Processing and Validation of FORMOSAT-7/COSMIC-2 Absolute Total Electron Content Observations

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CDAAC Absolute TEC Processing

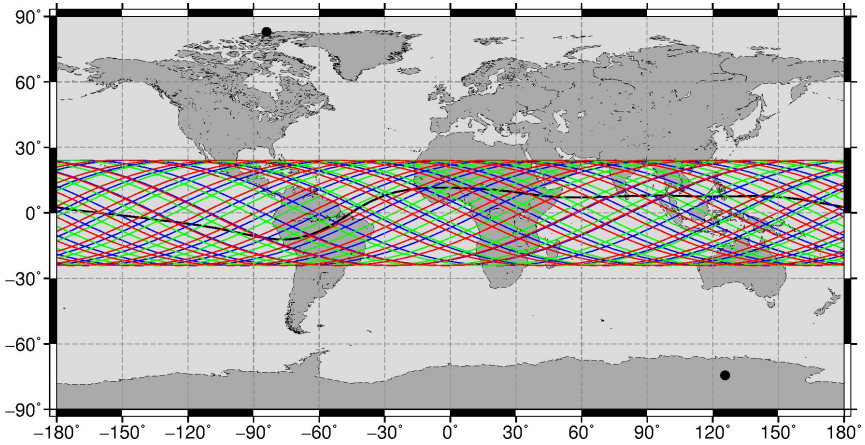
- Absolute TEC processing is based on the 1-Hz pseudorange and phase observations from the POD antennae
- Absolute TEC processing steps:
  1. Correct pseudorange for local multipath
  2. Fix cycle slips and outliers in carrier phase data
  3. Level phase TEC to pseudorange TEC
  4. Estimation and application of the LEO differential code bias (DCB)
- TEC is inverted to retrieve electron density profiles
- **F7/C2 GPS and GLONASS absolute TEC have been validated and released to the public**

Updates necessary for FORMOSAT-7/COSMIC-2

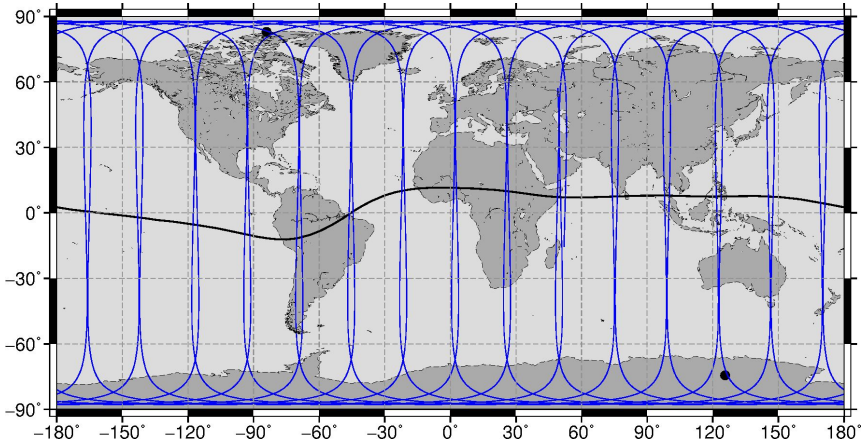
- The TGRS observes the L2C signal from certain GPS transmitter satellites and the L2P signal from others.
- The CDAAC processing software was updated to incorporate both L2C and L2P observations.
- Important updates include changes to the determination of multipath maps and the estimation of DCBs.
- Developed a new approach for estimating GLONASS DCBs.

