Lecture 16

Applications of passive remote sensing using emission: Remote sensing of precipitation

Objectives:

1. Classification of remote sensing techniques to measure precipitation.
2. Visible and infrared remote sensing techniques to measure precipitation.
3. Sensing precipitation in the microwave region.

Required reading:

G: 7.4

Additional/advanced reading:

Kidder and Vonder Haar (1995): Chapter 9

1. Classification of remote sensing techniques to measure precipitation.

Importance: Precipitation is a key element of the Earth's hydrological cycle.

- Only a small fraction of clouds produce rain => need to separate raining from nonraining clouds

Classification of remote sensing techniques:

- ✓ Passive remote sensing:
  (i) Visible and infrared techniques
  (ii) Microwave techniques
- ✓ Active remote sensing:
  Radar (e.g., TRMM radar; see Lecture 21)

Other techniques:

Meteorological Weather Stations (rain gauges)

2. Visible and infrared remote sensing techniques to measure precipitation.

Basic principles:

Clouds are not transparent in the IR and visible (i.e., rain drops can not be sensed directly), thus one needs to relate the independent measurements of rainfall to the properties of a cloud measured by IR and visible remote sensing (called **indirect** measurements of precipitation)

Main problem: a lack of ground truth data to establish a correlation between satellite data and rainfall.

Techniques

- Cloud Indexing:

developed by Barrett (1970).

Principle: assign a rate rain to each cloud type

$$Rr = \sum_i r_i \, f_i$$

where $\boldsymbol{Rr}$ is the rainfall rate, $\boldsymbol{r_i}$ is the rain rate assigned to cloud type i , $\boldsymbol{f_i}$ is the fraction of time (or fraction of area covered) by cloud type i.

- Cloud Visible Reflection:

developed by Kilonsky and Ramage (1970).

Principle: tropical oceanic rainfall dominates by deep clouds which are highly reflective in the visible. Highly reflective clouds are more likely to precipitate that "dark" clouds because reflection is related to optical depth and hence to cloud thickness => relate the frequency of highly reflective clouds to precipitation

Parameterization by Garcia (1981) for tropical oceanic rainfall

$$Rr = 62.6 + 37.4 N_D$$

$\boldsymbol{Rr}$ is the monthly rainfall (in mm), $\boldsymbol{N_d}$ is the number of days during the month that the location was covered by highly reflective clouds (e.g., analysis of GOES visible channel).

- OLR (outgoing longwave radiation):

developed by Arkin (1979) to estimate precipitation for climatological studies.

Principle: clouds that are cold in the IR are more likely to precipitate than warm clouds because cold clouds have higher tops (exception, cirrus clouds)

GOES Precipitation Index (GPI) for the tropical Atlantic : $GPI = 3 A_c t$

where GPI is the mean rainfall (in mm), A_c is the fractional area (unitless, from 0 to 1) of cloud colder that 235 K in $2.5^0 x 2.5^0$ box, and t is the time period (hours) for which A_c was determined.

- Bispectral techniques

Principle: clouds that have the high probability to produce rain are both **cold** (IR brightness temperature) and **bright** (high reflection in visible)

- Cloud model techniques

Principle: use cloud models to relate satellite visible and IR observations to precipitation

3. Sensing precipitation in the microwave region.

Advantages:

- microwave radiation penetrates clouds because cloud droplets only weakly interact with microwave radiation;
- rain-size drops interacts strongly with microwave radiation

Disadvantages:

- microwave radiometers have poor spatial resolution
- contamination from ice crystal scattering

Main principles:

Ice crystals scatter but do not absorb microwave radiation. Rain liquid drops both scatter and absorb, but absorption dominates => relate the optical depth associated with the emitting rain drops and brightness temperature measured by a passive microwave radiometer.

Recall the Marshall-Palmer precipitation size distribution (Lecture 8, Eq.8.5).

$$N(r) = N_0 \exp(-2\Lambda\ r)$$

where N_0= 8x10^{3}m^{-3}mm^{-1}, but, in general, N_0 depends on rain type;

Λ = 4.1 $Rr^{\mathbf{-0.21}}$ mm^{-1}, *Rr* is the rainfall rate (mm/hour) .

