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Atmospheric Chemistry and Physics Discussions

Interactive comment on "Do gravity waves significantly impact PSC occurrence in the Antarctic?" *by* A. J. McDonald et al.

A. J. McDonald et al.

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Initial Response to Reviewers Comments

A. J. Mcdonald and S. E. George

Given the high degree of correlation between the various reviewers comments on two subjects and the fact that the authors will obviously have some significant revision to do we have decided to provide some initial responses to the reviewers main concerns. Our hope is that these initial responses may act as a catalyst for further feedback from the various reviewers to identify the scale of the work necessary to produce a manuscript which is acceptable for publication (though we realise that the reviewers may not be able to respond due to time limitations). These initial responses will thus be followed by more detailed responses to all reviews and thus some of the lower priority (though

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Interactive Discussion
Discussion Paper

still important) issues raised by the reviewers will not be covered by this document. Before indicating our initial responses we would like to thank all of the reviewers for their interest in this work and the detailed reviews that they have provided.

The two areas of reviewer concern addressed in this initial response are:

1. Observational filtering of CHAMP data

2. POAM sampling issue

1. Observational filtering of CHAMP data:

All the reviewers have expressed concerns about the impact of observational filtering on CHAMP measurements. We obviously agree that the observations of temperature perturbations made by the CHAMP instrument will be affected by observational filtering as will all satellite measurements since no single instrument can observe the entire gravity wave field, though obviously different instruments may perform better than others. Our lack of discussion of this affect is clearly an error, but is perhaps (at least unconsciously) based on the fact that previous work (Baumgaertner and McDonald, 2006; Lange and Jacobi, 2003; McDonald and Hertzog, 2008) is highly indicative of two facts which we should have detailed, namely:

a) CHAMP observations do have some sensitivity to mountain waves (which we guess is one of the key concerns for the reviewers - we would be happy to have this point clarified if we are not correct). In particular, the following section taken from McDonald and Hertzog (2008) is very relevant:

"A study by Lange and Jacobi [2003] shows that while the weighting function of the RO measurements is 200-400 km along the LOS, the GPS measurements are sensitive to gravity waves with horizontal wavelengths greater than 100 km and vertical wavelengths between approximately 1.4 and 10 km. This is partially associated with the LOS having a parabolic path in the atmosphere and also the fact that the plane waves visible will depend on the angle between the LOS and the wavefronts. When the LOS is

ACPD

9, S902–S910, 2009

Interactive Comment

perpendicular to the wavefronts then spatial averaging will significantly affect the wave activity observed. In particular, work by de la Torre and Alexander [2005] has shown that the observability of mountain waves, which have horizontal wavelengths of tens to hundreds of kilometers, can be significantly impacted. Further work by Baumgaertner and McDonald [2007] suggested that the preponderance of LOS within 30 degrees of the north/south axis in the Antarctic region means that the viewing geometry over the Antarctic Peninsula and the Trans-Antarctic Mountains potentially favoured the detection of the mountain waves by CHAMP in these regions. However, all this previous work suggests that CHAMP RO measurements observe a limited portion of the gravity wave field."

b) The work by McDonald and Hertzog (2008) which compared coincident CHAMP and VORCORE measurements of the gravity wave field suggests that overall the wave field is such that CHAMP underestimates the magnitude of the potential energy per unit mass. Thus, in any analysis CHAMP would likely provide a conservative estimate of the impact of temperature perturbations associated with gravity waves.

Prompted by the reviewers concern about the omission of any discussion of this affect we will obviously work on adding a section discussing these ideas more thoroughly since this is an important omission.

In addition, while thinking about these concerns we came to the following (perhaps) simplistic view. Overall, the observational filtering of the CHAMP Radio Occultation data is dominated by the horizontal spatial sampling (associated with the CHAMP satellites weighting function) which is shown schematically in Figure 1 in Wu et al. (2006). The schematic (which I refer to because I can not include a schematic in this initial response) suggests that the GPS observations would represent the average over a number of cycles of a gravity wave in the horizontal and thus we might expect to observe very small temperature perturbations (the square of which is directly proportional to the potential energy per unit mass) relative to the maximum temperature perturbation at a point. A second case where the horizontal wavelength is longer would allow

ACPD

9, S902–S910, 2009

waves to be more observable and thus the temperature perturbation would be closer to the actual maximum perturbation observed. Given the added complication of the different horizontal scales of the CHAMP LOS it is very difficult to quantify the impact of these factors without apriori guesses about the make up and relative orientation of gravity wave propagation with respect to the LOS. Though previous analysis detailed in Baumgartner and McDonald (2007) suggests that the LOS of CHAMP may be preferentially orientated to observe mountain waves over the peninsula.

