Potential Contribution of CHAMP Occultation to Pressure Field Improvement for Gravity Recovery

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Summary. This paper studies one aspect of use of the CHAMP GPS occultation data, namely the improvement of the atmospheric pressure field, particularly over Antarctica. Previous studies indicate that pressure differences between ECMWF and ground truth data reach 5.18 hPa RMS over Antarctica [Ge et al., 2003]. In this study, comparisons of pressure profiles (January–March 2003) from data (CHAMP occultation and radiosonde) and models (ECMWF and NCEP), indicate large discrepancies over different regions, notably over southern polar region. Global pressure differences between CHAMP and radiosonde and model outputs reach 4 hPa RMS at 1 km above MSL. We found a positive bias in CHAMP data (CHAMP measures larger pressure values) when comparing with both radiosonde and ECMWF. Analysis shows the lack of adequate penetration of CHAMP occultation data in the planetary boundary layer particularly in the tropical region (only ~10% signal is within 1 km above MSL), as compared to ~80% penetration in Arctic and Antarctica. However, CHAMP provides improved data coverage in temporal, spatial and vertical resolution globally. We conclude that the CHAMP occultation data could potentially improve the surface pressure modeling to benefit temporal gravity recovery, in particular over data sparse region such as Antarctica.

Key words: GPS occultation, surface pressure, time variable gravity

1 Introduction

Atmospheric pressure from current operational weather analysis products is not adequate to compute atmospheric loading for accurate static and temporal gravity field recovery using CHAMP and GRACE data [Ge et al., 2003], in particular for GRACE data as it is significantly more accurate than the CHAMP data. Studies indicate that the discrepancy between the model and *in situ* observation is inadequate for GRACE data processing, especially in the data sparse region such as Antarctica [Ge et al., 2003]. In addition, Han et al. [2003] show that satellite sampling of atmosphere causes temporal aliasing of the signal, which corrupts high-frequency errors in GRACE monthly gravity field solutions. At present, atmospheric mass variations are modeled for GRACE using 6-hourly, $0^{\circ}.5$ ECMWF model outputs. An improved spatial and temporal resolution would reduce the aliasing error. In principle, GPS occultation data has improved spatial and vertical resolutions for measuring global atmospheric pressure field, shown in Fig. 1 comparing with meteorological and radiosonde stations over Antarctica.

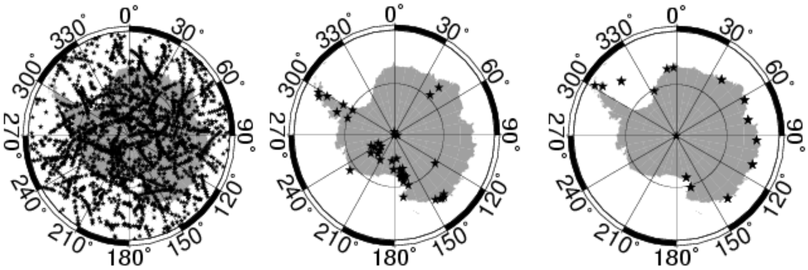


Fig. 1. Coverage map for CHAMP occultation data, January–March, 2003 (left), Automatic Weather Stations (middle) and Radiosonde Stations in Antarctica (right).

2 GPS Radio Occultation Technique

The principles and applications of GPS occultation have been extensively discussed in the literature [e.g. Wickert, 2002]. Overall, signal tracking and penetration are among the most critical limitations for accurate retrieval of surface pressure and its separation from water vapor and temperature.

