Assessing Cloud Spatial and Vertical Distribution with Infrared Cloud Analyzer

I. Genkova and C. N. Long
Pacific Northwest National Laboratory
Richland, Washington

T. Besnard
ATMOS SARL
Le Mans, France

D. Gillotay
Institute d'Aeronomie Spatiale de Belgique
Brussels, Belgium

Introduction

In the effort to resolve uncertainties about global climate change, the Atmospheric Radiation Measurement (ARM) Program (www.arm.gov) is improving the treatment of cloud radiative forcing and feedbacks in general circulation models. Understanding cloud properties and how to predict them is critical because cloud properties may very well change as climate changes. The amount of clouds and cloud spatial and vertical distribution at any given time are required input parameter for improving the performance of general circulation models.

This study is dedicated on assessing cloud spatial and vertical distribution with a recently developed infrared (IR) cloud analyzer, named Nephelo. The experiment took place at the ARM's central facility, located in Central Oklahoma (36° 37 'N, 97° 30 'W). The Nephelo was deployed and run for approximately 3 months from February 20, 2003, to June 3, 2003. One of the primary purposes of the experiment was to assess the performance and capabilities of the Nephelo, thus the instrument was located within less than 10 meters distance from other ARM's instruments used operationally for estimating cloud amount and cloud height.

Infrared Cloud Analyzer

The Nephelo is a commercial instrument produced by Group Leader, France. It operates 7 IR sensors, each with a 6-degree field of view, and spectral range 8-14 μm. The sensors are mounted at angles 0, 12, 24, 36, 48, 60, and 72 on a semi-circular azimuthally rotating curved band (Figure 1).

They are based on OMEGA OS 65–V-R2-4-BB model pyrometers. The original sensors were modified in order to reduce the total weight from 0.3 to 0.1 kg per sensor, and to prevent the accumulation of liquid water at the optics entrance. The main technical characteristics of the sensor are given in Table 1.

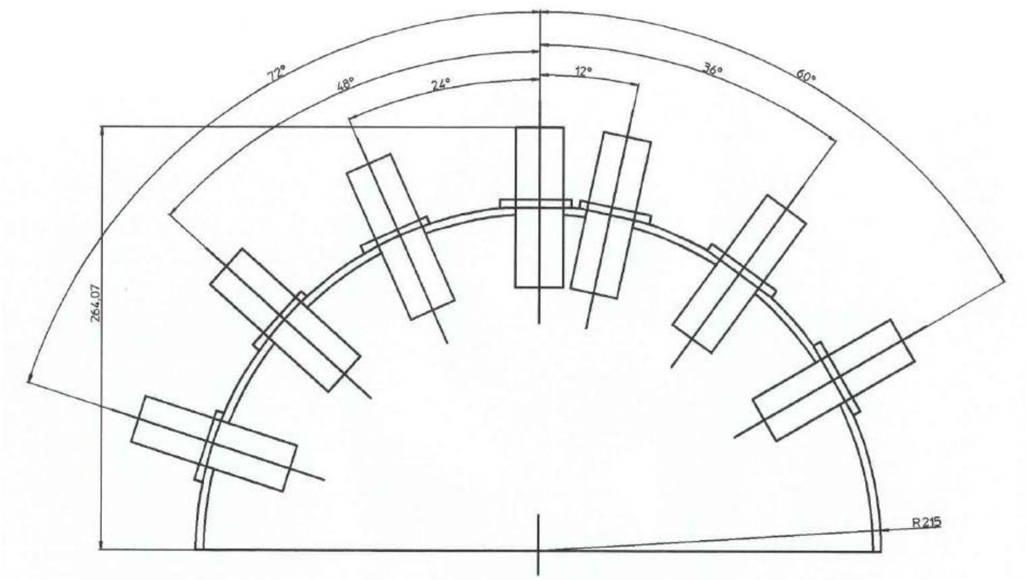

Figure 1. Schematic view of the instrument design.

Table 1. Technical Characteristics of the Pyrometer	
Spectral Range	8-14 µm
Temperature range	216K ÷ 398 K
Temperature accuracy	±1°K
Repeatability	±1°K
Response time	300 ms
Full field of view (FOV)	11.9
Emissivity	0.1 to 0.99

A "hemispherical" mosaic of 181 brightness temperature measurements centered on the zenith is obtained by the rotation of the semi-circular band around the vertical axis, performing 30 scans, every 12° from 0° (North) to 348°.

