Memo: Reference pressure for the Global Geodetic Observing System GGOS

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1. Introduction

There is a variety of effects in geodesy for which a reference pressure field is needed. So far, the geodetic community has lived without an 'official' reference field although we have implicitly used it. With this memorandum, we want to discuss several options in terms of accuracy and simplicity.

There is one point that we would like to stress out right from the beginning: If we have a reference pressure field for the Earth surface, we should also know the corresponding heights as well as the variation of the pressure with height in the vicinity of the Earth surface. In particular, we would like to know ellipsoidal heights because they are easier to be used with space geodetic techniques than mean sea level heights. However, since from numerical weather models we only obtain mean sea level heights, we have to apply geoid undulations to get ellipsoidal heights.

Let's first take a look at some very simple considerations on atmosphere loading. In the easiest form (Equation 1), atmosphere loading corrections can be determined locally from pressure differences with respect to a mean value $\underline{p}$ and a regression coefficient r that converts the pressure difference into a height change due to the surface load (Rabbel and Zschau 1985).

$$dh = \left(p - \underline{p}\right) \cdot r \qquad (1)$$

Whereas p can be measured locally, the mean or reference pressure $\underline{p}$ has to be taken from an appropriate model. Assuming an extreme regression coefficient r of 0.5 mm/hPa, we need to know the reference pressure with an accuracy of 2 hPa to achieve 1 mm accuracy for the station heights. In other words, if we want to apply atmosphere loading corrections and use a reference pressure $\underline{p}$ which is off by more than 2 hPa from the real mean pressure at a station this might shift the coordinates by 1 mm. Correspondingly, 10 hPa difference cause a coordinate shift of 5 mm in the worst case. Since 1 hPa roughly corresponds to 10 m height difference, we also have to know the heights of reference pressure values with an accuracy of 20 m.

2. Comparison of models

The comparison of pressure values is carried out for the surface of the Earth which is determined as follows: The geopotential in m^2/s^2 is downloaded from the ECMWF for the surface of the Earth with a resolution of 2.0° in latitude times 2.5° in longitude. Thereafter, the geopotential is divided by 9.80665 m/s^2 to get 'geopotential meters', and geoid undulations from the Earth Gravity Model EGM96 with the same grid resolution are added to get ellipsoidal heights of the Earth surface. These heights will be used for the following comparisons.

Reference pressure from ECMWF data:

2.0° times 2.5° grids of surface pressure values at 6 hourly epochs from 1994.0 to 2007.0 have been derived from pressure level data of the ECMWF, i.e. surface pressure values have been determined by interpolating vertically in the pressure levels. The mean grid (over all six-hourly grids) is used as reference for the following comparison.

Two empirical models were compared to this reference pressure:

(1) The Berg model (Berg 1948) as e.g. used in the Bernese GPS software package (Dach et al. 2007)

$$p = p_0 \cdot (1 - 0.0000226 \cdot h)^{5.225} \qquad (2)$$

The reference pressure p_0 is usually assumed to be 1013.25 hPa, and the ellipsoidal height h is used for simplicity. This implies that zero ellipsoidal heights are the heights that refer to 1013.25 hPa.

(2) The Global Pressure and Temperature model (GPT, Boehm et al. 2007).

GPT is a spherical harmonic expansion up to degree and order 9. In fact, it contains spherical harmonic expansions for the geoid undulations and for proxies of mean sea level pressure values which were derived from surface pressure by using Equation (2). To get the pressure at any arbitrary location on the Earth surface, the spherical harmonic expansion at mean sea level is evaluated and the same Equation (2) is applied to the pressure values on the Earth surface.

Apart from a few isolated grid cells in the Himalayan region where the difference exceeds several hundreds of hPa for both models (Berg and GPT), the maximum differences stay below 50 hPa for Berg and 25 hPa for GPT.

Figures 1a and 1b illustrate the pressure differences of Berg and GPT with respect to the 'reference values' described above. The differences between the reference values from the ECMWF and Berg are below 2 hPa for 27% of the whole Earth surface and 28% if only land is considered. The percentages are 71% (whole Earth) and 56% (only land) in case of the differences between ECMWF and GPT.

Table 1. Percentage in % of the area with pressure differences below a certain threshold (2 and 10 hPa) for GPT and Berg with respect to reference values from the ECMWF.

	GPT	Berg	GPT	Berg
	< 2 hPa		< 10 hPa	
land + ocean	71	27	98	83
land	56	28	96	85

However, relatively large deficiencies of GPT can be seen in regions with big height variations of the Earth surface. The reasons for the differences are the following: a) The limited resolution of a spherical harmonic expansion up to degree and order nine. b) Equation (2) for the vertical extrapolation of the pressure is not good enough for large height differences, and it might not be applicable for every region on Earth.

Figure 2 illustrates the maximum and minimum pressure differences as well as the median pressure differences (bold lines) per latitude band for Berg (blue lines) and GPT (red lines). The most striking features are the following: a) Berg shows very large errors for high southern latitudes (Antarctica). This confirms Figure 1a. b) The median error per latitude is significantly smaller for GPT than for Berg.

