

Climatology

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Introduction

Clouds are an important component of the Earth's climate system. They reflect solar radiation back to space, they absorb thermal infrared radiation emitted from below, and they produce rain and snow. A cloud climatology describes the time-averaged geographical distribution of cloud properties and the diurnal, seasonal, and interannual variations of those properties.

Cloud climatologies are used to determine the radiative effects of clouds on climate and to determine the extent to which interannual and multidecadal changes in the Earth's radiation budget can be attributed to changes in clouds. Cloud climatologies also find applications in assessing the prediction of clouds by climate models, assessing the significance of chemical reactions in clouds, quantifying climatic feedbacks involving clouds, estimating the radiative forcing by anthropogenic aerosols, selecting sites for astronomical observatories and atmospheric field experiments, and assessing the potential for solar energy development.

The properties of clouds most important for climate are those that affect radiation and precipitation, namely, cloud height, thickness, horizontal extent and horizontal variability, water content, phase (liquid or ice), and droplet and crystal sizes. It is therefore important to distinguish different types of clouds. The climatic effects of clouds further depend on the geographical location of the clouds, the albedo and temperature of the underlying surface, and the season of the year and time of day. The effect of clouds on the Earth's radiation budget, called the 'cloud radiative forcing' is generally negative in the daytime but positive at night (that is, clouds cool the surface in the day but warm the surface at night), so an accurate determination of the diurnal cycle of each cloud type is an important component of a cloud climatology.

Cloud Types

Clouds are classified according to their form and their height. Low clouds, with bases in the atmospheric boundary layer less than 2 km above the surface, are influenced by their proximity to the surface. Solar

heating of the surface can initiate convection and cause cumulus (Cu) clouds to form at the lifting condensation level. Cumulus clouds are small; they may develop further into large cumulonimbus (Cb) clouds. Cumulonimbus can extend vertically to the tropopause and often contain ice crystals in their upper parts. Cumulonimbus are associated with thunder, lightning, and showery rain or snow.

Stratus (St) and stratocumulus (Sc) are both horizontally extensive low clouds. They are distinguished in that stratocumulus contains convective elements but stratus does not. Fog is a cloud at the ground surface, usually in the form of stratocumulus. Stratus and stratocumulus cover large regions of the oceans. In the subtropics they are found over the eastern parts of the oceans, where subsidence is occurring in the free atmosphere above the boundary layer.

Nimbostratus (Ns) clouds are much thicker than Sc and St, extending vertically through several kilometers of the atmosphere. Nimbostratus clouds form as a result of large-scale uplift of moist air in frontal storms at middle and high latitudes, and they precipitate rain and snow.

Clouds with bases 2–6 km above the surface are termed 'middle' clouds, and are classified altostratus (As) or altocumulus (Ac) by their resemblance to stratus or cumulus.

Clouds with bases between 6 km and the tropopause are the 'high' clouds: cirrus (Ci), cirrostratus (Cs) and cirrocumulus (Cc). They consist of ice crystals and as a group are called 'cirriform' clouds. They can result from gradual uplift in large-scale storms in mid-latitudes, or can be sheared off the tops of cumulonimbus in the tropics.

Clouds above the tropopause are rare, but they can occur in the polar regions in the stratosphere at 15–25 km height as polar stratospheric clouds (PSCs; nacreous clouds), and in the mesosphere at 80 km height as polar mesospheric clouds (PMCs; noctilucent clouds). Those two types of clouds are discussed in other articles in the Encyclopedia; this article is concerned only with tropospheric clouds (*see Noctilucent Clouds*).

Satellite Observations

Cloud climatologies have been developed from two kinds of data: (1) using radiances measured by satellites in polar and geostationary orbits, and (2) using visual observations of clouds from the Earth's surface, as coded in weather reports from stations on

land and ships in the ocean. Satellites detect clouds principally at visible and thermal-infrared wavelengths. At visible wavelengths cloudy scenes appear brighter than cloud-free scenes when viewed from above. Clouds are usually colder than the underlying surface, so the emission of thermal-infrared radiation to space is less than for clear scenes. During the daytime clouds can be detected in both wavelength regions, but at night only in the thermal infrared. The altitude of the cloud top is inferred by relating the infrared emission temperature to the vertical profile of temperature obtained from radiosondes (carried by weather balloons) or satellite sounders. Cloud optical thickness (opacity) is inferred from reflectance in the visible channel. If a second solar channel (in the near infrared) is available, then the vertically integrated liquid water content, and the effective radius of the droplets, can also be inferred.