Measurements

The downward thermal emission from the clouds and the air column between the clouds and the instrument is measured by IR pyrometers. The temperature of the clouds is derived from a combination of Planck's and Stephan-Boltzmann's laws, resulting in an equation of the general form

$$F = \varepsilon f(T),$$

where F is the downward IR flux integrated for the band pass of the detector (Wm^{-2}), ε is the hemispheric emissivity and f(T) is a 4-order relationship between temperature and IR emittance in the spectral range of the detector.

The estimation of the hemispheric emissivity value is of great importance and can affect significantly the quality of the temperature measurement. For practical reasons and in agreement with the values published in the literature, a mean value of ε = 0.90 has been selected for the whole-sky dome in presence or absence of cloud cover. The consequence of this choice is that the emissivity variations are not taken into account inducing some error in the brightness temperature determination. However, temperature differences between cloudy and clear-sky conditions are for most cases large enough for discrimination.

As mentioned above, the variability of the hemispherical emissivity is not taken into account. The mean value (ε = 0.90) seems to be reasonable to describe practically all type of clouds. However, cirrus clouds with very variable emmissivity factors (0.7-1.0) will be probably poorly identified by this method.

A second source of error could be induced by the composition of the lower layer of the troposphere (0-2 km). An atmosphere rich in green-house effect constituents like ozone, carbon dioxide, water vapor can affect significantly the downward IR flux and consequently, the measured temperature. This contribution will depend of course of the zenith angle (minimum at the zenith and maximum for the observations close to the horizon).

Finally, under clear-sky or broken clouds conditions, the presence of direct sun radiation will disturb the temperature determination, but only in one solid angle element. This disturbance can be useful to determine the presence or absence of direct sun radiations.

To account for the uncertainty in the emissivity, we suggest and apply an algorithm that utilizes the brightness temperatures from the Nephelo and given the precipitable water vapor amounts and vertical profiles of the thermodynamic state of the atmosphere from independent measurements, derives clear-sky brightness temperature thresholds as a function of the precipitable water vapor. Line-by-Line Radiative Transfer Model is used to calculate the thresholds. The brightness temperatures measured by the Nephelo are then compared to these thresholds to classify a scene as clear or cloudy.

Results

The results presented below are for March, 2003. Figure 2 compares the day-time cloud amount (CA) frequency distributions as retrieved by a whole sky imager (WSI) (dark blue bars) (Slater 2002), total sky imager (TSI) (blue bars) (Long 2000), SW Flux Analysis (SWFA) (cyan bars) (Long 1999), Nephelo (yellow bars), atmospheric emitted radiance interferometer’s (AERI’s) fractional sky cover Ne (AERI Ne) (orange bars) (Takara 2003) and the opaque portion of the TSI measured sky cover (TSI Opaque) (brown bars).