Validation against Swarm GPS TEC observations

FORMOSAT-7/COSMIC-2



ESA Swarm-B

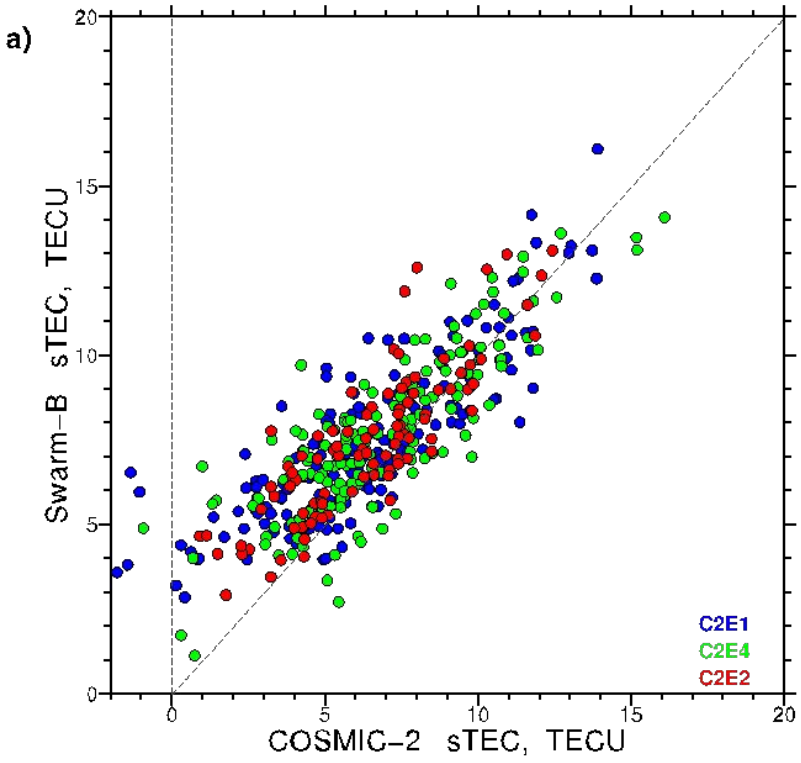


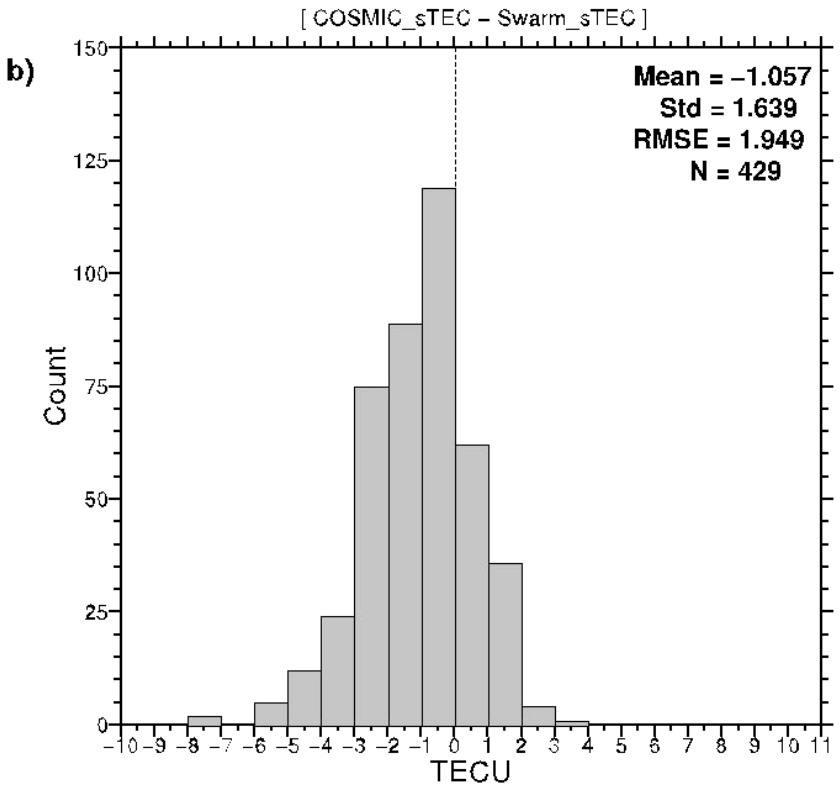
- FORMOSAT-7/COSMIC-2 GPS TEC observations are validated against collocated Swarm-B observations.

- Validate results for February-May 2020 after TGRS v4.3.4 software update

- Collocation criteria:
    1. $\Delta t = 0$ (i.e., zero temporal difference)
    2. satellite separation of less than 2°
    3. same GPS satellite observed

Comparison of FORMOSAT-7/COSMIC-2 and Swarm STEC





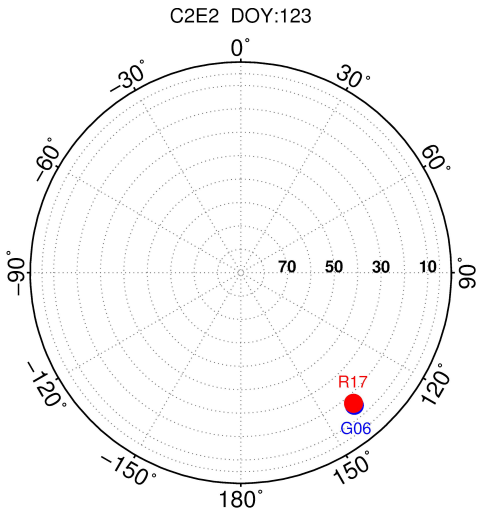
GPS TEC error: ~2.5 TECU

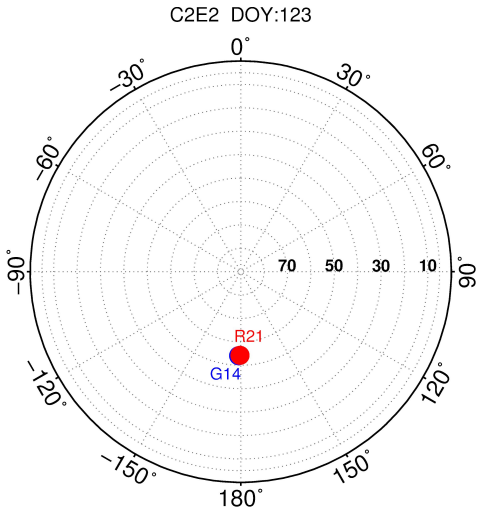
Results corrected for ~50 km altitude difference using IRI.

FORMOSAT-7/COSMIC-2 GLONASS TEC Validation

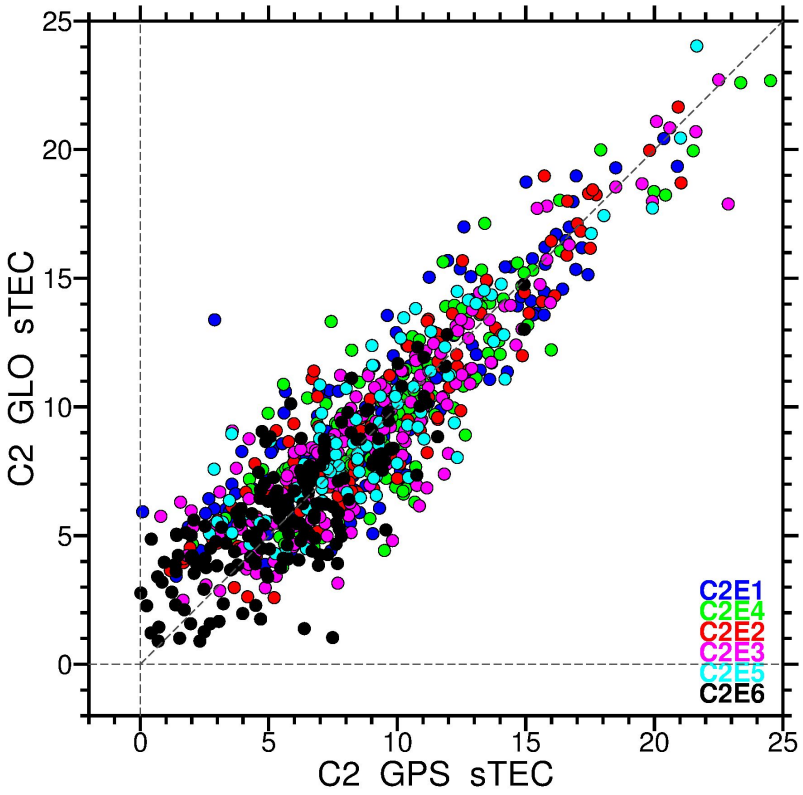
Validation Strategy: analysis of colocation events between GPS and GLONASS observations from the same F7/C2 satellite

