RECENT TRENDS IN CLOUDINESS OVER THE UNITED STATES

A Tale of Monitoring Inadequacies

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Despite large inadequacies in monitoring long-term changes in global cloudiness with surface and satellite observations, data from a small network of military stations suggest an increasing trend in U.S. total cloud cover from 1976 to 2004.

From space, Earth is a blue planet marked by stark white cloud structures that distinguish it from other planets. By reflecting sunlight, blocking outgoing longwave radiation, and producing precipitation, clouds have an enormous impact on Earth's weather and climate. The single largest source of uncertainty in global climate models has always been the response of clouds, especially low clouds, to climate change (Houghton et al. 2001), and it is still a challenge to simulate the observed climatologies of clouds in models (e.g., Dai and Trenberth 2004). It is therefore important to monitor changes in Earth's cloud cover and other properties, such as their vertical structures (Wang et al. 2000) and optical thickness.

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Traditionally, clouds have been observed visually by trained technicians at weather stations and onboard ships around the world (often in units of eighths, or oktas), following the general rules outlined by the World Meteorological Organization (WMO: 1975). These cloud data, together with other synoptic observations, are transmitted through the Global Telecommunication System (GTS) in real time to weather centers around the world. In the United States, the National Oceanic and Atmospheric Administration's (NOAA's) National Centers for Environmental Prediction (NCEP) receive and process the real-time GTS data, which are then archived at the National Center for Atmospheric Research (NCAR) and at NOAA's National Climatic Data Center (NCDC). Many countries, such as the United States, also build their own national archives of weather and climate using the data collected from national stations.

Individual visual observations of clouds by trained humans are subjective measures of sky cover (albeit following WMO guidelines) with large uncertainties that may vary from one observer to another. Although averaging over large samples may reduce the errors greatly, systematic changes in observational practice [e.g., from 1/10 to 1/8 units; see Henderson-Sellers (1992) and Sun et al. (2001) for more details] may induce inhomogeneities in surface cloud data, as found by Karl and Steurer (1990) for the U.S. cloud record before about 1948. Furthermore, mean cloud amount from surface observations may be biased compared with other observations (e.g., from space), and sparsely distributed stations may induce large sampling errors for regional estimates. For long-term change analyses, continuity and homogeneity of the record are most important, whereas the systematic biases may only affect the magnitude of the trends slightly. Because of the subjective nature and potential inhomogeneities associated with major changes in observational practices (usually before the 1950s), long-term changes in surface cloud records are treated cautiously and require validation with other records of physically related but independently measured variables, such as surface sunshine and diurnal temperature range (DTR) (e.g., Karl and Steurer 1990; Dai et al. 1999).

Despite the problems, the surface cloud observations have provided the only historical record for establishing long-term cloud climatologies (Warren et al. 1986, 1988; Hahn and Warren 1999), evaluating satellite cloud observations (e.g., Rossow and Schiffer 1999), and analyzing decadal and long-term changes in cloud cover during the last 100 yr or so. Many analyses of these cloudiness records suggest increased total cloud cover from ~1950 to ~1980 over the United States (Karl and Steurer 1990; Sun 2003; Groisman et al. 2004), the former United Soviet Socialist Republic (USSR) (Sun and Groisman 2000; Sun et al. 2001), Western Europe, midlatitude Canada, and Australia (Henderson-Sellers 1992). These trends in cloudiness are physically consistent with trends in precipitation and DTR (Dai et al. 1997, 1999) and a reduction in surface solar radiation (Liepert 2002). On the other hand, decreasing cloudiness over China during 1951–94 (Kaiser 1998, 2000) and over the United States (mostly in low-level clouds) since the 1980s (Sun 2003; Sun and Groisman 2004) has been reported. Over the oceans, the surface observations suggest that both total and low cloud amounts increased by 1.9%–3.6% of the sky cover from 1952 to 1995 (Norris 1999). The surface observations have also been analyzed to document changes in cirrus clouds (Minnis et al. 2004), and low-, mid-, and upper-level cloud cover (Norris 2005), and it is found that upper-level cloud cover may have declined by 1.5% (of sky cover) over global land from 1971 to 1996. In summary, in spite of the shortcomings, surface cloud observations have proven very useful.

