Obtaining Ionosphere TEC and RM corrections from GPS Observations

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Collaborators

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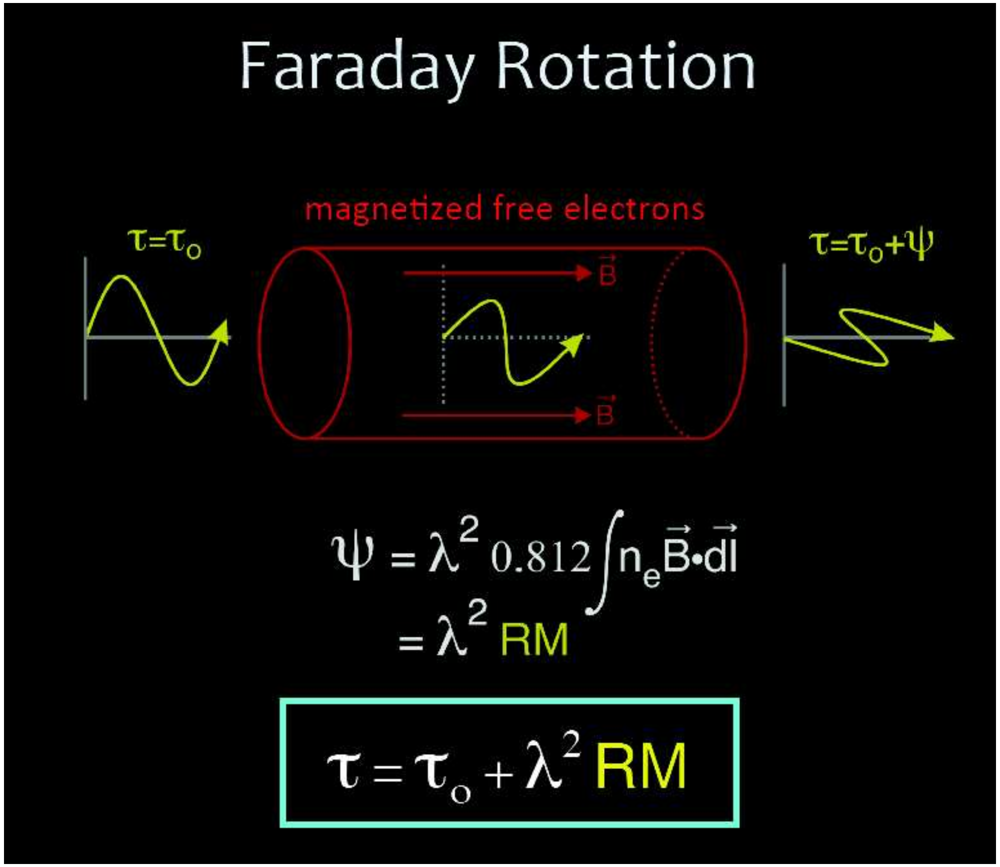
- Emil Lenc, Sydney
- Balwinder Singh Arora, Curtin

Outline of Talk

- Ionospheric Physics
- Global Navigation Satellite System (GNSS)
- Comparison of Different Ionosphere Modelling Packages
- Conclusions

Faraday Rotation



- The ionosphere has a magnetic field going through it plus a bunch of free electrons so ...
  - it produces Faraday rotation on electromagnetic waves coming in from space
- Diagram courtesy Jo-Anne Brown

Ionosphere Distribution of Free Electrons

Ionospheric regions

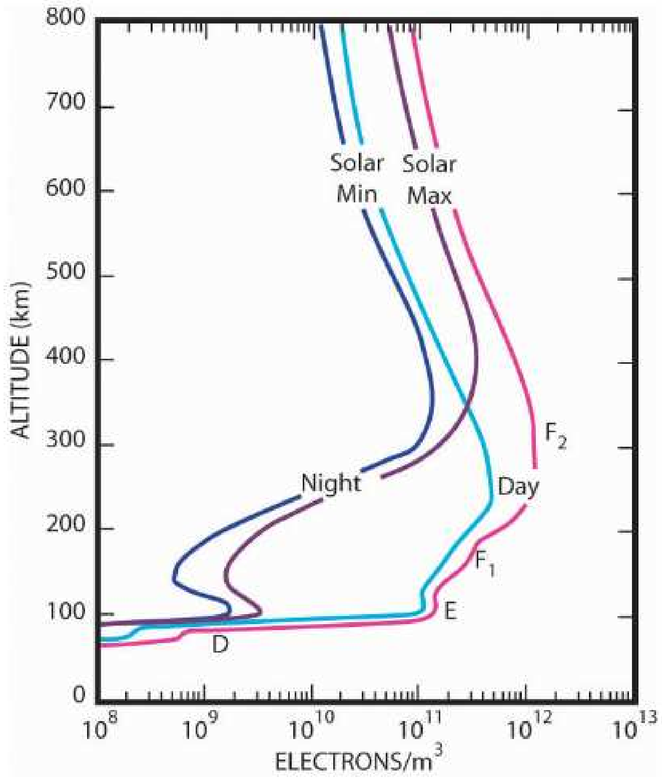


Figure: Typical ionospheric electron density profiles.

Ionospheric regions and typical daytime electron densities:

- D region: 60–90 km, $n_e = 10^8$–10^{10} m^{-3}
- E region: 90–150 km, $n_e = 10^{10}$–10^{11} m^{-3}
- F region: 150–1000 km, $n_e = 10^{11}$–10^{12} m^{-3} .

Ionosphere has great variability:

- Solar cycle variations (in specific upper F region)
- Day-night variation in lower F, E and D regions
- Space weather effects based on short-term solar variability (lower F, E and D regions)

- From ‘Introduction to the ionosphere’ presentation by Anita Aikio, University of Oulu, Finland, 2011

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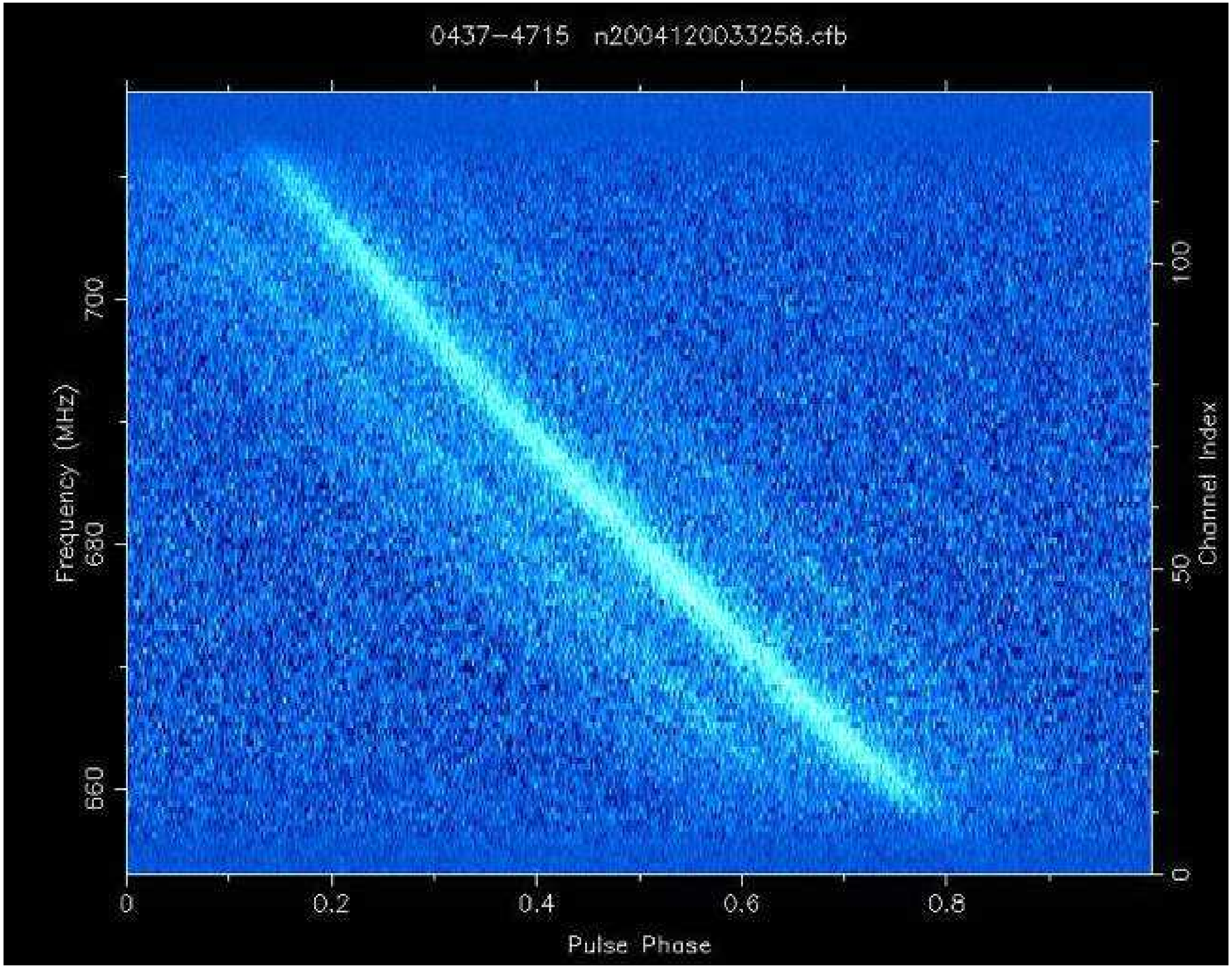
Example of Dispersion in an ionized medium



Really Really Really Basic GPS and Ionospheric Delay

- A GPS Satellite broadcasts at 2 Frequencies in L band
  - L1 = 1575.42 MHz = 19 cm wavelength
  - L2 = 1227.60 MHz = 24 cm wavelength (which is annoying for radio astronomers)
- ionosphere delay $\Delta r = (40.3 * TEC)/f^2$
  - Δr = delay in metres
  - TEC = column density of electrons measured in electrons m^{-2} (1 TECU = 10^{16} electrons m^{-2}) and the frequency is in Hz.
  - 1 TECU of electrons gives a delay of 0.163 metres for L1 and 0.267 metres for L2
  - So every excess of 0.104 metres on L2 - L1 delay corresponds to 1 TECU of electrons
- In an ideal world the only differences in (pseudo)range, P, measured between ground and satellite should be due to the ionosphere delay between L1 and L2
- So (in theory) electron column density in TECU = $(P_{L2} - P_{L1})/0.104m$
- In reality observed TECU = $(P_{L2} - P_{L1})/0.104m$ + instrumental delays + multipath + noise
- The BIG question - how to get rid of measurement errors?
- There’s a bit more to this story, but this is the basic concept
- NOTE: Basic ‘unit’ of GPS = 1 nanosecond, or 30 cm - the distance electromagnetic radiation travels in that time

A ‘Typical’ Example of GPS Antenna

- GPS antenna at DRAO used for Geodetic GPS measurements
- Ionosphere TEC measurements a byproduct

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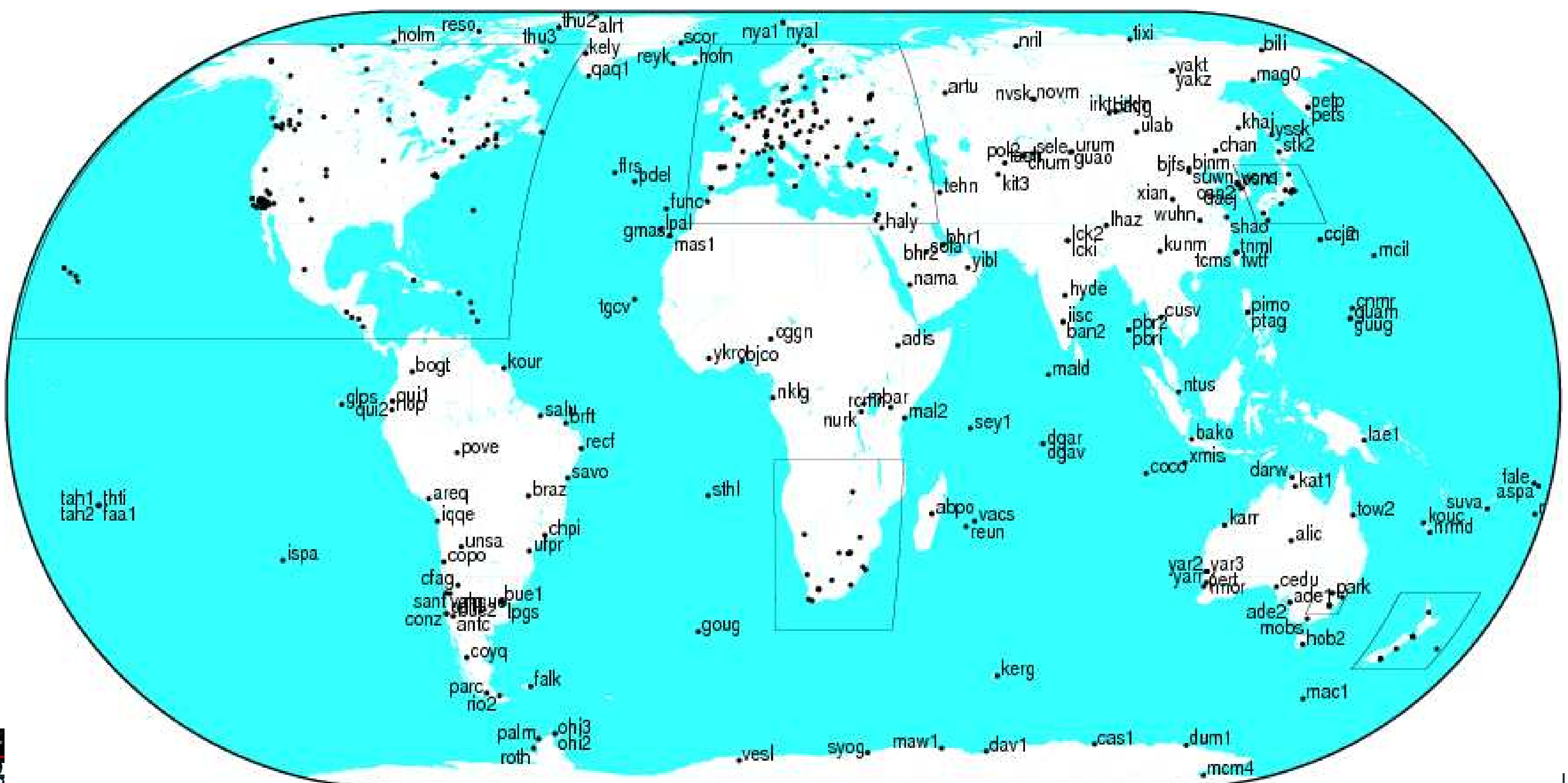
Location of DRAO GPS Antenna

Location of DRAO GPS Antennas (winter)

Locations of GPS Stations Used by CODE

- CODE = Centre for Orbital Determination Europe, located at University of Berne Observatory, Switzerland
- DRAO, WSRT, Parkes and Tidbinbilla are reference stations in this network



VTEC vs STEC

How to Convert STEC in to VTEC ?