Measurements from satellites can be used to produce a cloud climatology if the following criteria are satisfied: (a) pixel size is at most a few kilometers; (b) temporal sampling is conducted at regular intervals throughout the day and night; (c) the coverage is global; and (d) a long period of record (many years) is maintained. To satisfy these requirements, the International Satellite Cloud Climatology Project (ISCCP) uses five geostationary satellites that hover over the Equator at five longitudinal locations, and two polar-orbiting satellites. This project began in 1983 and is continuing.

More detailed information about clouds can be obtained from satellite instruments with finer spatial resolution (e.g., Landsat), and from satellites with more spectral channels (e.g., the Moderate Resolution Imaging Spectrometer (MODIS) on the Earth Observation Satellite (EOS)). Three-dimensional information about clouds can be obtained from satellites that look at the same scene from different angles (e.g., the Multi-angle Imaging Spectroradiometer (MISR)). These instruments are useful for studying cloud properties but do not yet offer sufficiently long periods of record to produce a climatology (*see Satellite Remote Sensing: Cloud Properties*). The principal satellite cloud climatology in use now is therefore that of ISCCP.

Surface Observations

Surface observations of clouds are made less frequently than satellite observations in many areas, and they have variable spatial density, but they offer a useful adjunct to satellite observations for the following reasons.

- The surface observer views clouds from below, and thus can observe the low clouds that are often

hidden from the satellite's view by higher clouds. Multiple cloud layers often occur together, so the views from above and below are complementary.

- Some clouds are difficult to detect from satellites (clouds over snow, low clouds at night) because they provide little contrast in albedo or temperature with the underlying surface.
- Surface observers are close to the clouds, so they can identify clouds by type, including clouds smaller than a satellite's pixel size, which is typically at least 1 km.
- The cloud types defined morphologically by surface observers are directly related to meteorology and cloud processes, whereas the satellite climatology defines cloud types by their radiative properties.
- Weather reports of clouds are available for several decades with no change in official observing instructions, so interdecadal variations and trends can be studied.

This review emphasizes the climatology obtained from surface observations, because that is the subject of the authors' own research.

Cloud Information in Surface Weather Reports

Cloud observations are coded into weather reports using the 'synoptic code' of the World Meteorological Organization (WMO). In some countries the observations are reported both in the synoptic code and in another code used locally. Reports in these other codes have been used to develop climatologies in some individual countries, but the synoptic code is the only one used worldwide. The information about clouds in the synoptic weather report consists of total cloud cover, low or middle cloud amount, low cloud type, middle cloud type, high cloud type, present weather, and base height of the lowest cloud.

About 6500 land stations routinely report cloud observations in the synoptic code. Usually they report every three hours beginning at 0000 UT, but about one-quarter of them report only every six hours. About 20% of the stations do not make observations at night. The average spacing of land stations is about 180 km, but it is far from uniform. Europe has more stations than needed for a cloud climatology, and Antarctica has too few. Some parts of the Sahara Desert and Western Australia are also inadequately sampled.

Most ships make weather observations four times per day; the observations are recorded in logbooks and also transmitted by radio to world meteorological centers. In a recent typical year, reports from an average of 1150 ships were received at 0000, 0600, 1200, 1800

UT and from 160 ships at 0300, 0900, 1500, 2100 UT. Most of these are merchant ships with volunteer weather observers; some are military ships and research ships, and a few (<10) are dedicated weather ships. Unlike on land, there is little tendency for fewer observations at night, but the nighttime observations may not be transmitted promptly by radio so it is important to have the complete logbook records. The average spacing of ships that report clouds is 600 km, much greater than for weather stations on land, but since the ships are moving they sample most parts of the ocean. A project to compile ship-based weather observations from all maritime nations, including many logbook reports, has resulted in the Comprehensive Ocean–Atmosphere Data Set (COADS), which is being used for research on air–sea interaction and climatic change throughout the world ocean.

In many parts of the ocean the accuracy of computed mean cloud amounts is limited by the scarcity of observations. This is not the case on land, where the random error due to inadequate temporal sampling is very small. Statistical tests performed on observations from weather ships indicate that 100 observations taken at random times during a three-month period will represent the seasonal mean cloud cover to within 3% in an oceanic grid-box of size 5° latitude by 5° longitude. If 1% accuracy is desired, then 1000 observations are needed.

The synoptic code was defined in 1929 but was changed in 1949; the reporting procedures became adopted worldwide in the early 1950s. Synoptic observations are available with global coverage for all oceans since 1952 and for all continents since 1971, about 400 million observations to date.