The total cloud cover from 1976 to 2004, derived from synoptic cloud reports averaged over global land areas, excluding the United States and Canada, is significantly correlated (correlation coefficient $r = 0.50$, attained significance level $p = 0.03$) with areal averages of independent rain gauge records of precipitation over the same areas (Fig. 1), as one

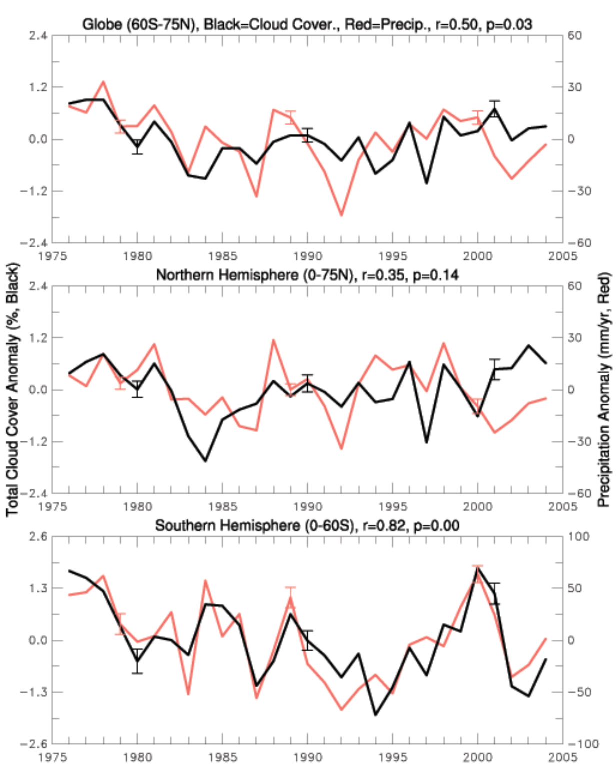

Fig. 1. Comparison of annual total cloud cover (black) and precipitation (red) averaged over the same land areas of the globe (60°S–75°N), Northern Hemisphere (0°–75°N), and Southern Hemisphere (0°–60°S), excluding the United States and Canada (because of the ASOS-induced discontinuity over these two countries). The cloud cover was derived using surface observations from over 15,000 weather stations (the GTS data archived at NCAR, see information online at http://dss.ucar.edu/datasets/ds464.0/). The station data were first arithmetically averaged within each 1° × 1° box and then the 1° anomalies were further averaged onto a 4° lat × 5° lon grid, on which the regional mean was derived using area-weighted averaging. Precipitation data are from Chen et al. (2002 and updates). The error bars represent ± one standard error estimated using the inter-grid-box variations.

would expect from the physical association between clouds and precipitation. The correlation is substantially stronger in the ocean-dominated Southern Hemisphere ($r = 0.82$, $p = 0.00$) than in the Northern Hemisphere ($r = 0.35$, $p = 0.14$). This may be partly related to the more complex terrain and larger land–sea contrasts in the Northern Hemisphere than the Southern Hemisphere, because mountains greatly affect precipitation. Obviously, many clouds do not precipitate. Nevertheless, Fig. 1 further suggests that the synoptic cloud observations are useful for studying decadal and long-term changes in Earth's cloudiness.

AUTOMATED SURFACE OBSERVATIONS.

Since the early 1990s, Automated Surface Observation Systems (ASOS)[1] have started to replace manned weather stations in North America and other parts of the world (Hahn and Warren 1999) as part of the effort to modernize the instruments and to reduce cost. Hence, the number of human observations of cloud amount and types has been declining, most drastically in North America (Fig. 2). This has occurred despite the early warning by the atmospheric scientific community that the ASOS would disrupt cloud records from surface observations (Warren et al. 1991) and the fact that visual cloud observations had already been used by the early 1990s in a number of studies to document long-term changes in cloudiness (see Karl and Steurer 1990; Henderson-Sellers 1992, and references therein; Houghton et al. 2001). Cloud reports over many ocean areas have been inadequate, and they also have been declining steadily in numbers since the late 1980s (Fig. 2). The spatial sampling of total cloud cover by human observations has become poor since the early 1990s over North America (Fig. 3), especially in the western United States and Canada, compared with earlier years and other regions in the Northern Hemisphere (e.g., most of Eurasia).

The switch to the ASOS from manned stations in the United States was accompanied by a U.S. policy change in 1995 that released the National Weather Service (NWS) from providing specialized weather information for individual agencies, such as the aviation weather needs of the Federal Aviation Administration (FAA). Since then, operations of a large number of weather stations at or near airports have been transferred from the NWS to the FAA, and both the NWS and the FAA have now completed the installation of the ASOS. Currently, FAA and NWS jointly operate about 1590 stations, of which only 82 stations are augmented with human observations

[1] Here we use ASOS to also include the Automated Weather Observation System (AWOS) used in the United States.

