Determination of cloud properties at the NCO-P site in the Himalayas (27.9°N, 86.8°E) and at Thule (76.5°N, 68.8°W) from ground-based observations of global shortwave irradiance.

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Figure 1. Image showing the position of the NCO-P site in the Himalayas.

Figure 2. Image showing the position of Thule in Greenland.

Instrumentation and data analysis

Measurements of surface shortwave global irradiance, I_{SW}, are carried out at the NCO-P (the Nepal Climate Observatory at Pyramid) GAW-WMO station in the Himalayas, Nepal, (27.9°N,86.8°E, 5079 m a.s.l.) (*http://evk2.isac.cnr.it/ncop.html*) with a Kipp&Zonen CMP-21 precision pyranometer, and at Thule (76.5°N, 68.8°W, 225 m a.s.l.), Greenland, (*http://ndacc.dmi.dk*) with a YES Total Solar Pyranometer (TSP). Data corresponding to the period March 2007 – March 2009 (with an interruption between November 2007 and February 2008) for the NCO-P site and February 2007 – June 2009 for Thule are considered in this analysis.

A simple algorithm, that uses only measurements of surface shortwave global irradiance, was implemented to detect cloud-free and cloudy periods. The main steps of this algorithm are the following:

1. a cloud-free day, characterized by pristine conditions, is identified; following *Long and Ackerman* [2000], the measured shortwave irradiance is fitted with the expression:

   $$I_{SW}(\theta)=A\,[\cos(\theta)]^{B}$$

   where θ is the solar zenith angle, and A and B are constants.

2. For each day of measurements, the mean, R_M, and the standard deviation, σ_R, of the ratio R between the observations and the fitting curve is calculated over 10-minute intervals.

3. CLEAR and CLOUDY periods are identified following the conditions in Table 1. Cloudy periods are further separated in three classes: thin/moderate, thick and scattered clouds.

Figure 3. The CMP21 pyranometer (up) installed at the NCO-P site (down).

Figure 4. The TSP pyranometer (up) installed at Thule (down).

	Condition on R_M	Condition on σ_R
CLEAR	$0.8 < R_M < 1.2$	$\sigma_R < 0.005$
CLOUDY		
thin/moderate clouds	$0.5 < R_M \leq 0.8$	-
	$0.8 < R_M < 1$	$\sigma_R > 0.005$
thick clouds	$R_M \leq 0.5$	-
scattered clouds	$R_M \geq 1.2$	-
	$1.0 < R_M < 1.2$	$\sigma_R > 0.005$

Table 1. Conditions applied on R_M and σ_R to identify cloud free and cloudy periods.

4. The cloud optical depth, τ, is derived by applying the formula by *Barnard and Long* [2004]. Because this formula is valid only for cases of surface albedo lower than 0.3, τ is calculated only for periods with surface not covered by snow or ice (June - August for the NCO-P site and June – September for Thule).

Results

Figures 5 and 6 show the monthly mean frequency of occurrence of clear and cloudy periods observed at NCO-P and Thule. At Thule, because of the polar day-night annual cycle, determinations of sky conditions are possible only in the period March – October.
Figure 7 shows, for the NCO-P site, the frequency of occurrence of clear and cloudy periods versus time of the day for the different seasons during 2007-2008 (pre-monsoon, monsoon, post-monsoon, and winter; see Table 2).
At the NCO-P site cloud-free sky is most common, as expected, during winter (with maxima of ~50%); the frequency of clear-sky occurrence decreases/increases during the pre-/post-monsoon season and reaches its minima during the monsoon season (<10%). The sky conditions show different diurnal cycles during different seasons. Thick clouds are present up to 50% of the cases in the afternoon during the pre-monsoon; their occurrence increases during the monsoon season, with a frequency of about 80% in the mid afternoon. Thick clouds are less frequent in the post-monsoon, and rare during winter. A distinct daily behaviour appears, with cloud-free conditions occurring mostly during the morning throughout the year. Thin/moderate clouds seem to display a smaller daily evolution, particularly in the pre-monsoon period. The diurnal cycle is large in the pre-monsoon, post-monsoon, and winter, while it is reduced during the monsoon.
At Thule, the frequency of occurrence of clear sky increases during spring and summer (with a maximum of ~50% in May 2008), while decreases towards the winter season (<10%). Thin/moderate clouds seem to display a small seasonal evolution. The occurrence of thick clouds displays a small increase during the summer season, with the exception of year 2008 with a maximum of ~70% in March.

