I. Introduction
Scientist are not only interested in developing precipitation climatologies just to be able to make better weather forecasts for certain areas, but also because they are useful for various other aspects of climate related studies. The amount of precipitation for instance affects the hydrology an area, and is therefore important determining sources for water use. Fresh water fluxes are also an indirect measure of local latent heating, which drives atmospheric circulations. These fluxes also affect the circulation in the oceans, which in turn have a large effect on the atmosphere.
In a similar way as with cloud climatologies, data for precipitation climatologies are collected by two ways: using surface measurements and/or remote sensing.

II. Measuring Precipitation
A precipitation climatology can be made by describing Rain Amount or Rain Rate of a certain area. Note that precipitation does not have to consist of rain solely; substitute Snow Rate/ Snow Amount, or Precipitation Rate/ Precipitation Amount. Rain amount is typically measured in millimeters or inches. Rain rate is a measure of amount per unit time, which is typically measured in millimeters per hour or inches per hour. While rain amount can be used to describe both total rain of an event and rain accumulated over a certain amount of time (say a year), rain rate is usually only used to describe the intensity of an event (i.e. shorter time periods).

A. Surface Measurements.
A large range of instruments can be used to measure precipitation rate (mm h$^{-1}$) or precipitation amount. An instrument used to measure rain amount is called a rain gauge, typically consisting of a graduated cylinder. Even though this is the simplest to measure it is still subject to errors. First of all there is human error (handling the cylinder). Secondly, water can continually be evaporating from the cylinder, which decreases total amount. Thirdly, incoming precipitation can splash off the instrument, which also causes a decrease in total amount. Aerodynamic effects can also influence the amount.
Because rain rate has a large range of values, it is harder to measure. A different instrument is needed depending on the intensity of rainfall expected. Instruments used to measure precipitation rate include a tipping bucket, a weighting bucket, a snow pillow, or a hotplate. Same errors as for precipitation amount apply to precipitation rate, along with some extra, including errors due to the fact that an instrument may not be ranged to sample certain precipitation rates, and mechanical errors of the (tipping) instruments themselves.
Rain rates can also be estimated from ground-based radar observations. According to the type (depending on area, season and intensity) of rain to be detected, a Z-R relationship is applied. Typically of the form: $Z = a\left(\frac{R}{R_0}\right)^b$. Where a and b are constants, Z is the reflectivity, and R is the rain rate. R and Z are obtained from rain gauges and radar. But the radar looks at a very large volume, while a gauge can only sample a very small area. Another problem occurs as the radar doesn’t sample the same area, in that it samples about a km above the gauge. This is solved by having the radar...
scan an entire volume, from which you can obtain a size distribution. By taking the 6th moment of this size distribution you obtain the reflectivity. This reflectivity is then related to the rain rate. An obvious advantage of the radar is that it can cover a wide area very fast. Radar observations are often used to ‘validate’ observations made by satellites (see Auto-Estimator; Vicente et al.,1998, Kebe et al. 2005).

Kebe et al., for example performed a study using an area-time integral (ATI) method using data from radar or satellite IR to estimate an area-averaged rain-rate distribution and rainfall amount.

**B. Satellite Measurements.**

Same as described in the cloud climatology, precipitation can be measured from space. Both polar and geostationary satellites are used to obtain a global coverage. Because rain doesn’t have much of a visible impact, using radiation in the visible range (which is used in cloud climatology) to detect rainfall is not very useful. There is also the fact that you’d have to see through cloud to detect rain. Passive remote sensing in the IR wavelengths combined with active remote sensing in the microwave region and space borne radar are used to obtain a description of the precipitation.

Rainfall estimates derived from passive radiometric observations can be divided into two classes: direct, or observations of precipitating particles, and indirect, or observations of anything else (Arkin and Ardanuy, 1989). Indirect estimates of rainfall rely on the fact that rainfall is nearly always associated with clouds of some type and temperature, and second on the observation that higher and/or thicker clouds appear to be associated with heavier of more frequent precipitation. Direct rainfall estimation techniques are based on observations of the radiative effect of precipitation-sized hydrometeors. It uses observations of radiation at frequencies in the microwave region, because they are not affected by cloud droplets or by the gaseous constituents of the atmosphere.

