IMPROVING CLOUD CLIMATOLOGY ANALYSIS USING SPACE LIDAR OBSERVATIONS:
COMPARISON OF SEVIRI AND PARASOL WITH CALIPSO

G. Sèze(1), J. Pelon(2), C. Vanbauce(3), F. Parol(3), H. Legleau(4), M. Derrien(4), J. Riedi(3)

1) Laboratoire de Météorologie Dynamique, Université Pierre et Marie Curie, 75252 Paris Cedex 05, France. Email: seze@lmd.jussieu.fr
2) Service d'Aéronomie, CNRS et Université Pierre et Marie Curie, 75252 Paris Cedex 05, France
3) Laboratoire d'Optique Atmosphérique, Université des Sciences et Technologies de Lille, 59655 Villeneuve d'Ascq Cedex, France
4) Centre de Météorologie Spatiale Météo-France, BP 50547, 22307 Lannion Cedex, France

Abstract

Coincident cloud occurrence, cloud type and cloud pressure data from the lidar CALIOP on board the CALIPSO (Cloud-Aerosol Lidar with Orthogonal Polarization) platform flying in the A-train Constellation, the POLDER (Polarization and Directionality of the Earth's Reflectances) radiometer on board the PARASOL (Polarization and Anisotropy of Reflectances for Atmospheric Sciences coupled with Observations from a Lidar) platform flying also in the A-train Constellation and the radiometer SEVIRI (Spinning Enhanced Visible and Infra Red Imager) on board the geostationnary satellite METEOSAT-8 are compared. 3 months of data during the 2006 summer (July, August and September) are analyzed. In this comparison, the thermodynamic cloud phase index derived from the POLDER polarized measurements is also used. The analyses are performed separately for daytime and nighttime data and for data from land and sea.

1. INTRODUCTION

Cloud amount and vertical distribution of cloud properties are key parameters of the climate system. They must be monitored accurately. New observations from active sounders may be very helpful for this purpose. New observations from active sounders are expected to give new insights in cloud altitude determination. The CALIOP lidar embarked on the CALIPSO platform and the radar CLOUDSAT embarked on the CLOUDSAT platform flying both in the A-train (Winker et al., 2007; Stephens et al, 2006), are now in operation since mid-June 2006. These data will greatly improve our understanding of the vertical distribution of cloud covering. They will not only enable the establishment of statistics on this vertical distribution but will also be a great help in validating and improving existing climatology. However such observations suffer from the lack of horizontal coverage offered by radiometric sensors instruments presently in orbit, such as the POLDER (Polarization and Directionality of the Earth Reflectances) radiometer on board PARASOL (part of the Aqua-train), or the SEVIRI radiometer on board the MSG geostationary satellite. Confrontations between observations are needed to improve our knowledge of both the vertical structure and time evolution of cloud systems as well as the micro-physical properties of clouds in these systems.

In this study, a first step is made toward these goals. We analyze and compare here the cloud occurrence frequencies, the cloud types and the cloud pressure distributions derived from the CALIOP lidar data and the POLDER and SEVIRI radiometer data. In this comparison, the thermodynamic cloud phase index derived from the POLDER polarized measurements is also used. 3 months of data during the 2006 summer (July, August and September) are analyzed. The analyses are performed separately for daytime and nighttime data and for data from land and sea. In section 2, the cloud occurrence frequencies and the zonal variations of these frequencies are compared. Then, the pressure distributions and the high cloud occurrence frequency maps are presented. In section 3 the CALIOP and SEVIRI cloud types are compared. Then, the distribution of CALIOP and SEVIRI cloud types according to the POLDER thermodynamic phase index is discussed. Conclusion and future work are given in section 5.

