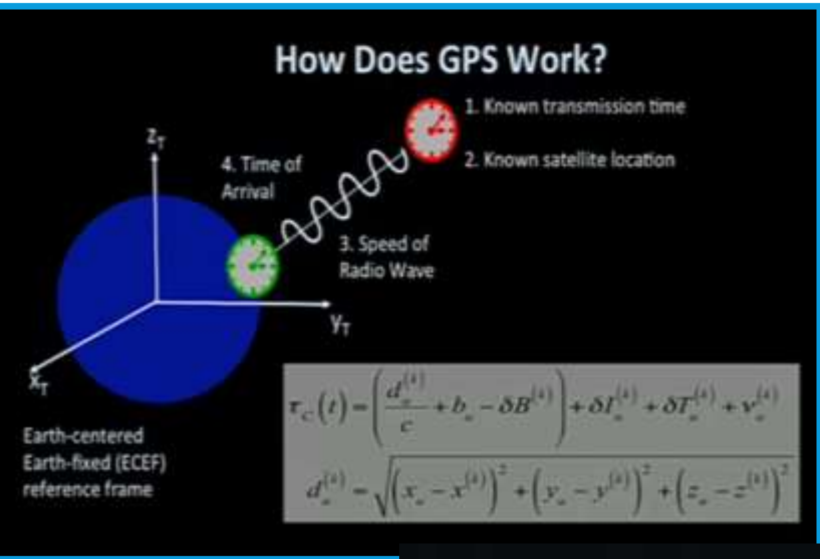
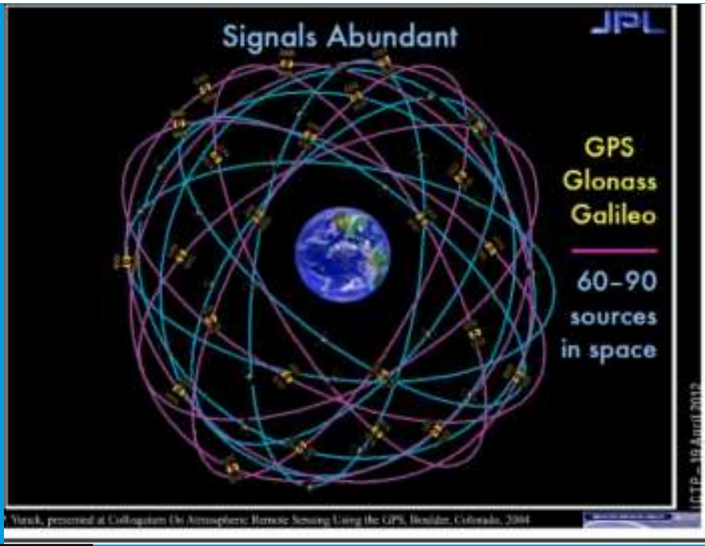
DEVELOPMENT & SIMULATION OF GNSS-RO RECEIVER FOR SOUNDING ATMOSPHERIC LAYERS IN WEATHER FORECASTING & SPACE WEATHER MONITORING

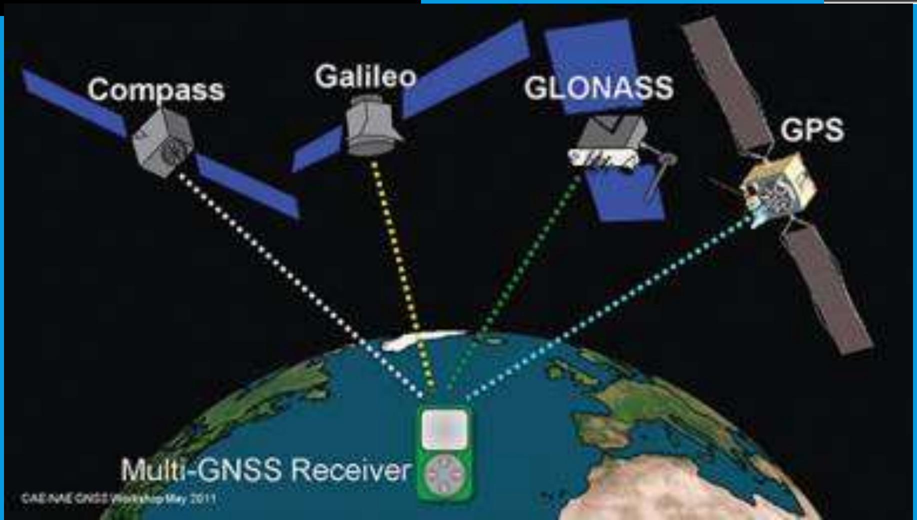
- **Kgabo Mathapo - Motseni-HI-TechSpace (MHTS)**
- MHTS Company specializes in Design & Development of:
  - GNSS Radio Occultation Receivers (& GNSS-R) For Weather Prediction and Space Weather Monitoring (TEC)
  - AIS, VDES for Maritime monitoring/Comms
  - RF & Microwave Subsystems , Satellite TT&C Transceivers
  - Radar Subsystems & Inter-Satellite Links Transceivers

