Harnessing GNSS and NavIC Signals for Weather and Ocean Winds

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"GNSS Meteorology"

Remote sensing of the troposphere and stratosphere by gauging the refraction (retardation and bending) of GNSS signals that propagate through the atmosphere.

Fundamental basis of GNSS Meteorology

Pressure, temperature and humidity dependence of microwave refractivity

Smith & Weintraub, 1954:

$$N = (n-1)\times 10^{6} = K_1 \bullet \frac{P_d}{T} + K_2 \bullet \frac{e}{T} + K_3 \bullet \frac{e}{T^2} + \left(-K_4 \frac{N_e}{f^2}\right)$$

Refractivity for Neutral Atmosphere

Ionospheric refractivity term

Top of the neutral atmosphere; ~60km

Values of constants at radio frequencies

$$K_1 = 77.67 \, K mb^{-1}$$
$$K_2 = 70.31 \, K mb^{-1}$$
$$K_3 = 3.734\times 10^{5} \, K^2 mb^{-1}$$
$$K_4 = 40.3\times 10^{6} \, m^3/s^2$$

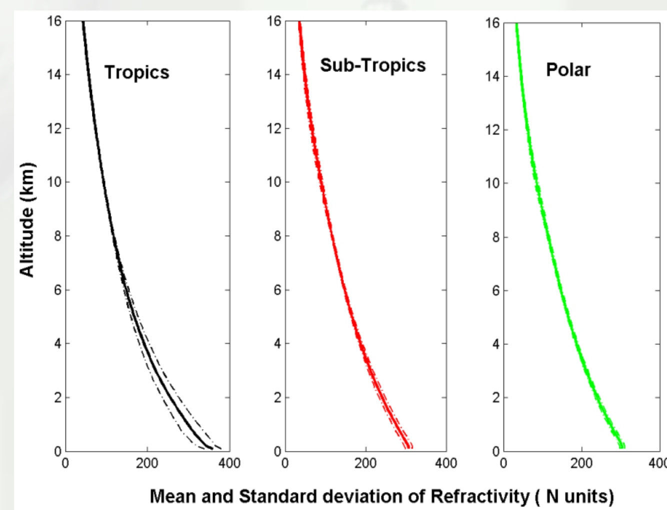
(Hydrostatic or dry Refractivity)

$$N_d = K_1 \bullet \frac{P_d}{T}$$

~ 8-10 km

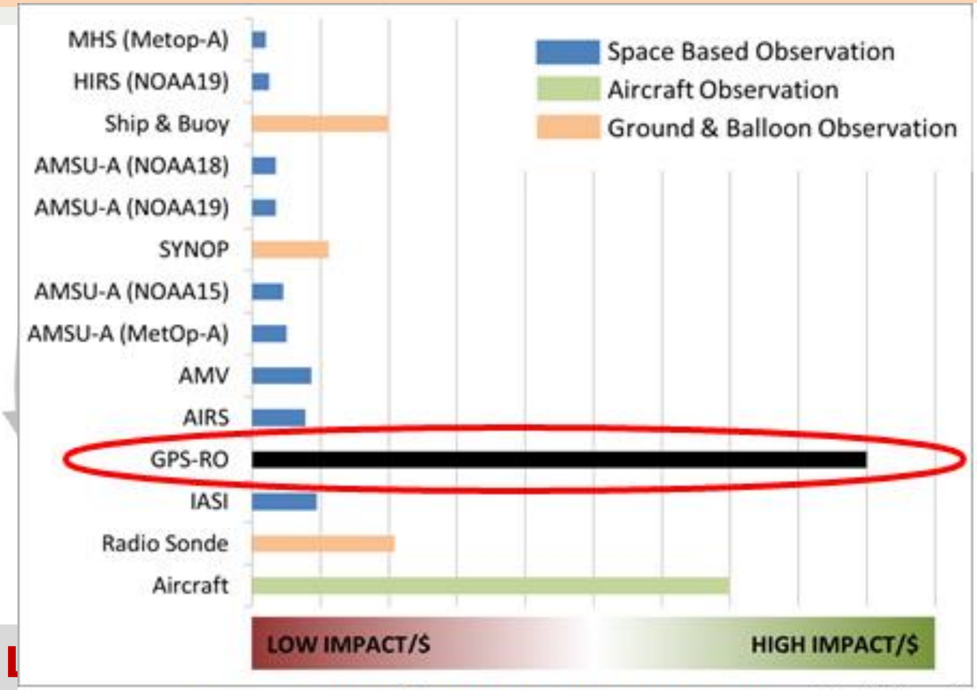
$$N_w = K_2 \bullet \frac{e}{T} + K_3 \bullet \frac{e}{T^2}$$

(Wet Refractivity)



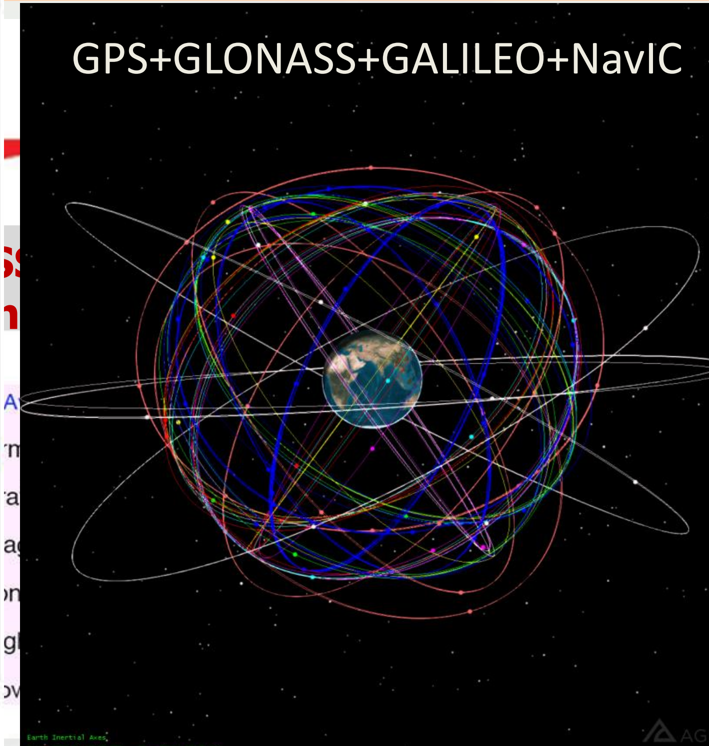
Space-based GNSS Meteorology using Radio Occultation Technique

Radio Occultation stands for occultation of radio signal transmitters by the intervening astronomical bodies, having essentially an atmosphere, with the signal received through refractive bending.