2. INSTRUMENTS AND OBSERVATIONS: THREE WAYS TO OBSERVE CLOUD PROPERTIES

CALIOP

The lidar CALIOP is on board the CALIPSO platform flying in the A-train Constellation. The AQUA-train overpasses are close to 13:30 pm and 1:30 am equator crossing times. The lidar CALIOP delivers observations along the satellite track. The laser beam diameter at surface is about 70m. Footprints are produce every 333m. The vertical resolution is 30m from the surface to 8.2km; higher than 8.2km it is 60m (Winker et al. 2007). Space lidars provide unambiguous cloud top height (CTH) retrieval of the uppermost layer in nearly all situations and the CTH of the lower layers in case of upper optically thin (optical thickness <3) or broken dense layers. They are able to detect very small cumulus and thin cirrus (optical thickness down to about 0.01, McGill et al, 2007). However, thin cloud layer detection depends on the signal to noise ratio. Lidar signals are usually required to be averaged to increase signal-to noise ratio to better detect optically thin clouds. During daytime, the background noise is much larger, due to sun light scattered by clouds. The cloud and aerosol CALIOP operational products (CALIPSO ATBD, 2005) are given at different scales (333m, 1, 5, 20 km).

In this study, cloud layer altitudes are taken from the operational Level 2 product with 5km resolution along track (~ 100m across-track) (Vaughan et al. 2004). With this resolution, an elevated 1km depth ice cloud should be detected by the CALIOP lidar provided its optical thickness is greater than 0.1

The POLDER radiometer

POLDER is a multidirectional, polarized and multispectral radiometer on board the PARASOL microsatellite. This instrument provides up to 16 different viewing angles per pixel for a single satellite pass. The full resolution pixel is 7x7 km^2.

The cloud properties are evaluated at 21x21 km^2 resolution (3x3 full resolution POLDER pixels). The operational cloud properties used in this study (*http://www.icare.univ-lille1.fr)* are the cloud cover, the cloud optical thickness, two cloud pressures and the cloud thermodynamic phase. All these parameters are computed for each full resolution pixels, for every viewing direction and then averaged (exception is made for the cloud thermodynamic phase parameter). See Buriez et al (1997) for a complete description of the algorithms. One cloud pressure, the Rayleigh pressure, derived from spectral polarization measurements at 490nm, is expected to show low bias in the absence of aerosols or thin clouds above the main detected cloud structure. The other one, the oxygen pressure, based on a differential absorption technique using measurements in the oxygen A-band (765nm), is expected to be close to the middle-cloud level due to in-cloud multiple scattering (Vanbauce et al., 2003; Sneep et al., 2007). The two cloud pressures are estimated only when the cloud optical thickness is above 3. The cloud top thermodynamic phase is retrieved from near-infrared polarized radiance(Riedi et al., 2000). This parameter discriminates ice cloud from liquid cloud. An overview of the cloud products can be found in Parol *et al*., (1999).

The SEVIRI radiometer

SEVIRI onboard the geostationary METEOSAT-8 satellite is a visible and infrared multi-channel imager which is operated on a 15-mn repeat cycle. The spatial resolution at sub-satellite point is 3x3 km^2.

Cloud detection and cloud type classification rely on multispectral threshold tests applied at the pixel scale to a set of spectral and textural features. The cloud top pressure is determined from infrared, CO_2 and water vapor radiances. For opaque clouds, the IR radiance is compared to the theoretical one obtained from radiative transfer calculations using ancillary Temperature and Humidity profiles. For thin and/or broken high-middle altitude mono-layer clouds, the retrieval of the cloud top pressure is based on the linearity of the radiance variations between different channels (Schmetz, 1993; Menzel, 1983). For multi-layered situations or pixels partially covered by low clouds, the pressure retrieval is still ambiguous. For low thick clouds, the solution may be non-unique due to temperature inversion. Here we use cloud type and cloud pressure products provided by the SAFNWC (Satellite Application facility in support of Nowcasting) at full pixel scale (Legleau and Derrien, 2005).

Region, period and data colocation

The studied region encompasses a large part of the SEVIRI field of view (figure 1). The analysis period extends from July 1st to September 30th, 2006. Only the SEVIRI and POLDER data co-located to the CALIOP profiles are retained. About 870 half orbits have been analysed, equally distributed between day and night. The 15' time sampling of the SEVIRI data set allows for a time lag of +/- 7.5' between the CALIOP observation and the SEVIRI pixel the closest in space. POLDER data are only available during daytime. POLDER and CALIPSO are separated by about 1 mn.