CYCLONES, STORMS, NATURAL DISASTERS, CLIMATE CHANGE & SPACE WEATHER EFFECTS ACCURATE WEATHER FORECASTING IMPORTANT

LEVERAGING EXISTING GNSS SPACE SEGMENT- GNSS SATELLITES

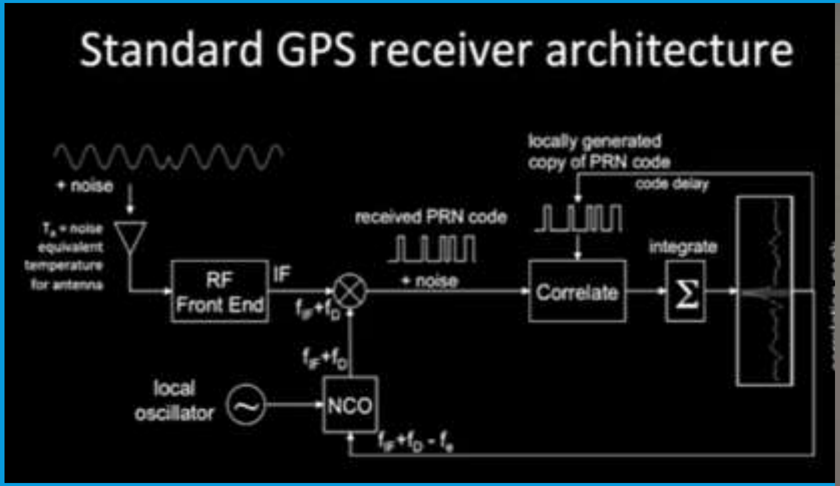


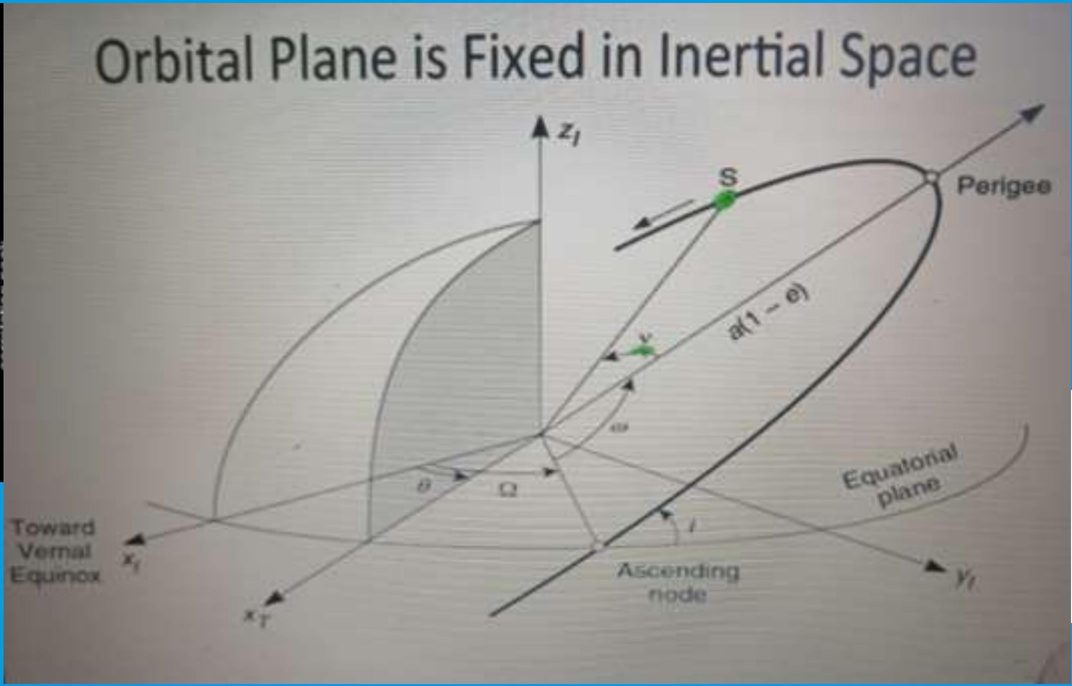




GPS-EXAMPLE OF GNSS SATELLITE SYSTEM

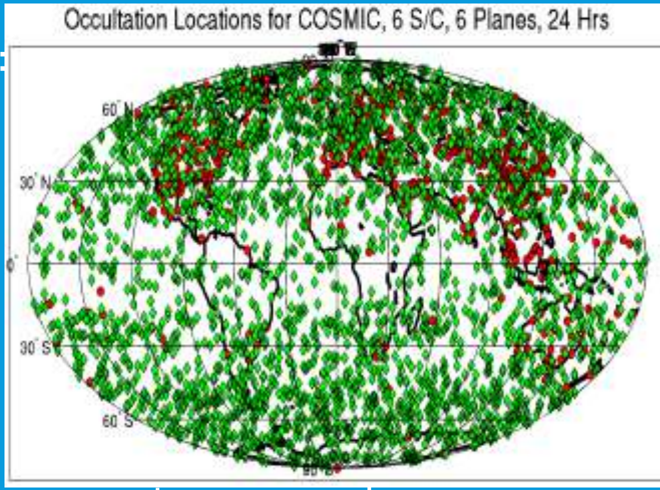
- GPS satellites – Precise atomic clock frequency of 10.23 MHz, Measurements
- L1 and L2- frequencies of 1575.42 MHz and 1227.60 respectively
- Both the L1, L1C and L2, L2C (new L5) carrier signals carry CA & P(Y) (PRN) Code
- Navigation Msg - satellite orbits Clock/Time Stamp, Position, Status and correction data.