Thus the volume extinction coefficient is

$$k_{e,rain} = N_0 \int_{r_1}^{r_2} \pi r^2 Q_e \exp(-2\Lambda r) dr$$

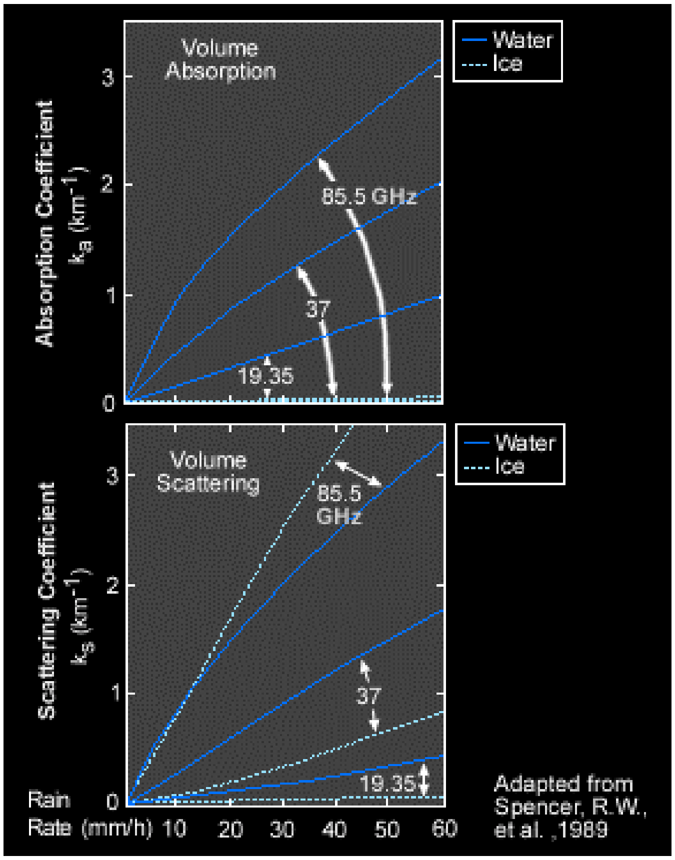

Figure 16.1 Volume absorption (top) and scattering coefficients (bottom) calculated with Mie theory for the Marshall-Palmer precipitation size distribution of water and ice spheres at three frequencies 19.35, 37, 85.5 GHz).

Recall the radiative transfer equation in the microwave region (Lecture 14, Eq.[14.13])

$$T_{b,\tilde{\nu}} = \varepsilon^p_{\tilde{\nu}} T_{sur} \exp(-(\tau^* / \mu) + \int_0^{\tau^*} T_{atm}(\tau') \exp(-\tau' / \mu) d\tau' / \mu$$

$$+ R^p_{\tilde{\nu}} \exp(-\tau^* / \mu) \int_0^{\tau^*} T_{atm}(\tau') \exp(-(\tau^* - \tau') / \mu) d\tau' / \mu$$

Let's assume that $\boldsymbol{T_{atm}}$ is constant in the rain layer and that the volume absorption coefficient is nearly zero except the rain layer.

$$\int_0^{\tau^*} T_{atm}(\tau') \exp(-\tau' / \mu) d\tau' / \mu \approx T_{atm} [1 - \exp(-\tau^* / \mu)]$$

We can re-write the above equation for the microwave brightness temperature observed by a nadir looking microwave radiometer in the following form

$$T_{b,\tilde{\nu}} = \varepsilon^p_{\tilde{\nu}} T_{sur} \exp(-\tau^*) + T_{atm}[1 - \exp(-\tau^*)]$$
$$+ (1 - \varepsilon^p_{\tilde{\nu}}) \exp(-\tau^*) T_{atm} \exp(-\tau^*)$$

where $\boldsymbol{\tau^*}$ is the optical depth associated with the emitting/absorbing rain drops:

$\boldsymbol{\tau^*} = \boldsymbol{k}_{\text{a,rain}} \, \boldsymbol{z}_{\text{rain}}$

$\boldsymbol{z}_{\text{rain}}$ is the depth of the rain layer.