Impact per $ of Observation Types

Credit: PlanetIQ



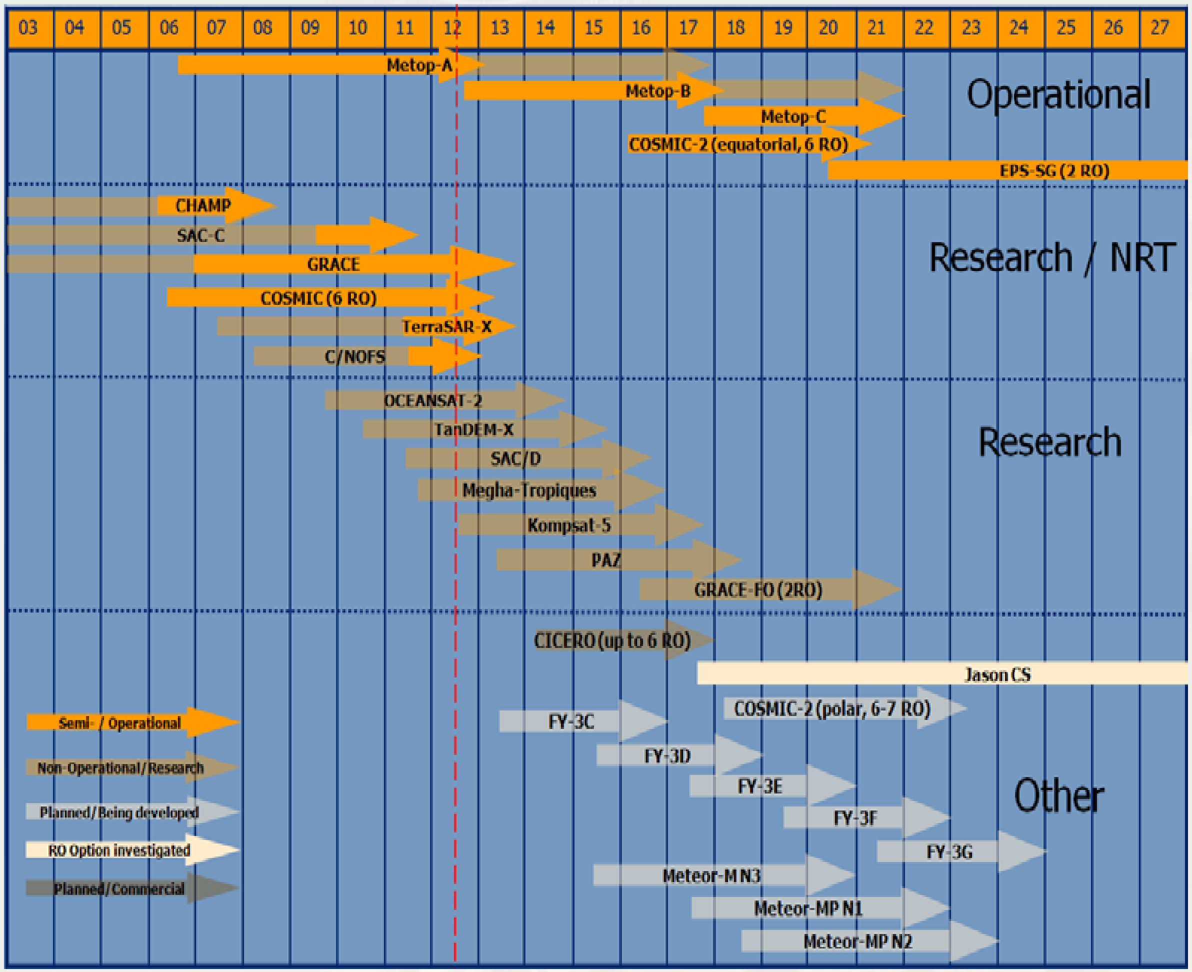
GCOS Implementation plan for Global observing system for climate:

Action A20 (AF13): GPS RO measurements should be made available in real time, incorporated into operational data streams, and sustained over the long-term. [GCOS-92, WMO/TD No. 1219, October 2004]; **recommended as an essential climate monitoring system by WMO in its "Vision for the GOS in 2025" document. IROWG in its 215 WG report advocates for use of open service signals of all GNSS viz. GLONASS, GALILEO and Beidou for more observations**

Current status & Gap Areas:

Justification for future RO missions

Radio occultation missions' timeline



- ISRO's RO missions: MT-ROSA (dual antenna; 550-600occ/day; tropical coverage) *[the only global mission giving high-data density in tropics, until COSMIC-2 is launched]*. OS2-ROSA: in polar orbit; single antenna; lesser (250-300 nominal) occ. events/day.

- Only two operational RO missions (METOP-A & B): Polar orbiting; event depletion observed in tropics. METOP-C recently launched (Nov. 2018).

- COSMIC-1 (constellation of 6LEO receivers), semi-operational, phasing out by 2016; *drastic drop of global occl./day (currently ~900-1000 from earlier ~1800) due to end-of-mission life for some 3 receivers.* COSMIC-2 (equatorial component) expected by 2016-17 *(could be delayed).*

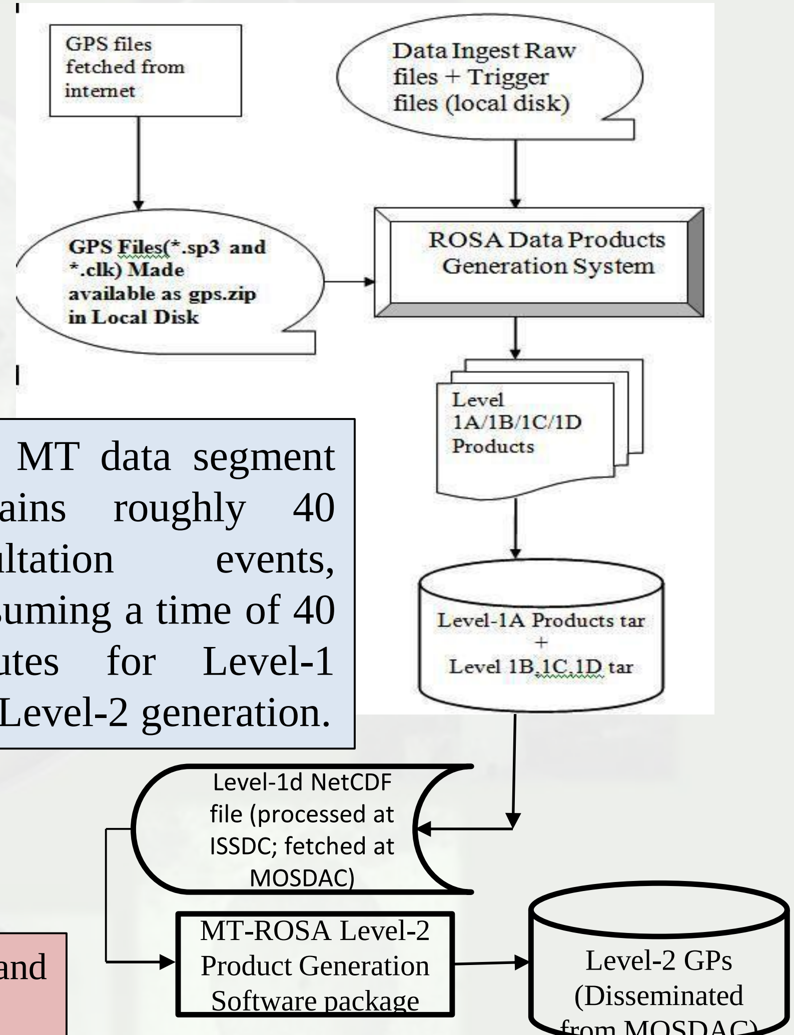
Megha-Tropiques ROSA (MT-ROSA) Data Products and Processing Chain

Processing Levels of Data Products

- **Level-0:** Sensor Data File & OAT file
- **Level-1A:** RINEX formatted file generated from Level-0 Raw data (s/w from TAS-I)
- **Level-1B:** Excess Phase profiles for each occultation event.
- **Level-1C/1D:** Bending angle, Refractivity, Impact Parameter, Geometric Height and profile of Latitude-Longitude of tangent point (only in Level-1D)
- **Level-2:** Atmospheric Profiles of Temperature, Pressure, their dry parameters, water vapour partial pressure in addition to tropopause height as value added parameter for each occultation event.

Number of Occultation events ≈ 500/day; Data Format: Netcdf and BuFR. [Netcdf Data available from www.mosdac.gov.in]

Overview of the Data Processing System



One MT data segment contains roughly 40 occultation events, consuming a time of 40 minutes for Level-1 and Level-2 generation.

