A Comparison of the Global Surveys of High, Mid, and Low Clouds from Satellites and General Circulation Models

F.-L. Chang and Z. Li
Earth System Science Interdisciplinary Center
University of Maryland
College Park, Maryland

Introduction

Understanding cloud vertical structure is crucial for climate studies due to its impact on both the magnitude and sign of net cloud radiative forcing; for example, low thick clouds like boundary layer stratocumulus have a net cooling effect, but high thin clouds like cirrus have a net warming effect (e.g. Liou 1986; Hartmann et al. 1992). The vertical distribution of clouds also modifies both the latent and radiative heating profiles of the atmosphere and affects general circulation and moisture transport (Webster and Stephens 1984; Randall et al. 1989). In a climate simulation study, Wang and Rossow (1998) found that changing the cloud vertical distribution can significantly modify the strength of the Hadley circulation. In their two-layer cloud simulations, the strength is a strong function of the separation distance between the two cloud layers. Placing a single-layer cloud at a mid-level gives rise to the strongest Hadley circulation. So far, we have poor knowledge of cloud vertical distribution on large scales, which due mainly to a shortcoming in direct measurements. The current passive satellite observations provide the only means of obtaining the large-scale and global cloud information, but unfortunately many limitations exist in the conventional satellite cloud retrieval schemes.

In essence, the most widely-used satellite cloud products are perhaps from the International Satellite Cloud Climatological Project (ISCCP, Rossow and Schiffer 1999) and from the new-millennium National Aeronautics and Space Administration Moderate-resolution Imaging Spectrometer (MODIS) data (King et al. 2003; Platnick et al. 2003). The ISCCP product provides an effective cloud top height that is retrieved based on total-column infrared thermal emission. The MODIS product provides the top of the highest cloud detected by the CO_2-slicing technique. In either product, no cloud overlapping information can be obtained due to the assumption of a single-layer cloud model. As satellite views from space, the occurrence of high clouds can obscure low clouds. As such, the single-layer model would significantly underestimate low cloud amounts on large-scale analyses. In addition, because many high clouds are thermally non-black, the ISCCP thermal-infrared method can underestimate a large fraction of high clouds by misplaced their altitudes at some lower altitudes (Jin et al. 1996; Chang and Li 2005). In this study, we compare the near-global surveys of several global cloud products derived from satellites and models. The main objective of this study is to survey the differences in the frequency occurrence of high, mid, and low cloud amounts among the different products.

Surveys of Satellite High, Mid, and Low Cloud Amounts

The comparisons are performed by applying three different satellite cloud retrieval methods, namely, the bispectral visible-infrared method, the MODIS operational method and a new method developed by Chang and Li (2005), to the raw radiance measurements observed by the MODIS instrument. The bispectral visible-infrared method is the most commonly employed satellite retrieval method like used by the ISCCP. It requires an infrared channel (~11 μm) measuring cloud-top brightness temperature for the retrieval of cloud top height and a visible channel (~0.6 μm) measuring the cloud reflectance for the retrieval of cloud optical depth. The bispectral method is regularly adopted by conventional weather satellites (AVHRR, GMS, GOES, METEOSAT, VIRS, etc.) because the two channels are in common and available from all meteorological satellite.

The MODIS operational method differs from the ISCCP by employing a CO_2-slicing technique to retrieve the cloud top height for all high-to-mid altitude clouds, but employing a similar visible channel to retrieve cloud optical depth. However, for all lower clouds with a cloud top pressure $Pc > 700$ hPa, the MODIS adopts a similar bispectral visible-infrared method as used in ISCCP. This is because the MODIS CO_2-slicing technique loses its accuracy if cloud top height is lower than 700 hPa. The new method of Chang and Li (2005) is a different MODIS-based method. It can deal with cirrus-overlapping-low cloud conditions and retrieve separate cloud tops and optical depths for the high cirrus and low cloud layers. The satellite measurements used in this study are from the Terra MODIS (equator passing time ~10:30 a.m.) observed in January, April, July, and October of 2001. The near-global datasets, excluding high-reflecting snow/ice covered regions, are analyzed.