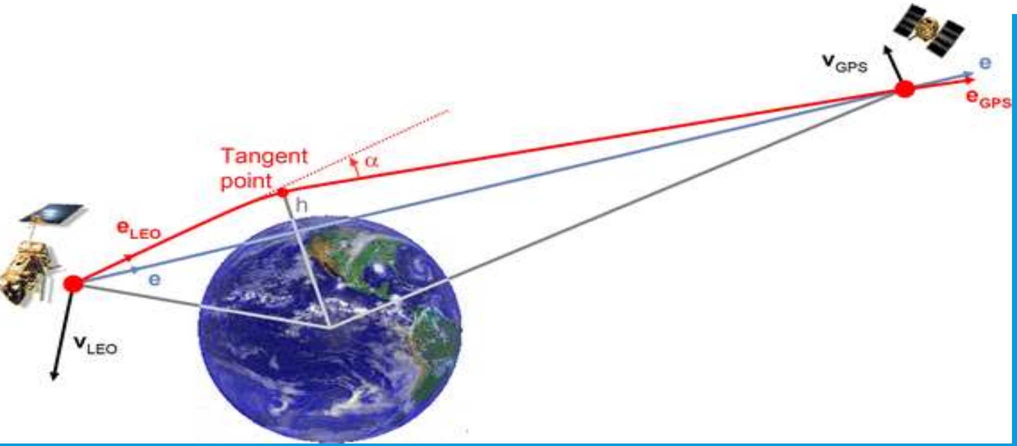


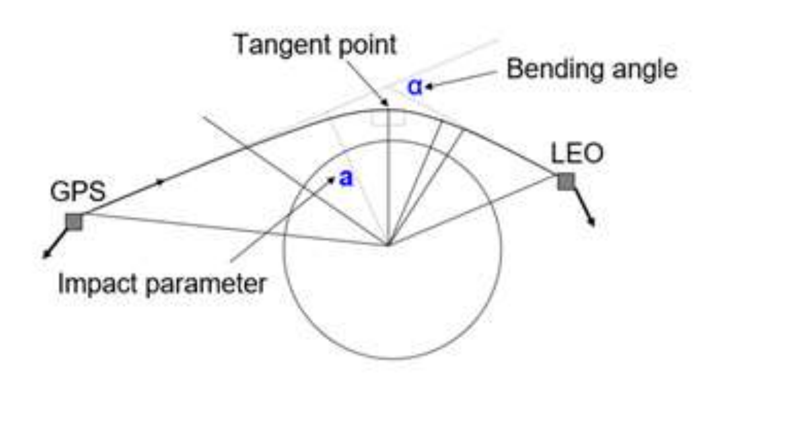
GNSS-RO AS A COMPLEMENTARY SYSTEM TO TRADITIONAL METHODS & IMPROVING ACCURACY OF FORECASTING

- Traditional methods for sounding the atmosphere and Ionosphere
- Weather forecasting & Space weather monitoring are:
- Radio Sondes & Radar – Weather
- Ionosondes, Digisondes & Radar – Space weather
- Systems performs bottom up sounding & Land based
- Limited in range
- Vast oceans and land in Africa & Southern Hemisphere are not measured
- Radio occultation fill in that gap



