ATM2 00113

a0005 # Clouds: Climatology

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AU1 s0010 ## Introduction

p0015 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. AU2

p0020 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.

p0025 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, the season, and the time of day. The effect of clouds on the Earth's radiation budget, called the 'cloud radiative effect', is generally negative in the daytime but positive at night (i.e., 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.

s0015 ## Cloud Types

p0030 Clouds are classified according to their form and 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. Cu clouds are small and may develop further into large cumulonimbus (Cb) clouds. Cb can extend vertically to the tropopause and often contain ice crystals in their upper parts. Cb are associated with thunder, lightning, and showery rain or snow. AU3, 4

p0035 Stratus (St) and stratocumulus (Sc) are both horizontally extensive low clouds. They are distinguished in that St contains convective elements but St does not. Fog is a cloud at the ground surface, usually in the form of Sc. St and Sc 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. Ns clouds form as a result of large-scale uplift of moist air near frontal boundaries in synoptic-scale storms at middle and high latitudes, and they precipitate rain and snow. p0040

Clouds with bases 2–6 km above the surface are termed 'middle' clouds, and are classified as altostratus (As) or altocumulus (Ac) by their resemblance to St or Cu. 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 midlatitudes, or can be sheared off the tops of Cb in the tropics. p0045 AU5

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. p0050 AU6

Satellite Observations s0020

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. p0055

Measurements from satellites can be used to produce a cloud climatology if the following criteria are satisfied: (1) pixel size is at most a few kilometers, (2) temporal sampling is conducted at regular intervals throughout the day and night, (3) the coverage is global, and (4) 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. That project began in 1983 and is still continuing. p0060 AU7, 8 p0065 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 Observing Satellites (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)). Cloud climatologies are also being developed using satellite-borne radar AU9 (CloudSat) and lidar (CALIOP, CALIPSO). 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.

s0025 Surface Observations

p0070 The 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.

u0010 1. The surface observer views clouds from below, and thus can observe the low clouds, which 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.

u0015 2. Some clouds are difficult to detect from satellites (clouds over snow, low clouds at night), because they provide little contrast in albedo or temperature to the underlying surface.

u0020 3. The 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.

u0025 4. 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.

u0030 5. Weather reports of clouds are available for several decades with no change in official observing instructions, so inter-decadal 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.

s0030 Cloud Information in Surface Weather Reports

p0100 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.

p0105 About 6500 land stations routinely report cloud observations in the synoptic code. Usually they report every 3 h beginning at 00.00 coordinated universal time (UTC), but about AU10 one-quarter of them report only every 6 h. 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.

p0110 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 00.00, 06.00, 12.00, 18.00 UTC and from 160 ships at 03.00, 09.00, 15.00, 21.00 UTC. Most of these are merchant ships with AU11 volunteer weather observers; some are military ships and research ships, and a few (less than 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 the ships are moving so they do 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 International Comprehensive Ocean-Atmosphere Data Set (ICOADS), which is being used for research on air–sea interaction and climatic change throughout the world ocean.

p0115 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 3-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.

p0120 The synoptic code was defined in 1929, but changed in 1949; the reporting procedures became adopted worldwide in the early 1950s. Synoptic observations are available with global coverage for all oceans since 1954 and for all continents since 1971, about 550 million observations to date.

Computation of Average Cloud Amounts s0035

p0125 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 Cu 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 Cu at that station is 12%.

p0130 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.

p0135 For the climatology, the Earth is divided into an array of boxes on a geographical grid, and cloud cover is computed for each box. There are several possible biases which may affect computed cloud cover but which 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 AU12 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.

p0140 The most serious bias, on both land and ocean, is the 'night-detection bias'. Visual observations of clouds are hindered at night due to 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 twilight from the sun less than 9° below the horizon.

p0145 A complete description of the climatology of clouds is the subject of atlases such as those in the bibliography, which give the average amounts of each 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. Updated plots and descriptions are available at the climatology website: www.atmos.washington.edu/CloudMap.

s0040 Global Averages

p0150 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.