Radio Occultation Processing Overview

p1,p2
a1,a2

Raw Phase and amplitude (L1 & L2 GPS signals) measurements

Derived from excess doppler (upper troposphere); multipath propagation effects addressed using suitable techniques (lower troposphere, humid regions)

Bending angles of L1 & L2

α1, α2

Ionosphere-corrected bending angle

Frequency-weighted linear combination applies

α

Neutral atmosphere(z < 60km) Refractivity

Auxiliary Climatology data & Abel Inversion (Spherical symmetry assump.)

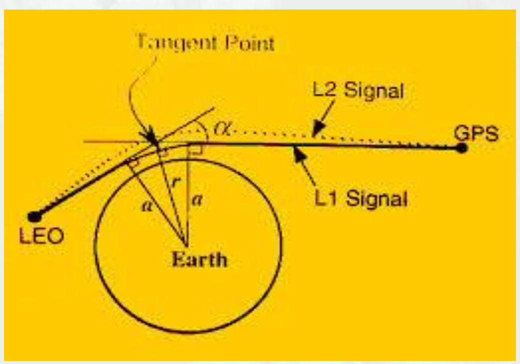
N

Raw (phase+amplitude) measurement → N (L1 product)

Level-1A → Level-1D [Geometric & Wave Optics Processing]

T, P & e

Neutral atmosphere (L2) Retrievals



GPS-RO Inversion: An Under-determined Problem!

Refractivity

$$N(z) = (\mu(z)-1)\times 10^6 = k_1 \frac{P(z)}{T(z)} + k_2 \frac{e(z)}{T^2(z)}$$

GRD/SAC/ISRO

Direct Method

- Use a' priori T information from in-situ/NWP
- Use a' priori surface T & P information from in-situ/NWP and $T = f((\log_e P)^2)$ PHYRET Method
- Use a' priori WVPP (e) information from
  - in-situ
  - NWP
  - ANN

Statistical Optimal Method such as One-Dimensional VARiational (1DVAR)

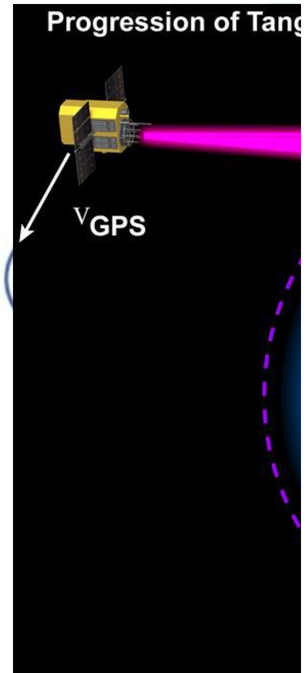
State-of-the-art

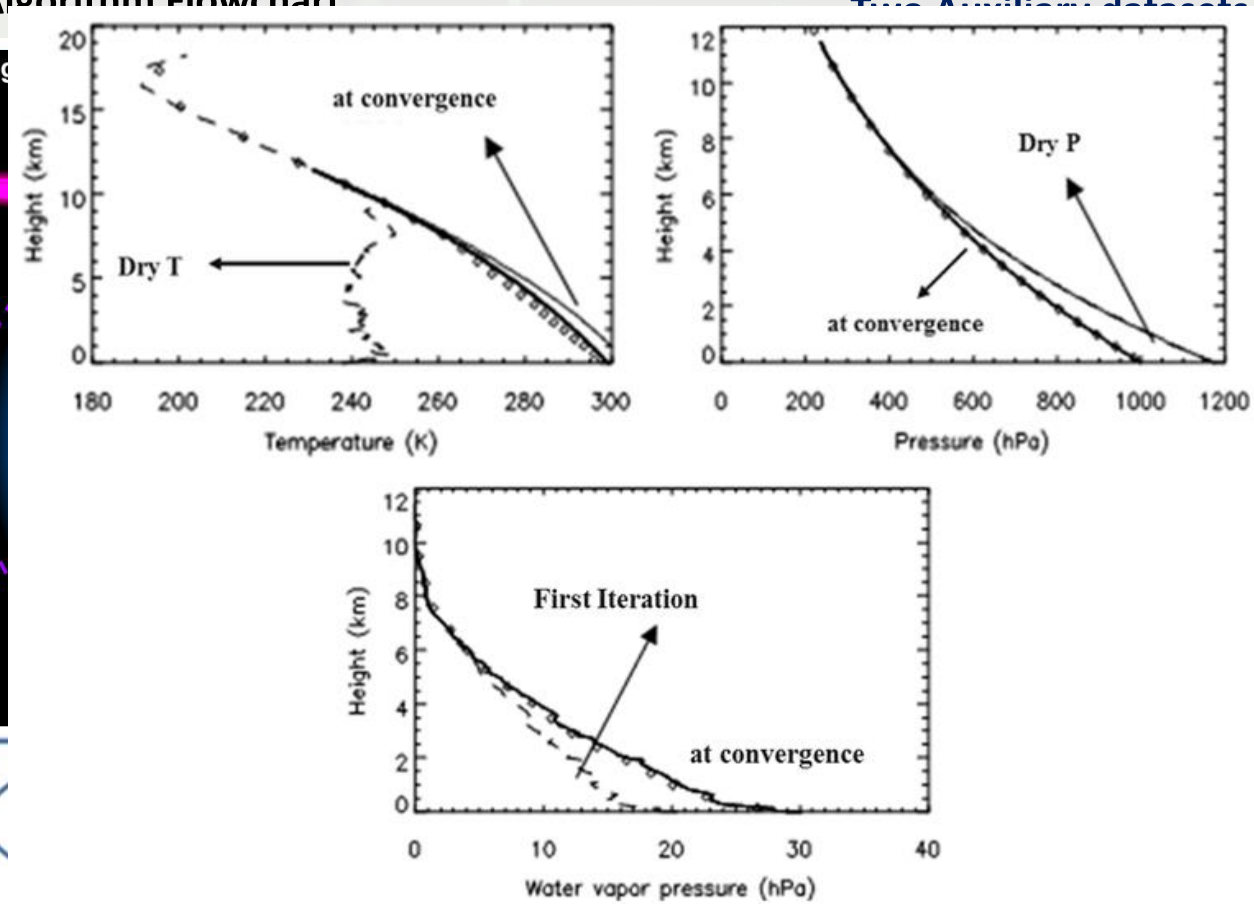
Use a' priori T, P and e profiles & their error covariance as background together with observation and its error covariance

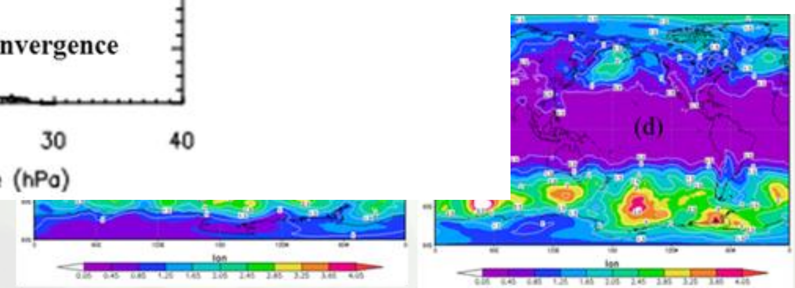
Description of the Algorithm for Retrieval of Geophysical Parameters from Refractivity

