The effect of orographic waves on Antarctic Polar Stratospheric Cloud (PSC) occurrence and composition

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Background

The Antarctic Peninsula is a well-known orographic-gravity wave hotspot. Case studies have shown that some of these waves are responsible for the formation of PSCs (e.g. Hopfner et al. 2006, Eckermann et al. 2009, Noel et al. 2009). We investigate orographic-gravity wave activity and PSC occurrence during the entire 2007 PSC season at 60-70S.

We use CALIPSO lidar backscatter data and the algorithm of Pitts et al. (2009) to separate the PSCs observed into four composition classes: super-cooled ternary solution (STS), ice and two liquid / NAT mixed classes called Mix 1 and Mix 2. The Mix 1 (Mix 2) class has lower (higher) number density per volume of NAT. We calculate the PSC volume over the altitude range 400K – 700K. COSMIC GPS-RO temperature profiles are used to extract gravity wave temperature variances, similar to Alexander et al. (2009). For both datasets, we bin the data into 10 degree latitude width, 20 degree longitude width and 7 days in time to ensure sufficient data coverage.

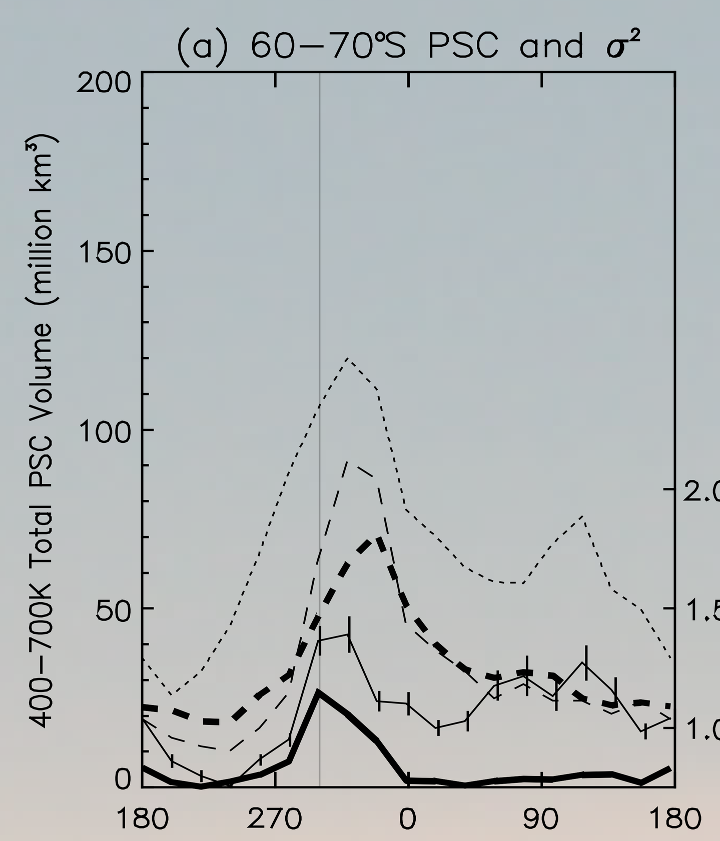

Figure 1: Winter total PSC volume and daily mean σ^2 (thin solid line) at 60-70S. PSC composition classes are marked by: ice (thick solid), Mix 1 (thick dashed), Mix 2 (thin dashed), STS (dotted)