Computation of Average Cloud Amounts

For low clouds the computation of average amount is straightforward, but for middle and high clouds the question of overlap must be considered. The ‘amount’ of a cloud type is defined as the fraction of the sky covered by that type, whether visible or hidden behind another cloud. The time-averaged amount can be obtained as the product of frequency-of-occurrence (fraction of weather observations in which a cloud of this type is present, whether visible or hidden) and amount-when-present (the average fraction of the sky covered by this cloud type when it is present, whether visible or hidden). For example, if cumulus is present in 30% of the weather observations from a station, and if it covers on average 40% of the sky when it is present, then the average amount of cumulus at that station is 12%.

The amount, or even the presence, of a middle or high cloud may be indeterminate when a lower cloud nearly or completely covers the sky. The average amounts of middle and high cloud types can be estimated by assuming that the frequency and amount-when-present are the same in observations where they cannot be calculated as in observations where they can be calculated. Also, to obtain amount-when-present, the clouds at different levels are assumed to be randomly overlapped. The amounts directly visible from below (the ‘nonoverlapped’ amounts) may also be calculated.

For the climatology, the Earth is divided into an array of boxes on a geographical grid, and cloud cover is computed for each box. Several possible biases may affect computed cloud cover but they may be reduced or eliminated with appropriate analysis procedures. Two small biases that oppose each other and are unique to ship observations are the fair-weather bias (the tendency for more ships to enter a grid-box on days of fair weather) and the foul-weather bias (the tendency of ships to oversample stormy or foggy weather because they are traveling more slowly). Two other biases that may affect both ship and land data are the diurnal sampling bias (somewhat more reports are transmitted by ships during the day than at night, and some land stations in a box with several stations may not report at night) and the trend bias (a box may be sampled by more ships in later years than in earlier years, or a land station may change location during the period of record). These situations can cause biases if the cloud amount undergoes a diurnal cycle or exhibits a long-term trend, but such biases can be eliminated by appropriate analysis procedures.

The most serious bias, on both land and ocean, is the ‘night-detection bias’. Visual observations of clouds are hindered at night by inadequate illumination of the clouds. This usually leads to an underestimation of the average cloud cover at night, especially for the amounts of middle and high clouds, in climatologies based on surface observations. The diurnal cycles of cloud amounts, if based on all the surface observations, are therefore in error, but the cycles can be obtained more accurately if the nighttime observations are screened to select those made under sufficient moonlight or twilight. A criterion for adequacy of moonlight or twilight has been established; it permits the use of about 38% of the nighttime observations. By this criterion, adequate illumination is provided by a full moon at an elevation angle of 6° or a partial moon at higher elevation, or by twilight from the Sun less than 9° below the horizon.

A complete description of the climatology of clouds is the subject of atlases such as those listed in Further Reading, which give the average amounts of each

Table 1 Annual average cloud cover from surface observations (1982–1991)

| | Land | Ocean | Globe |
|--------------------------------|------|-------|-------|
| Average total cloud amount (%) | 54 | 68 | 64 |
| Day–night difference (%) | +3 | 0 | +1 |

cloud type for each season in grid-boxes of 5° latitude by 5° longitude, as well as their diurnal cycles and interannual variations. A few illustrative examples from the climatology are shown in this article.

Global Averages

The annual average total cloud cover as determined from surface observations is summarized in **Table 1**. Average cloud cover is greater over the ocean than over land. Cloud cover over land tends to be greater in daytime than at night, but the ocean shows little day–night difference.

Cloud properties from eight years (1986–1993) of ISCCP are summarized in **Table 2**. The average cloud cover and the day–night differences are slightly different from those obtained from surface observations (**Table 1**). The optical thickness (opacity) and cloud-water path (vertically integrated liquid-water content) inferred from the satellite radiances are smaller than those usually obtained from aircraft in field experiments. This difference is probably due to horizontal inhomogeneity of the clouds; the ISCCP optical thickness is an effective optical thickness for a hypothetical horizontally homogeneous cloud.

Global average amounts for nine different cloud types defined in the surface observations are shown in **Table 3**. Globally, the most common types are stratocumulus, altocumulus, and high (cirriform) clouds. All the low cloud types are more common over the ocean than over land. The middle types altostratus and altocumulus together cover the same fraction of the sky over land as over ocean; cirriform cloud is the only type that is less common over ocean.

Table 2 Annual average cloud properties from the International Satellite Cloud Climatology Project (1986–1993)

| | Land | Ocean | Globe |
|---------------------------------------|------|-------|-------|
| Average total cloud amount (%) | 58 | 72 | 68 |
| Day–night difference (%) | +5 | –2 | 0 |
| Cloud top temperature (°C) | –20 | –7 | –11 |
| Day–night difference (°C) | +12 | +2 | +5 |
| Cloud top pressure (hPa) | 490 | 620 | 580 |
| Cloud optical thickness | 4 | 4 | 4 |
| Cloud-water path (g m ^{–2}) | 76 | 61 | 66 |

Adapted from Tables 4 and 5 of Rossow WB and Schiffer RA (1999) *Bulletin of the American Meteorological Society* 80: 2261–2287, American Meteorological Society, Boston, with permission.

