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# Comparison of Tropospheric Parameters Submitted to the 2nd IVS Analysis Pilot Project

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**Abstract**

At the IVS Analysis Workshop at GSFC in February 2001, it was agreed that the 2nd IVS Analysis Pilot Project should also deal with a comparison of tropospheric parameters to be submitted by the Analysis Centers (AC) in addition to the Earth orientation parameters. Nine ACs provided ten series of tropospheric parameters, derived from all NEOS-A sessions in the years 1999 and 2000. These parameters included total (hydrostatic and wet) zenith path delays and horizontal gradients. First comparisons show that the VLBI and IGS (International GPS Service) total zenith path delays are of comparable accuracy with regard to 24 h mean values as well as hourly values. However there is a constant offset between the VLBI and GPS time series of the individual sites.

## 1. Introduction

At the 2nd IVS Analysis Workshop at Goddard Space Flight Center (GSFC) in February 2001, the 2nd IVS Analysis Pilot Project (PP) was initiated. The submission of tropospheric parameters derived from all (104) NEOS-A sessions in 1999 and 2000 was requested in addition to the Earth orientation parameters. The Institute of Geodesy and Geophysics (IGG) at the Vienna University of Technology, Austria, which is in charge of the tropospheric part of the 2nd PP, received ten different solutions from nine ACs with the Onsala Space Observatory (OSO) submitting two solutions (Table 1). Four ACs used OCCAM software packages, another four CALC/SOLVE and the AC at Jet Propulsion Laboratory (JPL) applied the MODEST software package. Apart from two ACs (AUS, IAA) which used the Kalman filter technique, all other ACs applied the "classical" least-squares fit with the Gauss-Markoff model for their analyses. The Niell

Table 1. Overview of the participating Analysis Centers (AC). Ten solutions were submitted by nine ACs.

| | | |
|---|---|---|
| AUS | AUSLIG, Australia | Occam |
| BKG | BKG, Germany | Calc/Solve |
| CAN | NRC, Canada | Calc/Solve |
| DGF | DGFI, Germany | Occam |
| GSF | NASA GSFC, U.S.A. | Calc/Solve |
| IAA | IAA, Russia | Occam |
| IGG | IGG, Austria | Occam |
| JPL | NASA JPL, U.S.A. | Modest |
| OSO | OSO, Sweden | Calc/Solve |
| OS2 | OSO, Sweden | Calc/Solve |

mapping functions (Niell, 1996 [2]) were used for all analyses. The cutoff elevation angles were always below eight degrees, mostly set to five degrees elevation. As requested for this Pilot Project, all station coordinates were fixed to the ITRF2000.

## 2. Comparison of Total Zenith Path Delays

After manual editing (removal of outliers, closing gaps by interpolation), the total zenith path delays submitted by the individual ACs were compared with regard to

- 24 h mean values, i.e. one value per session,
- hourly values.

Furthermore, the total zenith path delays of a combined VLBI solution were compared to GPS total zenith path delays released as official IGS (International GPS Service) products (Gendt, 1996 [1]).

### 2.1. 24 h Mean Values

As the zenith path delays from AUS, IAA and CAN deviated significantly from the other time series (Figure 1) and the remaining seven solutions agreed very well, a combined VLBI solution was determined from the latter. This combined solution is the arithmetical mean per session of all time series after referring them to a common mean per station for the total time span (1999 and 2000) (Figure 2). Finally the combined solution was compared to the IGS time series of total zenith path delays. It is of comparable accuracy but there remains an offset between the two series (Figure 3) almost constant over the two years, even after accounting for the additional hydrostatic and wet path delays that are due to the height differences between the VLBI telescopes and the GPS antennas (see Table 2 for a detailed description). The remaining offsets might be due to

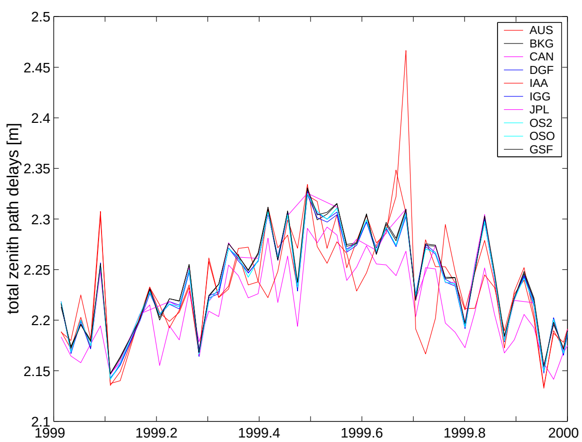


Figure 1. 24 h mean values of the total zenith path delays as submitted by the nine ACs for the station Wettzell. For clarity only the year 1999 is shown here.