GOES satellites use a technique that measures the cloud top temperature in the IR and relates it to rain rate. The GOES Precipitation Index (GPI) (Arkin and Meisner, 1989) assumes that a cloud with temperatures below 235K produces rain at a certain rate. It applies an algorithm with the basic equation: 

\[ P(\text{mm}) = \text{Rate} \times F_c \times t \]

Where \( P \) is the precipitation in mm, \( F_c \) the fractional coverage of IR pixels below 235K, and \( t \) is the time in hours, and the rate is a constant at 3 mm/hr.

This method works well over the plains and flat areas, but not over the mountains. This has the advantage that it can be applied over the oceans, where other means of rain detection are limited. It has the disadvantage that the geometrical effects result in increased apparent cloud cover, correspondingly lower brightness temperatures, and erroneously high rainfall rates in regions that are far from the satellite nadir point.

In cases where geostationary data are unavailable, the National Oceanic and Atmospheric Administration (NOAA) polar-satellites are used to provide three-class histograms of brightness temperature.

A GOES IR rainfall estimation technique that uses several rain rates is the Auto-Estimator (Vicente et al.,1998). Its precipitation rates are initialized using a power law fit between instantaneous radar derived rain fall estimates combined with satellite measurements of IR brightness temperatures at cloud top (see fig. 1). The regression fit is given by 

\[ R = 1.1183 \times 10^{11} \exp[-3.6382 \times 10^{-3} \times T^{1.2}] \]

where \( R \) is the rainfall rate in mm hr\(^{-1} \) and \( T \) is the cloud top brightness temperature (K). The ETA model generated relative humidity (RH) and precipitable water (PW) are used to analyze the environmental
moisture and scales the rainfall accordingly. The graph indicates that at temperatures < 210K, the rainfall rates increase rapidly with a small increase in T. And vice versa for T < 210. The Auto-Estimator can also apply a ‘mask’ in that it assumes that decaying clouds or clouds with cold cloud tops that are becoming warmer produce little or no rainfall. The rainfall rate is modified as follows: If the coldest IR pixels in the first image are colder in the second image, the convective system is intensifying and the pixels in the first image are associated with the heaviest precipitation rates. If the coldest IR pixels in the first image are warmer in the second image, the convective system is weakening and upward vertical motion has likely ceased. The rainfall rate for those pixels is then adjusted to zero. If there is no change in cloud top temperature in the pixels, the rainfall rate remains the same.

POES satellites have the advantage that they are able to use active remote sensors because they are in closer orbit to earth. Active sensors, like the radar, have to be close to the target, because they measure their own returned signal. Due to their wavelength they can ‘see’ through the cloud to obtain information that most passive instruments can’t. Examples of satellite based radar include the one mounted on the Tropical Rainfall Measuring Mission (TRMM) and the future short wavelength radar to be mounted on the CLOUDSAT. A passive instrument that can ‘see’ through the cloud is a microwave radiometer. The microwave brightness temperature ($T_b$) depends on the emission from the earth’s surface and is modified by the intervening atmosphere, mostly due to hydrometeors. The radiometers use two algorithms, one for ocean regions based on emission and the other for land areas based on scattering.

There are four NOAA satellites carrying Microwave Surface and Precipitation Products System (MSPPS) instruments. The newer instruments are called Advanced Microwave Sounding Units (AMSU) and Microwave Humidity Sounders and are used to retrieve rain rates. Some earlier microwave sounders are the Defense Meteorological Satellite Program (DMSP), the Special Sensor Microwave Imager (SSM/I), and the Temperature Sounder/2 (SSMT/2). The current MSPPS products include: rain rate, total precipitable water, cloud liquid water, falling snow, snow cover, snow water equivalent, sea ice concentration, ice water path, emissivity (23.8 GHz, 31.4 GHz, and 50.3 GHz), and land surface temperature. The rain retrieval over land however is much more difficult that over the ocean. Water surfaces have low emissivity, so the emission signal in the lowest-frequency channels is clearly detectable over oceans. Because the suspended liquid associated with clouds/rain and the land surface are both strong emitters, retrieval over land is based on the scattering signal of millimeter sized ice hydrometeors in precipitating atmospheres. There are two steps to retrieve rain rate: rain identification and rain rate retrieval (Ferraro et al., 2000). Rain is identified by identifying a scattering signal at frequencies above 37 GHz, while the rain rate is retrieved empirically or physically.