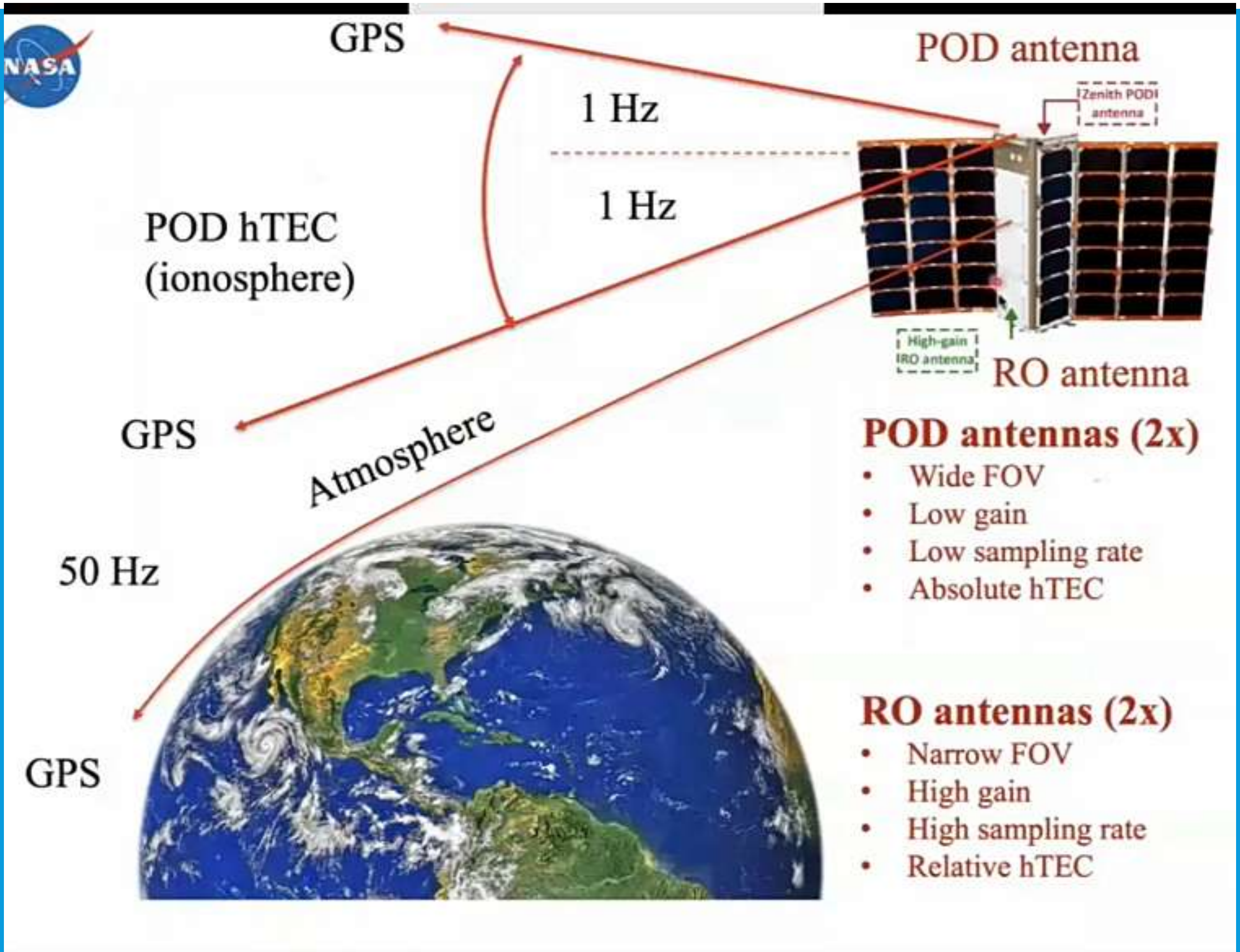
RADIO OCCULTATION (RO) PRINCIPLES



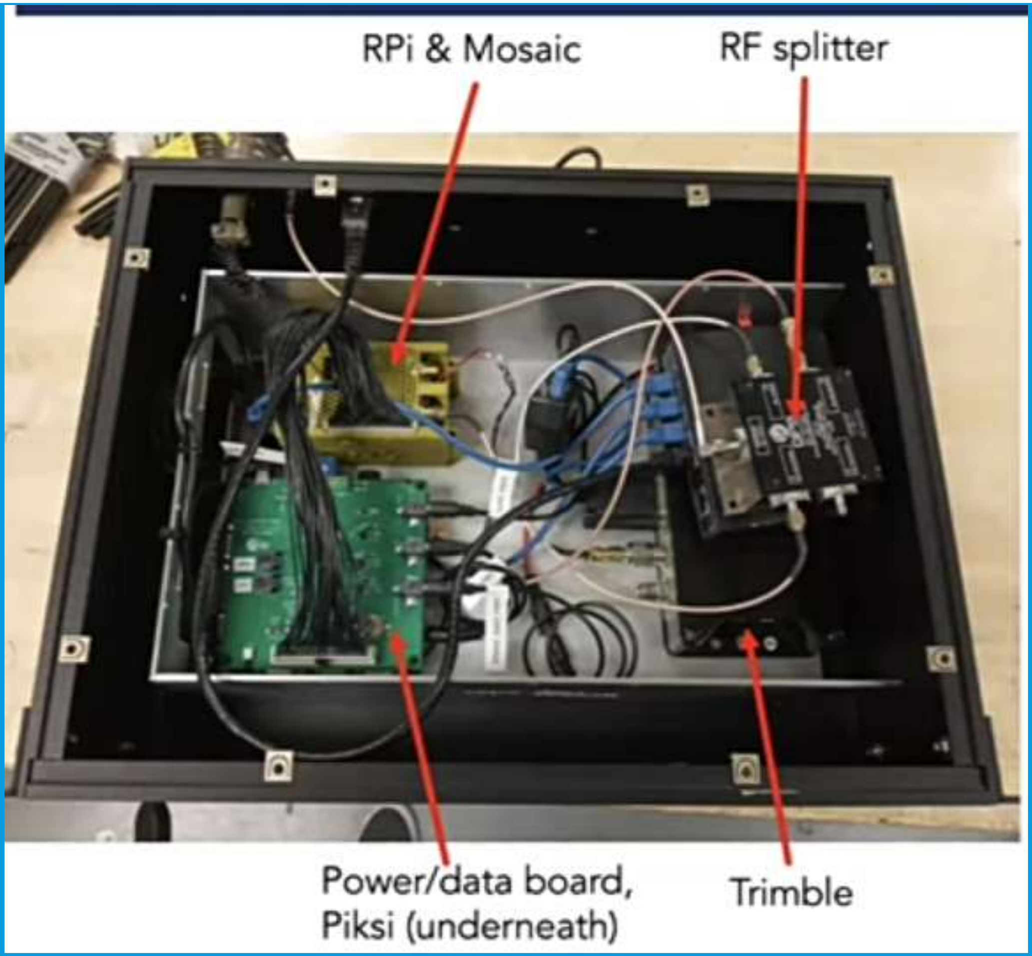


- Radio Occultation is the exploitation of GNSS satellites signals in an active limb sounding
- A GNSS signal will bend/refract when it encounters changes in the Earth's atmosphere.
- Receiver on LEO satellite tracks these signals as the GNSS satellite rises and sets behind Earth
- Enable computation of the vertical refractivity profile from the LEO orbit height down to the surface.
- That bend is used to collect specific weather data for e.g Oceans & Southern Hemisphere
- From the I&Q signals we get doppler (excess phase), and from doppler bending angle.
- refractivity profiles can be extracted from bending angle using inversion methods.

