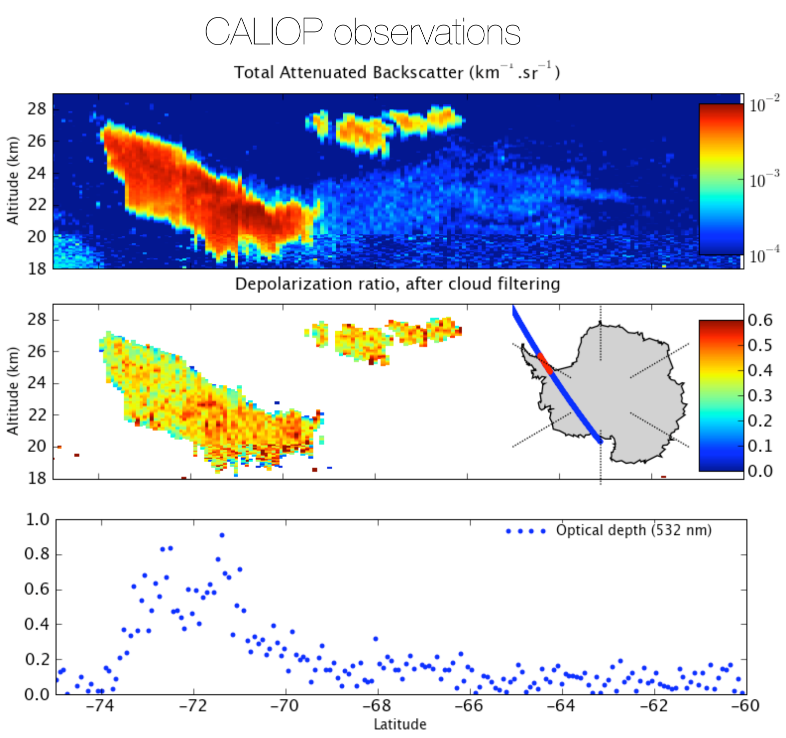
Optically thick Gravity-Wave PSCs over Antarctica seen by CALIOP, 2007-2008

V. Noel, A. Hertzog, H. Chepfer - LMD/IPSL-CNRS

Ground-based and satellite observations have long hinted at the existence of optically thick Polar Stratospheric Clouds (PSCs), even if the available litterature is sparse and optical depth values hard to come by. Here a Type II PSC is observed from spaceborne lidar, with visible optical depth up to 0.8. Comparisons with multiple temperature fields, including reanalyses and results from mesoscale simulations, suggest that intense small-scale temperature fluctuations due to gravity waves play an important role in its formation; while nearby observations show this GW PSC could trigger heterogeneous nucleation processes and Type I PSC formation further down the polar vortex. The geographic distribution and microphysical properties of visible PSCs are explored over Antarctica south of 60°S during the 2006 and 2007 austral winters.

