Lecture Notes **Prepared by Prof. J. Francis Spring 2003, updated '07**

Remote Sensing of Precipitation

Primary reference: Chapter 9 of KVH

I. Motivation -- why do we need to measure precipitation with remote sensing instruments?

=> QPF (Quantitative precip forecasting) is still a major weakness in weather forecasting

=> Climate models show large differences in simulated precipitation -- see following figure from the IPCC (Intergovernmental Panel on Climate Change) report.

Only small fraction of clouds produce rain, so **primary goals are** 1) identify precipitating clouds, i.e., is precip occurring or not? and 2) if it is precipitating, at what rate is it falling?

Three categories of methods to estimate precipitation remotely:

II. Visible and infrared techniques

III. Passive microwave techniques

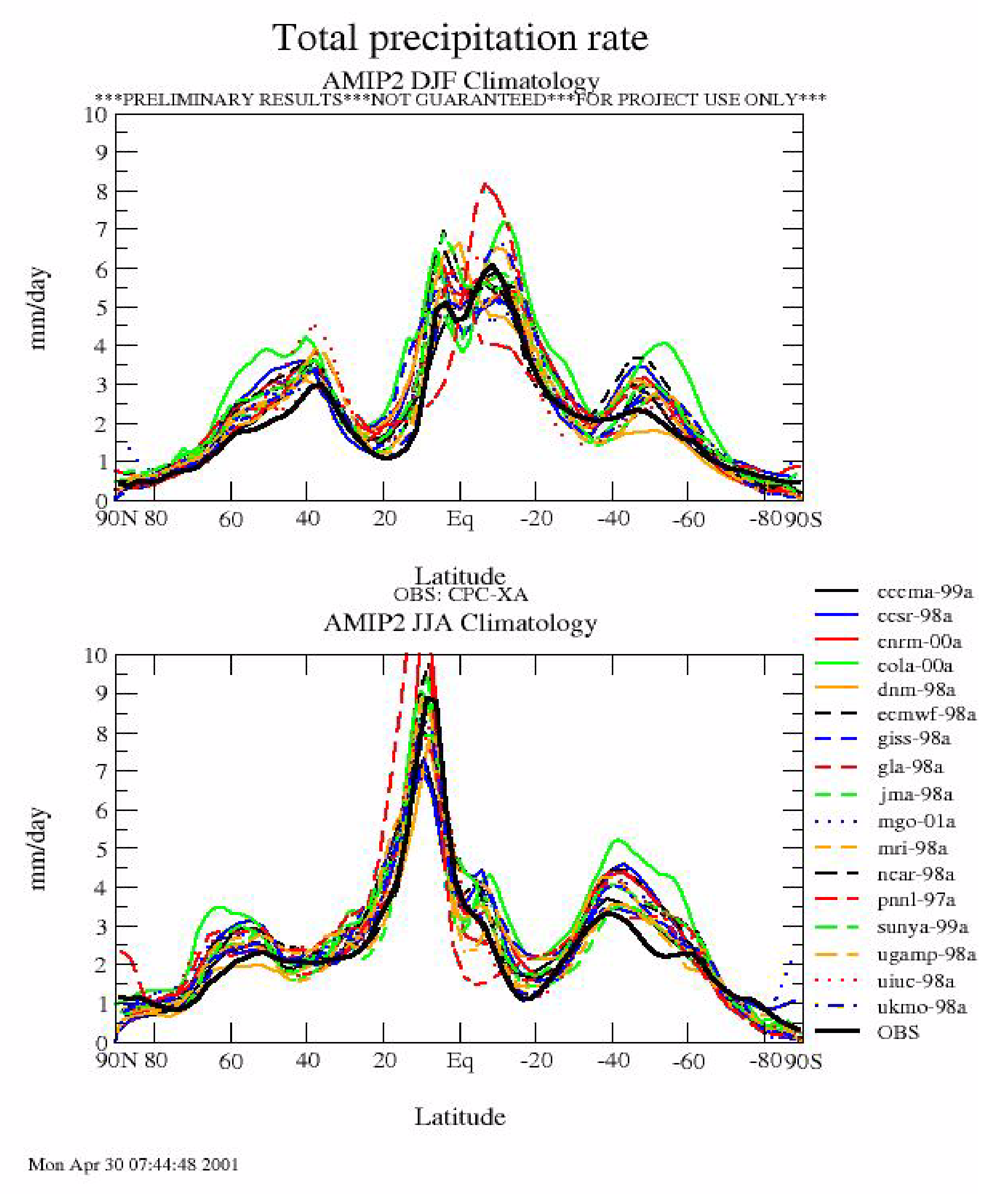
IV. Radar techniques

A problem common to all techniques is VALIDATION

=> Rain gauges are sparse and often not representative of large areas

=> No in situ measurements over oceans

=> Observations and remotely sensed quantities are sometimes apples and oranges



A comparison of climatological precipitation simulated by 17 global climate models. Black line is best estimate of truth. Top is December - February, bottom is June - August.