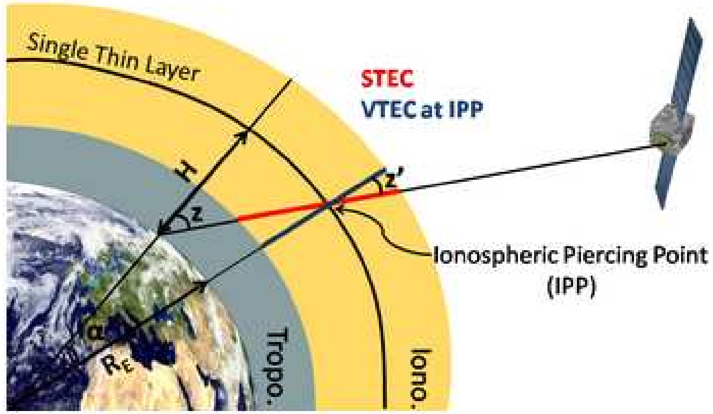


Figure 5: STEC vs VTEC.

The STEC depends on the length of the signal's path trough the ionosphere and is consequently dependant on the satellite elevation. To correct for this effect, an estimation of the Vertical TEC (VTEC) above a given point on the Earth surface is necessary. To determine this, the Single Thin Layer Model is usually employed. This model assumes that all the free electrons are concentrated in a layer of infinitesimal thickness located at the altitude *H* (figure 5).

The VTEC is estimated at each Ionospheric Pierce Point (IPP) from the ionospheric mapping function MF_I according to figure 5:

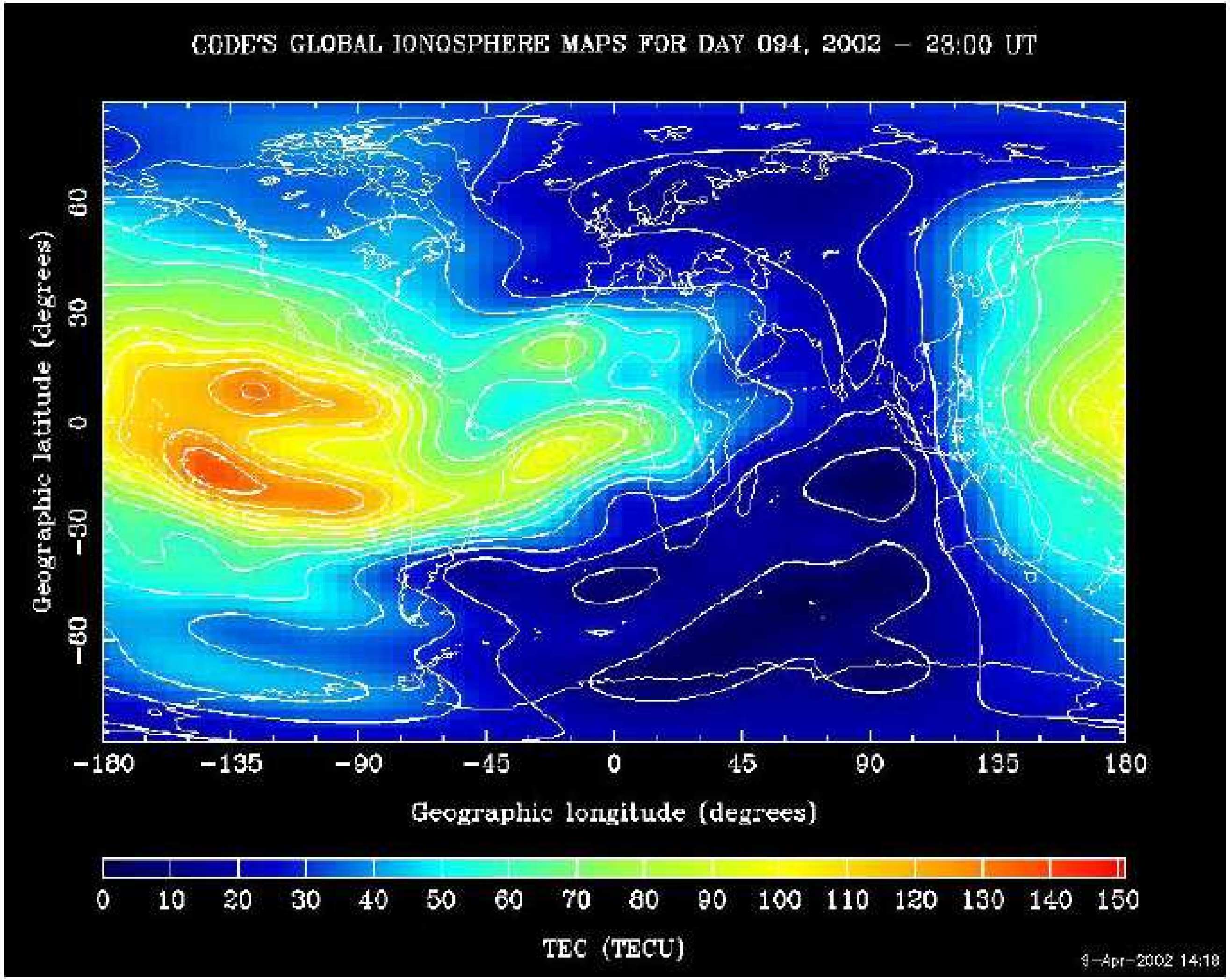
$$MF_I(z) = \frac{STEC}{VTEC} = \frac{1}{\cos z'} \qquad (2.15)$$

with

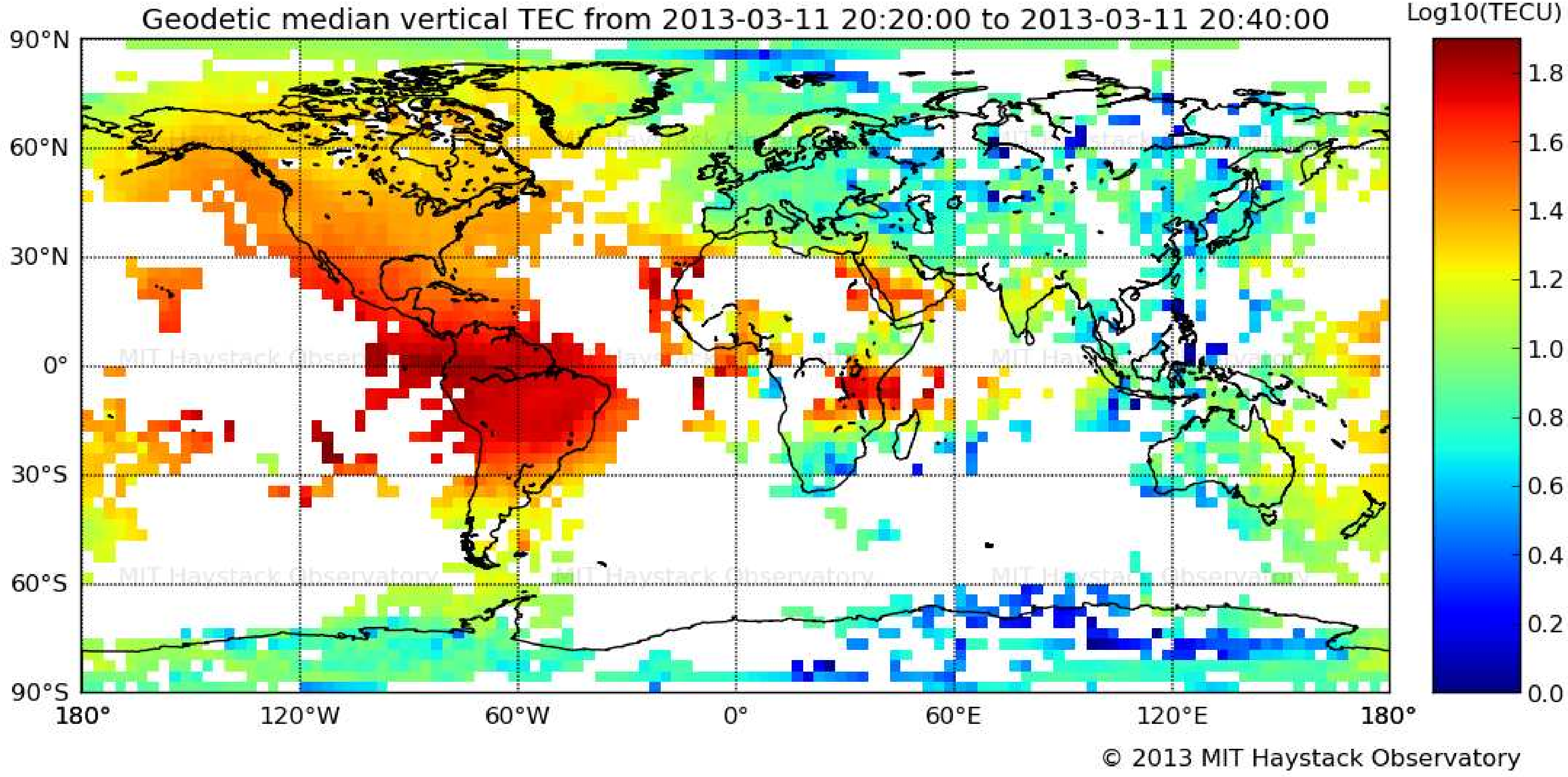
$$\sin z' = \frac{R_E}{R_E + H} \sin(z) \qquad (2.16)$$