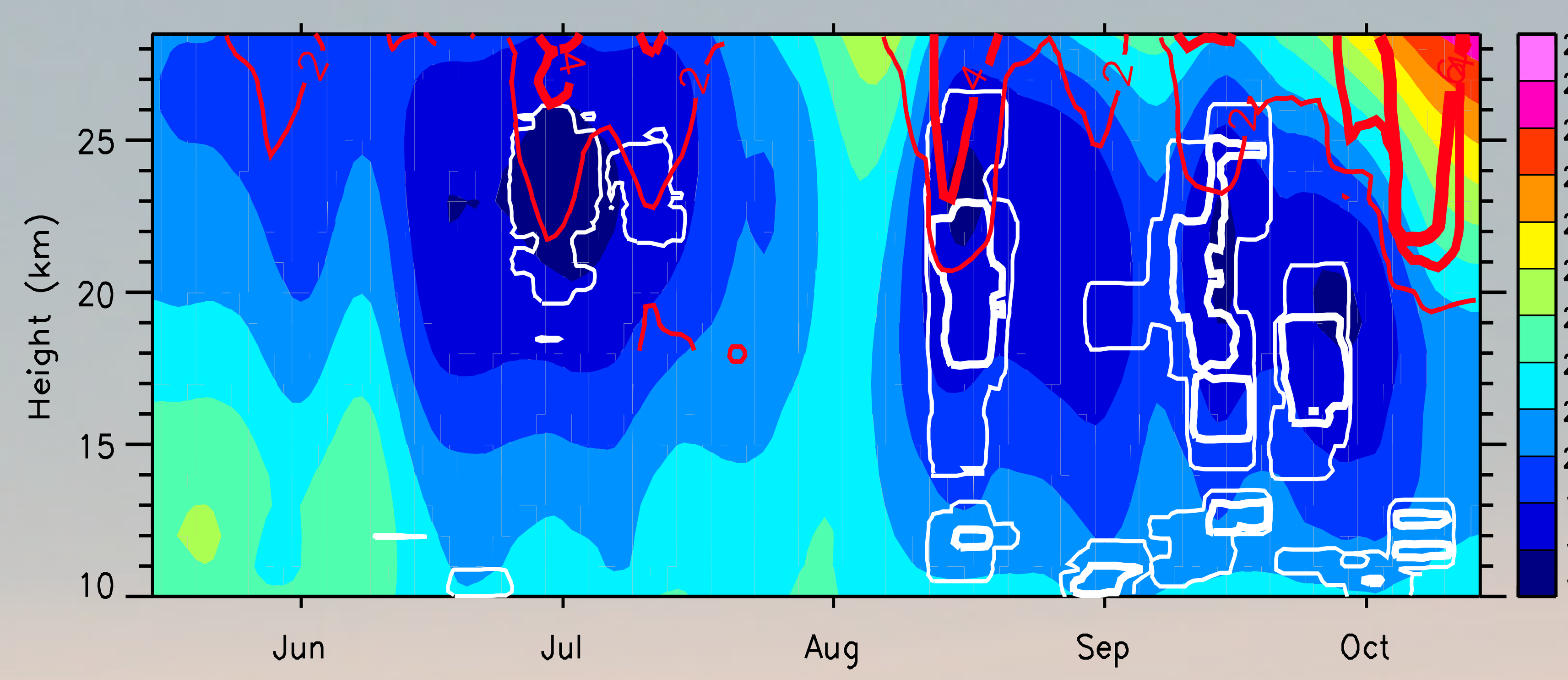

Figure 2: COSMIC Temperature (colour) and COSMIC σ^2 (red, units of K²). CALIPSO H_2O ice PSC areas of 0.02 million km² (0.1 million km²) are marked by the thin (thick) white lines.

Orographic-gravity wave activity and H_2O ice PSCs above the Peninsula

The winter PSC total volumes (1 June – 1 October 2007) are shown in Figure 1 for each composition class, along with the 550K daily mean COSMIC σ^2. A distinct peak in wave activity and all PSC composition classes occurs at or immediately downwind of the Peninsula. The time series of temperature, COSMIC σ^2 and H_2O ice areas above the northern half of the Peninsula (290-310E, 60-70S) is shown in Figure 2 throughout the lower stratosphere. Note the presence of large H_2O ice areas co-incident in time with enhanced orographic gravity wave activity, over much larger regions than the background temperature would imply.

