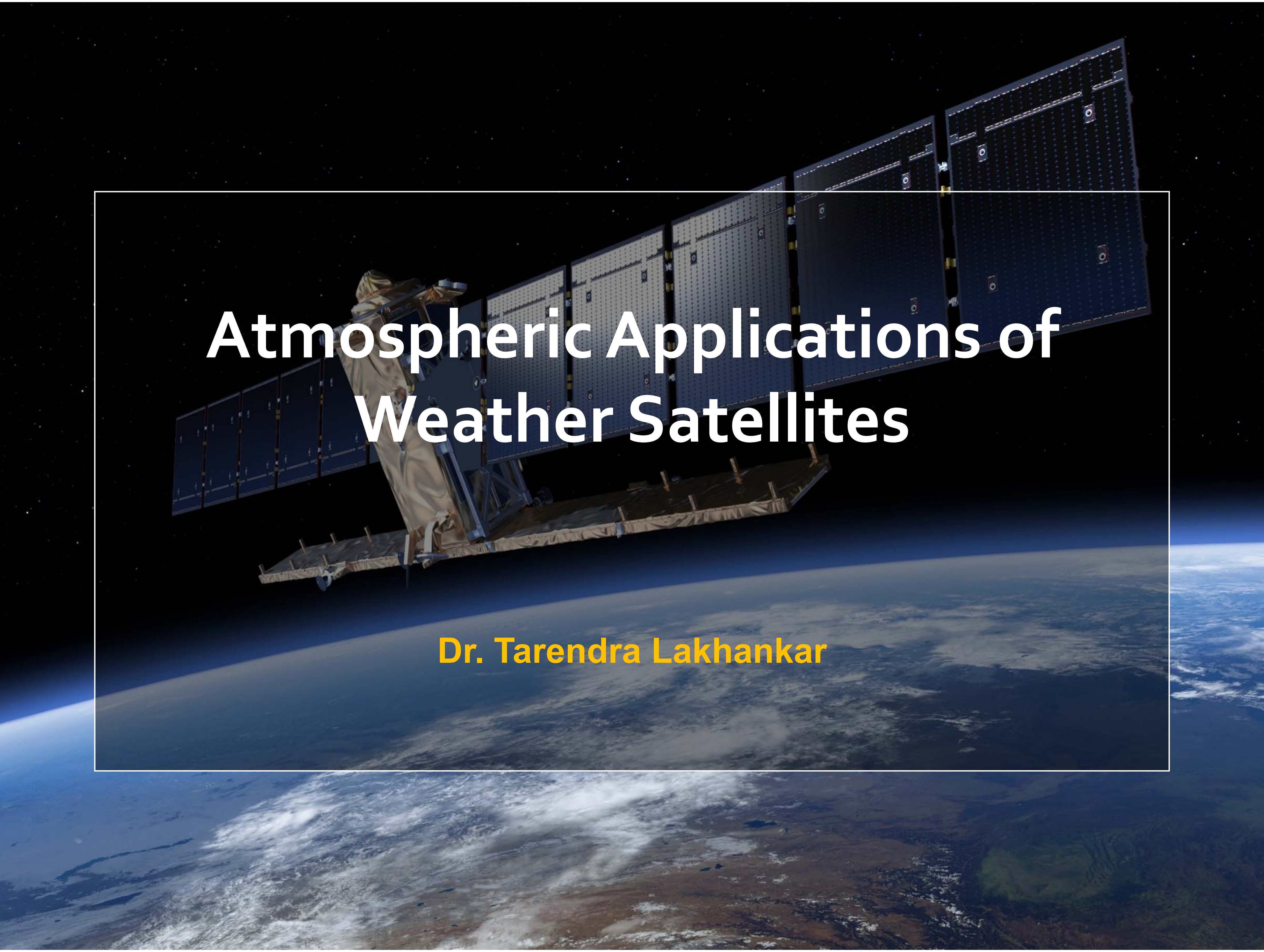


Atmospheric Applications of Weather Satellites

Dr. Tarendra Lakhankar

In this lecture:

- How satellite data are used to get information on
- - Precipitating/rainfall
- - Winds

Precipitation observed from satellites

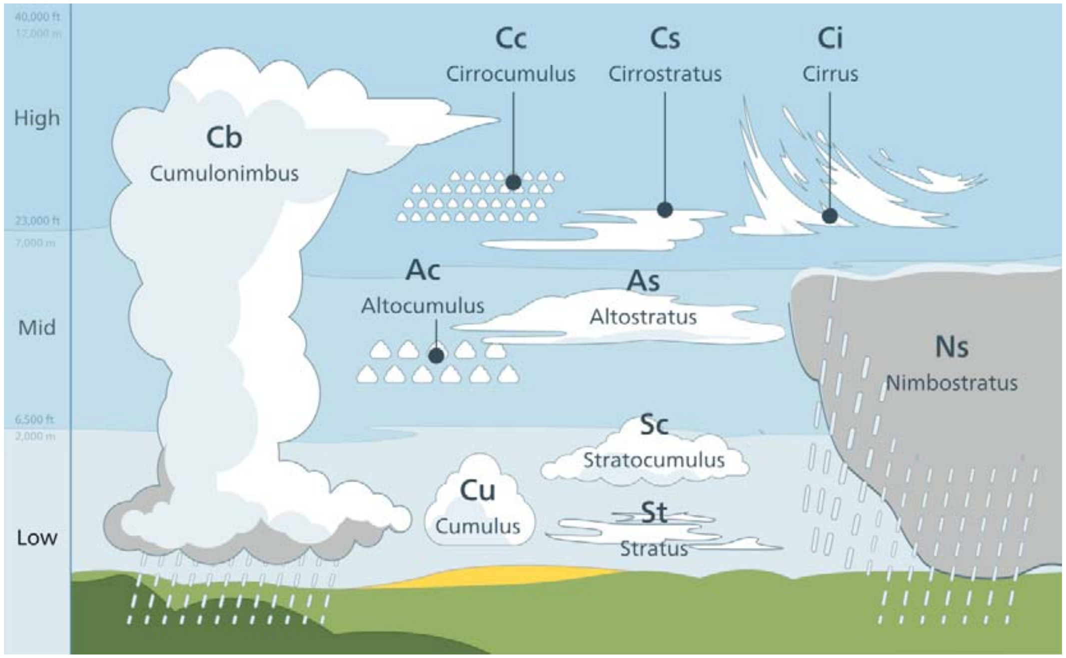
Motivation for precipitation monitoring

- It is one of major climatic parameters
- It is an important element of the Earth's water circulation system
- It is an important source of fresh water
- May be solid (snow, hail) or liquid (rain)
- May cause flooding and flood-related damage (land-slide)
- Lack of precipitation results in droughts, crop loss, etc.

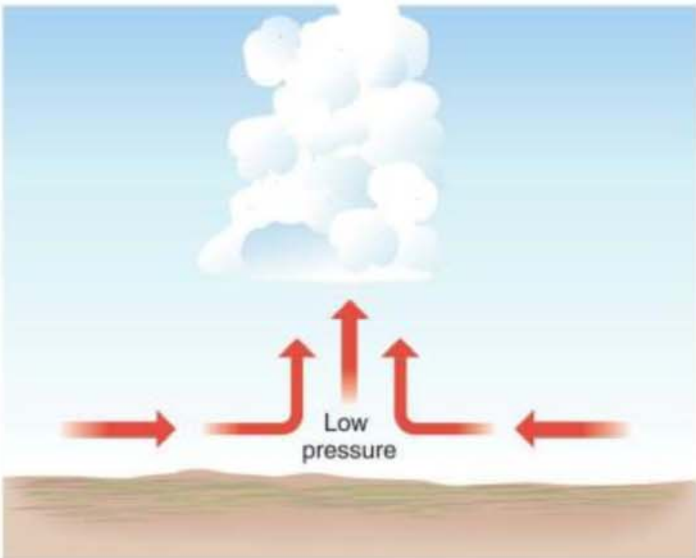
- **We typically want to know**
  - How strong the rain is, or precipitation rate (mm/h)
  - How much water the rain brought (rainfall amount)

Cloud Types

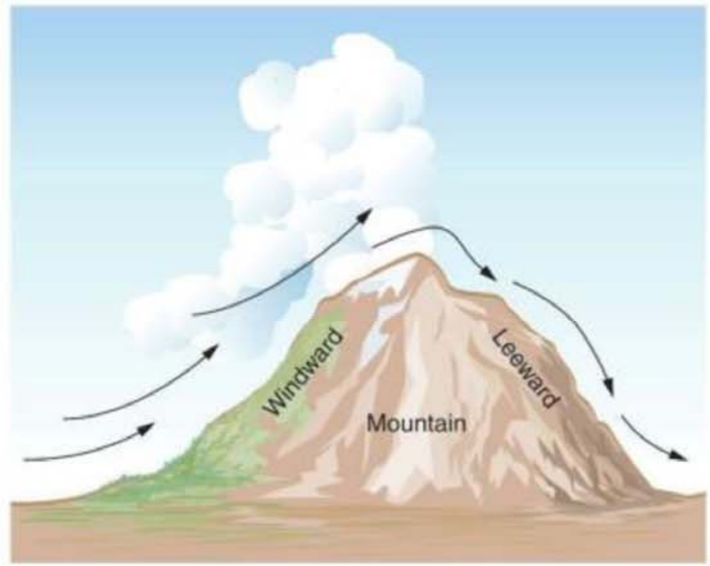
- Precipitating cloud types: Cumulonimbus and nimbostratus
- Cumulonimbus typically develop due to convective processes involving relatively fast vertical transfer of warm moist air to higher altitudes. May have ice particles in the top portion of the cloud.
- Nimbostratus develop as a result of collision of two air masses when warm less dense air slowly rises over the cold air mass.



