P7.14 Cloud optical depth from UW-NMS and GEOS-DAS and comparisons with MODIS and ISCCP satellite observations

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1. INTRODUCTION

Clouds have an important influence on tropospheric photochemistry through modification of solar radiation that determines photolysis rates (J-values). The enhanced photolysis rates have been found above and in the upper levels of clouds while reduced rates are found below optically thick clouds and absorbing aerosols. Cloud optical depth is thus a critical parameter needed to describe these radiative effects of clouds on tropospheric photochemistry. For example, a fast and accurate numerical method (so-called Fast-J) for calculating photolysis rates (Wild et al., 2000) in three-dimensional chemical transport models (3-D CTMs) requires as input the cloud optical depth in vertical model layers. Current estimates of cloud optical depth and its vertical distribution, however, have large uncertainties. As part of our study of the radiative effect of clouds on tropospheric chemistry, we evaluate here the cloud optical depths from two modeling systems with those from satellite retrievals. The radiative effect of clouds on tropospheric chemistry will be presented elsewhere (Liu et al., 2004).

On one hand, we use the University of Wisconsin Non-hydrostatic Modeling System (UW-NMS), a regional-scale meteorological prediction model (Tripoli, 1992ab) where distributions of cloud water are explicitly predicted, to simulate cloud optical depth in the Asian Pacific region in spring 2001. On the other hand, empirically diagnosed global cloud optical depth for all seasons of the same year is available from the GEOS3 archive of the Goddard Earth Observing data assimilation system (GEOS-DAS) at the NASA Global Modeling and Assimilation Office (GMAO) (Schubert et al., 1993). The calculated cloud optical depths from these two modeling systems are compared with the satellite retrieval products from the Moderate Resolution Imaging Spectroradiometer (MODIS) (Platnick et al., 2003) and the International Satellite Cloud Climatology Project (ISCCP) (Rossow and Schiffer, 1999).

2. MODELS

UW-NMS. UW-NMS (Tripoli, 1992ab) is a non-hydrostatic research model, used primarily to investigate the interaction of convection with mesoscale and synoptic-scale weather phenomena. It provides twice daily mesoscale meteorological forecasts at the University of Wisconsin-Madison. The UW-NMS meteorological forecast model is also used as the dynamical core for the regional component of the Regional Air Quality Modeling System (RAQMS), which is a global- to regional- scale air quality modeling system recently developed by Pierce et al. (2003). UW-NMS resolves atmospheric structure on spatial scales as low as a few kilometers in the horizontal and 200-400m in the vertical. It includes multiple interactive grid nesting, tropospheric microphysics, radiative transfer, and surface processes. It uses a revised Emanuel scheme to parameterize subgrid-scale convection**.** The UW-NMS model has been applied to tropical cloud clusters, hurricanes, midlatitude cyclones, polar lows, gravity waves, lake effect snow storms, and mesoscale convective complexes (e.g., Tripoli, 1992ab). It was recently used to study the impact of synoptic waves on summer column ozone during the POLARIS aircraft campaign, and to study an East Asian convective complex during March 2001 (Hitchman et al., 2004). Kittaka et al. (2004) used UW-NMS with sulfate chemistry to estimate the role of clouds in the East Asian sulfate budget and Pierce et al., (2003) used the model as part of RAQMS to estimate East Asian ozone budgets during the Transport and Chemical Evolution over the Pacific (TRACE-P) aircraft mission. TRACE-P took place during February-April 2001, and was designed to determine the chemical composition and evolution of the Asian outflow over the western Pacific. In this study, we use the model configuration of Pierce et al. (2003) for TRACE-P and UW-NMS was run using a rotated equidistant projection centered at 26.5^{o}N and 115.0^{o}E with 110km horizontal resolution (60 grid points in east-west direction and 45 grid points in north-south direction).

To take account of the impact of cloud and aerosol layers on tropospheric chemistry, we have implemented in the RAQMS regional model the Fast-J2 scheme (Bian and Prather, 2002) for calculating photolysis rates. As part of the effort, we use the cloud water explicitly predicted by UW-NMS to calculate the visible cloud optical depth with the parameterizations of Stephens (1978) and Slingo and Schrecker (1982) for water clouds and that of Fu and Liou (1993) for ice clouds. The Slingo and Schrecker parameterization scheme is found to perform better than the Stephens scheme and is used as the default scheme in the model:

$$\tau = \beta\, dz, \quad \beta = 3\, LWC / (2\, r_e),$$

where τ is the cloud optical depth, β is the extinction coefficient (m^{-1}), LWC is the cloud liquid water content (g/m^3) as calculated by the model, dz is the thickness of cloudy layer (m), and r_e is the effective radius for cloud droplets (assumed a value of 10μm). The Fu and Liou (1993) parameterization for ice cloud (visible) optical depth is expressed as:

$$\tau = \beta\, dz, \quad \beta = IWC\, (a_0 + a_1/D_e),$$

where IWC is the cloud ice water content (g/m^3), a_0(=-6.656×10^{-3}) and a_1(=3.686) are empirical coefficients, D_e is the effective radius of ice particles (assumed a value of 60μm).

