Cloud variability and depiction in analyses and observations

Progress Report 2003

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Introduction

Clouds strongly modulate the gain and loss of energy at the surface, which in turn affect the surface fluxes of sensible and latent heat. Thus an accurate depiction of clouds is central to the ability to understand the energy balance at the surface. This study attempts to explore differences in the depiction of clouds in observations and analyses, and assess how these differences may impact the surface energy balance over the United States. We investigate the geographical distribution of these cloud impacts in the time-mean, and in the annual cycle.

Project Goals

An overall goal of this project is to attempt to quantify the effects of clouds on the surface radiation budget over the GAPP region. This goal will be achieved through the use of a quantity known as the surface cloud forcing (Charlock and Ramanathan, 1985), which is based on the downward and upward radiative fluxes under clear and cloudy conditions. The surface cloud forcing represents the radiative effects of clouds at the surface. The observed shortwave, longwave, and total surface cloud forcing are determined from satellite observations. The spatial and temporal patterns of the surface cloud forcing will be related to cloud properties and distribution. Further, the observed surface cloud forcing and cloud distribution will be compared to those from a global analysis.

Method

We have obtained a surface radiation budget (SRB) data set produced by NASA (Gupta et al., 1993) that contains surface cloud shortwave, longwave, and total cloud radiative forcing based upon analysis on the cloud observations in International Cloud Climatology Project

(ISCCP) C1 data set (Rossow, 1991) and parameterized radiation models (Darnell et al., 1988; Darnell et al., 1992; Gupta et al., 1992). This data set contains monthly values of surface cloud forcing, total ISCCP C1 cloud amounts, and TOVS water vapor burden for the 8-year period July 1983 to June 1991.

The cloud radiative forcing is defined as the difference between surface radiative fluxes under all-sky and clear-sky conditions. Its shortwave (SW) component may therefore be defined as:

$$CF(S)_{SW} = F(S)_{SW} - F(S)_{SW}^{cl}$$

and the longwave (LW) component as:

$$CF(S)_{lw} = F(S)_{lw} - F(S)_{lw}^{cl}$$

where $F(S)_{SW}$ and $F(S)_{lw}$ are the SW and LW all-sky net radiative fluxes at the surface, and $F(S)_{SW}^{cl}$ and $F(S)_{lw}^{cl}$ are the corresponding clear-sky quantities. The total CF at the surface can be written as the sum of the SW and LW components:

$$CF(S) = CF(S)_{SW} + CF(S)_{lw}$$

We have also obtained total cloud amount and surface cloud forcing from the NCEP/NCAR reanalysis for comparison with those derived from satellite data. We have computed long-term mean shortwave, longwave, and total surface cloud forcing from the NASA SRB and NCEP/NCAR data sets. To show the annual cycle of surface cloud radiative forcing, we create monthly means of all Januarys, Februarys, etc. in the eight year period. We then compute annual harmonics based on the monthly mean data. We have also computed long-term means and harmonics of meteorological parameters that affect surface cloud forcing, such as cloud optical thickness, cloud amount, and atmospheric water vapor.

Results and Accomplishments

A. Time-mean surface cloud forcing

Figure 1 shows the mean total cloud amount for the ISCCP C1 data for the 8-year period July 1983 to June 1991. The cloud amounts are greater over the oceans than over the continent, with greatest values in the storm tracks off the East and West coasts. Over the land, there is a minimum of cloud amount over the southwestern United States, and maximums of cloud amount over the northern Great Plains and the over the Northeastern US. In general, there is more cloudiness in the eastern and northern portions of the US than the southern and western portions.

Figure 2a shows the time mean NASA SRB shortwave surface cloud radiative forcing for the period July 1983 to June 1991. In all discussions of surface cloud forcing, the terms "greatest" and "smallest" refer to magnitude of the terms. The geographical distribution of the shortwave surface cloud forcing in the NASA SRB data is sensitive to cloud amount and cloud opacity, available insolation, and surface albedo. From Figure 2a, the shortwave surface cloud forcing is negative everywhere, indicating that the effect of clouds in the shortwave is to cool the surface. The shortwave surface cloud forcing is greatest over the oceans, due to the lower surface albedo and higher cloud amount in this region. Figure 2b provides the optical thickness from ISCCP C2 data, which is a measure of the opacity of clouds in the time-mean. The smallest values of cloud optical thickness extend into the southern portion of California, in a region of the lowest cloud amount and low shortwave surface cloud forcing. East of the Mississippi River, greater cloudiness and optical thicknesses combine to create a region of large shortwave surface cloud forcing.

The longwave surface cloud forcing (Fig. 3) shows positive values everywhere, representing a warming effect of clouds on the surface in the longwave, although the magnitude of the longwave surface cloud forcing is less than the shortwave forcing except over the southwestern United States where the magnitudes are comparable. The distribution of the longwave surface cloud forcing in the NASA SRB data is influenced by cloud amount, cloud-base height, water vapor burden in the atmosphere, and to a lesser extent surface temperature. The longwave forcing is greatest over the oceans in regions of persistent low stratus clouds off the west coast of the United States and in the storm tracks off the East Coast. Over the continent, the largest positive values are over the northern Great Plains, in a region of relatively large cloud amounts. Lower values of longwave surface cloud forcing exist over the southwestern United States, in a region of relatively low cloud amounts. Low values of longwave surface cloud forcing also exist immediately east of the Mississippi in a region of relatively low cloud amount.

The total surface cloud forcing (Fig. 4), which is the sum of the shortwave and longwave surface cloud forcing, shows negative values almost everywhere over the US, indicating that clouds tend to cool the surface in the time-mean. The largest negative values, and hence the most cooling, are over the eastern US, while a region of weak warming exists over the southern portion of California. In general, cooling of the surface by clouds is greater east of the Mississippi River than west of the River, and this distribution is a result of large surface cooling in the shortwave by clouds.