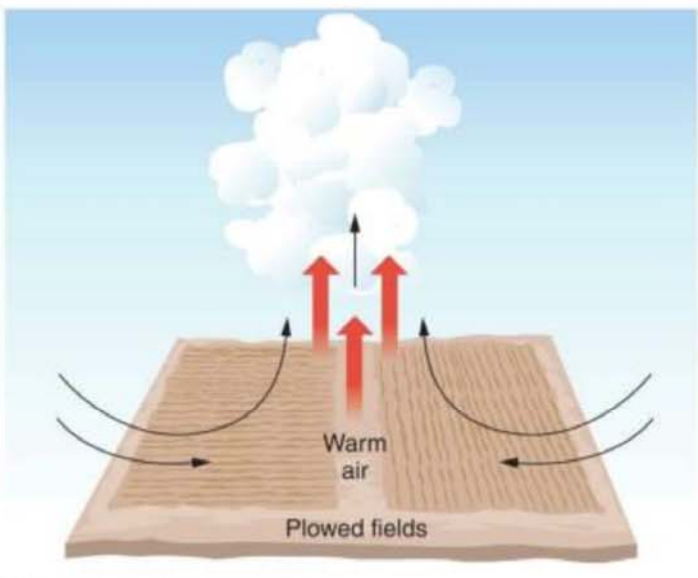
Atmospheric Lifting Mechanisms



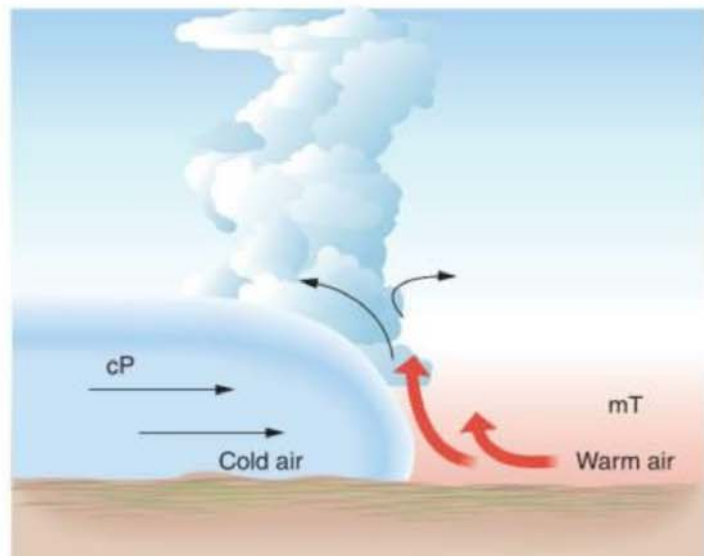
(a) Convergent



(c) Orographic (barrier)



(b) Convectional (local heating)



(d) Frontal (e.g. cold front)

Figure

Local Heating and Convection

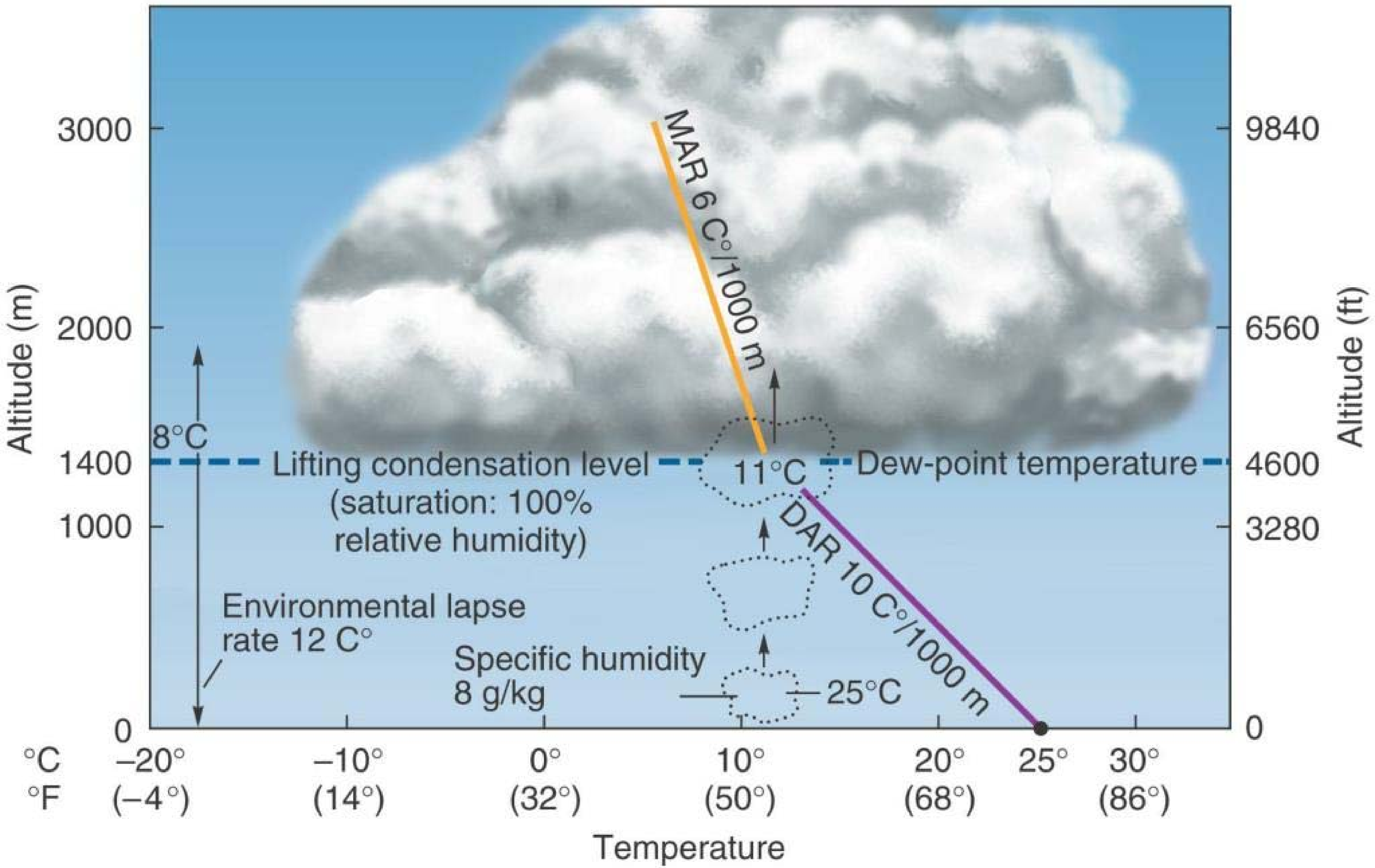
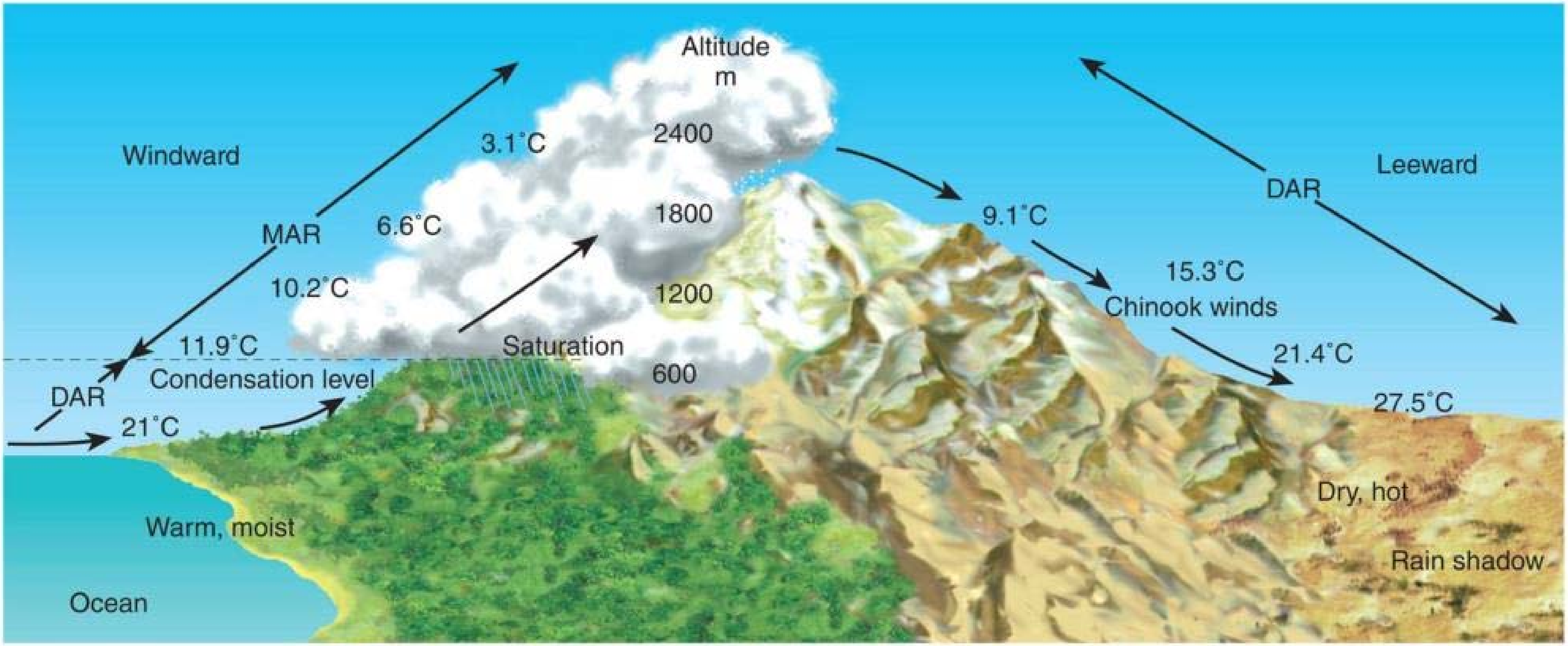


Figure 8.7

Orographic Precipitation



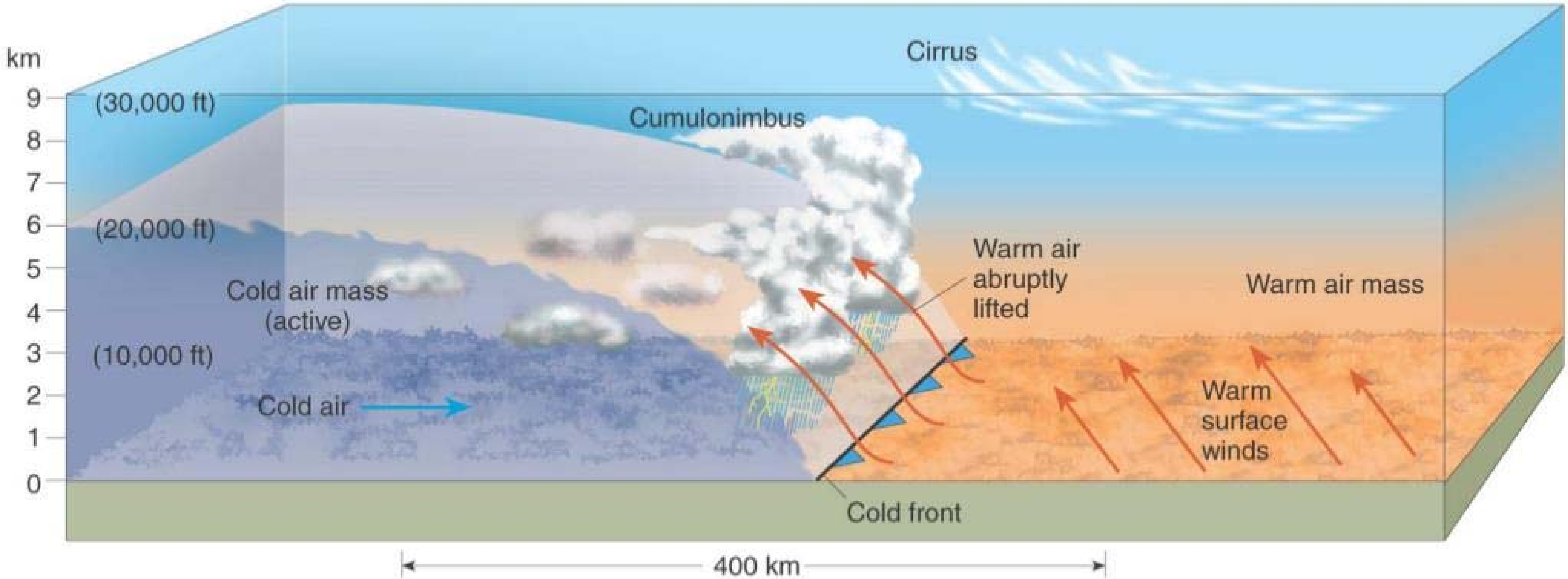
(a)

