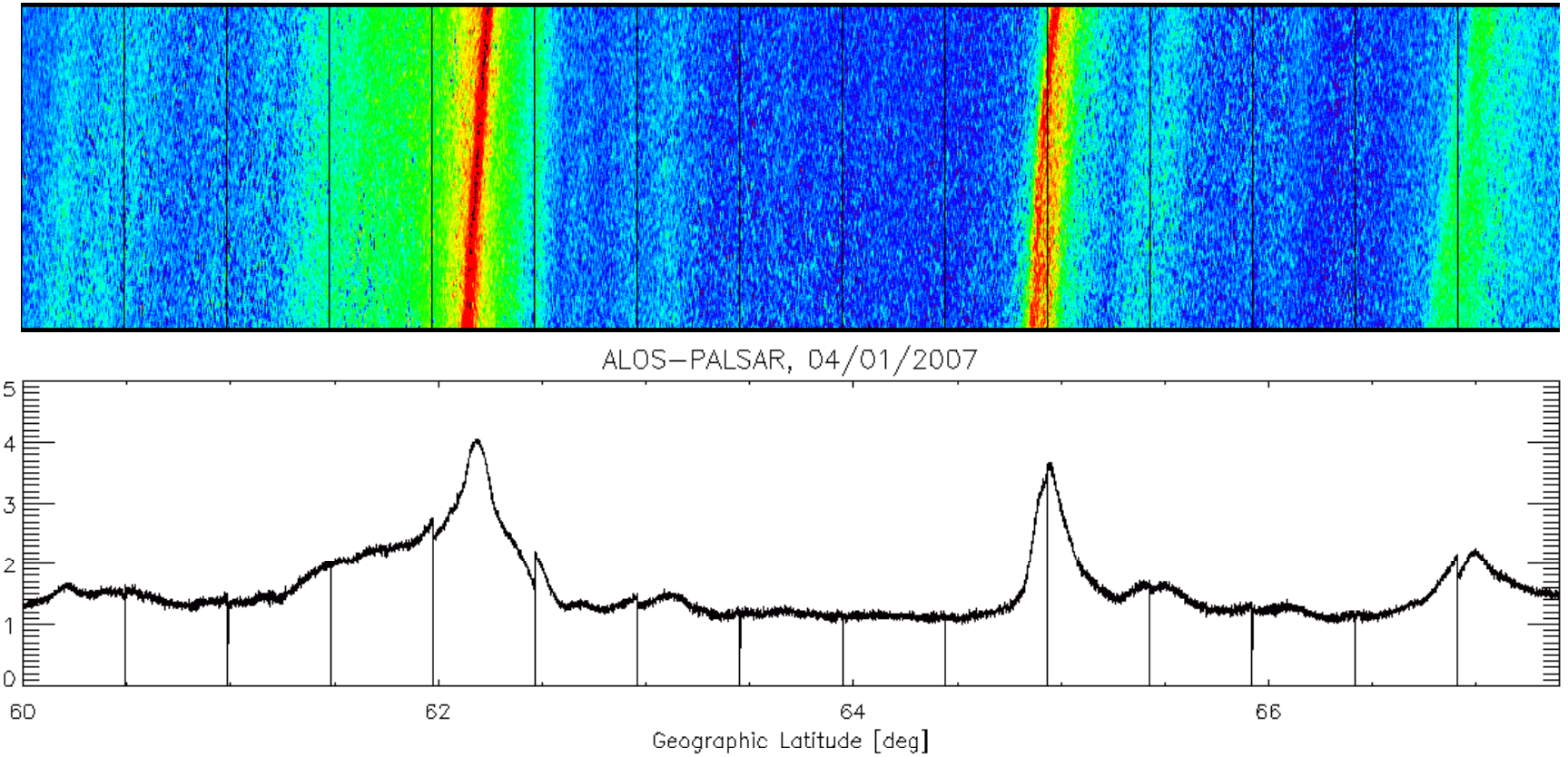
(220.796°, 62.027°)