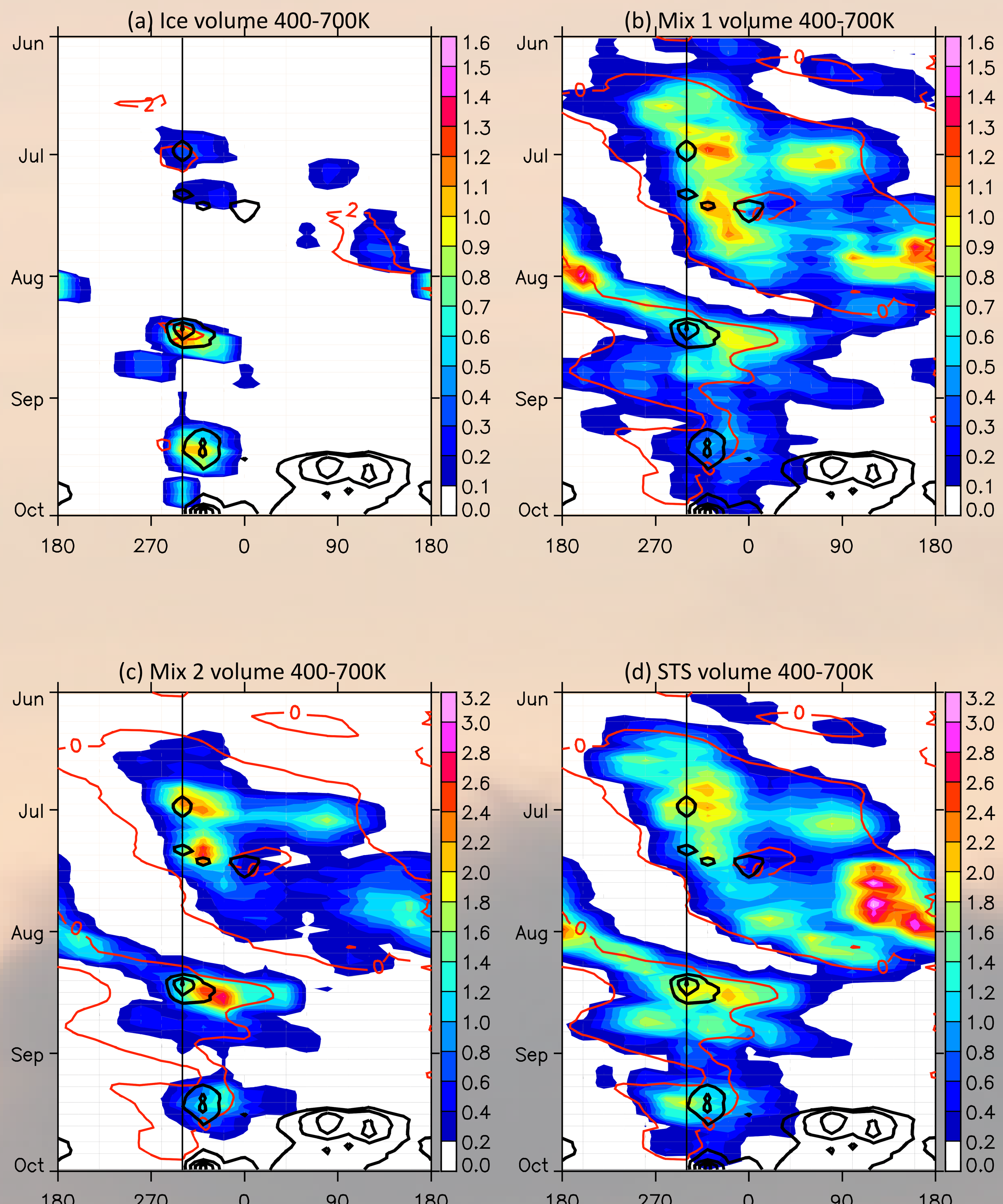

Figure 3: 60-70S 400-700K PSC volumes (colour, units million km³) with COSMIC 550K σ^2 (black, units of K²) and MLS 550K $T-T_{NAT}$ or $T-T_{ice}$ (red) for (a) water ice, (b) Mix 1, (c) Mix 2, (d) STS. Vertical lines indicate the Peninsula. Longitude east is marked on the x-axis.

