Comparison of Numerical Weather Models in the Area of the Antarctic Peninsula

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Abstract

The Earth's neutral atmosphere with its dry and wet component affects the radio waves emitted by GPS satellites or extragalactic radio sources. Thus, modelling the effect of the neutral atmosphere is a limiting factor for GNSS applications (e.g. GPS) and VLBI, respectively. In the related literature this phenomenon is usually called tropospheric resp. neutrospheric refraction. For satellite-based precise point positioning applications, one has to model and estimate the tropospheric refraction in order to guarantee results of highest quality. In the opposite, neutrospheric effects can also be used to derive the important meteorological parameter water vapour.

In the framework of a case study carried out at the Geodetic Institute of the University of Karlsruhe (TH) (Germany), GPS data collected at several sites of the Antarctic Peninsula were used to evaluate a realistic measure for the precision and the accuracy of GPS-based integrated precipitable water vapour estimates. As external references NCEP (National Center for Environmental Prediction) Reanalysis data were used.

At the Institute of Geodesy and Geophysics of the Vienna University of Technology (Austria) detailed and numerous investigations based on VLBI and GPS data have been carried out to derive accurate mapping functions based on data from the numerical weather model provided by the European Centre for Medium-Range Weather Forecasts (ECMWF).

The poster will present a comparison of the two numerical weather models ECMWF and NCEP based on different parameters in the area of the Antarctic Peninsula. The meteorological data base of this area is affected by the small quantity of meteorological observations. Therefore the quality of the numerical weather models has to be investigated. Furthermore, the effort of obtaining reliable estimations of precipitable water will be an additional source to improve the knowledge about climate variability in the area of the Antarctic Peninsula.

GPS-related Motivation

Within the redundant parameter estimation of differential GPS software the effect of the neutrosphere is handled in two ways:

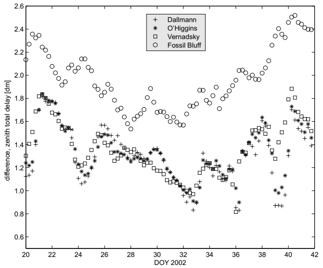
$$_{NEU} \; z \quad \left[f_{MF1} \; z \; {}^{Zenith}_{NEU} \right]_{PRE} \quad f_{MF2} \; z \left[{}^{Zenith}_{NEU} \; t \right]_{v}$$

- Prediction (*PRE*) based on models (e.g. Saastamoinen, Askne/Nordius) and mapping functions (e.g. $Niell_{MF}$), developed for specific regions and under various assumptions
- Site-specific and time-dependent improvements (v) for these predictions are estimated based on GPS observations

Both parts depend on meteorological (e.g. T, p, e resp. rh), site- and/or time-dependent parameters (e.g. H, doy,). As data source of the meteorological parameters

- surface measurements,
- surface values based on standard atmosphere resp.
- profiles or numerical weather models

are used. If surface values based on standard atmosphere approximations have to be introduced in prediction models, the calculated neutrospheric refraction is not sufficient to fulfill highest quality requirements (see figure), therefore one has to estimate additional site-specific and time-dependent parameters, which normally are highly correlated with height estimates.



Comparison of zenith delay values of the adapted approach of Askne/Nordius using standard atmosphere surface values and NCEP-based zenith delay values of representative sites of the densification network in the area of the Antarctic Peninsula

Basic Formulas

The functional relation between the refractivity index n resp. the refractivity N and the neutrospheric refraction along the curved propagation path s is given by

$$_{NEU} \quad n \quad 1 \; ds \quad 10^{-6} \quad N ds$$

Hereby N is represented as a function of the meteorological parameters p_d, e, and T, experimentally determined constants k, and compressibility factors Z using

$$N \quad k_1 \frac{p_d}{TZ_d} \quad k_2 \frac{e}{TZ_w} \quad k_3 \frac{e}{T^2 Z_w}$$