3. MEAN FEATURES

Similar spatial features are observed on the cloud occurrence frequency maps constructed from the three instruments (ITCZ, sub-tropical subsidence regions over ocean, over land, etc…), as shown in Figure 1. CALIOP detects more clouds than SEVIRI whatever the latitude above the continents, but mainly in the tropical region over ocean. Over ocean in the tropical and sub-tropical regions, the cloud cover occurrence decreases during day. The magnitude and zonal extension of this decrease is larger for CALIOP than SEVIRI as shown by the zonal mean curves of the cloud occurrence frequency in Figure 2. On the opposite, over land in the south hemisphere, the observed increase in the daytime data of the cloud occurrence frequency is larger for SEVIRI than CALIOP.

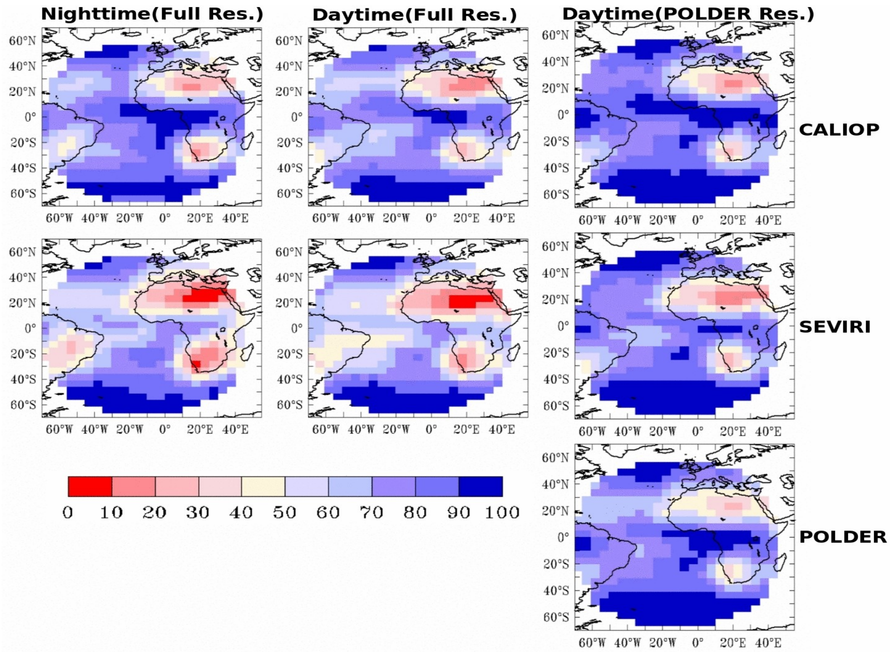

Figure 1: **Cloud occurrence frequency for CALIOP (first line) , for SEVIRI (second line), for POLDER (third line), for night-time data (first column) , daytime data (second column), daytime data averaged on the POLDER (21x21km^2) grid (third column).**

In column 3 of figure 1 and second raw of figure 2, only daytime SEVIRI and CALIOP data are considered and analysed at the POLDER spatial scale 21x21km^2. In this analysis, cloud occurrence is set to one when at least one full resolution pixel (3x3 km^2) or one lidar 5km footprint shot is cloudy in the POLDER grid mesh (21x21km^2). This leads to increase the cloud cover. We note that the expected increase in cloud occurrence frequency is larger for the SEVIRI data than the CALIOP data. However, SEVIRI still detects less cloud over land than CALIOP but also than POLDER. In second raw of figure 2 is given not only the cloud occurrence frequency (“non-clear” pixels reported as dotted line) but also the frequency of overcast pixel occurrence (solid lines). The frequency of partial cloud cover is defined by the difference between these two frequencies. The frequency of fully overcast pixels is much smaller and also quite different between sensors, especially between 30S and 30N. CALIOP detects more overcast cloudy pixels and less partially cloudy pixels than POLDER and SEVIRI. However, the opposite is true above sea, between 30S and 30N. Over land, POLDER retrieves more partially cloudy pixels than SEVIRI whatever the latitude.