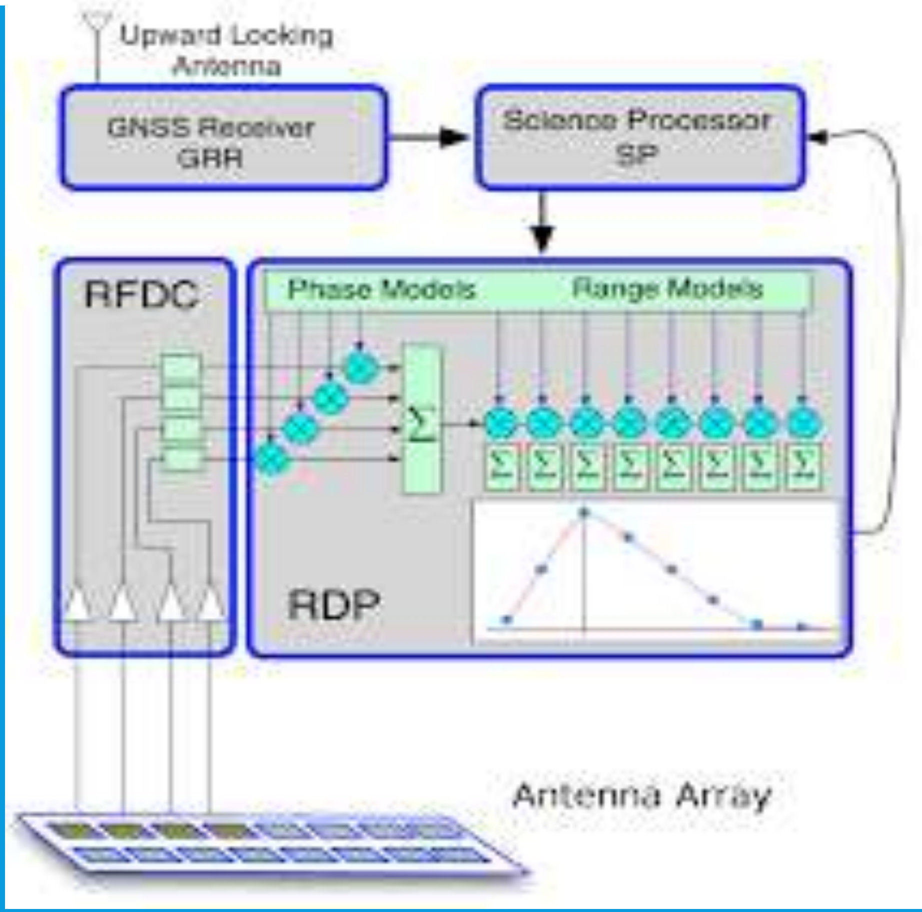
GNSS-RO PAYLOAD ONBOARD CUBESAT

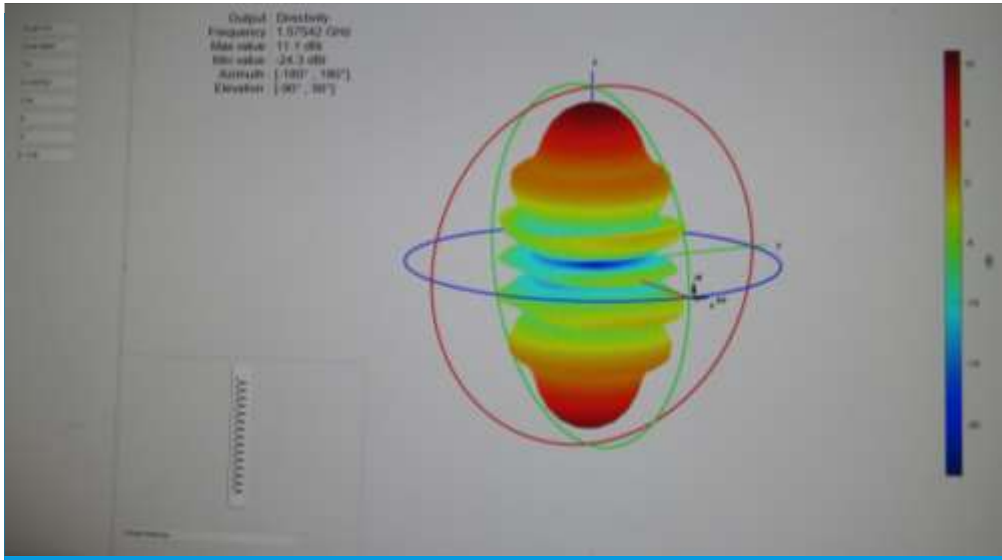


GNSS RO RECEIVERS: DOWN-CONVERTER & I&Q PROCESSING