Table 1 Annual average cloud cover from surface observations (1971–96, land; 1954–97, ocean) t0010

	Land	*Ocean*	*Globe*
Average total cloud amount (%)	54	69	64
Day–night difference (%)	4	−1	0

AU24

Table 2 Annual average cloud properties from the ISCCP (1986–93) t0015

	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 (K)	+12	+2	+5
Cloud top pressure (mbar)	490	620	580
Cloud optical thickness	4	4	4
Cloud water path (g m^{-2})	76	61	66

Reproduced from Rossow, W.B., Schiffer, R.A., 1999. Advances in understanding clouds from ISCCP. *Bulletin of the American Meteorological Society* 80: 2261–2287, Boston, MA: American Meteorological Society. AU25

p0155 Cloud properties from 8 years (1986–93) of the ISCCP are summarized in Table 2. The average cloud cover and the day–night differences are slightly different than those obtained from AU13 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; ISCCP's optical thickness is an effective optical thickness for a hypothetical horizontally homogeneous cloud.

p0160 Global average amounts for nine different cloud types defined in the surface observations are shown in Table 3. Globally, the most common types are Sc, Ac, and high (cirriform) clouds. All the low cloud types are more common over the ocean than over land. The middle types As and Ac together AU14 cover the same fraction of the sky over land as over ocean; cirriform cloud is the only type that is less common over ocean.

p0165 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 s0045

p0170 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. Ns is likewise rare in the tropics but common in middle and high latitudes. Cb 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'.

p0175 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 t0020 **Table 3** Cloud type amounts and heights from surface observations

	Annual average amount (%)		Base height (meters above surface)	
Cloud type	*Land*	*Ocean*	*Land*	*Ocean*
Fog	1	1	0	0
St	5	13	500	400
Sc	12	22	1000	600
Cu	5	13	1100	600
Cb	4	6	1000	500
Ns	5	5		
As	4	6		
Ac	17	18		
High (cirriform)	22	12		
Clear sky (frequency)	22	3		

AU26 Land values for the years 1971–96. Ocean values are new analyses for the years 1954–2008, from Table 9 from: www.atmos.washington.edu/CloudMap/Atlases/DistOcean.pdf. The amounts of all the cloud types add up to more than the total cloud cover because of overlap.

Red, Mediterranean, and Arabian Seas are the most cloud-free parts of the world ocean.

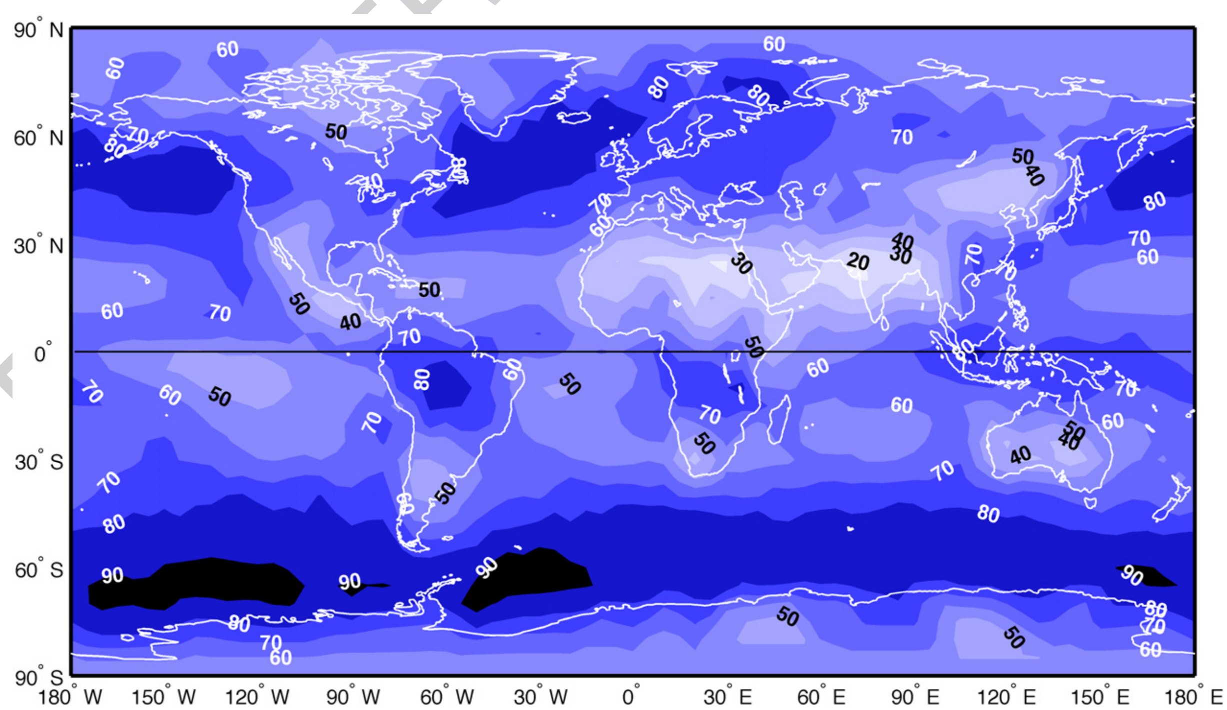
p0180 AU15 The geographical distribution of total cloud cover for Dec.–Jan.–Feb. (DJF) is shown in Figure 1. This is the only season in which complete global coverage is available from surface observations, because ships avoid the Antarctic Ocean in other seasons when it is ice-covered. The largest cloud 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 (Jun.–Jul.–Aug. (JJA)). Values of cloud cover below 40% are found in the deserts of Australia, Central Asia, Arabia, North Africa, Southern Africa, and Mexico. Most of the Indian subcontinent has cloud cover 20–30% on this map, during the winter monsoon dry season. The Eastern Sahara is the clearest large region on the 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. A complete set of maps (for all types in all seasons) is available at the website: www.atmos.washington.edu/CloudMap. AU16