III. The Global Precipitation Climatology Project

The Global Precipitation Climatology Project (GPCP) was established by the World Climate Research program (WCRP) in 1986 with the initial goal of providing monthly mean precipitation data on a 2.5°× 2.5° latitude -longitude grid. Starting in 1979 monthly mean precipitation estimates were being produced, and are planned to go through 2005. The GPCP has accomplished this by merging IR and microwave satellite
estimates of precipitation with rain gauge data from more than 6,000 stations. Infrared precipitation estimates are obtained from GOES (United States), GMS (Japan) and Meteosat (European Community) geostationary satellites and National Oceanic and Atmospheric Administration (NOAA) operational polar orbiting satellites. Microwave estimates are obtained from the U.S. Defense Meteorological Satellite Program (DMSP) satellites using the Special Sensor Microwave Imager (SSM/I). These data sets are used to validate general circulation and climate models, study the global hydrological cycle and diagnose the variability of the global climate system. Data sets have been expanded so that in addition to the monthly mean product available, the GPCP now has a 2.5°×2.5° degree pentad data set starting in 1979 and a 1°×1° daily data set starting in 1997. (Huffman et al., 1997)

IV. Some Results

- On a continental scale, rain amount is mostly affected by two things: the topography, in that mountains cause increased rainfall in certain areas, and also the land/ocean relationship, which has a great effect on the West-Coast of the USA, and the Gulf area. These effects however can also be seen on a smaller scale: The Western states get most precipitation in winter, whereas the eastern states get most precipitation in summer. In the Northeast precip amounts are pretty much equal during the year. The middle of the country has a max of precip in summer. The USA has a unique geographical influence; these patterns are not seen on other continents.
- On a global scale (Huffman et al., 1997) the topographic influence has much less of an effect than on a local scale due to the resolution of the satellites. Combining data from microwave sensors, GPI (multi-satellite) and rain gauges, the main lobes of highest amount of annual precipitation can generally be found to the east of the North American, South American, Asian, and Australian continents, and along the ITCZ (Fig. 2).
- Annual-mean precipitation in the equatorial region is 8-16 mm day$^{-1}$.
- Annual-mean precipitation in the mid-latitude region is 0-4 mm day$^{-1}$.
- Passive microwave techniques generally work very well for maritime clouds over the ocean, but the performance is poor for warm clouds over land. Only with applied algorithms, which can identify clouds with a cloud-top microstructure favorable for precipitation, can these cases be handled well.
- The microwave radiometer uses algorithms that work best in convective systems. Comparing the AMSU microwave product against the NEXRAD radar, the rain patterns and regions of heaviest rainfall are in agreement. However, regions of light rainfall are not at all detected by the AMSU because of their weak intensity and small scales.
- Results show that the auto-estimator does moderately well at the 1-hr time resolution for a spatial resolution of 12 km, and that results improve with increasing grid size. This makes it a good technique for providing rainfall estimates of fast moving deep convective systems (flash-floods, etc.).
V. Conclusion

Same as with the cloud climatology, it is obvious that a precipitation climatology is very complex, if not more complex, to describe and study. There are many ways to collect data on precipitation rate and amount. The simplest ways is by means of surface observations through rain gauge type instruments. These can however only sample a very small area as compared to the that a radar or satellite looks at. The global coverage of gauges is also extremely minimal.

Again, a whole range of studies can be performed, averaging precipitation amount and/or rate over time or space, so that ultimately a precipitation climatology can be made. Of course the same problem arises here, in that it is hard to combine the results from these differing studies. Little also seems to be known about the specific biases of the retrieval methods.

The main goal is I think to look for means by which observations and estimates of rainfall, of widely differing characteristics, can be integrated into a global analysis. This would use rainfall estimates made from various instruments in differing ways, along with radar and station observations, with an initial guess possibly derived from a forecast model to produce a global analysis of rainfall accumulations for some short time period. This includes a lot of research on the effect of resolution and method of data analyzation of the satellite data.

VI. Figures
Fig. 1. Radar rain rate and GOES-8 temperature.

Fig. 2. NASA GPCP Annual Precipitation Climatology
Fig. 3. Eight-year (1988-95) annual mean precipitation in mm day\(^{-1}\) for SG (top), Jaeger climatology (J; middle), and Legates-Willmott climatology (LW; bottom). For each grid box, the J and LW averages only have contributions for months that have SG data. Blacked out areas denote regions with not estimate.

VII. References:

Figures:
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