The cloud optical depth calculated as above does not include the direct contribution from cumulus convection. However, the cumulus cloud fraction is presumably small, limiting its effective effect on radiation on a grid scale.

GEOS-DAS. GEOS-DAS includes successive generations of meteorological archives, namely, GEOS1, GEOS-STRAT, GEOS3, and GEOS4, depending on the year. The archives are available for the years 1985 to present. The GEOS assimilated meteorological observations have 6-hour temporal resolution (3-hour resolution for surface fields and mixing depths) and are used to drive GEOS-CHEM, which is a global 3-D model of tropospheric ozone-NO_x-hydrocarbon chemistry (Bey et al., 2001). GEOS-CHEM uses the Fast-J scheme (Wild et al., 2000) to calculate photolysis rates. We focus in this study on the evaluations of the GEOS3 cloud optical depth and cloud fraction for the year of 2001. The original GEO3 archive has 1^ox1^o degree horizontal resolution; for computational efficiency, the fields are degraded to 4^ox5^o horizontal resolution at which GEOS-CHEM is run. We use here this degraded field.

The occurrences of clouds in GEOS3 are diagnosed based on grid-scale relative humidity and subgrid-scale convection (L. Takacs, personal communication, 2004). The cloud optical properties are empirically prescribed to strive for a reasonable simulation of top-of-the-atmosphere longwave and shortwave cloud forcing. For large-scale clouds, cloud optical depth is empirically assigned values proportional to the diagnosed large-scale liquid water. For convective clouds, cloud optical depth is prescribed as 16 per 100mb. A temperature dependence is used to distinguish between water and ice clouds.

3. PRELIMINARY RESULTS

UW-NMS. During TRACE-P it was found that the major process driving Asian pollution outflow in spring is frontal lifting ahead of southeastward-moving cold fronts and transport in the boundary layer behind the cold fronts (Liu et al., 2003). It was also suggested that clouds associated with these fronts have a large impact on photolysis frequencies and short-lived radicals (Tang et al., 2003). A strong event of frontal outflow occurred on March 7, 2001. For this event, we compare in **Figure 1** the cloud optical depth simulated by UW-NMS with the MODIS/Terra retrievals in the Asian Pacific region. We use the level-3 MODIS gridded atmosphere daily global joint product, MOD08_D3, which contains daily 1^ox1^o degree grid average values of cloud optical and physical properties. Since the reported MODIS cloud optical depths represent the cloudy conditions only, we have multiplied them by the MODIS cloud fractions (i.e., Cloud_Fraction_Infrared_Day_Mean) to reflect both cloudy and clear conditions. Model outputs are averaged over a 6-h period around the MODIS overpass time (10:30am LT). MODIS retrievals are featured by high values of cloud optical depths associated with the cold front, which extended from Southeast China to south of Japan. The model simulates correctly this feature, in particular the location of the frontal clouds. While the simulated frontal cloud optical depth is comparable to (or somewhat higher than) the retrieval, the model underestimates the low cloud optical depth in other parts of the region.

Shown in **Figure 2** is the zonal mean cloud optical depth over the model domain for individual days during March 7-14, 2001. Both the UW-NMS and MODIS values are generated in the same way as those in Figure 1. Generally UW-NMS simulates well the latitudinal variability, although it tends to overestimate high values and underestimate low values. The overestimate at high values is worse if the Stephens (1978) parameterization for cloud optical depth were used. This overestimate is probably less of a problem because cloud albedo saturates at high cloud optical depths. Also often overestimated are the cloud optical depths south of 10^oN, as shown in **Figure 2** for the days of March 9, 12, 14. This partially reflects the effect of cumulus convection on the large-scale environment but may also reflect the artificial effect due to domain boundary. We conclude that the UW-NMS calculated cloud optical depths are appropriate to be used as input to the Fast-J2 scheme in order to take account of the radiative impact of large-scale clouds on tropospheric chemistry.