Figure 3 shows the cloud top pressure distributions for CALIOP and SEVIRI over land and ocean for day time data and night-time data (2 first lines) and the POLDER oxygen and Rayleigh pressure (last column). These statistics have been established using the full resolution pixel value for SEVIRI and CALIOP and using the average value at the 21x21km^2 scale for POLDER.

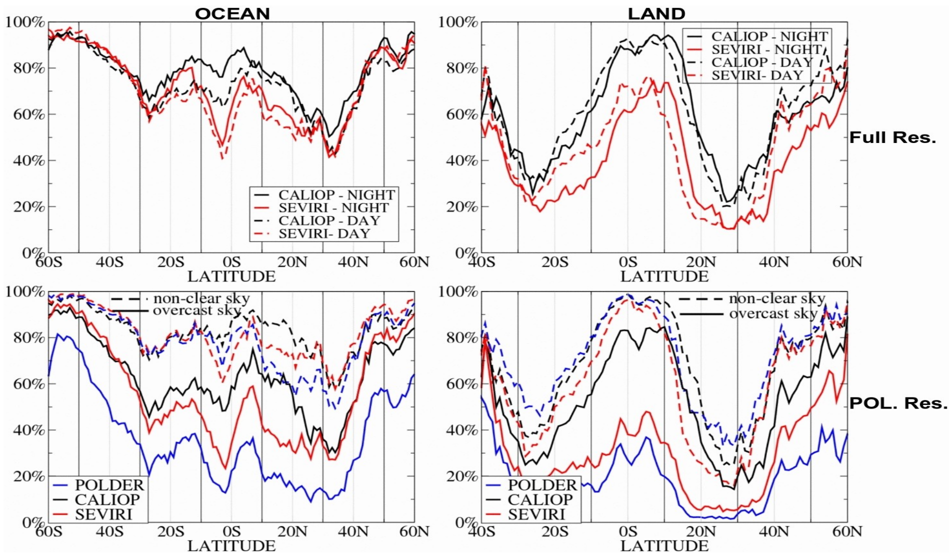

Figure 2: **Zonal mean of the cloud occurrence frequency over ocean (left) and land (right) for CALIOP and SEVIRI for daytime and night-time data (first line), and for CALIOP, SEVIRI and POLDER for daytime data (second line).**

Over ocean SEVIRI and CALIOP cloud-top pressure distributions observed during night-time have two well-defined peaks associated to the presence of low and high clouds respectively (Figure 3). Over land, during night-time, this distribution is characterized by a large frequency of high clouds but a very small