Figure 8.9

Frontal Lifting

- Font: The boundary between two air masses , i.e. the “battle” front between two air masses.
  - Cold Fronts
    - Cold air forces warm air aloft
    - 400 km wide (250 mi)
  - Warm Fronts
    - Warm air moves up and over cold air
    - 1000 km wide (600 mi)

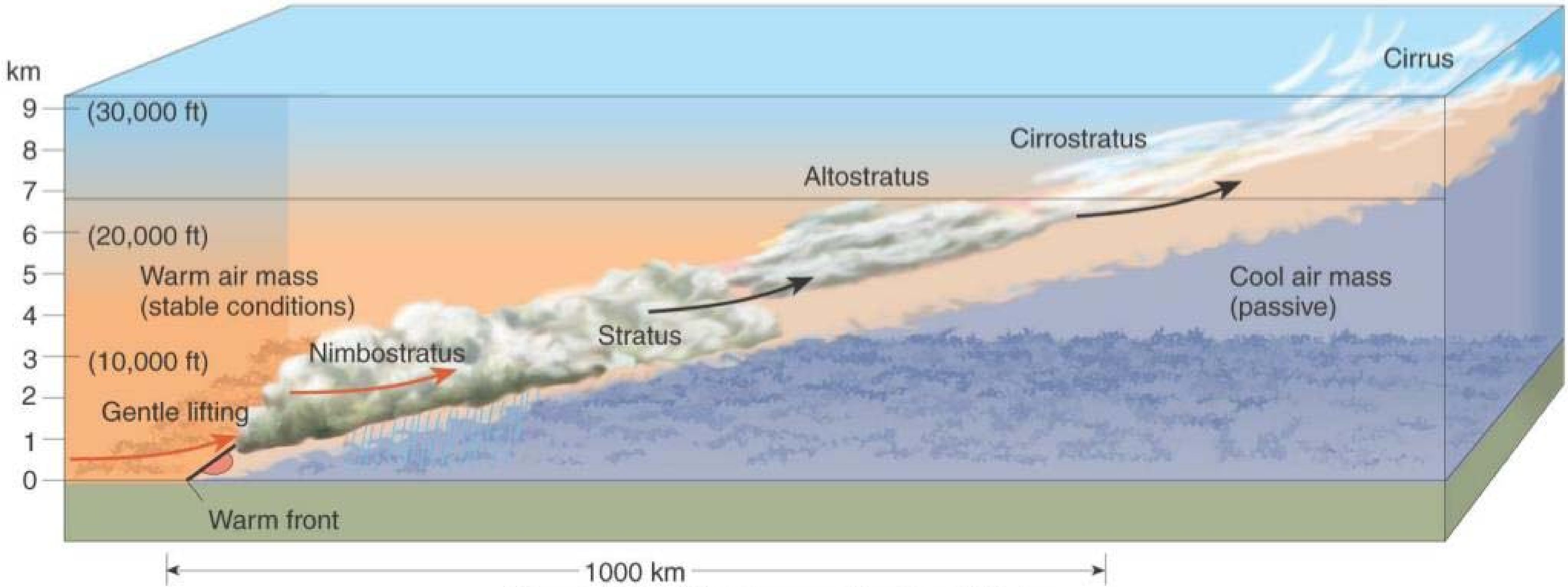
Cold Front



1. Cold air advances into the warm air, forcing the warm air the rise.
2. Cold air is heavier than warm air, thus the warm overruns the cold air.
3. Slope is 1:100, i.e. the frontal surface rise 1 km in height over 100 km distance on the ground.
4. Intense precipitation over shorter period of time compared to warm front.

Figure 8.11

Warm Front



1. warm air advances, pushing the cold air to retreat.
2. Cold air is heavier thus more difficult for the warm air to displace.
3. Slope is 1:200, i.e. the frontal surface rise 1 km in height over 200 km distance on the ground.
4. Light-to-moderate rain over large area for an extended period.

Figure 8.13

Conventional Precipitation Data

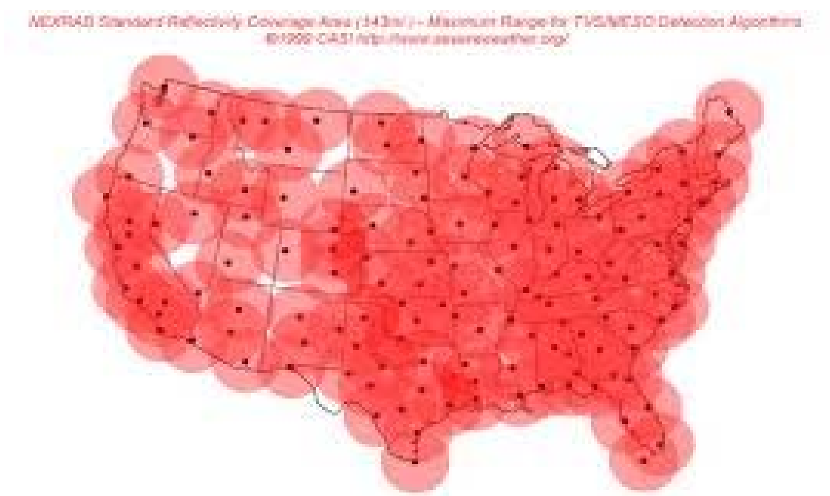
Ground-based data:

- Relatively sparse network
- Report accumulated precipitation in 12 or 24 hours
- No instantaneous estimate of rain rates

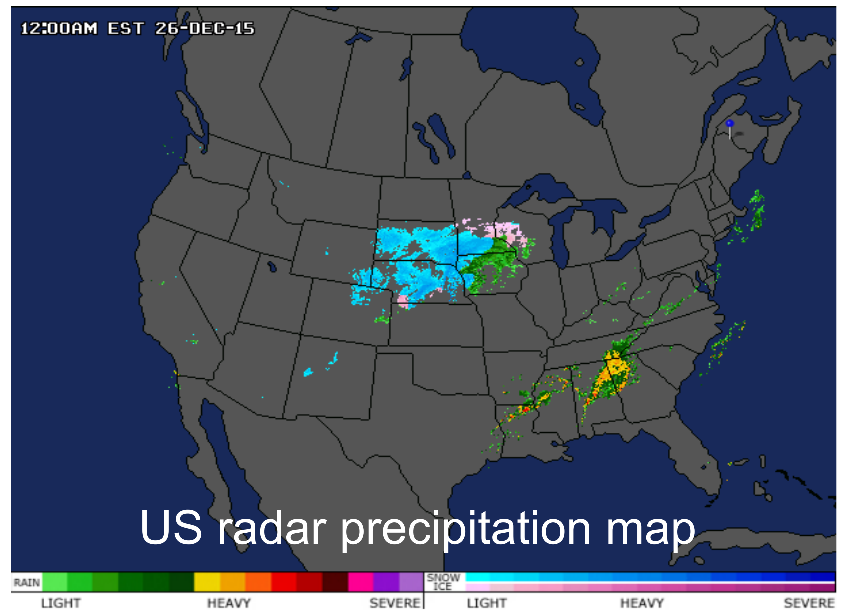
Conventional Precipitation Data

Ground-based Weather Radars:

- Provide accurate, high spatial resolution and timely information on the rainfall and snowfall rates



Radar coverage of Conterminous US



US radar precipitation map

However:

- Sparse coverage in many parts of the world
- No coverage over oceans
- Mountains affect the coverage (beam block)

Why using satellites:

Large-scale coverage including oceans

Practically no gaps in the coverage

Less maintenance than radars

Satellites Do Not See Rainfall

- But they can identify clouds that are likely to produce rainfall
- These clouds can be identified using observations
  - In thermal infrared
  - In the microwave

Visible (VIS)/Infrared (IR) Algorithms: Physical basis

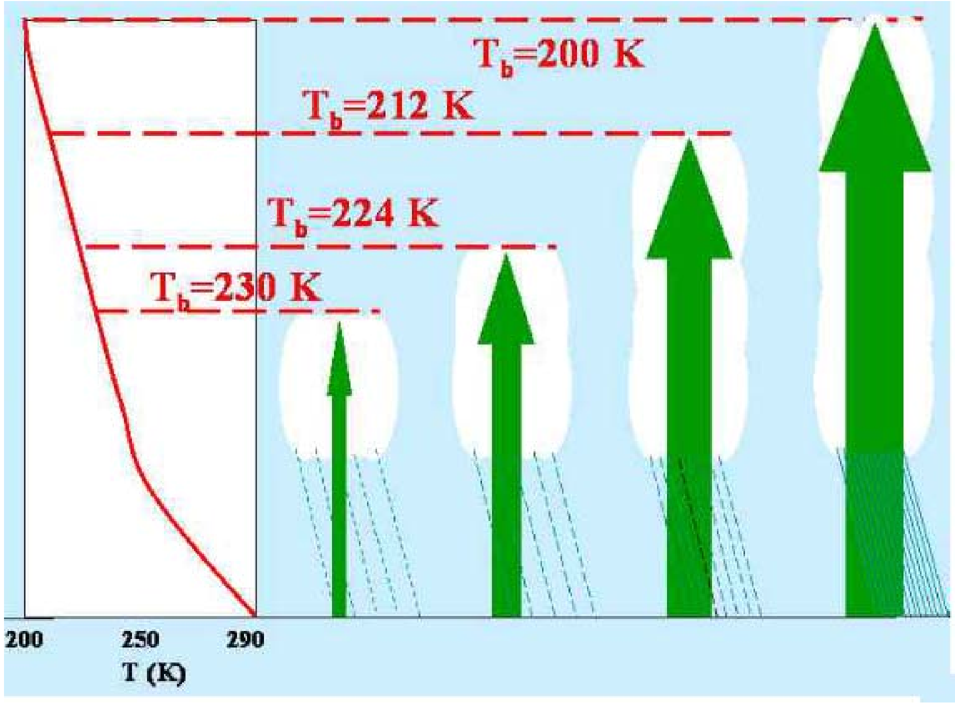
- Relationship between cloud-top temperature, cloud brightness, cloud-top thickness, and precipitation:

  - Colder cloud-top temperatures imply higher and thicker clouds, which imply heavier precipitation

- Relationship between changes in cloud-top temperature and precipitation:

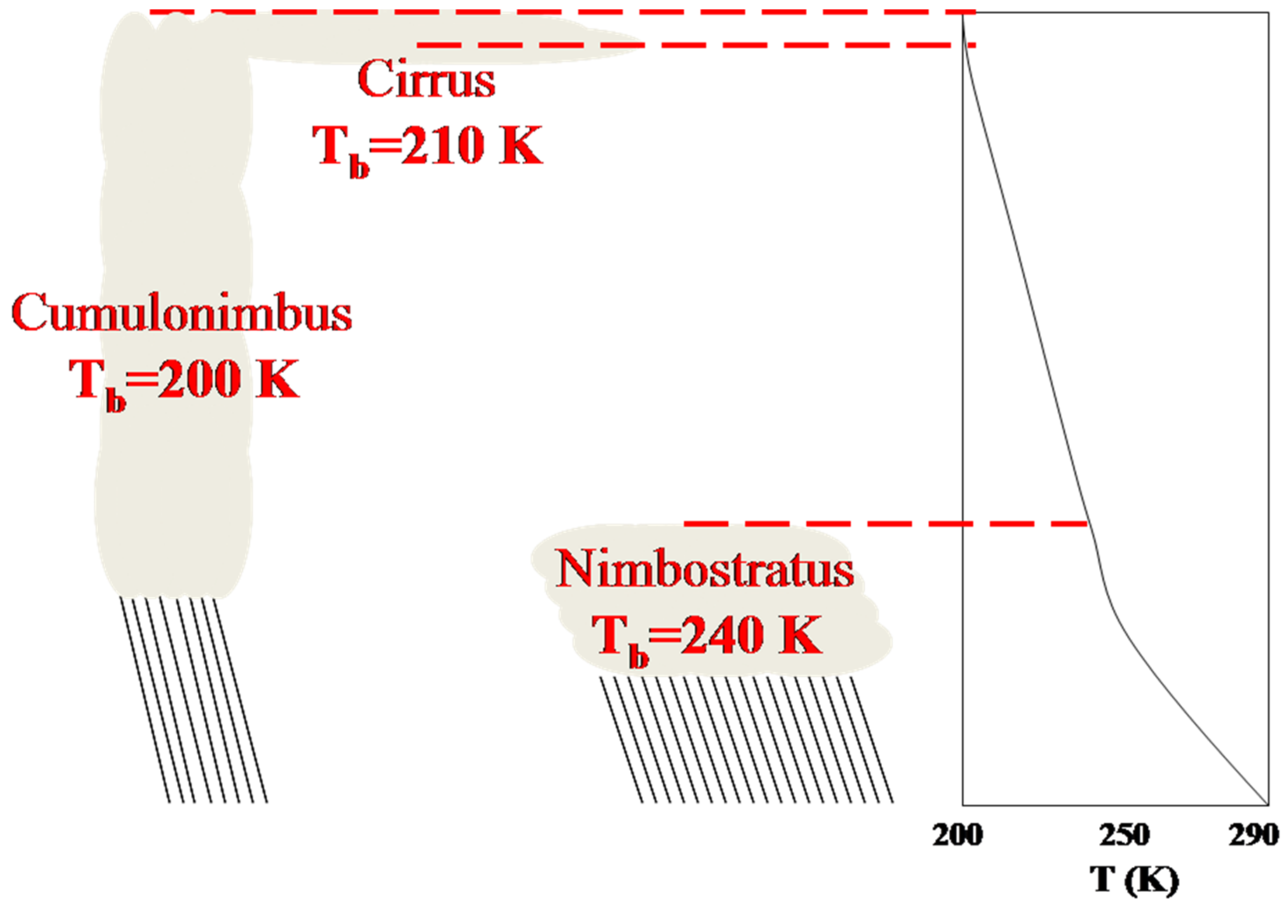
  - Vertically growing clouds are associated with precipitation while decaying clouds are not

This assumption works well for convective clouds (cumulonimbus)



However this assumption is not good

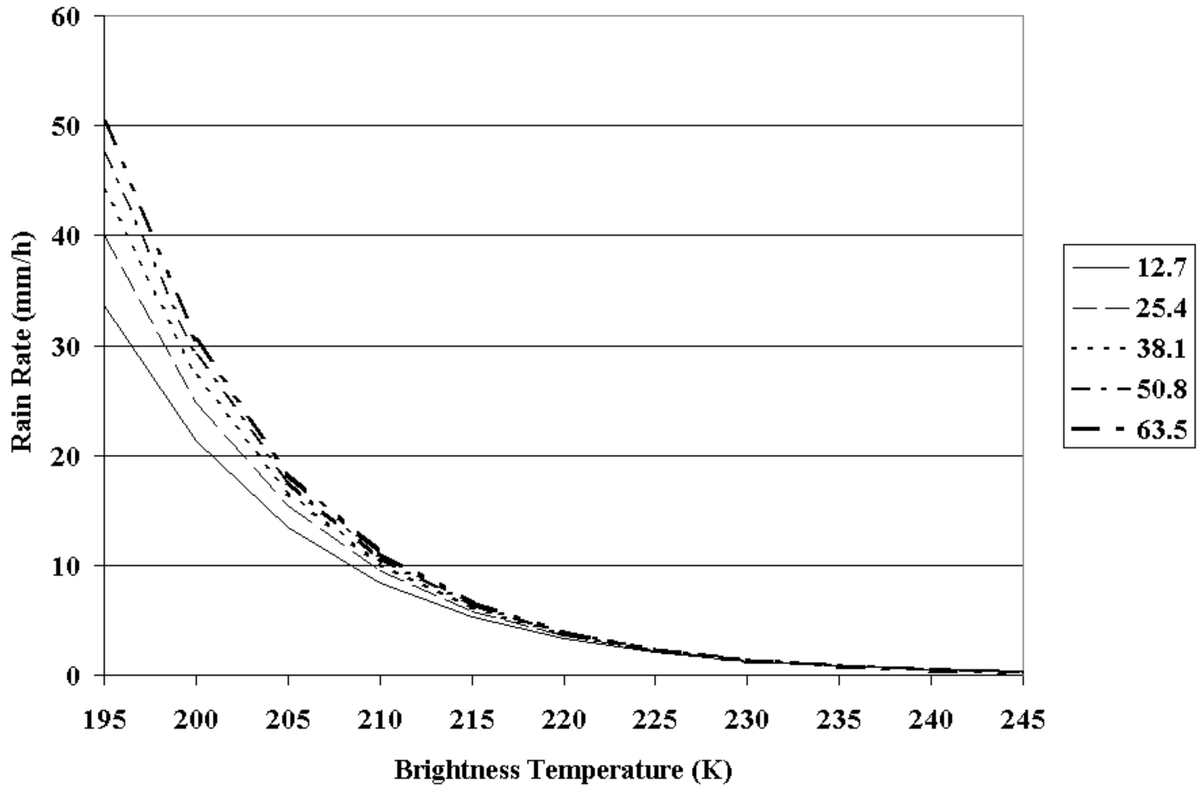
- for cirrus clouds (cold but rain-free)
- for stratiform clouds, e.g., nimbostratus (warm but wet)



Therefore application is most effective in low latitudes and over mid-latitudes in summer

NOAA Hydro-Estimator Algorithm: Cloud top temperature is related to **rain rate**

$$R = 1.1183 \times 10^{11} \times \exp(-3.6382 \times 10^{-2} \times T^{0.5})$$



Correction is made for different levels of available water vapor in the atmosphere

Detailed description: http://www.star.nesdis.noaa.gov/smcd/emb/ff/HEtechnique.php

Practical Application of IR Algorithm

Measure cloud top temperature (IR temperature data) and calculate potential precipitation from the curve

Check if moisture is available in the atmosphere

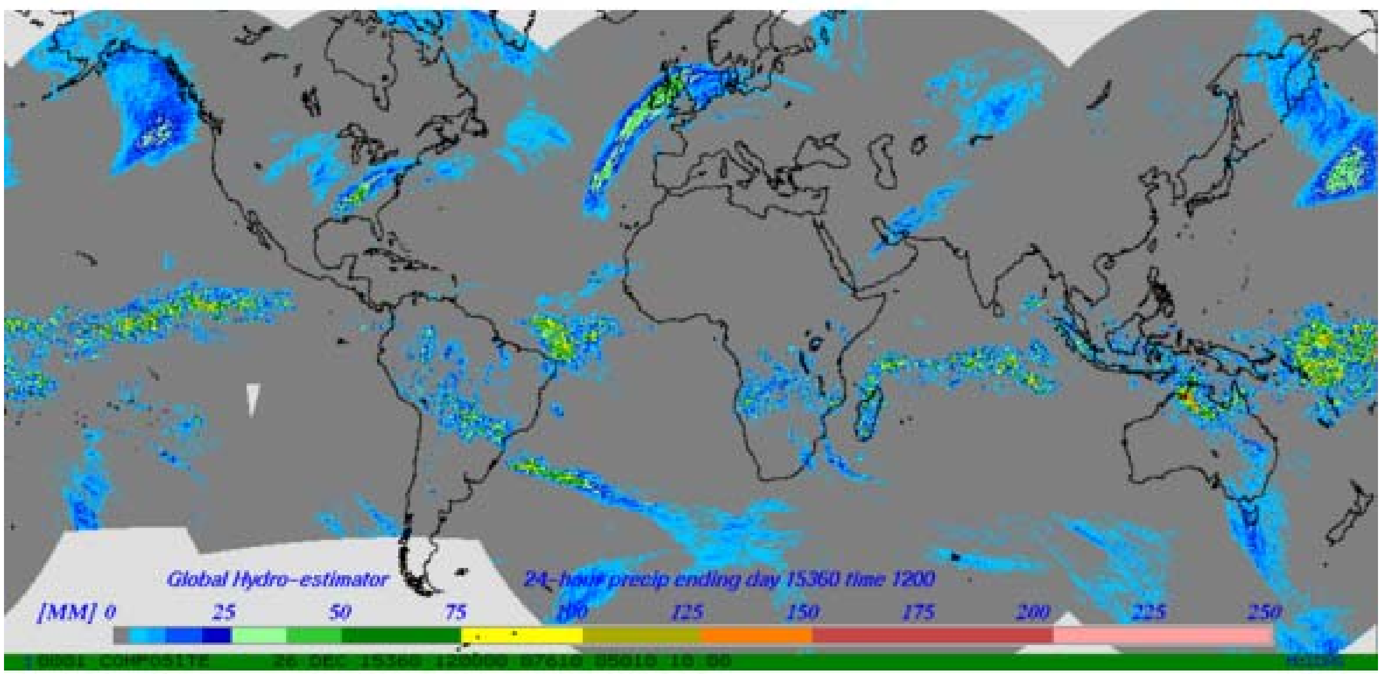
Check if the cloud is growing (temperature decreasing)

Geostationary Satellite

- Most accurate estimates of the daily rainfall amounts are made with data from geostationary satellites which provide imagery every 15-30 min.
- Aggregating precipitation rate retrievals during a day yields daily total rainfall.