GEOS-DAS. We show in **Figure 3** the global distribution of GEOS3 monthly mean (grid-scale) cloud optical depths as compared to MODIS (MOD08_M3, level-3 monthly global product at 1^ox1^o resolution) and ISCCP (D2, 280km equal-area grid) retrievals for March 2001. Zonal mean plots for all months of 2001 are shown in **Figure 4**. The MODIS and ISCCP values used in both figures are the product of the original (in-cloud) optical depth retrievals with their respective cloud fraction and therefore represent the averages over both cloudy and clear conditions. This is necessary for a consistent comparison with model monthly mean optical depths. Both MODIS and ISCCP cloud optical depths reveal the maxima associated with tropical convection, extratropical cyclones in the Northern Hemisphere, and the marine stratiform clouds in the Southern Hemisphere (SH, ~50-60^{o}S). GEOS3 shows the same feature in cloud optical depths but tends to overestimate the values at ~50-60^{o}S as well as in the tropics. At northern high latitudes, GEOS3 cloud optical depths do not show values as high as those from MODIS and ISCCP retrievals; the latter is presumably due to uncertainties associated with snow cover in the satellite retrievals for these regions. We also find that GEOS3 captures the variability in cloud optical depth associated with synoptic-scale frontally induced cloudiness in the Asian Pacific region during spring (not shown). It is pointed out that both MODIS and ISCCP monthly mean cloud optical depths used here (**Figure 3** and **Figure 4**) are linear averages and their magnitudes are comparable. Previously reported large differences between MODIS and ISCCP monthly mean cloud optical depths (Pinker et al., 2003) were probably due to the use of non-linearly averaged values for ISCCP. Similar plots are constructed for monthly mean cloud fraction (**Figure 5** and **Figure 6**). MODIS, ISCCP, and GEOS3 cloud fractions are overall consistent. The above evaluations of GEOS3 cloud optical depth and cloud fraction provide a quantitative estimate of errors in the model cloud optical properties that will be used to assess the radiative effect of clouds on global tropospheric chemistry (Liu et al., 2004).

4. SUMMARY

We have used the University of Wisconsin Non-hydrostatic Modeling System (UW-NMS), a regional-scale meteorological prediction model where distributions of cloud water are explicitly predicted, to simulate cloud optical depth in the Asian Pacific region in spring 2001. Empirically diagnosed global cloud optical depth for all seasons of the same year is also available from the GEOS3 data assimilation system. We have compared the calculated cloud optical depths from these two modeling systems with the satellite retrieval products from MODIS and ISCCP. Both UW-NMS and GEOS-3 reproduce the prominent features in the satellite data. In particular, both models capture the variability in cloud optical depth associated with synoptic-scale frontally induced cloudiness in the Asian Pacific region during spring. We have shown that the MODIS and ISCCP monthly mean cloud optical depths (linear averages) are actually comparable in magnitude.