However, the temperature perturbation observed by CHAMP can be thought of as a spatial average of the temperature perturbations over the satellite's weighting function. Now in reality PSC formation will be impacted only by regions where the temperature is sufficiently cool for formation to occur (Note that Reviewer 2 indicates the temperature thresholds are a necessary but insufficient condition for formation). Thus, since the POAM instrument is also a limb sounder (and effectively produces a spatially averaged extinction) it will observe the integrated affect of a heterogeneous temperature field on PSC occurrence. Given high resolution lidar observations of heterogeneous structures associated with PSC fields which display clear phase structures related to gravity waves (e.g. see work in Klekocuik et al. (2009) displayed at the 9ICSHMO conference in Melbourne). We would suggest that the spatial average temperature field is actually a useful measure of the PSC formation potential averaged over an area. Note other studies have observed similar structure in clouds, for example Pitts et al. (2007). However, it should be noted that this measure is by no means perfect because the nonlinear hysteresis affect inherent in PSC microphysics (as mentioned by Reviewer 2) would impact the spatial averages differently. But, we'd argue that the consistency between observation methodologies might reduce the impact of this observational filtering. Though we also note that the impact of background winds on Doppler shifting of the wave and the advection of PSC away from PSC formation zones associated with cool phases of the wave perturbations would be important.

Overall, this thought process also suggests that comparisons which mix nadir and limb

ACPD

9, S902–S910, 2009

viewing satellite sensing strategies may need to be treated particularly carefully - which might be an important point to make. Thus, based on our viewpoint we would suggest that the temperature perturbation information provided by CHAMP observations would provide conservative estimates of the impact of gravity waves on PSC formation and that the similar observational methodologies of POAM and CHAMP (both limb sounders) might act to limit the impact of this observational limitation. We would be grateful for opinions on our viewpoint which we would obviously aim to clarify in any future draft.

One major impact of observational filtering effect is that we can not guarantee that the temperatures observed are accurate enough to identify whether PSC formation can occur at temperatures near to T_{NAT} and this will require either caveats to be included in this discussion or for this discussion to be removed. Though this is a very strong constraint and effectively suggests that only in-situ measurements could do this job which significantly limits further progress on this issue.

2) POAM sampling issue

Again this is an issue which we obviously have not paid enough attention to and we can see that this issue will require further analysis as well as rewriting and reorganisation of the draft paper. We believe our viewpoint was perhaps biased by the lower panel of Figure 4-1 in the Polar Ozone Chapter of the WMO/UNEP scientific assessment of ozone depletion (Newman and Rex, 2007) (again apologies for not being able to include a diagram) and the fact that we had made the CHAMP and POAM latitude sampling consistent and thus potentially removed some sampling errors. Figure 4-1 in Newman and Rex (2007) clearly shows temperature varies strongly with time of year up until mid-July at 50hPa for temperatures averaged between 50^o and 90^oS based on NCEP/NCAR analyses and thus assuming this as a background variation we expected the importance of gravity wave perturbations on PSC formation to be most pronounced in those periods where a temperature threshold (T_{NAT}, T_{STS} or T_{ICE}) crossing forced by gravity wave temperature perturbations was potentially most likely

ACPD

9, S902–S910, 2009

to occur. For T_{NAT} this would obviously most likely occur early in the winter. Our viewpoint is perhaps also supported by the fact that overall gravity wave perturbations will only be important when the synoptic temperatures allow thresholds to be crossed (i.e. PSCs won't be observable over Antarctica in April for instance because gravity wave temperature perturbations will not move you passed a threshold).

In addition, the work by Baumgartner and McDonald (2007) also suggests that seasonal variations in the magnitude of temperature perturbations are more important in CHAMP observations of the gravity wave potential energy per unit mass than latitudinal or longitudinal variations. Though as noted in Baumgartner and McDonald (2007) this may partly be related to observational filtering. Thus, if the POAM and CHAMP sampling is as consistent as possible the impact of latitudinal variations would be minimized.

However, we agree that the POAM sampling is not representative of the entire vortex and thus we need to attempt to determine and potentially deconvolve the affect of the varying latitudinal and temporal sampling on the CHAMP and POAM measurement. In particular, we feel that the following question needs to be answered:

Is the enhanced importance of gravity waves in PSC formation in June controlled by synoptic temperatures hovering close to PSC formation temperature thresholds in this period or is it due to enhanced gravity wave perturbations which occur over the Antarctic Peninsula or perhaps (more likely in our opinion) a combination of both?

Though we are unsure whether this is the core issue for Reviewer 2 and would like further clarification if possible.

The analysis in the draft paper suggests that a combination of both effects are likely to be important (i.e. both timing associated with changing seasons and the gravity wave 'hotspot' over the peninsula could contribute). It should be noted that observations in June and for a large portion of July are in very similar latitudinal bands yet the impact of gravity wave temperature perturbations on producing extra temperature threshold

ACPD

9, S902–S910, 2009

crossings is very different. This suggests that temporal variation might be dominant - but this is far from conclusive.