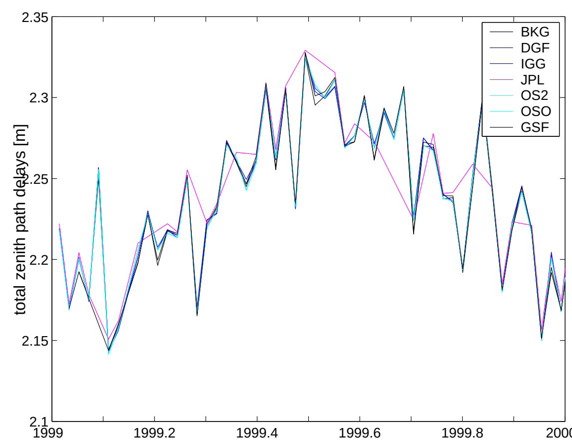


Figure 2. 24 h mean values after shifting them to a common mean for the total time span (1999 and 2000) for Wettzell. All time series except those from AUS, IAA and CAN were used for computing the common mean.

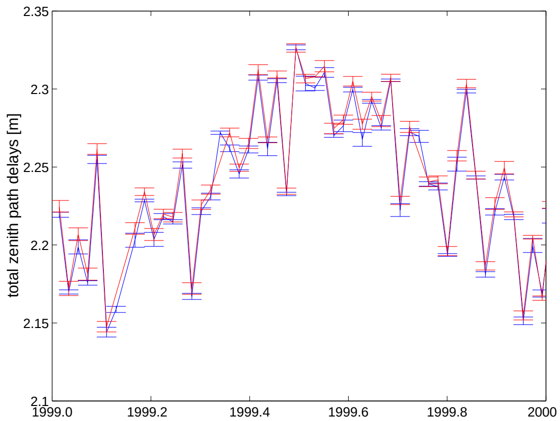


Figure 3. Combined VLBI solution of mean values per session of the total zenith path delays at Wettzell compared with the IGS 24 h mean time series. Again, only the year 1999 is shown here.

different estimation strategies (cutoff angles, mapping functions, ..), GPS phase center variations, VLBI subreflector bending, different ITRFs and geophysical models used for data analysis.

## 2.2. Hourly Values

The data submitted by AUS and IAA could not be used for the comparison of hourly values, because these ACs used the Kalman filter technique and provided only one value per session. In a first step the eight time series from the other ACs (Figure 4) were referred to a common mean (Figure 5). The total zenith path delays from CAN were not used for the calculation of the common mean because the CAN time series were always significantly shifted with respect to the others. Then a combined VLBI solution was calculated by simply determining the arithmetical mean of the time series for the hourly time epochs (Figure 6). Data were removed as outliers if the difference to the combined time series was larger than 2.5 times the standard deviation at a certain epoch. Finally the combined VLBI solution was compared to the IGS time series (Figure

Table 2. Mean offsets between the combined VLBI solution of 24 h mean total zenith path delays and the corresponding parameters from IGS. The second column shows the offsets and standard deviations resulting from a first comparison. The third column provides the height differences between the VLBI telescopes and the GPS antennas and the fourth column the corresponding hydrostatic and wet zenith path delays calculated for the mean temperatures, atmospheric pressures and relative humidities at each station. After applying these corrections there still remain offsets between the VLBI and GPS time series (fifth column) that are always negative.