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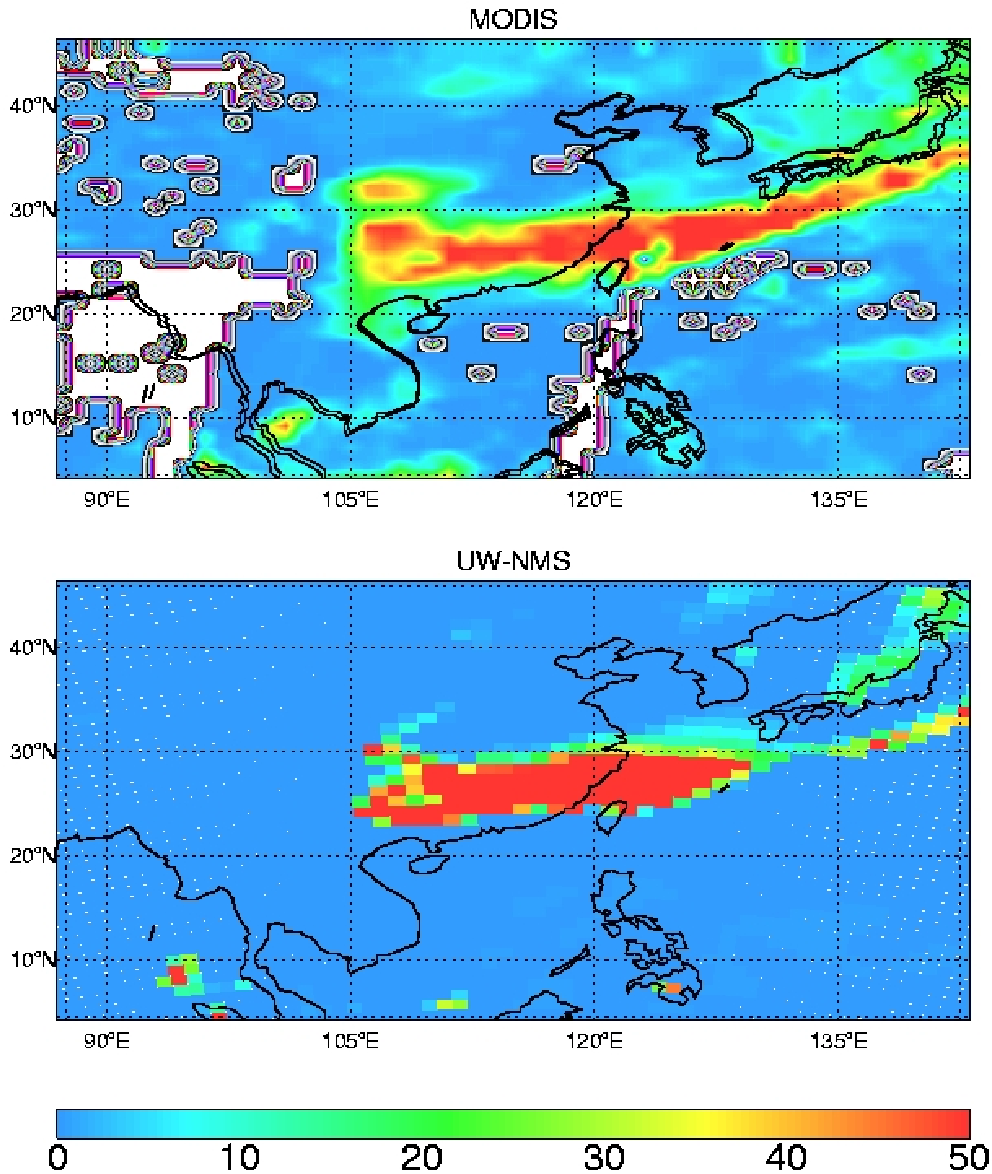

Figure 1. Comparison of cloud optical depths simulated by the UW-NMS and retrieved from the MODIS/Terra observations in the Asian Pacific region on March 7, 2001. Model outputs are averaged over a 6-h period around the MODIS overpass time (10:30am LT). See text for details.