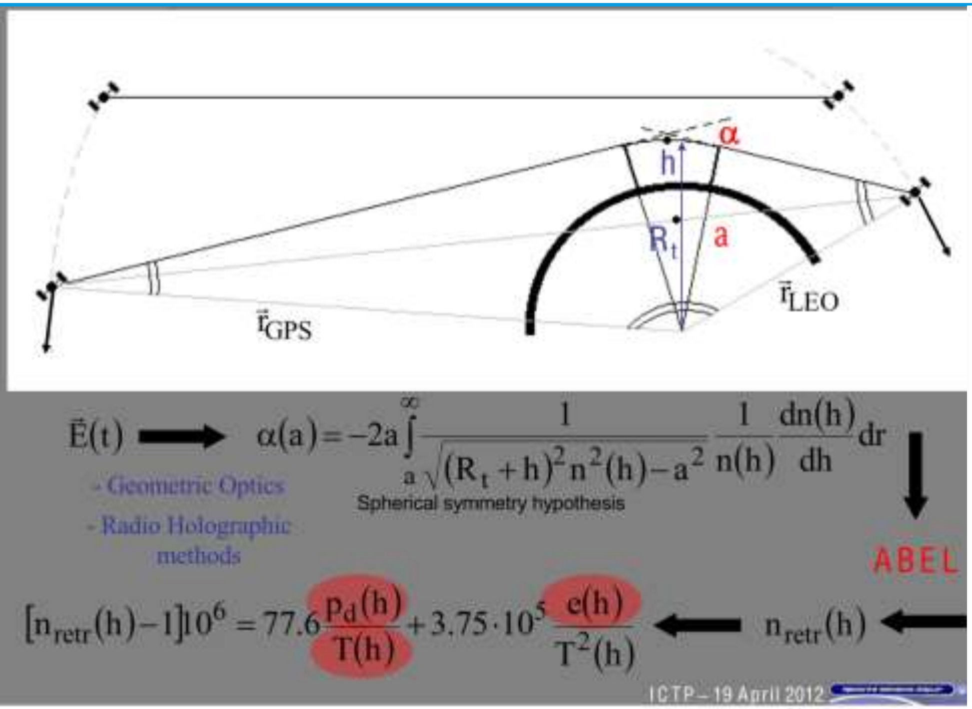


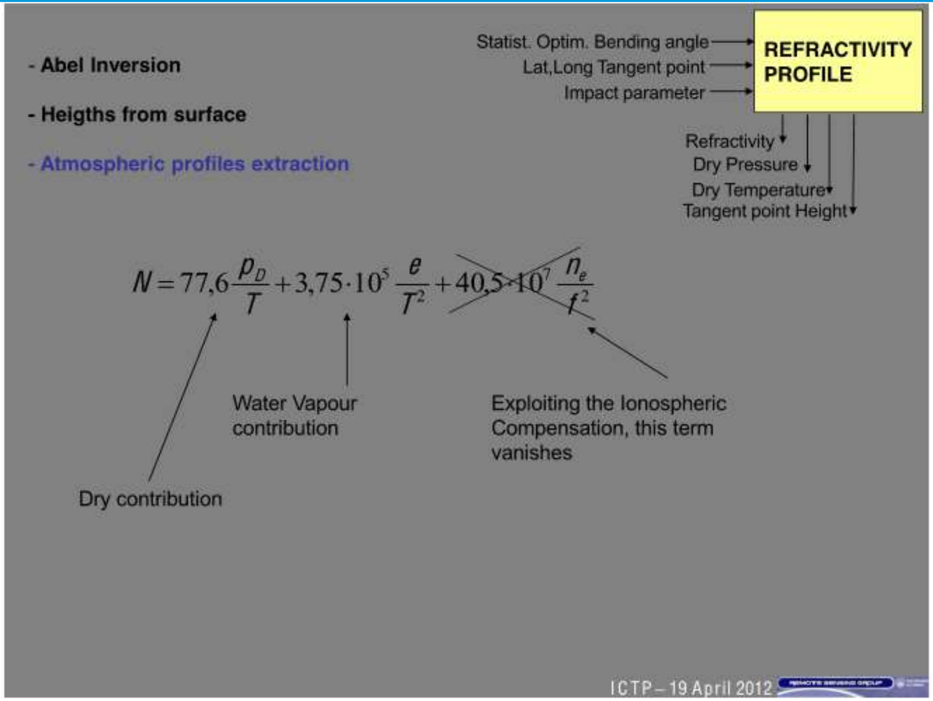
GNSS RO RECEIVER FUNCTIONAL DIAGRAM NEE TWO (2) RECEIVERS =POD & GNSS-RO RECEIVERS