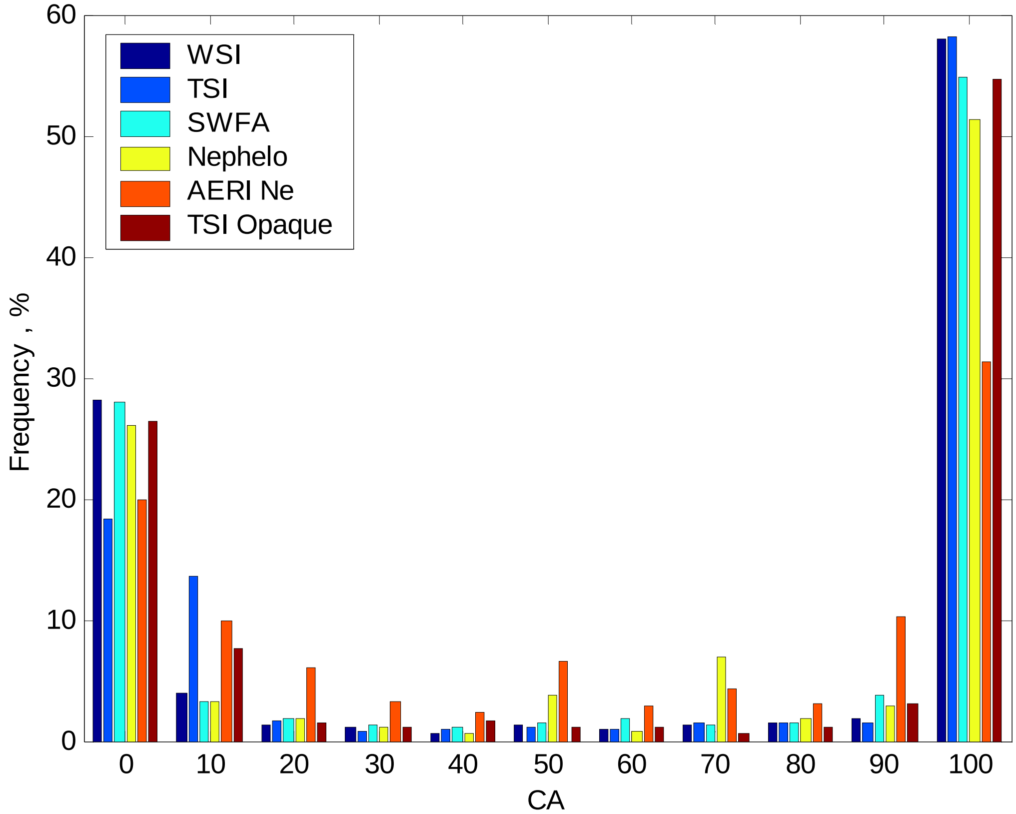

Figure 2. Frequency distribution of cloud amounts retrieved with various techniques during daytime.

At first, we notice difference between the Nephelo cloudiness histogram and the other retrievals. However, one must keep in mind that these techniques are based on different physical phenomena, work in different spectral ranges, some employ specific FOVs, and last but not least; each instrument has different time resolution. The correlation coefficients between the Nephelo's cloud amounts and the cloudiness from other retrievals are as follow: 0.73 with WSI, 0.73 with TSI, 0.77 with TSI Opaque, 0.75 with SWFA, 0.51 with AERI's Ne.

The best agreement is observed with TSI opaque cloud amounts. This result confirms our expectation that the Nephelo will be detecting better opaque clouds.

One of the Nephelo advantages is its ability to assess cloud distributions during night-time. We study the Nephelo performance by comparing it to the WSI - the WSI is the only hemispherical nighttime imager available at the ARM central facility. Figure 3 illustrates the CA frequency distribution for WSI and the Nephelo. The correlation coefficient is 0.69.

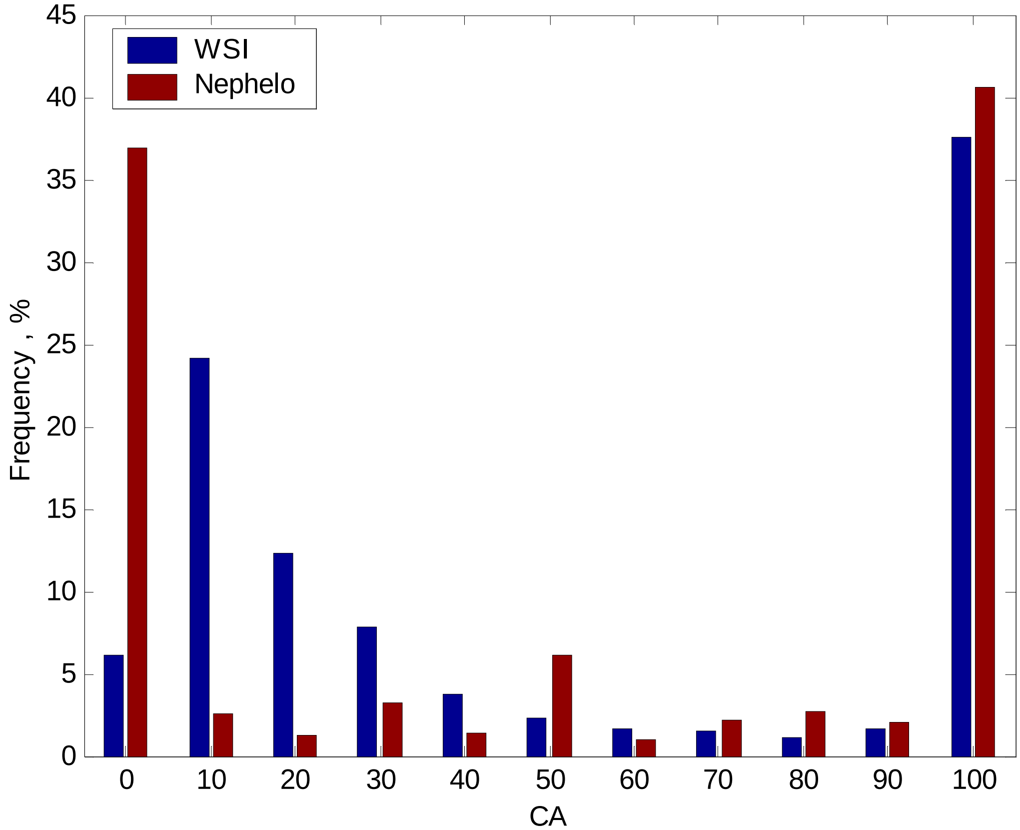

Figure 3. Frequency distribution of cloud amounts retrieved with two techniques during nighttime.

