OBSERVATIONS OF STRATOSPERIC CLOUDS AND THEIR CONNECTION WITH CONDITIONS FOR VERTICAL PROPAGATION OF MOUNTAIN WAVES

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Abstract: Forty years of synoptic observations of polar stratospheric clouds (PSCs) over Iceland are analyzed. The PSC are most frequent in January, followed by December and February. Only a handful of observations have been made in November and March and none outside this period of the year. Observations of PSCs are much more frequent in N- and E- Iceland than in SW-Iceland and there is large interannual variability in the occurrence of these clouds. An investigation of the atmospheric flow when PSCs are observed reveal that in most cases, the conditions are very favourable for the generation of orographic gravity waves and propagation of these waves far upwards in the atmosphere. This suggests that localized cooling in the ascending part of a gravity wave may be crucial for the formation of most PSCs over Iceland. This corresponds with the relatively low frequency of PSCs over SW-Iceland: PSCs are only observed when there are no or only few tropospheric clouds and under such conditions the low-level winds are usually from the north in SW-Iceland. In northerly flow, there is often a reverse wind shear in the troposphere inhibiting upward propagation of wave energy.

Keywords *–polar stratospheric clouds, mother of pearls, mountain waves, Iceland*

1. INTRODUCTION

Reports of PSCs are regularly included in the monthly reports from Icelandic synoptic and climatiological stations. However, these observations are very dependent on the vigilance of the observer. Some are very concious of the appearence of the phenomena, but other only include the most spectacular displays in their reports. Reports of PSCs became more regular after 1964, than before. This was not because of any policy change at the Icelandic Meteorological Office (IMO) and it remains to be seen if there was a real jump in the frequency at this time, which seems rather doubtful. In this paper the seasonal and interannual variability of PSCs over Iceland will be explored. The mean condition of the atmosphere during these cases is presented and discussed in view of existing theories of vertically propagating mountain waves.

2. SEASONAL VARIABILITY

The frequencies presented here must be considered as minimum values of the actual occurences. Low-level clouds often inhibit observations of PSCs and it must again be emphasised that the reports are very observer-dependent. It is quite possible that a spectacular display as e.g. the one of 9 Jan. to 11 Jan 1967 makes some observers more alert for some months or even years afterwards. Conversely it is not unlikely that during quiet periods many observers do not care so much about a small light speck in the sky during sunset or sunrise.

The total number of days reporting PSCs during the years 1964 to 2001 were 92. There are many years without any reports at all. The maximum was in 1981. All of that year's reports were made in January in a total of 12 days.

Figure 1 shows the seasonal cycle of the PSC observations. The clouds are most frequent in December and January, they are common during the first half of February as well, but the frequency reduces rapidly

before the end of that month. The earliest report of the season was made on 13 Nov, and the latest on 8 March. All of the reports are thus made during period of 16 weeks during the mid winter, as seen in the figure this is broadly the time period when the average sounding temperature at 100hPa over Keflavík is below -58 to -59°C.

3. CHARACTERISTICS OF THE ATMOSPHERIC FLOW DURING EVENTS OF PSCs

The only permanent upper-air station in Iceland is located at Keflavík, SW-Iceland. As PSCs are only observed visually during the daytime it was considered appropriate to base the following composite sounding for all PSC-days in December and January on the 12utc observation only. A few soundings on PSC-days are not available so the composite is based on about 58 soundings, fewer at the uppermost levels. The results are seen in figures 2 to 4.

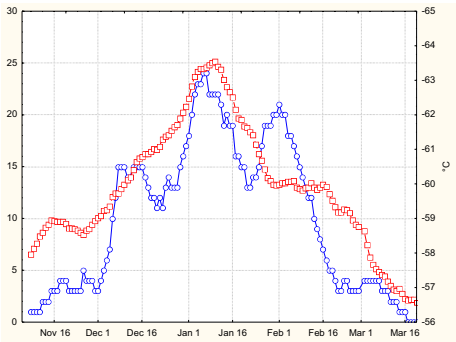

Figure 1. The seasonal variation of PSC-days over Iceland 1964 to 2001, 15-day running means (blue). The average temperature at 100hPa over Keflavík 1993 to 2004 (red – reverse scale). When the temperature drops below -60°C in early December there is a marked jump in the PSC frequency and, when it rises above this temperature in mid-February the frequency of the clouds drops considerably.

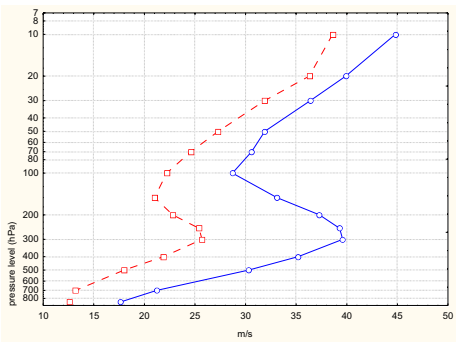

Figure 2. The average wind speed profile in December and January in Keflavík (red – dashed) and the average wind profile on PSC-days (blue line)

Figure 2 shows the average wind speed profile in December and January in Keflavík compared to the average profile on PSC days. It is clear that the wind speed is far above average at all levels on PSC-days. The maximum deviation occurs at tropopause level (200hPa), 14m/s. At 500hPa it is down to 12m/s, and decreases rapidly further below. The deviation is also significantly less in the lower stratosphere than at the tropopause level. In fig. 3. the average wind direction profile on PSC-days is compared to the mean profile. In the mean, there is strong wind veering, but on PSC-days there is very little change of wind direction with height. The pressure level temperatures also show a marked variation (fig 4), a cooling above the tropopause, but a warming in the upper troposphere, the maximum warming occuring at the

400hPa and 300hPa levels. The deviation of the height of pressure levels during days with PSCs is shown in figure 5. Below cca. 80 hPa the geopotential height is greater than in the mean and a maximum deviation from the mean is close to 300 hPa level. Above ca. 80 hPa, the PSC-days feature geopotential height below average.

