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PRECIPITATION CLIMATOLOGY

General Overview

In constructing the global precipitation climatology, data from two modes of measurements are employed viz. point measurements and remote sensing. Precipitation measurements using these two modes have their own strengths and weaknesses. So, a combination of these modes is usually applied to derive the global precipitation climatology. Global precipitation climatology constructed using these two modes of precipitation measurements show distinct spatial and seasonal pattern. The maximum amounts of precipitation occurs within the Inter Tropical Convergence Zone (ITCZ) and so follow the ITCZ during its seasonal migration from south to north in transition from the austral summer to boreal summer. The minimum amounts are found at the subsidence zone, around 30° latitudes in both the hemispheres, where most of the world's deserts are located.

The global pattern clearly shows its dependence on the general circulation of the atmosphere but local effects, most notably orographic, modify it significantly. On a finer spatial scale, the precipitation pattern over land is clearly dominated by the orographic effects.

Introduction

Precipitation, a term that refers to aqueous deposits in solid and/or liquid phase falling from the clouds on to the surface of the earth, is a major component of the hydrological cycle. Rain is the most common form of precipitation but snow, hail, sleet, freezing rain are all collectively termed as precipitation.

The global distribution, seasonal and diurnal variation and intensity of precipitation affect not only human activity and economy but also the human settlement pattern, distribution of vegetation and animals. It is also a major source of natural disasters when it occurs at high intensity over an extended period of time causing inundation problems. It is, by far, the single most important component of weather and thus the climate. Because of its direct impact on human activity, economy and climate it is important to understand its pattern seasonal and diurnal variation.

Precipitation is a quantity that can be measured using measuring devices. The measure of precipitation is expressed in the units of length (volume per unit area), usually in millimeters or inch. There are instruments that measure its intensity (precipitation rate) and cumulative amounts. It is possible to measure the instantaneous precipitation rate but rates are commonly expressed in depth of precipitation per hour (mm/hour). Cumulative amounts are usually measured for periods of 24 hours.

There are two modes of precipitation measurement viz. point measurement, which includes the use of instruments e.g. gauges that measure precipitation falling on a given cross sectional area of the measuring device, and remote sensing using satellite and radar. Point measurements employ devices that can collect the precipitation falling over a known area and convert the volume collected to depth of precipitation by dividing the collected volume by the surface area of the collector device. Remote sensing method includes passive satellite estimation and active radar estimation. Radars are used both on grounds and airborne e.g. in aircrafts and satellites. Estimation using satellite remote sensing is difficult to carry out as it relies on physical, microphysical and radiative properties of clouds to estimate the precipitation.

Surface Measurements

Surface measurements provide a lot of data on point precipitation used to derive the precipitation climatology. Among the instruments for surface measurements, gauges are the simplest and the most widely used. Gauges are of two types (i) non-recording type that measure the amounts of precipitation collected for a specified time period, usually 24 hours and (ii) recording type that can measure the intensity of precipitation.

Non-recording gauges comprise of a receiver, usually having circular receiving cross section and a collector having smaller cross section than the receiver to increase the precision of the measured precipitation. For convenience, most collectors have one-tenth the cross-sectional area of the receiver so the depth of precipitation is tenth of that shown on the collector device. These are manual devices and need a trained human to read and record the precipitation. The reading is usually done once in 24 hours but twice or even four times in 24 hours is also common practice.

Recording gauges convert the volume of precipitation falling on the sensor to depth and record it. For rainfall, the most commonly used gauges are the tipping bucket and weighing bucket type. In the weighing bucket rainwater is collected on a cylinder and the weight causes a marker to record it on a rotating drum. It is calibrated to convert the weight of water to depth and is continuous as the drum is rotating so can be used to infer the instantaneous rain rates. The tipping bucket has two collectors that tip over when filled and the number of tips is recorded in the instrument. It also gives the rain rate.

Snow depth is estimated simply by using a gridded scale on the ground to measure the accumulated snow depth but the snow rates are usually expressed in their water equivalent. Snow is collected on snow gauge and melted down to convert to water equivalent depth. Various methods are employed to estimate the snowfall rates, the most common being the measurement of energy required to evaporate the snow falling on a plate to estimate the snowfall.

Instruments used to take precipitation measurements at the surface have their own shortcomings. Wind and turbulence, splashing on the receiver surface and evaporation from it introduce errors in the measurements. Besides, these instruments take point measurements and are taken to represent the region around it. A dense network is required to represent statistically sound estimates of precipitation.

