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VLBI as a Tool to Probe the Ionosphere

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Abstract

By a method, developed within project VLBIonos[1] at the IGG, Vienna it is possible to estimate ionospheric parameters in terms of vertical total electron content from VLBI data without any external information (Hobiger et al., 2006, [2]). This paper deals with the results from this approach and cross-validates them against GPS, satellite altimetry data and measurements of solar flux. As geodetic VLBI observations cover more than two complete solar cycles, longer than all other space geodetic techniques using radio signals, the relation to space weather indices on long time-scales can be shown. It can be stated that the overall agreement between VLBI and GPS is within the formal error of each technique and that both systems detect the same periods of ionospheric variations.

1. Ionospheric Parameters from VLBI

It is possible to derive absolute values of vertical total electron content (VTEC) for each station from VLBI data. A description of the estimation strategy can be found in Hobiger (2005, [1]) and Hobiger et al. (2006, [2]). Applying such a method to the whole database of geodetic VLBI observations enables us to study long-term trends of the ionosphere such as the solar cycle of about 10.5 years.

2. Comparison to GPS

Figure 1 shows the results of the estimated vertical total electron content values for station Wettzell (Germany) using all available 24 hours VLBI experiments. As for the analysis only sessions with a duration of 24 hours or more were selected, daily mean VTEC values can be computed (Figure 2), which clearly reveal the annual variation of the ionosphere. For a cross-technique validation of our results with GPS, the VTEC values for station Wettzell were computed from global ionosphere models, provided by the Astronomical Institute of the Univ. Berne[2]. Figure 3 shows a histogram of the differences (GPS minus VLBI) for station Wettzell, with a mean bias of +0.5 TECU and a standard deviation of 4 TECU. Small biases between the techniques can be explained by contributions from the plasmasphere and by mapping function mis-modelling (Hobiger, 2005, [1]). In order to reveal the spectral characteristics wavelet scalograms were computed for each technique and compared against each other. The upper plot of Figure 4 presents the wavelet scalogram of the VLBI time-series for station Wettzell and the lower plot shows the corresponding one from the (shorter) GPS series. Annual and semi-annual signals are detected by both techniques, and the good overall agreement is confirmed by the cross-scalogram (Figure 5). Normalized wavelet

[1] http://iono1.hg.tuwien.ac.at/
[2] Center for Orbit Determination in Europe (CODE), AIUB, http://www.aiub.unibe.ch/ionosphere.html