Figure 4 shows an example of a 24 hours record of Nephelo cloud amounts along with the other available techniques. During the night, the difference between the WSI and Nephelo CA varies from 5% to 50%. On one hand, this is a manifestation of the uncertainty in the cloud emissivity as explained above. On the other hand, we will speculate that one possible reason for the difference is the fact that the WSI has not been compared to any other instrument to date. Hence, the WSI CA uncertainty is to be considered a reason as well.

Once measured, the brightness temperature of the cloud could be easily converted to cloud height, given a vertical profile of the atmospheric state. This approach was applied to the Nephelo's data to assess the vertical distribution of clouds as depicted on Figure 5. The retrieved parameter is cloud base height and it is first retrieved using all 7 Nephelo sensors (Nephelo), and then only the top 3 sensors, thus allowing for a smaller FOV of 40 deg. This two time series are compared to an independent cloud base retrieval (ARSCL) (Clothiaux 2000), and then to a Vaisala ceilometer measurement (VCEIL).

Our study shows that Nephelo cloud base heights agree with the other retrievals under two conditions - warm law clouds and high cloud amounts.

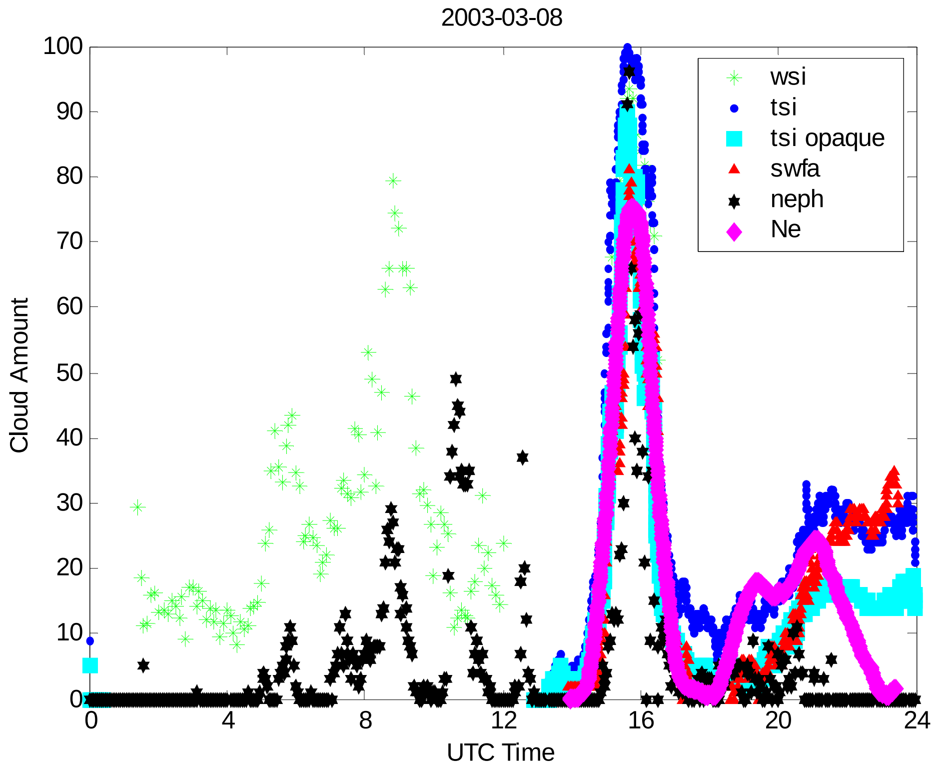

Figure 4. Cloud amounts for March 8, 2003

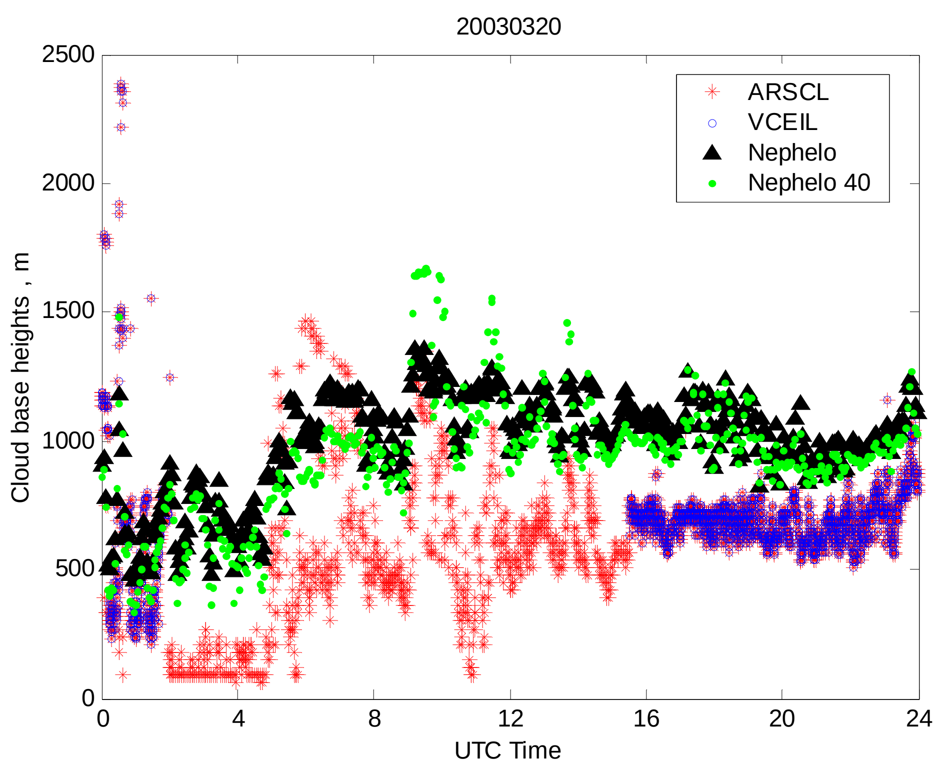

Figure 5. Cloud base heights for March 20, 2003

Conclusions

We investigated the possibility of estimation cloud spatial and vertical distribution with a recently developed IR cloud imager.

We suggested an algorithm that utilizes the brightness temperatures from the Nephelo given the precipitable water vapor amounts and vertical profiles of the thermodynamic state of the atmosphere from independent measurements. The algorithm estimates the cloud amount and determines the vertical distribution of the clouds. We tested the algorithm and the instrument performance through inter-comparison with well studied ground-based retrieval techniques developed within the ARM Program.