NOAA routinely generates global maps of instantaneous precipitation rates as well as of rainfall amount accumulated over 1 to 6 days at 8 km spatial resolution

Precipitation rates are estimated routinely with 5 geostationary satellites GOES-W (135W) , GOES-E(75W), Meteosat-10(0E), Meteosat -7(58E), MTSAT(145E) and combined in one product



NOAA global map of daily rainfall amount derived from satellite infrared observations.

Observations from five geostationary satellites are combined

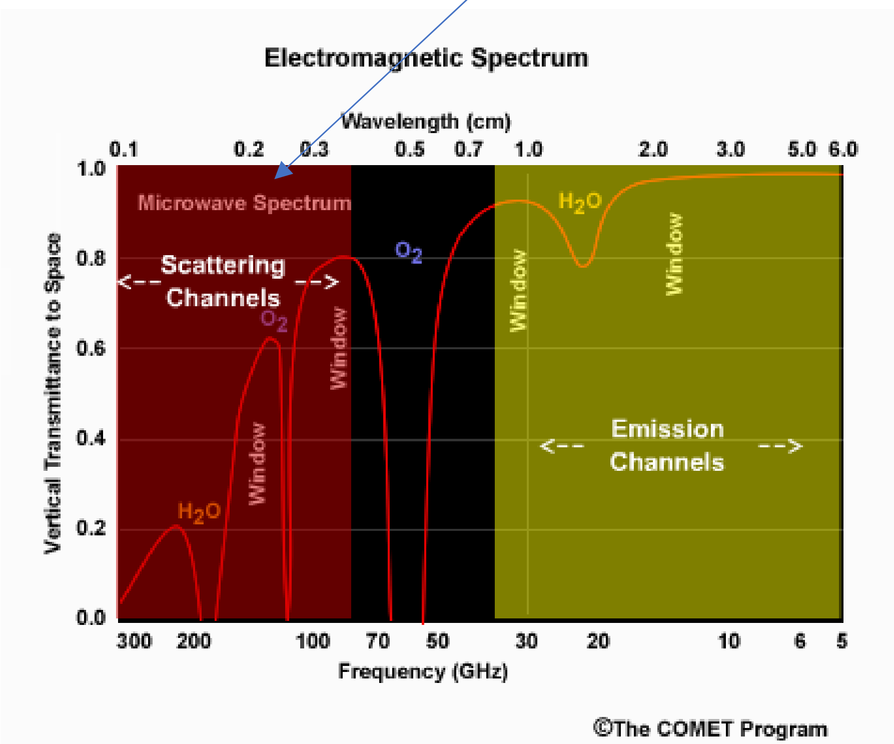
Passive Microwave (MW) Algorithms:

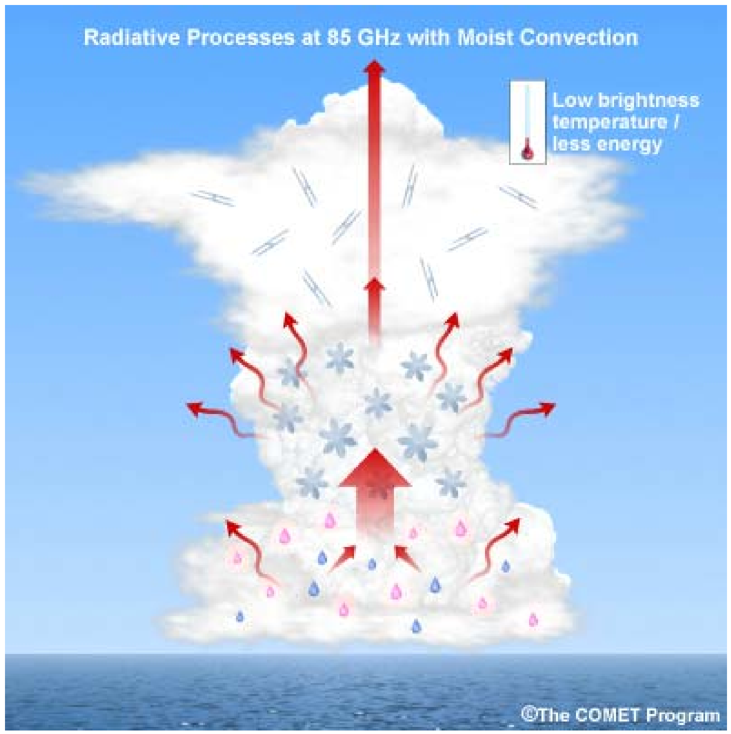
1. Scattering (used over oceans)

Precipitating clouds with high cloud top altitude contain ice particles

<u>At high frequencies (over 85 GHz) ice scatters terrestrial radiation</u> back down to the surface making precipitating clouds appear “colder” than the background

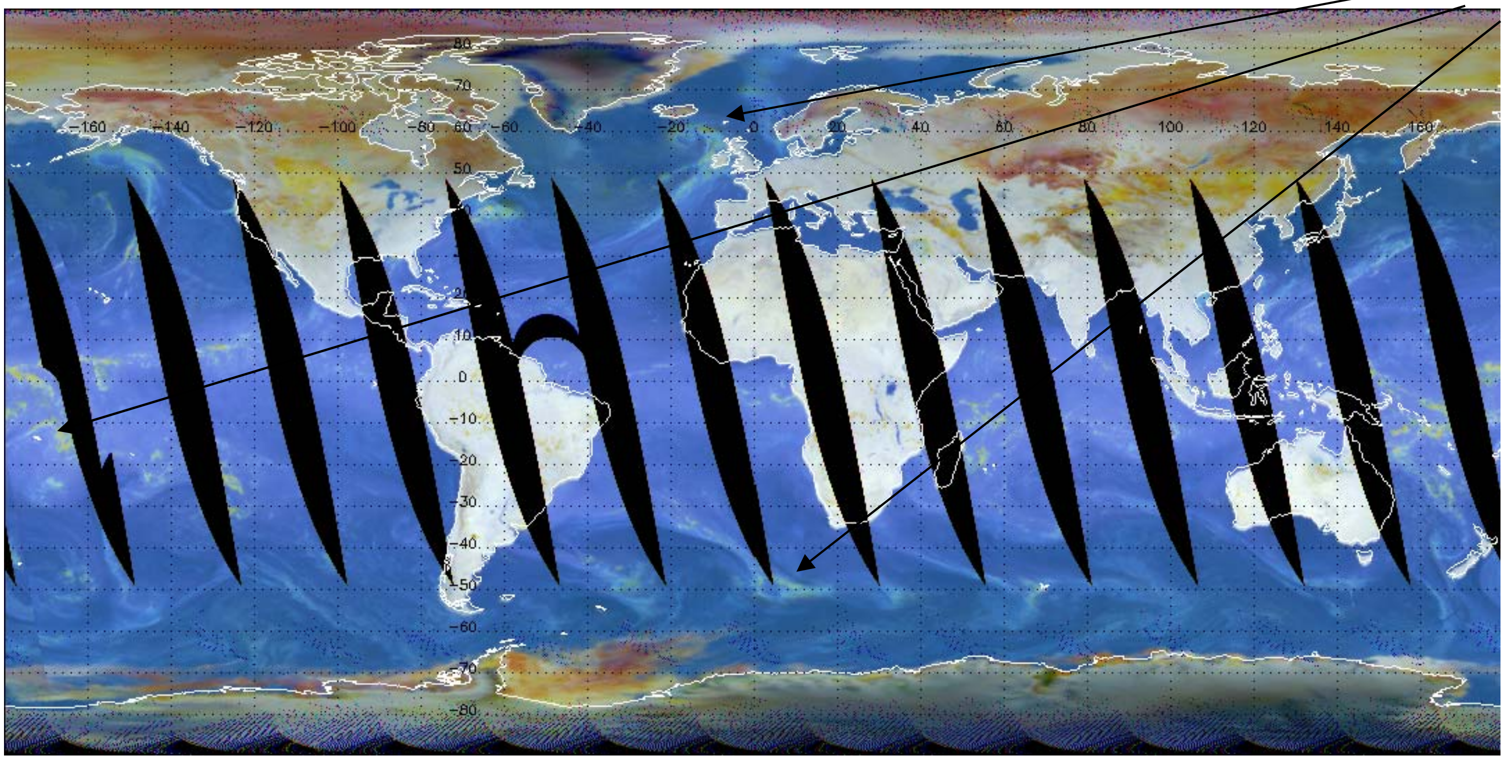
Precipitating clouds are identified by temperature contrasts. Most effective is identification of precipitating clouds over oceans





Precipitating clouds over ocean

Microwave brightness temperature RGB composite
Red: 19GHz(V), Green: 37 GHz(V), Blue: 91GHz (V)
DMSP F-18 Ascending mode, Dec 30, 2015



- Precipitating clouds over ocean are clearly seen (have whitish color)

• Passive Microwave (MW) Algorithms:

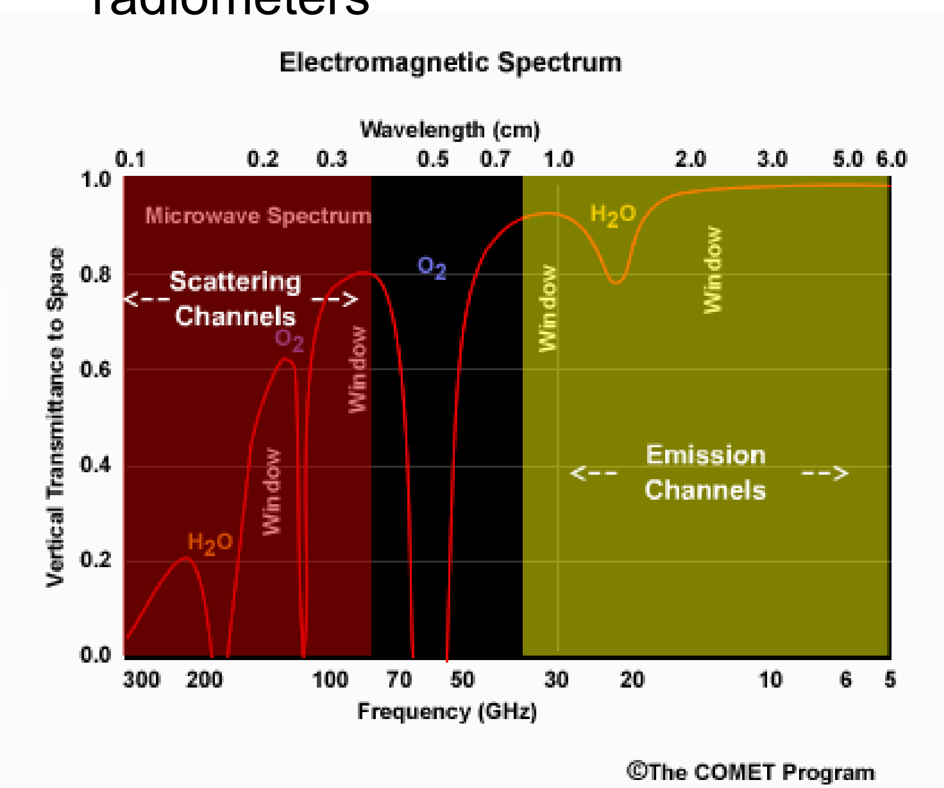
2. Emission (used over land surface)