For the low clouds, **Table 3** also shows the observers' estimate of the height of the cloud base above the ground surface. The bases are on average twice as high over land as over ocean, and the heights increase with distance inland from the ocean.

Geographical Variations

What the averages of **Table 3** cannot show is that there are striking geographical variations. Fog is rare over most of the globe but its frequency exceeds 10% over the North Atlantic and North Pacific oceans in summer poleward of 40° N, and reaches 20–40% in the Sea of Okhotsk. Nimbostratus is likewise rare in the tropics but common in middle and high latitudes. Cumulonimbus amount exceeds 10% in a narrow band along the Intertropical Convergence Zone (ITCZ) near the Equator and over a much broader region of warm water in the western Pacific called the 'warm pool'.

Completely clear sky, also given in **Table 3**, is common over land but rare over the ocean. Over most of the open ocean there are almost always some low clouds visible from ships; the reports of clear sky are mostly confined to coastal regions. The Red, Mediterranean, and Arabian Seas are the most cloud-free parts of the world ocean.

The geographical distribution of total cloud cover for December–January–February (DJF) is shown in

Table 3 Cloud type amounts and heights from surface observations

| Cloud type | Annual average amount (%) | | Base height (meters above surface) | |
|-----------------------|---------------------------|-------|------------------------------------|-------|
| | Land | Ocean | Land | Ocean |
| Fog | 1 | 1 | 0 | 0 |
| Stratus | 5 | 11 | 500 | 400 |
| Stratocumulus | 12 | 22 | 1000 | 600 |
| Cumulus | 5 | 12 | 1100 | 600 |
| Cumulonimbus | 4 | 6 | 1000 | 500 |
| Nimbostratus | 5 | 6 | | |
| Altostratus | 4 | 22 | | |
| Altocumulus | 17 | | | |
| High (cirriform) | 22 | 13 | | |
| Clear sky (frequency) | 22 | 3 | | |

Land values are new analyses for the years 1971–1996. Ocean values are for the years 1952–1981, adapted from Table 9 of Warren SG, Hahn CJ, London J, Chervin RM and Jenne RL (1988) *Global Distribution of Total Cloud Cover and Cloud Type Amounts over the Ocean*, Tech. Note TN-317+STR, National Center for Atmospheric Research, Boulder, Colorado. For the ocean analysis, altostratus and altocumulus were combined into a single group. The amounts of all the cloud types add up to more than the total cloud cover because of overlap.