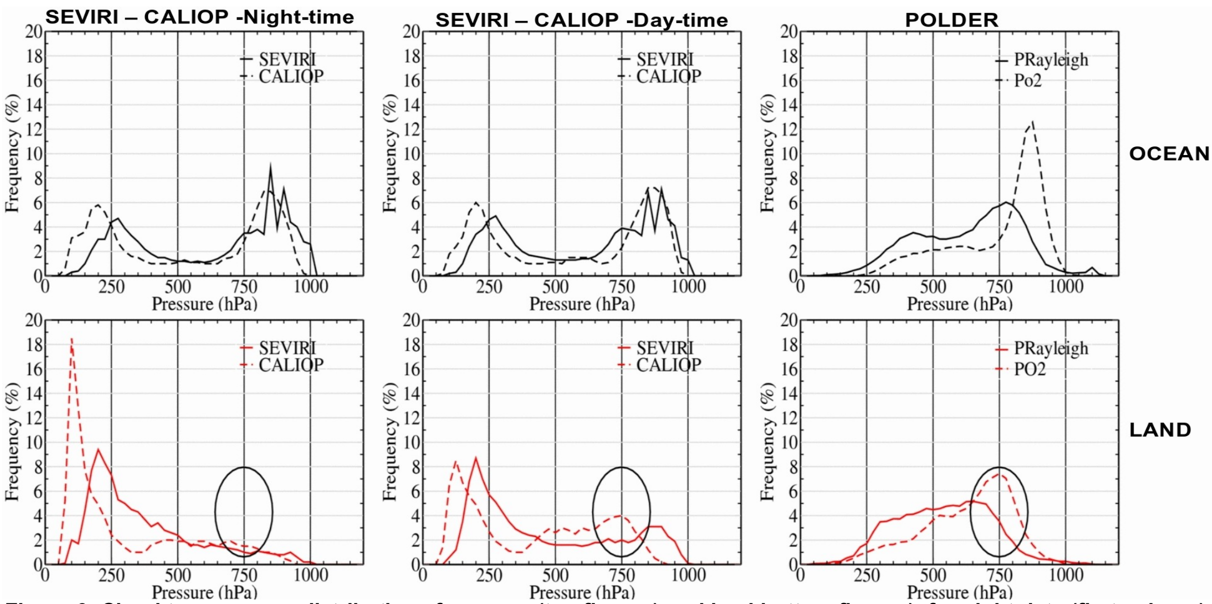

Figure 3: **Cloud top pressure distributions for ocean (top figures) and land bottom figures), for night data (first column), daytime data (second column) and for POLDER Poxygen and Prayleigh cloud top pressure (last column).**

frequency of low-clouds. These features were also observed in a previous comparison between SEVIRI and GLAS (Geoscience Laser Altimeter System) (Sèze et al., 2006). In the POLDER PO2 cloud pressure distribution, the peak at pressure levels smaller than 300hPa (closer to the tropopause) observed in the SEVIRI and CALIOP cloud top pressure distributions, is absent. The pressure value of the low-cloud peak retrieved using the POLDER PO2 method is much larger than for CALIOP or SEVIRI. This is coherent with the fact that this pressure does not correspond to the cloud top pressure but to an intermediate level between the top and the base of the cloud layer or below in the case of multilayered clouds, and is thus lower in altitude. The cloud top pressure distribution with the POLDER Prayleigh also shows two peaks as compared to CALIOP and SEVIRI, but much closer to mid-pressure levels. This is under investigation. The Prayleigh pressure which is retrieved from the measurement of the atmospheric molecular optical thickness above the cloud top is expected to be close to the cloud top pressure. One could argue that the differences observed between the POLDER pressures distributions and the SEVIRI or CALIOP distributions come from the spatial averaging to $21x21km^2$. Tests performed by averaging the SEVIRI cloud top pressure to that spatial scale do not support this argument.

Figure 4 shows the geographical distributions of the high cloud occurrence frequency when clouds are present. Here, the high cloud definition is a cloud with a top pressure below 400hPa for SEVIRI, CALIOP and POLDER (using the Prayleigh pressure). For POLDER, when the Poxygen pressure is used, the pressure threshold is 500hPa. Although the magnitude of the frequency is strongly dependent on the instrument, al the maps in figure 4 show the well known spatial structures associated with the main climate regimes.