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. p0185

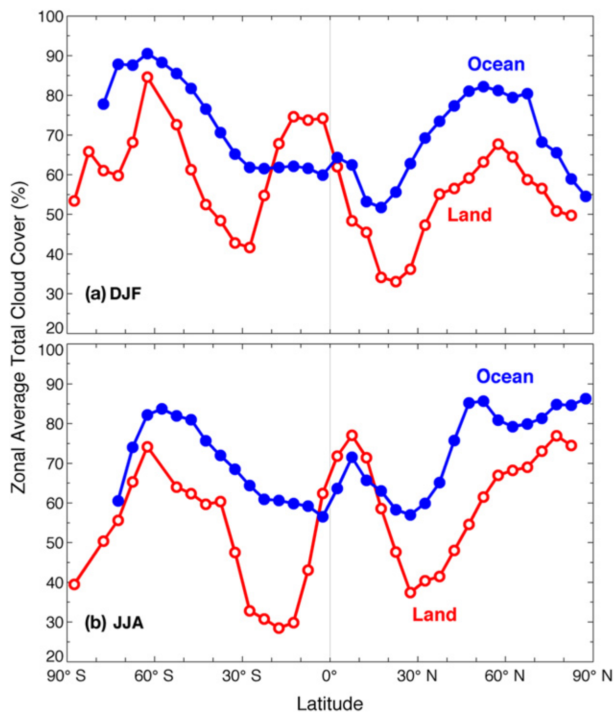
The total cloud cover averaged around latitude zones is shown in Figure 2 for the two extreme seasons. The figure shows that the average cloud cover is less over land than over ocean, and that the latitudinal variation of cloud cover is greater over land than over ocean. The peak cloudiness in the ITCZ 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. p0190

Diurnal Variations s0050

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 Pacific in winter exhibits no diurnal variation, with total cloud cover averaging about 82% at all p0195



f0010 **Figure 1** Percent total cloud cover for DJF from surface observations (weather stations on land, ships in the ocean) for the 26-year period 1971–96 over land and the 44-year period 1954–97 over the ocean.



f0015 **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) DJF; and (b) JJA. Data span the periods 1971–96 over land, and 1954–97 over the ocean.

hours. The largest oceanic diurnal variations are in the Sc 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 AU17 of 80% at 4.00 a.m. and minimum of 55% at 4.00 p.m. 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.

p0200 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 which produces Cu clouds in the morning. In the afternoon many of these clouds further develop into Cb, which continue precipitating into the evening.

s0055 Seasonal Variations

p0205 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 5(a). In Southwest 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.

p0210 In contrast to the sinusoidal pattern of the Indian and Australian monsoons, the Central Arctic Ocean (Figure 5(b)) 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 St' 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 5(b)) which have almost no seasonal variation of cloud cover.