Magnetic Inclination



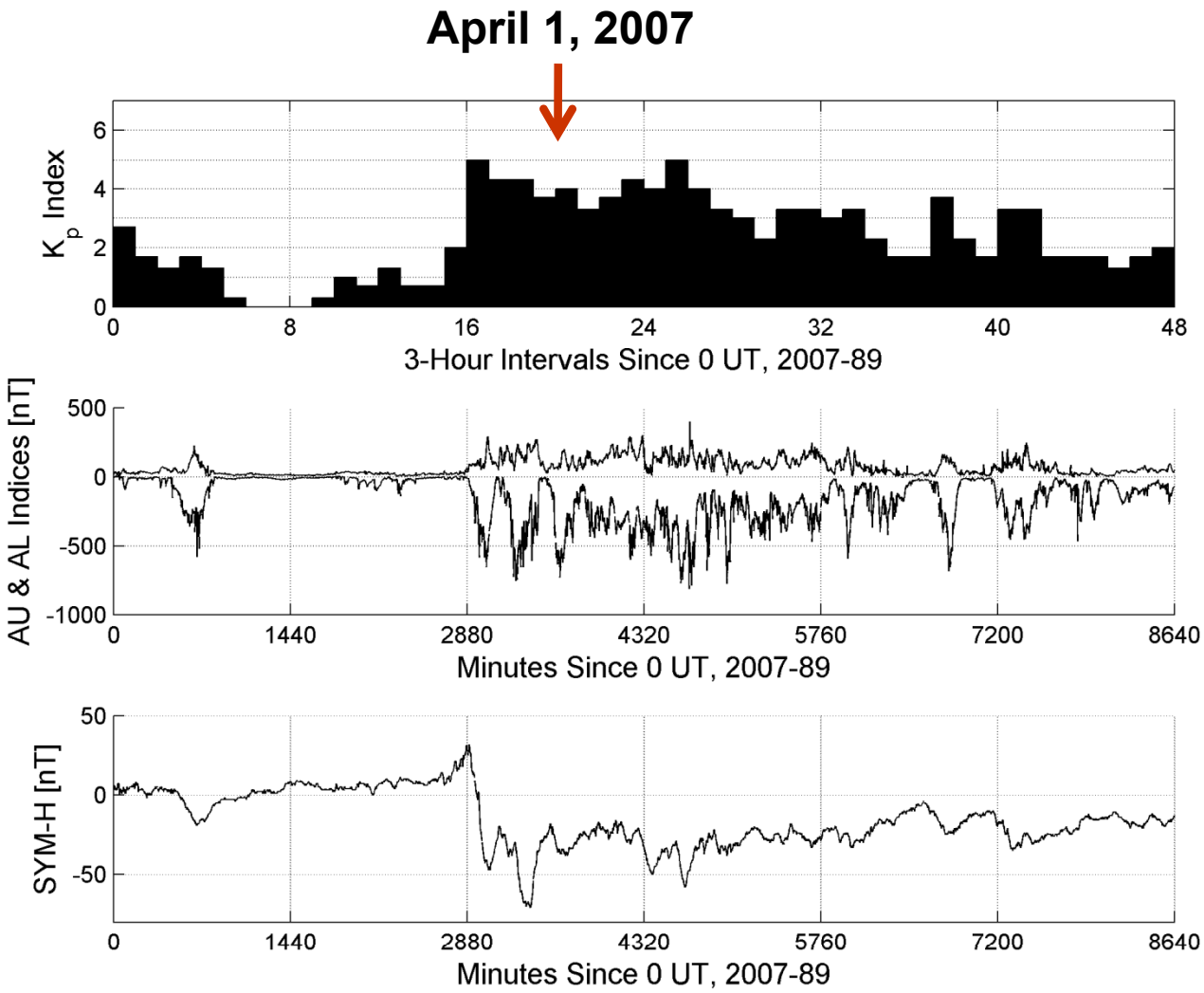
A Series of ALOS Scenes over Alaska

Polar Ionospheric Features Captured in Polarimetric SAR images

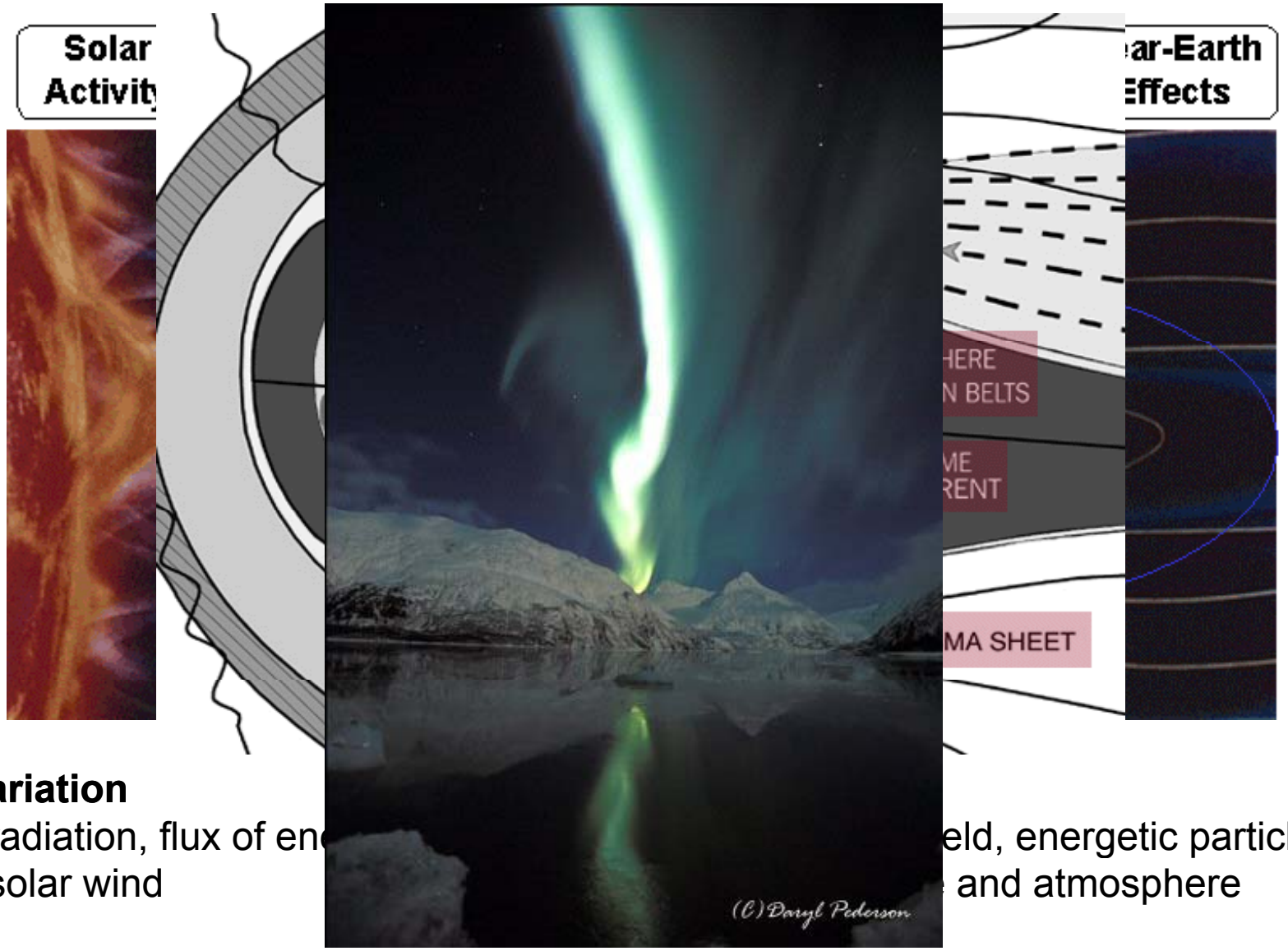


- Multiple strips of enhanced Faraday rotation aligned with magnetic inclination contours are observed in a single path over polar region by PALSAR in a polarimetric mode.
- FR structures as small as 0.1~0.2 degrees are identified after smoothing to reduce noise.
- FR Discontinuity between the images raise possible calibration (by JAXA) or processing issues.