- From Royal Observatory Belgium tutorial

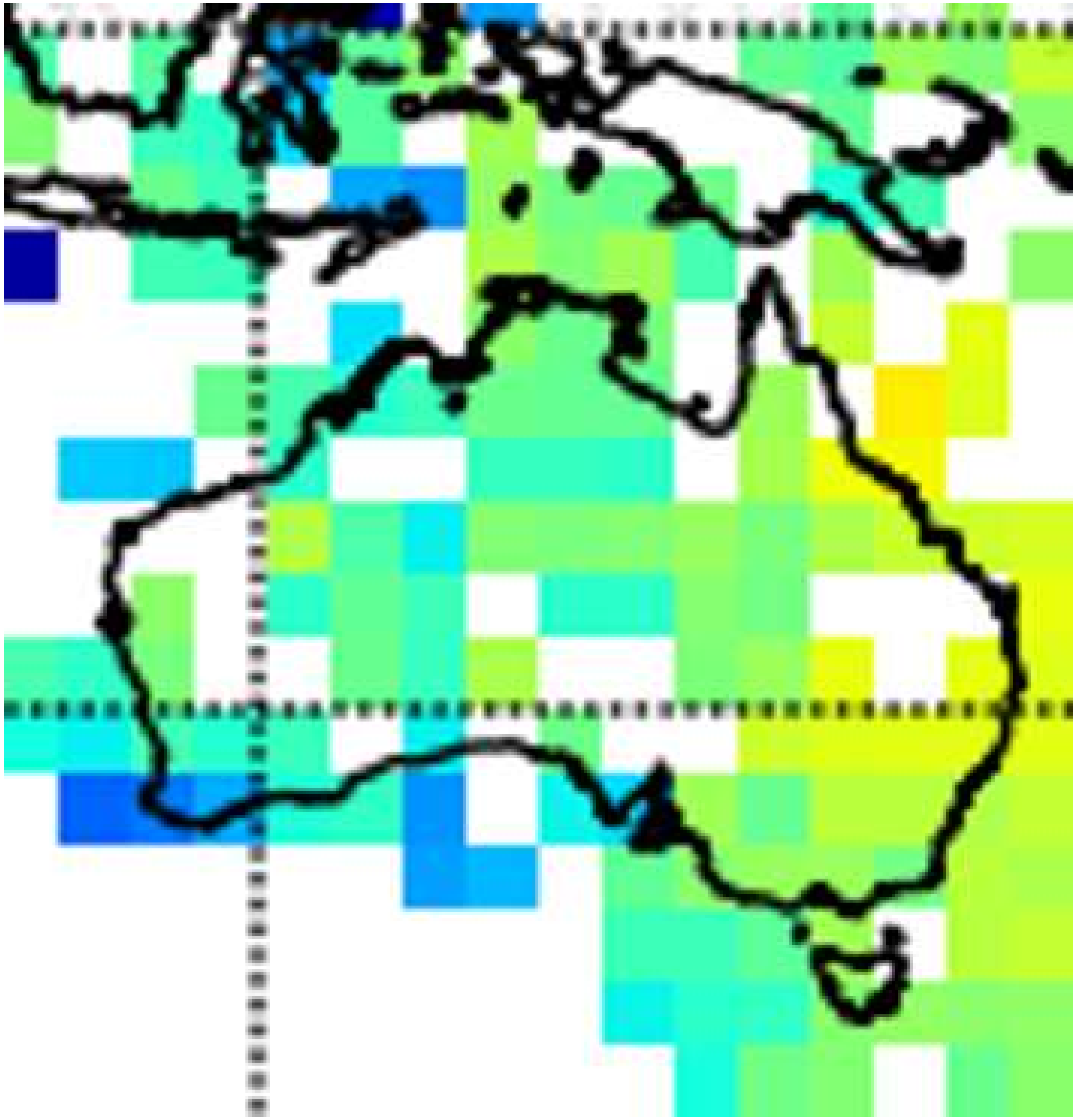
A Typical CODE Map of VTEC



A Typical Haystack Map of VTEC



Australia - a bit thin on the ground



Background - The James Anderson Software Package

- Developed at ASTRON/JIVE by James Anderson as part of the ALBUS (Advanced Long Baseline User Software) project
- original goal - correct for ionospheric phase jitter in VLBI observations
- He offered to adapt this software for use by the ASPAP POSSUM polarization project
- Currently has a database of about 3500 GPS stations
- ASKAP will observe from 700 to 1800 MHz so ionosphere corrections are certainly necessary at the lower frequencies

GPS Stations within 700 km of an Observatory

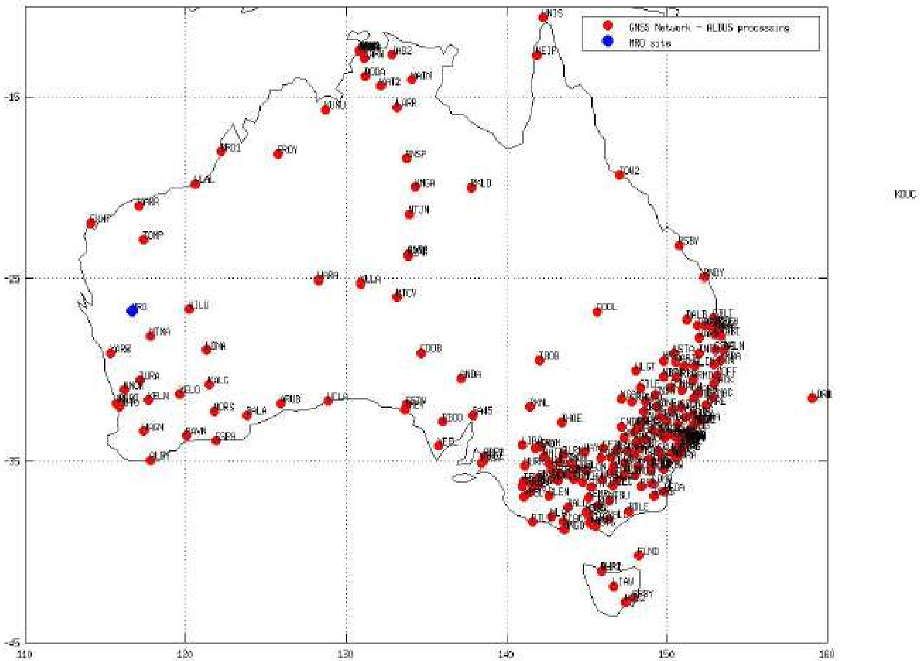
GPS Stations within 700 KM	
Observatory	GPS Stations with Data
ATCA	23 out of 112
MWA	12 out of 17
MEERCAT	30 out of 34
LOFAR	77 out of 195
GMRT	1 out of 1
VLA	66 out of 95
DRAO/CHIME	125 out of 146
Hat Creek	360 out of 445
OVRO	578 out of 703

CHIME - Canadian Hydrogen Intensity Mapping Experiment

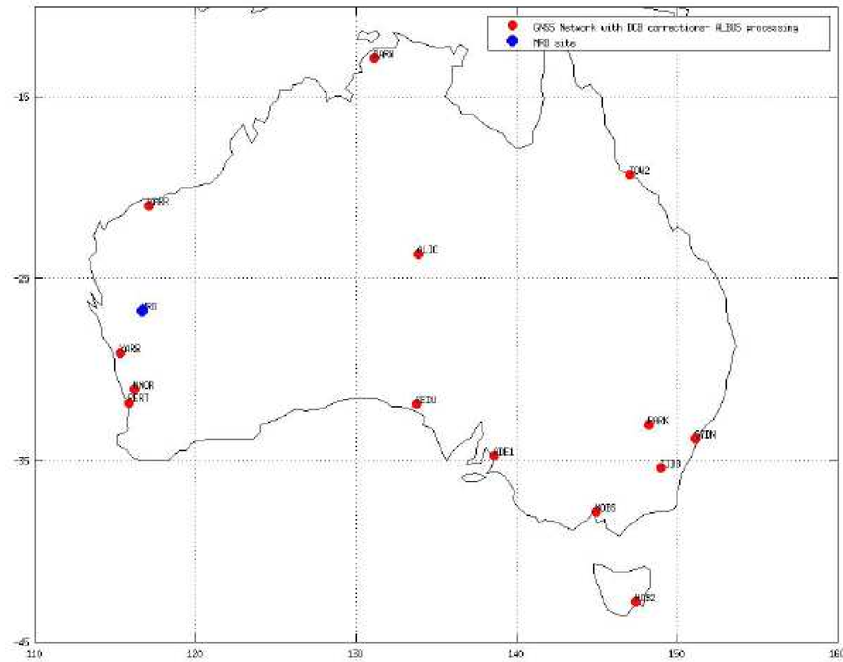
- Will look for BAOs in range 400 to 800 MHz

Tests of IonFR and ALBUS packages

- ionFR (Sotomayor et al. 2013) uses CODE maps + IGRF magnetic field to predict rotation measure contribution due to Ionosphere
- Which washing machine gets your clothes whiter?
- test observations
  - ATCA observations of PKS 1903-80 on Dec 12, 2012
  - DRAO observations of 3C286 on Dec 12, 2012
  - DRAO observations of 3C286 on May 15, 2013
  - South Africa May 2005 Study (comparison of ALBUS results with that from local analysis)



(c) Australian GNSS network considered



(d) Australian GNSS network with DCB correction

- courtesy Balwinder Singh Arora

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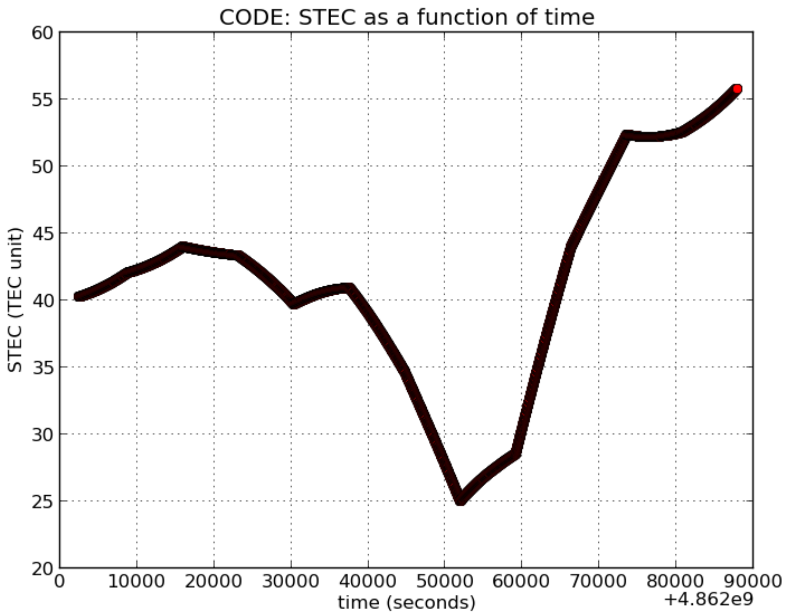
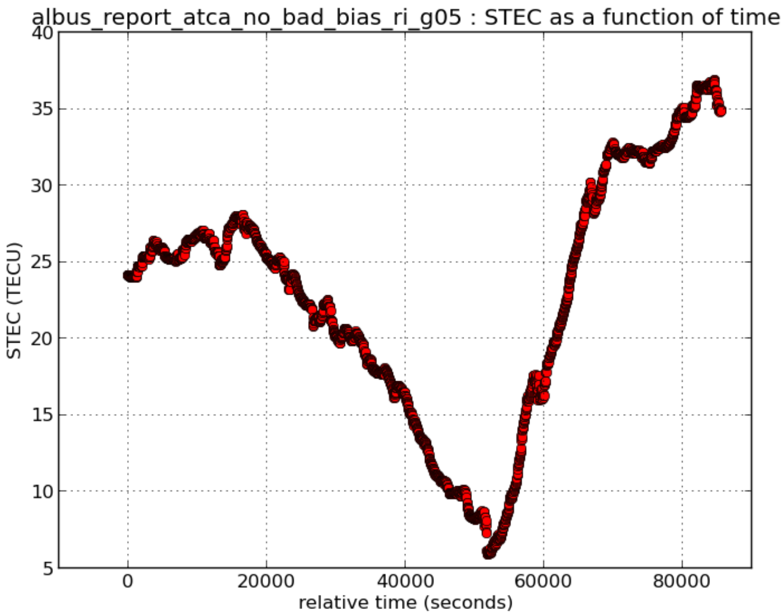
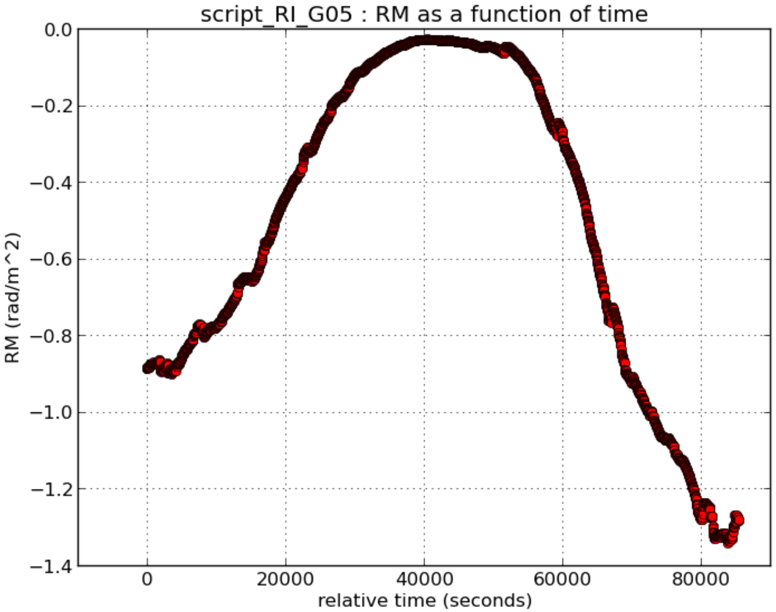
ATCA Observation of PKS 1903-80 Dec 12, 2012; more STECs