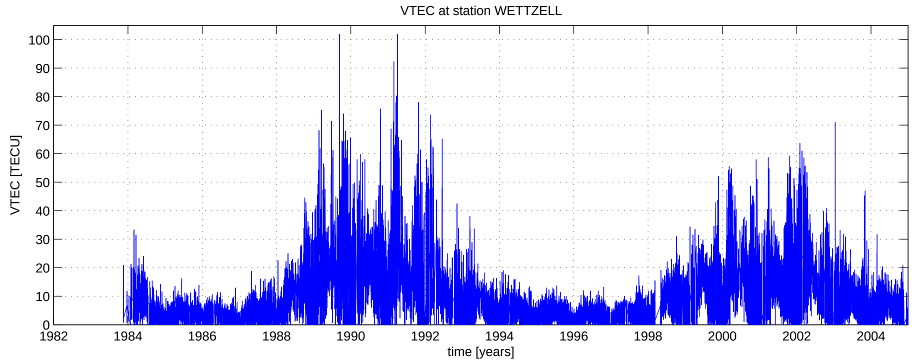

Figure 1. VTEC at station Wettzell (Germany) from VLBI

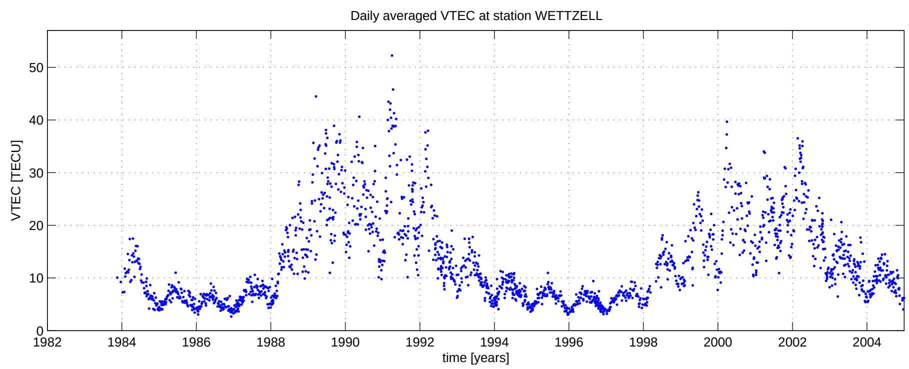

Figure 2. Daily mean values of VTEC at station Wettzell (Germany) from VLBI

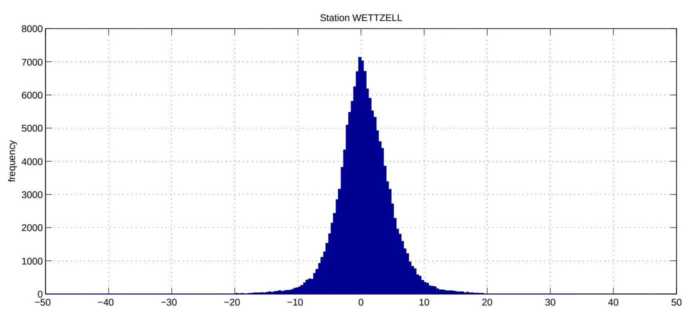

Figure 3. Differences of VTEC at station Wettzell (Germany) between GPS and VLBI

coherency (left part of Figure 5) is close to one for periods longer than 100 days, and always bigger than 0.7, which demonstrates that both techniques are able to detect the same periods in the range of 10 days to 2 years.

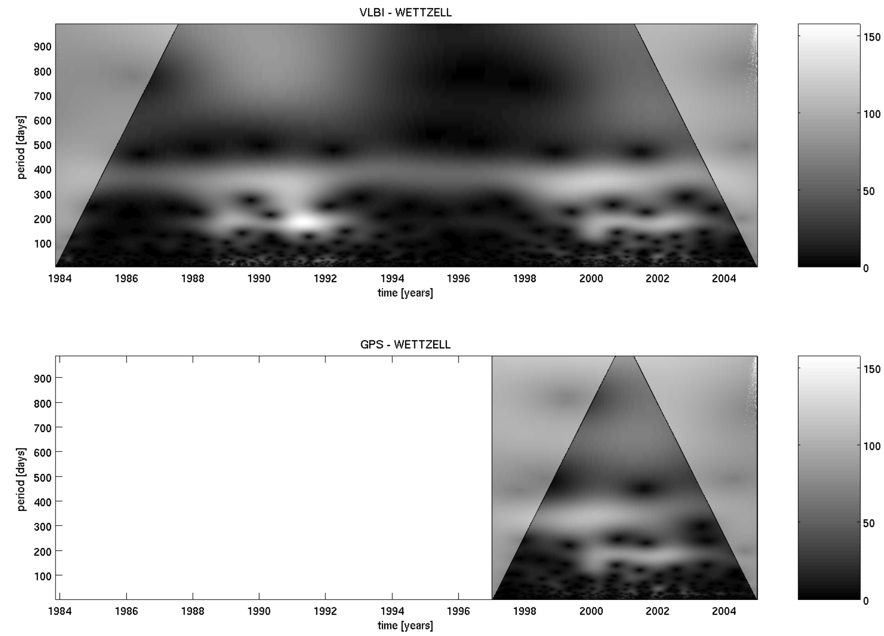

Figure 4. Wavelet spectra of VLBI and GPS (both Wettzell)

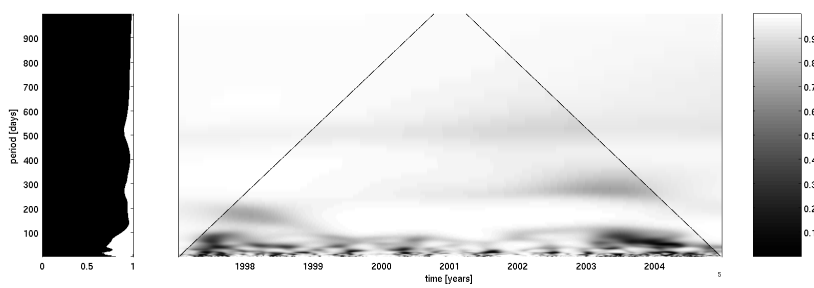

Figure 5. Quadratic cross-scalogram (right) and normalized Wavelet coherency (left) at station Wettzell

3. Correlations with Solar Flux

Solar flux at 10.7 cm[3] was compared with the VTEC time-series of VLBI and GPS at station Wettzell. The Fourier spectra of each series were computed using the CLEAN algorithm (Baisch and Bokelmann, 1999, [3]) and the results are displayed in Figure 6. The diurnal, semi-annual and annual signals can be seen from the results of VLBI and GPS. But only VLBI is able to exactly reveal the signal of the solar cycle with a period length of 10.5 years. Additionally, correlation coefficients between solar flux and a reduced (i.e. annual and semi-annual signals removed) mean

[3]Space Physics Interactive Data Resource, National Oceanic & Atmospheric Administration (NOAA), http://spidr.ngdc.noaa.gov/spidr/

VLBI VTEC time series were computed for time lags between -10 and 10 days (Figure 7). Maximum correlation is found for a time lag of 2-3 days, which is equal to the travelling time caused by a coronal mass ejection with a speed of 500-600 km/s (Lara et al., 2003, [4]).

