I. Introduction
Clouds are important in the earth’s climate system in that they affect the Radiance balance of the earth. Clouds affect the albedo of the earth, which has an immediate effect on the temperature of a region. Clouds act as ‘blankets’ because they absorb and re-emit IR radiation. Clouds vary in form, thickness, size, lifetime, phase and water content. Each cloud is therefore unique in properties. This introduces complexity.
Clouds can be classified into certain cloud types. An object of cloud climatology is not only to identify whether clouds are present, but also to describe how many, and what type is present. The better description of cloud amount and (co-occurrence of) different cloud types, the more precise radiation calculations of climate prediction models can be made.

II. Cloud Models
Clouds are tough to predict in a model: 1) covers a very large scale from aerosol (<0.1µm) to entire system (>1000km), 2) different growth rates of clouds, 3) each cloud has a different lifetime, 4) each cloud has a different climatological impact. A climate model cannot deal with all these variables. Several properties that are important in climate include integrative properties like scattering coefficient or emissivity, and physical properties like shape, size or number of particles. Clouds are also important in other aspects, including the water cycle, chemistry (chemical balance of the atmosphere), atmospheric electricity (which effects temperature), visibility, and human activity.
Besides the fact that clouds affect the earth’s climate because they affect its radiance balance, there is also a two-way relationship between cloud chemistry and climate in the radiation system: 1) the cloud influences the chemistry in that it can promote certain chemical reactions, and because it increases the surface available for reactions. 2) Chemistry influences the cloud, for example in the case of CCN.

III. Cloud Detection
Clouds can be detected in two ways: from an observer at the surface, or via remote sensing (i.e. satellite climatologies). An observer at the surface can describe the cloud coverage of the sky by dividing the sky into parts (e.g. oktas, or eights). He will then describe how much cloud, or what type of cloud is in that area. According to Goodman and Henderson-Sellers (1988) many surface-based observations offer the only satisfactory means of detecting (a) small scale structures, especially fair weather cumulus and gaps in cloud desk, (b) thin cirrus, and (c) low cloud amount and type in the presence of middle- and high-cloud layers. These observations however depend on the observer-cloud geometry. For example, if you look at an angle to the cloud, the cloud appears to be larger than what the satellite detects from straight above. A ground observer also would not be able to see upper level clouds if there are low level clouds. Cloud identification also depends on the observer; one might name it this, they other might name it differently. There is also the problem of coverage; observers are not spread across the
globe evenly. Another aspect is that cloud detection is almost day-time only; it is hard to observe clouds at night.

Most of these problems are fixed by the use of satellites. Two types of satellites are used: Geostationary and Polar Orbiting. Geostationary, or GOES, satellites have the advantage that they can look at the same area to provide continuous monitoring needed for intensive data analysis, because they orbit the equatorial plane of the earth. They do however have less spatial resolution. Data from GOES series is used to look at local events in more detail.

Polar Orbiting, POES, satellites have the advantage of daily global coverage, because they make (nearly) polar orbits roughly 14.1 times daily. It has more spatial resolution. The POES system includes the Advanced Very High Resolution Radiometer (AVHRR) and the Tiros Operational Vertical Sounder (TOVS). Data from POES series are used in a wide range of environmental monitoring applications.

Another type of Polar Orbiting satellite is the SAGE (Stratospheric Aerosol and Gas Experiment) satellite. Unlike POES and GOES, which look down through the atmosphere, SAGE looks through the atmosphere horizontally, towards the sun (or moon). It obtains direct measurements of solar intensity, by continuously scanning the atmosphere from “top to bottom” during events (sunrise and sunset). SAGE is mostly used for detecting (no classification) high clouds, which other satellites cannot see. It has the advantages of having a low detection threshold, and a high vertical resolution. Satellites have the advantage that they can look at cloud cover with different wavelengths. From the amount of radiation absorbed, emitted reflected or scattered (dependent on the wavelength) the amount or even type of cloud cover can be determined.

Several types of ground-based observational studies have been performed. Warren et al. for example expressed their results as frequency of occurrence (excluding cloud amount) of different cloud types and as so called contingency probabilities where probabilities of certain cloud types to occur together is computed. New et al. on the other hand did a study on zonal mean cloud cover, which includes the amount of cloud. This makes it hard to compare results between the studies.

IV. Satellite-climatology: cloud retrieval algorithms.
The satellites used are passive radiation instruments taking measurements, including in the visible and IR, of incoming solar radiation, absorption, re-emission and reflectance, to detect and quantify clouds using cloud retrieval algorithms. A minimum brightness (or background radiation) of a region is determined when no clouds are present. It is subtracted from the total brightness of an area to determine the brightness, or albedo, from the clouds alone. A threshold technique (Goodman and Henderson-Sellers, 1988) is used to derive cloud cover from the data. A single channel technique looks at one pixel at a time and determines whether it is cloudy or clear. The threshold is defined as an increment in either visible reflectance or infrared brightness temperature, where a pixel is labeled cloudy if \( R > R_s + \Delta R \) or \( T > T_v + \Delta T \). However, problems with this threshold algorithm arise as it is hard to ascribe a radiance value to partially cloudy pixels or semi-transparent clouds. Even the value of the background radiance is hard to determine: averages have to be made over certain areas (green trees vs. snow) and in time (it could
be cloudy for days). Noise due to cloud contamination is removed by spatial filtering. After this the threshold increments, typically 3% reflectance and 6K brightness temperature can be applied.