B. Comparison with NCEP/NCAR reanalysis

Figure 5 shows the total cloud amount for the NCEP/NCAR data. Across the entire domain, the cloud amount in the NCEP/NCAR data is generally less than in the ISCCP data. Regionally, the total cloud is a maximum over the oceans, as in the ISCCP data, although the cloud amounts are generally less. There is a minimum of cloud amount over the southwestern United States, as in the ISCCP data, and a second minimum over the central United States. This second minimum over the central US does not exist in the ISCCP data. The maximum shown in the northern Great Plains in the ISCCP data is also not apparent in the NCEP/NCAR data.

Figure 6a shows long term mean shortwave surface cloud radiative forcing from the NCEP/NCAR data for the 8-year period July 1983 to June 1991. The shortwave forcing is everywhere negative, indicating that clouds tend to cool the surface in the shortwave in the NCEP/NCAR reanalysis. The large values in the storm track off of the East Coast are not as well defined as in the NASA SRB data, and the large values off the western coast of Mexico are greater than in the NASA SRB data. The values of shortwave surface cloud forcing in the Gulf of Mexico are larger than in the NASA SRB data. Over the land, the smallest negative values are located over the southwestern US and extend into southern California, with values that are similar to the NASA SRB data. In a region that extends from the northern Plains to the eastern US, however, NCEP/NCAR values are smaller than NASA, indicating less cooling by clouds in this broad region. This region of smaller shortwave surface cloud forcing in the NCEP/NCAR reanalysis may be related to generally lower cloud amounts over this region in the NCEP/NCAR data.

The NCEP/NCAR surface longwave forcing (Fig. 6b) shows positive values everywhere, indicating that cloud tend to warm the surface in the longwave in the NCEP/NCAR data. Over the entire region, the values of longwave surface cloud forcing are generally less than in the NASA SRB data set. Regionally, the largest values of longwave surface cloud forcing are off the western coast of Mexico and in the storm track off the East Coast, similar in location to the NASA SRB data but with smaller magnitudes. Over the land, the smallest values are over extreme southern California, which agrees with the NASA SRB data set. A relative minimum extends from Texas into the central portion of the US that is not present in the NASA SRB data set. This discrepancy in the longwave surface cloud forcing may be related to lower cloud amounts over the central US shown in the NCEP/NCAR reanalysis.

The NCEP/NCAR total surface cloud forcing (Fig. 6c) is mostly negative, with small positive values in the vicinity of the Great Salt Lake. Hence clouds tend to cool the surface in NCEP/NCAR as in the NASA SRB data. The greatest values are over off the west coast of Mexico, and over the Gulf of Mexico. These locations are in contrast to the NASA SRB data set, where the largest values are over the Eastern US. The larger shortwave surface cloud forcing over the Eastern US in the NASA SRB data is primarily responsible for this difference in the total surface cloud forcing. This difference gives the impression of more east-west contrast of total surface cloud forcing in the NASA data, whereas the NCEP data has more of a north-south contrast in total surface cloud forcing.

C. Annual Variations

To indicate the annual cycle of the cloudiness and ultimately its impact on the surface cloud forcing, the first harmonic of total cloud amount is shown in Fig. 7. The amplitude of the second harmonic is considerably less than the first harmonic, except over the Sierra Madres, where there is a considerable semi-annual of equal magnitude to the annual component. Therefore, the second component will not be shown. Moving from east to west across the US, cloud amount exhibits a late winter maximum across the eastern US, a spring maximum across the central US, an early summer maximum over the southwestern US, and a late winter maximum across the west coast and northwestern United States.

To indicate the annual cycle of the surface cloud forcing, Figs. 8 and 9a show the first harmonic of the NASA SRB data for the shortwave and longwave surface cloud forcing. Higher harmonics were calculated, but contained little amplitude, and so are not discussed. The amplitude of the shortwave surface cloud forcing (Fig. 8) increases in a poleward direction indicating the impact of the greater annual variance in solar zenith angle (and hence insolation) in the northern latitudes. The tendency for the poleward-directed vectors across the domain indicates that the greatest shortwave surface cloud forcing occurs in the summer months over almost the entire US.

Fig. 9a shows the first harmonic for the longwave surface cloud forcing. The amplitude of the longwave forcing is less than the shortwave forcing by about a factor of two. There are two regions of maximum amplitude; one over the south-central United States and one off the East coast. Both exhibit a late winter maximum. Figure 9b shows the first harmonic of the water vapor burden. Water vapor burden tends to be a maximum in summer months over the entire region, as warm air temperatures prevail. There is a region of maximum amplitude over the south-central United States, which implies a marked minimum in water vapor burden in the wintertime. This region also corresponds to a marked maximum in cloudiness in the wintertime (Fig. 7). The combination of high cloud amounts and low water vapor burdens in the winter months may explain the maximum in longwave surface cloud forcing over this region in the winter. Off the East Coast, the pattern shown in the first harmonic of the longwave surface cloud forcing may be explained in part by the maximum in cloudiness over this region in winter (Fig. 7). The first harmonic of the total surface cloud forcing at the surface is dominated by the patterns contained in the shortwave surface cloud forcing, and so will not be shown.

Future Work

We will continue to investigate causes for the differences between surface cloud forcing in the NASA SRB and the NCEP/NCAR data. A focus for these differences will be discrepancies in cloud amount and properties. We will look for a reflection of the time-mean and annual cycle of surface cloud forcing in the shortwave and longwave radiative surface fluxes shown in the satellite measurements in surface observations.

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