GNSS RO - SPHERICAL GEOMETRY - GEOMETRIC OPTICS & WAVE OPTICS





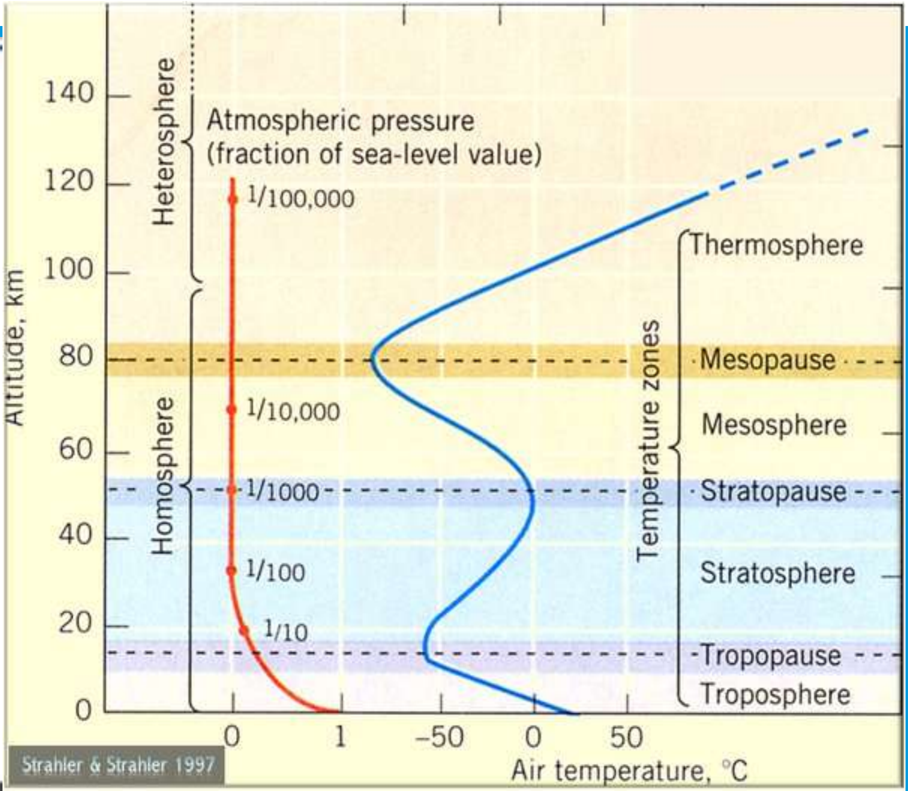
GEOMETRIC OPTICS & WAVE OPTICS

ATMOSPHERIC REFRACTIVITY

- Function of
  - Pressure (P)
  - Temperature (T)
  - Water vapor (P_W)
  - Electron density (n_e)

$$N = 77.6\frac{P}{T} + 3.73\times10^{-5}\frac{P_w}{T^2} - 4.03\times10^{7}\frac{n_e}{f^2}$$

  - Ionosphere free combinations processed to remove n_e
- Operational weather models ingest bending angles and compute their own N, P, T, P_W



IONOSPHERIC ERRORS CORRECTION USING DUAL FREQUENCY

Dual Frequency for Ionospheric Measurement

Ionospheric errors are around 10 - 20 meters

Single frequency users use a model to cut the error in half.

Dual frequency users can measure the ionosphere in real time.

$$\tau_{L1} = \rho + \frac{40.3TEC}{f_{L1}^2} \text{ meters and } \tau_{L2} = \rho + \frac{40.3TEC}{f_{L2}^2} \text{ meters}$$

$$\tau_{\text{iono-free}} = \alpha\tau_{L1} + \beta\tau_{L2}$$

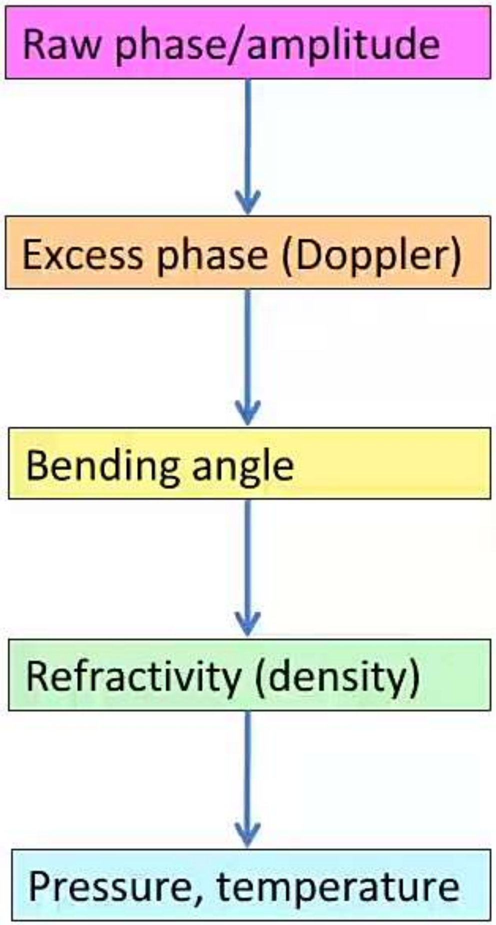
$$\text{where } \alpha + \beta = 1 \text{ and } \alpha\frac{40.3TEC}{f_{L1}^2} + \beta\frac{40.3TEC}{f_{L2}^2} = 0$$

$$\alpha = 2.54573 \text{ and } \beta = -1.54573$$

GNSS RO RETRIEVAL PROCESS DATA PROCESSING CENTRES

- GNSS Ground data (NTRIP) real time files
- IGS Orbit products (GNSS Orbit clocks, Antenna phase centers)
- Ground Station to download the data
- Data Processing & Archive Units
- GNSS Precise Orbit Determination (POD) Data
- LEO Navigation Observations (LEO Attitude)
- LEO GNSS RO Observations (50 – 100 Hz) &
- GND Navigation message Bits – resolve ambiquities