Due primarily to the complexity of water vapor and signal tracking problem in the Planetary Boundary Layer (PBL), radar signals often cannot penetrate down to the surface. Fig. 2 illustrates the distribution of CHAMP occultation penetration over three regions. In the tropical region (30°N–30°S), which is warm and moist, only ~10% of signals penetrate down to 1 km above the MSL (Fig. 2b), while in the cold and dry Arctic oceanic area (Fig. 2a), ~80% of the profiles reach within 1 km above the MSL due to lack of water vapor and rapid changing small scale features. Before removing the topographic inconsistency, only ~50% profiles reach 1 km MSL in Antarctica (Fig. 2c), which is a high elevation, cold and dry region. After referencing the occultation profiles to the ECMWF topography, Ge and Shum [2003] show that the Antarctica signal penetration is similar to the Arctic region (~80% signals penetrate to within 1 km above the MSL).

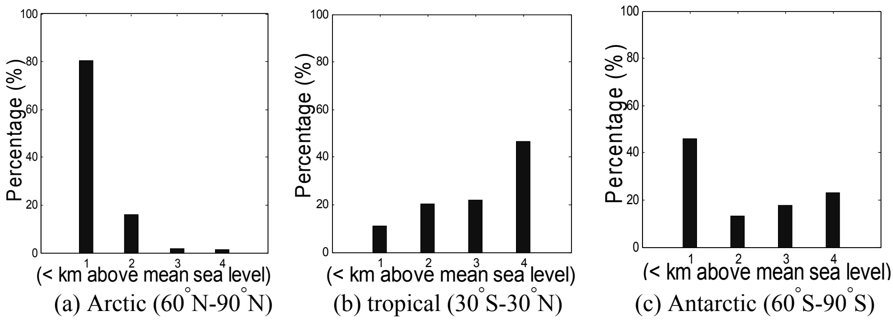


Fig. 2. Histograms of CHAMP occultation penetration depth (Jan-March, 2003, referencing to the MSL) over Arctic (~80% penetration), tropical (~10%) and Antarctic (~50%) region.

3 Comparison of GPS Derived Pressure with ECMWF, NCEP and Radiosonde data

3.1 GPS Occultation Datasets

The period chosen in this study is from Jan–Mar 2003 (or day of year–doy 001–093, 2003). The CHAMP wet profiles were obtained from the COSMIC website (http://www.cosmic.ucar.edu). doy 016, 028, 044, 053 are excluded from this analysis because the data are unavailable at the time. ECMWF and NCEP profiles were obtained by interpolating along the occultation path. If only CHAMP and ECMWF data are considered, there are a total of 13,422 matched profiles. When all 4 types of data are considered, there are only 3,891 matched profiles.

3.2 Method

To compare the profiles, CHAMP, ECMWF, NCEP and radiosonde pressure profiles are interpolated between 1 km and 30 km altitude above the MSL in 1 km steps. The comparison is conducted for the data only when all 4 types of data exist so that there would be no extrapolation. We divide the study areas into 5 regions from 30° to 60° latitude zonal bands: southern polar (SP), southern mid-latitude (SM), tropical (TP), northern mid-latitude (NM) and northern polar (NP) regions (Fig. 3). The mean and RMS are computed for each pair of data in the analysis period. Large amount of profiles in other datasets have to be edited, simply because radiosonde measurements only exist over land area, and there are very few data match-ups in the southern hemisphere (Fig. 3, right panels). Without losing generality, we compute and compare the statistics of 13,422 and 3,981 matched CHAMP and ECMWF profiles (reduced to 3,981 in order to match radiosonde profiles). In this study, we only discuss results for the reduced dataset.

3.3 Results

The differences between 4 types of pressure profiles are shown in Fig. 3. We compare CHAMP with ECMWF, NCEP and radiosonde pressure profiles in Fig. 3a, 3b and 3c, respectively. It is obvious from left panels (mean differences) of Fig. 3a, 3b and 3c that CHAMP pressure is positively biased or larger than other three data types. If one relates pressure to temperature through hydrostatic equation and the universal gas law, CHAMP derived temperature is colder than models and radiosonde measurements, which agrees with other analysis [e.g., Leroy, 1997]. The bias is shown to have larger discrepancy at tropopause (TP and SM), above Planetary Boundary Layer (PBL) (TP, SM) and near ground (SP) in Fig. 3a. It is nearly 3 hPa at 1 km altitude for the Antarctic region (SP). Larger differences for NM and SP region at 1 km altitude are shown in the middle panel (RMS) in Fig. 3a. With the exception of the tropical region, the 1 km altitude cases for other regions are generally larger than 3 hPa RMS. It is surprisingly to find that tropical region has the smallest RMS. Similar to the previous study [Ge et al., 2003], the comparison of ECMWF and CHAMP pressure in the SP region is found to be the worst both in terms of bias and RMS.