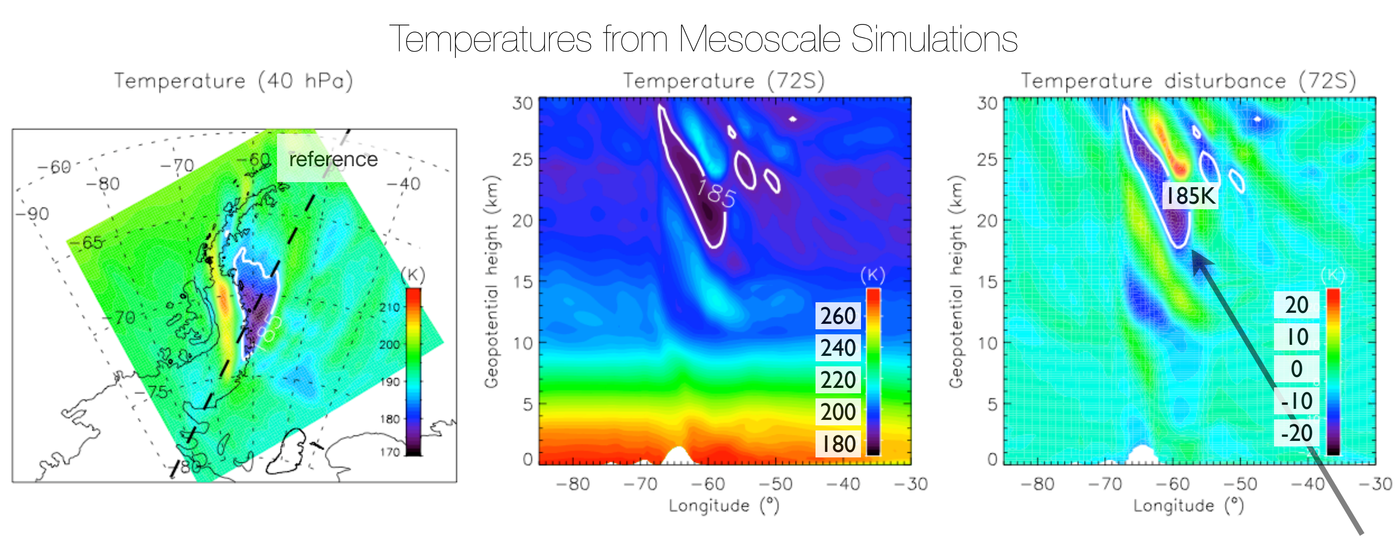
June 27th 2006 PSC Case



Signal analysis and Cloud detection. Backscatter was normalized on molecular backscatter between 28 and 30 km. Clouds were detected by imposing a minimum threshold (4 10^{-4} $km^{-1}.sr^{-1}$) above the molecular backscattering. Optical depths were retrieved by relating the attenuation in backscatter due to the PSC to modelled molecular backscatter (i.e. transmission-loss).

The high backscatter, depolarization ratio and low lidar ratio (S~20, not shown) are both typical of a Type II PSC made of ice crystals. **Optical depths go as high as 0.8.**

Mesoscale simulations using the WRF model (see temperature comparisons box below) highlight the presence of large-amplitude disturbances above and in the lee of the Antarctic Peninsula. The cross sections furthermore reveal that these disturbances are observed throughout the atmosphere from the ground to the stratosphere. This kind of meso-scale feature is typical of a gravity-wave packet generated by the tropospheric flow passing over the Peninsula and propagating upward in the atmosphere. **The shape of the case study PSC closely follows the temperature perturbation.**