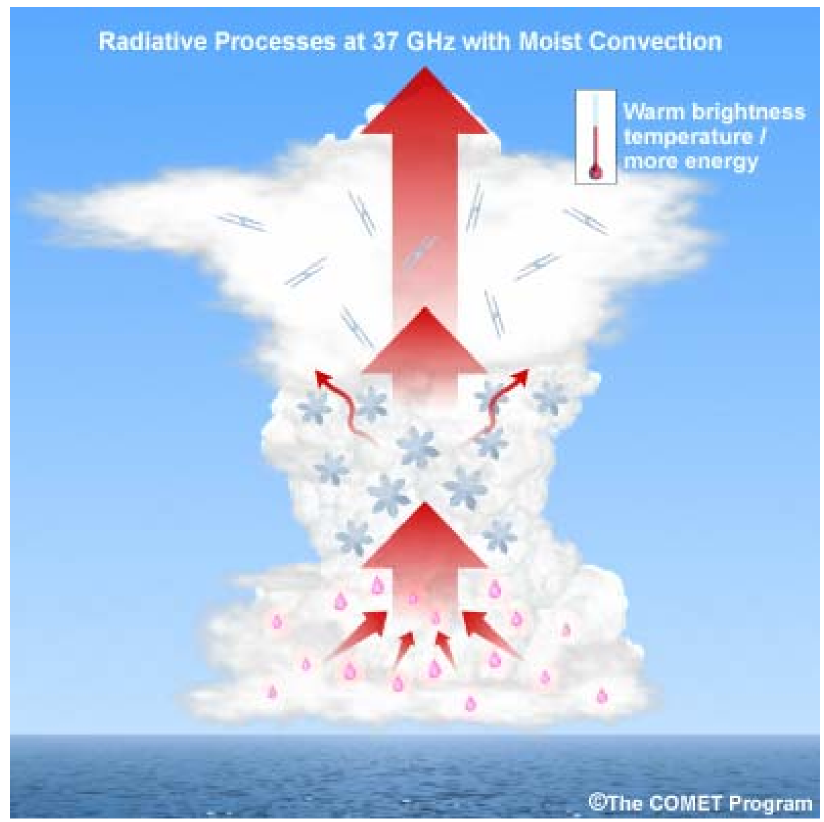
At low frequencies (37 GHz and below) water droplets in clouds emit radiation.

This radiation increases radiation from the land surface

As a result precipitating clouds appear warmer than the land surface

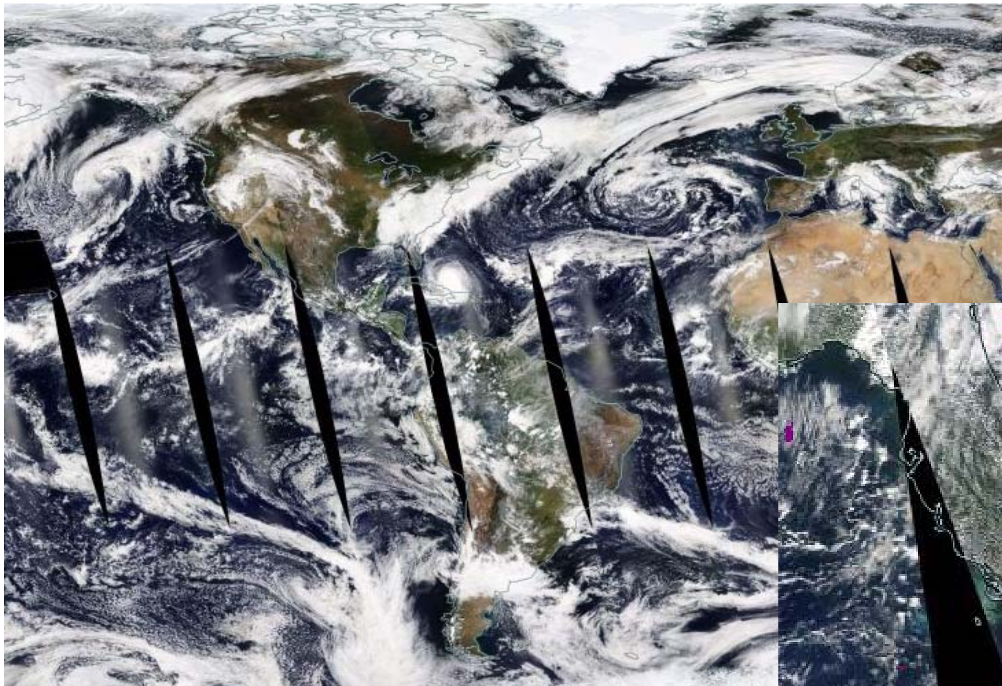
Spatial resolution is coarse (about 50 km) due to large footprint of microwave radiometers



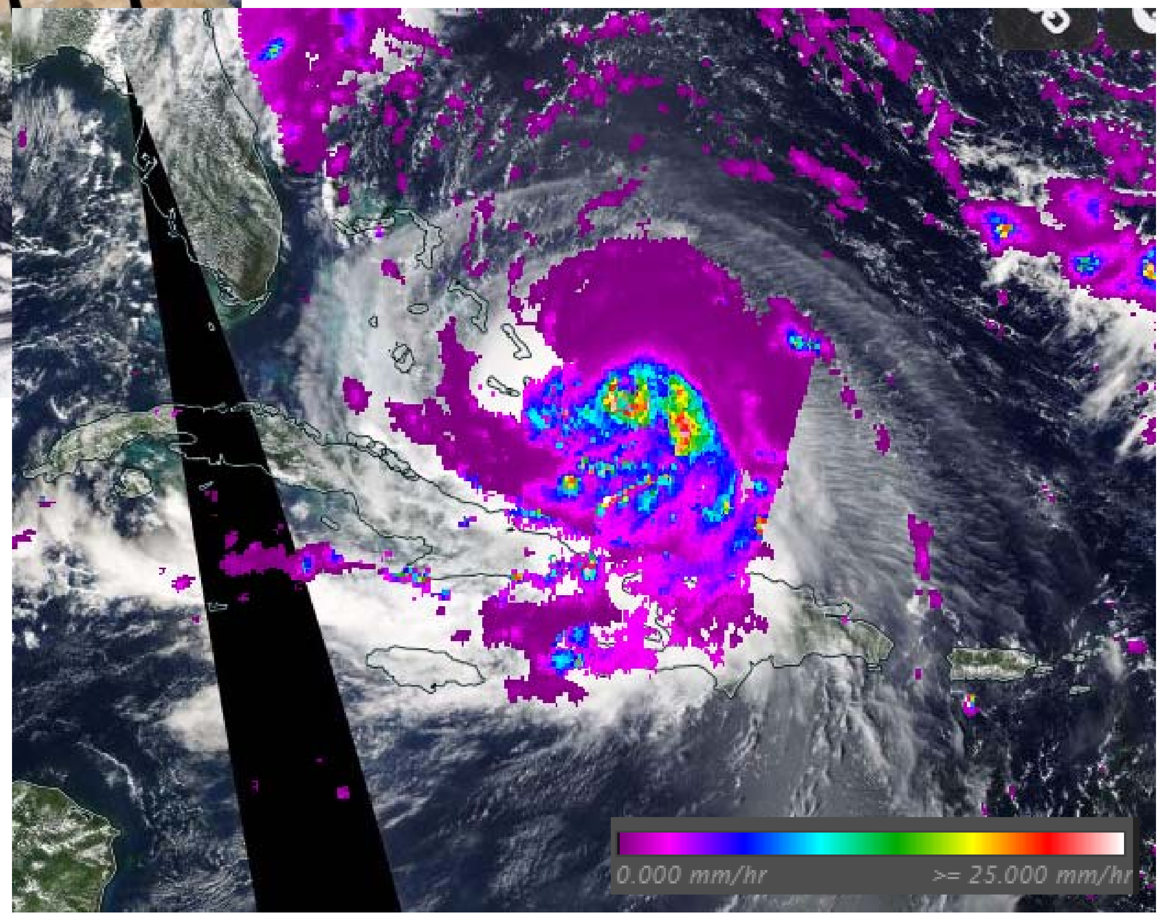


Example of precipitation retrieval with microwave data

Hurricane Joaquin
Oct 1, 2015



MODIS True Color image



MODIS True Color image with overlaid rain rate derived from AMSR2 onboard GCOM satellite

Images generated using NASA WorldView at https://earthdata.nasa.gov/labs/worldview/

Summary of Features of Visible/Infrared and Microwave Precipitation Techniques

Advantages of infrared retrievals:

- Rain rates estimates are available at high temporal resolution (15-30 min)
- High spatial resolution (4-8 km)
- Estimates of daily rainfall amount are possible
- Retrieval technique is most effective for convective clouds