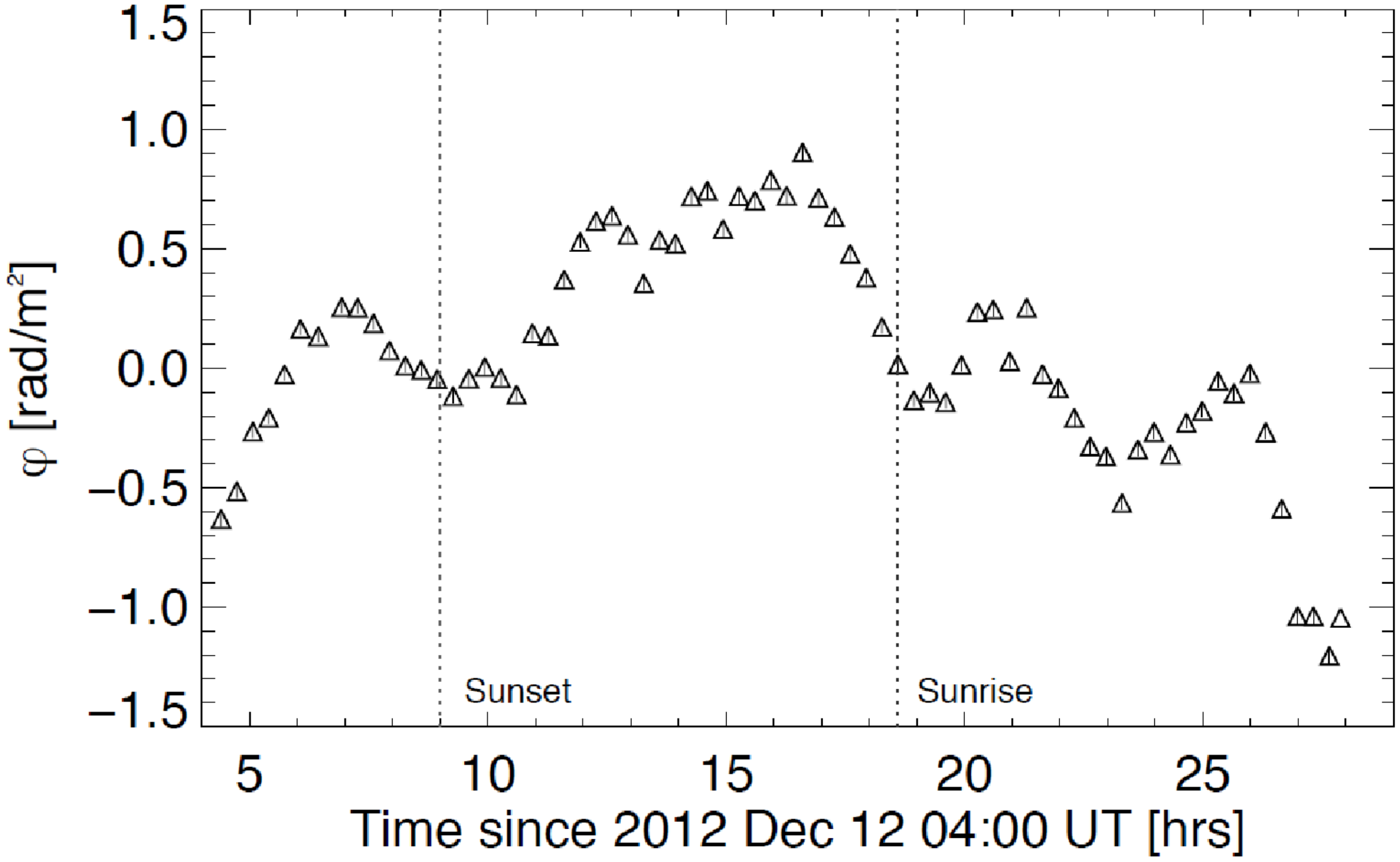
- Left STEC from 2 hr CODE Maps; Right STEC from ALBUS RI_G05 fit

ATCA Observation of PKS 1903-80 ALBUS RM Predictions



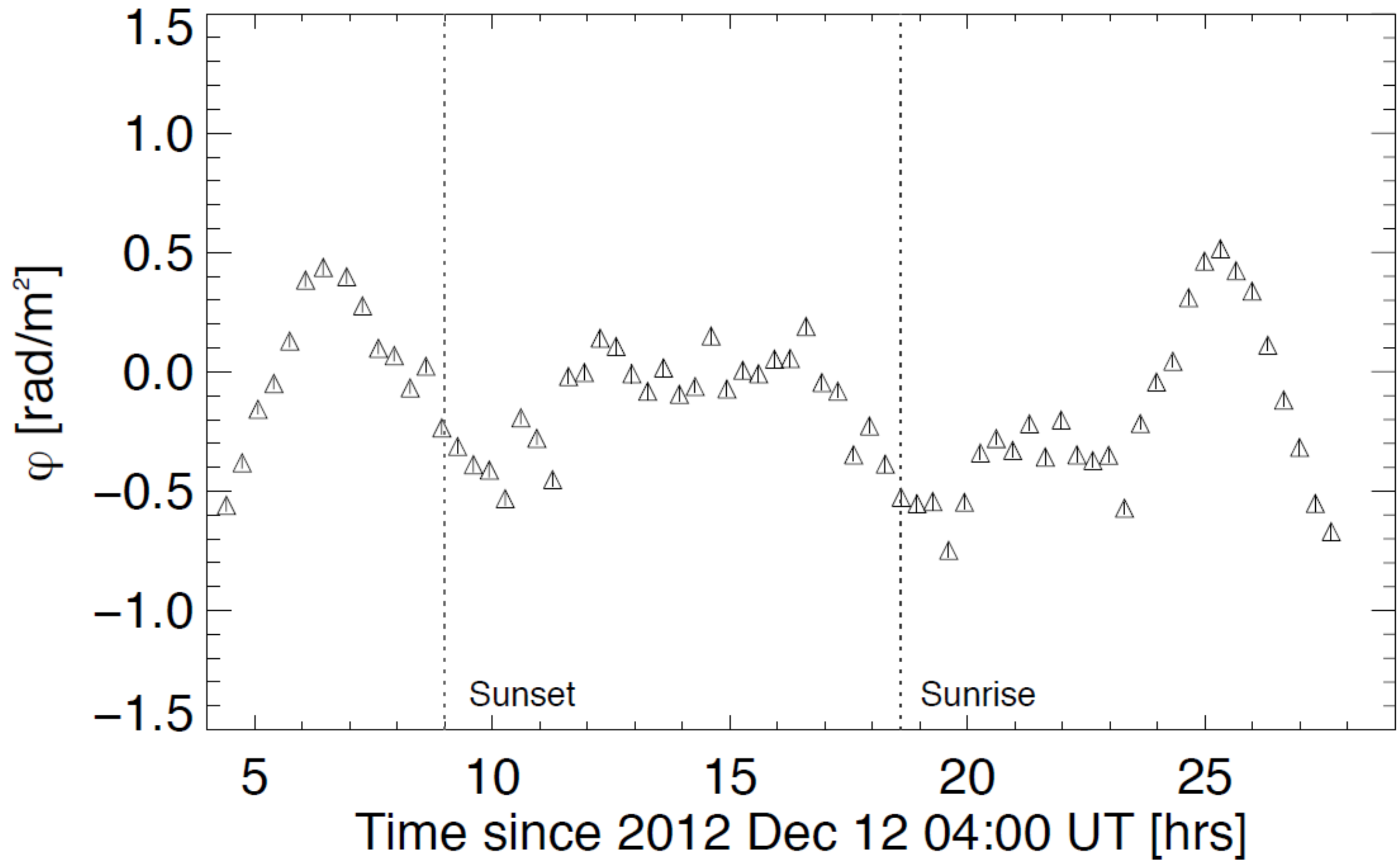
- RM from RI_G05 fit

ATCA Observed Uncorrected RMs of PKS 1903-80



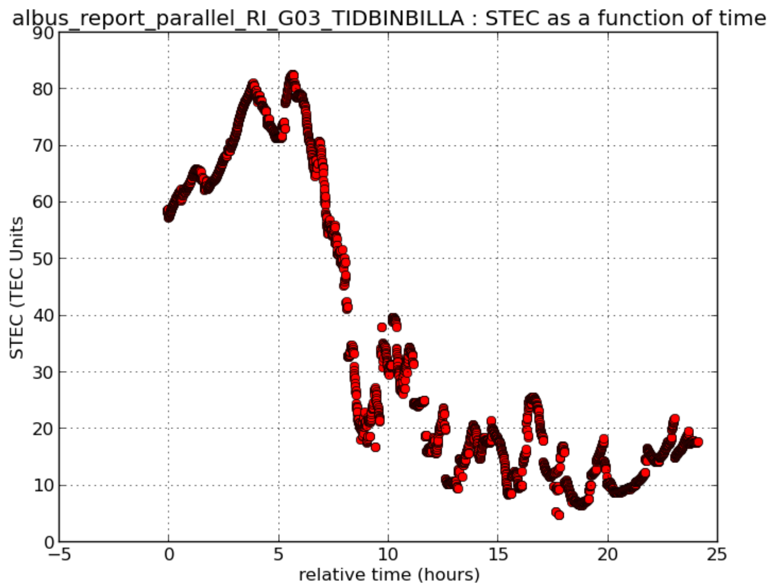
- Plot from Shane O'Sullivan

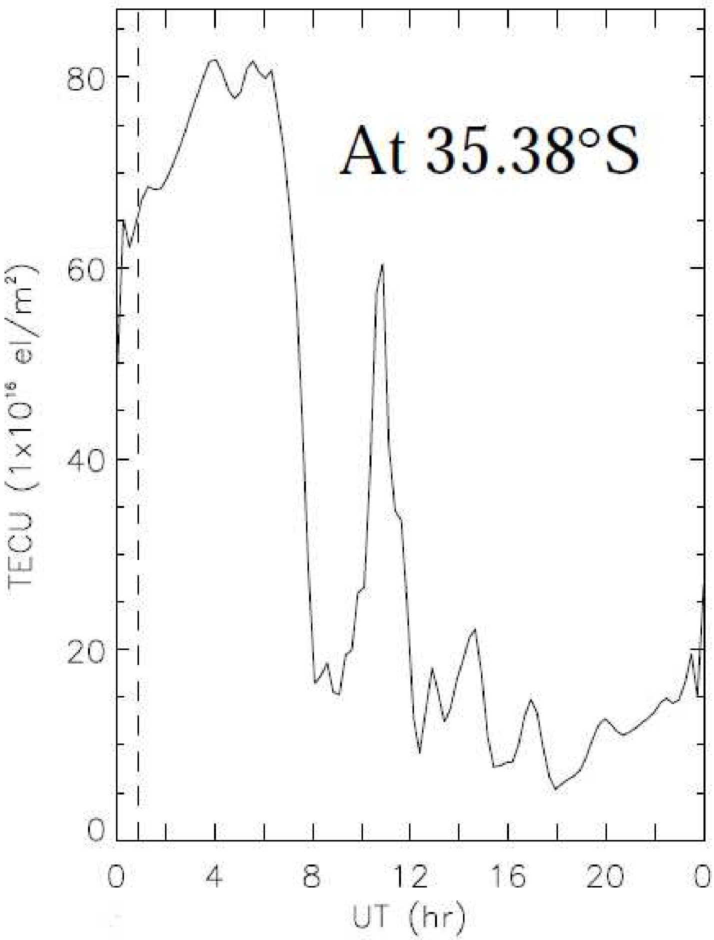
ATCA Corrected RMs PKS 1903-80



- Plot from Shane O'Sullivan

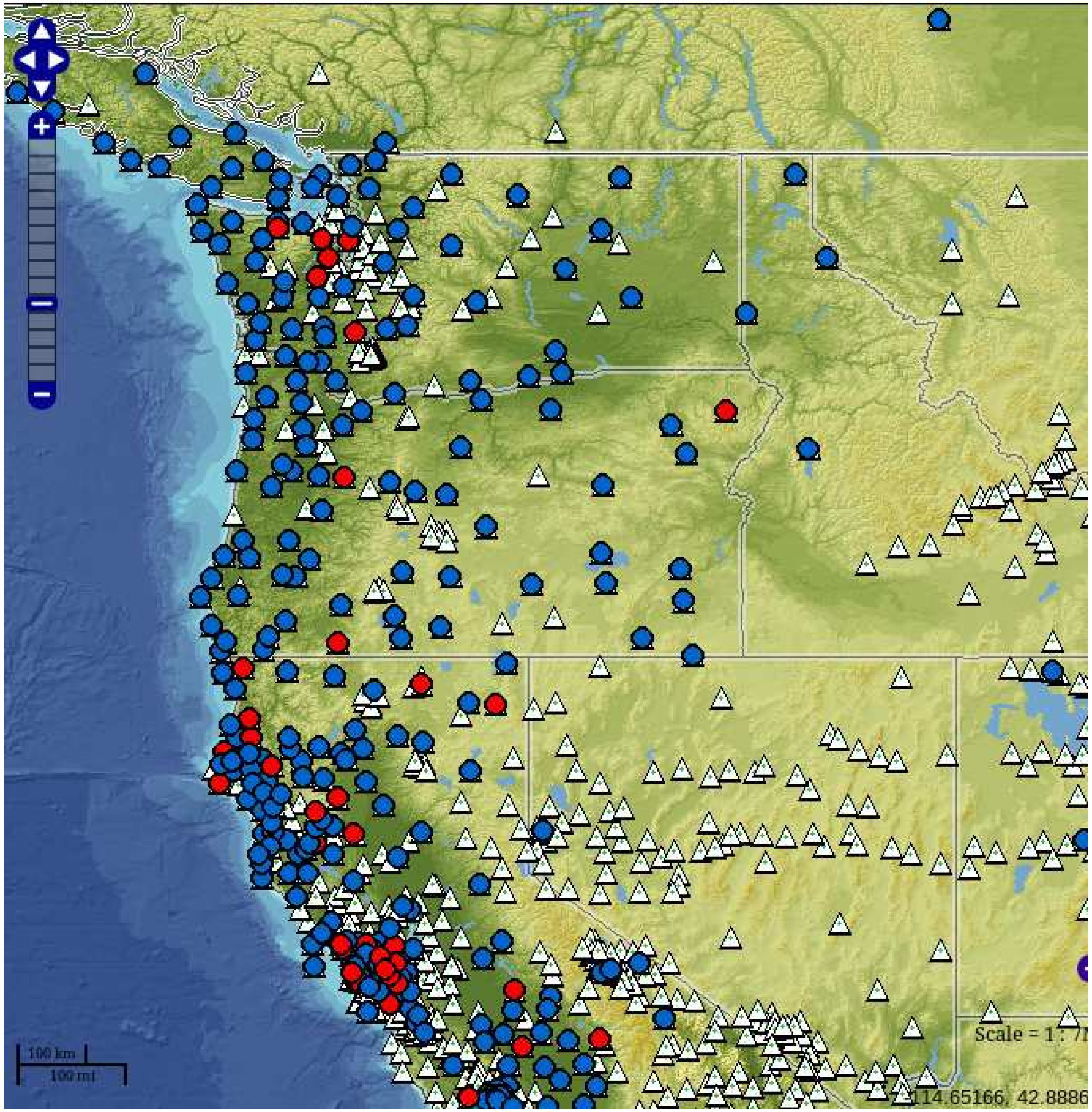
Tidbinbilla 2001 TEC





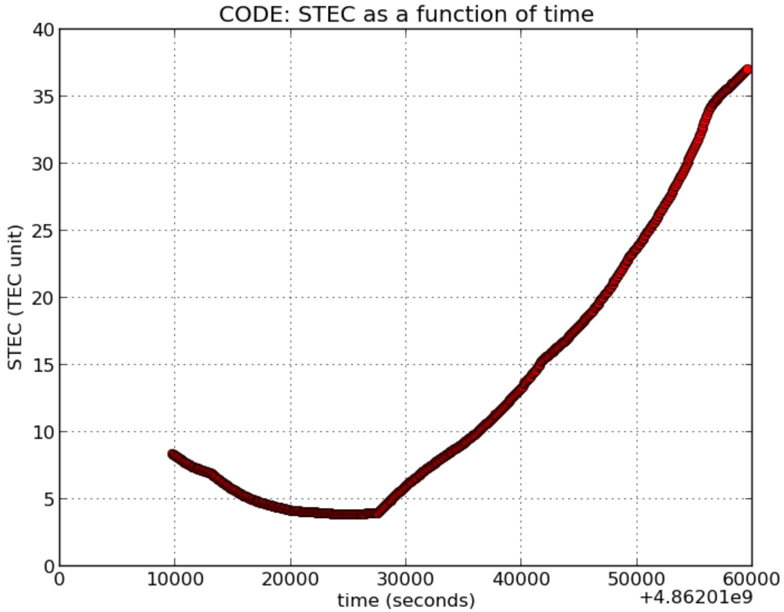
- VTEC from ALBUS prediction
- VTEC from Yizengaw et al (2004):

