Clouds are a very important part of the earth-atmosphere system. They affect and are a part of a multitude of processes. The radiation budget is affected by clouds because of mainly their reflectance of the incoming shortwave radiation, and their re-emittance of the long wave radiation back to the surface. The distribution of clouds can affect the radiation budget which may change the local and global surface temperature. This change of temperature may in turn have an effect on the global cloud distribution.

Clouds are also important for certain chemical processes. The most notable example of this is polar stratospheric clouds, which allow heterogeneous chemical reactions to occur on the droplet surface and ultimately leads to the destruction of ozone. Clouds are also incredibly important in the water cycle, because clouds transport quite a bit of water through the atmosphere and clouds also are where water condenses and falls back to earth. One last phenomenon, which clouds are necessary for, is lightning.

Clouds themselves are highly variable in many aspects including size, location, composition, lifetime, lifecycle, formation mechanisms, and many other properties. This variability leads to some trouble in defining clouds. However, clouds may be defined as a suspended population of hydrometeors. Differentiating cloud type is also important since there is this high variability in cloud type. Cloud classification is now pretty well established.

The first step in gaining some insight into cloud climatology is to simply observe them. A good historical review of cloud observations is discussed in Hughes (1984). Before the use of satellites, the primary tool to study the clouds was through human surface observations, which come from various locations over land and from detailed ship logs over the ocean. These observations may be compiled to get a good representation of the global average cloud cover. This was done by Warren, et al (1985). There are several limitations to this observing method. These include no information at night, limited coverage (especially over the oceans and sparsely populated regions), multiple cloud layers may be undetectable, non-independent observations (if the
observations are taken too close to each other), and a possible human bias, but this error may be only contained in the statistical noise if a large enough sample size is used.

Using this information, a global, zonally-averaged cloud cover frequency may be obtained. Warren, et al. have plotted this and that figure is shown in Fig. 1 at the end of the text. This analysis produces a reasonable plot. Looking at the plot of clear sky frequency (bottom left), minima are observed in three locations. The most intense minimum is near the equator where the inter-tropical convergence zone is located. This convergent zone explains why there is a quite a bit of cloud cover here. The two maxima represent where subsidence is generally occurring on climate scales, hence there are not as many clouds are here. The secondary minima near mid-latitudes are present due to the presence of mid latitude weather systems. The cloud cover tends to be less near the Polar Regions but the data here begins to become rather sparse. Additional plots are shown using more specific cloud properties such as plotting the frequency of cirrus or cumulonimbus for example. The same general reasoning as above may be used to explain these more specific plots.

With the advent of satellites, quite a bit of additional information may be added to our examination of cloud climatology. These satellites are basically passive radiometers that orbit the earth in either a geostationary or polar orbit. They can observe what is below them by detecting the radiation that is received. There are two main regions of radiation that are frequently used and both have slightly different interpretations. The first region is shortwave radiation. This is typically in the visible range of the radiation spectrum and is the reflected shortwave radiation that originates from the sun. Because of this, visible detection is only useful during the day. The second region is the long wave radiation. This is radiation that comes from the objects themselves with an intensity depending primarily on temperature and is not reflected as the shortwave is. Because of this, the detection of clouds may occur both during the day and at night.

A great source of satellite information pertaining to cloud climatology comes from the International Satellite Cloud Climatology Project (ISCCP), which was established in 1982. This source of data allows for a good quantitative assessment of the global cloud cover. Rossow, et al (1993) presents some ISCCP data that is compared with other sources of data such as surface weather station reports and the Nimbus-7
satellite information. While this paper discusses that there is some uncertainty in the results, it shows a reasonable agreement between the different data sets and their associated, inferred cloud cover. Most notably, the global, annual cloud cover given by all methods is just under two thirds percent with a root mean square error of 5.7% including all the data sources, and only 1.4% excluding the Nimbus-7 data. This data is also broken down by region and season to provide further insight into the general cloud climatology.

As of now, the method of detecting clouds using satellites has not been discussed. The basic idea behind detecting the presence of clouds is simply the difference in radiation received between the clouds and the surface. This basic idea becomes quite complicated, however, when it is implemented. For example, when looking in visible ranges, there may be white snow on the ground reflecting quite a bit of shortwave radiation and covering part of this snow covered region there may be white clouds, reflecting nearly the same amount of shortwave radiation as snow. Similarly, when looking at longer wavelengths such as IR there might be a case where there are relatively low clouds over a cold surface. Both would emit radiation that is similar, since they are near in temperature. An example of this is may be broken low marine stratus at night over a relatively cold ocean.

There are several specific methods that are used to objectively determine cloud cover with satellites. Some are simply cloud detection schemes, while others detect clouds and also provide some analysis, such as cloud type (cirrus vs. fog). These specific methods are now briefly presented and are obtained primarily from Goodman (1987). The first method detects clouds using a single channel threshold technique. The appropriate property is measured by the satellite and compared to some set criteria that determine whether the measured radiation is significantly different from a non-cloudy radiation measurement. This is represented mathematically as

\[
R > R_s + \Delta R \\
T < T_s - \Delta T
\]

where \(R_s\) and \(T_s\) are the criteria and \(\Delta R\) and \(\Delta T\) are the thresholds for the separate channels.
A second method, referred to as multispectral, combines both channels to detect the presence of clouds by plotting IR vs. visible. This method also provides some additional insight into the cloud type depending on what region one is in. For example, a relatively cold cloud that reflects a high amount of shortwave radiation would suggest some type of cirrus.

A method known as statistical retrieval uses the peaks and clusters of a histogram to identify the presence of clouds and the type of clouds. Finally, there is a technique that plots the radiation against the variability. This produces a scatter plot that tends to arc with points of low variability at the ends of the arc that indicate a totally clear sky and a totally cloudy sky. There are other methods that include logical diagrams that attempt to further refine the results by the combined use of the various sources of data to provide one result.

SAGE is another type of satellite that may detect clouds, but it is quite different then the standard satellites in that it gets its information from looking at the occultation at sunrises and sunsets so that it looks at near horizontal slices of the atmosphere. This method has the distinct advantage of being able to detect high thin clouds that may be undetectable by the standard satellites. However, the spatial and temporal resolution is limited in that it uses information only by looking directly at the sun (moon) during only the sunrise or sunrise (moonrise or moonset).
Fig. 1. Zonal, annual average frequency of occurrence of each cloud type, of clear sky, and of sky obscured due to fog, for land and ocean parts of each zone. ["Frequency of occurrence" is the fraction of weather observations in which a cloud type was reported present, given that it was possible to see whether it was present, irrespective of the fraction of the sky actually covered by that cloud.] A smooth curve is drawn through the points, which represent 10° zones over land and 15° zones over ocean (except for the high-latitude ocean zones 60°-80° N and 60°-70°S). The points are averages of all four seasons. Clear sky, fog, and cumulonimbus frequencies are plotted in the lower frames on an expanded scale. Gaps appear in most of the plotted values for land at 40°-60°S because the small amount of land there (less than 5%) often resulted in unrepresentative or meaningless zonal averages.
References