Re-arranging the terms in the above equation, we have

$$T_{b,\tilde{\nu}} = T_{atm}[1 + \varepsilon^p_{\tilde{\nu}} (\frac{T_{sur}}{T_{atm}} - 1) \exp(-\tau^*) - (1 - \varepsilon^P_{\tilde{\nu}})(\exp(-\tau^*))^2]$$

[16.1]

Eq.[16.1] helps to understand the brightness temperature-rain rate relationships:

- No rain ($\tau^* = 0$) => $T_{b,\tilde{\nu}} = \varepsilon^{p}_{\tilde{\nu}} T_{sur}$

  (ε is small for water surfaces, and $\varepsilon = 0.9$ for dry land)

- Rain increases (τ^* ***increases)*** => $T_{b,\tilde{\nu}} \rightarrow T_{atm}$ Therefore, for water surfaces, the brightness temperature strongly increases with the increases of rain rate => raining areas are easily detected over the oceans

  => over the dry land, the changes in brightness temperature are small with increasing rain rate: not useful for rainfall estimations

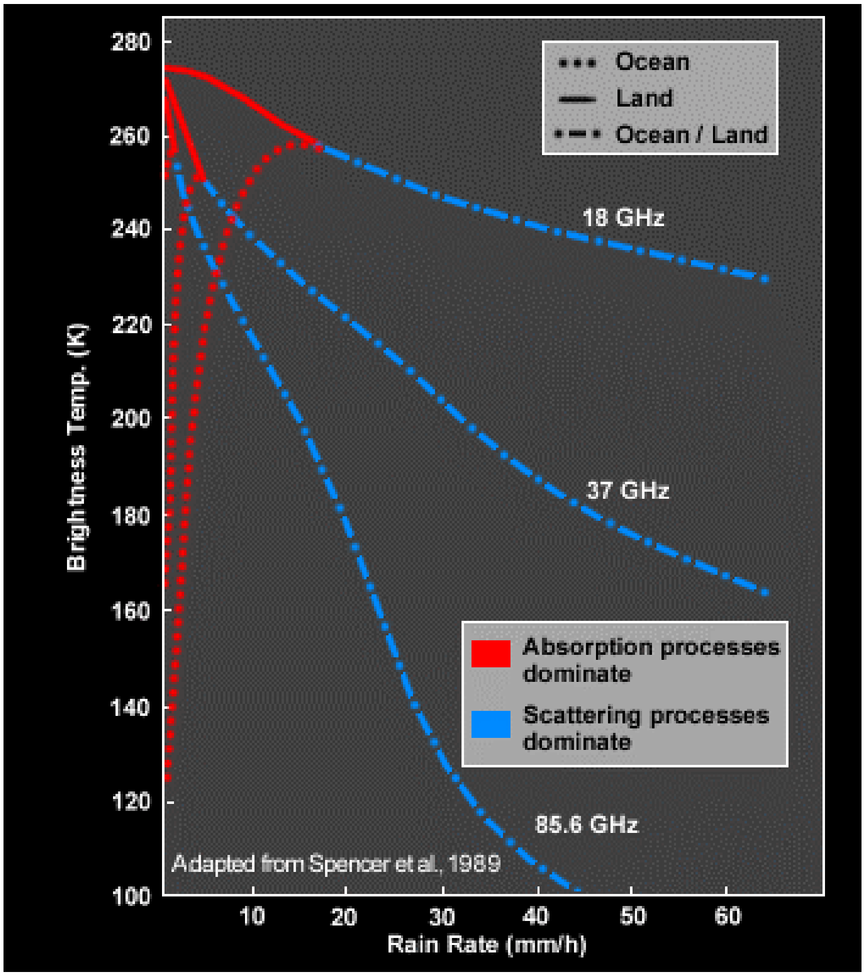

Figure 16.2 Brightness temperature versus rain rate for three frequencies.

MSPPS (Microwave Surface and Precipitation Products System) project:

Uses new NOAA microwave radiometers: Advanced Microwave Sounding Unit (AMSU)

AMSU-A and AMSU-B: launched on NOAA 15, 1998

AMSU-A: 15-channel cross track scanning microwave radiometer; mixed polarization

AMSU-B: 5-channel cross track scanning microwave radiometer

Table 16.1 Microwave sensing of precipitation: AMSU vs. SSM/I

AMSU Frequency	SSM/I Frequency	Microwave processes	Retrieved product
		Controlled by absorption/emission by cloud water:	
31 GHz	9 GHz	- large drops/high water content	cloud water and rainfall over oceans
50 GHz	37 GHz	- medium drops/moderate water content	cloud water and rainfall over oceans
89 GHz	85 GHz	- small drops/low water content	non-raining clouds over oceans
89 GHz	85 GHz	**Controlled by ice-cloud scattering**	rainfall over the land and ocean