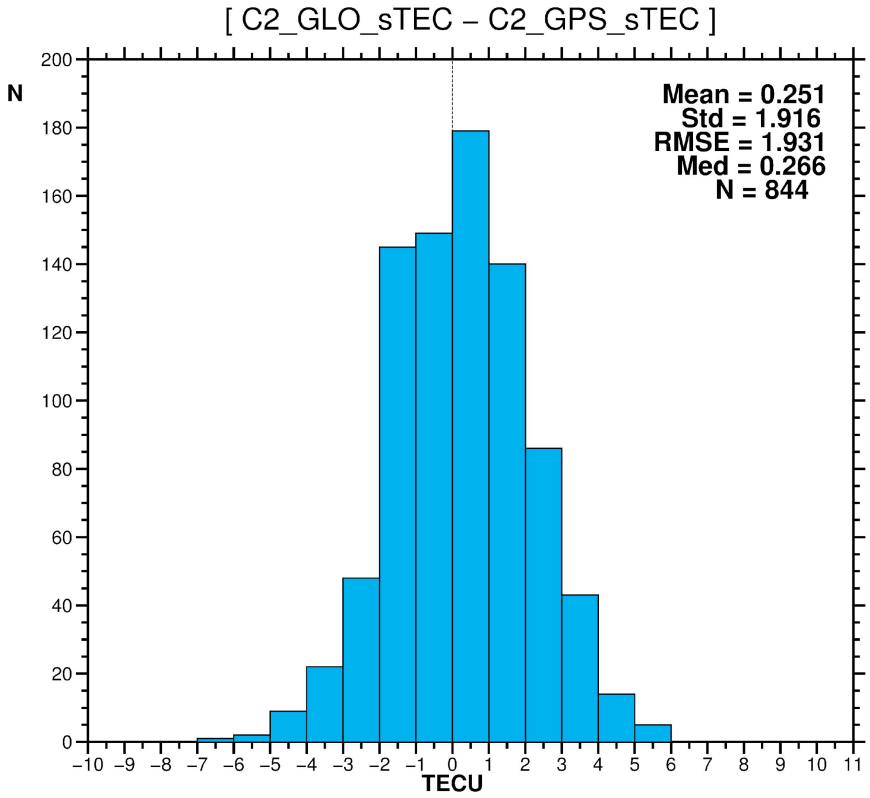
- Evaluate observations with TGRS V4.3.5 (October-November 2020)
- Spatial separation less than 2 degrees in azimuth and elevation
- GPS and GLONASS observations at the same time
- Only observations above 10 degrees elevation





FORMOSAT-7/COSMIC-2 GLONASS TEC Validation

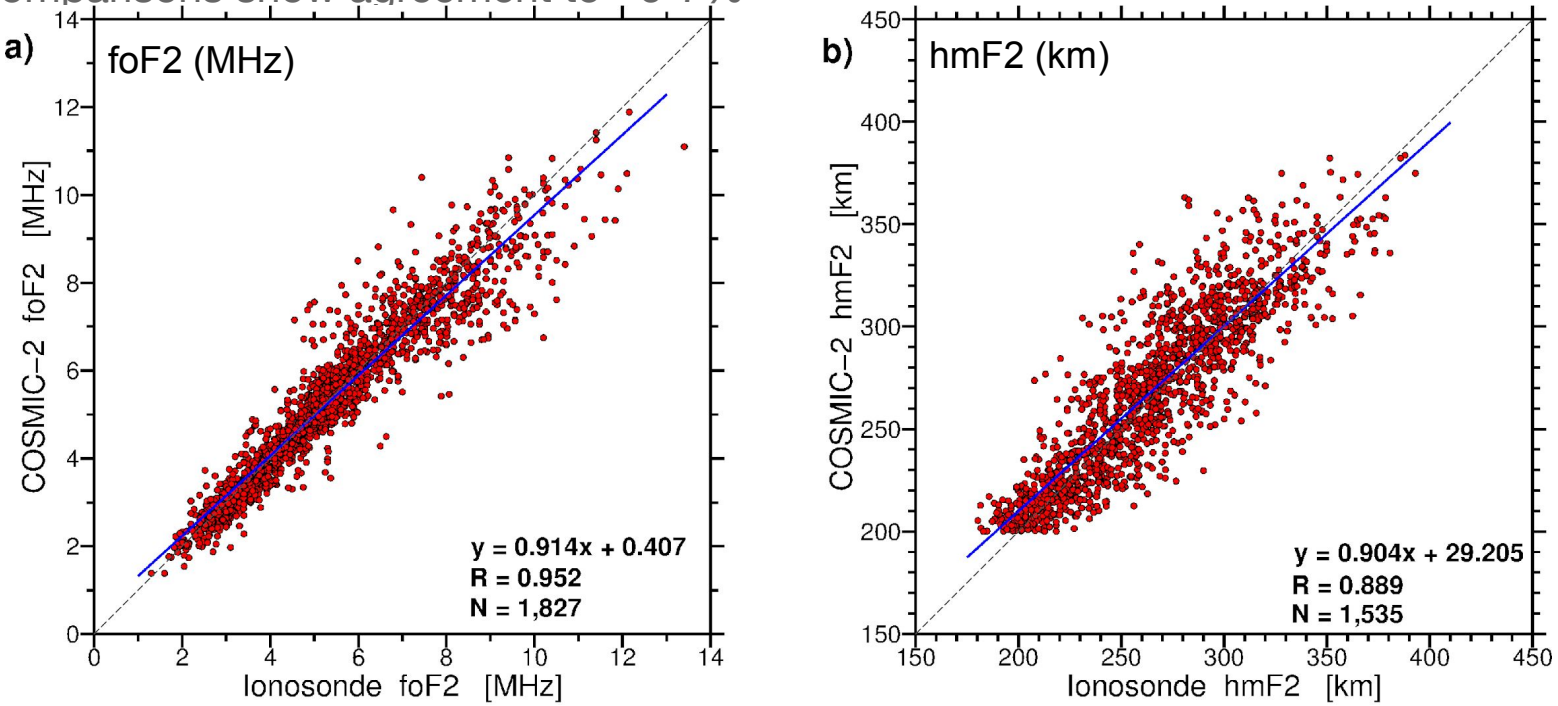




GLONASS error: ~2.6 TECU

FORMOSAT-7/COSMIC-2 Electron Density Profile Validation

- Electron density profiles compared against manually scaled ionograms
- Geomagnetic quiet time conditions only
- Spatial colocation criteria of 5 degrees
- Temporal colocation criteria of 15 minutes
- Comparisons show agreement to ~6-7%