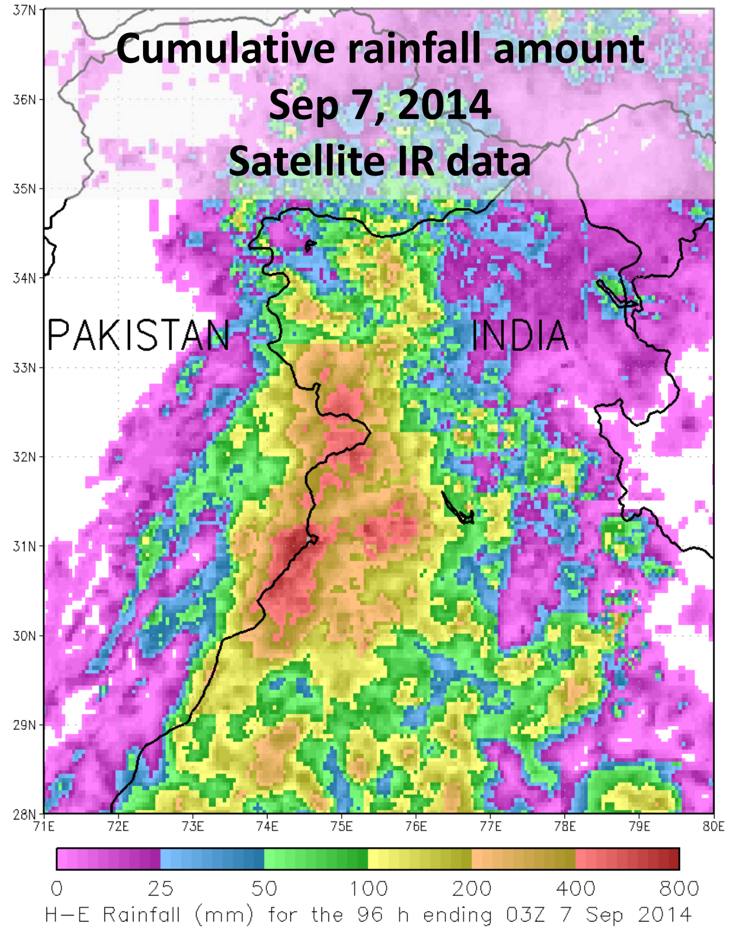
Advantages of microwave retrievals

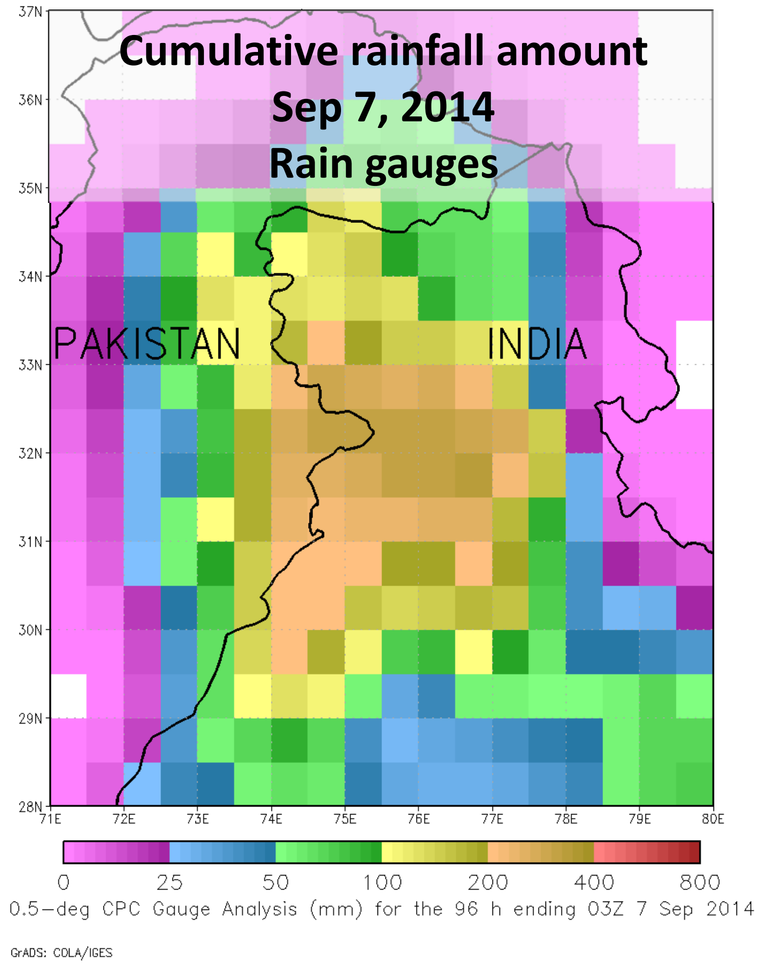
- Rain rates 2 times a day at coarse , 15-50 km spatial resolution
- More robust, accurate, physically-based retrieval approach
- Retrievals are available from a number of satellites (DMSP, NOAA, METOP, etc.)

Algorithms combining two approaches are being developed

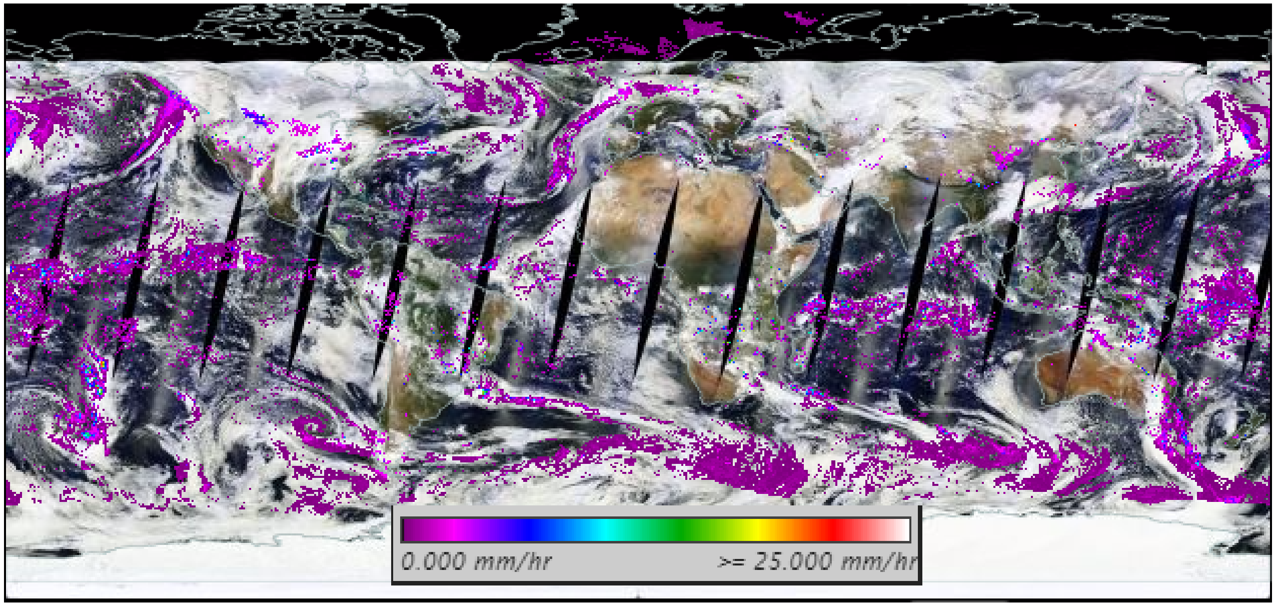
Satellite retrievals provide much more spatially detailed characterization of rainfall amounts than conventional ground-based observations.

Example: Heavy monsoonal rain in Sep 2014 over India and Pakistan



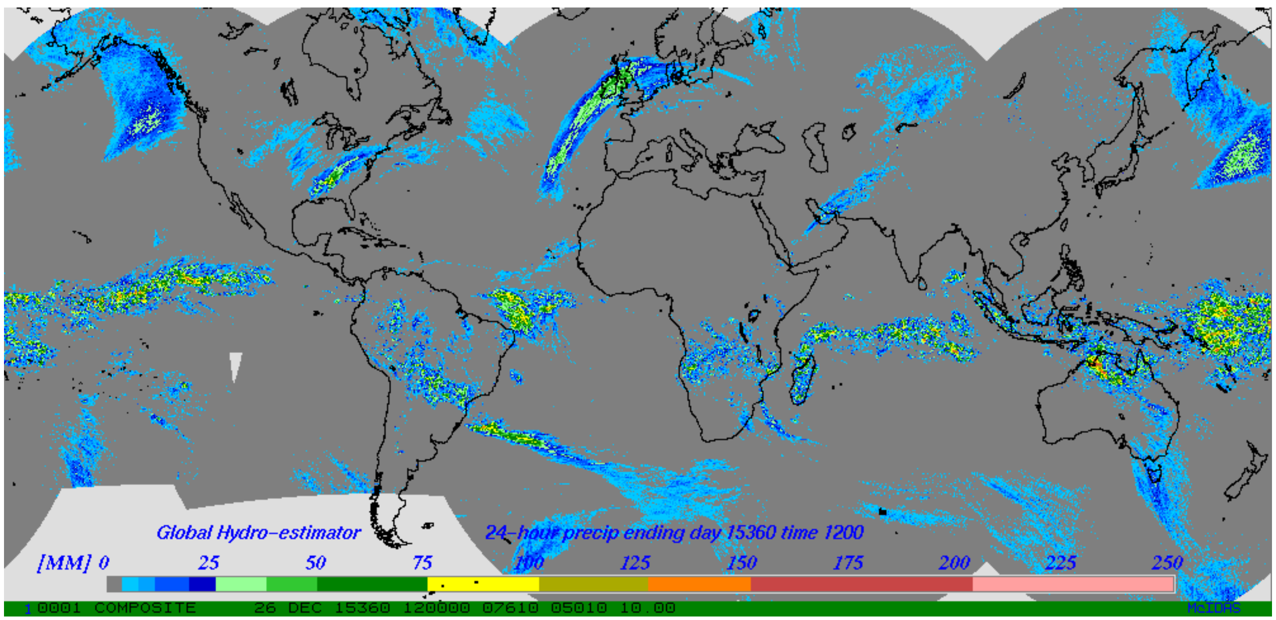


Infrared data used



December 26, 20015

MODIS True color image with microwave-based precipitation rate overlaid



Geostationary satellite infrared –based daily rainfall amount

Infrared and microwave products have lots of similarities but not always and not everywhere.