Figure 1 shows the geographic distributions of the April 2001 monthly-mean high-cloud (< 440 hPa), mid-cloud (440-680 hPa), and low-cloud (> 680 hPa) amounts obtained by the three methods: the bispectral visible-infrared method in Figure 1a, the MODIS operational method in Figure 1b, and the new method of Chang and Li in Figure 1c. Figure 2 compares the latitudinal variations of zonal-mean high-cloud (top panel), mid-cloud (middle panel), and low-cloud (bottom panel) amounts obtained by the three methods. As seen from the figures, the bispectral visible-infrared method shows similar amounts of high, mid, and low clouds on a near-global average, whereas the MODIS and Chang and Li methods show much more high-cloud amounts but much less mid-cloud amounts. The Chang and Li method also shows the most low-cloud amounts resulting from the addition of overlapped low clouds that are recovered underlying the high clouds. Note that these cloud amounts are analyzed for overcast pixels only that do not include partly cloudy pixels according to the MODIS cloud mask (Ackerman et al. 1998).

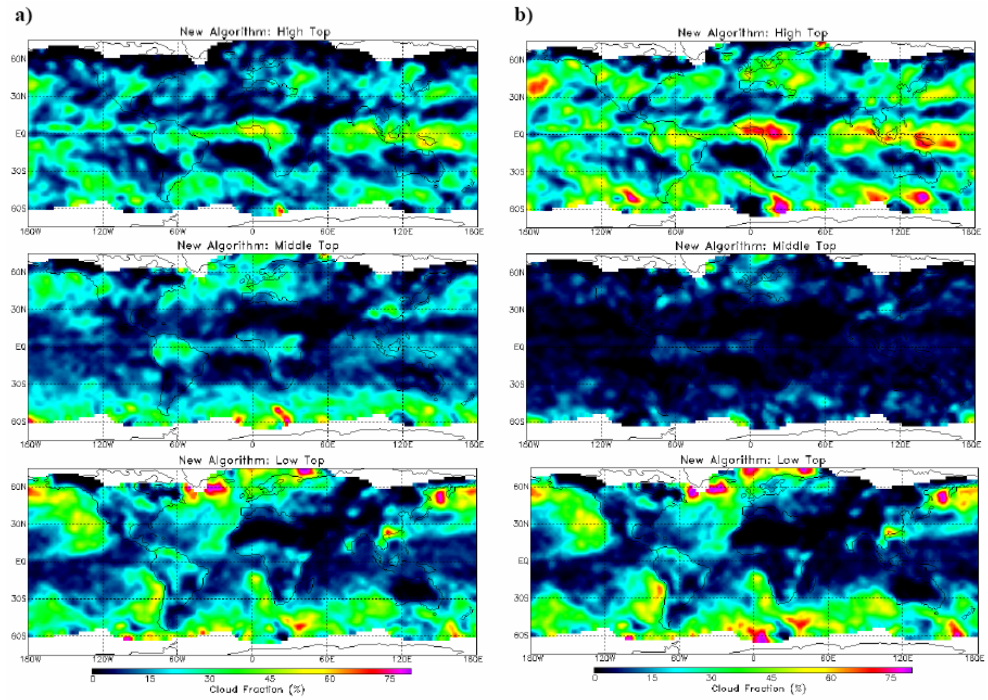

Figure 1a and 1b. Comparisons of monthly-mean high-cloud (top panel), mid-cloud (middle panel), and low-cloud (bottom panel) amounts obtained by a) the bispectral visible-infrared method and b) the operational MODIS method for April 2001.