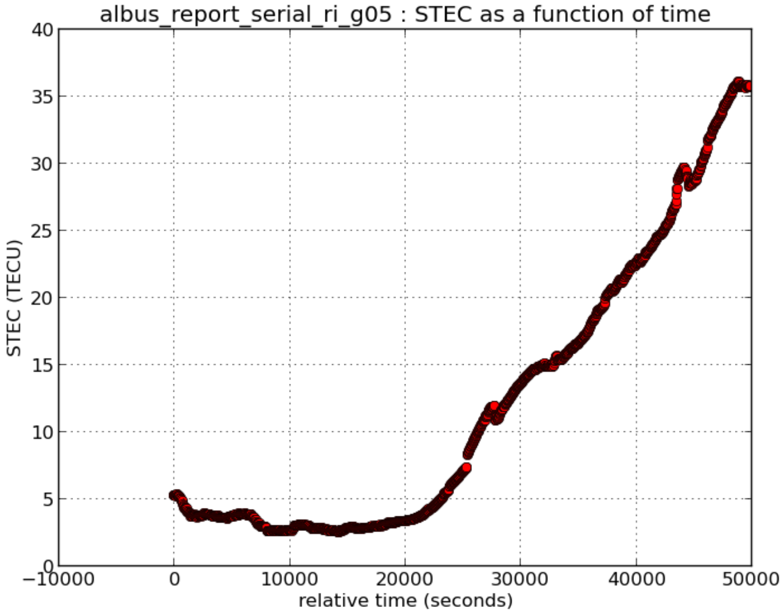
GPS Stations in Western North America



Map from SOPAC - Scripps Orbital and Permanent Array Center UCSD

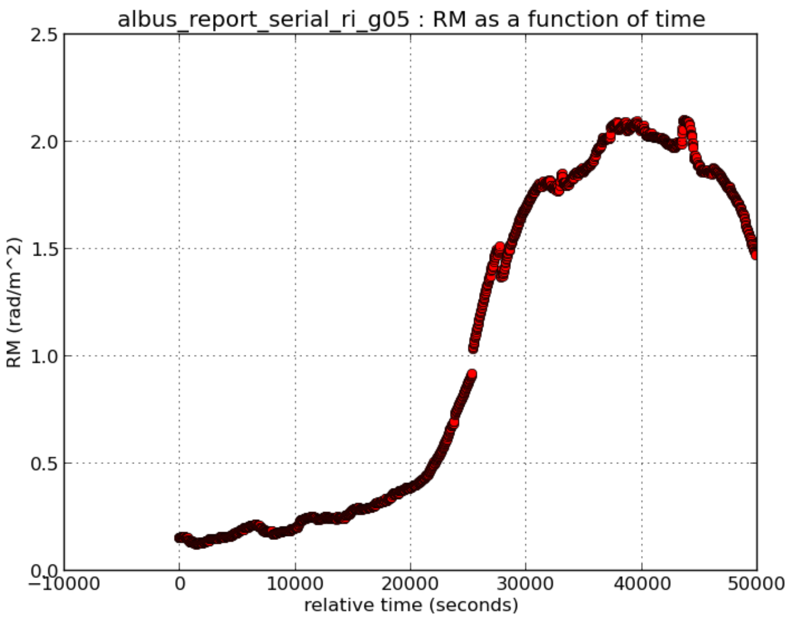
DRAO Observation of 3C286 Dec 12, 2012

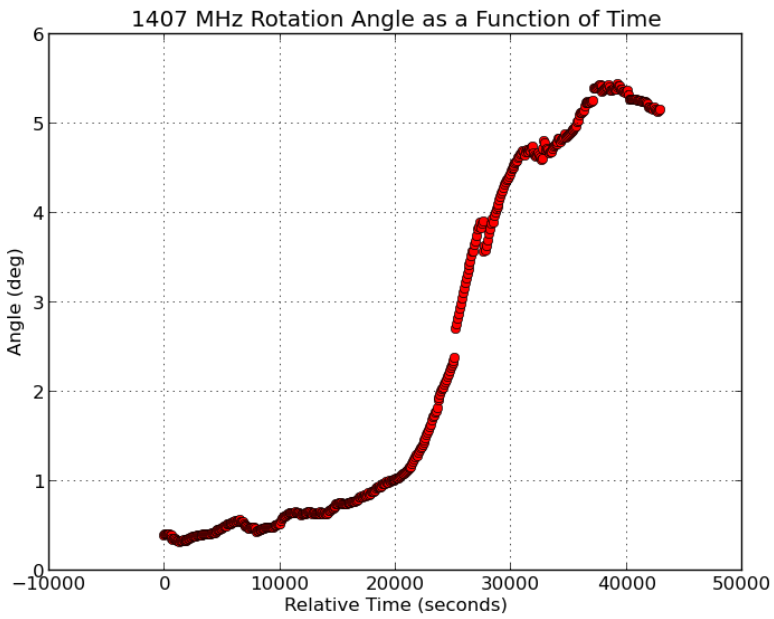




- Left STEC from 2 hr CODE maps; Right STEC from JMA RI_G05 fit

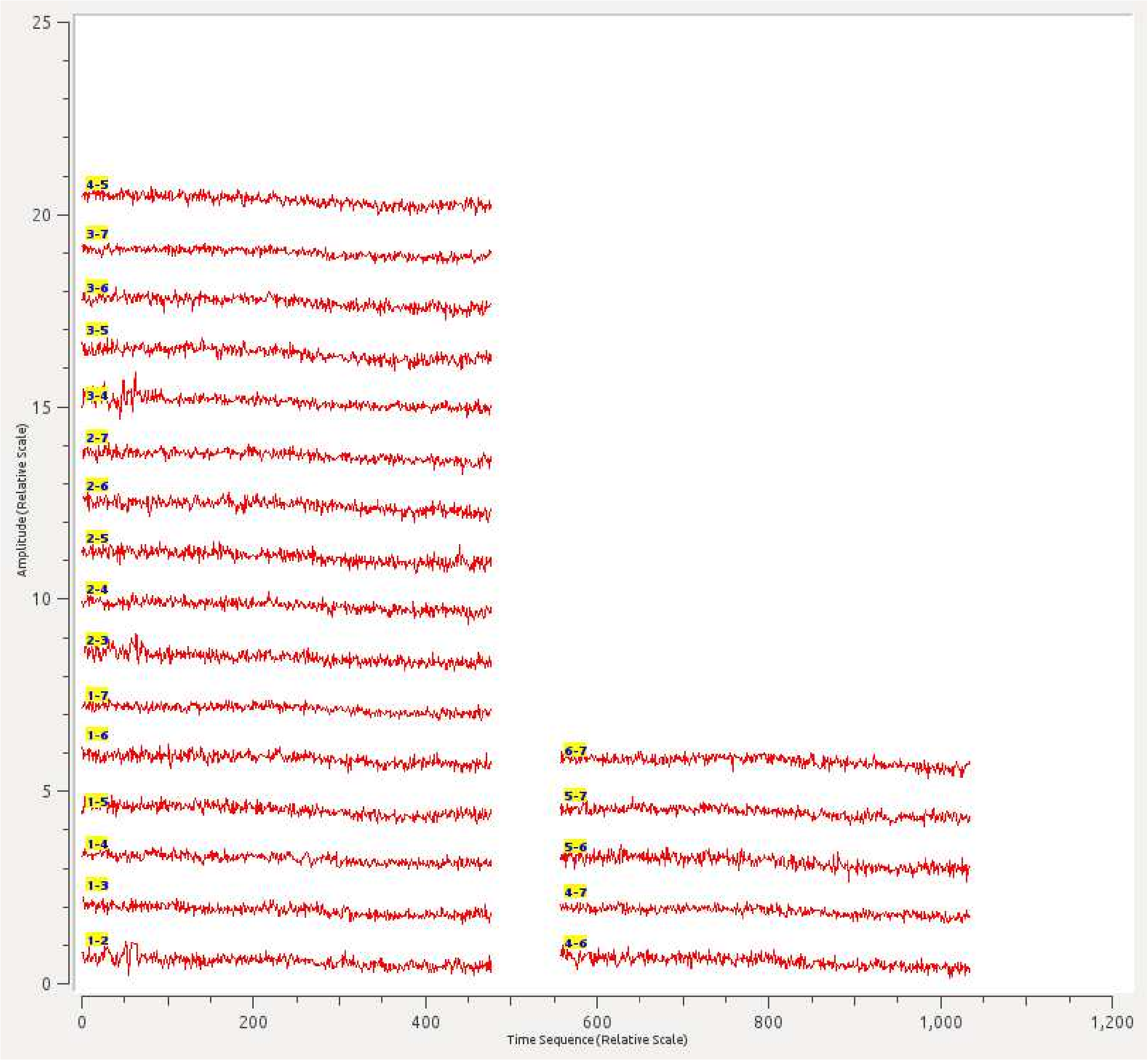
DRAO Observation of 3C286 Dec 12, 2012



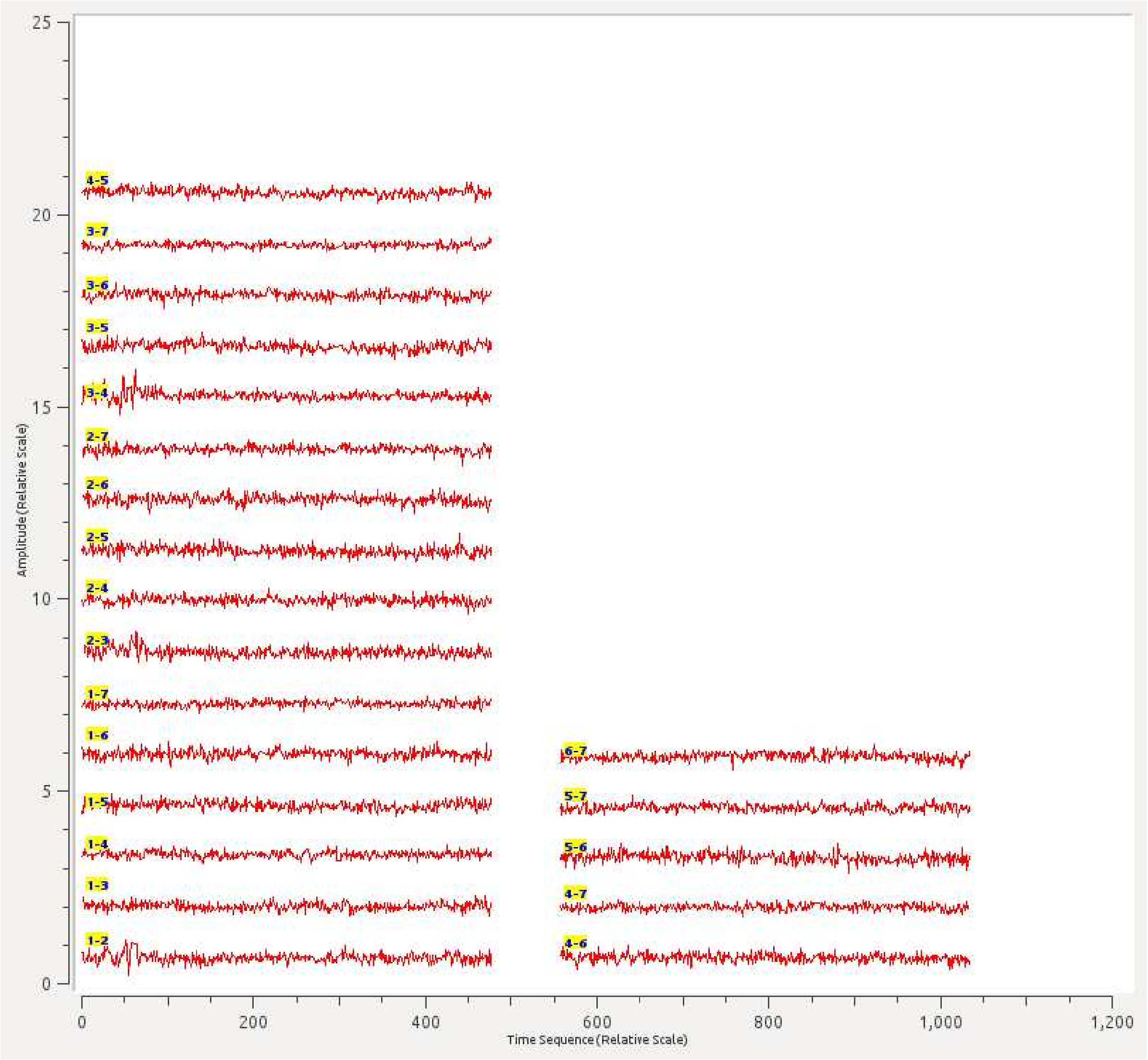


- Left RM from RI_G05 fit; Right resulting rotation angle at 1407 MHz

DRAO Uncorrected Stokes Q