Storm Conditions Indicated by Magnetic Indices



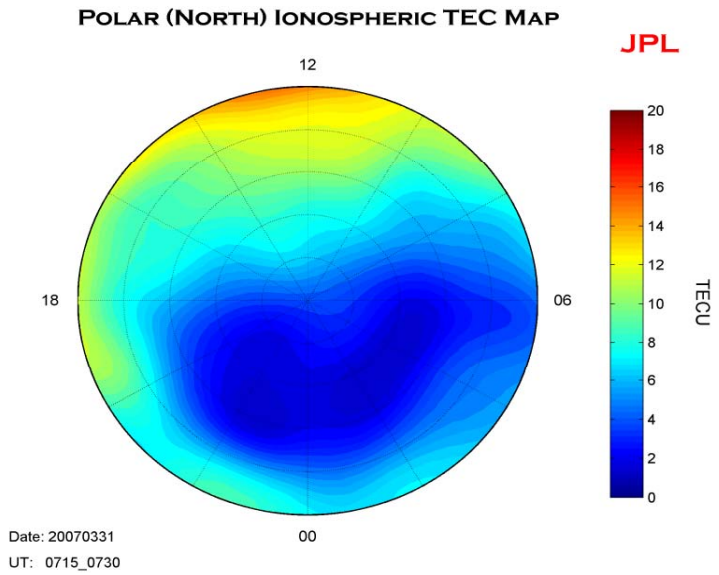
Sun-Earth Connection & Space Weather

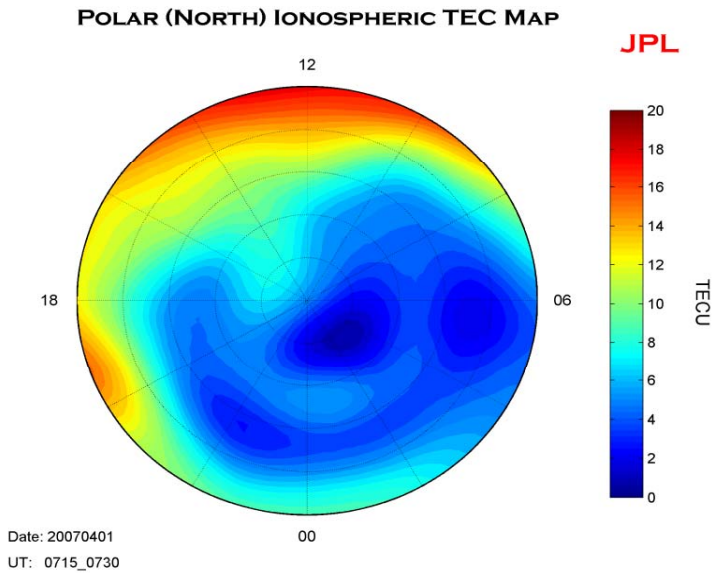


Variation

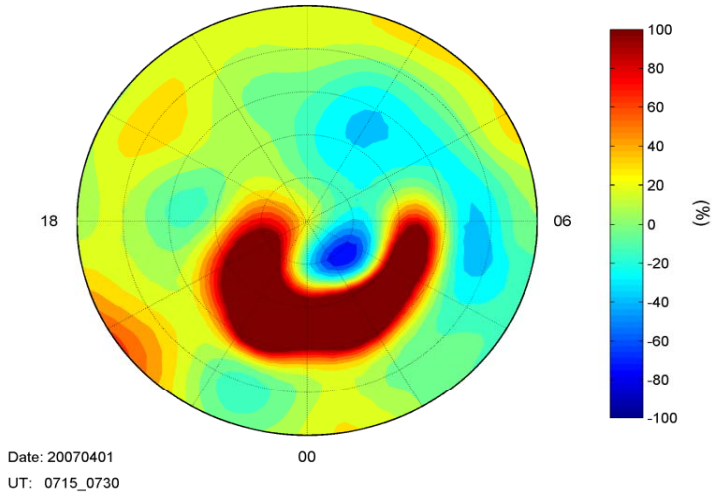
- radiation, flux of en eld, energetic particles
- solar wind and atmosphere