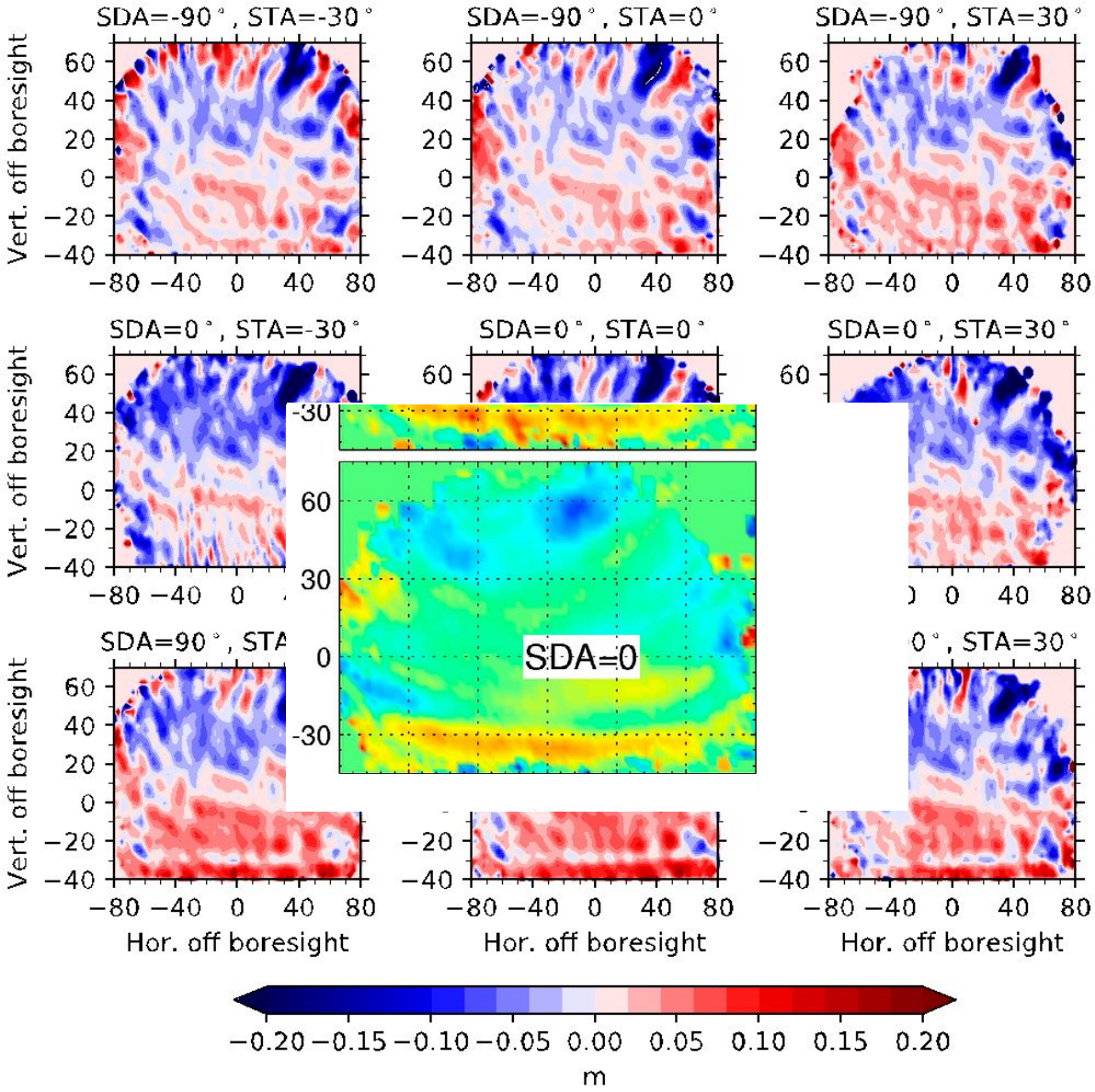


(Cherniak et al., 2021, doi:10.1051/swsc/2020080)

Summary and Conclusions

- The CDDAC absolute TEC processing has been updated to incorporate TGRS observations of both L2P and L2C signals.
- Important updates include the determination of multipath maps as well as the estimation of the LEO DCBs for both L2C and L2P.
- The absolute TEC was validated against independent observations from the Swarm-B satellite.
- The estimated error on the absolute TEC is ~2.5 TECU for GPS and ~2.6 TECU for GLONASS.
- Data are currently available to the operational and scientific communities.

Pseudorange multipath maps (MC1)