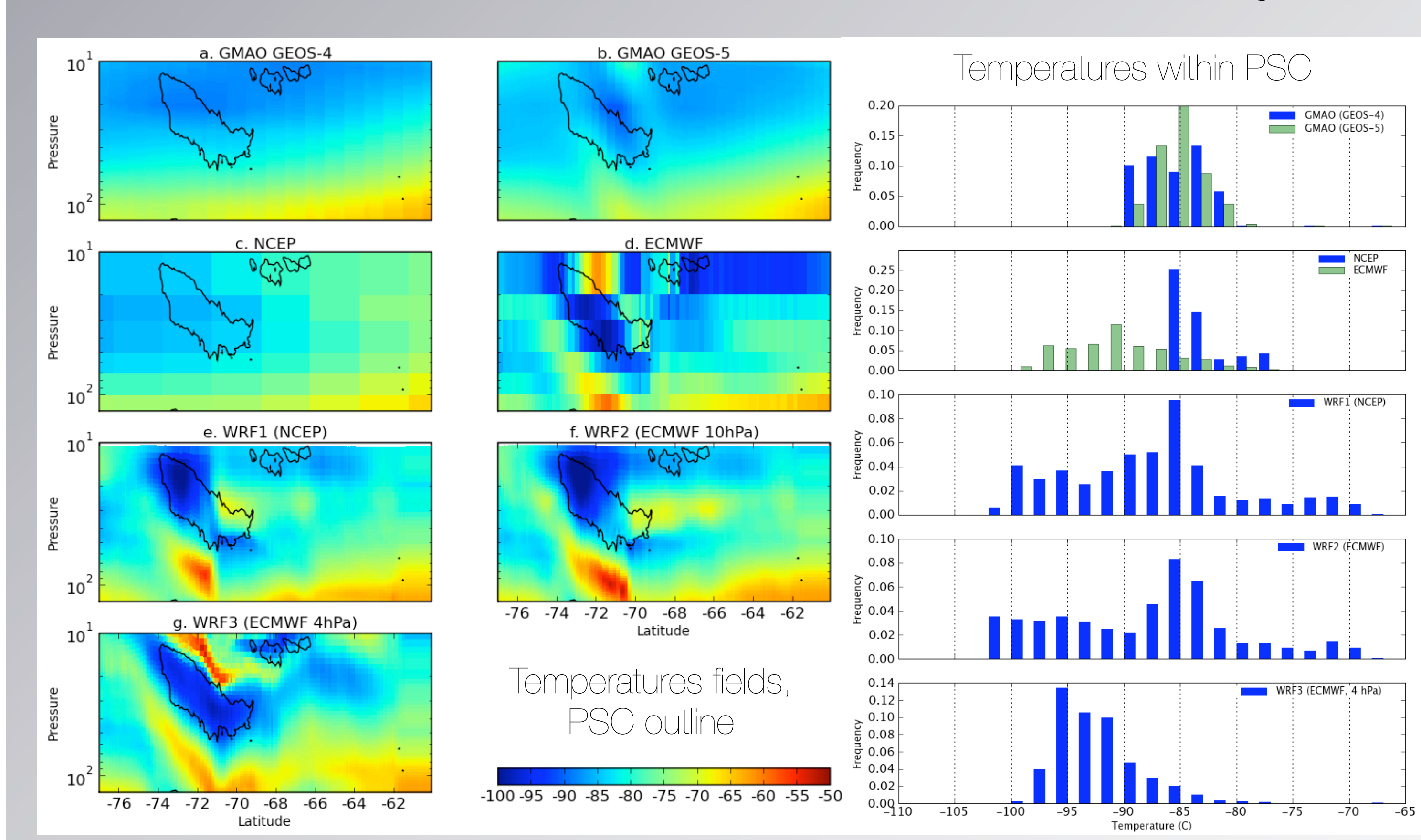


According to WRF simulations (see box below), the amplitudes of the mountain wave are very strong, e.g. at 25 km (about 20 hPa) and 72°S, the peak-to-peak amplitudes of temperature and zonal-velocity disturbances locally reach **30 K** and **120 m s-1**, respectively. Disturbances in meridional velocity are typically less than 10 m s-1, i.e. the mountain wave is primarily zonally propagating.

CALIOP observations compared with 7 temperature fields: GEOS-4, GEOS-5, NCEP, ECMWF + 3 mesoscale model simulations

Temperature fields were extracted from large-scale global models and reanalyses, and from the results of 3 WRF v.2.2 simulations using a 100x100 grid at 20 km resolution centered on the Antarctic Peninsula with 120 vertical levels and a 5 km damping layer right below the top of the simulated atmosphere.

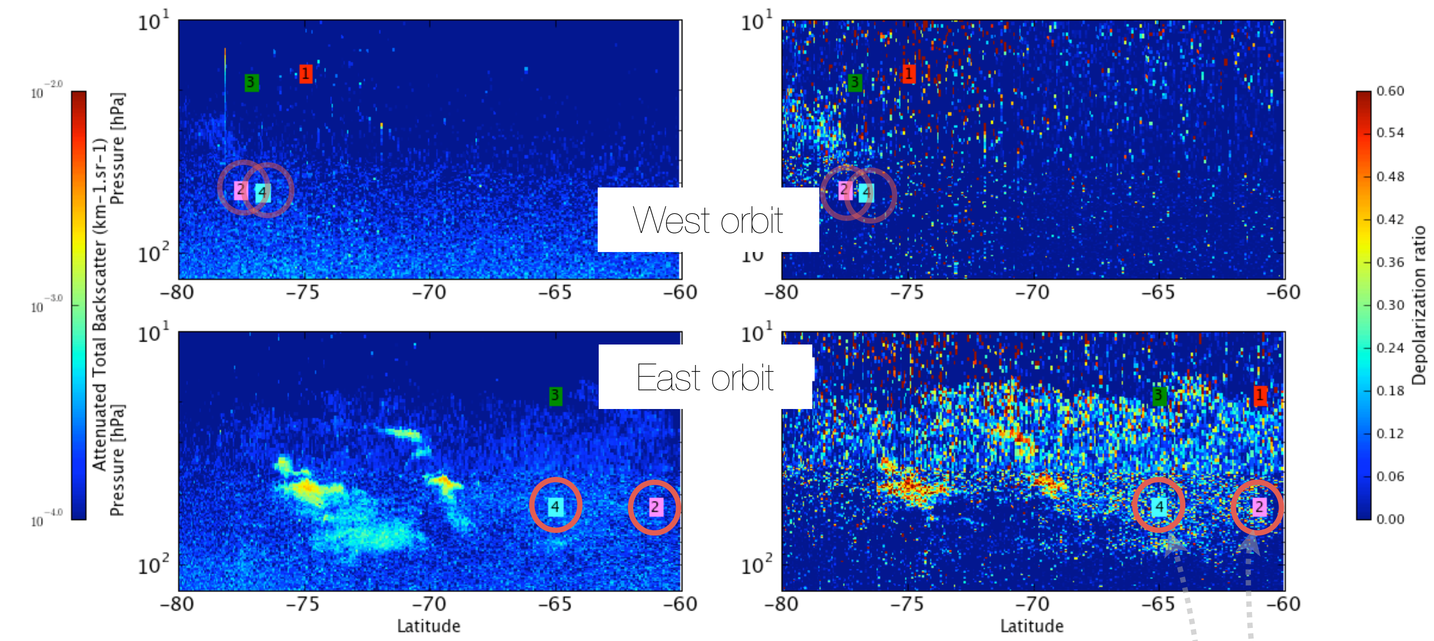
- GMAO fields provided in CALIOP L1 data files: **GEOS-4** (L1 v.1), and **GEOS-5** (L1 v.2)
- **NCEP** fields at 2.5° and 17 levels, 1000 to 10 hPa.
- **ECMWF** fields at 0.5° on 21 levels,1000 to 1 hPa.
- **WRF1** initialized with NCEP 2.5°, top at 10 hPa
- **WRF2** initialized with ECMWF 0.5° top at 10 hPa
- **WRF3** initialized with ECMWF, 0.5° top at 4 hPa