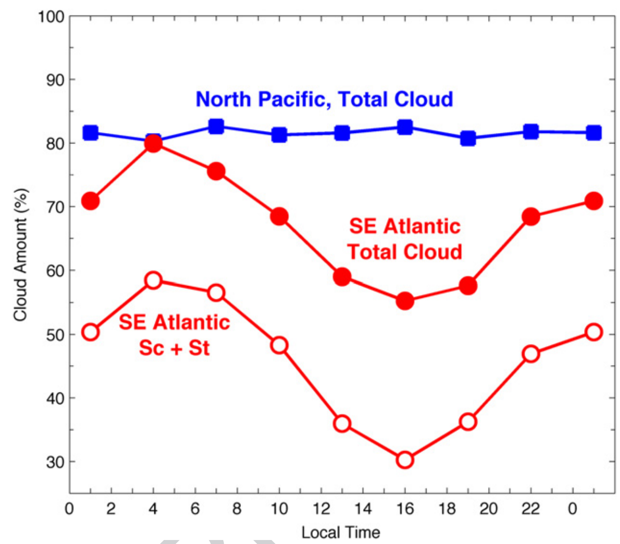


Figure 3 Diurnal cycles of oceanic cloud, from ship observations in DJF (1954–97). North Pacific: 40–50° N, 170–150° W; Southeast Atlantic: 20–30° S, and 0–20° E. f0020

Figure 6 shows a map of the amplitude of the seasonal cycle of total cloud cover over both land and ocean. With the exception of the North Atlantic, the regions shown in Figure 5 appear in Figure 6 as darker areas, indicating a large amplitude. Other areas showing a large seasonal cycle include tropical South America, Central America, the Sahel, and Southern Africa. This figure also illustrates the tendency for ocean areas to have a less pronounced seasonal cycle than land areas. p0215

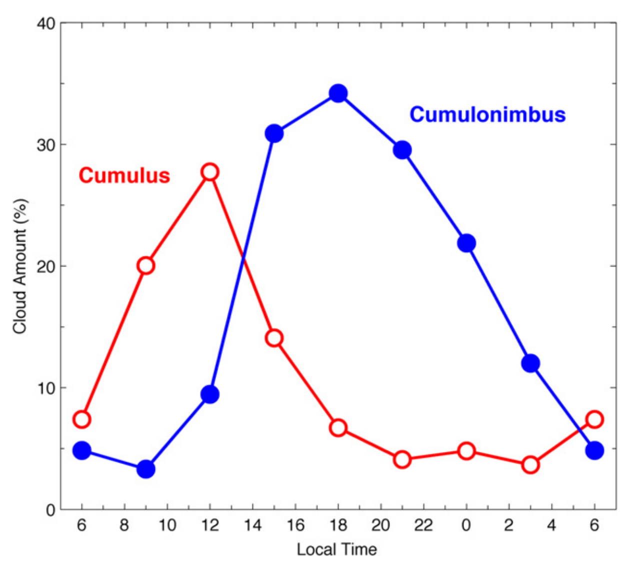
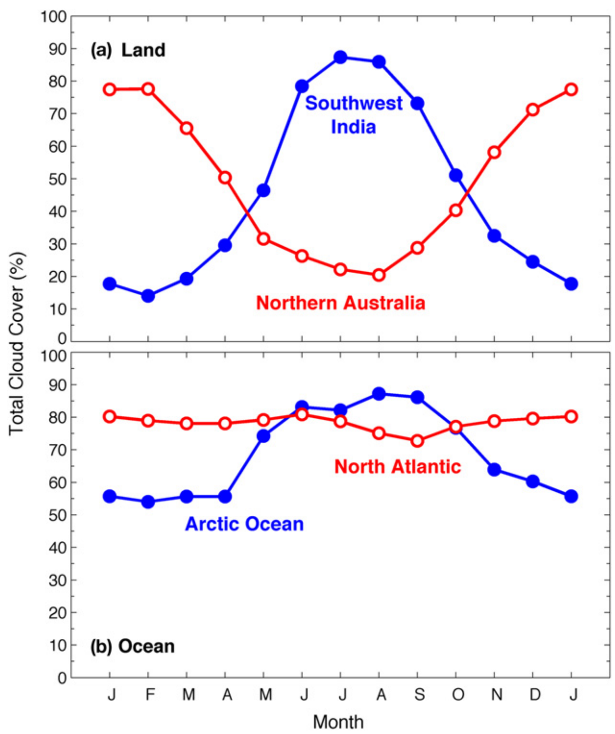


Figure 4 Diurnal cycles of Cu and Cb amounts reported from weather stations in Central America (10–15° N, 85–90° W) in summer (JJA 1971–96). f0025