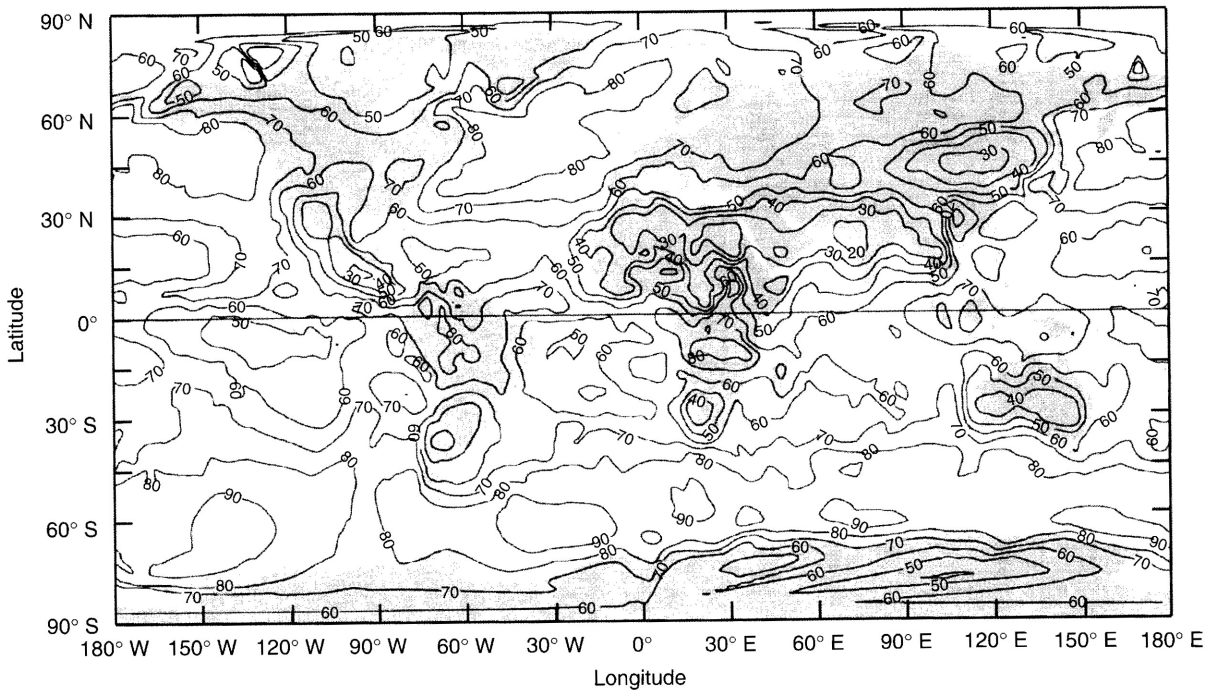


Figure 1 Percent total cloud cover for December–January–February from surface observations (weather stations on land, ships in the ocean) for the 10-year period 1982–1991, average of day and night.

Figure 1. This is the only season in which complete global coverage is available from surface observations, because ships avoid the Antarctic Ocean in other seasons when it is ice-covered. The largest cloud amounts are found in the high-latitude oceans, particularly in summer, exceeding 90% in the sub-Antarctic in DJF. The North Atlantic and North Pacific cloud amounts reach similarly high values during the northern summer (June–July–August; JJA). Values of cloud cover below 40% are found in the deserts of Australia, Mongolia, Arabia, North Africa, Southern Africa, Argentina, and Mexico. Most of the Indian subcontinent has cloud cover of 20–30% on this map, during the winter-monsoon dry season. The eastern Sahara is the clearest large region on Earth, with cloud cover below 20% on this map for DJF, but it is even clearer in summer when a large area of less than 5% cloud cover extends on across northern Arabia.

The ITCZ appears in **Figure 1** as a latitudinal maximum near the Equator in the Atlantic and north of the Equator in the eastern Pacific, then south of the Equator through Indonesia, and at about 10° S across the Indian Ocean, Africa and South America. This is in agreement with the location of the ITCZ as determined by measurement of winds and pressure.

The total cloud cover averaged around latitude zones is shown in **Figure 2** for the two extreme seasons. The figure shows that the average cloud cover is less

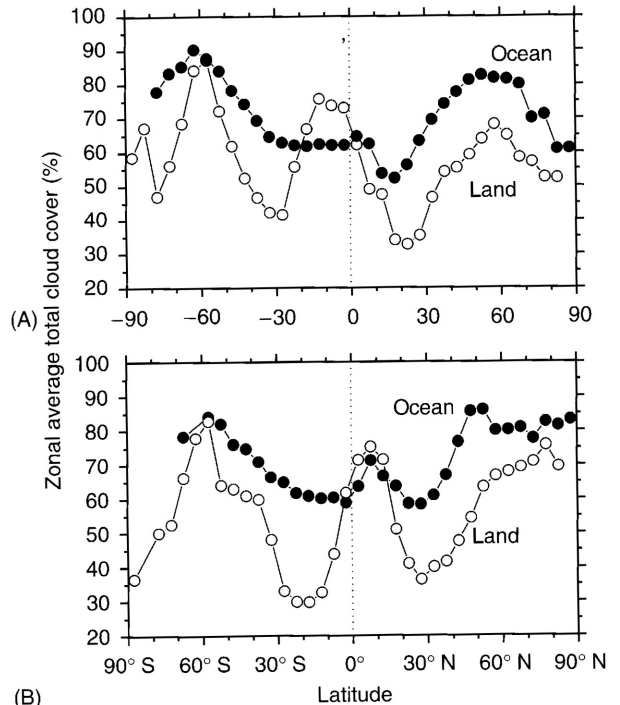


Figure 2 Zonal average total cloud cover (average of day and night) for 5° latitude zones. Separate averages are formed for the land and ocean parts of each zone. (A) December–January–February 1982–1991. (B) June–July–August 1982–1991. (Adapted from Figure 4 of Hahn CJ, *et al.* (1995) *Journal of Climate* 8: 1429–1446, American Meteorological Society, Boston, with permission.)

over land than over ocean, and that the latitudinal variation of cloud cover is greater over land than over ocean. The peak cloudiness in the ITCZ moves from 7° N in JJA only to 2° N in DJF over the ocean, but to as far as 12° S over land. The latitudes of maximum cloud cover near 60° N, 60° S, and the Equator correspond to the latitudes of maximum precipitation, and the latitudes of minimum cloud cover on land are the latitudes of the great deserts.