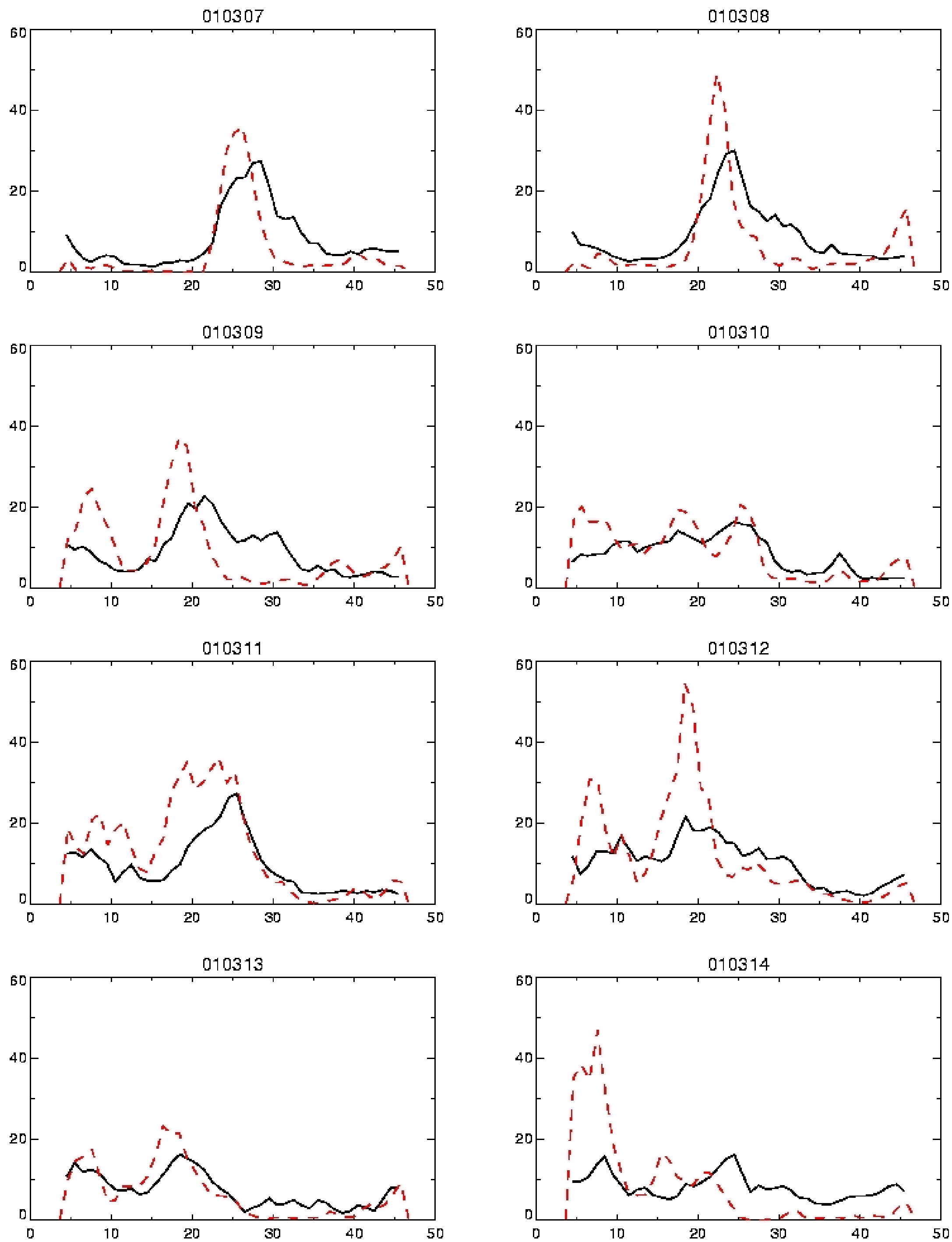

Figure 2. The zonal mean cloud optical depths in the Asian Pacific region (see Figure 1) during March 7-14, 2001, as calculated by UW-NMS (dashed line) and observed by MODIS (solid line). Both the UW-NMS and MODIS values are generated in the same way as those in Figure 1.