obtained from http://www-pcmdi.llnl.gov/amip/quick-look/

I. Visible and infrared techniques

Visible and infrared radiation does not pass through thick clouds, which means that radiation emanating from the cloud-top is being used to estimate precip from the cloud bottom (indirect measurement)

Algorithms may not be applicable globally -- e.g., techniques designed for tropical convection may not work for stratiform rain

A. **Cloud indexing technique** (e.g., Barrett (1970). still in use)

**** Fig. 9.2 in KVH*

Based on visible images only

Assign rain rate r to each cloud type i to determine total rain rate R in a region:

$$R = \sum_i r_i f_i ,$$

where f = fraction of time a pixel is covered by cloud type i, r_i is determined with gauge data, f_i determined subjectively. Works well for convective type precip.

**** Fig. 9.4* shows modifications by Follansbee (1973) for a regional mean

B. Cloud visible reflection method (Kilonsky and Ramage)

For conditions of tropical convection only

Tropical oceanic rainfall dominated by deep convection (highly reflective clouds, HRCs)

$$R = 62.6 + 37.4 N_D \quad \text{(Garcia, 1981)}$$

where N_D = number of days in month a location is covered by HRCs, R = monthly rainfall in mm.

****Fig 9.6*

C. OLR (outgoing longwave radiation) method (Arkin)

GOES Precipitation Index (GPI) -- rain depth in mm, mainly for tropics

$$GPI = 3f\Delta t$$

where f = fraction of area where temperature (estimated by OLR) < threshold, Δt = time period of interest.

E.g., for tropical S. Atlantic, threshold = 235 K, Δt = 3 hrs.

D. Bispectral techniques

Bright, cold clouds are most likely to precipitate.

Construct two plots with visible reflectance on x-axis and OLR intensity on y-axis. Weather radar is used to determine whether in each pixel in an image it is either raining or not raining.

***Fig. 9.8 shows resultant probability distribution of precipitation in vis/OLR space.

This technique works well for tropical conditions where rain is associated with thick, bright clouds that have high (cold) tops. This method works better than those using only vis or IR information. Regional dependence on probability and vis/IR values for rain/no-rain.

E. Cloud model method

Use numerical model to determine precipitation rates based on water vapor convergence, and relate this to observed visible and OLR.

II. Passive microwave techniques

Advantages: clouds (precipitating or not) are not opaque in microwave frequencies
precipitation-sized drops interact with microwave radiation and can be detected

Disadvantages:
microwave sensors have lower spatial resolution
ice crystals can contaminate signal

****Fig. 9.15* shows relationships among rain rate and rain drop scattering and absorption properties for ice and water in several microwave channels. The following properties are important for estimating rain rate from microwave observations:

- Ice crystals: scattering >> absorption, especially at high frequencies
- liquid drops: absorption > scattering, especially at low frequencies
- absorption k_a and scattering k_s coefficients are proportional to the rain rate R and channel frequency ν
- k_s for ice precip increases more rapidly with ν than does k_s for liquid drops
- for $\nu < 22$ GHz absorption in liquid dominates => ice has little influence on k_s or k_a so can measure rain rate well
- for 22 GHz $< \nu <$ 60 GHz absorption and scattering occur
- for $\nu > 60$ GHz scattering dominates, so signal corresponds to amount of ice particles

In terms of brightness temperature (or equivalent temperature) in microwave channels:

$$TB \approx TB_S \tau + TB_A (1 - \tau)$$

where TB is brightness temperature observed by satellite, TB_S is brightness temperature of the surface, τ is the atmospheric transmission, and TB_A is the brightness temperature of the rain layer.

So if there is no rain, $\tau = 1$ and TB ~ TB_S.

For increasing rain:

=> τ decreases

=> TB => TB_A, i.e., surface is obscured in heavy rain

****Fig. 9.16* shows TB in 3 microwave frequencies versus rain rate.

Ocean surface ε is small so TB increases rapidly with increasing rain rate. Rain is most accurately observed over low-ε surfaces, thus this technique does not work well over land, snow, and ice.

Example of global rain rate and standard deviation retrieved from the Special Sensor Microwave Imager (SSM/I) sensor for 1988-1995 by Ferraro *et al*, 1996 (next page).