| Station | dZPD [mm] | dH [m] | dZPD h+w [mm] | dZPD res. [mm] |
|---|---|---|---|---|
| ALGO | -14.1 ± 2.9 | 23.1 | 7.1 + 2.1 | -4.9 |
| FORT | -14.1 ± 8.3 | 3.6 | 1.1 + 0.8 | -12.2 |
| GILC | -4.6 ± 2.6 | 13.1 | 3.9 + 0.5 | -0.1 |
| KOKE | -13.6 ± 2.9 | 9.2 | 2.5 + 1.5 | -9.6 |
| NYAL | -3.7 ± 2.7 | 8.8 | 2.7 + 0.3 | -0.7 |
| WETT | -3.6 ± 2.4 | 3.1 | 0.9 + 0.3 | -2.4 |

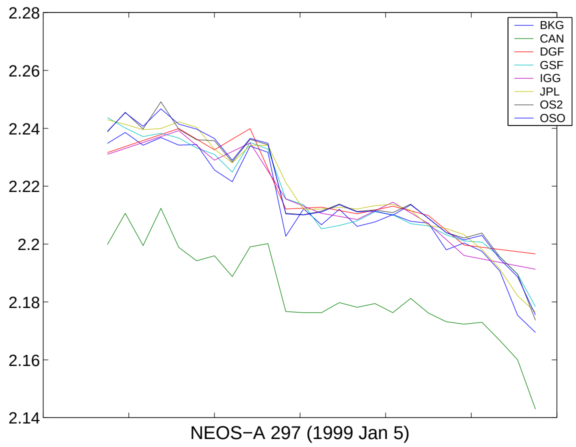


Figure 4. Hourly total zenith path delays at Wettzell for NEOS-A 297 as submitted by the ACs.

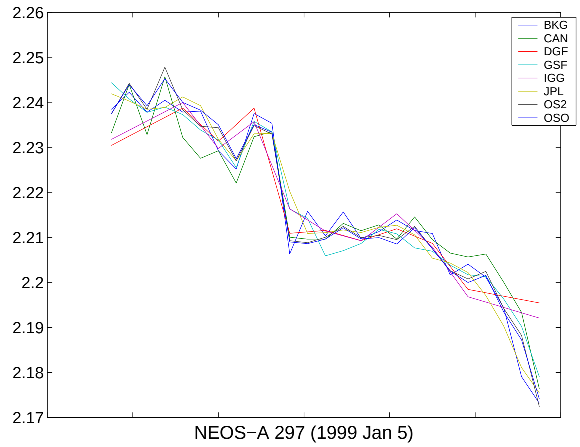


Figure 5. Hourly total zenith path delays at Wettzell for NEOS-A 297 referred to a common mean.

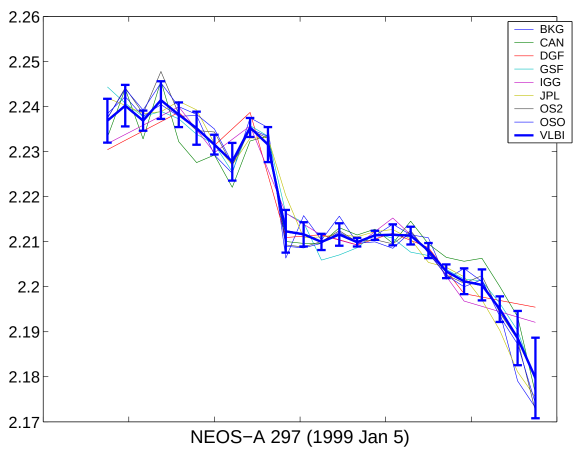


Figure 6. Individual submissions and combined VLBI solution (in blue, with one-sigma error bars) of hourly total zenith path delays at Wettzell for NEOS-A 297.

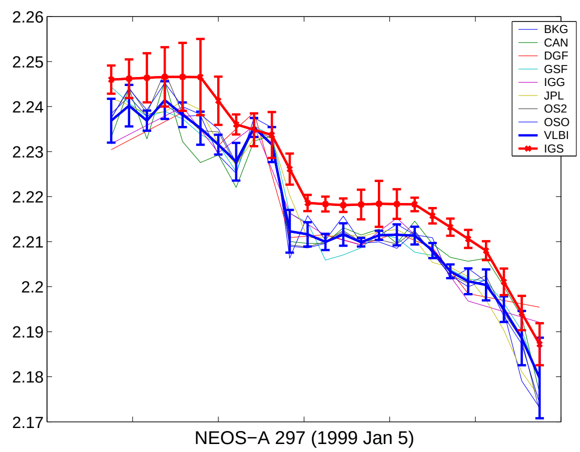


Figure 7. Combined VLBI solution of hourly total zenith path delays at Wettzell for NEOS-A 297 compared to the IGS time series (red). The latter are published in 2h time intervals and are interpolated in between.