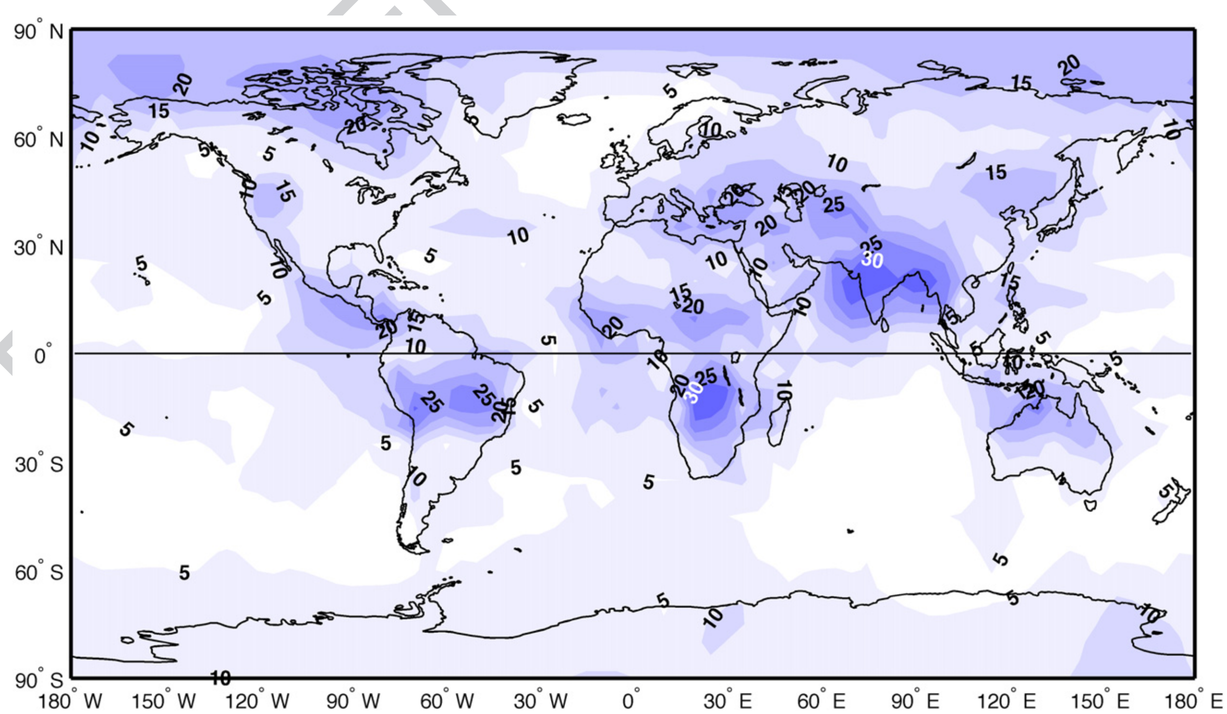


f0030 **Figure 5** Examples of seasonal cycles of total cloud cover from surface observations. (a) Land (1971–96): Southwest India, 15–20° N, 70–75° E; Northern Australia, 10–15° S, 130–135° E. (b) Ocean (1954–97): North Atlantic, 40–50° N, 20–30° W; Arctic Ocean, 80–90° N. Observations in the Arctic Ocean were made from drifting stations established on perennial sea ice.

Interannual Variations and Trends s0060

p0220 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 not well understood, but the long historical climatic record 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 $10° \times 10°$ 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. AU18

p0225 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 with the cloud changes. Some examples are shown in Figure 7. Interannual variations of the amount of marine stratiform cloudiness (St°+°Sc) commonly correlate negatively with interannual variations of SST. Figure 7 shows how St°+°Sc and SST (both measured aboard ships, but by different methods) covary at two locations



