GNSS for Ionospheric Studies

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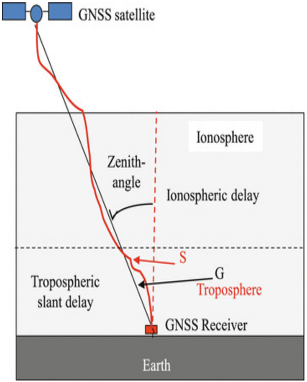
Global Navigation Satellite Systems (GNSS)

A satellite system primarily for navigation. Now days GNSS is used for surveying, geodesy, geophysics and meteorology. GNSS include

- Global Positioning System (GPS) - USA
- GLObal NAvigation Satellite System (GLONASS)
- Galileo - Europe
- Compass or (Beidou-2) - China
- etc

GNSS signal propagation



- The atmosphere delays Radio signals
- The excess path $\propto$ refractive index (N)
- Total delay $= \underbrace{\int_R^S N_A(\rho) dl}_{\text{Tropospheric}} + \underbrace{\int_R^S N_I(n_e) dl}_{\text{Ionospheric}}$
- Tropospheric $= \underbrace{\text{ZHD}}_{\text{dry delay}} + \underbrace{\text{ZWD}}_{\text{wet delay}}$
- The ionospheric delay is given by

$$I = \pm \frac{40.3}{f^2} \int_R^T N_e ds$$

How is the TEC derived?

- GNSS signals are transmitted at two coherent frequencies
- The delays on each frequency are

$$
\left.
\begin{aligned}
P1 &= \rho + I_{1g} + \gamma_1^r + \gamma_1^s && \text{(a)} \\
P2 &= \rho + I_{2g} + \gamma_2^r + \gamma_2^s && \text{(b)} \\
L1 &= \rho + I_{1\phi} + \Omega_1 + \varepsilon_1^r + \varepsilon_1^s && \text{(c)} \\
L2 &= \rho + I_{2\phi} + \Omega_2 + \varepsilon_2^r + \varepsilon_2^s && \text{(d)}
\end{aligned}
\right\}
$$

- The delays are computed by the receiver

A typical observavation file

```
     2.11           OBSERVATION DATA    G (GPS)             RINEX VERSION / TYPE
teqc  2010Mar17     gpsops              20110414 21:54:45UTCPGM / RUN BY / DATE
    30.0000                                                 INTERVAL
     1     1                                                WAVELENGTH FACT L1/2
     7    L1    L2    P1    P2    C1    S1    S2            # / TYPES OF OBSERV
Linux 2.4.21-27.ELsmp|Opteron|gcc -static|Linux x86_64|=+   COMMENT
     2.10           OBSERVATION DATA    GPS                 COMMENT
soc2rnx ver 1.20    gpsops              14-Apr-2011 21:54:45COMMENT
S1, if present, is the SNR for the C/A data stream on L1.   COMMENT
 SNR is mapped to RINEX snr flag value [1,4-9]              COMMENT
    SNR:    >316  >100  >31.6  >10  >3.2    >0 bad=0        COMMENT
L1 & L2:        9     8     7     6     5     4     1       COMMENT
GGN                 JPL                                     OBSERVER / AGENCY
CR519993001         ASH701945B_M    SCIS                    ANT # / TYPE
  5482951.3876  3260442.6429   -66519.8489                  APPROX POSITION XYZ
        0.0083        0.0000        0.0000                  ANTENNA: DELTA H/E/N
UC120031617         ASHTECH UZ-12       CQ00                REC # / TYPE / VERS
MBAR                                                        MARKER NAME
33901M001                                                   MARKER NUMBER
                                                            COMMENT
This data is provided as a public service by NASA/JPL.      COMMENT
No warranty is expressed or implied regarding suitability   COMMENT
for use.  For further information, contact:                 COMMENT
Dave Stowers, NASA/JPL m/s 238-600                          COMMENT
4800 Oak Grove Drive, Pasadena CA 91109 USA                 COMMENT
                                                            COMMENT
Forced Modulo Decimation to 30 seconds                      COMMENT
  2011     4     9     0     0    0.0000000     GPS         TIME OF FIRST OBS
                                                            END OF HEADER
 11  4  9  0  0  0.0000000  0  7G25G31G29G22G21G18G12
 108500900.84747  84546128.03247  20647055.3234   20647062.0414   20647056.1884
        50.000          45.000
 122288475.36247  95289692.80647  23270744.9294   23270750.9654   23270743.8644
        40.000          36.000
 124235097.42547  96806562.51647  23641161.1934   23641166.5824   23641161.1134
        40.000          35.000
 120216270.87147  93675004.93347  22876404.9704   22876406.3404   22876405.3104
```

How is the TEC derived?

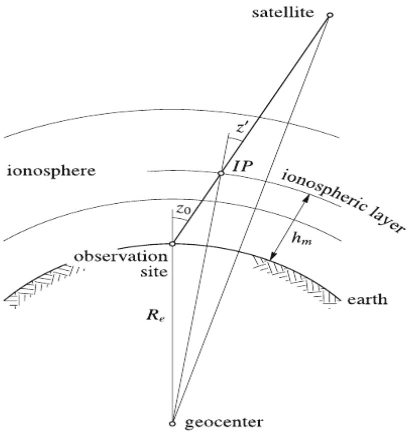
- TEC is obtained from the geometry-free linear combination

$$(\mathrm{P2} - \mathrm{P1}) = 40.3\mathrm{sTEC}_g \left(\frac{1}{f2^2} - \frac{1}{f1^2}\right) + \mathrm{BRS}_g$$

$$(\mathrm{L1} - \mathrm{L2}) = 40.3\mathrm{sTEC}_\phi \left(\frac{1}{f2^2} - \frac{1}{f1^2}\right) + (\Omega_1 - \Omega_2) + \mathrm{BRS}_\phi,$$

- TEC obtained from the above equations is slant TEC

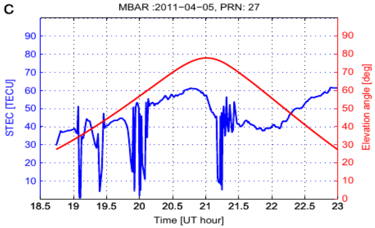
Vertical TEC

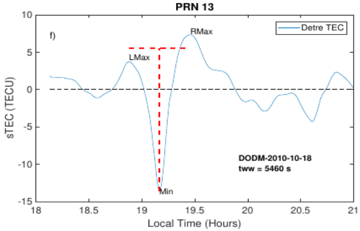


- sTEC is often converted to vTEC using thin shell model
- $\sin z' = \frac{R_e}{R_e+h_m} \sin z_o$,
- The sTEC and the vTEC related by

$$\text{sTEC} = \frac{1}{\cos z'} \text{vTEC}$$

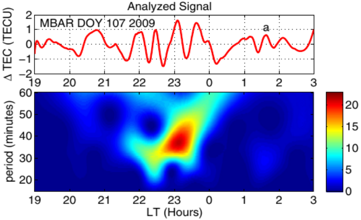
What information can be obtained from TEC?





TIDs

EPBs



TIDs

EPBs

THANK YOU