Large-Scale Ionospheric Disturbances

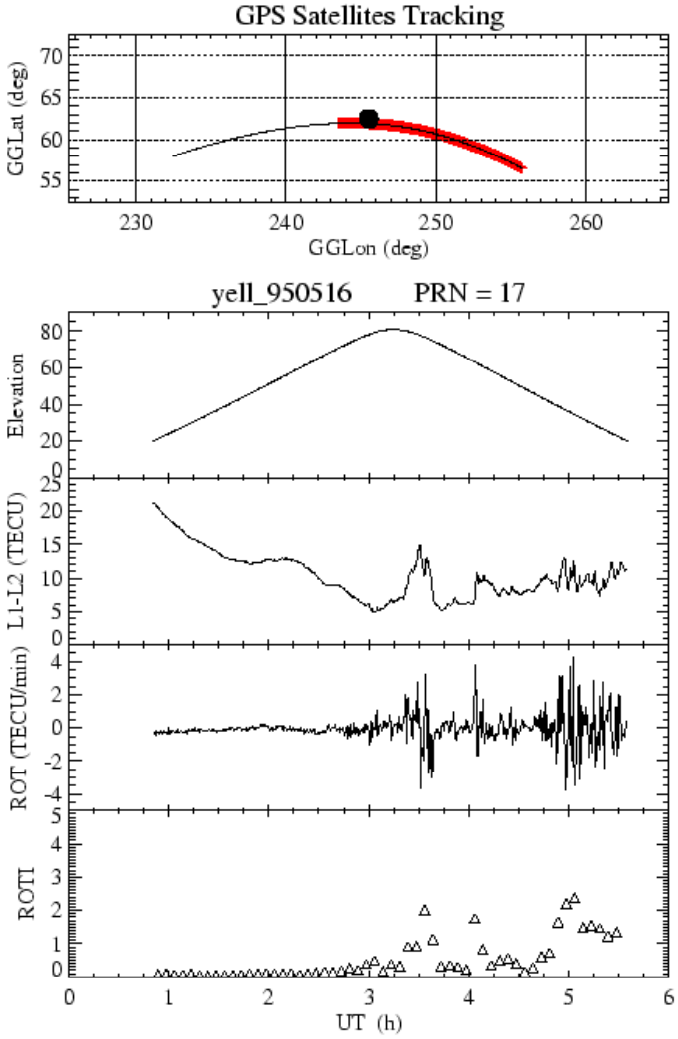


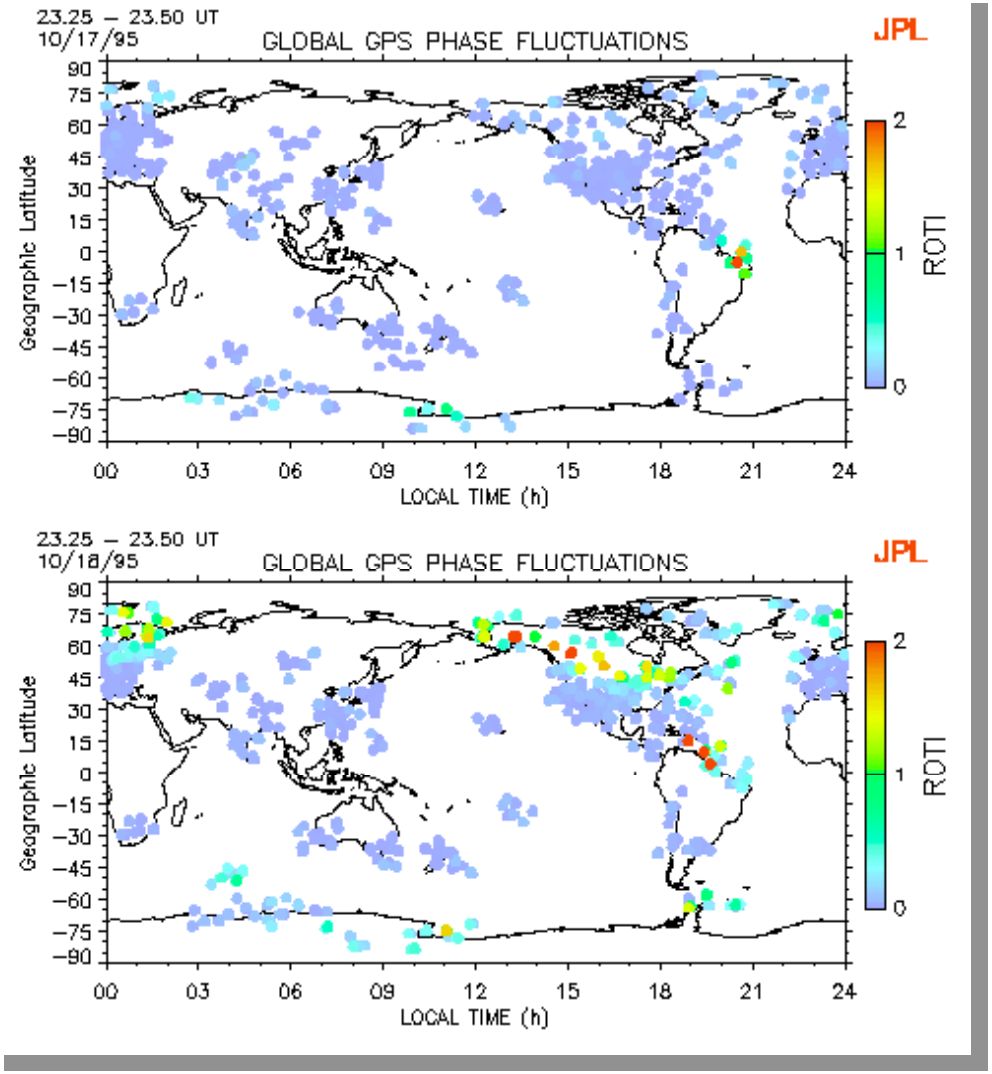


- *Above*: A **quiet-time** TEC map during 0715-0730 UT interval on 3/31/2007.
- *Upper right*: An **event** TEC map during the same UT interval on 4/1/2007.
- A **TEC difference map** (*right*) is obtained from percentage difference between the event map and the map of quiet-time pattern