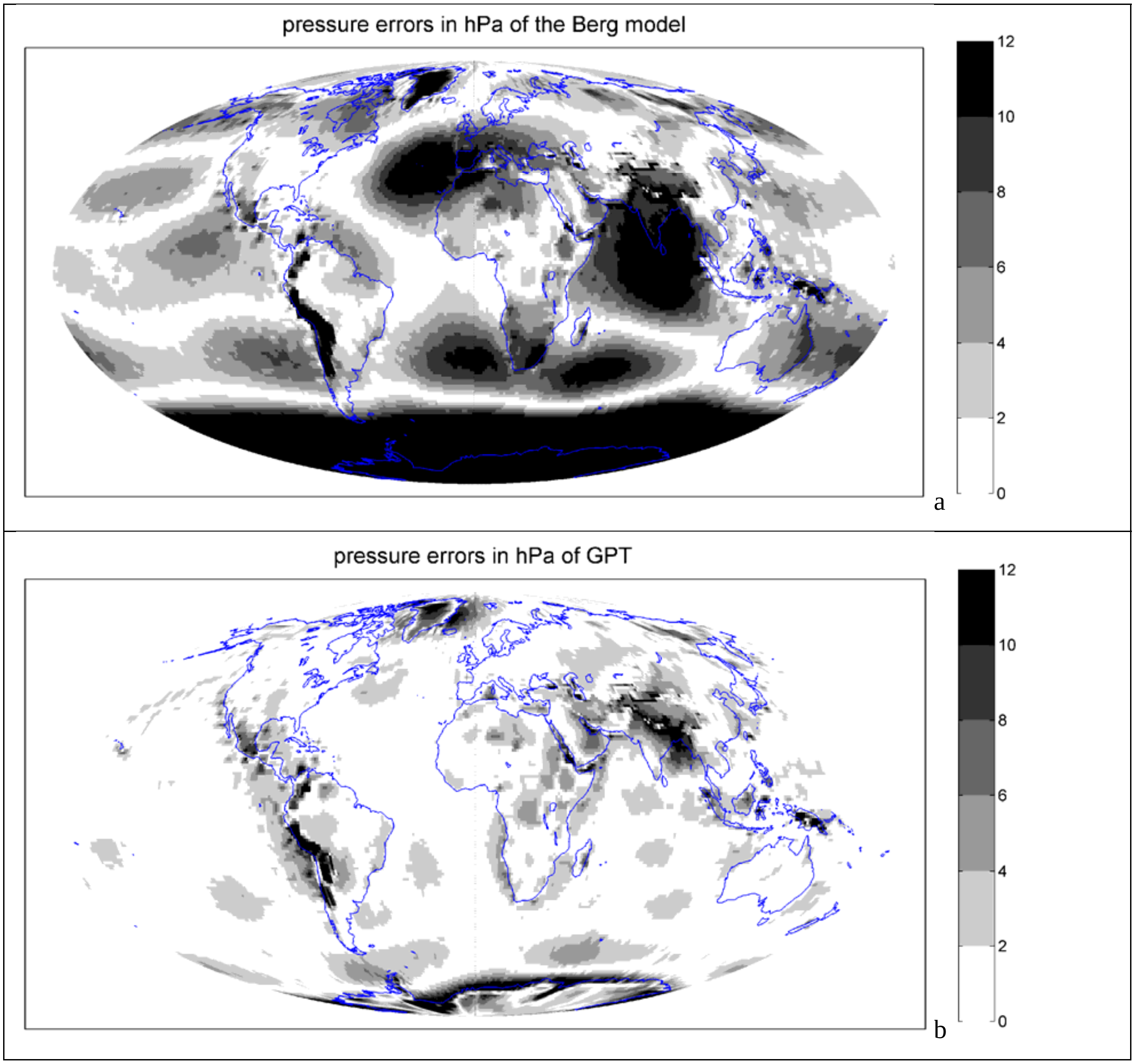

Figure 1. Absolute values of pressure differences in hPa with respect to the reference field for the Berg model (upper plot) and GPT (lower plot). An identical scale is used for better comparability although the differences for the Berg model can be as large as 50 hPa over the Antarctica.

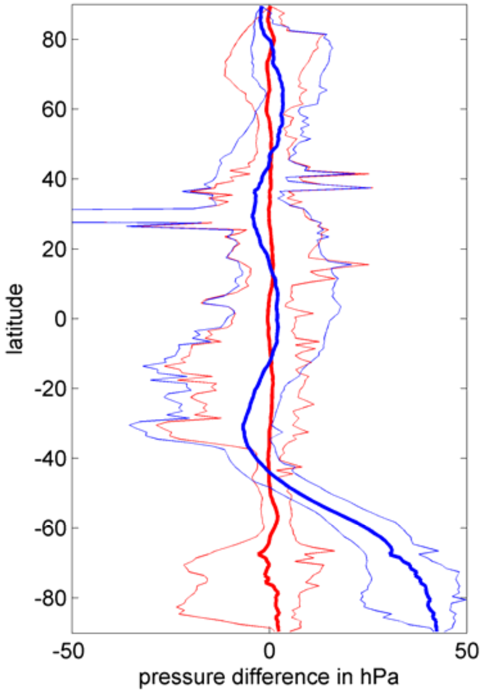

Figure 2. Minimum and maximum pressure differences in hPa per latitude band (thin lines) for Berg (blue) and GPT (red). The bold lines show the median pressure differences per latitude band.

3. Discussion

The following discussion gives just an overview about open questions.

'The model for the reference pressure should be as simple as possible. The same reference pressure should be unambiguously determinable now and any time in the future.' Then we need to take Berg, GPT, or something similar.

'The model for the reference pressure should be as accurate as possible.' Then something like the ECMWF reference values of this memo can be taken. Or perhaps 5' x 5' grid values as provided by H.P. Plag (http://geodesy.unr.edu/hanspeterplag/tools/air_pressure_refs/), which are based on the ETOPO5 height model.

References

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