We therefore suggest the following set of analysis (which is similar to ideas expressed by Reviewer 2) which might help us to clarify this issue:

Analysis of the synoptic (background) temperature variation over the entire polar region as a function of time based on an average using a defined latitudinal region and based on a polar vortex only analysis (using a equivalent latitude and potential temperature coordinate system). Analysis of temporal variations using temperatures identified over the POAM sampling region. For consistency we would complete this analysis using CHAMP data.

Analysis of the gravity wave temperature perturbations as a function of latitude and season and their potential impact on PSC formation using an Antarctic vortex wide sampling (as previously defined) and a more limited POAM defined sampling.

Comparison of the magnitude of the different variations from these different analyses should help to clarify whether the varying impact of gravity waves is affected more by the POAM latitudinal sampling variations or the seasonal variations. Perhaps a technique such as ANOVA should also be utilised to provide some clarification of the relative importance of these variations?

We have not completed this analysis yet and wonder whether the reviewers believe that this analysis along with major reworking of the manuscript (particularly moving the discussion of POAM latitude sampling to much earlier in the document as suggested by Reviewer 1 and 4) would potentially (we are only asking for your best guess here) provide enough evidence to support a conclusion based on these observational datasets. If not it would be very beneficial to gain an idea of what other analysis would potentially be needed? We also note the idea made by Reviewer 4 that perhaps we should focus on the interannual variability between similar periods. This might additionally provide some information on the seasonal variability of gravity wave impacts. Though

ACPD

9, S902–S910, 2009

we note that given the intermittent nature of the gravity wave field the different years gravity wave impacts, displayed in Figure 9 of the draft, are remarkably similar. This might again be suggestive of the importance of the background synoptic temperature variation.

Based on these thoughts we would come to the following conclusion on this issue at present:

We can only attempt to separate out the importance of spatial and temporal variations in the POAM sampling with any analysis. But, that further analysis is warranted to at least attempt to clarify the relative importance of the temporal and spatial variations on our results. The analysis presented currently is perhaps indicative of both temporal and spatial variations playing a role. Updating this section based on new analysis would help to identify the dominant role of temporal or spatial sampling. However, perhaps we need to just focus on the fact that enhanced PSC occurrence observed in POAM in June compared to that expected matches with CHAMP observations which suggest gravity wave temperature perturbations have a large potential impact on PSC formation in the same period. We could then simply indicate that the POAM sampling does not allow us to determine the reason for this observation.

We welcome feedback on whether our initial suggestions for a way forward meet with the approval of the various reviewers or whether we are still missing points which we will need to address related to these two key issues. We note there are important points in the reviews that we still need to deal with other than these issues.

References:

Baumgaertner, A. J. G. and A. J. McDonald (2007). "A gravity wave climatology for Antarctica compiled from Challenging Minisatellite Payload/Global Positioning System (CHAMP/GPS) radio occultations - art. no. D05103." Journal of Geophysical Research-Atmospheres 112(D5), D05103, doi:10.1029/2006JD007504,

ACPD

9, S902–S910, 2009

Interactive Comment

Klekocuik et al. (2009), The influence of small-scale wave processes on polar stratospheric clouds and stratospheric ozone depletion, 9th International Conference on Southern Hemisphere Meteorology and Oceanography, Melbourne, Australia.

Lange, M. and C. Jacobi (2003). Analysis of gravity waves from radio occultation measurements. First CHAMP Mission Results for Gravity, Magnetic and Atmospheric Studies. H. L. Ch. Reigber, P. Schwintzer. Berlin, Springer: 479-484.

McDonald, A. J. and A. Hertzog (2008). "Comparison of stratospheric measurements made by CHAMP radio occultation and Strateole/Vorcore in situ data." Geophysical Research Letters 35(11), L11805, doi:10.1029/2008GL033338,

Newman, P. A., and M. Rex (Lead Authors) P. O. Canziani, K. S. Carslaw, K. Drdla, S. Godin-Beekmann, D. M. Golden, C. H. Jackman, K. Kreher, U. Langematz, R. Muller, H. Nakane, Y. J. Orsolini, R. J. Salawitch, M. L. Santee, M. von Hobe, S. Yoden, Polar Ozone: Past and Present, Chapter 4 in Scientific Assessment of Ozone Depletion: 2006, Global Ozone Research and Monitoring Project - Report No. 50, 572pp., World Meteorological Organization, Geneva, Switzerland, 2007.

Pitts, M. C., L. W. Thomason, et al. (2007). "Characterization of Polar Stratospheric Clouds with spaceborne lidar: CALIPSO and the 2006 Antarctic season." Atmospheric Chemistry and Physics 7(19): 5207-5228.

Wu, D. L., P. Preusse, et al. (2006). "Remote sounding of atmospheric gravity waves with satellite limb and nadir techniques." Advances in Space Research 37(12): 2269-2277.

Interactive comment on Atmos. Chem. Phys. Discuss., 9, 3401, 2009.