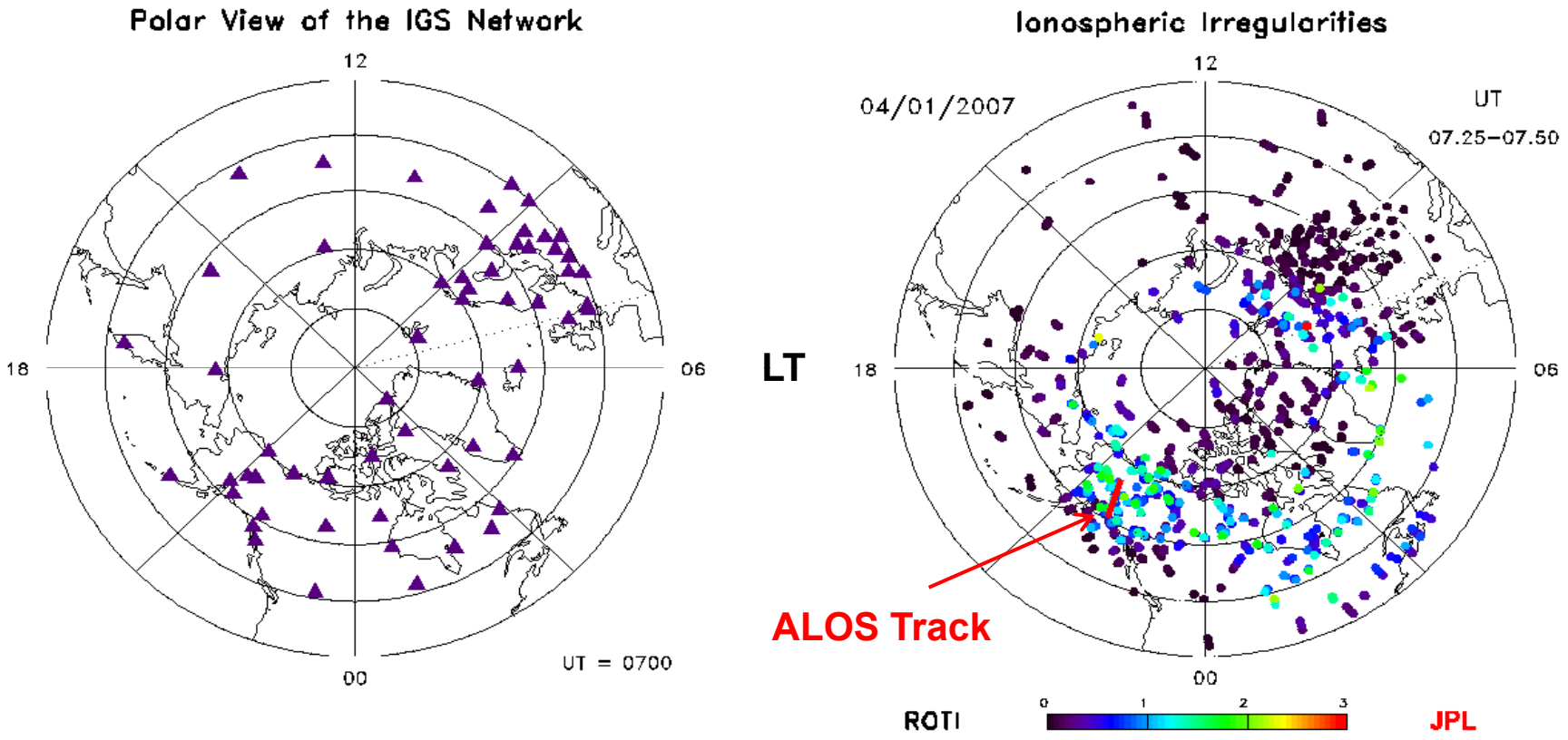


Measurement of Ionospheric Irregularities: Rate of TEC Index (ROTI)





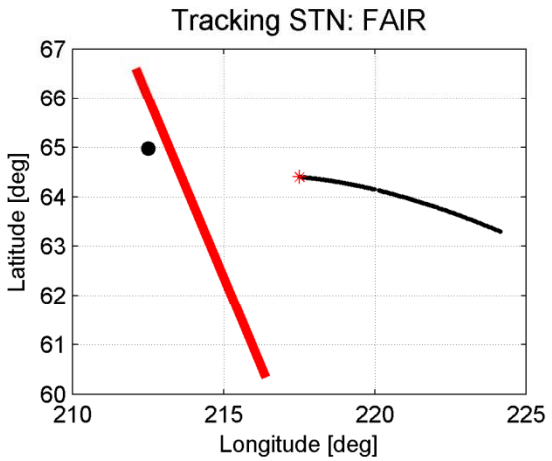
Snapshot of Ionospheric Irregularities Measured Using GPS