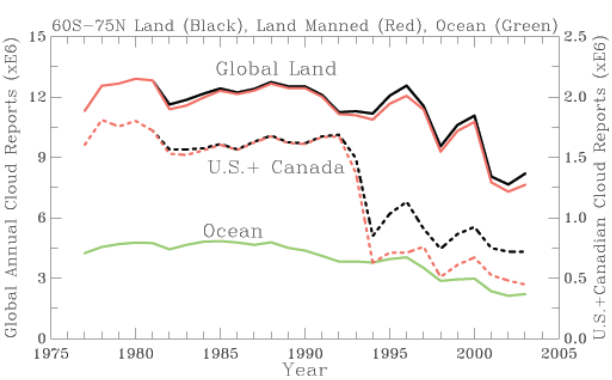

FIG. 2. Annual number of reports of total cloud cover from manned (red) and automated plus manned (black) stations from global land (upper curves), the United States and Canada (middle dashed curves, scales on the right side) (from the GTS data archived at NCAR, see information online at http://dss.ucar.edu/datasets/ds464.0/), and global oceans [green, all reports, from the International Comprehensive Ocean–Atmosphere Data Set (ICOADS) information online at www.cdc.noaa.gov/coads/]. Units: millions.

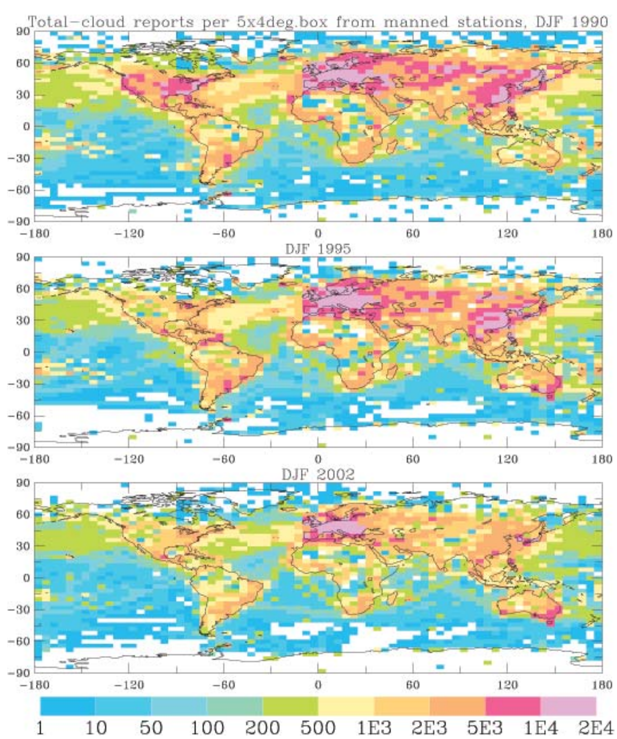

FIG. 3. Spatial distributions of the number of reports of total cloud cover per each 4° lat × 5° lon box from manned stations during December–February in (top) 1990, (middle) 1995, and (bottom) 2002. See Fig. 2 for data sources.

of cloud layers above 12,000 ft and cloud-type information, but not total and low cloud amount (FAA 2003). In addition, the U.S. military maintains human observers at its ~130 weather stations (of which 124 are within the contiguous United States), whose weather reports are included in the NCDC Integrated Surface Hourly Database (Lott et al. 2001). These human observations of cloud amount are reported in the following five categories for each layer: clear (0), few (1/8–2/8), scattered 3/8–4/8), broken (5/8–7/8), and overcast (8/8) (see OFCM 1995 for more details). The NOAA cooperative observing stations are staffed with voluntary human observers, but they do not provide cloud observations.

The ASOS was designed specifically to support aviation and forecast needs (NWS 1998), not climate monitoring. The instrumental changes associated with the installation of the ASOS has introduced discontinuities in precipitation (negative biases), air temperatures (cooler, especially for maximum temperatures), and winds (slightly lower) (Guttman and Baker 1996; Lin et al. 2001; Doesken et al. 2002), whereas the biases due to changes in siting and local environments can be either positive or negative (Guttman and Baker 1996; Sun et al. 2005). These discontinuities are difficult to quantify and are often not removed in climate datasets derived from the NWS/FAA ASOS stations. Thus, they present a major difficulty for analyses of recent climate changes in North America. For cloud observations, the changes induced by the ASOS are so drastic that the ASOS no longer observes the same cloud variables as before. It uses a vertically pointed laser beam ceilometer to sample overhead sky conditions in a small vertical column of air (up to 12,000 ft, or ~3600 m; the sensors of the Canadian Automated Weather Observation Systems measure clouds up to about 3.8 km, see information online at www.msc-smc.ec.gc.ca/msb/manuals/awos/chap1_e.html#126_e) at 30-s intervals, and then averages these data over the most recent 30 min to derive the time-averaged cloud amount based on the number of "cloud hits" out of total hits possible (NWS 1998); this is in contrast to human observations, which are "snapshots" of cloud conditions from horizon to horizon, not just overhead, in the whole atmospheric column. This sampling difference is illustrated by the following example. Suppose the sky dome was covered only by 1 okta of clouds right above a station and they stayed there for the 30 min when the ASOS ceilometer scanned. The ASOS would report 100% hits of clouds (i.e., 100% cloud cover), while a human observer would correctly report 1-okta cloud amount. In addition to the sampling difference, ASOS ceilometers also tend to miss some scattered cumulus (NWS 1998; Sun and Groisman 2004) and they do not provide cloud-type information. Because of these limitations, the cloud reports from the NWS and FAA weather stations since around 1995 are inadequate for monitoring atmospheric cloudiness and, as shown below, are not comparable with prior records of human observations.