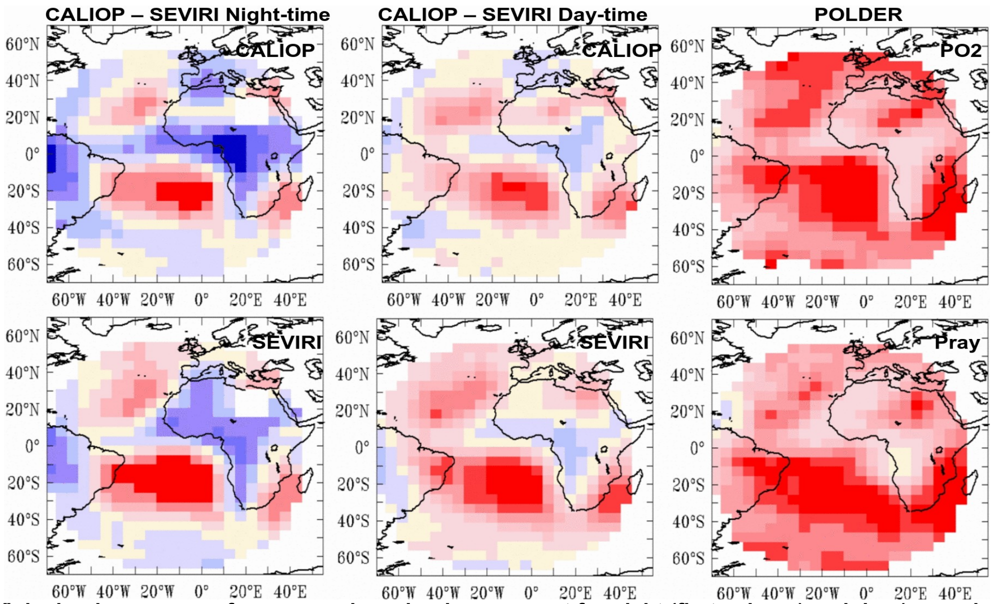

Figure 4: ***H*****igh cloud occurrence frequency when cloud are present for night (first column) and day (second column) for CALIOP (top raw, first and second column) and SEVIRI (bottom raw, first and second raw), for POLDER Po2 (last column top figure), and POLDER Prayleigh (last column, bottom figure).**

In the tropical regions CALIOP retrieves more high clouds than SEVIRI. However, in the two data set, comparison of day-time and night-time maps displays smaller high-cloud frequency during the day.

3. ANALYSIS OF THE DIFFERENCES AT PIXEL SCALE

CALIOP and SEVIRI cloud types

A classification in four main cloud types(clear , low, middle and high cloud) has been performed. Over ocean during day-time, when comparing SEVIRI and CALIOP cloud type classifications, 73% of the pixels fall in the same class. Over land or over ocean at night, this percentage is about 64%. These values are not as good as the one obtained for SEVIRI and GLAS for October 2003 (Sèze et al. 2006). For the cloud detection itself (classification in cloudy and clear) the disagreement found between the two classifications remains smaller than 20%. The pixels corresponding to the SEVIRI partial cloud class have been excluded of the comparison(2% to 7% over land and 15% to 20% over ocean).

Figure 6 and figure 7 show the cloud type distribution obtained from one instrument (SEVIRI or CALIOP) for each cloud type class obtained with the other one (CALIOP or SEVIRI, respectively). Figure 6 focuses on daytime observations, and Figure 7 on night-time ones. The cirrus over class is included in the high cloud class and also reported separately. The SEVIRI high cloud type over land and ocean are consistent with the CALIOP classification in more than 77% of the cases. On the opposite, the CALIOP high clouds are classified as clear or partial by SEVIRI in more than 30% of the cases. Over land at night, half of the CALIOP high clouds are not detected by SEVIRI.

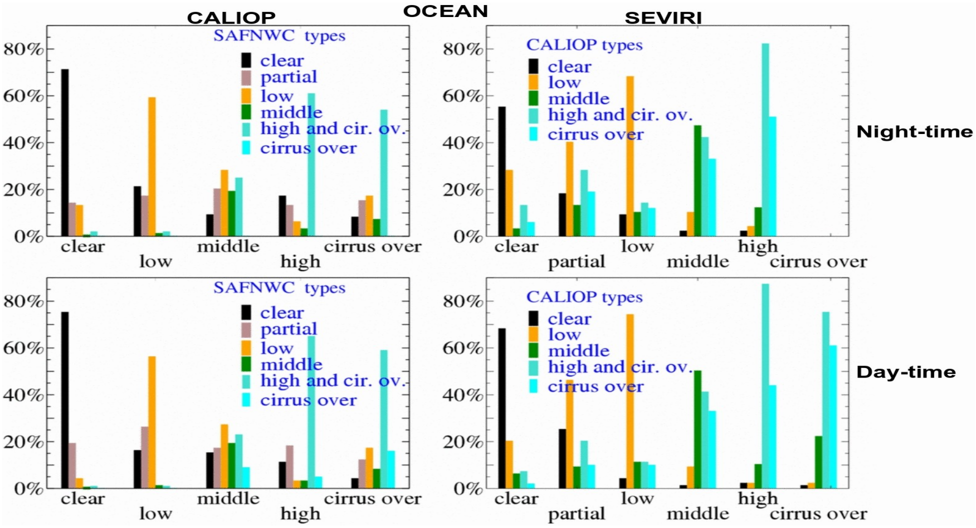

Figure 6: **For ocean SEVIRI type distribution for each CALIOP type (left column), CALIOP type distribution for each SEVIRI type (right column), for nighttime data (first raw) for daytime data (second raw) .**

