Determination of a realistic Precision Measure for Integrated Precipitable Water Vapour Values in the Area of the Antarctic Peninsula

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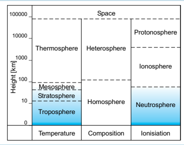
Introduction

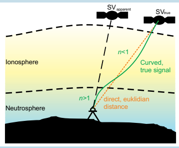


Within the data evaluation process of global satellite navigation systems (e.g. GPS) one has to handle all limiting factors with care in order to guarantee highly precise and accurate point positions. The factors, which are affecting the GPS, are classified in satellite-related, atmospheric, and site-specific factors.

Analyzing the limiting atmospheric effects, the most important and most critical areas of the earth's atmosphere are the ionosphere (approx. 50 - 1000 km) and the subjacent electrical neutral atmosphere (neutrosphere).

The poster will focus on the neutrosphere consisting of troposphere, stratosphere, and mesosphere, and especially on the water vapour of the neutrosphere. Thus, water vapour is a limiting factor for GPS applications. For precise point positioning applications using GPS data, one has to model and estimate the neutrospheric effects in order to guarantee results of highest quality. Based on the standard evaluation of GPS data the neutrospheric noise could be used to determine values of the integrated water vapour (*IWV*).

In the framework of a case study carried out for the area of the Antarctic Peninsula efforts are made to evaluate a realistic measure for the precision and the accuracy of GPS-based integrated water vapour estimates. As external reference the meteorological data of the NCEP Reanalysis is used.



Basic Formulas

Within the determination of values of the *IWV* based on GPS observations the functional conection between the refractivity index n resp. the refractivity N and the neutrospheric effect $^{Zenith}_{NEU}$ along the curved way path s in the direction of the local topocentric direction is given by

$$^{Zenith}_{NEU} \quad n \quad 1\,ds \quad 10^{6} \quad N ds \; .$$

Hereby N could be calculated with respect to meteorological parameters pressure of the dry air, water vapour pressure, and temperature and experimentaly determined constants k_i using

$$N \quad k_1 \frac{p_d}{T} \quad k_2 \frac{e}{T} \quad k_3 \frac{e}{T^2} \; .$$

Based on the estimates of the wet part of the zenithal neutrospheric effect values for the integrated water vapour and the integrated precipitable water vapour (*IPWV*) could be determined using

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

whereas the parameter depends on the empirical constants k_i, on the specific gas constants of dry and wet air $R_{d/w}$ as well as on the mean atmospheric temperature T_m and the density of water $_w$.

$$\frac{10^6}{R_w \; \frac{k_3}{T_m} \quad k_2 \quad k_1 \frac{M_w}{M_d}} \qquad \frac{10^6}{R_w \; \frac{k_3}{T_m} \quad k_2 \quad k_1 \frac{R_d}{R_w}} \qquad \frac{10^6}{R_w \; \frac{k_3}{T_m} \quad \overline{k_2}}$$

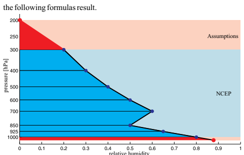
If it is not assumed, that the atmosphere behaves like a mixture of two ideal gases, T_m could be calculated depending e.g. on the compressibility factor Z_w.

$$T_m \quad \frac{\frac{e}{TZ_w} dH}{\frac{e}{T^2 Z_w} dH}$$

In addition to the GPS-based determination of *IPWV* values these values could be calculated using independent data sources like weather models (e.g. NCEP reanalysis) e.g. with respect to specific humdity q and gravity g under the ideal gas asumption by means of

$$IPWV_P \quad _{p_0}^{p} \frac{q}{g} dp \quad \text{and} \quad IPWV_H \quad \frac{1}{R_w} \; _{H_0}^{H} \frac{e}{T} dH \; .$$

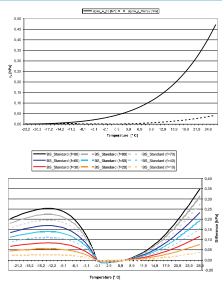
Are only limited (height, resolution) model data sets existing (e.g. relative humidity of NCEP reanalysis), one has to extrapolate to the surface resp. height of GPS site (lower limit). If the value of the highest layer (scetch: 300 hPa) is not equal to zero, an extrapolation to the upper limit (presented investigations: 200 hPa) is also needed. Both extrapolations can only be carried out under certain constraints (linear extrapolation downward; $f_{200hPa}=0$), so that the following formulas result.



$$IPWV_P \quad _{p_{surf}}^{p_{200}} \frac{\overline{q_{i,i\;1}}}{\overline{g_{i,i\;1}}} \quad p_{i,i\;1}$$

$$IPWV_H \quad \frac{1}{R_w} \; _{H_{surf}}^{H_{200}} \frac{\overline{e_{i,i\;1}}}{\overline{T_{i,i\;1}}} \quad H_{i,i\;1}$$

Results



Within the redundant parameter estimation of standard GPS applications the effect of the neutrosphere is handled in two ways. On the one hand the neutrospheric effect is predicted based on modells (e.g. Saastamoinen, Askne and Nordius, Niell), developed for specific regions and under various assumptions (i.E. standard atmosphere conditions), on the other hand site-specific and time-dependend improvements for this predictions are estimated based on real GPS observations. Both modelling elements depend e.g. on the value of the so-called absolute zero-point of the temperature scale. This value varies between 273.00 and 273.16. The effect of an error due to the difference of the absolute zero-point on the water vapour pressure [hPa] with respect to the temperature [°C] is shown for two calculation approaches of the water vapour pressure, called BS and Murray.