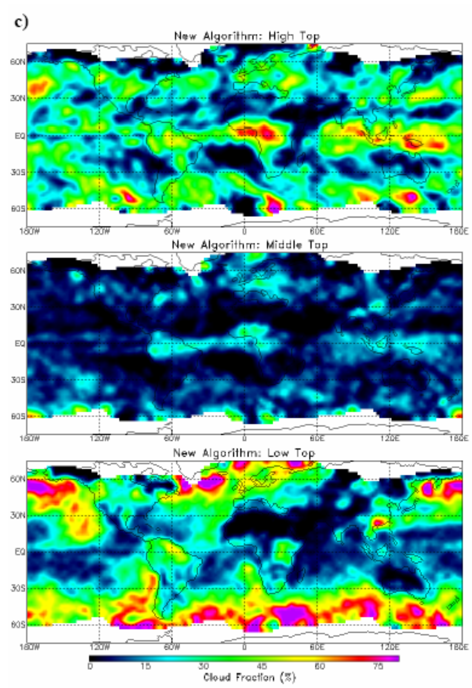

Figure 1c. (continued) Same as in Figures 1a and 1b, except for the high, mid, and low clouds obtained by the Chang and Li method.

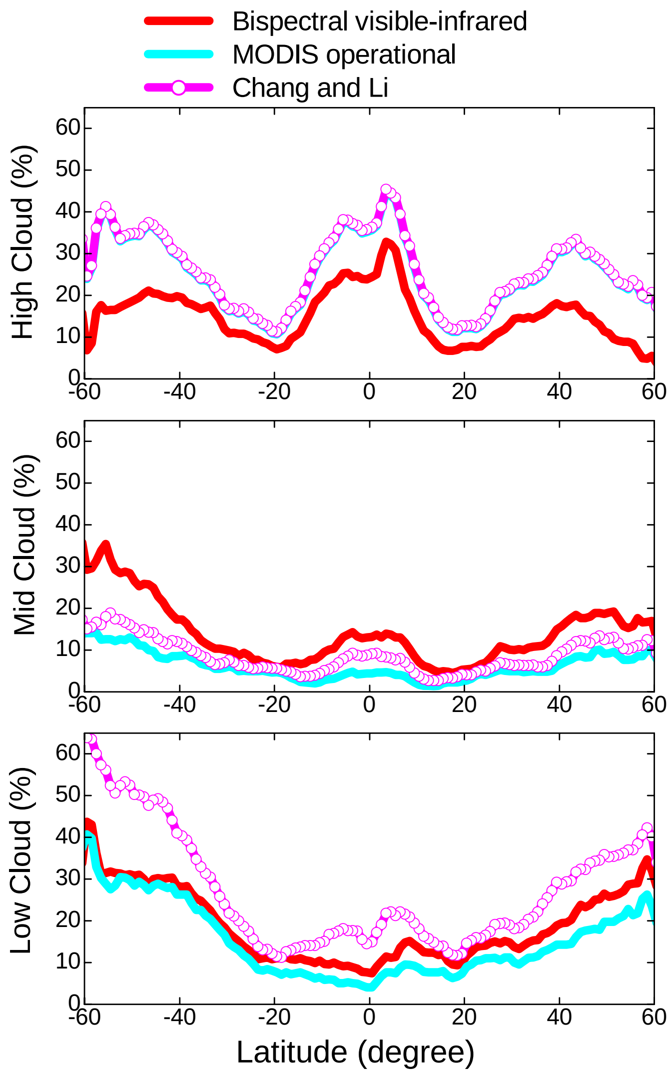

Figure 2. Comparisons of latitudinal variations of zonal-mean high-cloud (top panel), mid-cloud (middle panel), and low-cloud (bottom panel) amounts obtained by the bispectral visible-infrared method (red), the operational MODIS method (blue), and the Chang and Li method (pink).