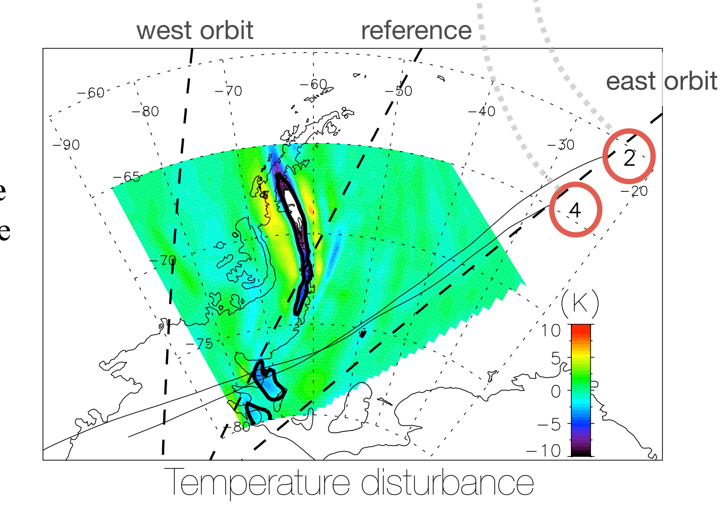
Assuming the temperatures obtained with WRF3 are the most realistic (based on the correlation between PSC shape and temperature), comparison with CALIOP observations suggests that: 1) low-resolution reanalyses (2.5° NCEP, GMAO) are not able to represent the cold temperatures created by orographic waves, leading to an overestimation of the PSC temperature; 2) fine-resolution analyses from ECMWF can partly reproduce the intensity of temperature variations due to orographic waves but still cannot provide the resolution required for comparisons with CALIOP observations, leading to dispersion in the PSC temperature distribution; 3) mesoscale simulations are able to reproduce the intensity and the generic features of temperature variations due to orographic waves, but 4) in order for the model to place the temperature variations with enough vertical and zonal accuracy to make the comparison with CALIOP meaningful, it has to be allowed a high ceiling. At least for PSCs similar to the case study, comparisons of CALIOP cloud detections with lower-accuracy temperature fields **can underestimate PSC temperatures by 10K** depending on wind speed and gravity wave intensity.

Impact on downstream Type I PSC Formation

Inspection of nearby CALIPSO orbits reveals the presence of an optically thin, low-backscatter, non-depolarizing (δ < 0.2) PSC **downstream** with respect to polar vortex winds (eastward orbit). Such optical properties suggest this cloud is NAT or LTA-based (Type I). By contrast, no PSC appears in **upstream** observations from the westward CALIPSO orbit.