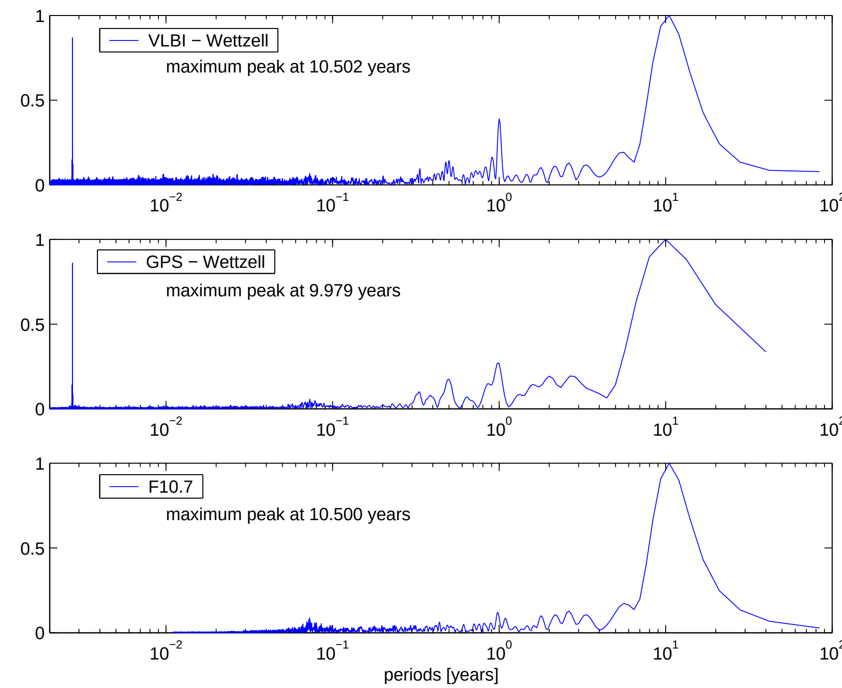

Figure 6. CLEANed spectra of VLBI and GPS (both Wettzell) and F10.7

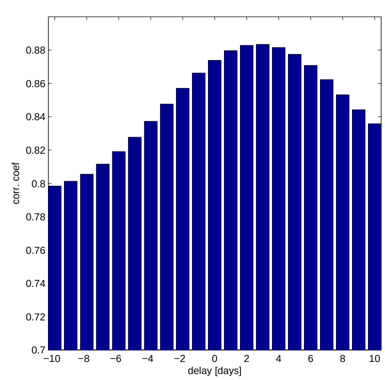

Figure 7. Correlation coefficient between reduced mean VTEC and solar flux (F10.7) for several time lags

4. Comparison with Satellite Altimetry Data

VLBI station Kokee Park located on Hawaii was selected for a comparison with VTEC values, which were obtained from satellite altimetry data. Data were taken for comparison, when the footprints of JASON-1 and TOPEX/POSEIDON satellites were within a radius of 0.5 degree from Kokee Park. The measured VTEC values from each satellite were compared to the VLBI results (Figures 8 and 9), revealing a small overall bias of +1.2 TECU in the differences (JASON-1 or TOPEX/POSEIDON minus VLBI) and a standard deviation of about 9.0 TECU.

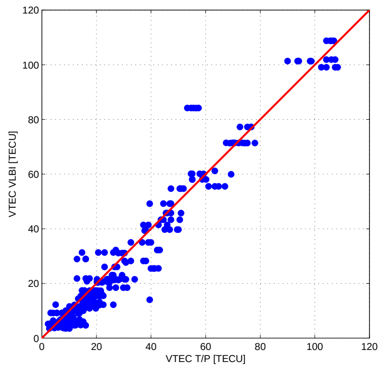

Figure 8. VTEC values of TOPEX/POSEIDON vs. VLBI

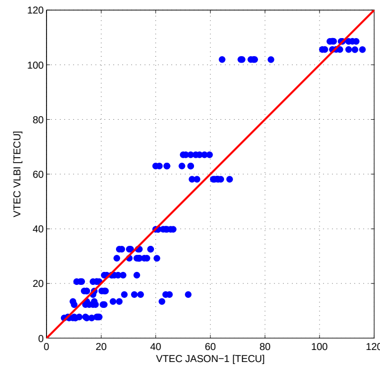

Figure 9. VTEC values of JASON-1 vs. VLBI

5. Summary and Outlook

It was shown that ionospheric parameters computed from VLBI data agree well with results from GPS and satellite altimetry missions. The relation to solar activity was verified and it was pointed out that VLBI is still the only space geodetic technique which can contribute to precise long term studies of the ionosphere as it covers two complete solar cycles, i.e. more than 20 years. VTEC values from VLBI can be used for validation purposes of existing ionosphere models or can be incorporated into global models representing the ionosphere in space and time.

6. Acknowledgements

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