Algorithm Flowchart

Two Auxiliary datasets used in the

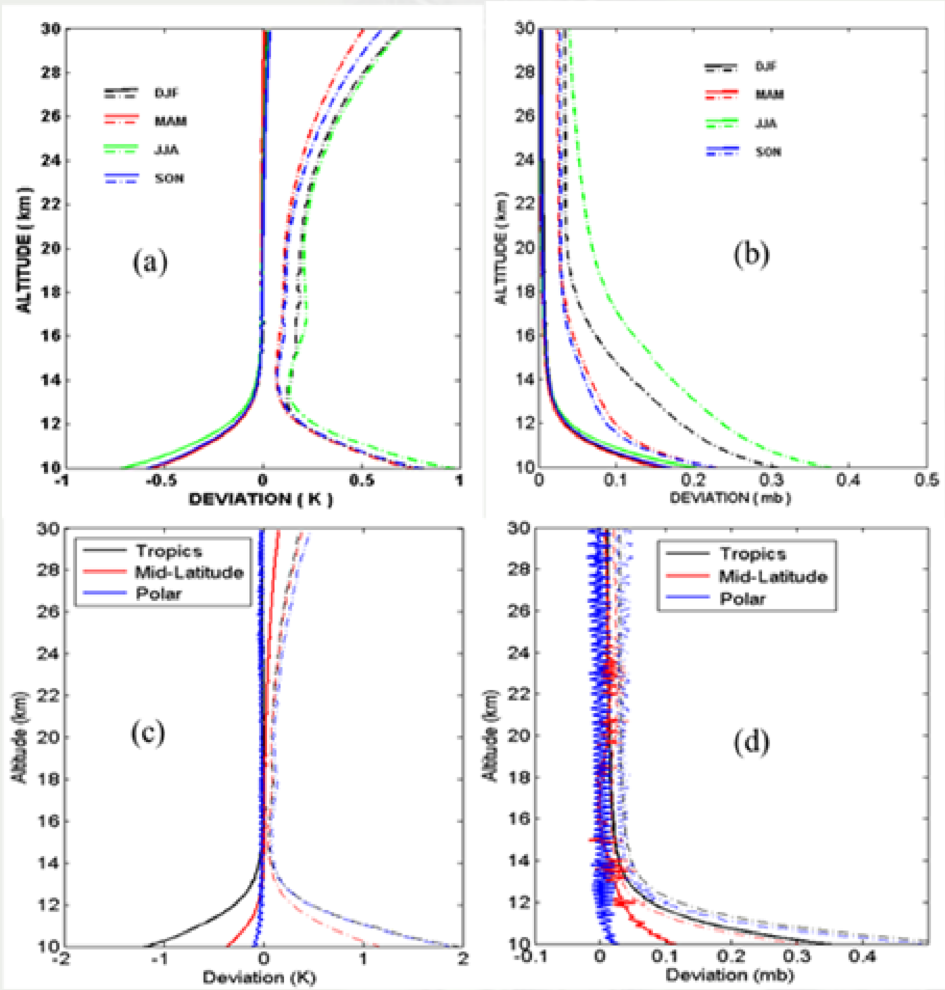




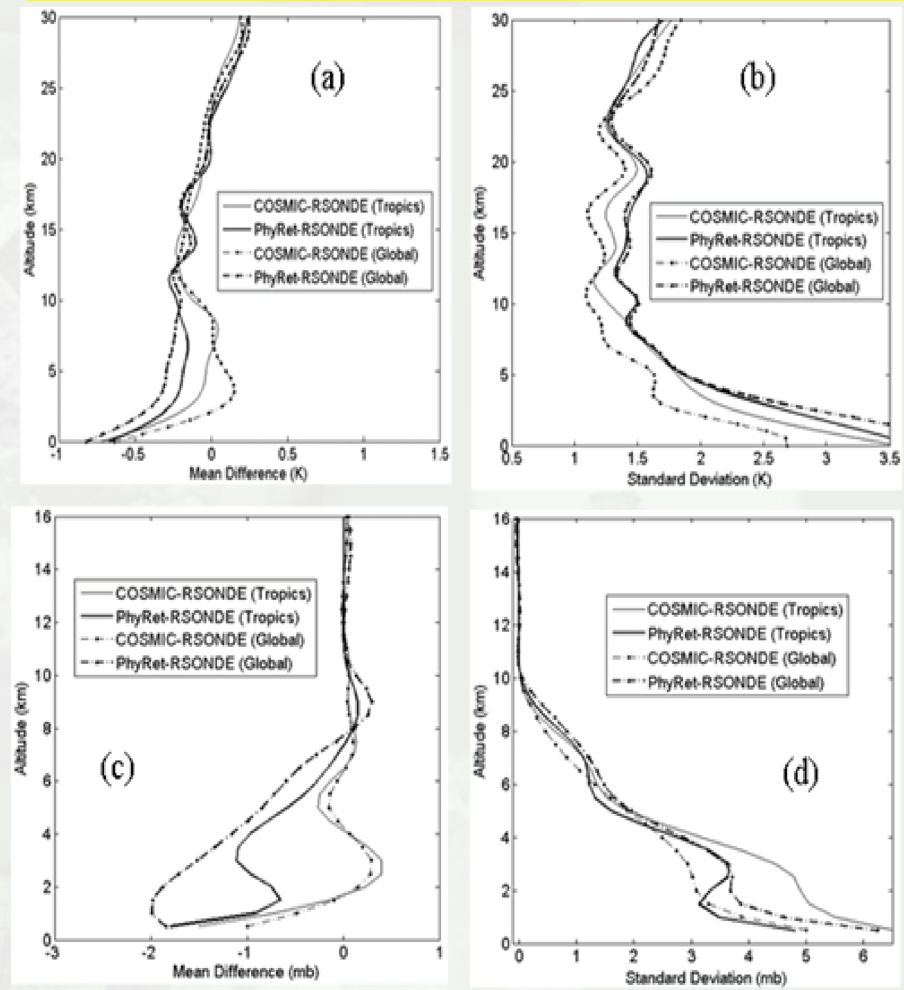


Validation of derived 'Dry' and Actual Geophysical Parameters

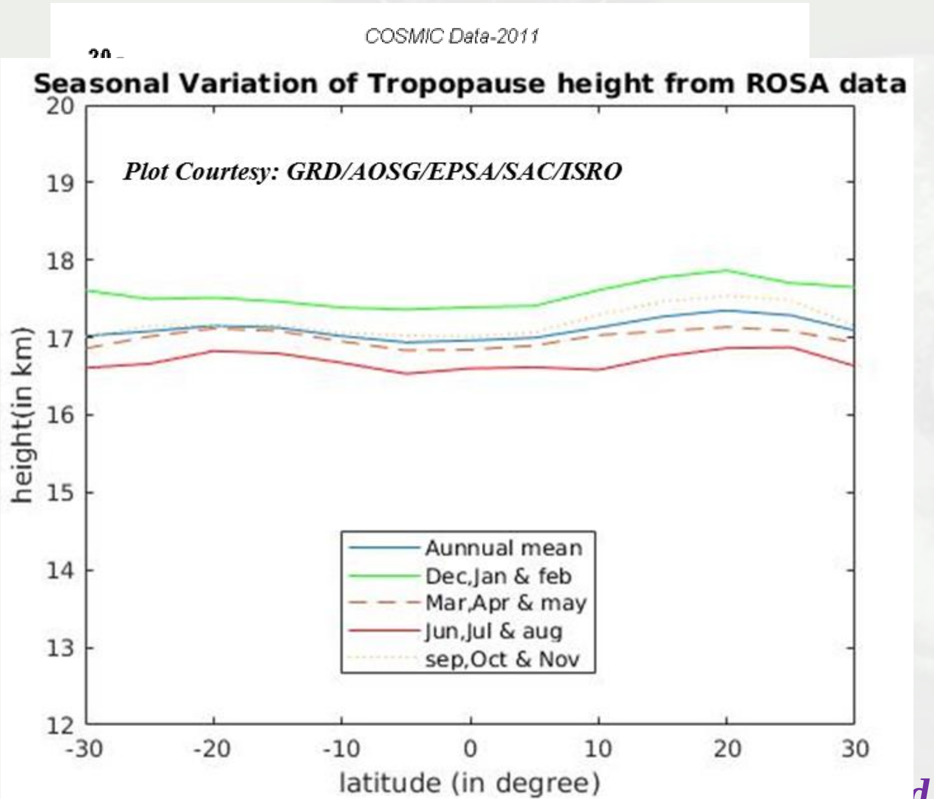
Seasonal and Geographical comparison of 'Dry' Retrieval from MT-ROSA against COSMIC 1DVAR