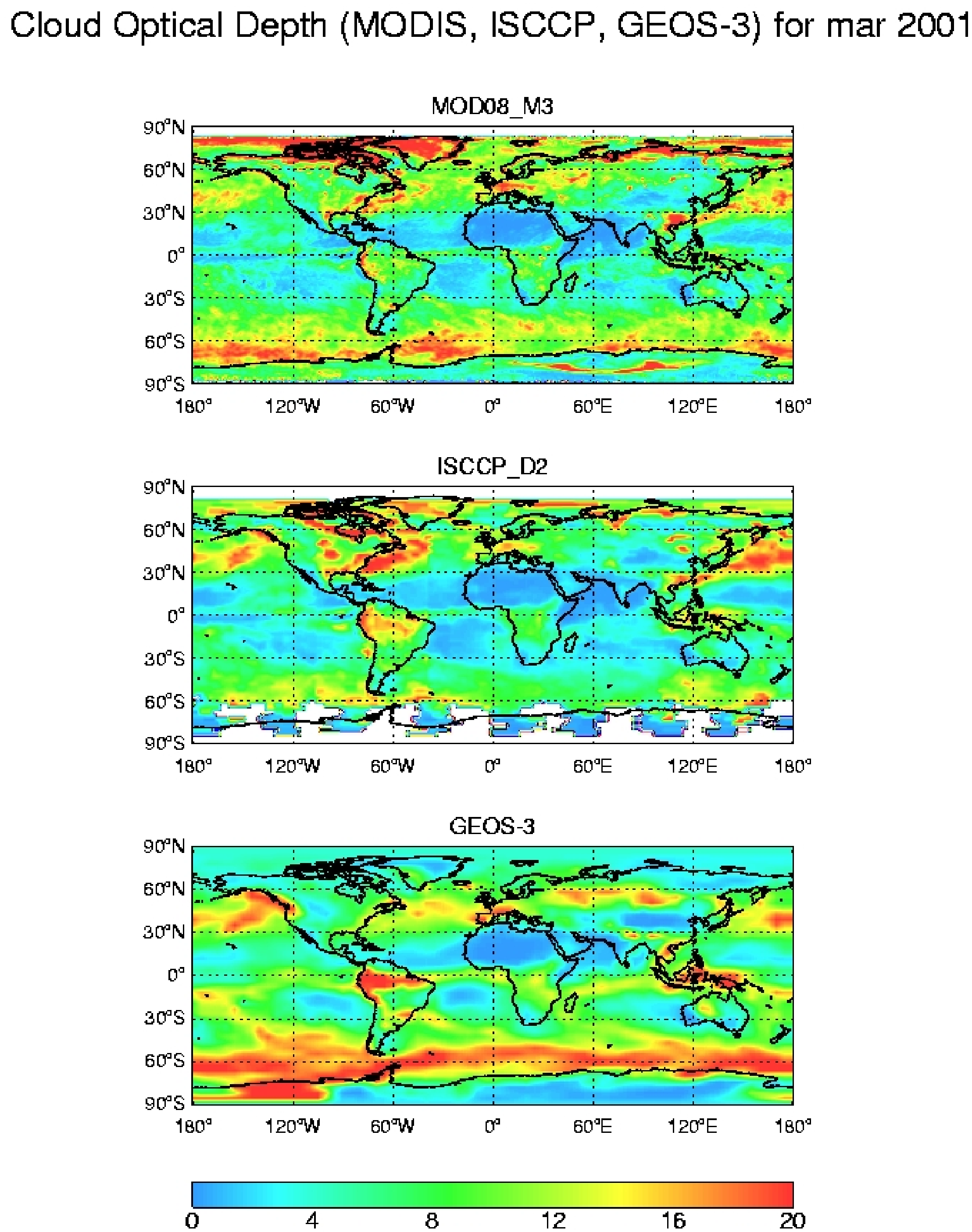

Figure 3. The global distribution of GEOS3 monthly mean (grid-scale) cloud optical depths (bottom panel) is compared to ISCCP (D2, 280km equal-area grid, middle panel) and MODIS (MOD08_M3, level-3 monthly global product at $1^o x 1^o$ resolution, top panel) retrievals for March 2001. See text for details.