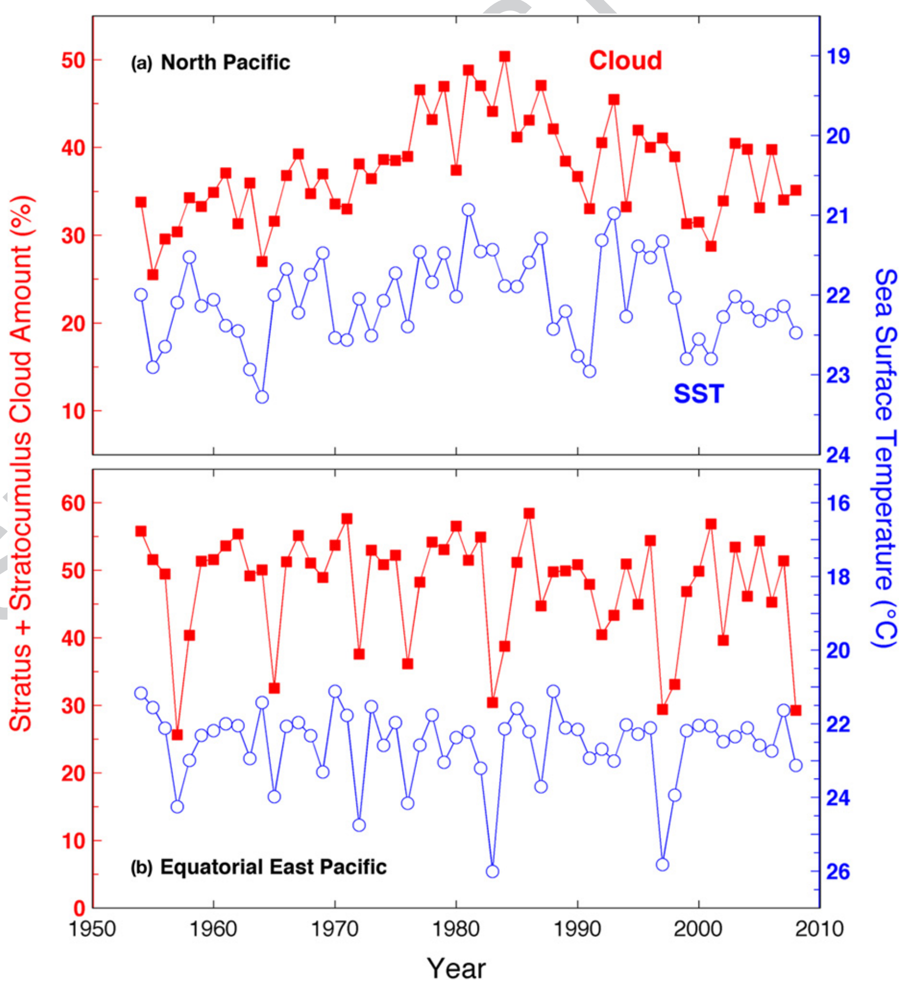
f0035 **Figure 6** Amplitude (percent) of the seasonal cycle of total cloud cover over land (1971–96) and ocean (1954–97).

in the Pacific Ocean. Many of these interannual variations are related to cycles of El Niño and the Southern Oscillation. Frame b shows downward spikes in stratiform cloud cover coinciding with high SST (plotted as increasing downward) during strong El Niño years: 1972–73, 1982–83, and 1997–98. That clouds and SST are measured differently but correlate well argues for the reality of both time series. The strong correlations in Figure 7 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.

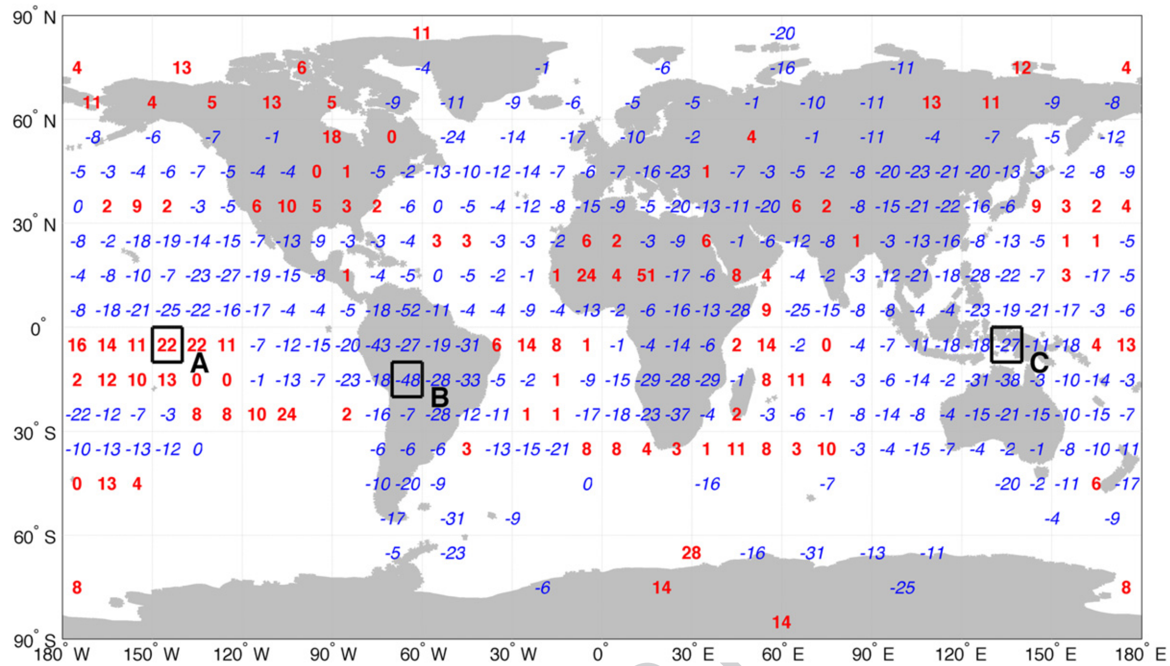
p0230 Cloud cover changes may accompany the global warming brought on by anthropogenic increases in greenhouse gases. Regional changes in cloud cover may also be expected from anthropogenic sulfate aerosols that can act as cloud condensation nuclei. Figure 8 shows trends (0.1%/decade) in total cloud cover for grid boxes from 1971 through 1996. Decreases in total cloud cover are observed over South America, Southern Africa, and in a large area between Southern Australia and Northern China. Decreases in cloud cover are also seen in all eastern subtropical ocean basins. Increasing cloud cover is observed in the Central Equatorial Pacific, Western Africa, and Arctic North America. The causes of these observed changes in cloud cover are still under investigation.