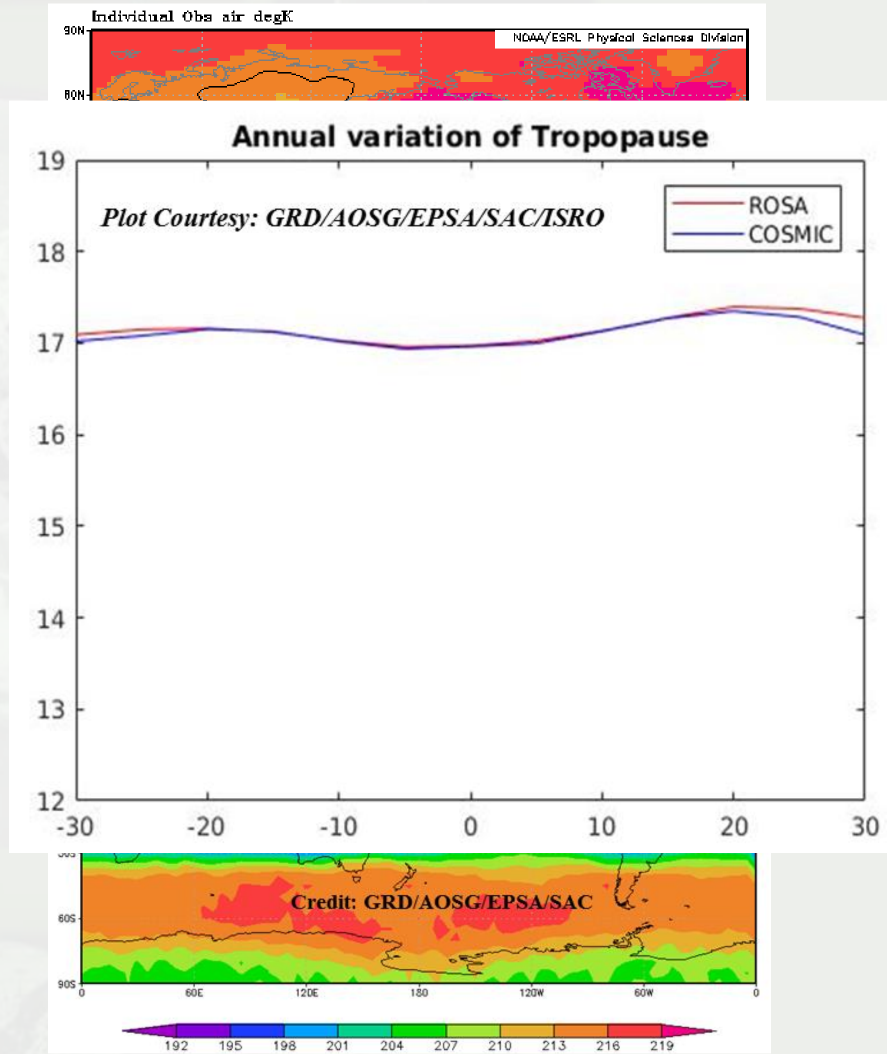


Mean and Standard deviation of actual T & wvpp for MT-ROSA and COSMIC against Radiosonde



Tropopause determination using GNSS-RO Refractivity from COSMIC and Comparison against NCEP Reanalyses





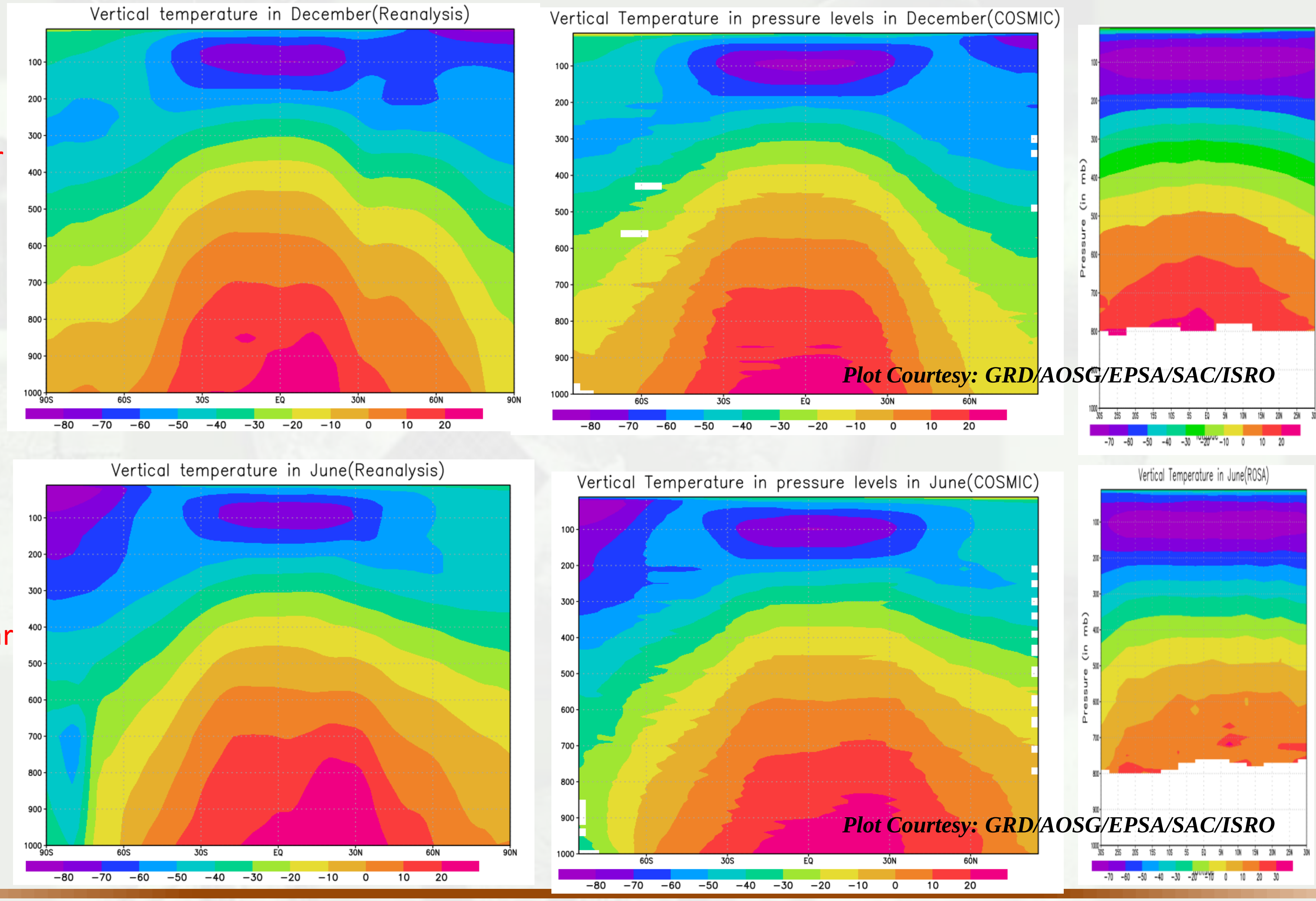
match with the NCEP reanalysis data; cold point Method show anomaly in the extra-tropics but is a good representative for tropics.