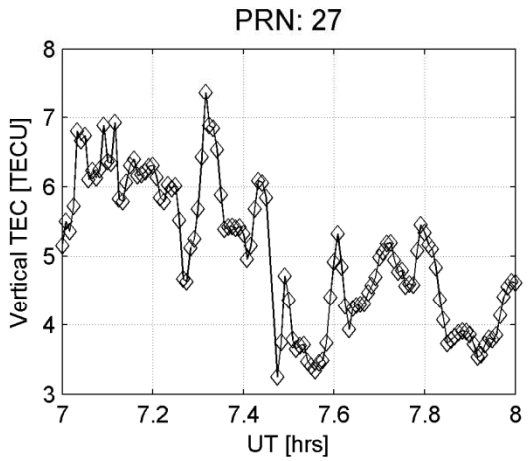


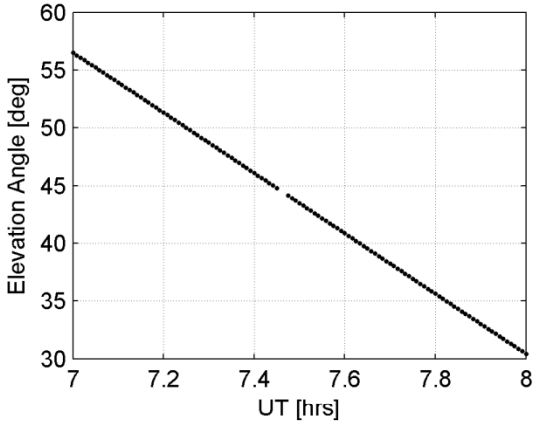
- Dual-frequency GPS observations from 58 stations in the polar region (LAT ≥ 50°) are processed to produce rate of TEC (ROT) and rate of TEC index (ROTI) measurements
- Increased ROTI values indicate ionospheric irregularities during the storm
- The PALSAR path falls into a perturbed ionospheric region

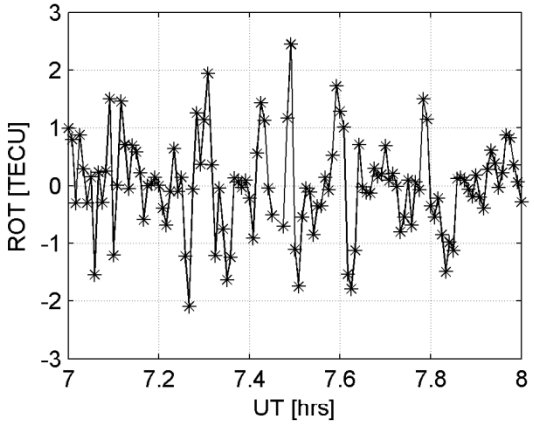
Ionospheric Irregularities Near Radar Path Measured Using GPS

Red: ALOS Track









- Ionospheric irregularities were captured by a GPS receiver at Fairbanks, Alaska, tracking L1 and L2 signals transmitted from GPS27 satellite.
- At ~07:28 UT, GPS data show TEC perturbations in nearly longitude direction near the ALOS path.
- Horizontal resolution of GPS measurements is about 1~2.3 km at zenith with data sampled at 1/30-sec

Conclusions

- Ionospheric structures aligned with magnetic inclination contours are captured by ALOS polarimetric SAR operations in a polar region over Alaska.
- The structures show Faraday rotation gradient and curvature within individual radar scenes. The study demonstrates that an L-band POLSAR is capable of reconstructing 2D ionospheric images at resolutions finer than ~1 km with precision of about 0.°~0.2° Faraday rotation.
- GPS-based TEC images indicate ambient conditions of ionospheric disturbances during a space weather event, while ROT measurements show ionospheric irregularities near the time and location of the ionospheric structures.
- GPS-based models (3D & 2D) provide ambient ionospheric conditions at large scales – horizontally hundreds of kilometers, while ROT measurements provide snapshot fine-resolution irregularity info.
- Combined capability of ISSG has a great potential to investigate ionospheric perturbations caused by Earth activities, such as tsunamis and earthquakes, and space weather disturbances.
- Large-scale TEC maps derived from GPS data and assimilative models can provide correction to SAR data at gross level and trend for Earth science imaging if needed. However, correction to SAR data to remove the ionospheric structures within individual SAR scenes requires fine resolution measurements such as radar techniques, such as polarimetric or split spectrum approach, or individual TEC arcs through GPS links.