CALIOP middle level clouds do not belong to a well defined class in the SEVIRI classification. SEVIRI middle level cloud belongs as well to the CALIOP middle level cloud class than to the CALIOP high

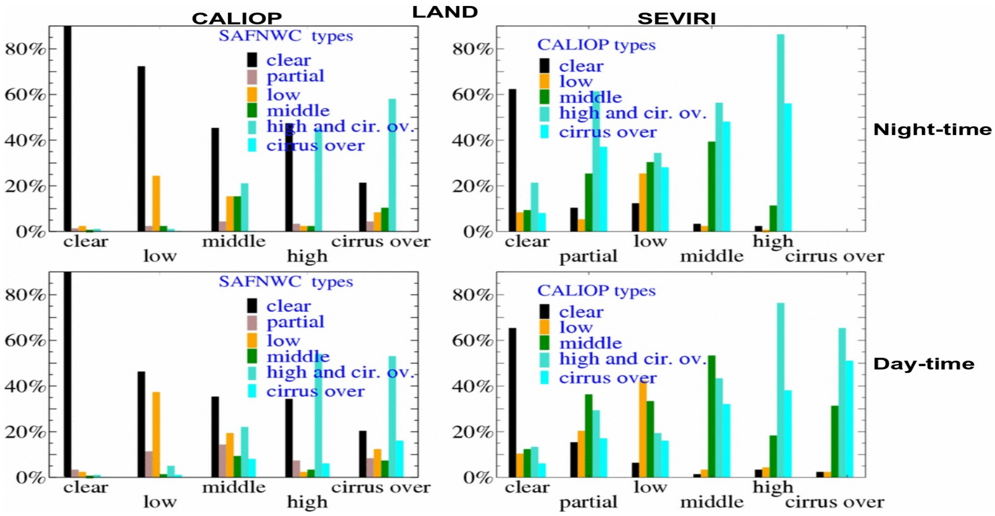

Figure 7: **As figure 6 but for land.**

level cloud class. If the SEVIRI low cloud type is consistent with the CALIOP type in 75% of the cases over ocean, over land this percentage falls under 40%. For the night-time data set, the results of this comparison of CALIOP and SEVIRI cloud type classifications are close from those obtained in a previous comparison between SEVIRI and GLAS cloud type classifications (Sèze et al, 2006). But, for day time data, more differences are observed. In the present comparison, the differences between day time and night-time results are smaller. This may be due to the fact that CALIOP measurements are less perturbed by sunlight background noise than GLAS ones.

POLDER cloud phase and CALIOP and SEVIRI cloud types

Figure 8 shows the SEVIRI and CALIOP cloud type distribution for each POLDER cloud phase type. We indicated the agreement as good (poor) when the POLDER cloud phase has been obtained with a high (low) confidence index. The distributions of the CALIOP and SEVIRI cloud types in the POLDER cloud phase classes are coherent with that is expected (Sèze et al., 2004): a large percentage of high cloud is in the ice water class and large percentage of middle and low cloud in the liquid class. Almost all the CALIOP high clouds which are classified as liquid water clouds by POLDER. correspond to multi-layered situations. The distribution of the CALIOP and SEVIRI classes for the POLDER mixed phase is very similar to those of the liquid water cloud classes.