Estimation using Remote Sensing

The use of remote sensing in developing precipitation climatology have been used since the late 1970s. Remote sensing estimate of precipitation includes both passive and active sensors.

Passive sensors comprise the satellite estimation inferred from cloud properties and radar estimates based on the Z-R relationships.

Precipitation is difficult to directly measure with airborne satellite measurements. Indirect methods use cloud physical and microphysical properties like cloud top temperature and cloud drop size distribution to estimate the precipitation rate. Visible and Infrared regions are used in the indirect measurement. Direct estimates are based on the radiative effects of precipitation-sized hydrometeors (Arkin and Meisner, 1987). Microwave region of the spectrum is employed in the direct estimation, as it is transparent to clouds and gaseous constituents of the atmosphere.

Indirect estimation of precipitation is based on the observation of clouds. It is based on the fact that clouds cause precipitation and higher and thicker clouds are associated with heavier precipitation. Visible reflectance from clouds and infrared brightness temperature of cloud tops is a common quantity used to infer the rain rates. For convective rainfall in the tropical region, Arkin and Meisner (1987) show that the precipitation can be estimated from the cloud top temperatures alone. Effective cloud top black body temperature from the GOES satellite is used to derive an index termed GOES Precipitation Index (GPI) and this index is used to estimate the precipitation rate from the convective clouds. For tropical convective clouds, it is taken temperatures below 235 K give precipitation of 3 mm/hr so the GPI is expressed as $GPI = 3F_c t$, where F_c is the cloud fraction with temperature below 235 K and t is the time for which F_c was the mean fractional cloudiness. Gilberto et al. (1998) derived a similar relationship between rain rate and cloud top temperature. In this estimate, cloud top brightness temperature derived from GOES satellite and rainfall estimate from radar are plotted to get the relationship between the cloud top brightness temperature and rain rate. The study shows that the rain rate and brightness temperature follow power law.

Direct estimation uses the radiative properties at the microwave region of the spectrum. It is affected by the emissivity of the underlying surface, absorption and scattering by the interacting medium, the precipitation hydrometeors. Absorption is dominant in the region below 22 GHz and scattering above 60 GHz (Arkin and Ardanuy, 1989). Both absorption and scattering properties of the hydrometeors are used in the estimation of precipitation. The scattering at higher frequency region can be used to determine ice and water hydrometeors in a cloud. Low brightness temperatures at the high frequency region of the microwave spectrum correspond to scattering by frozen hydrometeors and this is associated with heavy precipitation at the surface.

Some of the most commonly used passive microwave imaging instruments are Special Sensor Microwave/Imager (SSM/I) aboard Defense Meteorological Satellite Program (DMSP), Advanced Microwave Sounding Unit (AMSU) aboard NOAA polar orbiter satellites, Thematic Microwave Imager (TMI) etc. These instruments are multi-channel and provide more robust ways to estimate precipitation.

Radar is an active remote sensing instrument that operates at microwave region of the spectrum. It uses back-scattered signal from the scatters to derive a quantity called Radar Reflectivity Factor (Z) that depends on the size and the population of the scattering medium. The radar reflectivity factor can be used to estimate the precipitation by deriving a relationship between it and measured precipitation. This relationship is termed as Z-R relationship and is commonly employed to relate Z to precipitation rates.

Global Precipitation Climatology Project (GPCP)

GPCP was established to create global precipitation climatology with data from the operational satellites, both geostationary and polar orbiters, and surface observations. All three modes of estimation have their own limitations so a combination of these is sought to produce better climatology. GPI (Arkin and Meisner, 1987) is used for tropical region extending up to 40° N/S latitudes and it is supplemented by the Outgoing Long wave radiation (OLR), an index for precipitation derived from polar orbiting NOAA satellites. The microwave estimates are derived from SSM/I from the polar orbiters DMSP and is used to estimate the precipitation rates over ocean. The surface measurements have better accuracy than the satellite estimates but are limited to land areas and not evenly distributed over the world. Besides, measurement with gauges represents point measurement and averaging over unevenly spaced grids introduces inaccuracies. However, these data, both gauge and radar data are used in generating the precipitation climatology and as they are more accurate they are also used to validate and calibrate the satellite estimates.