III. Radar -- active microwave remote sensing

Pulse of microwave radiation transmitted, measure reflected energy and relate this to rain rate

***Fig. 9.22

=> Choose ν with very little absorption by atmospheric gases and cloud droplets

=> Choose ν with little scattering by cloud droplets and precipitation

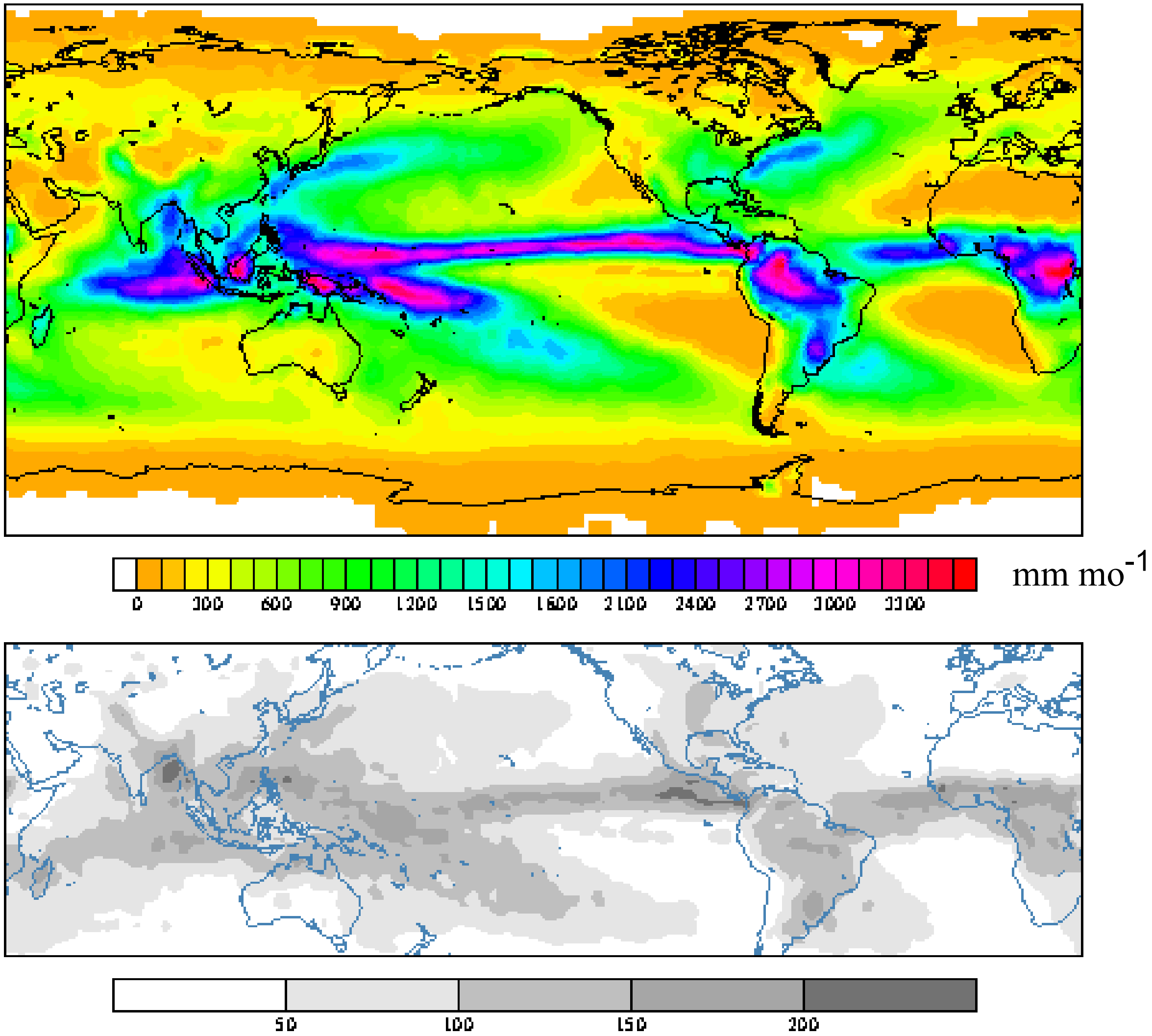
=> Power returned to receiver measured in decibels

=> Return signal depends on radar characteristics, drop size, and drop concentration

$$Z = aR^b \quad \text{“Z-R relationship”}$$

Z = radar reflectivity factor [mm^6m^{-3}], R = rain rate [$mm\ h^{-1}$], a,b = empirical constants. Measure Z, want to know R. (continued after figure)