Based on estimates of the wet part of zenithal neutrospheric refraction, values of the integrated water vapour (*IWV*) and the integrated precipitable water vapour (*IPWV*) in zenithal direction can be determined using

$$IWV = \; {}^{Zenith}_{NEU,w} \qquad IPWV = IWV \quad _{w}$$

$$\frac{10^6}{R_w \; \frac{k_3}{T_m} \quad k_2 \quad k_1 \frac{M_w}{M_d}} \qquad T_m \quad \frac{\frac{e}{TZ_w} dH}{\frac{e}{T^2 Z_w} dH}$$

In contrast to the VLBI- resp. GPS-based determination of *IPWV*-values, independent data sources like numerical weather models could be used

$$IPWV_H \quad \frac{1}{R_w} \int_{H_0}^{H} \frac{e}{TZ_w} dH$$

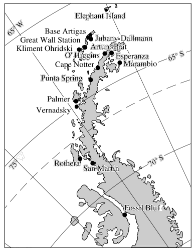
These *IPWV*-values depend on the resolution (horizontal, verical) of the weather models. If there are limited (height, resolution) model data sets existing (e.g. relative humidity of NCEP-reanalysis), one has to extra- resp. interpolate to the Earth's surface resp. to the height of the GPS site. If the *rh*-value at the highest layer is not equal to zero, an extrapolation to the upper limit (presented investigations: 250 hPa) is also needed. Both extrapolations can only be carried out under certain constraints (e.g. linear approximation downward; $rh_{250hPa} = 0$).

$$IPWV_H \quad \frac{1}{R_w} \sum_{H_{surf}}^{H_{250}} \frac{\overline{e_{i,i\;1}}}{\overline{T_{i,i\;1} \; Z_w}} \quad H_{i,i\;1}$$

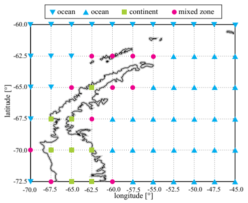
By means of this approach one is also able to calculate meteorological surface values based on numerical weather model data, which could be introduced in surface data dependent prediction models or mapping functions, if no measurements are available.

Case Study

Since 1995 an ITRF densification network was established in the area of the Antarctic Peninsula in the framework of the Scientific Committee on Antarctic Research in order to determine deformation rates of the near to the coastline situated sites by means of GPS. The results are therefore affected by neutrospheric refraction. Several strategies to model the neutrospheric effects were evaluated at the GIK. As external reference NCEP data were used.



The analysed NCEP data cover the months January and February (GPS observation period) of the years 1995, 1998, and 2002. The NCEP data have a temporal resolution of 6 h. The number of the pressure layers up to 300 hPa is 8. The horizontal resolution is 2.5° (latitude, longitude). NCEP provides e.g. information for geopotential height, relative humidity, and temperature at different pressure layers. Using these data gridded and site-related *IPWV*-values were calculated and compared to GPS-based *IPWV*-values.

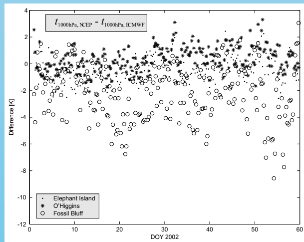


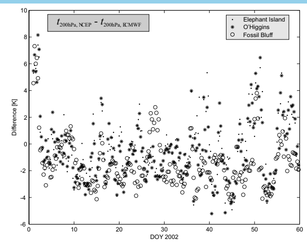
In order to derive quality measures of NCEP-based *IPWV*-values a comparison between NCEP and ECMWF products is carried out.

ECMWF data provide 15 (years 1995, 1998) resp. 21 (year 2002) pressure levels containing geopotential heights, temperature and specific humidity. In contrast to NCEP data ECMWF data do not comprise a 600 hPa layer, but contain more information of higher pressure layers (8 resp. 14 levels for $p < 300$ hPa). The higher pressure levels do not contribute significantly to the *IPWV*-determination, normally.

The horizontal and temporal resolution of the used ECMWF data is identical to the NCEP resolution.