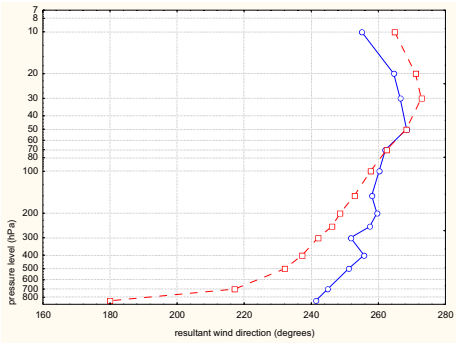

Figure 3. The average wind direction over Keflavik during PSC days (blue trace) and "normal" days (red trace)

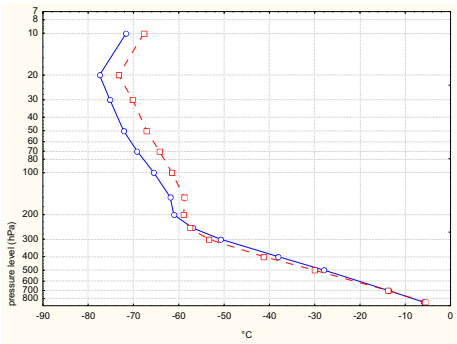

Figure 4. The average temperature profile in December and January in Keflavík (red – broken trace) and the average temperature profile on PSC days (blue line)

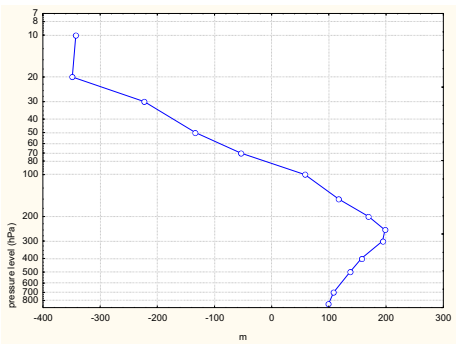

Figure 5. The pressure level height anomaly on PSC days relative to the December/January average condition

4. DISCUSSION

All parts of the Iceland have reported PSCs but not every weather station. For a ground based observation of PSCs there must be a break in lower cloud layers, and this is not always the case. The

investigation of the mean charactersistics of the atmospheric flow during the PSC cases presented here suggest that vertically propagating mountain waves are important for the formation of the PCSs. To generate the waves it is important to have a stable airmass at low levels. This is not very evident from our data, but on average, the airmass is relatively stable over Iceland. Strong low level winds are also important, and this corresponds well with the mean wind speed shown in Fig. 2. For the waves to be able to amplify and propagate vertically up to the stratosphere it is important not to have substantial changes with height in wind direction, but an increase in wind speed with height is favourable for the amplification of the waves. These conditions are particularly well fulfilled (fig. 2 and 3). Finally, a cold stratosphere favours the formation of PSCs. This is also the case in our dataset (fig. 4). The fact that PSCs are mainly observed when conditoins for amplified gravity waves are present suggests that localized cooling in the ascending part of a gravity wave may be crucial for the formation of most, if not all PSCs over Iceland. The above connection with mountain waves corresponds with the relatively low frequency of PSCs over SW-Iceland: PSC are only observed when there are no or only few tropospheric clouds and under such conditions the low-level winds are usually from the north in SW-Iceland. In northerly flow over SW-Iceland, there is often a reverse winds shear in the troposphere inhibiting upward propagation of wave energy. The importance of mountain waves for the creation of PSCs corresponds with recent studies such as Kuhl et al. (2004). The particularly favourable conditions for mountains waves does of course not rule out the possibility of PSCs existing without vertical motion induced by mountain waves (Pagan et al., 1999), but is it an interesting outcome of this study that temperature in the lower stratosphere is not necessarily the first indicator to look for when predicting PSC over Iceland.

5. FURTHER WORK

The period in question must be searched more thoroughly for possible leftover reports. The record before 1964 must be scrutinised as well. A system for forecasting PSCs will be developed where high low level wind speed and stability, increase of wind speed with height throughout the troposphere and only small changes in wind direction with altitude will be key indicators, in addition to temperature in the stratosphere.

6. EPILOGUE ON EARLY OBSERVATIONS OF PSCs AND SEA-ICE

For some of the oldest generation, polar stratospheric clouds are linked with the occurence of sea-ice at the coasts of Iceland, as one of the alternative Icelandic names indicate (ísaský litt. = ice clouds). This name was used in a newspaper report (Austri) in the connection with major episodes in 1887 and 1892 (both years giving very much sea-ice). An even older reference from the early 19th century (Árbækur Espólíns) mentions golden clouds (gylliniský). The data presented here do not particularly support such a sea-ice-connection, but sea-ice actually became much more frequent in the mid 1960s than for some decades before, and observations indicate that this was also the case for PSCs. It would be interesting if possible to confirm a minimum of PSCs during this sea-ice low frequency period (ca. 1920 to 1964). The sea-ice incidence is partly attributable to abnormally prevalent westerly winds to the north of Iceland. Such periods are often accompanied by a northerly shift (and/or split) in the polar jet over the North Atlantic, something which might have some influence on the formation of the PSCs. Interestingly the recent winter 2004-2005 brought a few prominent displays of PSCs – and the ice promptly arrived in March.

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