Figure 4 compares the daytime total cloud cover from three NWS/FAA stations and nearby U.S. miliary stations. It clearly shows the discontinuities induced by the introduction of the ASOS at the NWS/FAA stations around the mid-1990s. The large drop in the ASOS cloudiness data occurs because the ASOS measures only overhead clouds below ~3.6 km. Figure 4 also shows that the total cloud cover made by human observers at a nearest military station (cf. Fig. 8a) is highly correlated with the NWS station data before the mid- 1990s and does not contain spurious changes.

A possible application of the ASOS cloud observations is to derive low-level cloud cover (Sun and

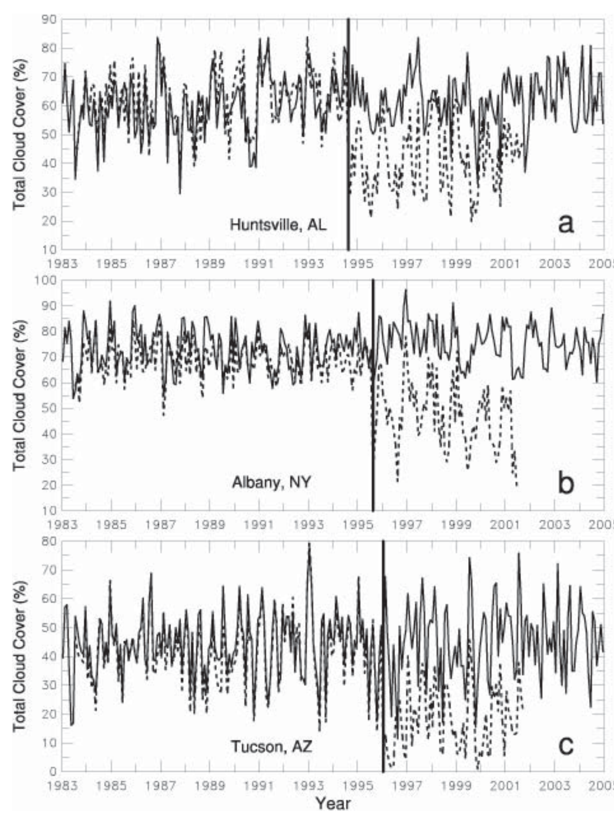

Fig. 4. Time series of monthly mean daytime total cloud cover (dashed line) from three NWS/FAA stations at (a) Huntsville, AL, (b) Albany, NY, and (c) Tucson, AZ. The vertical line indicates the time when the ASOS was introduced. Also shown are human visual observations of daytime total cloud cover from a closest military weather station (solid line).

Groisman 2004; Sun and Bradley 2004). Indeed, the discontinuity in U.S. low cloud cover is relatively small (e.g., due to scattered cumulus clouds missed by the ASOS and the differences in the spatial and temporal sampling between the ASOS and a human observer) (Fig. 5), and it may be bridged through the use of the frequency of overcast or broken cloudiness that is captured by the ASOS (Sun and Groisman 2004). In order for the ASOS cloud data to be useful for long-term climate monitoring, however, it seems that improvements to the ASOS ceilometer's horizontal sampling and more calibrations and comparisons (e.g., with nearby human observations) are needed.

The cloud data from the relatively small number of U.S. military weather stations seem to be useful in estimating total cloud cover over the contiguous United States since the early 1990s (see below), thus diminishing the disruption by the ASOS. However, the U.S. military stations use a different code system that does not contain cloud-type information (although it contains cloud-base height and amount for each layer). Hence, more detailed cloud information, such as cloud-type frequency (Warren et al. 1986, 1988; Norris 2005), cannot be derived from the military weather reports. Furthermore, the military stations do not cover many regions in the western and other parts of the country and thus are inadequate for many regional analyses, although, as shown below, they may have been able to capture the main features in the contiguous U.S. mean cloud cover during the last 20–30 yr.

Therefore, the historical records of total cloud amount and cloud type from many weather stations over North America accumulated during the entire twentieth century have been significantly degraded for climate change analyses over the region. The U.S. military weather reports do, however, provide useful information for total cloud cover over the contiguous United States. The continued decline in marine cloud reports (Fig. 2) raises another concern.