Results

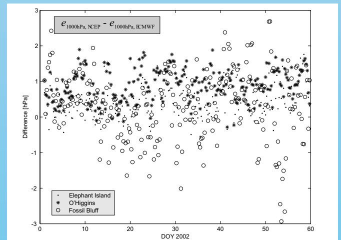




Temperature und water vapour pressure values are used to calculate *IPWV*-values. In order to get an impression of the differences of these NCEP- and ECMWF-related input parameters the temperature values at the lowest pressure level ($p = 1000$ hPa, left figure) and the p_{200hPa}-level (right figure) are analysed. The pressure level 200 hPa is chosen, because NIELL (2001) realised a high correlation between the height of the 200 hPa pressure level and mapping functions derived from radio soundings.

Shown are the bilinear interpolated temperature differences (NCEP-ECMWF) of the 3 sites Elephant Island, O'Higgins and Fossil Bluff. Elephant Island is one of the most northern sites of the densification network, O'Higgins is situated in the Bransfield Strait representing the center network sites, and Fossil Bluff is the southernmost site. The figures illustrate the behavior of the weather model data of the first two months of 2002. There are no significant differences detectable with respect to the data sets of 1995 and 1998.

The $RMS_{t1000hPa}$-values of northern and centered sites are in the range of 1.0 - 1.5 K; these differences are nearly normally distributed, whereas the NCEP temperature values of southern sites are systematically (approx. 2 K) lower than the ECMWF-based values. The bandwidth of the temperature difference variations of the p_{200hPa}-level is larger and no geographic dependency could be detected. If the gridded weather model data is analysed these statements are valid, too.



Based on temperature, humidity, and pressure values of the NCEP data sets the water vapour pressure is calculated by means of the formulas of Murray

$$e \quad \frac{rh}{100} e_{sat} \quad \begin{cases} e_{sat,ice} & 6.1 \quad 10^{\frac{9.5T}{T \quad 265.5}} \\ e_{sat,water} & 6.1 \quad 10^{\frac{7.5T}{T \quad 237.2}} \end{cases}$$

In contrast, the ECMWF-based e-values are determined by means of

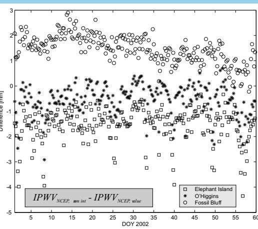
$$e = \frac{sh \cdot p}{0.622 + 0.378 \cdot sh}$$

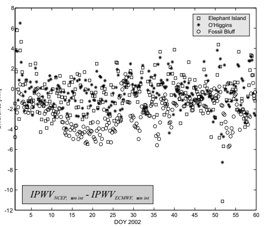
Shown are the e-differences (NCEP-ECMWF) of the $p_{1000hPa}$-level. The corresponding absolute values of these pseudo-surface-layer vary in the range of 3 hPa (southern sites) up to 8 hPa (northern sites), normally, and decrease rapidly with increasing height. The RMS increases for southern sites (Fossil Bluff: 1.1 hPa). e_{NCEP} is mostly larger than e_{ECMWF}.

In order to derive precise *IPWV*-values based on weather model data the vertical resolution of the meteorological values is virtually increased ($dp = 1$ hPa), after interpolation vertically to site height. The *IPWV*-values above the sites of the densification network vary between approx. 2 mm and 22 mm (average value: 10.4 mm). If the compression factors are neglected differences up to 0.5 mm result. The differences increase for southern sites.

The NCEP data sets contain also *IPWV*-estimates. The comparison of these values with the *IPWV*-values resulting from numerical integration of meteorological NCEP parameters shows a latitude-dependent behavior (figure: top right). The *IPWV*-differences vary between -5 mm and +3.5 mm.

If the meteorological parameters of the pressure levels of NCEP and ECMWF data sets sre numerically integrated the *IPWV*-differences vary mostly in the range of -5 mm and +3 mm (figure: down right). The RMS-values of all time series are nearly identical. Additionally, there is a weak site-dependent behavior of the time series detectable: $IPWV_{ECMWF}$-values of the southern-most sites are larger than the $IPWV_{NCEP}$-values.





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