DRAO Corrected Stokes Q



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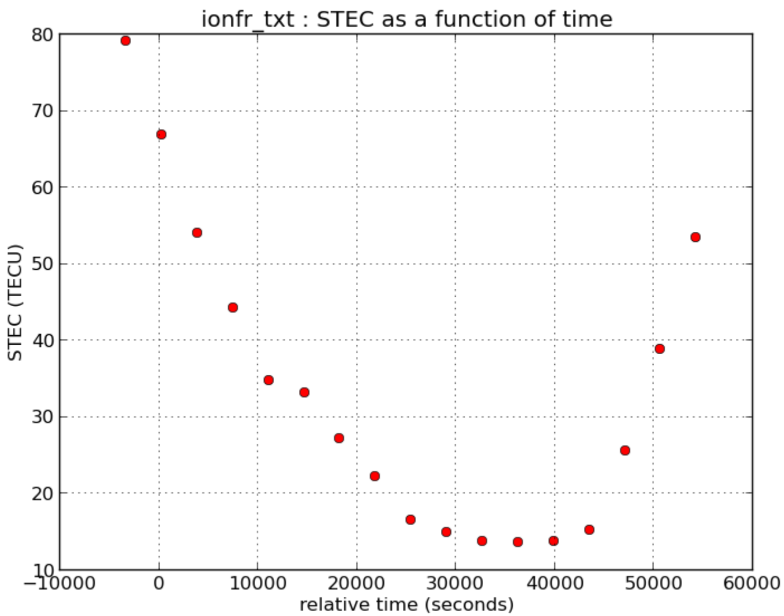
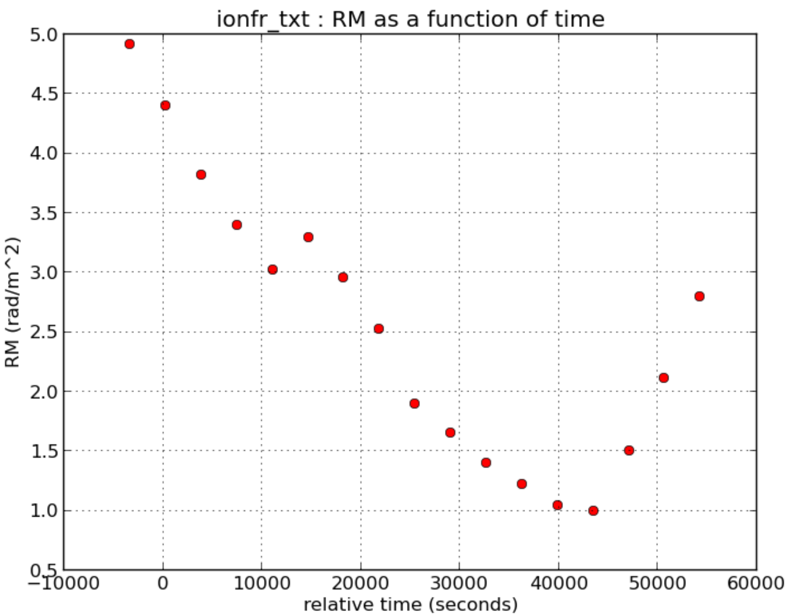
DRAO Observation of 3C286, May 15 2013





- Left ionFR prediction of STEC from CODE maps; Right ionFR prediction of RM from CODE maps and IGRF magnetic field

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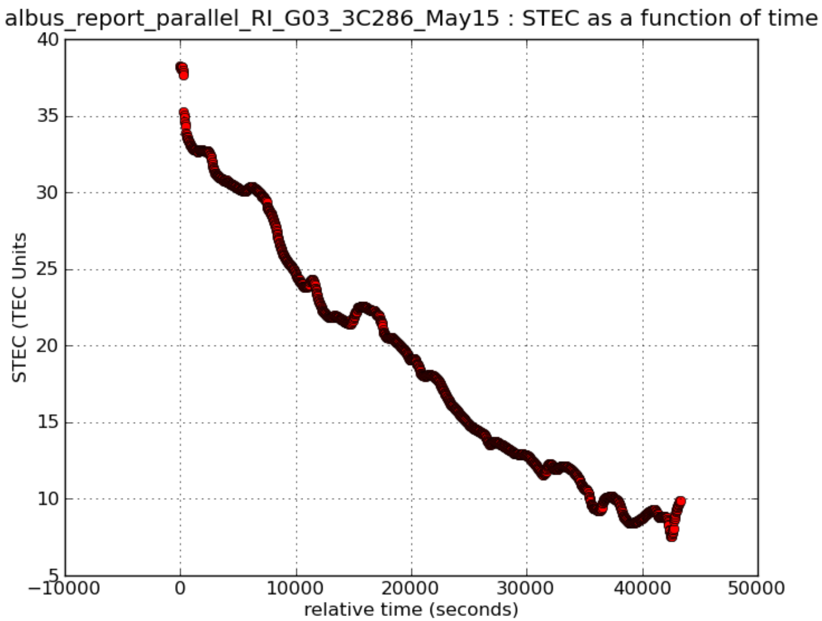
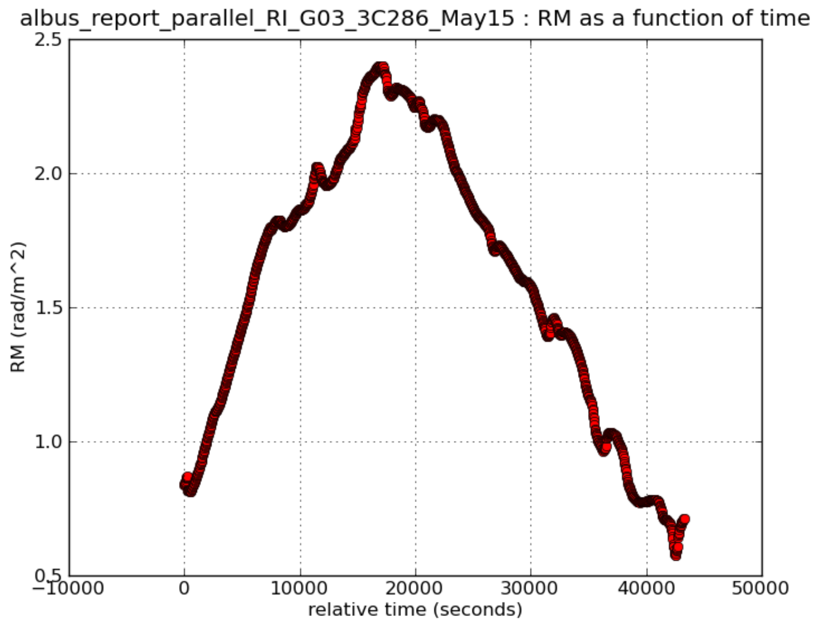
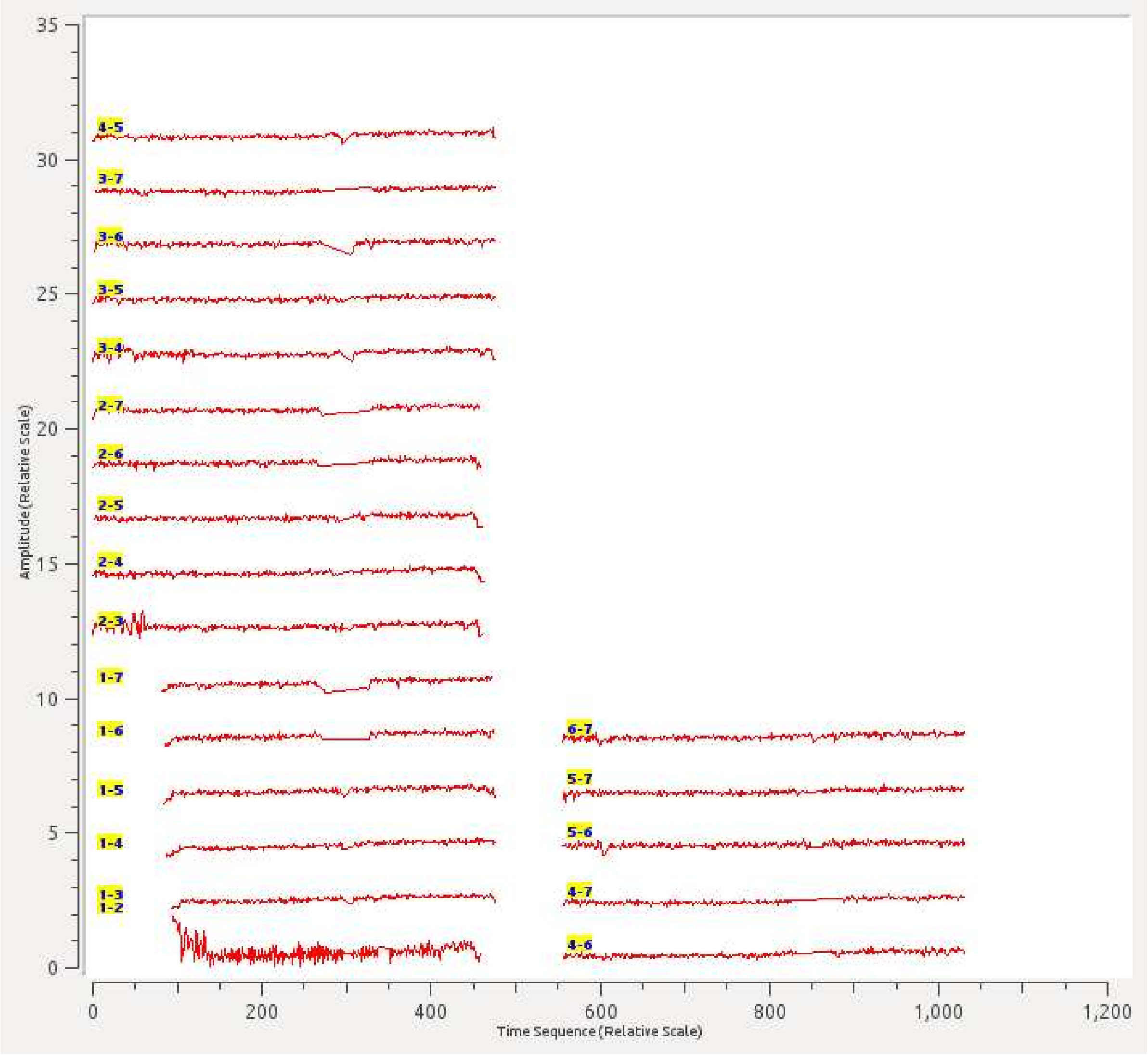
DRAO Observation of 3C286, May 15 2013