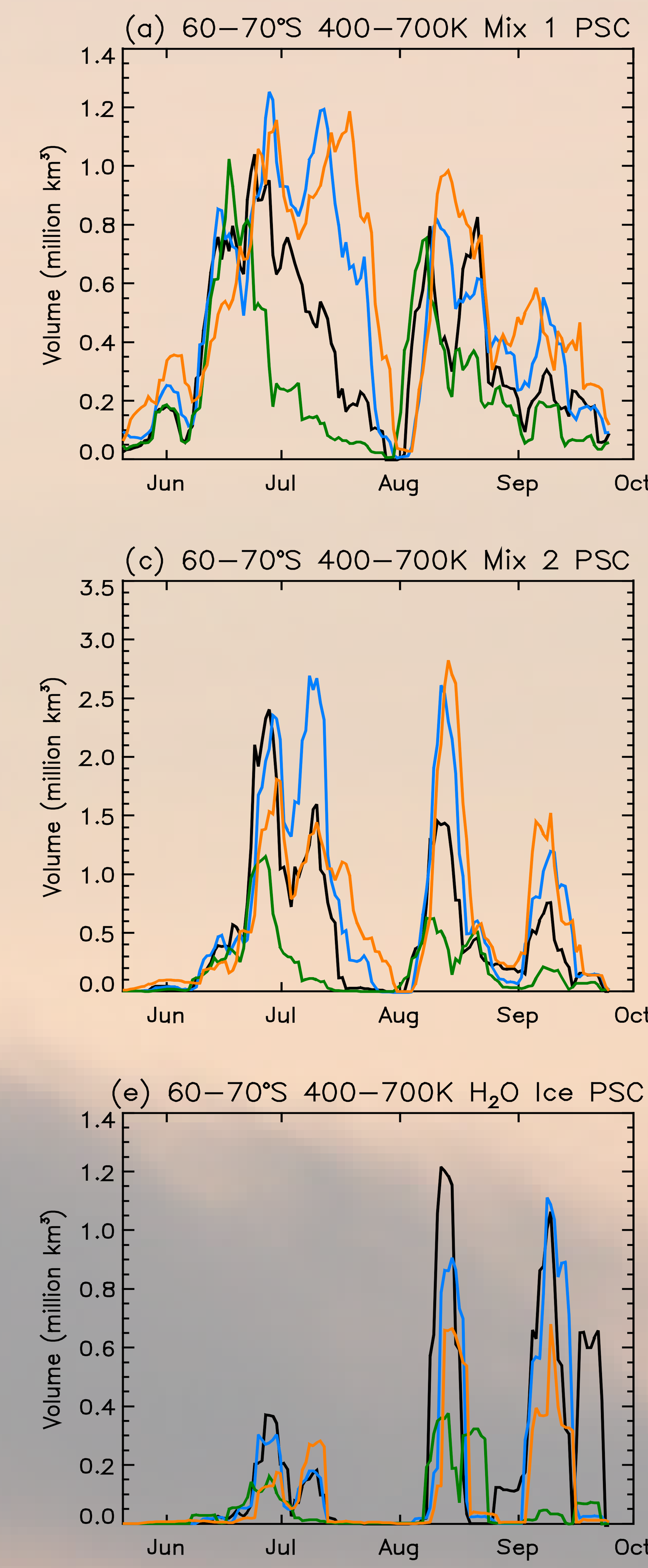

Figure 4: PSC volume time series for the composition classes marked in the titles at 60-70S at: 280E (green), 300E (Peninsula, black), 320E (blue), 340E (orange)

PSC composition class variations around Antarctica

The 400-700K volumes for the four different composition classes of PSCs are shown at 60-70S in Figure 3, along with the σ^2 and temperature difference from NAT or water ice cloud formation from MLS data. Note the clear correspondence between Peninsula orographic waves and ice cloud volume. Enhancements in Mix 2 (high NAT content) are seen downstream of the orographic wave events and ice clouds, indicating that the ice clouds are seeding NAT mother clouds downstream (Fueglistaler et al. 2003). The results also show that these NAT clouds extend later in time and a long way around Antarctica.

The 400-700K PSC volume time series for Mix 1, Mix 2 and water ice are shown in Figure 4. The August event shows around a factor of 4 increase in water ice PSC above the Peninsula, which decreases eastward. In contrast, the Mix 1 and Mix 2 peaks increase downwind of the Peninsula, and also the peak occurs later in time as the PSCs are advected eastwards.

These plots, along with Figure 1, enable us to make an approximate calculation of the amount of various PSC composition classes at 60-70S due to orographic gravity wave activity. Using the upwind region of the Peninsula as a background level (to minimize planetary wave and synoptic influences), around 50% of both H_2O ice PSCs and a high NAT number density liquid/NAT mixture class (Mix 2) of PSCs above and downwind of the Peninsula are due to these waves, and around 30% of total PSCs. We also study the 70-80S results (not shown here), although due to the colder synoptic conditions, a lower proportion of PSCs are directly attributable to orographic gravity wave activity.

Conclusions

These results support the mountain-wave seeding hypothesis at various intervals throughout the entire Antarctic winter and illustrate the important role of mesoscale orographic-gravity wave forcing in determining PSC occurrence and composition near the edge of the Antarctic vortex. We clearly observe the relation between enhanced orographic gravity wave activity, H_2O ice PSC formation and downstream increases in NAT at 60-70S. We attribute around 50% of H_2O ice PSCs in this latitude band as being due to orographic gravity wave activity above the Peninsula.

The results presented here are discussed in more detail by Alexander et al. (2011).

References:

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