Individual time series for selected boxes (shown in Figure 8) showing significant trends in total cloud cover are plotted in Figure 9. Time series are plotted as seasonal anomalies (the departure from the multiyear seasonal mean cloud cover). Figure 9(a) shows the time series over the Equatorial Pacific. While an increasing trend of about 6% over 26 years can be seen, the year–year variation ranges up to 20% with three distinct spikes, likely associated with El Niño activity. Frames b and c show decreasing cloud cover over boxes in South America and Indonesia, respectively. The year–year variations in these boxes are also greater in magnitude than the trends, which show a decrease of roughly 10% over 26 years. This figure shows that while significant trends in these areas are apparent, the trends are not drastic and it is still normal to see above or below average cloud cover during any given season. p0235

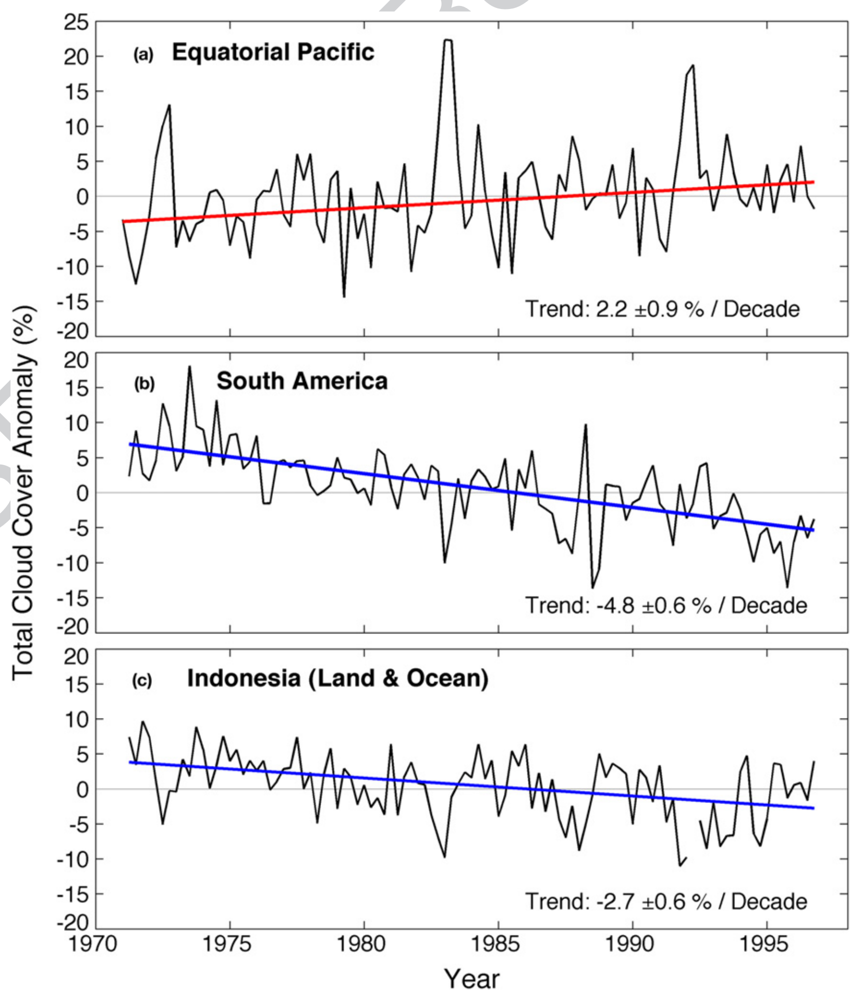
At present it is difficult to obtain reliable multiyear trends of cloud amounts from satellite observations because of the short p0240