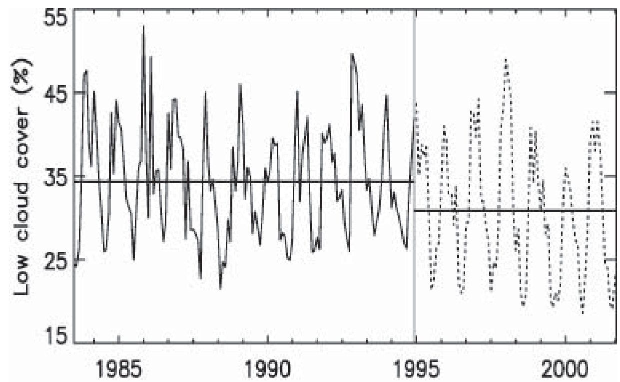

Fig. 5. Monthly time series of daytime low cloud cover (with cloud-base height below 2 km) over the contiguous United States from surface visual (black solid line) and ASOS (dashed line) observations (see Sun and Groisman 2004 for more details about the data). The mean for the visual and ASOS observations are 34.4% and 30.9%, respectively, as indicated by the horizontal lines.

SATELLITE CLOUD DATA. Since the 1980s, satellite radiance and other data have been used to retrieve cloud amount, type, and optical thickness on a global scale. Compared with surface observations, these satellite data have many advantages, such as improved temporal and spatial sampling, especially over the open oceans where surface observations are sparse. Examples of satellite cloud datasets include the widely used International Satellite Cloud Climatology Project (ISCCP) cloud products (Rossow and Schiffer 1999) and the High Resolution Infrared Radiation Sounder (HIRS) cloud dataset (Wylie et al. 2005). The ISCCP cloud data were originally produced mainly for studying short-term variations, but they have been increasingly used in climate studies (e.g., Rozendaal et al. 1995; Sun 2003; Dai and Trenberth 2004; Wylie et al. 2005) as the record length increases. The ISCCP and other satellite cloud data have provided invaluable information about clouds' spatial, seasonal, and interannual variations. Because of the varying nature of satellite observations (e.g., short lifetime of individual satellites and slowly changing orbits), long-term satellite data often contain spurious changes resulting from satellite changes and progressive changes in orbit and instrumental parameters during the lifetime (~several years) of individual satellites (Trenberth 2002; Jacobowitz et al. 2003). Considerable efforts (e.g., Rossow and Schiffer 1999) have been devoted to minimize spurious changes in long records of satellite cloud data due to calibration problems (Klein and Hartmann 1993). However, long-term homogeneity still remains a challenge in many satellite cloud products.

Figure 6 (also see Rossow and Duenas 2004 for global monthly time series) shows that there are large decreases in the ISCCP total cloud amount from 1984 to 2000, especially at low latitudes where the striping and discontinuities in the change patterns look suspicious. Although surface and satellite observations of cloud cover are not fully comparable quantitatively because of their differences in the view angle and detection method (e.g., for thin cirrus), it is worrisome that even the sign of the trends (which are large) in the surface and satellite cloud data differs completely for tropical (Fig. 6b) and