Diurnal Variations

The amounts of many cloud types vary from day to night. Two examples of diurnal variations for oceanic regions are shown in **Figure 3**. The central North Atlantic in winter exhibits no diurnal variation, with total cloud cover averaging about 75% at all hours. The largest oceanic diurnal variations are in the stratocumulus regions of the eastern subtropical Atlantic and Pacific. The region displayed, in the Atlantic Ocean west of Namibia, exhibits a strong diurnal cycle in total cloud cover with a peak of 73% at 07.00 and minimum of 53% at 16.00. This cycle is paralleled by the diurnal cycle of low stratiform clouds, indicating that these cloud types are the types responsible for the diurnal cycle here. These boundary-layer clouds develop during the night and dissipate during the day under the influence of solar heating.

Figure 4 shows an example of diurnal cycles on land in Central America during the summer rainy season. Solar heating of the surface begins at sunrise, leading to convection that produces cumulus clouds in the morning. In the afternoon, many of these clouds

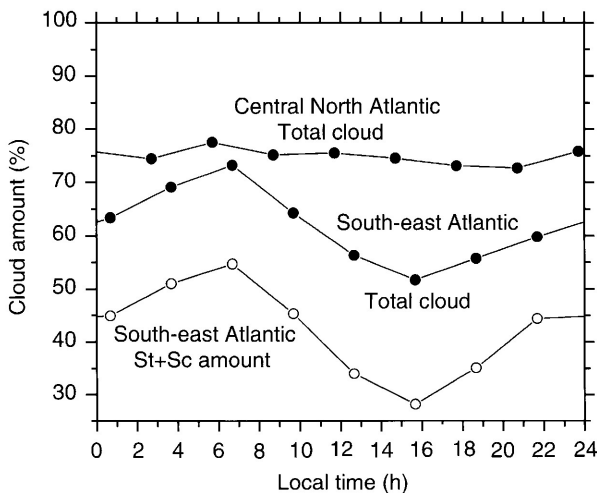


Figure 3 Diurnal cycles of oceanic cloud, from ship observations in December–January–February (1982–1991 for the North Atlantic (30–40° N, 40–60° W); 1952–1981 for the Southeast Atlantic (20–30° S, 0–20° E)).

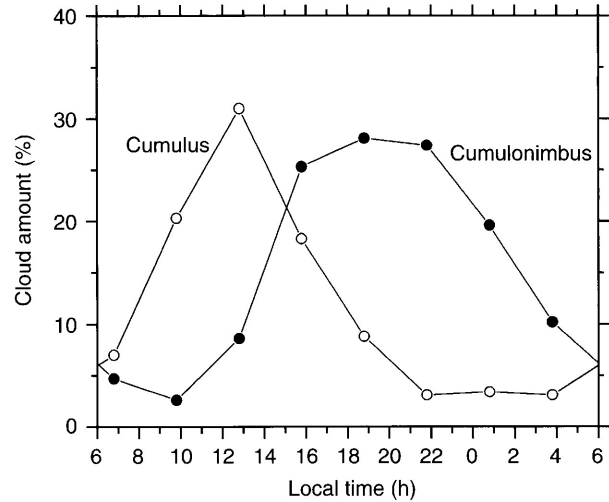


Figure 4 Diurnal cycles of cumulus and cumulonimbus amounts reported from weather stations in Central America (10–15° N, 85–90° W) in summer (June–July–August 1971–1981).

further develop into cumulonimbus, which continue precipitating into the evening.

Seasonal Variations

The largest seasonal variations of cloud cover are associated with the subtropical monsoons of Africa, South America, India, and Australia. Cloud variations in the Indian Ocean region are shown in **Figure 5A**. In south-west India the average total cloud cover increases from 16% in February to 89% in July. During India's dry winter, northern Australia experiences its cloudy and rainy summer.

In contrast to the sinusoidal pattern of the Indian and Australian monsoons, the central Arctic Ocean (**Figure 5B**) exhibits a peculiar boxlike seasonal cycle, in which cloud cover increases rapidly during May. The greater cloud cover from June to September is due mainly to the low, thin 'Arctic summer stratus' clouds that form over the perennial sea ice during the melting season. A still different pattern is exhibited in parts of the North Atlantic (**Figure 5B**), which have almost no seasonal variation of cloud cover.