Comparison of RO Temperature Profiles against NCEP Reanalysis

NCEP-Reanalysis | COSMIC | MT-ROSA

Boreal Winter (Year 2017)

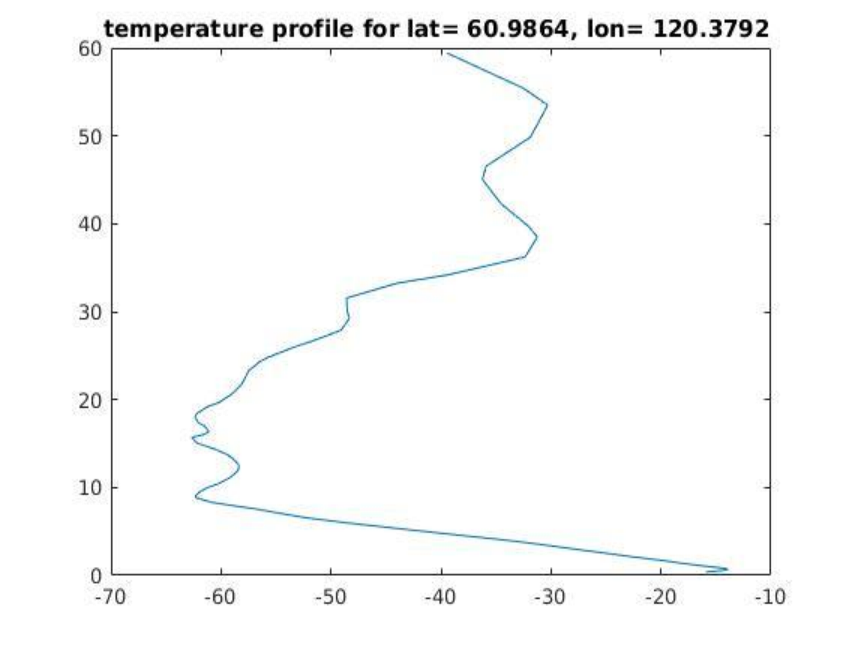
Boreal Summer (Year 2017)

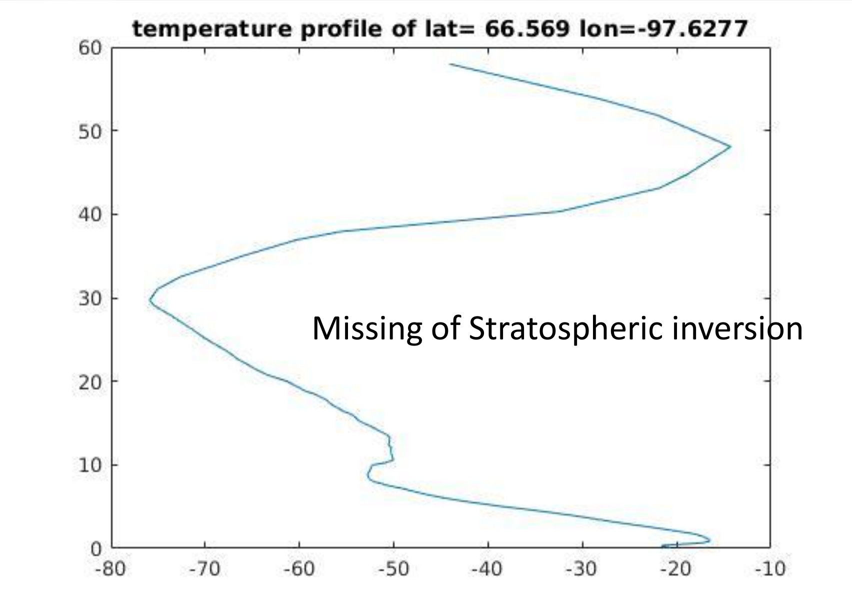


Hidden phenomena revealed by high-resolution GNSS-RO Temperature profile

Two cases of apparently unusual temperature profiles but with signatures of underlying phenomena

Multiple tropopauses as shown by figure below are normally unrevealed in nadir-based sounding technique. Excellent capture in GNSS-RO temperature data.

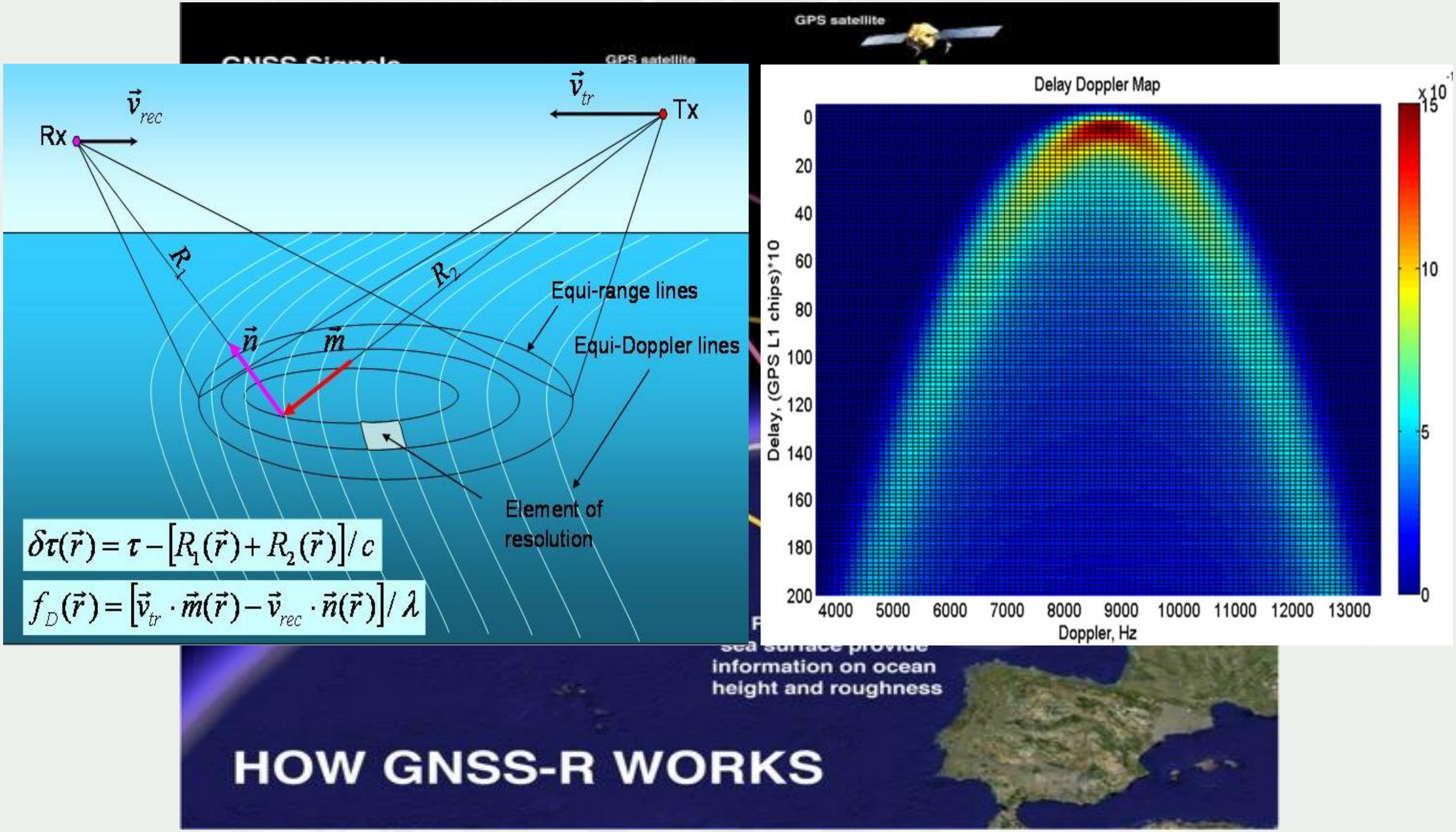




Theoretically, temperature should increase in stratosphere. But, the figure above shows different pattern from normal observations as seen in COSMIC GPS-RO Temperature profile.