- Left ALBUS prediction of STEC; Right ALBUS prediction of RM

DRAO Uncorrected Stokes Q May 2013



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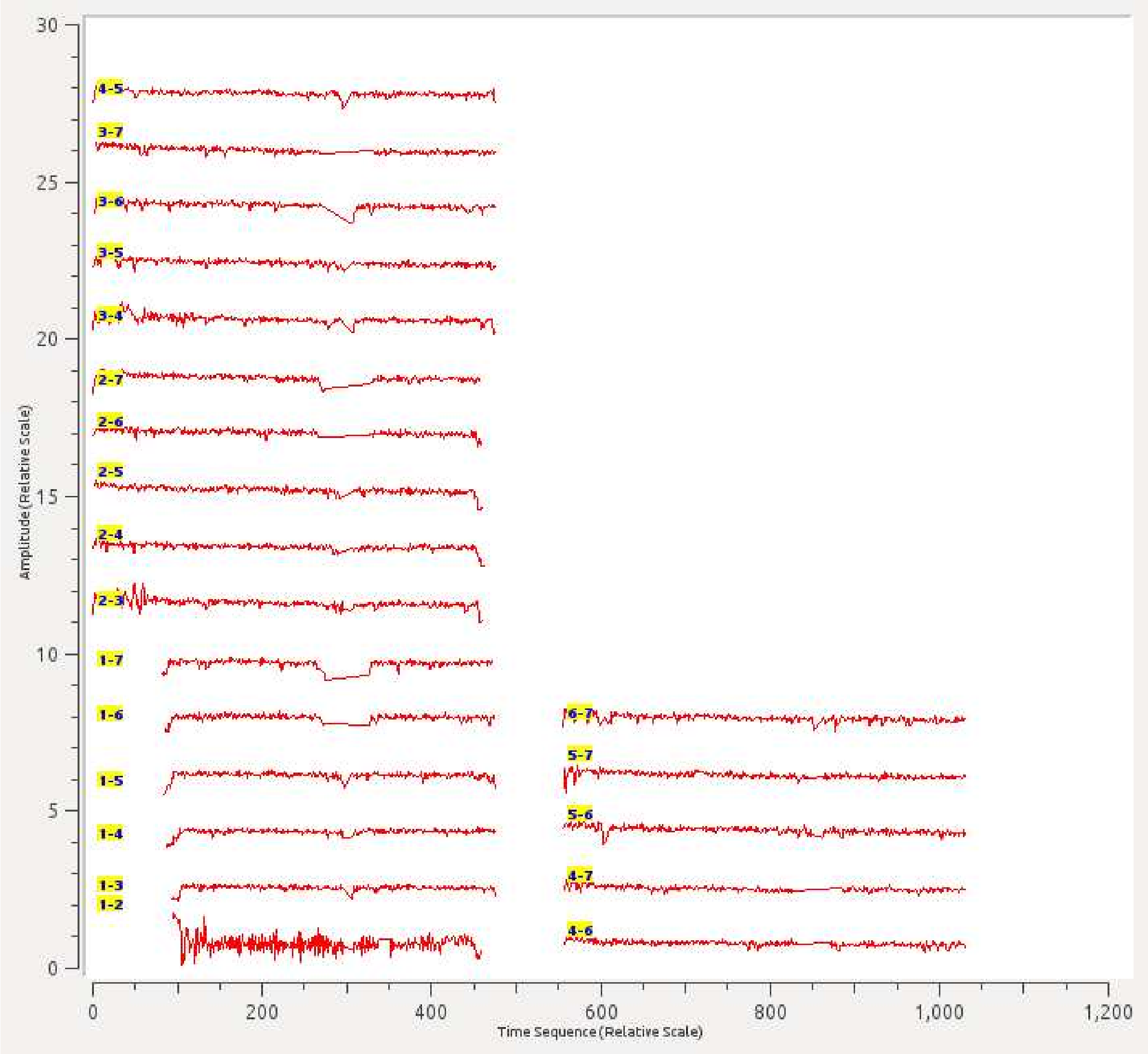
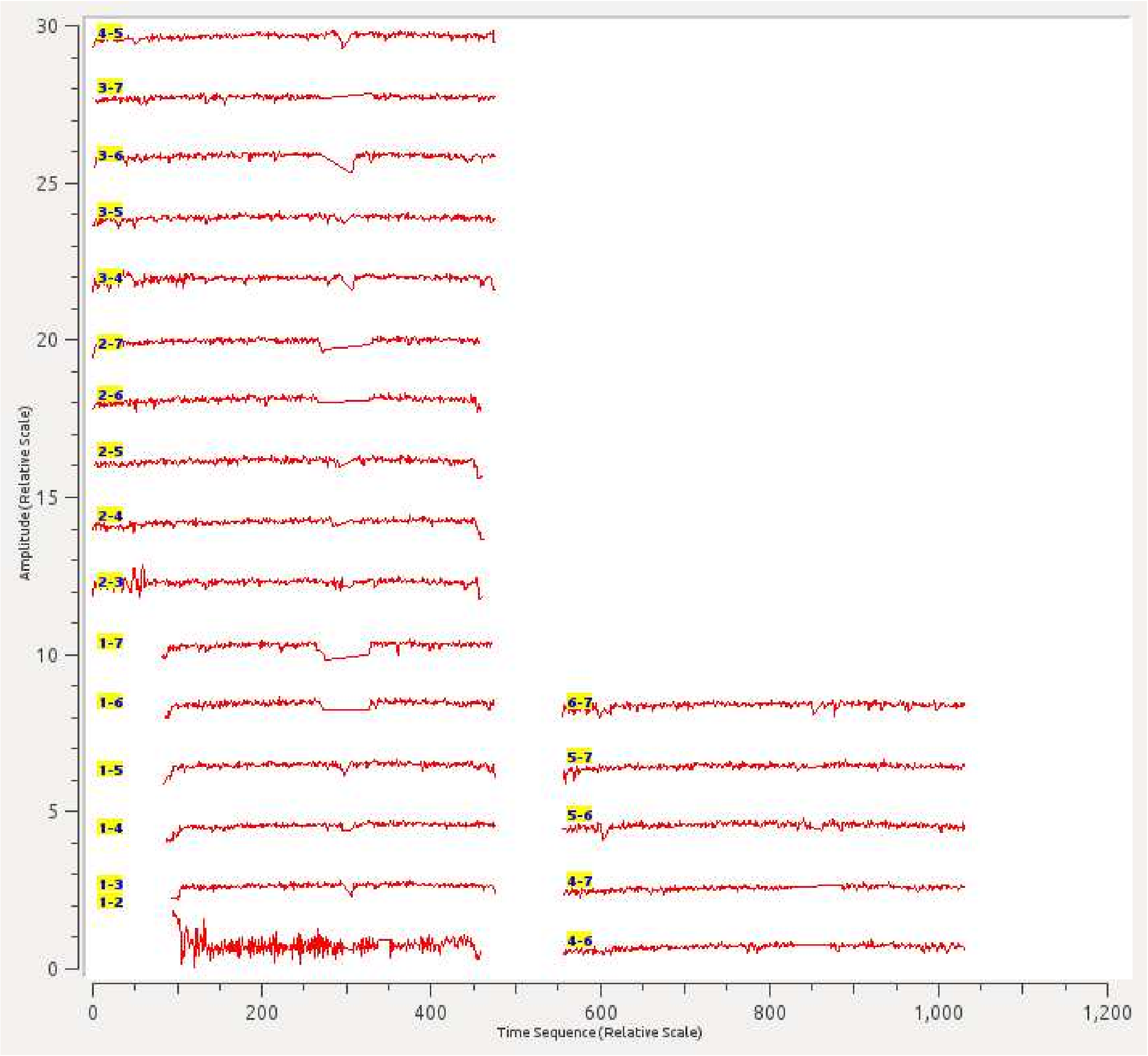
IonFR DRAO Corrected Stokes Q



ALBUS DRAO Corrected Stokes Q



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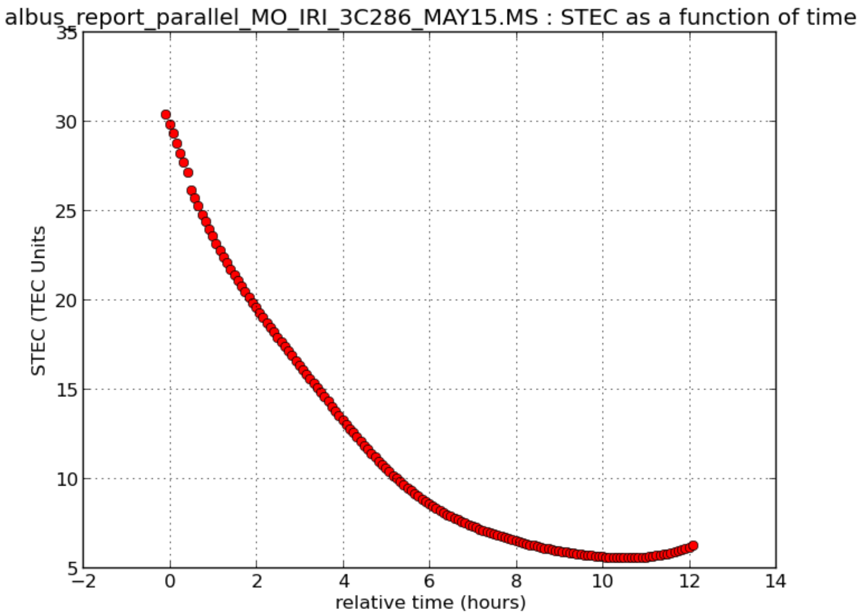
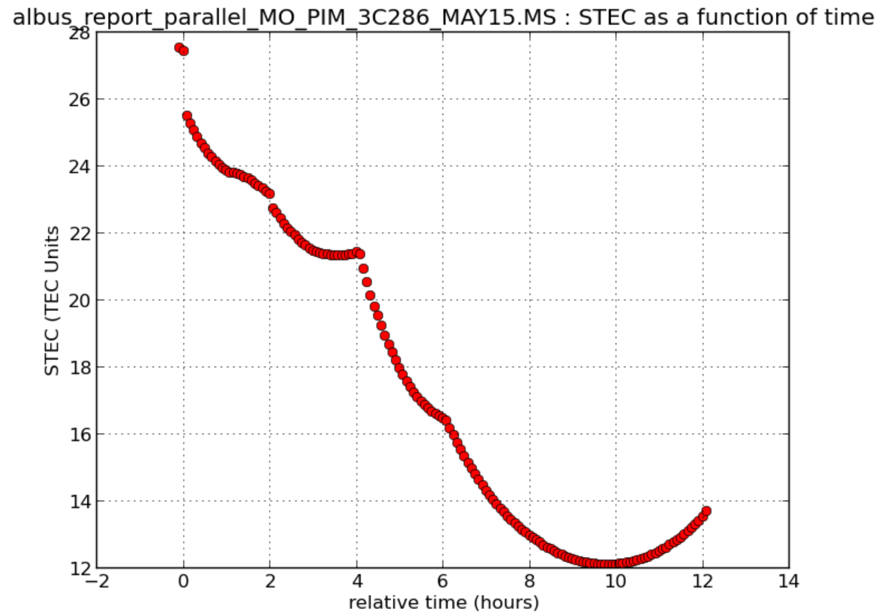
DRAO May 15, 2013 STEC from standard ionosphere models