In Fig. 3b, the large bias between NCEP and CHAMP pressure profiles also occurs at tropopause (TP and SM). SP is still the area has the largest bias at 1 km altitude above MSL. It is expected that the bias would be even larger at the surface. The RMS figures (middle panels) show similar pattern for the ECMWF/CHAMP comparison. Tropical region (middle panels) still has the smallest RMS. The similarity of Fig. 3a and Fig. 3b implies that ECMWF agrees relatively well with NCEP as shown in Fig. 3d. The bias and RMS for comparisons in all regions are smaller than 2 hPa. The largest bias occurs at around 4 km altitude cases. Although the RMS is relatively small compared to other cases, the SP region has the largest discrepancy between the two models.

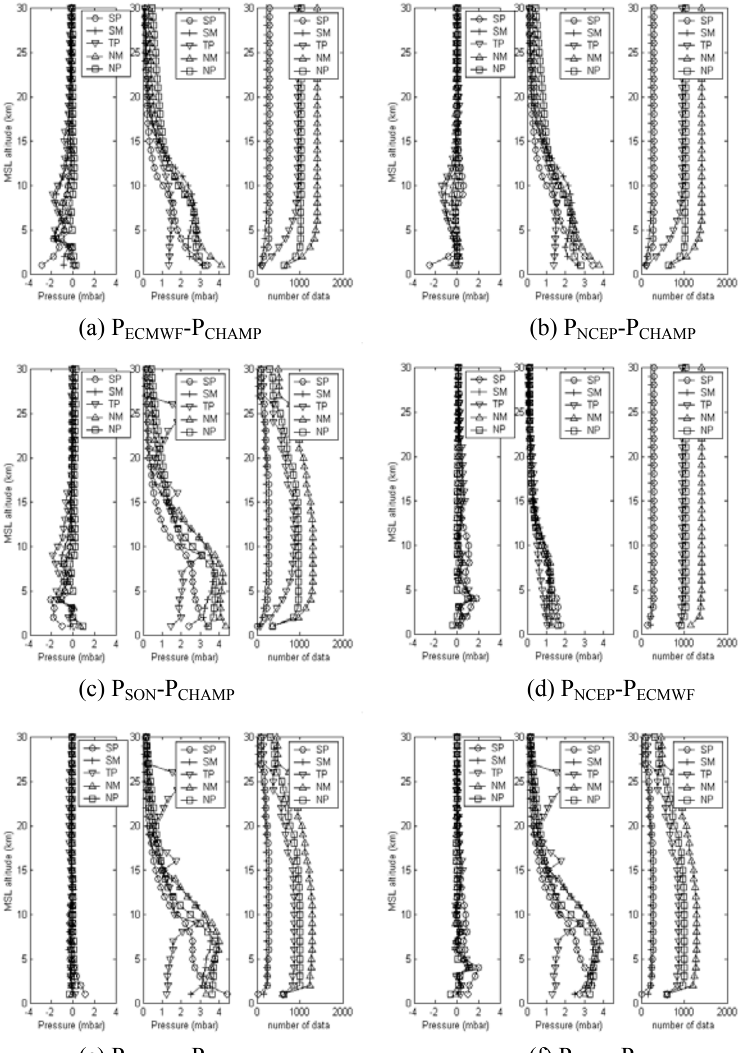
Radiosonde is an invaluable independent data source in this study. Fig. 3c, 3e and 3f compare the radiosonde with CHAMP, ECMWF and NCEP. Fig. 3c (left panel) could probably confirm that the bias between CHAMP and ECMWF and between CHAMP and NCEP comes from CHAMP pressure profile. Fig. 3c (middle panel, RMS differences) also shows that the largest RMS is near the surface, with the TP region has the smallest discrepancy. However, it is interesting to note that there are several pikes in the TP curve. Comparing with Fig. 3a and 3b, we find no similar patterns. This seems to imply that the pikes could be originated from radiosonde measurements. One possibility is that the radiosonde measurements are less accurate in these 3 locations, since usually occultation has the best performance in these areas. Similar pikes are also found in Fig. 3e and 3f for the TP region case. One should note that there also could be errors in the profiles because of quality control or interpolation errors, since CHAMP occultation cannot exactly match radiosonde both in location and time.