Interannual Variations and Trends

Clouds interact with other components of the climate system, so changes in cloud amounts can be expected to accompany changes in other climatic variables, and also to feed back on those other variables. The magnitudes, and even the nature, of the possible climatic feedbacks involving clouds are far from understood, but the long historical climatic record

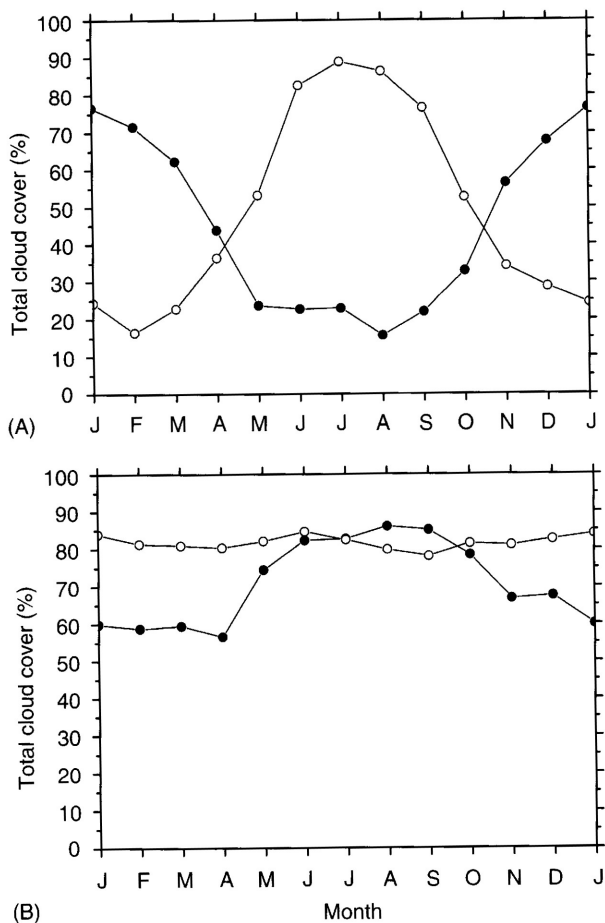


Figure 5 Examples of seasonal cycles of total cloud cover, 1982–1991, from surface observations. (A) Land: \circ , South-west India, 15–17.5° N, 72.5–75° E; \bullet , Northern Australia, 12.5–15° S, 130–132.5° E. (B) Ocean: \circ , North Atlantic, 45–50° N, 20–25° W; \bullet , Arctic Ocean, 80–90° N. The observations in the Arctic Ocean were made from drifting stations established on perennial sea ice.

may help to identify them. The degree to which the actual variations of the amounts of the different cloud types are faithfully recorded in the analysis of visual observations is itself variable, depending on the spatial and temporal density of observations, the ability to detect and remove biases, and the spatial scale of the analysis. Real interannual variations of cloud amount in a $10^\circ \times 10^\circ$ box, for example, are often large enough to overwhelm any subtle progressive changes in observing procedure. However, interannual variations of zonal average cloud amount are smaller than those of grid-box cloud amount because of partially compensating positive and negative changes in different parts of the zone. For zonal averages it is therefore more difficult to dissect the observed changes into climatic and nonclimatic causes.

A powerful way to assess the validity of observed cloud changes is to identify likely causes (e.g., changes in sea surface temperature (SST) or atmospheric

circulation) and effects (e.g., diurnal temperature range) of the cloud changes and to correlate these related climatic variables to the cloud changes. Some examples are shown in **Figure 6**. Interannual variations of the amount of marine stratiform cloudiness (St+Sc) commonly correlate negatively with interannual variations of SST. Many of these interannual variations are related to cycles of El Niño and the Southern Oscillation. **Figure 6** shows how St+Sc and SST covary at two locations in the Pacific Ocean: one location that exhibits a long-term trend and another that does not. Both sets of data came from shipboard observations. The fact that clouds and SST are measured by different methods but correlate well argues for the reality of both time-series. The good correlations in **Figure 6** also suggest that the error in a seasonal mean due to random sampling of weather situations during a particular season is small. In other grid-boxes traversed by fewer ships, seasonal means suffer from sampling error and the correlation of St+Sc with SST is not as strong.

The global average reported cloud cover over the oceans has apparently increased by 1–2% since 1952. The largest increase is in the tropical regions. How