Plot Courtesy: GRD/AOSG/EPSA/SAC/ISRO

Overview of GNSS-Reflectometry and basic observable



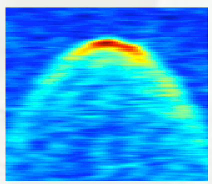
Approaches for Retrieving Ocean Surface Winds from GNSS-R derived DDM

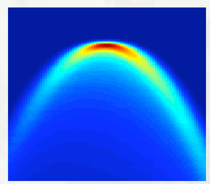
Wind Retrieval Approaches

Hybrid Method (Combined Physical-empirical modeling)

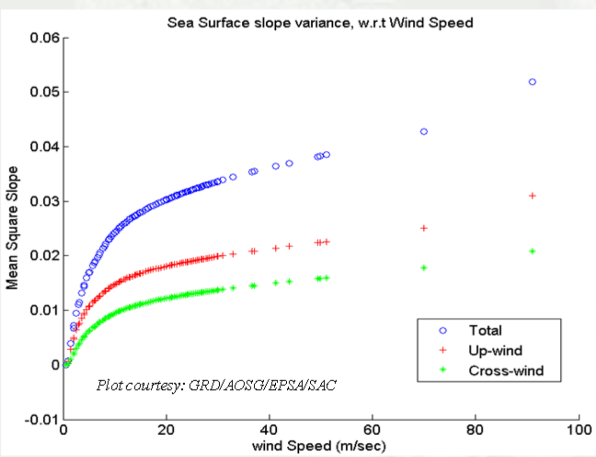
$$[DMSS, PWSD]_{opt} = \underbrace{\min_{\substack{DMSS\\PWSD}} arg} \{[\langle P_{meas}(\hat{\tau}, \hat{f}^D)\rangle - \langle P_{Z-V}(\hat{\tau}, \hat{f}^D)\rangle]^2$$