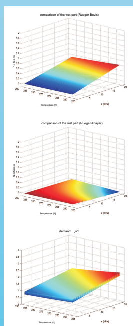
The model used within the Bernese GPS Software (BS) is given by

$$e \quad \frac{f}{100} \, e^{-37.2465 \quad 0.2131665T \; K \; -0.000256908T \; K \; ^2}$$

The meteorologicly well-accepted modell of Murray takes the state of aggregation into account and is given by

$$e \quad \frac{f}{100} \, 6.1078 e^{\frac{a \; T \; K \quad 273.16}{T \; K \quad b}} \qquad \begin{cases} a_{ice} = 21.8745584 \\ a_{water} = 17.2693882 \\ b_{ice} = 7.66\,K \\ b_{water} = 35.86\,K \end{cases}$$

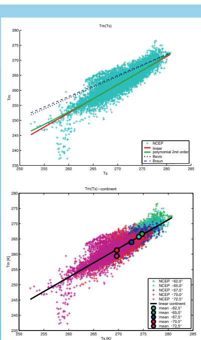
The differences between this two modells increase for high temperatures. In the area of the Antarctic Peninsula this effect could be neglected.



Within the associated literature (e.g. Thayer or Bevis et al.) different values for the empirical constants k_i could be found. Rueger compared and analysed various experiments and methods in order to find a best set of constants k_i.

The upper and the middle graph show the wet refractivity differences of the above mentioned models with respect to temperature and water vapour pressure. To be able to evaluate the significance of the effect of these differences the third graph shows the standard deviation of the temperature depending on temperature and water vapour pressure. These values were determined under the demand: $N=1$.

An effect of these differences on $I(P)WV$ values is not detectable.



In order to calculate values of integrated (precipitable) water vapour the mean atmospheric temperature has to be determined. Therefore different formulas are existing, e.g. developed by Bevis et al. or Braun et al., enabling the calculation based on values of the surface temperature (T_s).

Using NCEP values of the continental part of the Antarctic Penisula these suface-temperature-based approaches were compared to Peninsula-adapted approaches.

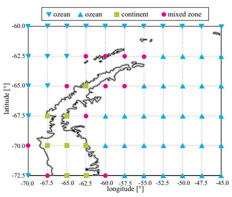
Detectable are:

- a significant difference between the standard and the Peninsula-adapted approache
- no dependence on the latitude
- no significant difference between linear and 2[nd] order polynomial approach.

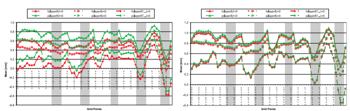
Therefore, in order to guarantee results of highest quality the determination of a regional-adapted functional model to calculate the mean atmospheric temperature based on the surface temperature is recommended.

In order to evaluate an area of precision which guarantees reliable NCEP-based *IPWV* values investigations with respect to different affecting parameters were carried out, especially the mean atmospheric temperature, the formulas used to calculate water vapour pressure, the effect of compressibility factors, the resolution (vertical, horizontal) of the NCEP data, the values of the empirical constants k_i, and the integration approach including gravity formulas and height definitions were taken into account.

The analysed NCEP data covers the months January and February of the years 1995, 1998, and 2002. The NCEP data has a temporal resolution of 6 h. The standard vertical resolution 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, humidity, and temperature at different pressure layers.

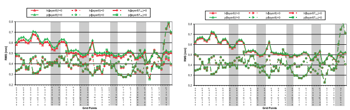


The most important affecting parameter is due to the vertical resolution of the layered NCEP reanalysis data. The increment of the NCEP pressure levels varies between 75 hPa and 100 hPa. If this standard vertical resolution is used to carry out the piecewise summation in order to gain $I(P)WV$ values a systematic and significant difference between the two summation approaches p (summation with respect to the pressure difference of two consecutive pressure layers) and H (summation with respect to the geopotential height difference corresponding to two consecutive pressure layers) results. Within the associated graphs the mean values are shown as well as the corresponding RMS-values for the 66 grid points each based on 708 NCEP-realizations of the earth's atmosphere. The graphs also contain three different characteristics of both summation approaches. Hereby the expression "layer8!=0" stands for "value of the highest layer of relative humidity is not equal to 0 hPa", whereas "layer8=0" stands for "value of the highest layer of relative humidity is equal to 0 hPa", and "layer87=0" stands for "values of the minimum two highest layers of relative humidity are equal to 0 hPa".



If the vertical resolution is virtualy increased by means of the hydrostatic governing equation (e.g. 5 hPa) the difference between both summation approaches is highly reduced. So that only by means of virtual increasing of the vertical resolution the p- and the H-approach provide the same $I(P)WV$ values.

The other above mentioned effects (e.g. effect of compressibility factors) are not or weakly significant, normally.



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