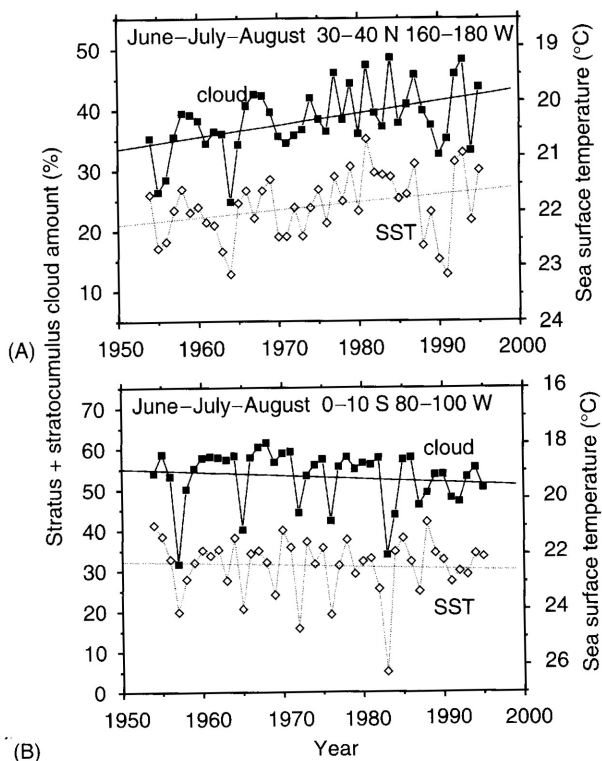


Figure 6 Seasonal average daytime amounts of stratus plus stratocumulus, and seasonal average sea surface temperatures (SST) for two grid-boxes in the Pacific Ocean. (A) June–July–August, 30–40° N, 160–180° W. (B) June–July–August, 0–10° S, 80–100° W. The SST is plotted on a reversed scale to illustrate the correlation. (Data supplied by Dr Joel Norris.)

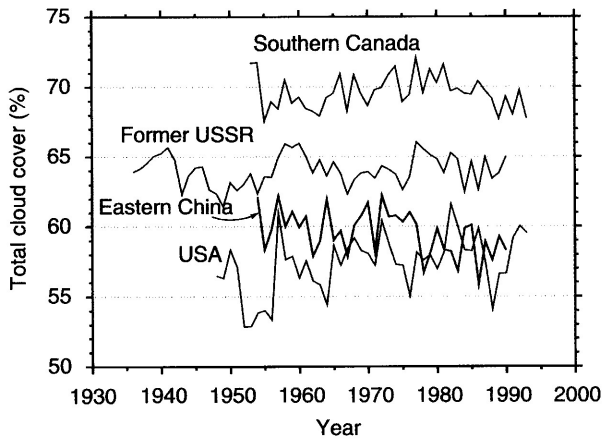


Figure 7 Interannual variations in mean annual daytime cloud cover area-averaged over four regions: Canada south of 55° N, former USSR south of 60° N, contiguous USA, and China east of 110° E. (Adapted from Figure 5A of Sun B, *et al.* (2000) *Journal of Climate* 13: 4341–4357, American Meteorological Society, Boston, with permission.)

much of this trend is a real climatic change is not yet established.

Much effort is currently under way to investigate interannual variations and trends of cloud amounts over land. Regional changes may be expected from anthropogenic sulfate aerosols that can act as cloud-condensation nuclei. Cloud changes are suspected as a contributor to regional decreases in the diurnal temperature range because clouds cause a cooling in the daytime but a warming at night. Figure 7 shows variations of total cloud cover reported over the last half-century for four large regions of the Northern Hemisphere. The only region exhibiting a significant trend is eastern China, but its cause is as yet unidentified.

The Future of Cloud Observations

The long time-span of cloud reports, covering the transition period from a time of perhaps minimal human impact on climate in the 1950s, to the anthropogenically altered climate of the future, is a valuable resource that is appreciated by many national meteorological agencies. There has been remarkable worldwide international cooperation in reporting weather observations in compliance with the WMO regulations. Except for brief periods of political instability (Iran in 1979; Zaire in the late 1990s), essentially all nations have been contributing their weather observations reliably. Recently, however, two nations (United States and New Zealand), in conjunction with the automation of their weather stations,

have essentially ceased reporting of visual cloud observations in the WMO synoptic code. Changes of codes or changes of observational methods (laser ceilometers in place of the human eye), or even changes of station location, make it difficult to infer reliable climatic changes over a span of years that includes the time of the change. The number of US stations with useful synoptic weather reports decreased slowly throughout the 1980s and rapidly in the mid-1990s so that the geographical coverage of the United States declined from 241 stations in 1981 to only about 27 by the end of 1996. The United States and New Zealand together represent 2% of the Earth's surface, so future global analyses of cloud changes from surface observations will be restricted to the remaining 98% of the globe.

At present it is difficult to obtain reliable multiyear trends of cloud amounts from satellite observations because of the short lifetimes of individual satellites and the difficulty of intercalibrating instruments on different satellites, especially because the spectral response of the radiation detectors may change from one satellite to the next. However, efforts are under way to address these problems, and we can expect in the future to see an increase in the use of satellite observations for the climatology of clouds.

See also

Cloud Chemistry. Cloud Microphysics. Clouds: Classification; Cumuliform; Measurement Techniques *In Situ*. **Convective Cloud Systems Modelling. Noctilucent Clouds. Parameterization of Physical Processes:** Clouds. **Radiative Transfer:** Cloud-radiative Processes. **Satellite Remote Sensing:** Cloud Properties.

Further Reading

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