- Left: IRI prediction; Right: PIM prediction

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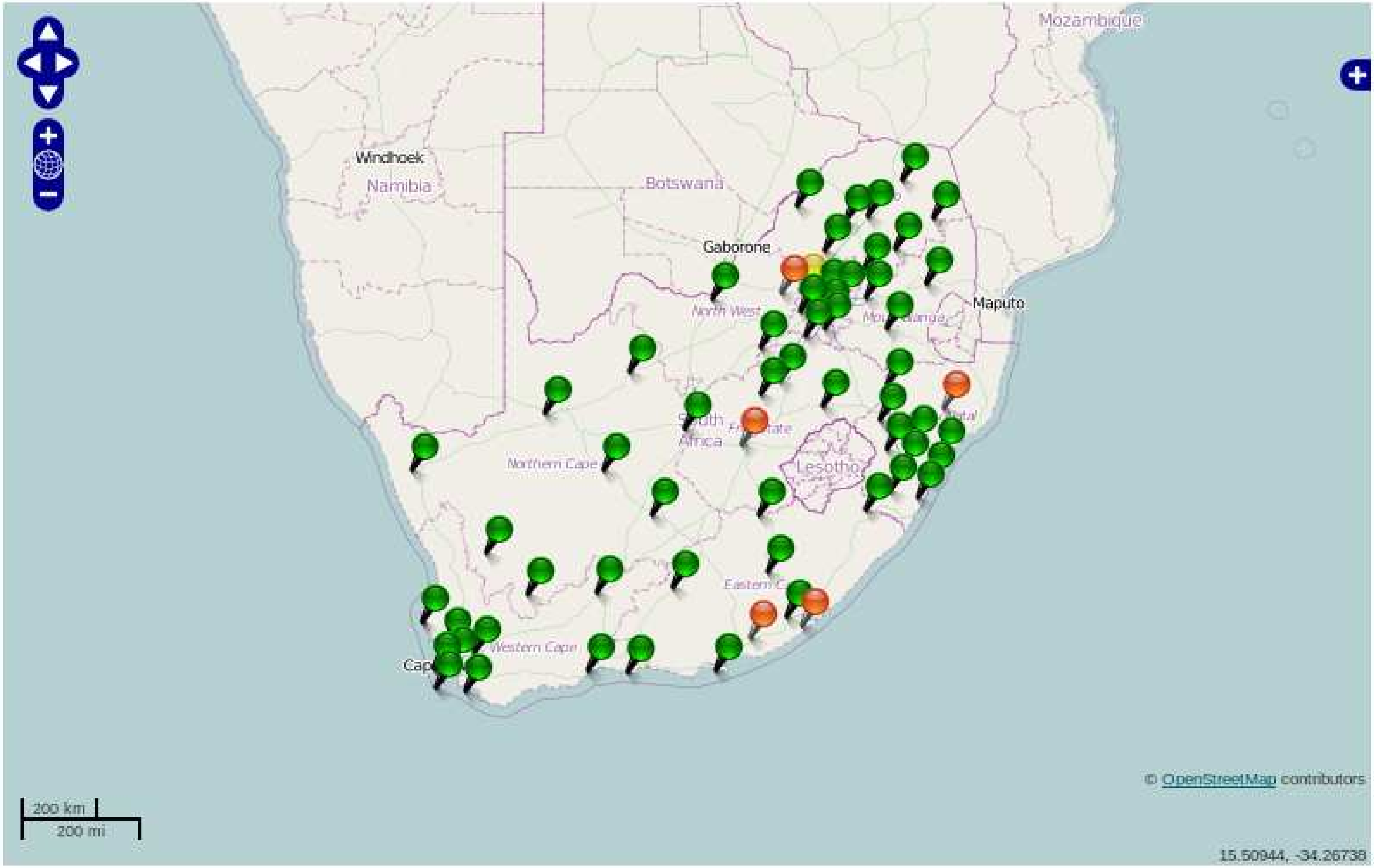
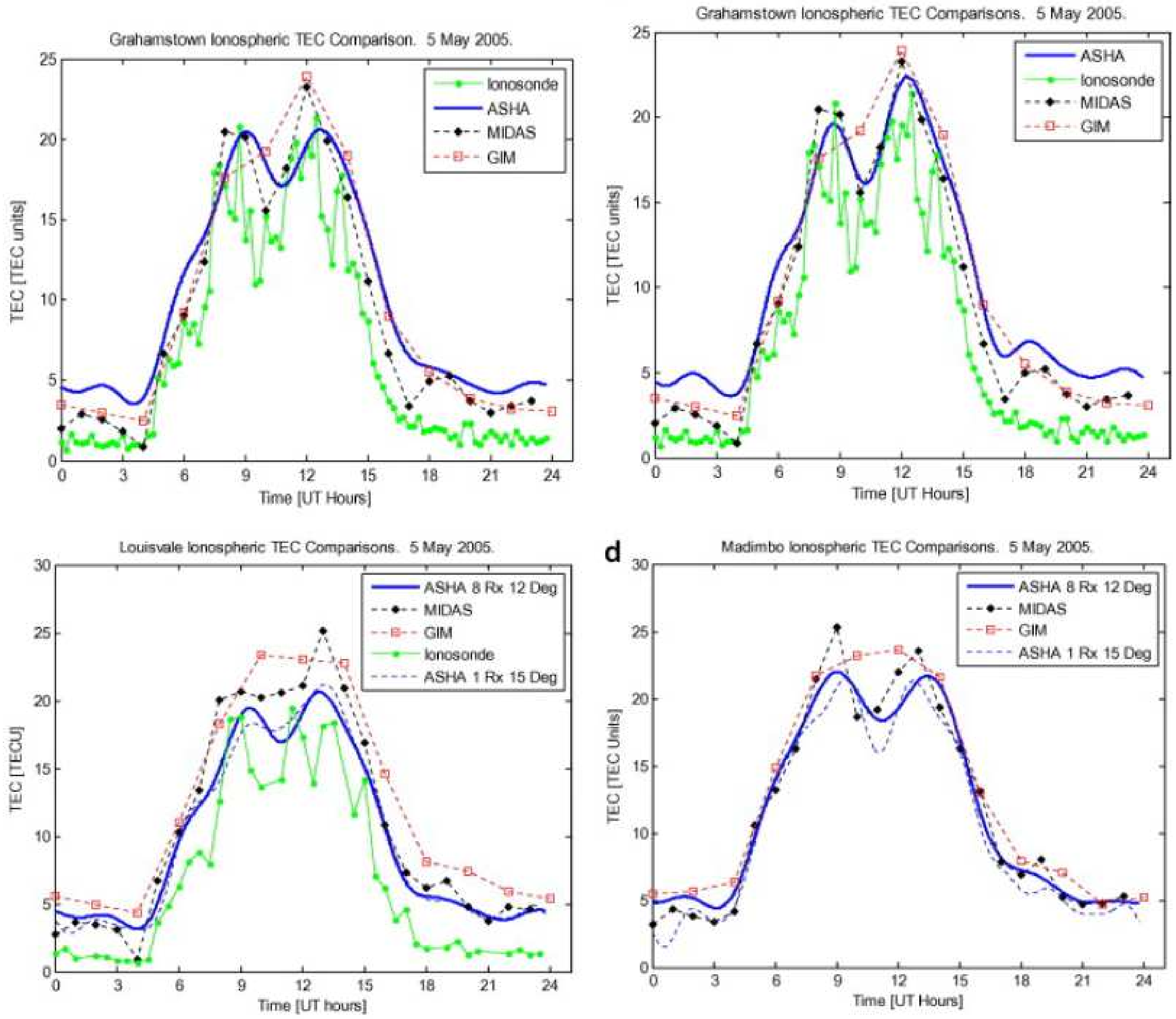
South Africa Trignet GPS Network Locations



South Africa VTEC May 2005 -Opperman et al Study



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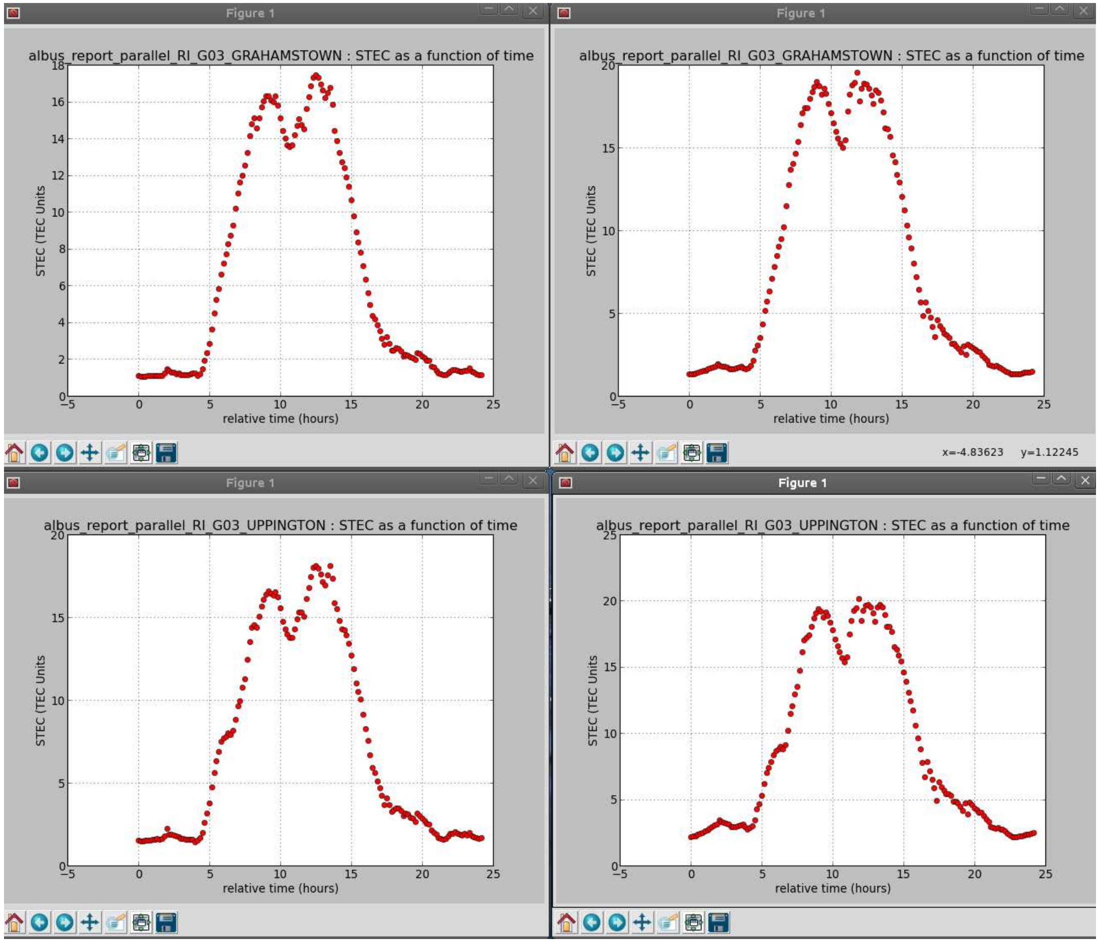
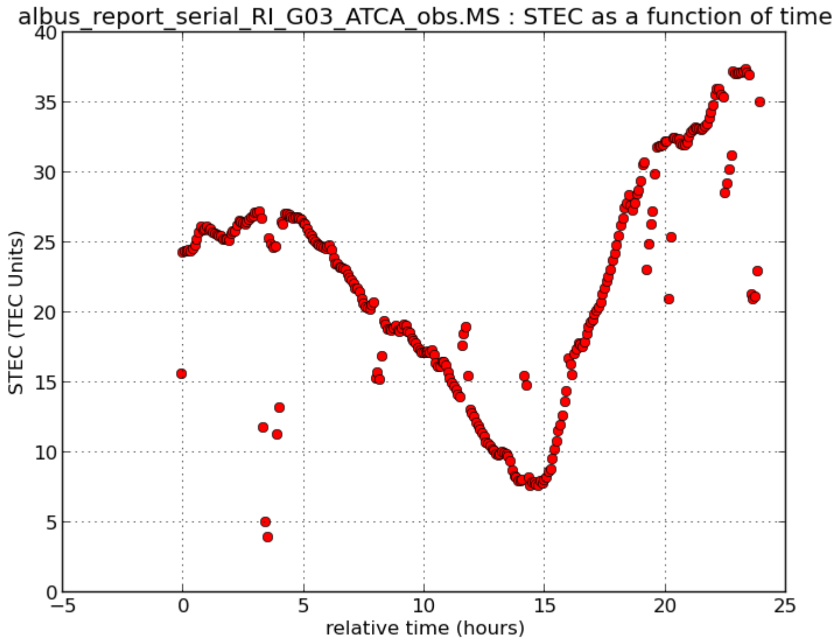
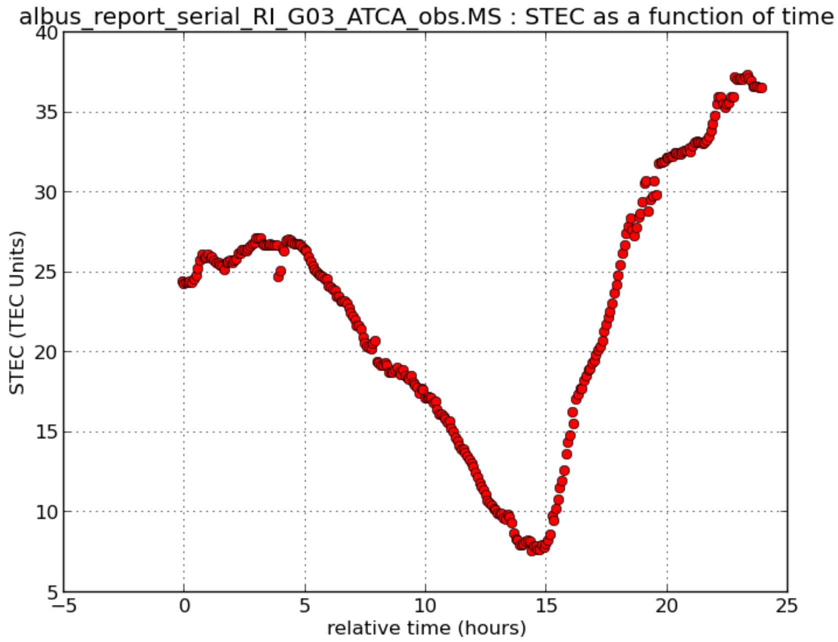
South Africa VTEC May 2005 -ALBUS Results



- Left column includes global GPS stations; right column just uses Trignet data

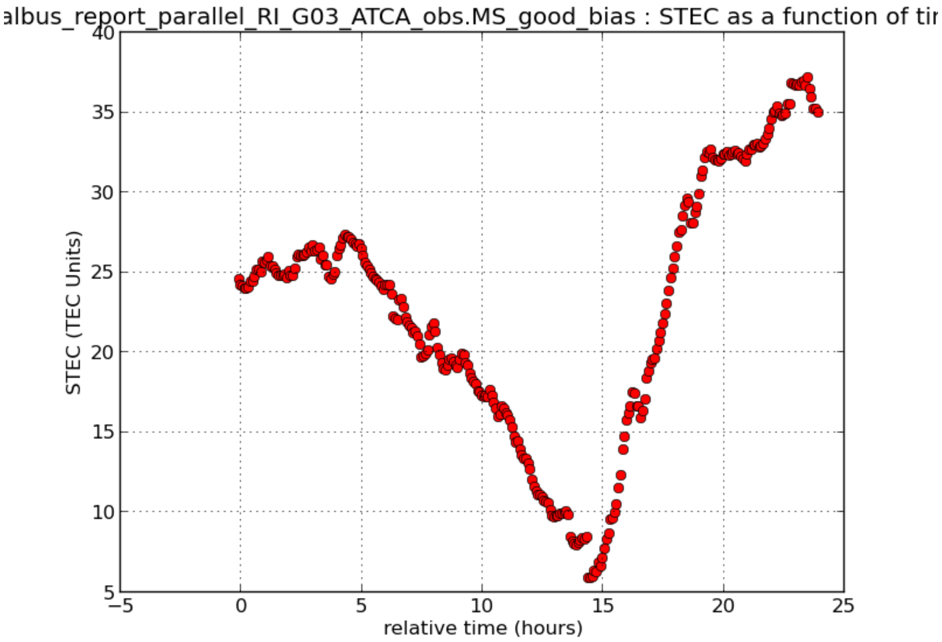
Bias Issues





- Left STEC from 188 receivers; Right ALBUS STEC corrected by Hampel filter

Bias Issues



- ALBUS STEC when using only GPS receivers with good bias corrections

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Conclusions

- TEC determined by ionFR(CODE) is always greater than or equal to TEC determined by ALBUS
- CODE-based results seem to work better for LOFAR (Europe) than does ALBUS
- Elsewhere ALBUS seems as good or better than CODE
- Further Investigate of the inner workings of the ALBUS code is needed
- If you want to apply corrections for the ionosphere to CASA measurement sets, a procedure using MeqTrees is available right now. (Or you could wait xxx years for the CASA developers to implement something themselves.)
- SKA should develop its own network of high-quality GPS receivers