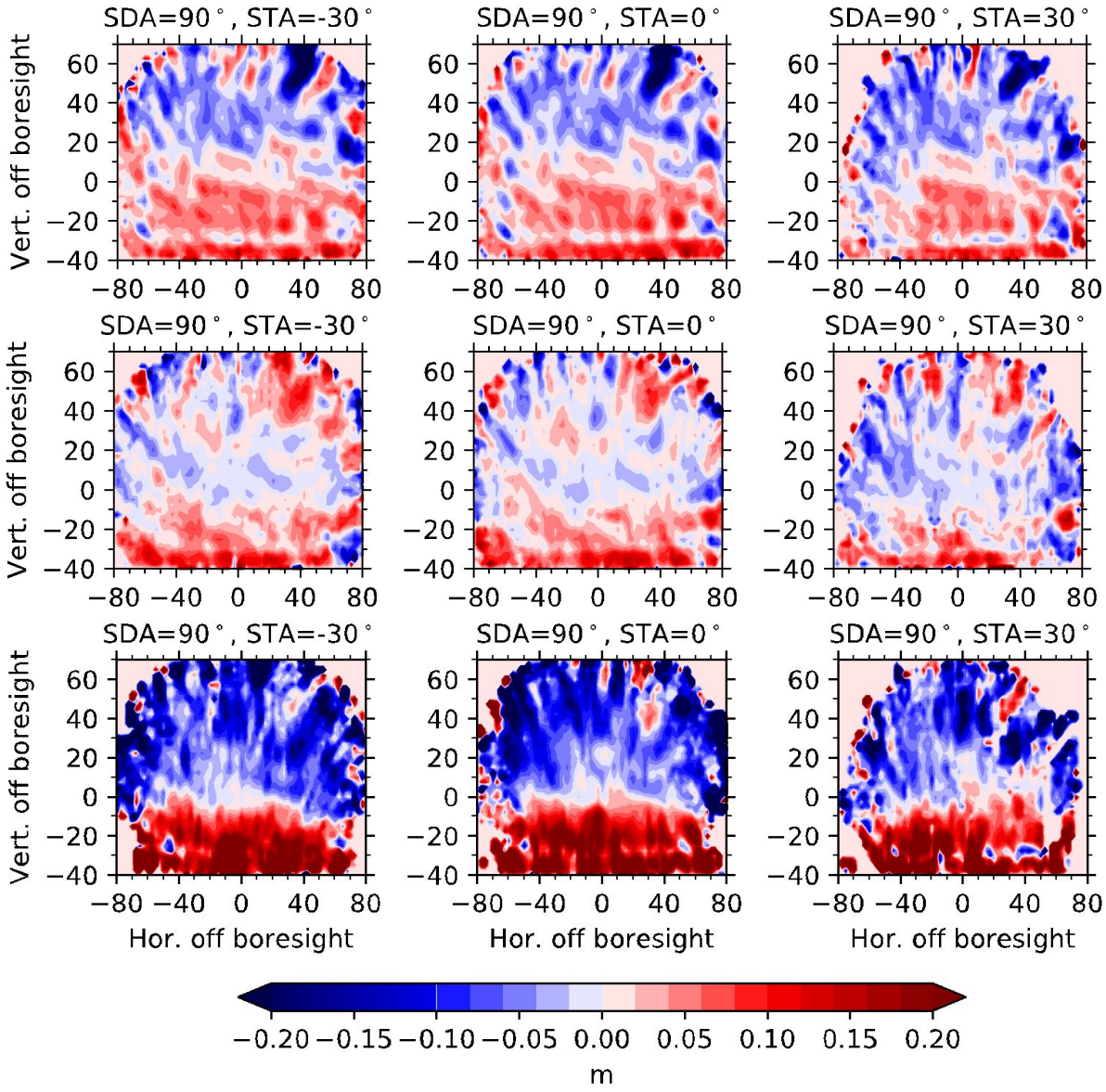


Pseudorange multipath maps

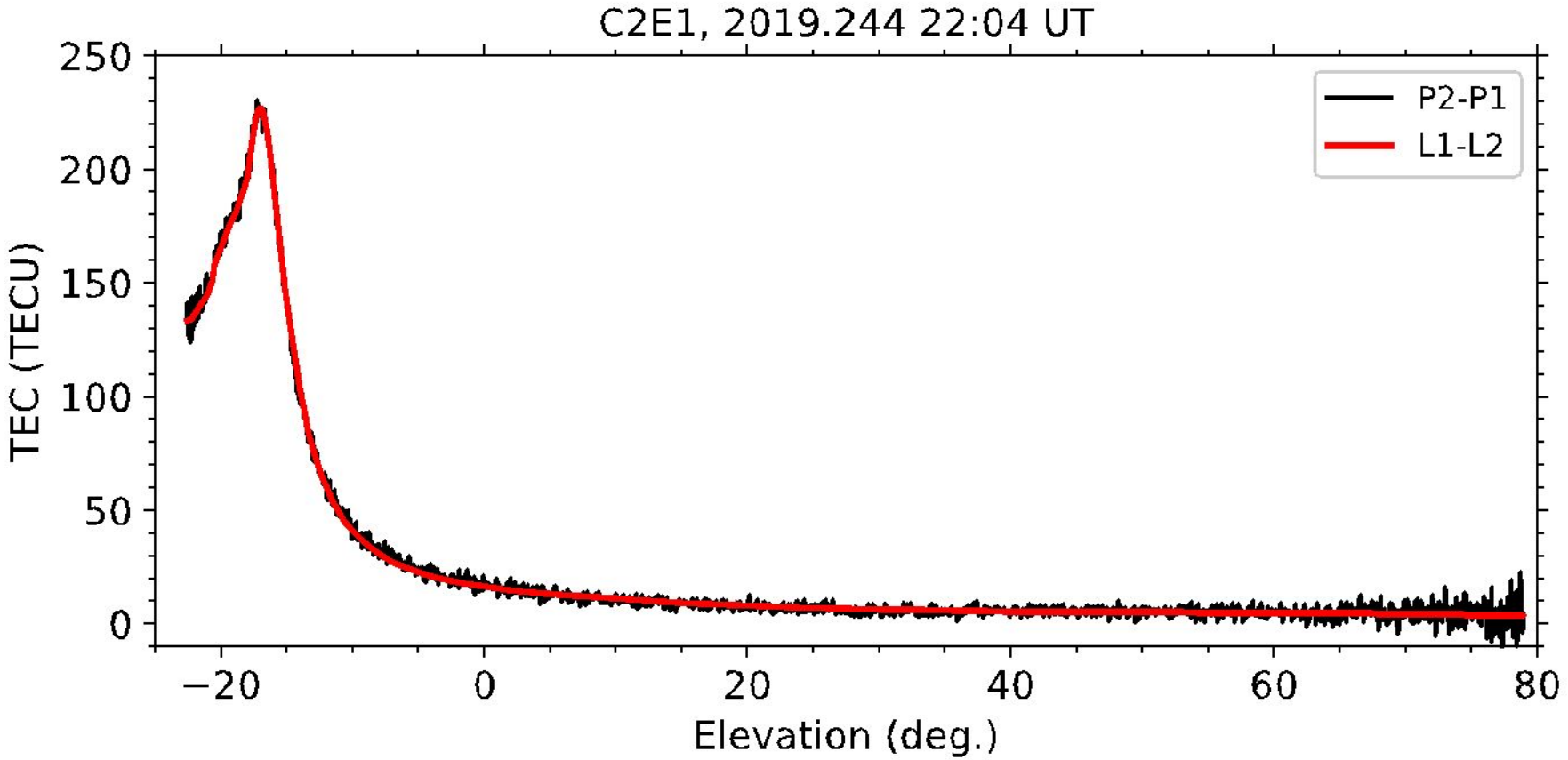
MC1

MC2

MP2



Phase to pseudorange leveling



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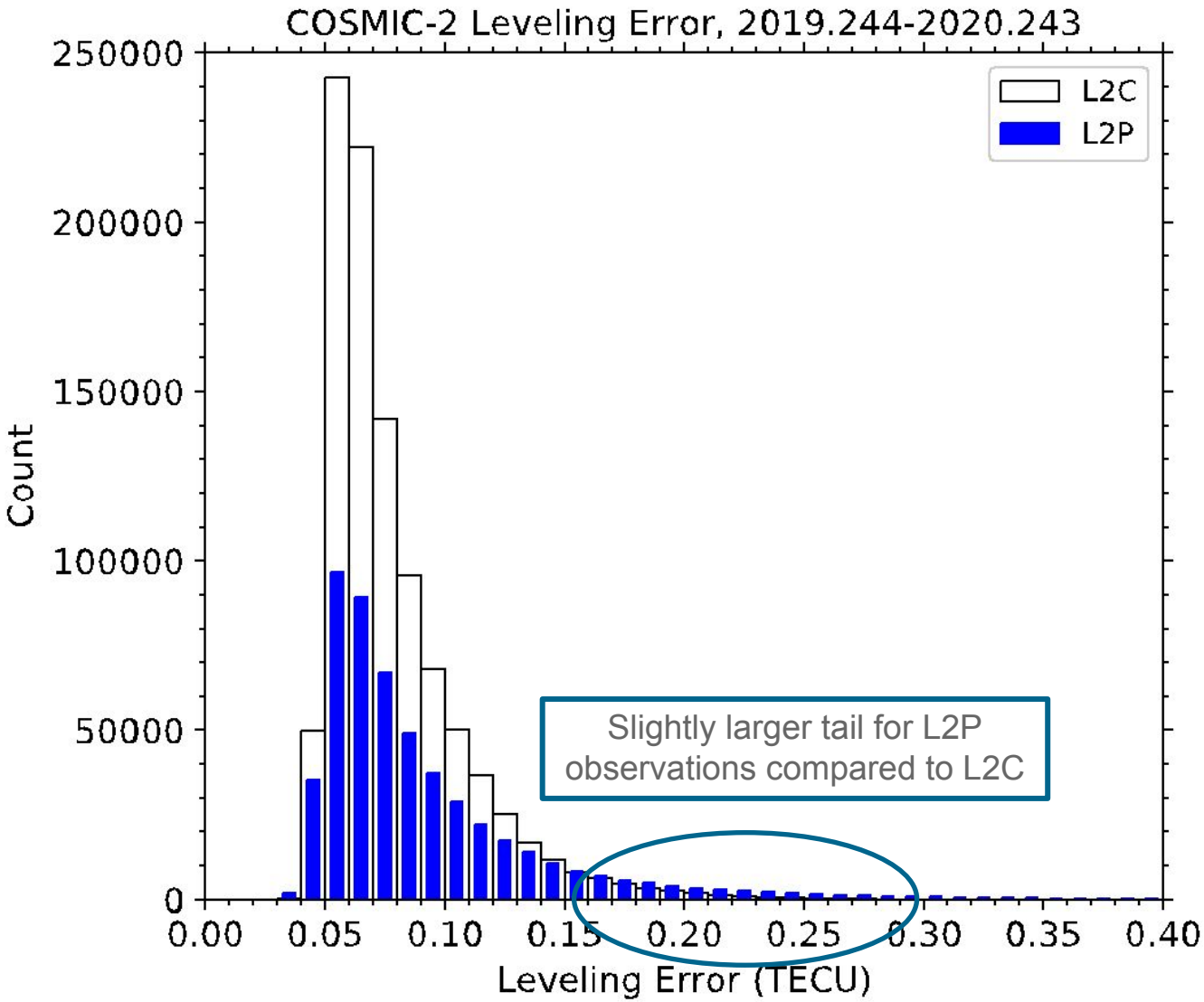


FORMOSAT-7/COSMIC-2 DCB Estimation

- To determine the absolute TEC, it is necessary to know the differential code biases (DCB), which is due to interfrequency hardware delays, for both the receiver and transmitter.

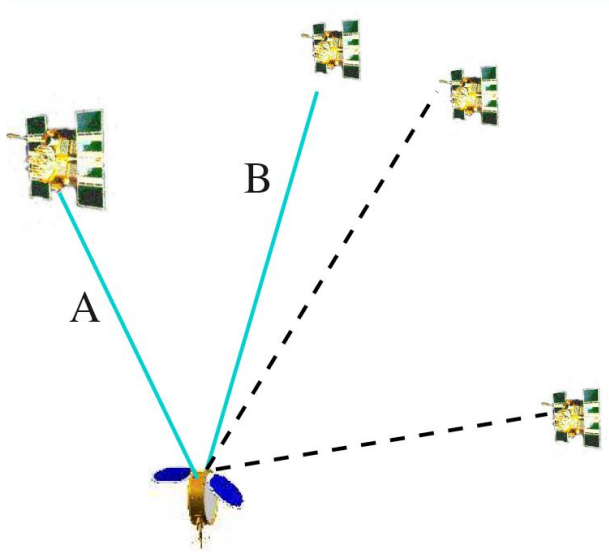
$$TEC_{absolute} = TEC_{relative} + DCB_{receiver} + DCB_{transmitter}$$

- We use transmitter DCBs provided by the Center for Orbit Determination in Europe (CODE), and receiver DCBs are estimated using a least squares weighted average:

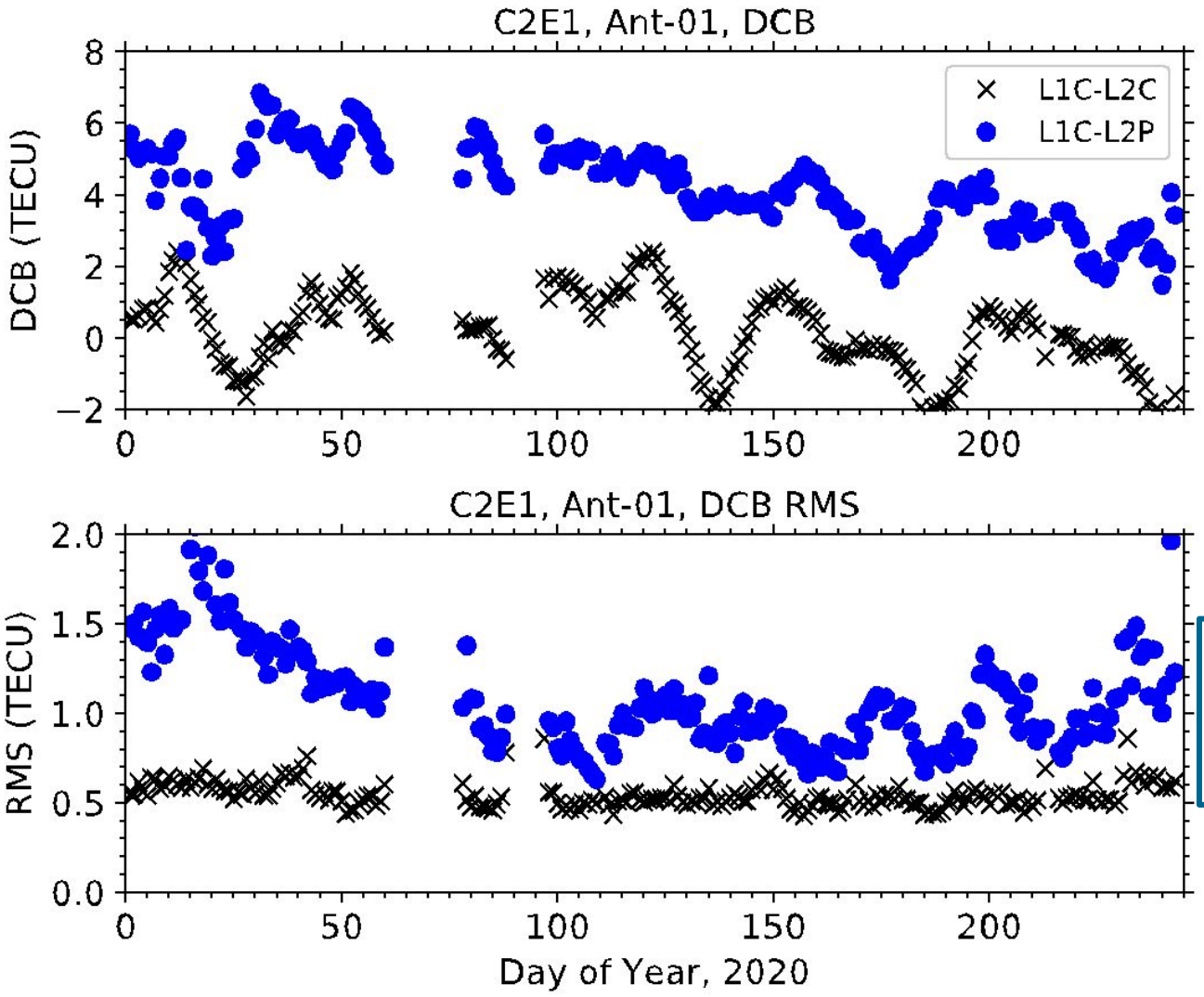
Assume that $TEC_a M(\theta_a) = TEC_b M(\theta_b)$, where $M(\theta)$ is a geometric mapping function

$$DCB_{receiver} = \frac{\sum\left(M(\theta_a) - M(\theta_b)\right) \times \left(TEC_a M(\theta_a) - TEC_b M(\theta_b)\right)}{\sum\left(M(\theta_a) - M(\theta_b)\right)^2}$$

- For FORMOSAT-7/COSMIC-2, we independently estimate separate DCBs for (L1C-L2C) and (L1C-L2P).



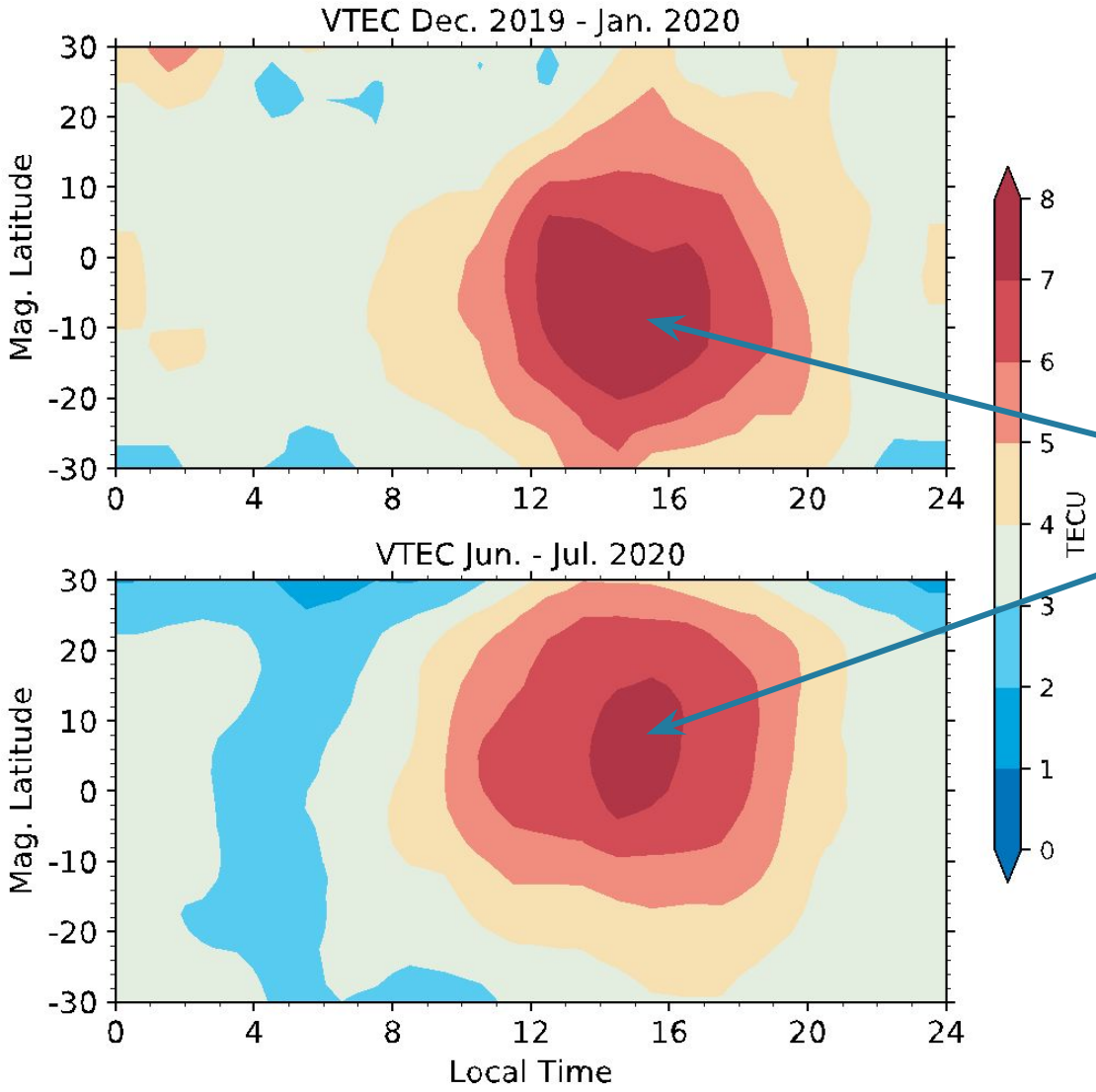
LEO DCB estimation



Different DCB values for (L1C-L2C) and (L1C-L2P)