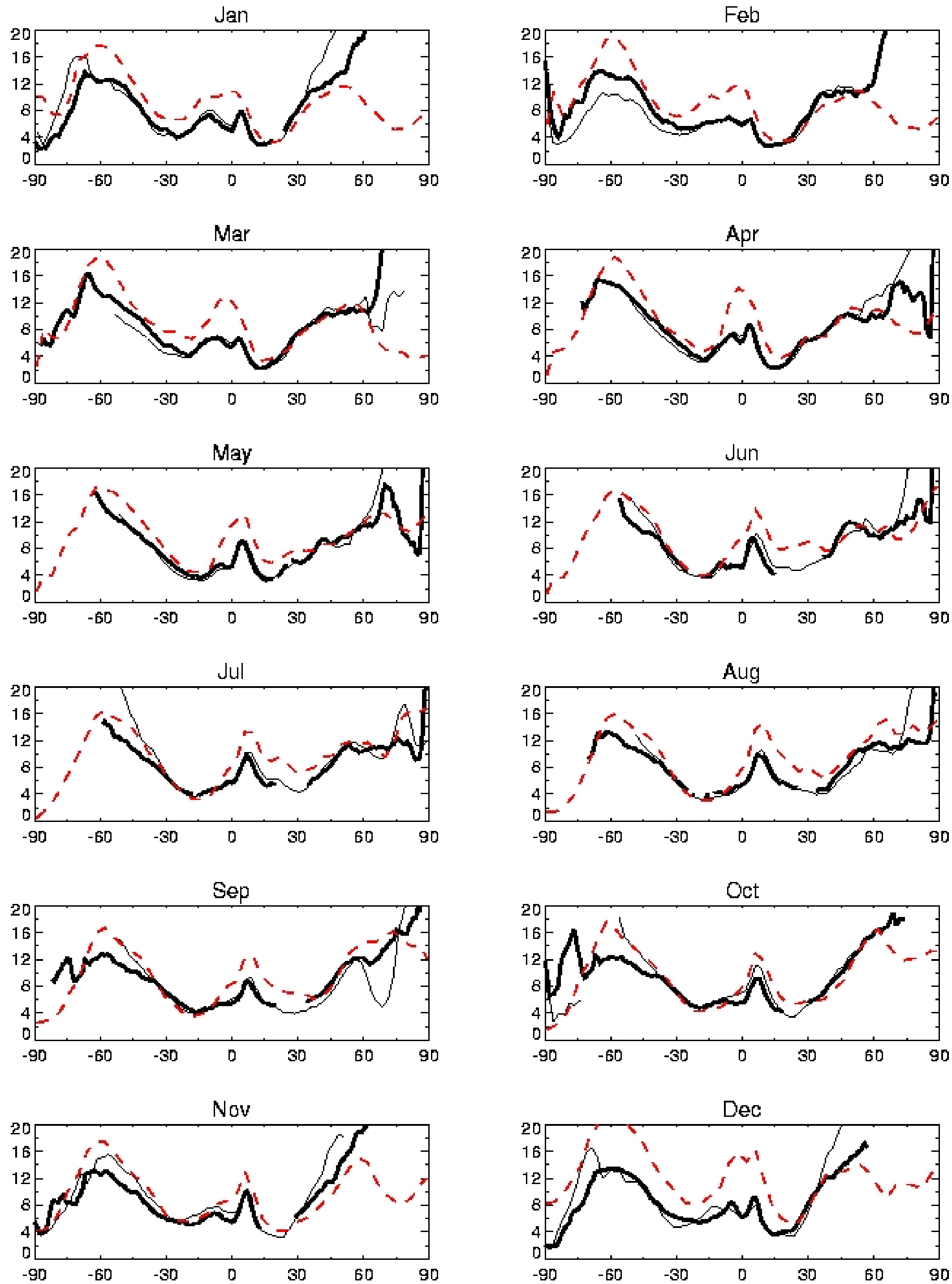

Figure 4. Same as Figure 3, but shown as zonal mean plots for all months of 2001. MODIS, ISCCP, GEOS3 cloud optical depths are thick, thin, and dashed lines, respectively. ISCCP values for Oct-Dec are from the year of 2000. See text for details.

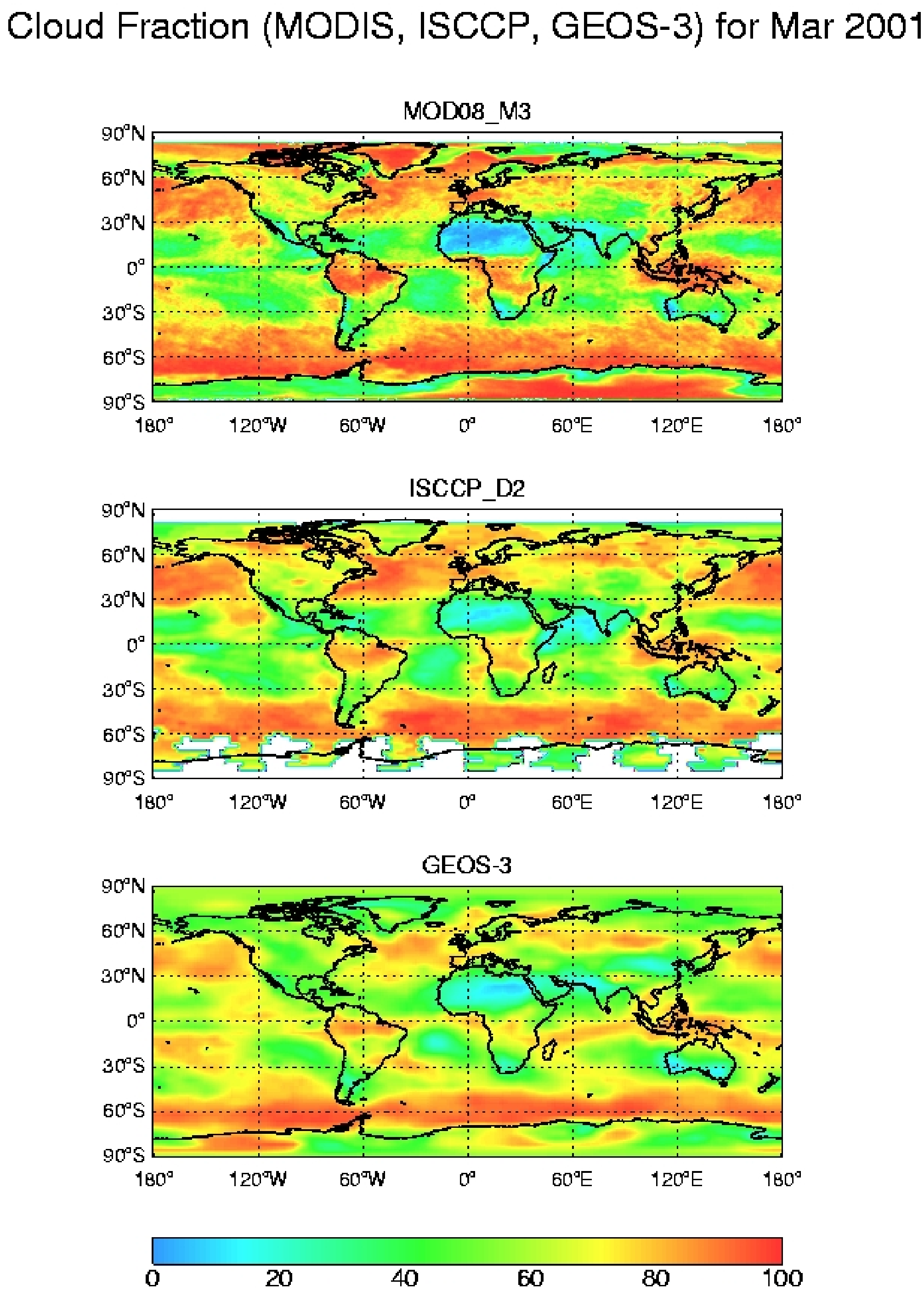

Figure 5. Same as Figure 3, but for monthly mean cloud fraction.