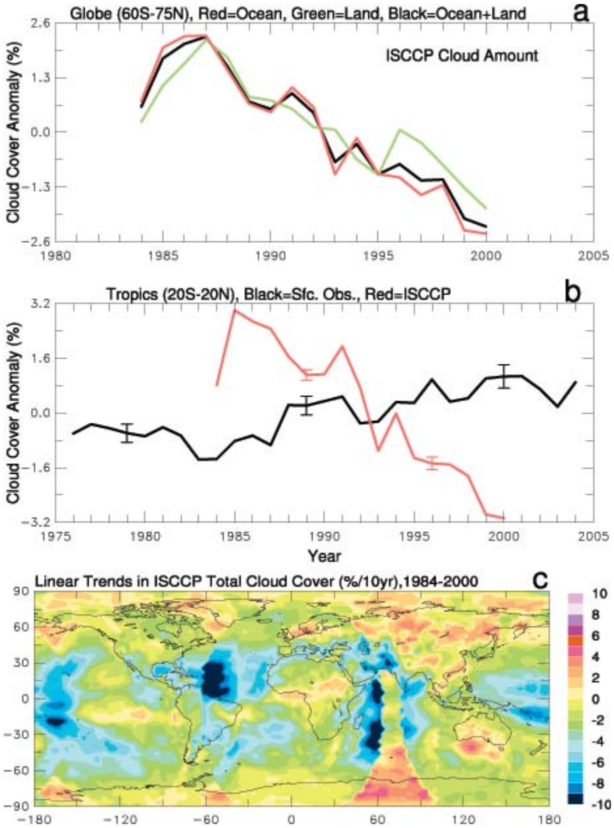

FIG. 6. (a) Time series of ISCCP D2 annual total cloud cover averaged over global (60°S–75°N, as in Fig. 1) land (green), ocean (red), and land plus ocean (black) areas from 1984 to 2000. (b) Total cloud cover averaged over the whole Tropics (20°S–20°N) from surface observations (black line, see Fig. 1 for details) and ISCCP D2 cloud data (red line). The error bars represent ± one standard error estimated using the inter-grid-box variations. (c) Spatial distributions of the linear trend (percent sky cover per decade) in the ISCCP D2 total cloud cover during 1984–2000.

U.S. cloud cover (cf. Fig. 6c and Fig. 8 below). Both the surface and satellite estimates in Fig. 6b likely contain large uncertainties. For example, Rossow and Schiffer (1999) suggest that the ISCCP cloud amount data have an error of 3%–5% (of the sky) outside the polar regions based on comparisons with surface cloud observations and other data. We do not have reliable estimates of the absolute error bars for the surface observations; the standard error bars in Fig. 6b represent mostly sampling errors, which are relatively large in the Tropics because of the sparse sampling there (cf. Fig. 3). A new comparison between the trends of occurrence frequency of total and high clouds from the ISCCP and HIRS datasets (Wylie et al. 2005) also revealed contrasting trends, with the HIRS data showing no change or small increases from 1985 to 2001 in total and high clouds over most of the globe, including the Tropics. The fact that these different cloud datasets show contrasting changes during the recent decades further demonstrates the inadequacies in existing cloud observations.

Recent analyses by Campbell (2004), and Campbell (2005, personal communication) suggest that the ISCCP cloud trend may result partly from an artifact of changes in satellite view angles (as more geosynchronous satellites have been added to the ISCCP cloud analysis), because the current ISCCP data are not corrected for limb brightening, and from discontinuities associated with changes in satellites. Additional studies are needed to quantify the potential discontinuities in the ISCCP and other satellite cloud records. It is desirable to further improve the homogeneity of the ISCCP cloud data through reprocessing of the satellite data with enhanced algorithms to handle the discontinuities associated with changes in satellite, satellite orbits, limb brightening, and discrepancies among overlapping satellites and sensors.

RECENT CHANGES IN U.S. CLOUDINESS AND DTR. Upward trends of total cloud cover from the late 1970s to 2004 are seen at many of the 124 military stations within the contiguous United States that have continuous human observations. Three examples from Grand Forks, North Dakota, Oklahoma City, Oklahoma, and a station near Cape Canaveral, Florida (Fig. 7), show increasing trends of 1.9%–2.7% (of sky cover) per decade, which are statistically significant ($p < 0.5\%$). Although it is difficult to derive error bars for the station cloud time series, the increasing cloudiness is physically consistent with the decreasing DTR at nearby stations (Fig. 7), because clouds block sunlight and reduce daytime maximum temperatures, which is the dominant effect on DTR, as shown by Dai et al. (1999). Other factors such as soil moisture and precipitation have only secondary effects on DTR, while water vapor and longwave radiative effects of clouds increase both daytime and nighttime temperatures and thus have only small effects on DTR (Dai et al. 1999).

Figure 8 shows the spatial distribution of the linear trend of daytime cloud cover during 1976–2004 derived using the military station data and anomaly time series of area-averaged daytime total cloud cover over the contiguous United States, as sampled by the military stations (black line in Fig. 8b) and all available weather stations (from 1976 to 1993 only, red line). Plots for daily mean cloud cover (not shown)