A multispectral technique compares visible properties to IR properties of clouds and land, and ocean and cryospheric surfaces as a function of their optical depth, height, density and thermodynamic phase to infer cloud type. A simplified box classification diagram (see figure 1) can be used to show the results of the separation of various cloud types and surfaces in a two-dimensional radiance space.

To determine cloud type more effectively, a statistical retrieval technique is used. Statistical techniques can treat large groups of pixels at once, corresponding to each surface type. There are three ways to partition the multidimensional frequency histograms into representative classes. The first is a Gaussian histogram analysis (see figure 2), which fits a normal distribution function to one- and two-dimensional frequency histograms, so that it can isolate certain clusters. The second uses a dynamic clustering algorithm, which involves the use of several thousand pixels in a test-run. The histograms are then produced from this test-run. It produces the number of classes separated, their centers of gravity and variances, and the percentage of pixels from the test-run in each class. This scheme however does not do very well in larger-scale classification, because it has difficulty with pixels of adjacent segment, and segments at varying time-intervals.

The third is a spatial coherence algorithms (see figure 3), which assumes that (a) the clouds are situated in distinct layers with each layer possessing a temperature appropriate to its altitude, and (b) all the clouds in a layer emit radiation that is characteristic to that layer. This allows estimations of radiances of each layer in a completely cloudy region to be made. Because it uses only the IR channel, it can be used for diurnal cycles. The fractional cloud cover ($A_c$) for a single layer region is given by:

$$A_c = \frac{(I - I_s)}{(I_c - I_s)}$$

where $I$ is the mean radiance.

(Right side of the plot indicates clear sky; left side indicates full cloud)

Several types of satellite-based studies have been performed. The International Satellite Cloud Climatology Project (ISCCP) started analyzing cloud cover and cloud properties globally in 1983. It uses both GOES and POES satellites, sampling both in the visible and infrared spectrum. Its detection procedure is applied to each month of satellite data at eight times of day and consists of five steps (Rossow and Garder 1993a). Each step tests a certain aspect of what the satellite sees, sometimes averaged over time or space, to determine the whether an area is cloudy or clear over land or ocean: 1) space contrast test; applied to individual IR images, looks at temperature differences of cloud vs ground over land and over ocean to determine cloud. 2) Time contrast test; three consecutive IR images at constant diurnal phase, at the same place, same hour, over 3 days. 3) Cumulation of space/time statistics (both in IR and VIS images). 4) Construction of clear-sky composites for both IR and VIS (once every 5 days at each diurnal phase and location, and 5) radiance threshold (both VIS and IR). Results ISCCP indicate that global annual mean cloud amount is ~63%, being ~23% higher over oceans than over land. Most seasonal variation is found at mid-latitudes, with least at the poles. It also shows
that land has a higher cloud value during daytime as compared to nighttime and ocean as a higher value during daytime as compared to nighttime (Rossow and Garder, 1993). ISCCP tends to underestimate low cloud amounts as compared to surface observers, but overestimates as compared to very high spatial resolution satellite observations. In general though, human observers tend to overestimate low cloud amounts as compared to satellite, and vice versa for high cloud amounts.

V. Conclusion
It is obvious that clouds and the effect of clouds on climate are very complex to describe and study. There are many ways to test cloud amount and properties. Cloud detection from an observer’s point of view is the most direct, but the variety of studies performed makes it hard to compare results; cloud amount vs. cloud type vs. frequency of occurrence, etc.. Cloud detection from a satellite is even more complex. Depending on the type of satellite, different aspects (amount vs. type vs. height) of cloud can be retrieved. Satellites use complex retrieval algorithms and contrast or threshold tests to infer cloud from the amount of Visible and IR radiation measured. A range of studies can be performed, averaging cloud amount and/or type over time or space, so that ultimately a cloud climatology can be made. Of course the same problem arises here, in that it is hard to combine the results from these differing studies. Improvements to cloud models and ways to describe clouds are continually made. Because cloud detection and classification from an observer’s point of view will probably never be perfected on global scale (people will never completely agree with each other on classifying clouds, and there is always the problem of coverage), I think satellites will become more and more important. A lot of research, including on effect of resolution and method of data analyzation, has to be done to increase the accuracy of cloud detection and classification by satellites.
Fig. 1. Position of various surfaces in visible (channel 1, 0.58-0.68 μm) and infrared (channel 11.5-12.5 μm) intensity space from NOAA-7 AVHRR data from August 10, 1983.
Fig. 2. One dimensional frequency histogram for the infrared AVHRR channel (11.5-12.5 µm) for a certain subscene.
Fig. 3. Spatial coherence plot of local mean infrared radiance AVHRR channel (11.5-12.5 µm) versus local infrared standard deviation for 3x3 pixel array. Units are radiometric counts.