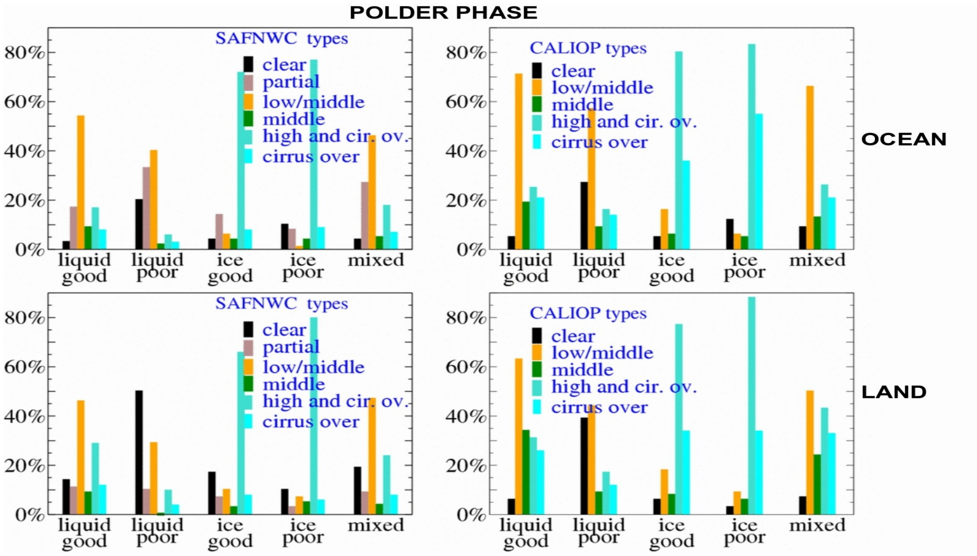

Figure 8: **For ocean (top figures) and land (bottom figures), SEVIRI cloud type distribution for each POLDER cloud phase type (left column), CALIOP cloud type distribution for each POLDER cloud phase type (right column).**

Over land, the categorization as liquid/poor often corresponds to clear sky cases, for CALIOP as well as for SEVIRI.

4. CONCLUSION AND OUTLOOKS

Coincident cloud occurrence data from the lidar CALIOP, the visible infrared radiometer SEVIRI and the POLDER multi-directional, polarized and multi-spectral radiometer are compared for the July 1st to September 30th, 2006 period. Similar features are observed in the 3 sets of cloud occurrence frequency maps. On average, the cloud occurrence frequency for the SEVIRI 3x3 km^2 full resolution data is smaller than those found for CALIOP profiles at the resolution of 5km. This is especially true in the tropics over ocean and land and sub-tropics over land. The SEVIRI and CALIOP diurnal increase or decrease of cloud occurrence frequency as a function of latitude are correlated, but the magnitude of these diurnal variations can be very different between the two data sets. This may be due to the difference in sensitivity between the two instruments, which will be investigated. At the 21kmx21km^2 POLDER super pixel scale, POLDER and CALIOP cloud occurrence frequencies are close. Exception is over ocean around 20°N. The frequency of partially covered super pixels is much larger for POLDER over land.

The shapes of the CALIOP and SEVIRI cloud top pressure distributions are close. On the average, SEVIRI cloud top pressures are larger than CALIOP cloud top pressures. The global shape of the POLDER cloud top pressure using Prayleigh and Poxygen are distinct from each other and also differ from the CALIOP and SEVIRI cloud top distributions. The Poxygen pressure is more representative of average cloud levels in agreement with what is expected. For Prayleigh pressure, differences observed need more investigations.

In spite of these differences in cloud pressure distributions, similar features are observed in the high cloud occurrence frequency maps. However, the magnitude of the frequency is strongly dependent on the instrument.

The comparison at pixel scale of the CALIOP and SEVIRI cloud type classifications shows that clouds not detected by SEVIRI are often low clouds over ocean and high clouds at night over land (more than 50%). Over land also, a large fraction of the CALIOP low and middle clouds are not detected by SEVIRI.

The SEVIRI high cloud type over land and ocean are consistent with the CALIOP classification in more than 77% of the cases. Clouds in the CALIOP middle level cloud class do not belong to a well defined class in SEVIRI classification. The POLDER liquid and ice classes are relatively coherent with the CALIOP and SEVIRI cloud types. In more than 78% of the POLDER ice phase cases, CALIOP detects a high cloud layer. More difficult is the identification of mixed-phase and liquid clouds with respect to cloud type.

The next step will be to analyze more carefully the differences observed between these three data set in order to relate these differences to well defined cloud situations. More investigations will be performed to interpret the daytime to nighttime variations observed in the CALIOP and SEVIRI cloud cover, and difference in detection sensitivity.

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