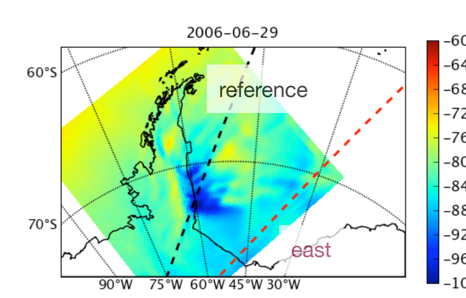
Isentropic back-trajectories from four points inside the downstream PSC (numbers in figures up and right) were computed using ECMWF wind fields. They show **air masses were subject to temperature fluctuations associated with mountain waves** in the vicinity of the Peninsula, either on the location corresponding to the case study ice PSC, or more south (near 77°S and 70°W). In each case, the back-trajectories crossed areas where wave-induced fluctuations led to temperatures cold enough to sustain ice PSC formation.

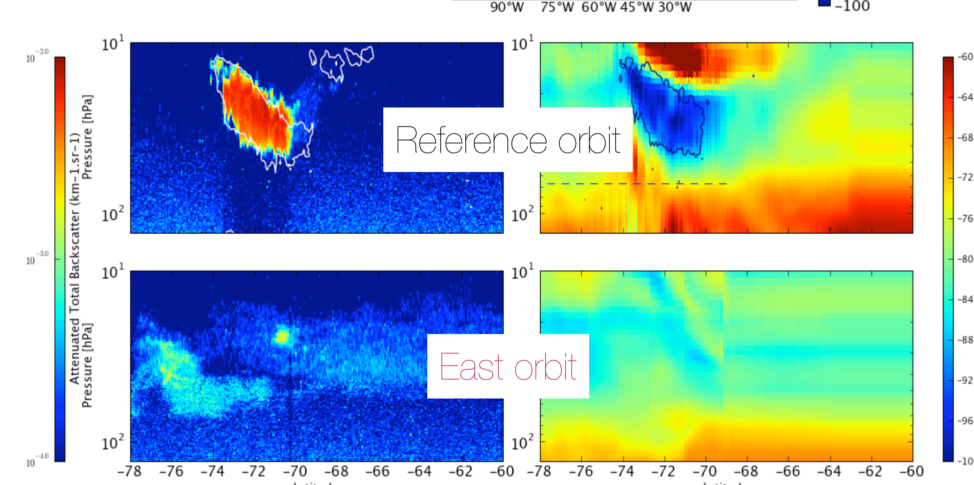


It is not unreasonable to assume that the downstream PSC was formed through heterogeneous nucleation occurring on ice crystals formed in these areas of cold temperatures, followed by long-range advection, a phenomenon already documented downstream of the Antarctic Peninsula in *Hopfner et al.* (2006) using observations from MIPAS.