Fig. 3e and 3f show that there are large mean differences between the models and radiosonde measurements in the SP region. This is reasonable because of lack of data in the southern polar region which causes poor model performance. The differences are probably larger near the surface.

4 Conclusion

In conclusion, we found that there exists a positive bias in CHAMP derived pressure comparing with model (ECMWF and NCEP) and in situ data (radiosonde). The bias is larger in the SP region than any other regions globally. The RMS difference between the CHAMP pressure and other data sets is as large as 4 hPa globally at 1 km above MSL. It is surprising that the best comparison occurs at the TP region which is usually expected worst because of large water vapor signal and poor penetration of radar signals to the surface.

The comparison of ECMWF and NCEP agrees better than any other comparisons both in bias and RMS. This reflects the two models are consistent to a certain degree. However, SP region is still the area where the largest discrepancy exists.



(a) P_{ECMWF}-P_{CHAMP} (b) P_{NCEP}-P_{CHAMP}

(c) P_{SON}-P_{CHAMP} (d) P_{NCEP}-P_{ECMWF}

(e) P_{ECMWF}-P_{SON} (f) P_{NCEP}-P_{SON}

Fig. 3. Intercomparison of CHAMP derived pressure profile (P_{CHAMP}), ECMWF pressure profile ((P_{ECMWF}), NCEP pressure profile (P_{NCEP}) and radiosonde pressure profile (P_{SON}). SP—southern polar region (60°S–90°S), SM—southern mid-latitude region (30°S–60°S), TP—tropical region (30°S–30°N), NM—northern mid-latitude region (30°N–60°N), NP—northern polar region (60°N–90°N). For each figure: left panel—mean of pressure difference, middle panel—standard deviation of pressure difference, right panel—number of values in each level used for the comparison.

This once again confirms our conclusion that models have worse performance in this area. Radiosonde, as an independent measurement, provides us another alternative to evaluate the occultation data. Through the comparison of CHAMP pressure with radiosonde pressure, we conclude that CHAMP pressure is positively biased. Biases or errors exist in one or both measurements. One possibility is the poor vertical resolution from the radiosonde could cause larger differences in the tropospheric region. Poor temporal and spatial sampling could contribute to the differences. Meanwhile, the radiosonde data does not agree well with the models (NCEP and ECMWF) in data sparse regions such as SP. After "correcting" the CHAMP occultation profiles to reference to the ECMWF topography over Antarctica, the signal penetration improves to 80%, similar to the penetration in the Arctic region. The cause of the CHAMP bias is at present unknown and the understanding of its origin and eliminating it would provide a validated CHAMP occultation data product. Then, the CHAMP (along with other) GPS occultation observations, with better vertical resolution and global coverage, could improve global pressure field modeling and in particular, over Antarctica.

Future works include using techniques such as 1DVAR to potentially enhance accuracy and penetration of signals. The use of a finer resolution (3 hr sampling, 50 km or finer) mesoscale model in a 4DVAR scheme to assimilated GPS occultation measurements [Kuo et al. 2002] is anticipated to further improve pressure field accuracy and reduce temporal aliasing for gravity field mission data.

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