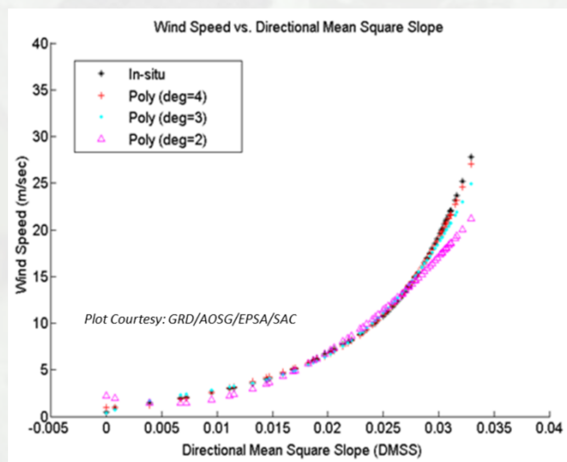
Measured DDM of avg. reflected power





Simulated avg. power using Zavorotny-Voronovich model

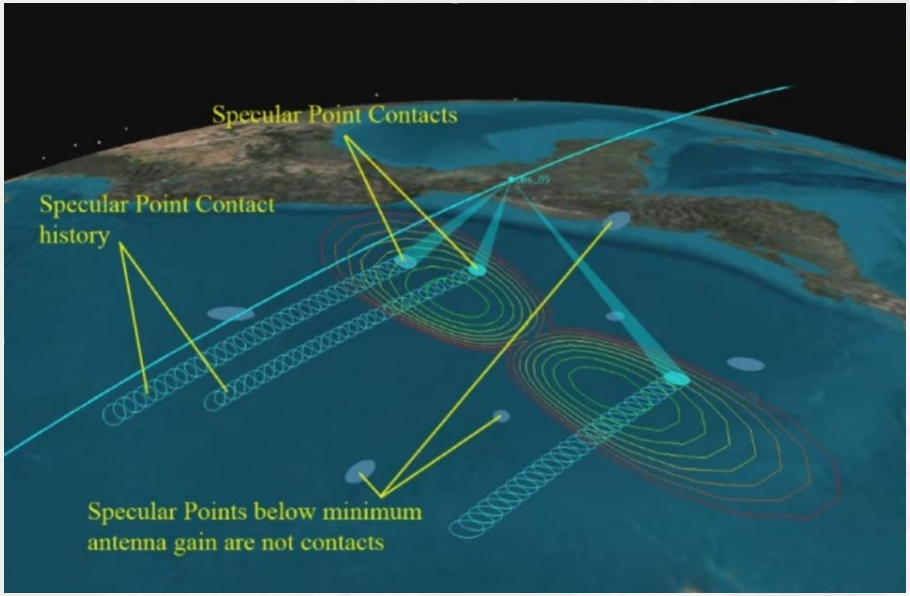


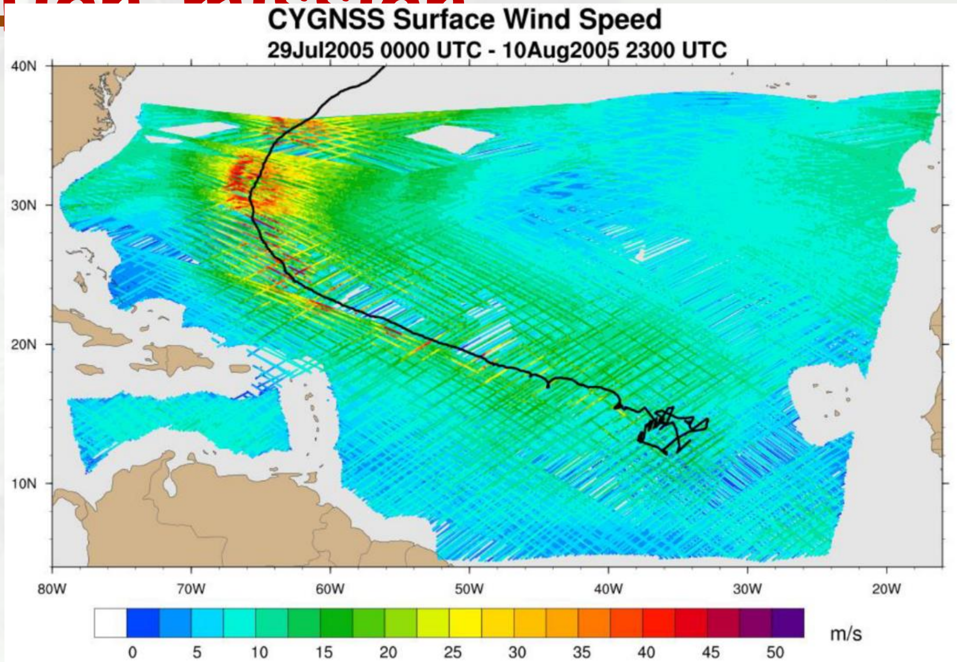


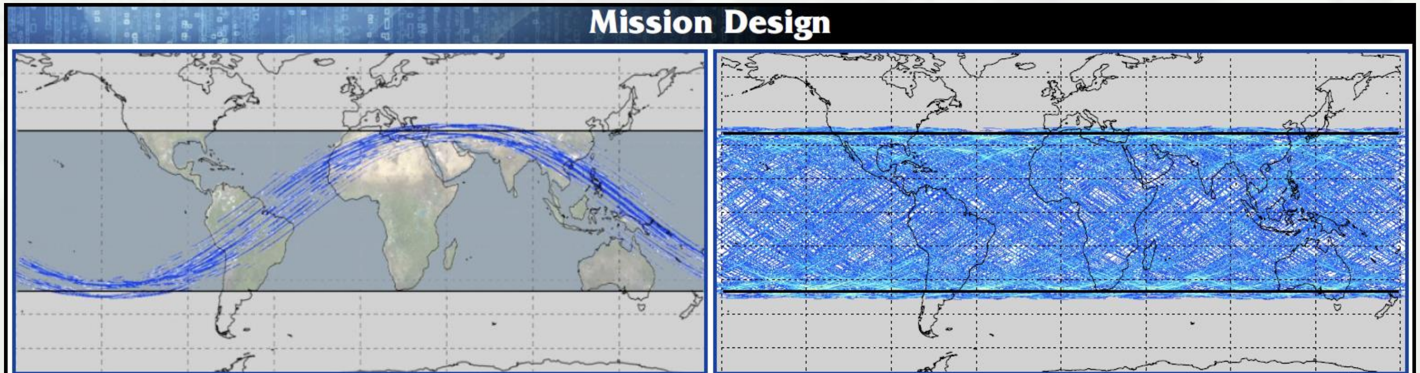
Empirically derived Wind GMF Method

- Derive NRCS at specular point from DDM inversion
- Prepare match-up wind data with collocated NRCS.
- Establish Geophysical Model Function (GMF) between match-up wind and NRCS
- Wind retrieval using the GMF applied to derived NRCS from satellite measured DDM.

CYGNSS: First-ever GNSS-R constellation mission



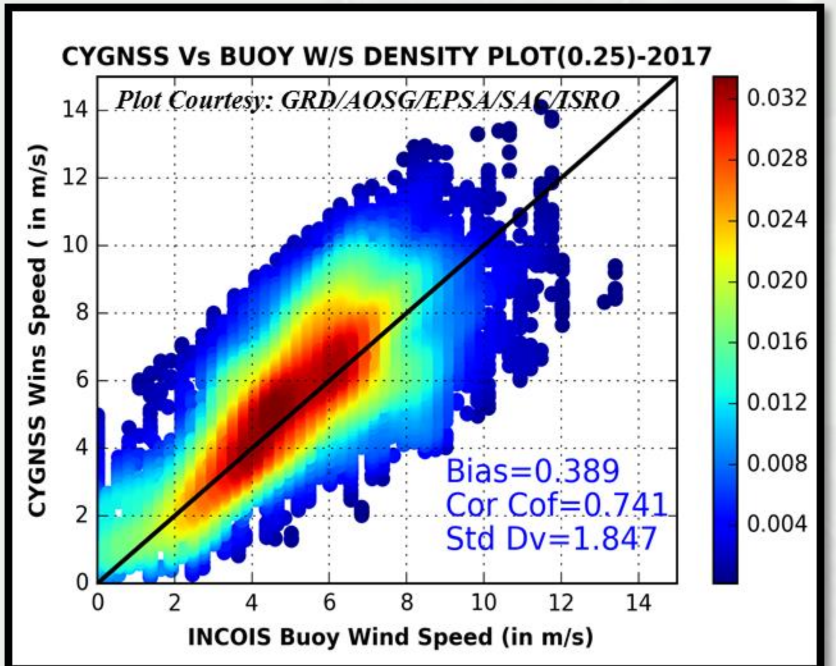


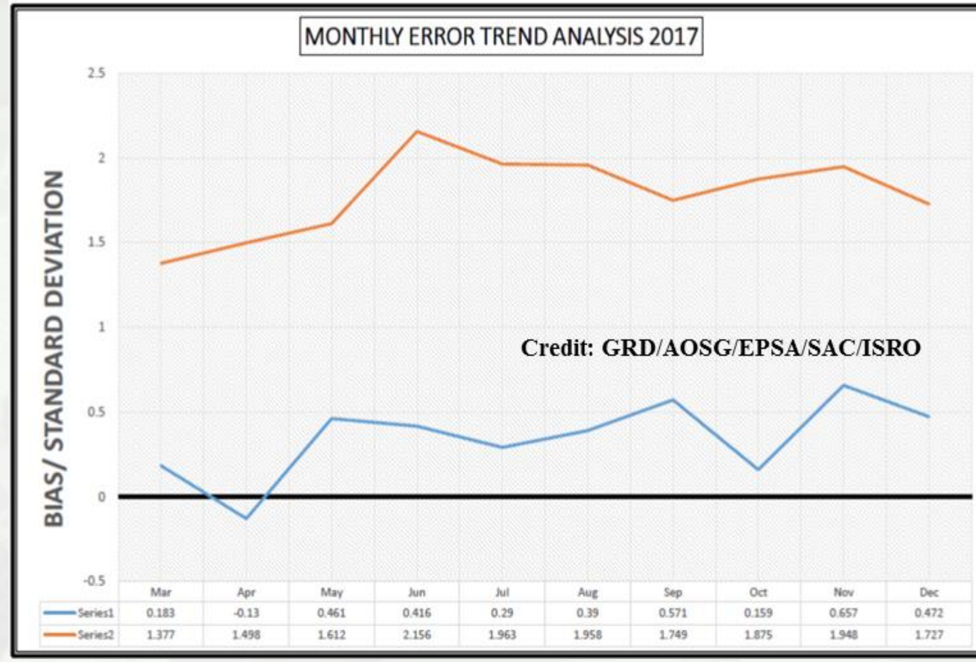


The 8 LEO S/C orbit at an inclination of 35°, and are each capable of measuring 4 simultaneous reflections, resulting in 32 wind measurements per second across the globe. Ground tracks for 90 minutes (left) and a full day (right) of wind samples are shown above. The number of S/C, their orbit altitudes and inclinations, and the alignment of the antennas are all optimized to provide unprecedented high temporal-resolution wind field imagery of TC genesis, intensification and decay.

Courtesy: www.nasa.gov/cygnss

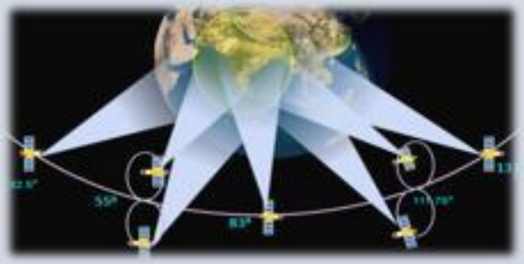
Assessment of Wind Potential of GNSS-R: Validation of CYGNSS Wind Speed





Remarks:

- CYGNSS wind speed shows bias of 0.35 m/s and standard deviation of 1.84 m/s against in-situ buoy wind speed for the year 2017 with a correlation coefficient of 0.74.
- Monthly bias trend (right fig.) is within ±0.5 m/s except for 0.65 m/s in November 2017. Standard deviation is better than 2 m/s in all the months except for June 2017 with a value of 2.1 m/s.
- The validation outcome demonstrates the comparable wind speed accuracy in all weather conditions from CYGNSS with that from scatterometers.




Thank You