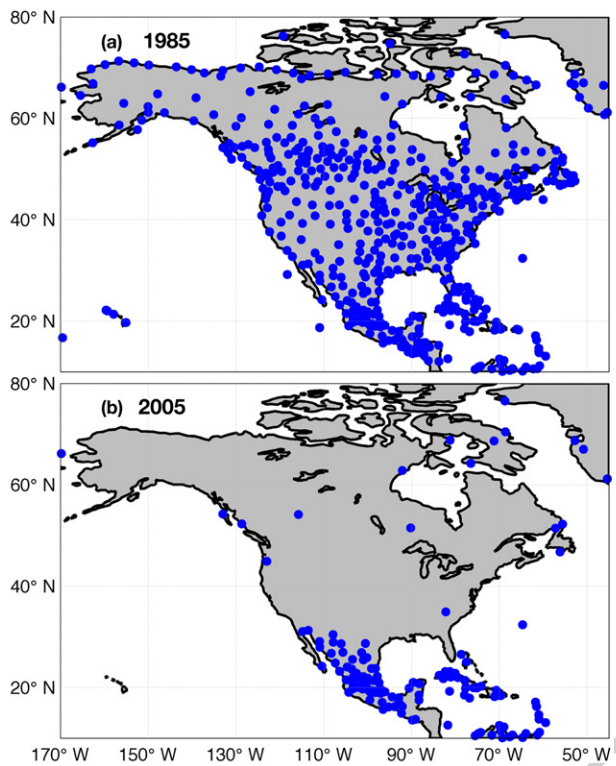
f0040 **Figure 7** Seasonal average daytime amounts of St plus Sc, and seasonal average SST for two grid boxes in the Pacific Ocean. (a) JJA, 30–40° N, 160–180° W. (b) JJA 0–10° S, 80–100° W. The SST is plotted on a reversed scale to illustrate the correlation. (SST data provided by the Hadley Centre HadISST1 product.)



f0045 **Figure 8** Yearly average trends (0.1%/decade) in total cloud cover over land and ocean (1971–96). Boxes A, B, and C used in **Figure 10** are labeled.



AU22 f0050 **Figure 9** Time series of anomalies (percent departure from seasonal average) of total cloud cover in the three grid boxes outlined in **Figure 9**. Each point represents one seasonal anomaly. Trend lines are fit to the time series and shown in red (increasing) or blue (decreasing).



f0055 **Figure 10** North American weather stations contributing cloud observations to the global climatology in (a) 1985; and (b) 2005. AU23

lifetime 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 underway to address these problems, and it can be expected in the future to see an increase in the use of satellite observations to detect long-term changes of cloud amounts.

s0065 The Future of Cloud Observations

p0245 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, three nations (United States, Canada, 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 US declined from 241 stations in 1981 to only about 27 by the end of 1996. This transition is illustrated in Figure 10, which plots the locations of weather stations reporting visual cloud observations in 1985 and 2005. While Mexico, the Caribbean, Bermuda, Venezuela, remote Eastern Siberia, and Greenland have dutifully continued to report cloud observations, the United States and Canada currently furnish only a handful of reliable weather stations. The United States, Canada, and New Zealand together represent 4% of the Earth's surface, so future global analyses of cloud changes from surface observations will be restricted to the remaining 96% of the globe.

See also: Cirrus Clouds; Climate: Radiative Aspects; Cloud Chemistry; Cloud Microphysics; Cloud Modeling; Cloud-Radiative Interactions; Clouds: Classification; Clouds: Formation Processes; Clouds: Measurement techniques *in situ*; Cumuliform clouds; Noctilucent Clouds; Parameterization of Physical Processes: Clouds; Polar stratospheric clouds; Radiative Transfer: Cloud-Radiative Processes; Satellite Remote Sensing: Cloud Properties; Stratus and Stratocumulus Clouds. AU19

Further Reading

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