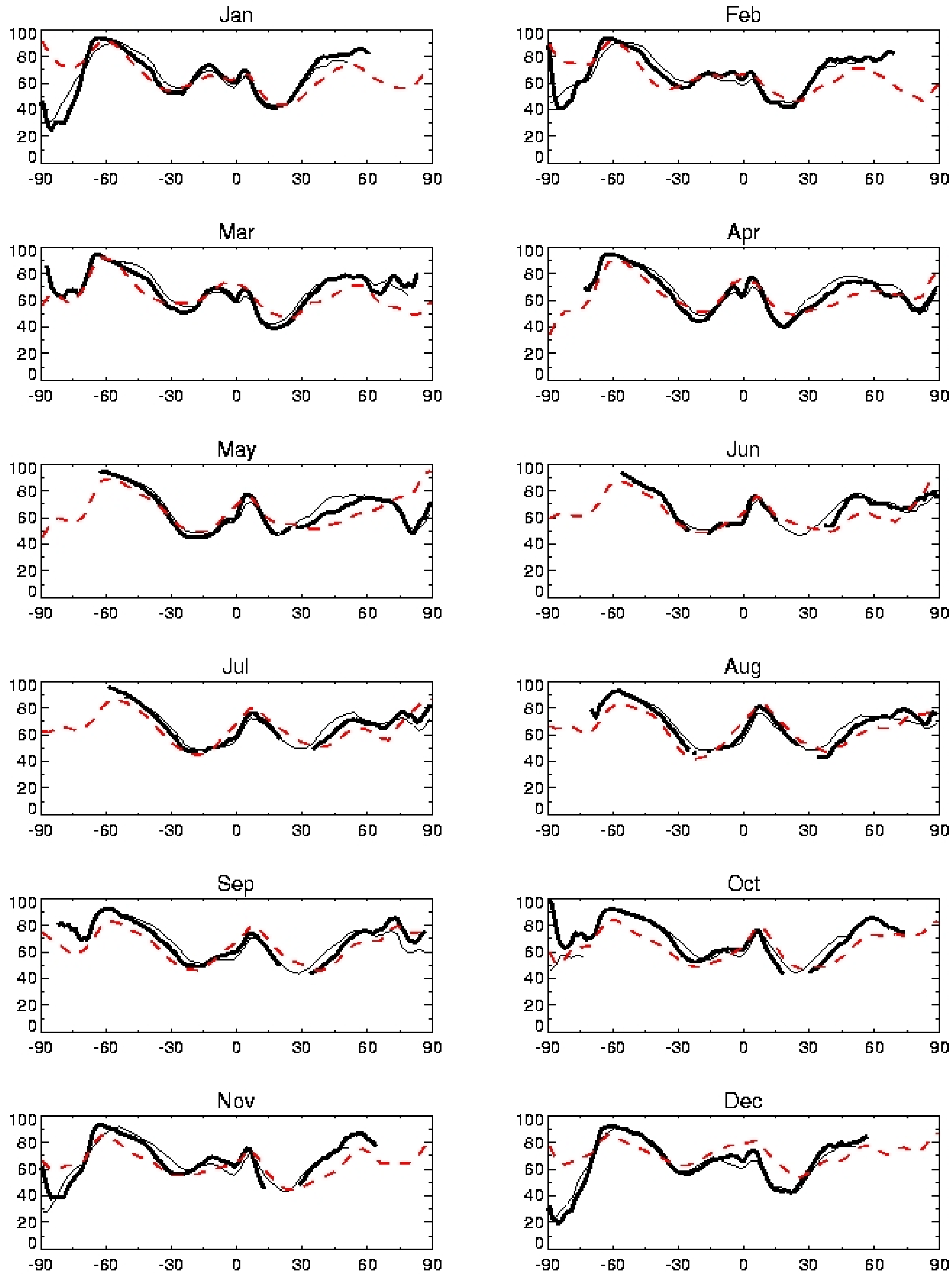

Figure 6. Same as Figure 4, but for monthly mean cloud fraction. MODIS, ISCCP, GEOS3 cloud optical depths are thick, thin, and dashed lines, respectively. ISCCP values for Oct-Dec are from the year of 2000.