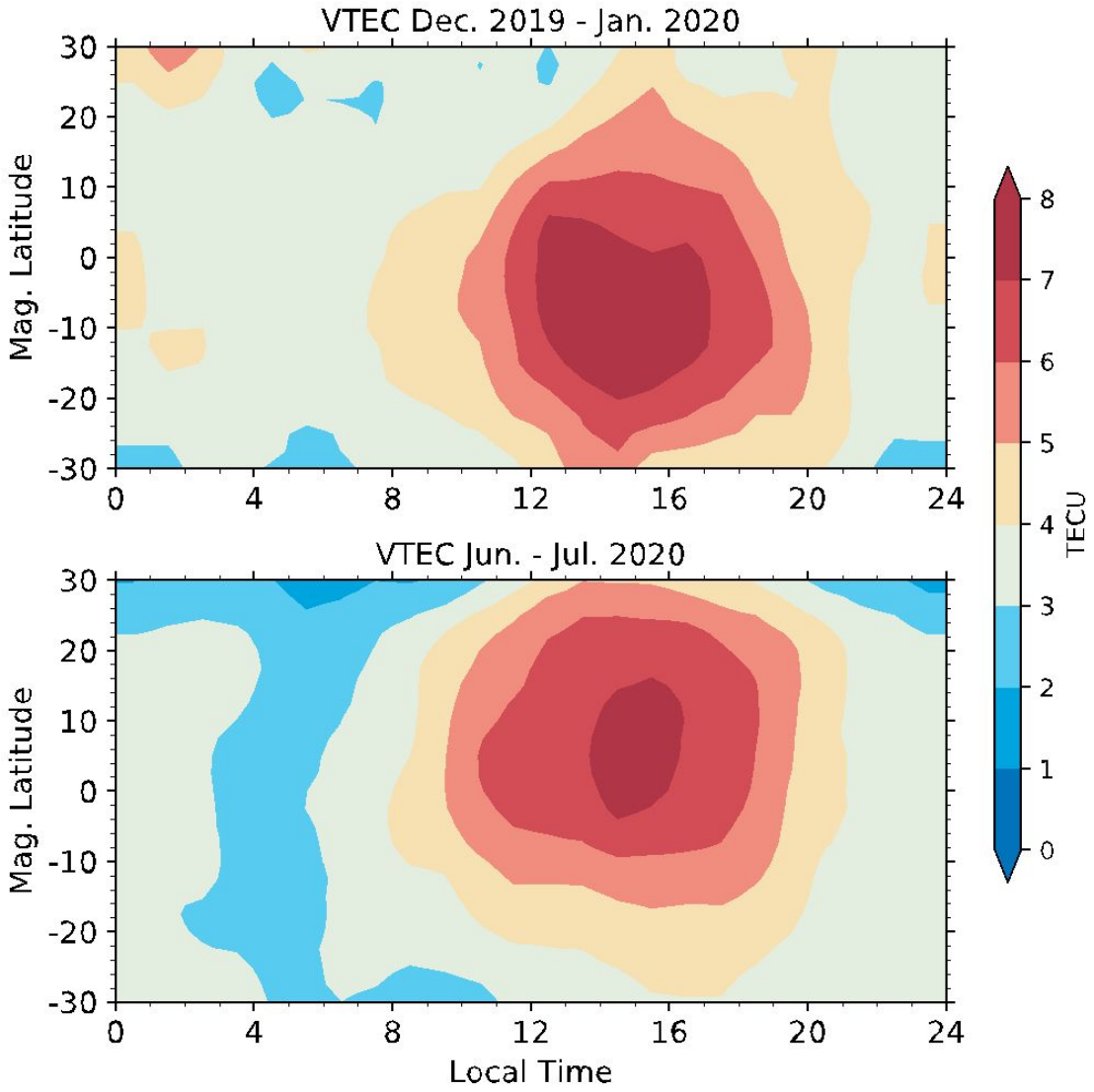
- DCB RMS error ~0.5-1.0 TECU
- Lower error for L2C➔more & higher quality observations

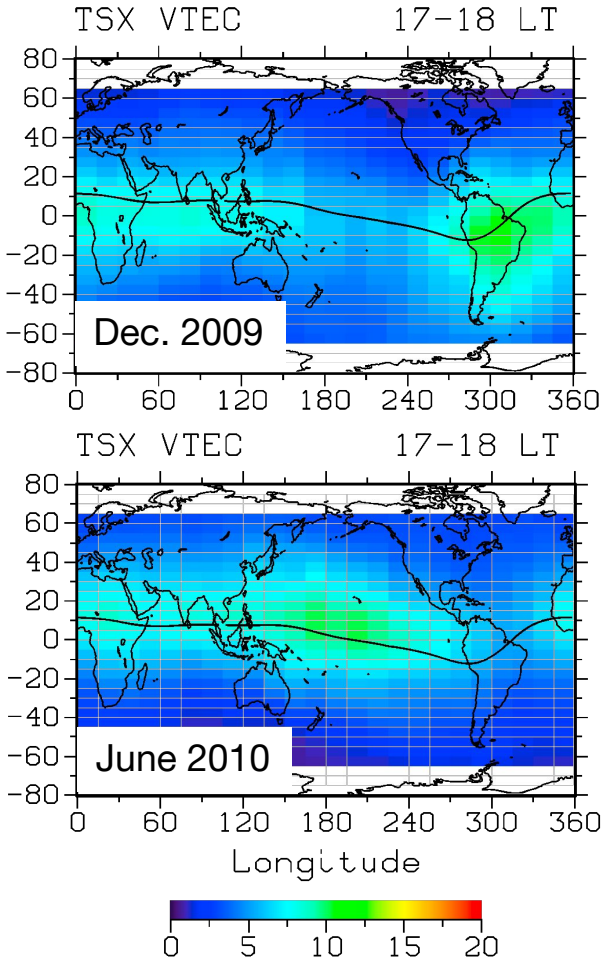
Example application: FORMOSAT-7/COSMIC-2 topside TEC



Seasonal distribution of VTEC above ~550 km is apparent

Example application: FORMOSAT-7/COSMIC-2 topside TEC





(Zakharenkova and Cherniak, 2015)