Comparisons with General Circulation Models Results

The near-global mean high, mid, and low cloud amounts obtained by the three methods shown in Figure 2 are calculated, respectively, to be about 14%, 15%, and 17% for the bispectral visible-infrared method, about 23%, 6%, and 17% for the MODIS method, and about 24%, 9%, and 29% for the Chang and Li method. We compare these numbers with the study of Zhang et al. (2005) which also compare the high, mid, and low clouds that are derived from several different general circulation models (GCMs). Figure 3 shows the near-global (60°S-60°N) mean high, mid, and low cloud amounts obtained from our satellite studies (solid squares) in comparisons their GCM results (open circles). As seen from the figure

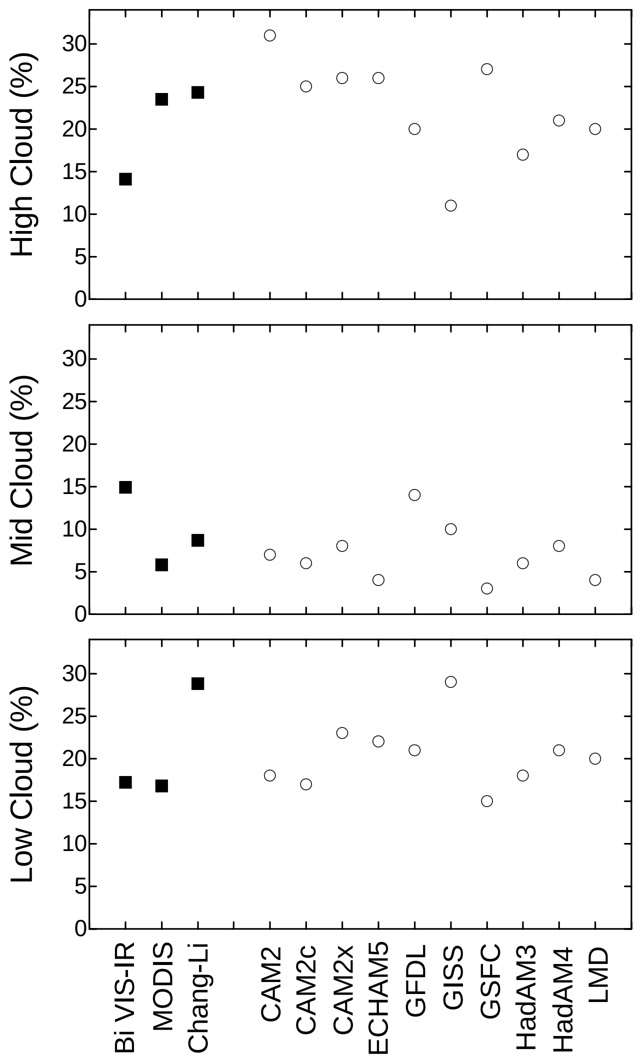

Figure 3. Comparisons of near-global averaged high-cloud, mid-cloud, and low-cloud amounts derived by the three satellite methods (solid squares) and from various versions of GCMs (open circles) shown in Zhang et al. (2005).

for the high cloud, the Goddard Institute for Space Studies (GISS) model produces the least high-cloud amount that is closest to the bispectral method. The other model mean high-cloud amounts are all larger with a general mean value closer to the mean high-cloud amount of both the MODIS and Chang and Li methods. For the mid cloud, GFDL is the highest and the closest to the bispectral method. Most other models have a mean value smaller than 10% (GISS model ≈ 10%) and closer to the MODIS and Chang and Li methods. As for the low cloud, only the GISS model produces as much as the largest high-cloud amount from the Chang and Li method. The other models are at least 6 or 7% less and closer to the bispectral and MODIS methods. In general, the GCMs have much less mid clouds than the high and low cloud amounts. The overall average amounts for the high and low clouds are similar, but are three times larger than the average amount of mid clouds.