Initial analyses show good cloud amount assessment and spatial mapping abilities. The vertical distribution understanding is currently limited; however, the amounts of low, middle, and high clouds could be determined and studied further.

Acknowledgement

Authors would like to thank Dave Turner, from Pacific Northwest National Laboratory, for his helpful comments and the Line-By-Line Radiative Transfer Model runs.

Corresponding Author

Iliana Genkova, iliana.genkova@pnl.gov, (509) 372-6020

References

Clothiaux, E. E., T. P. Ackerman, G. G. Mace, K. P. Moran, R. T. Marchand, M. A. Miller, and B. E. Martner, 2000: Objective determination of cloud heights and radar reflectivities using a combination of active remote sensors at the ARM CART sites. *J. Appl. Meteor*., 39, 645–665.

Long, C., T. Ackerman, J. J. DeLuisi, and J. Augustine, 1999: Estimation of fractional sky cover from broadband SW radiometer measurements. In *Proceedings of the Tenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, U.S. Department of Energy, Washington, D.C.

Long, C., D. Slater, and T. Tooman, November 2001: *Total Sky Imager (TSI) Model 880 Status and Testing Results*, ARM-TR-006. Available URL: http://www.arm.gov/publications/tech_reports/arm-tr-006.pdf

Slater, D. W., C. N. Long, and T. P. Tooman, 2002: A comparison of the TSI/WSI cloud fraction estimates at the SGP. In *Proceedings of the Twelfth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, ARM-CONF-2002. U.S. Department of Energy, Washington, D.C.

Takara, E. E., and R. G. Ellingson, 2003: Using narrow and wide field of view instruments to evaluate longwave parameterizations for fair weather cumulus cloud fields. In *Proceedings of the Thirteenth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, ARM-CONF-2003. U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/publications/proceedings/conf13/extended_abs/takara-ee.pdf