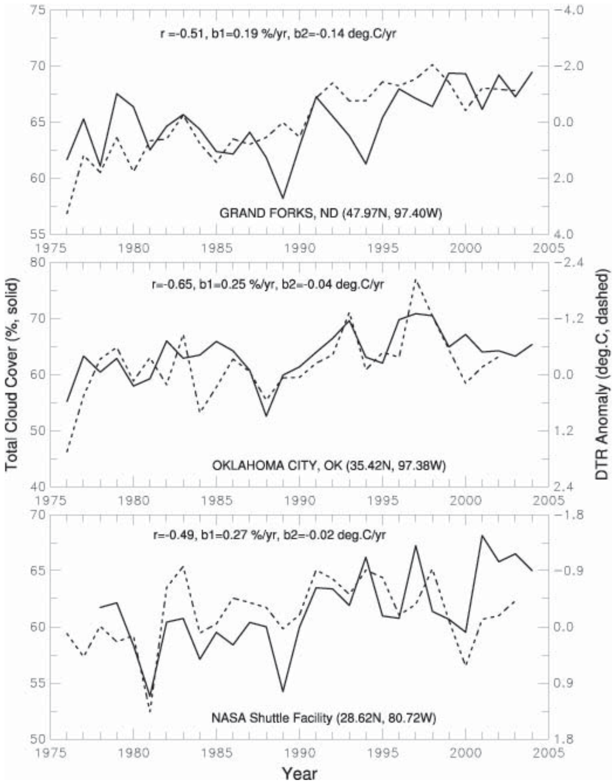

FIG. 7. Time series of annual mean daytime (0600–1800 local solar time) total cloud cover (percent of the sky, solid line) at three U.S. military weather stations, compared with the annual mean DTR anomaly (°C, dashed line, increases downward on the right-side ordinate) from a nearby synoptic weather station. Also shown are the correlation coefficient (*r*) between the two curves and the slope of the curves (b1 for cloud cover and b2 for DTR). The station DTR data were extracted from the updated GHCN v2 dataset (Peterson and Vose 1997).

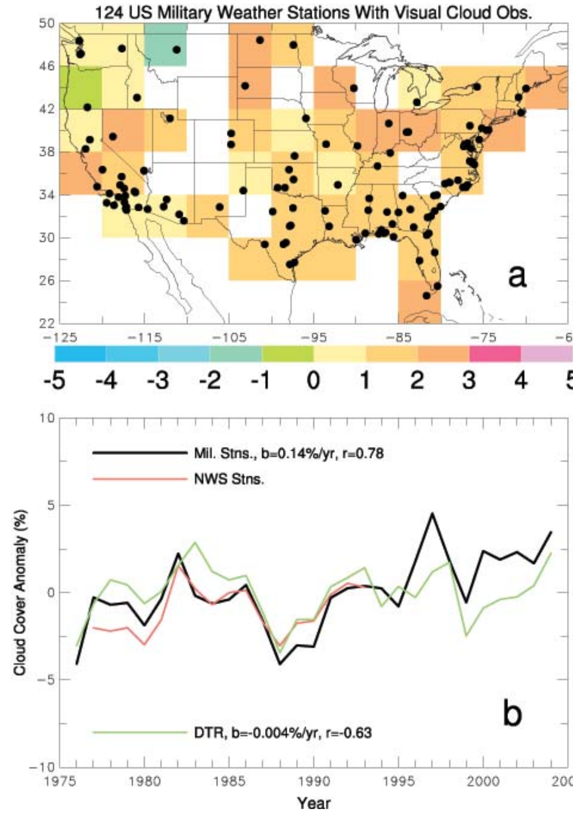

FIG. 8. (a) Distribution of 124 U.S. military weather stations (dots) with continuous human visual observations of total cloud cover, together with linear trends (color, percent sky cover per decade) of annual daytime total cloud cover during 1976–2004. (b) Anomaly time series of annual daytime total cloud cover averaged over the 4° lat × 5° lon boxes that have at least one of the stations shown in (a) (black line, *b* is its slope and *r* is the correlation with the red line) and derived using all the NWS/FAA stations (red line, from 1976 to 1993 only). Also shown is the DTR anomaly (green line, decreases downward on the right-side ordinate, *b* is its slope and *r* is the correlation with the black line) averaged over the same areas with data in (a) using the updated GHCN v2 dataset (Peterson and Vose 1997).

revealed slightly larger increasing trends than those shown in Fig. 8. The cloudiness time series derived from the military stations is correlated with that derived from the NWS stations ($r = 0.78$, $p = 0.03$), but it only accounts for about 60% of the variance of the NWS time series mainly because of sparse sampling by the military stations over the Rockies and other regions. Thus, there exist inadequacies in monitoring the U.S. cloud cover with the military stations, although they appear to be able to provide a useful estimate of contiguous U.S. mean cloud cover up to the present. Figure 8 suggests that the U.S. total cloud cover has been increasing steadily since the late 1970s at about 1.4% (of sky) per decade, with increases over most of the country except for the Northwest.

To further validate the U.S. cloudiness trend, we also analyzed historical records of DTR, which should negatively correlate with cloud cover, as noted above (Dai et al. 1999). We used the Global Historical Climatology Network (GHCN) version 2 (v2) adjusted minimum (T_{min}) and maximum (T_{max}) temperature data (Peterson and Vose 1997 and updates) to derive the DTR changes. Figure 8b shows that the DTR averaged over the areas with cloud data is negatively correlated with the daytime cloud cover derived from the military stations ($r = -0.63$, $p = 0.00$), although the trend in the DTR time series from 1976 to 2004 is small and statistically insignificant. Plots of the DTR trend map for 1976–2004 (not shown) revealed decreasing trends over many areas in the central and eastern United States, but increasing trends over the

Rockies, where cloudiness observations by the military stations are sparse (Fig. 8a).