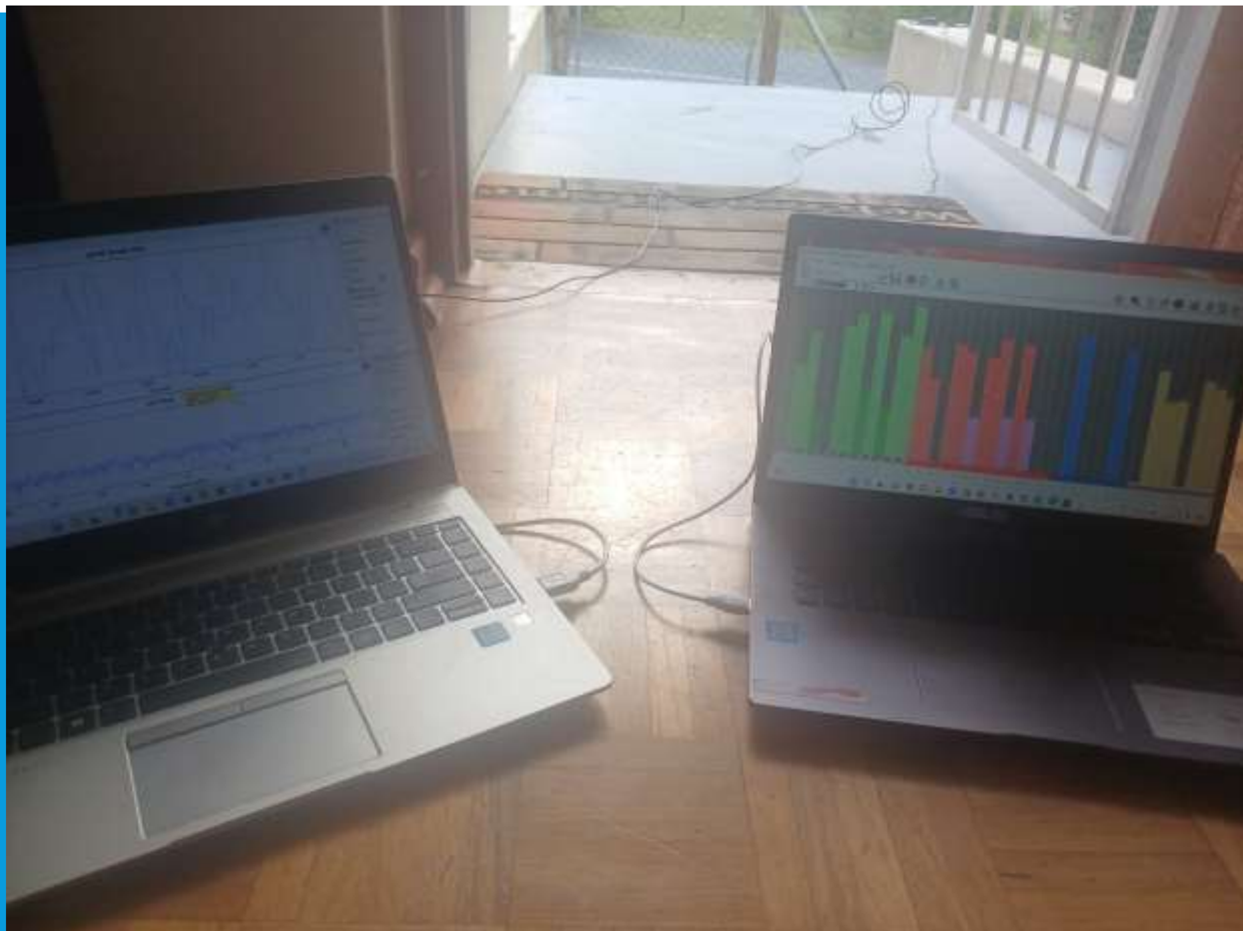
GNSS RO RETRIEVAL PROCESS



- Precise orbit determination, excess phase computation (extra path length)
- Local transform, no error propagation
- Non-local transform, error propagation downward
- Non-local transform (hydrostatic integration), error propagation downward

MEASUREMENTS WITH REAL GNSS SIGNALS: OVER THE AIR TESTING

MEASUREMENTS WITH REAL LIVE GNSS SIGNALS



GNSS RO RECEIVER SPECS

- Spatial Resolution
  - High vertical resolution of ~100m -500m in the troposphere,
  - And 1.5km above the troposphere.
  - horizontal resolution of ~200-400 km, due to the limb sounding geometry.

- Temporal Resolution/ repeat coverage
  - With one satellite, One or four times a day (6-12 hours)
  - But if ground stations are increased, four or eight times a day (3 -6 hours)
  - With 6 satellites in Constellation, and 3 -4 ground stations, 12-24 times a day~ 0.5 to 1 hour revisit

GNSS RO BENEFITS & CONCLUSION

- WMO climate monitoring requirements are: 0.5 K accuracy and 0.04K/dec stability.
- RO measurements that are calibrated using atomic clocks.
- The RO technique provides measurements with very high accuracy (<1 K for individual profiles and <0.2 K for averages) and precision (<0.05 K)
- Low operational costs, Insensitivity to clouds, and high precision and absolute calibration.
- RO can collect information about atmospheric conditions in remote parts of the globe where air balloons, digisondes and weather stations can't reach, e.g Beyond offshore & deep seas.
- RO has Low Horizontal resolution
- RO is precise, accurate, and all-weather global observations/global profile
- Forecasts of tropical cyclone formation and tracking in oceans.
- Major Global NWP centres now assimilate GNSS-RO measurements. NWP centres assimilate either: –Bending angle profiles (ECMWF, MF, Met Office, DWD, NRL, NCEP) –Refractivity (EC, JMA
- The RO soundings provide global measurements of ABL heights and their seasonal
- RO is precise, accurate, and all-weather global observations/global profile

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