Rain rate and standard deviation from SSM/I 1988-95



Ferraro et al, 1996

$$P_r = \frac{c|K|^2 Z}{r^2}$$

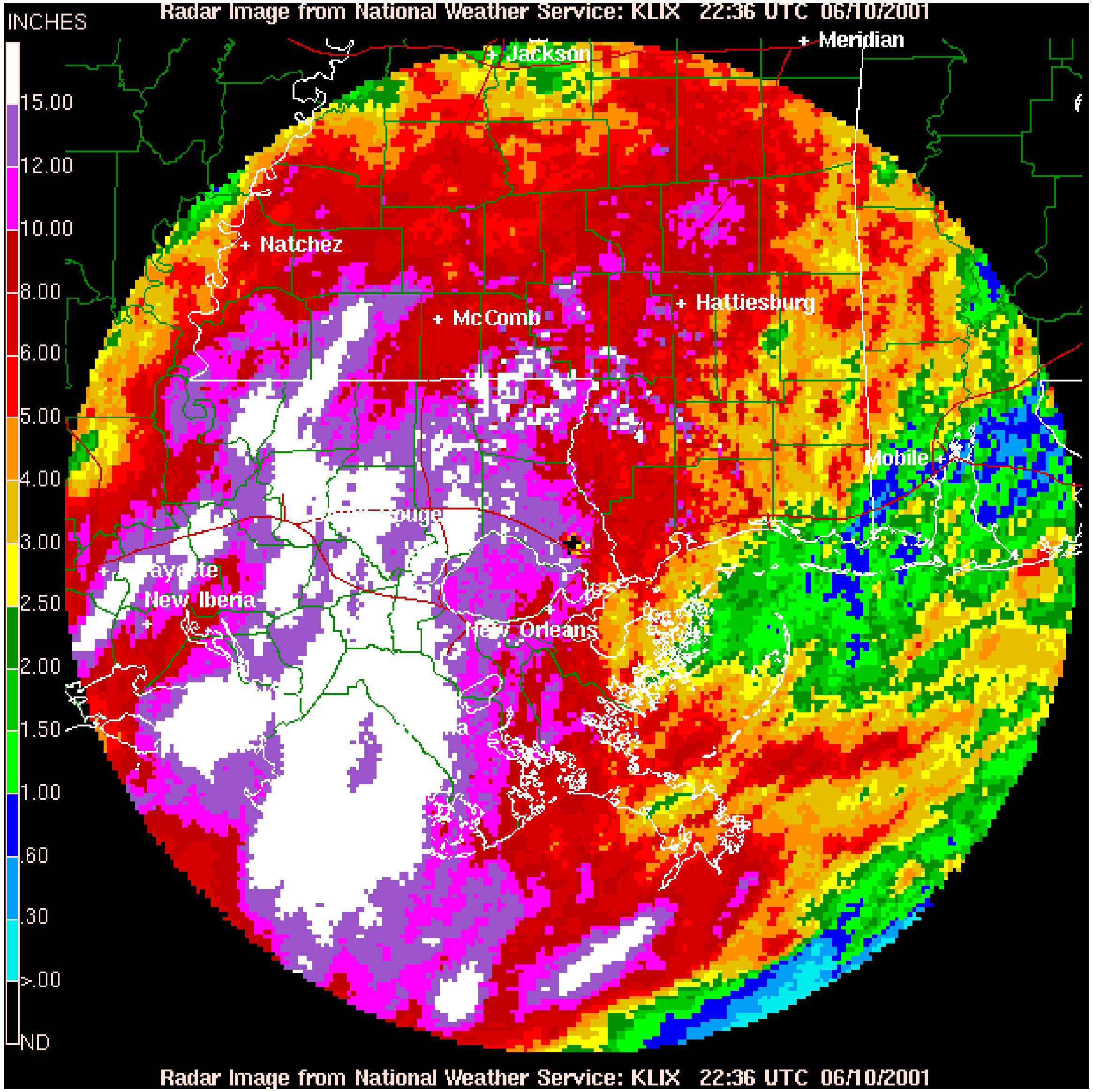
where P_r = return power, K is related to the extinction, r = range to target, c = constant (depends on radar channel), and Z = radar reflectivity factor. $Z \propto D^6$, where D is drop diameter. Need 2 frequencies to retrieve Z and K.

Typical values:

stratiform rain	$Z = 200R^{1.6}$
upslope rain	$Z = 31R^{1.71}$
heavy convective rain	$Z = 486R^{1.37}$
snow	$Z = 2000R^{2}$

Example of radar-derived storm-total precipitation during storm in June 2001 along Gulf Coast.

Polarization -- can also be very useful in determining rain rate, as drop shape varies with drop size (large drops flatten as they fall)


Radar Image from National Weather Service: KLIX 22:36 UTC 06/10/2001
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Radar Image from National Weather Service: KLIX 22:36 UTC 06/10/2001