Sun and Groisman (2004) showed that U.S. low clouds decreased from the early 1980s to 2001. This implies that the total cloudiness increases shown in Fig. 8 come from mid- and high-level clouds. Because the damping effect of clouds on DTR comes mostly from low clouds (Dai et al. 1999), this may partly explain the weak relationship between the recent trends of DTR and total clouds. Furthermore, owing to the sparse sampling by the military stations, the derived U.S. cloud trends may contain considerable uncertainties.

Other uncertainties also exist. For example, the upward trend of cloud cover is enhanced when all the cloud reports (including those between hours) in the military dataset are used instead of using only the reports at each hour, as is the case here. Furthermore, the U.S. DTR data based on the T_{min} and T_{max} records in the GHCN v2 were derived primarily from NOAA cooperative stations, which were not affected by the ASOS,[2] but experienced changes in time of observation and instruments. However, a series of corrections for biases associated with these changes (Karl and Williams 1987; Quayle et al. 1991; Vose et al. 2003) should have removed most of the nonclimatic changes in the DTR data.

Quantitative estimates of the uncertainties of the U.S. cloud trend during 1976–2004 shown in Fig. 8b are difficult to derive because of the poor coverage by the 124 military stations and the subjective nature of the human observations. Nevertheless, the general agreement between the cloud records from the military stations and the large network of NWS stations before 1994 and the negative correlation with the DTR record (Fig. 8b) add confidence in the military cloud data.

CONCLUDING REMARKS. Automated Surface Observation systems were widely introduced to replace manned weather stations around the mid- 1990s in the United States and Canada. While laser beam ceilometers of the ASOS measure overhead clouds within the lower 3.6–3.8 km of the atmosphere, the ASOS cloud reports do not contain cloud-type and opacity information and are not comparable with previous cloud records made by human observers. The ASOS has also induced discontinuities in surface temperature and other records. As a result, climate researchers can no longer make full use of the historical records of the last 100–150 yr to study the climate. Although the 124 U.S. military stations provide useful data for total cloud amount up to the present, they have limited spatial coverage and are inadequate for monitoring regional trends in the western and other parts of the country. Satellite observations still have relatively short records, often disagree with surface-observed trends, and continue to face various inhomogeneity problems. Meanwhile, surface climate records, such as visual cloud observations, have an irreplaceable role in climate and global change research. The widespread use of the ASOS in North America, with its present mode of monitoring clouds, has and will continue to hamper our ability to monitor Earth's climate and study its variability. At present, a reliable system to monitor clouds consisting of both surface and satellite observations for climate change detection does not exist, but must be a high priority to help resolve one of the largest uncertainties in understanding climate change. Clearly, a U.S. and global strategy for such observations should be part of any basic global climate observing system.

One way forward is to reprocess satellite cloud records to improve their homogeneity, given our current knowledge. This could lead to a greatly improved historical record for climate change analyses. For the future, however, progress is likely to come from improved three-dimensional information from new satellites such as CloudSat and Cloud–Aerosol Lidar and Infrared Pathfinder Satellite Observation (CALIPSO), and with close links among analyses of clouds, radiation, water vapor, aerosols, and precipitation, rather than analyzing them separately. For long-term monitoring, continuity and calibration are essential for any observations. Thus, it is vital for any new satellite mission and surface station network to be calibrated with some reference records so that the new observations are comparable with prior records and can be used for climate change analyses.

The analysis of continuous visual observations of cloud cover from the U.S. military stations suggests that the previously reported increasing trend of total cloud cover over most of the contiguous United States has continued to 2004. Although variations in cloudiness correlate negatively with diurnal temperature range, the recent cloudiness trend (~1.4%

[2] We found that T_{max} and daily mean air temperature from NOAA cooperative stations (with nonaspirated systems) are considerably higher than those from ASOS stations (with aspirated systems), while the difference in T_{min} is small. This makes the ASOS DTR data not comparable with previous records, although the ASOS temperatures may be more accurate than those from the cooperative stations (Sun et al. 2005).

of sky per decade) is not entirely consistent with the small changes in recent DTR over the contiguous United States. The increasing trend of cloudiness during the last five decades is consistent with the observed reduction in U.S. surface solar radiation from 1961 to 1990 reported by Liepert (2002). This apparent inconsistency with the DTR change may arise from errors in temperature data, sparse cloud sampling by the military stations, or from increases in mid- and high-level clouds, which have only a small damping effect on the DTR. Improved cloud observations are needed to cross validate the recent (1976–2004) DTR change, which differs from the earlier (1950–93) decreases in DTR over the United States (e.g., Easterling et al. 1997).

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