GPCP provides monthly global precipitation climatology on a 2.5°×2.5° latitude, longitude grids. In the preparation of global climatology the microwave estimates from SSM/I is matched in time and space with the geostationary infrared GPI values. In regions lacking the geostationary satellite data, infrared GPI is used from the polar orbiter data and these are merged to produce adjusted GPI (AGPI) precipitation field (Huffman et al., 1997). The combination of the AGPI estimates, microwave adjusted polar orbiter data and microwave data in the region beyond 40° N/S is termed as multisatellite (MS) estimate and this estimate is used with gauge data to produce satellite/Gauge (SG) estimate.

The SG precipitation estimates produced from GPCP gives the global precipitation climatology. Global mean from SG estimate shows the basic features of the global precipitation pattern. Figure 1 shows the global precipitation climatology from GPCP. The global precipitation pattern clearly shows maxima around the ITCZ, Congo basin in Africa and Amazon basin in South America. Another maxima is seen in the western part of the continents extending up to sub-tropical region.

The dry zones lie in the eastern part of the sub-tropical oceans, the interior Asian continental region, the Sahara desert and the Asian gulf countries. Monthly means clearly show the northward migration of the ITCZ and thus the precipitation maxima. July mean from GPCP estimate shows the effect of South Asian monsoon with heavy precipitation in the Bay of Bengal area.

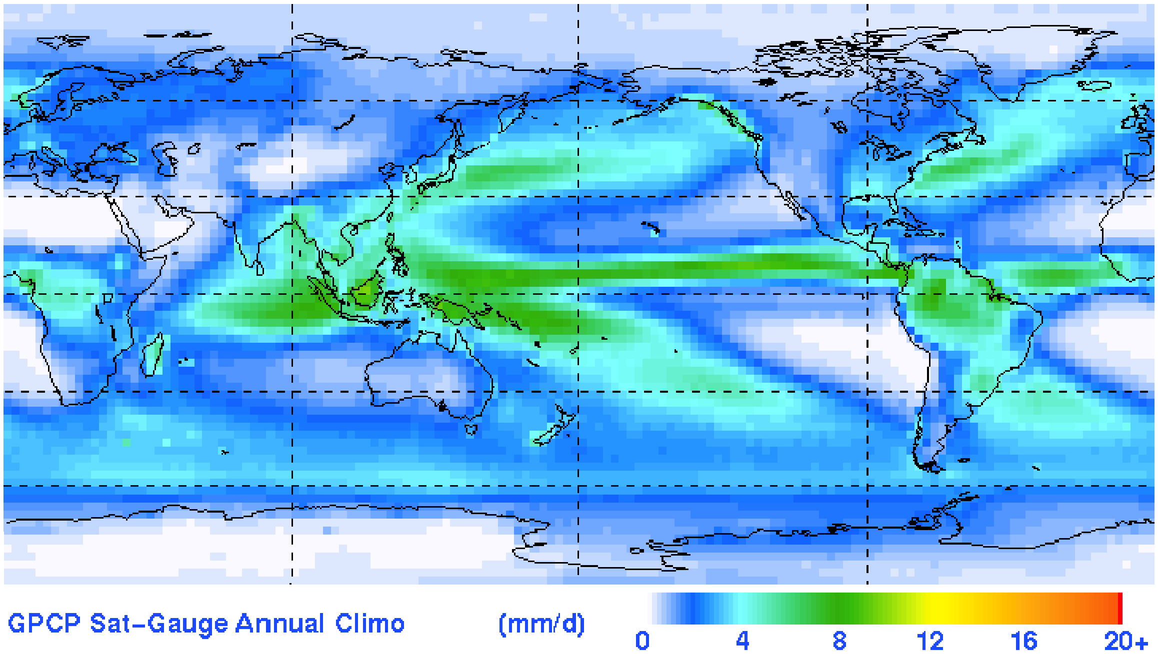

Figure 1: annual mean precipitation in mm/day

Conclusion

Satellite estimates of precipitation using visible and infrared spectrum relies on cloud properties and microwave retrieval mostly uses radiative effects but there is a large uncertainty associated with satellite retrieval. However, for climatological purpose and at a coarser resolution it provides some useful information on global precipitation. Based on these data, it is evident that global precipitation pattern is closely linked to the general circulation of the atmosphere but the uneven distribution of land and ocean causes changes in the precipitation pattern. On a finer spatial scale orography also plays a dominant role in the precipitation distribution.

References:

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