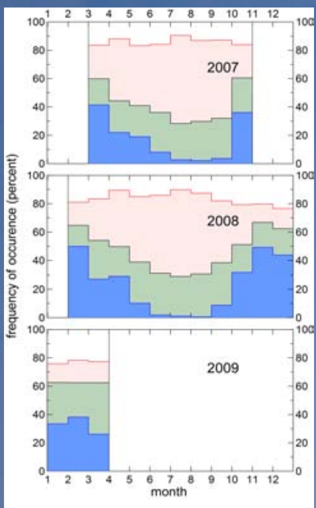

Figure 5. Frequency of occurrence of clear sky (light blue), thin/moderate clouds (grey), thick clouds (pink), and scattered clouds (white) versus month of the year, as derived at the NCO-P site from the CMP-21 observations.

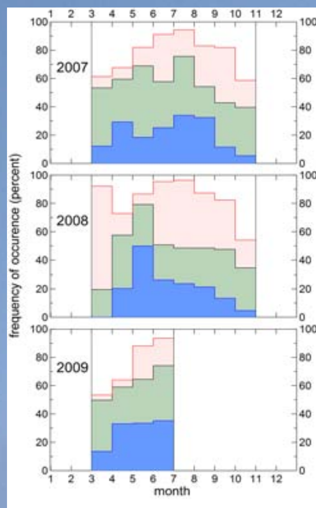

Figure 6. Frequency of occurrence of clear sky (light blue), thin/moderate clouds (grey), thick clouds (pink), and scattered clouds (white) versus month of the year, as derived at Thule from the TSP observations.

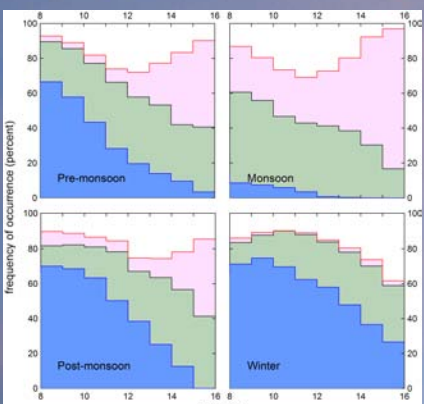

Figure 7. Frequency of occurrence of clear sky (light blue), thin/moderate clouds (grey), thick clouds (pink), and scattered clouds (white) versus time of the day for the different seasons, as derived at the NCO-P site from the CMP21 observations.

Season	Start – End date
Pre-Monsoon	1 February – 5 June 2007; 19 February – 10 May 2008; 31 January – 31 March 2009
Monsoon	6 June – 12 October 2007; 11 May – 26 September 2008
Post-Monsoon	13 October – 14 November 2007; 27 September – 6 November 2008
Winter	15 November 2007 – 18 February 2008; 7 November 2008 – 30 January 2009

Table 2. Season onset and decay dates at the NCO-P for the period 2007 – 2009.

Figure 8 shows the frequency of occurrence of the cloud optical depth for the periods June–August 2007 and 2008 at NCO-P, and June–September 2007, 2008, and 2009 at Thule. At the NCO-P site, the frequency of occurrence of the cloud optical depth is almost constant up to values of 10-20 and then decreases slowly at greater values. At Thule, the cloud optical depth shows a maximum of occurrence for values lower than 2.5 and a rapid decrease for greater τ.

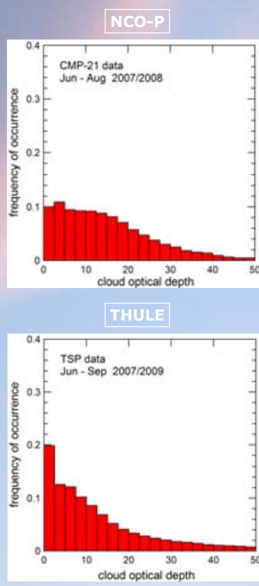

Figure 8. Frequency of occurrence of the cloud optical depth as derived from the CMP21 (NCO-P site) and TSP (Thule) observations.

References

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