TWO DAYS LATER

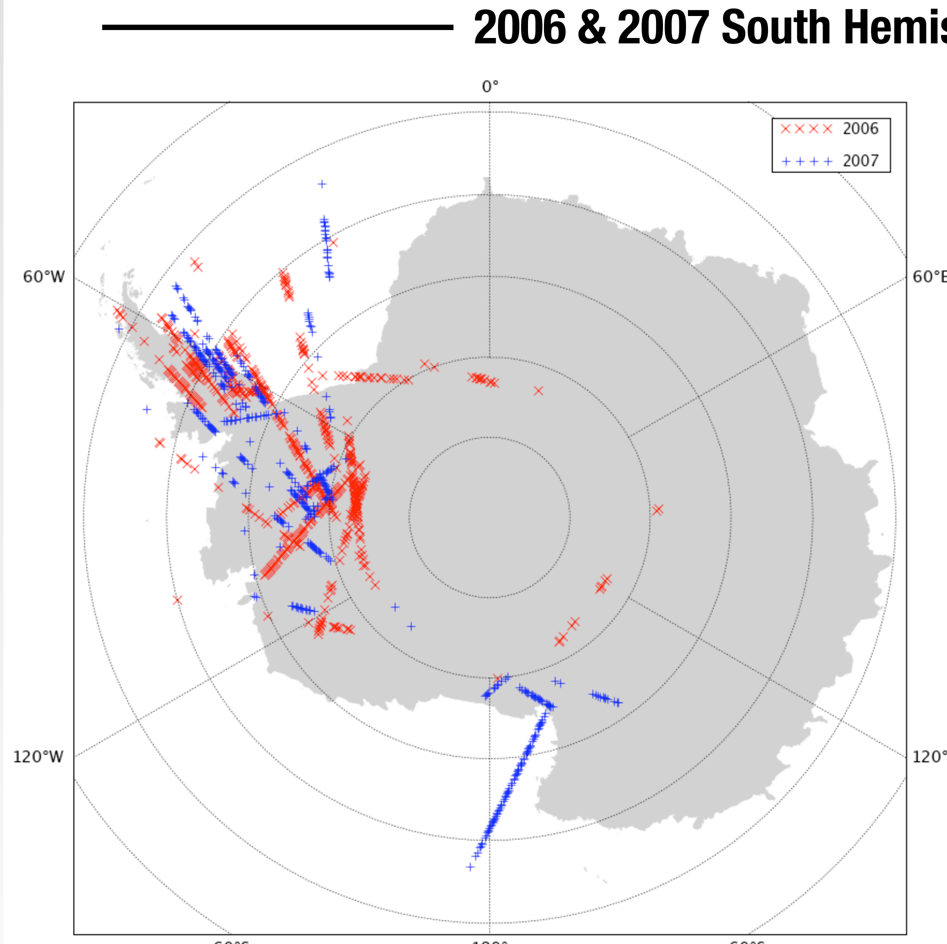
... The gravity wave and the PSC(s) are still here

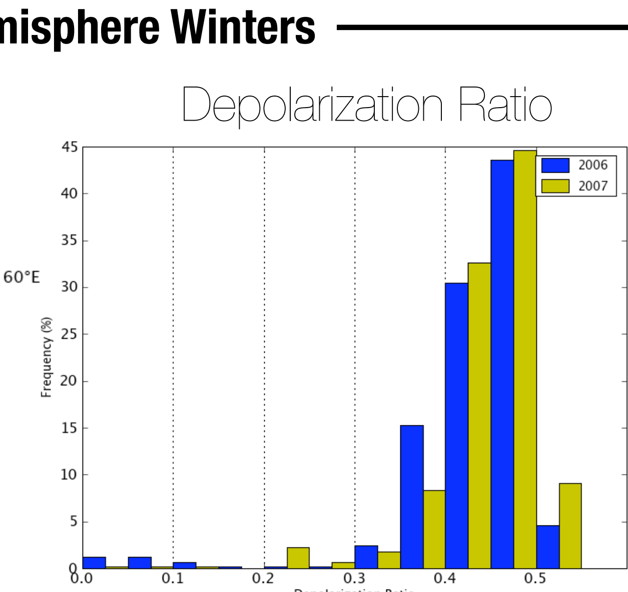




CALIOP observations made 2 days later over a similar domain still show a Type II PSC in the same location and altitude as the case study (left), with very similar shape and optical properties. Since according to WRF the gravity wave was in effect until June 29th, resulting in two days of temperatures compatible with Type II PSC persistence, it can be assumed, barring any exceptional coincidence, that this is the same PSC lasting more than 48h. Nearby CALIPSO orbits still show a Type I PSC downstream and upstream clear-sky. This configuration suggests the NAT-belt effect could have been active for the same 2-days period.

2006 & 2007 South Hemisphere Winters





Over 2006 and 2007 seasons, visible PSCs appear in less than 1% of profiles, localized West, mostly over the Antarctic Peninsula. These PSCs are overall colder than average PSCs (based on GMAO reanalyses), and consistently produce high depolarization ratios, all of which strongly suggest they are ice-based (e.g. *Massoli et al.* 2006).

It is not clear yet if all visible PSCs detected during the 2006 and 2007 austral summers are due to gravity waves, but since their geographic concentration and microphysical properties (from depolarization and lidar ratios) appear very similar to the case study the conditions which initiated the formation of the June 27th, 2006 PSC could also apply.

Since formation mechanisms for ice act on much smaller time scales than for NAT or STS, Type I PSCs generated in short-lived gravity-wave temperature fluctuations could potentially be triggers for Type II PSC formation. Such clouds would then be able to persist after the dissipation of the Gravity Wave, at warmer temperatures able to sustain NAT and STS particles but not ice.