Conclusion

To date, we still have very poor knowledge of cloud vertical structure on a global scale. Differentiating clouds appearing in different vertical layers is still a challenging task when using passive satellite remote sensing methods. In light of the substantial differences that shown in comparing the cloud vertical distributions derived from satellites and climate models, much caution is warranted in validating GCMs while attempting to improve cloud parameterization schemes. At present, results of cloud simulations from many GCMs are often validated against the ISCCP cloud amounts, resulting in many improvements in the models. More attention is now being paid to more detailed comparisons concerning the vertical distribution of clouds, or cloud occurrences in different layers. For example, Zhang et al. (2005) found that most GCMs produce substantially less mid clouds than the ISCCP. In our analyses, we found that this substantial less mid-cloud amount is in good agreement with the MODIS and our new retrieval results. However, the low-cloud amounts from GCM are generally less than our retrievals. Clearly, it is critical to sort out these differences in order to improve the performance of GCMs and other types of climate simulation models.

Acknowledgement

This work is supported by the United State Department of Energy Atmospheric Radiation Measurement Program grant DE-FG02-01ER63166 managed by Dr. Wanda Ferrell.

Reference

Ackerman, SA, KI Strabala, WP Menzel, RA Frey, CC Moeller, and LE Gumley. 1998. "Discriminating clear-sky from clouds with MODIS." *Journal of Geophysical Research* 103, 32,141-32,158.

Chang, F-L, and Z Li. 2005. "A new method for detection of cirrus-overlapping-water clouds and determination of their optical properties." *Journal of Atmospheric Science,* in press.

Hartmann, DL, ME Ockert-Bell, and ML Michelsen. 1992. "The effect of cloud type on the Earth's energy balance Global analysis." *Journal of Climate* 5, 1281-1304.

Jin, Y, WB Rossow, and DP Wylie. 1996. "Comparison of the climatologies of high-level clouds from HIRS and ISCCP." *Journal of Climate* 9, 2850-2879.

King, MD, WP Menzel, YJ Kaufman, D Tanre, BC Gao, S Platnick, SA Ackerman, LA Remer, R Pincus, and PA Hubanks. 2003. "Cloud and aerosol properties, precipitable water, and profiles of temperature and humidity from MODIS." *IEEE Transactions of Geosciences Remote Sensings* 41, 442-458.

Liou, KN. 1986. "Influence of cirrus clouds on weather and climate processes: A global perspective." *Monthly Weather Review* 114, 1167-1199.

Platnick, S, MD King, SA Ackerman, WP Menzel, BA Baum, JC Riedi, and RA Frey. 2003. "The MODIS cloud products: Algorithms and examples from Terra." *IEEE Transaction Geosciences Remote Sensings* 41, 459-473.

Randall, DA, DA Harshvardhan, TG Dazlich, and TG Gorsetti. 1989. "Interactions among radiation, convection, and large-scale dynamics in a general circulation model." *Journal of Atmospheric Science* 46, 1944-1970.

Rossow, WB, and RA Schiffer. 1999. "Advances in understanding clouds from ISCCP." *Bulletin of the American Meteorological Society* 80, 2261-2287.

Wang, J, and WB Rossow. 1998. "Effects of cloud vertical structure on atmospheric circulation in the GISS GCM." *Journal of Climate* 11, 3010-3029.

Webster, PJ, and GL Stephens. 1984. "Cloud-radiation interaction and the climate problem." *The Global Climate*, edited by J. Houghton, pp. 63-78, Cambridge University Press, New York.

Zhang, MH, SA Klein, JT Bacmeister, S Bony, RT Cederwall, AD Del Genio, JJ Hack, U Lohmann, P Minnis, I Musat, R Pincus, P Stier, MJ Suarez, MJ Webb, JB Wu, SC Xie, M-S Yao, and JH Zhang. 2005. "Comparing clouds and their seasonal variations in 10 atmospheric general circulation models with satellite measurements." *Journal of Geophysical Research* 110:D15S02, doi:10.1029/2004JD005021