7). The agreement is quite good, but again there is an offset between the VLBI and GPS results. The mean standard deviations of the hourly total zenith path delays per station for 1999 and 2000 can be found in Table 3; Figure 8 provides the mean standard deviations and offsets w.r.t. the common mean per session per AC at Wettzell.

## 3. Conclusions and Future Outlook

This preliminary comparison shows a good agreement between the zenith path delays submitted by most ACs. Weaknesses of individual AC solutions can be detected by the Pilot Project in terms of offsets or outliers and useful feedback to the ACs can be given. First combined VLBI series yield standard deviations of about ± 4.1 mm for the total zenith path delays. This value will probably decrease if more rigorous outlier tests are applied. Further results including the comparison of horizontal gradients describing the azimuthal asymmetry of the refractivity at a site will be provided in a final report that will be accessible via the IVS homepage in spring 2002. Based on these results a new Pilot Project was approved at the 7th Directing Board Meeting in Tsukuba (Feb. 2002) in preparation of official IVS tropospheric products.

Table 3. Mean standard deviations of the hourly total zenith path delays per station for 1999 and 2000 in [mm].

| Algo | Fort | Gilc | Koke | Nyal | Wett |
|---|---|---|---|---|---|
| 4.1 | 5.6 | 3.4 | 4.1 | 3.8 | 3.9 |

## References

[1] Gendt, G., Comparisons of IGS tropospheric estimates, Proceedings IGS Analysis Center Workshop, 19-21 March 1996 Silver Spring, Maryland USA, Eds. R E Neilan, P A Van Scoy, J F Zumberge, pp. 151-164, 1996.

[2] Niell, A.E., Global Mapping Functions for the Atmospheric Delay at Radio Wavelengths, J. Geophys. Res., 101 (B2), pp. 3227-3246, 1996.

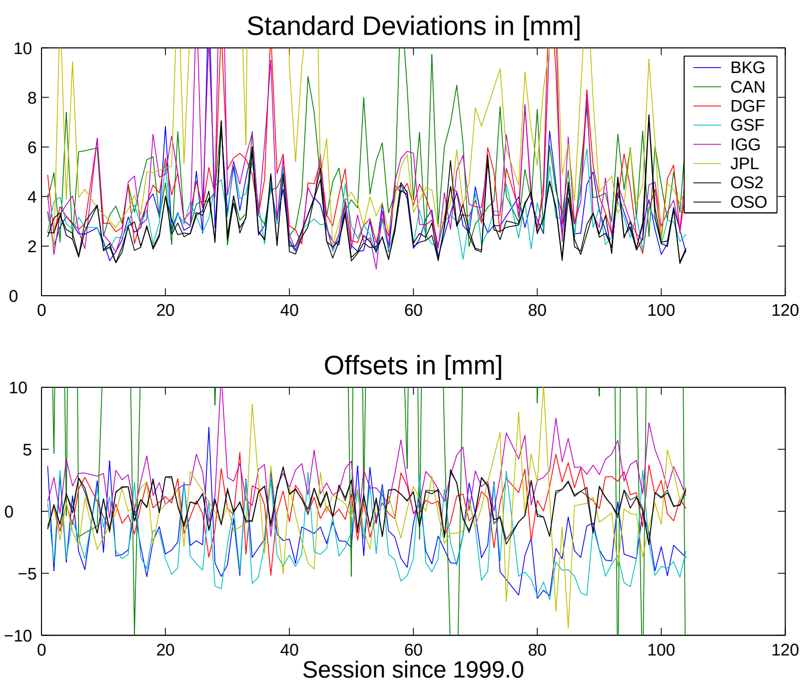


Figure 8. Mean standard deviations of the hourly total zenith path delays and offsets w.r.t. the common mean in 1999 and 2000 at Wettzell for all ACs.