Two more aspects:

NEED FOR VALIDATION, LIMITED ACCURACY OF RETRIEVALS

PRECIPITATION CLIMATOLOGY

Satellite precipitation data online

NOAA Satellite-based precipitation products
http://www.ospo.noaa.gov/Products/atmosphere/spe/
Web page provides links to NOAA image and digital products

NASA WorldView
https://earthdata.nasa.gov/labs/worldview/
Provides global daily rain rate data derived from microwave observations of AMSR2/GCOM as one of the map layers

WMO product access guide
http://www.wmo-sat.info/product-access-guide/domain/atmosphere/precipitation
Provides links to satellite-based precipitation products generated by various national agencies (NOAA, NASA, EUMETSAT, JMA)

Winds from satellites

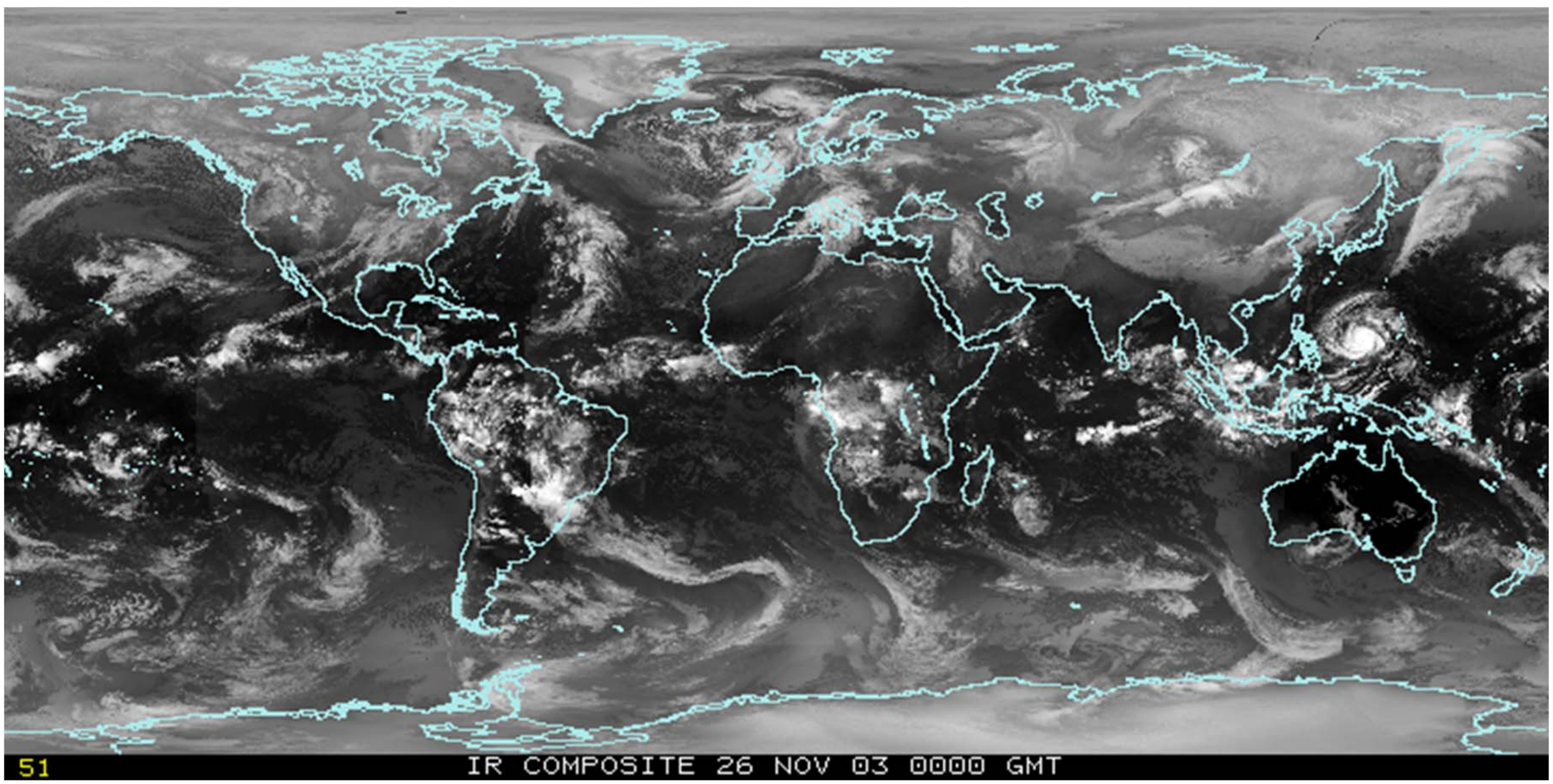
Satellites Do Not "See" Winds

But they "see" cloud motion which is caused by wind

They can also see change in the sea surface roughness which is most likely caused by winds

Cloud-Motion Winds: History

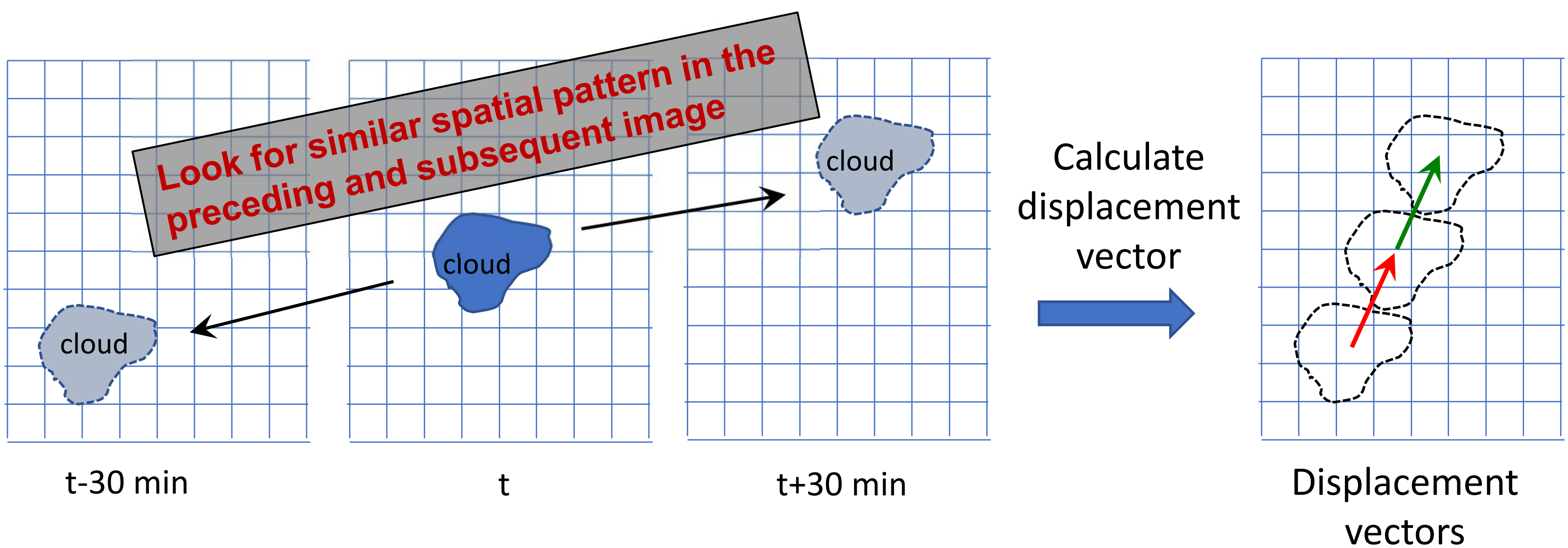
- One of the oldest applications of geostationary satellite imagery (since 1966)
- Wind vectors were first derived interactively
- Later automated algorithms were developed



Motion Vectors: Cross-Correlation Technique

- Uses sliding window over preceding and subsequent image to locate spatial patterns matching the ones in the reference image (cross-correlation technique)
- May be applied to satellite imagery in the visible (daytime only) and infrared (day and night)
- Needs a careful selection of tracer clouds which are further used to estimate displacement: Objects with large spatial temperature or reflectance gradients at the edge are selected

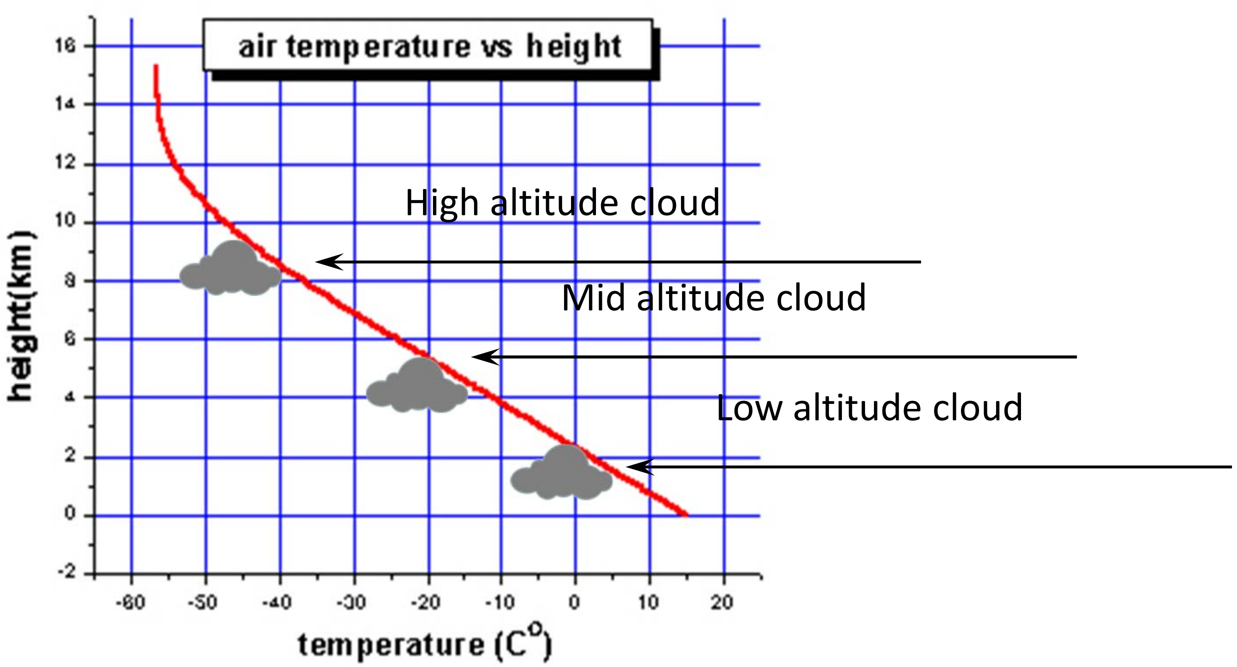
Determining tracer displacement



Wind vector height assignment

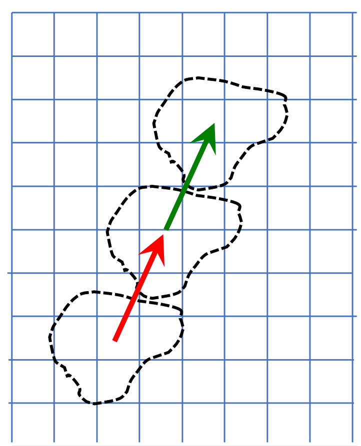
- Cloud top height is used to assign the height to each wind vector
- Cloud top height is determined from the observed cloud top infrared brightness temperature and atmospheric temperature profile

Tracer height assignment



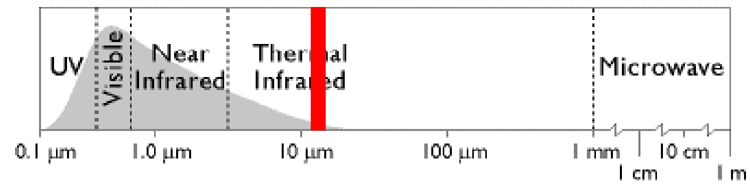
Wind quality control/editing

- Two consecutive displacement vectors derived from three consecutive images should agree on the wind speed and direction
- Derived wind vectors are also checked for general consistency with the wind field forecast from numerical weather prediction models.

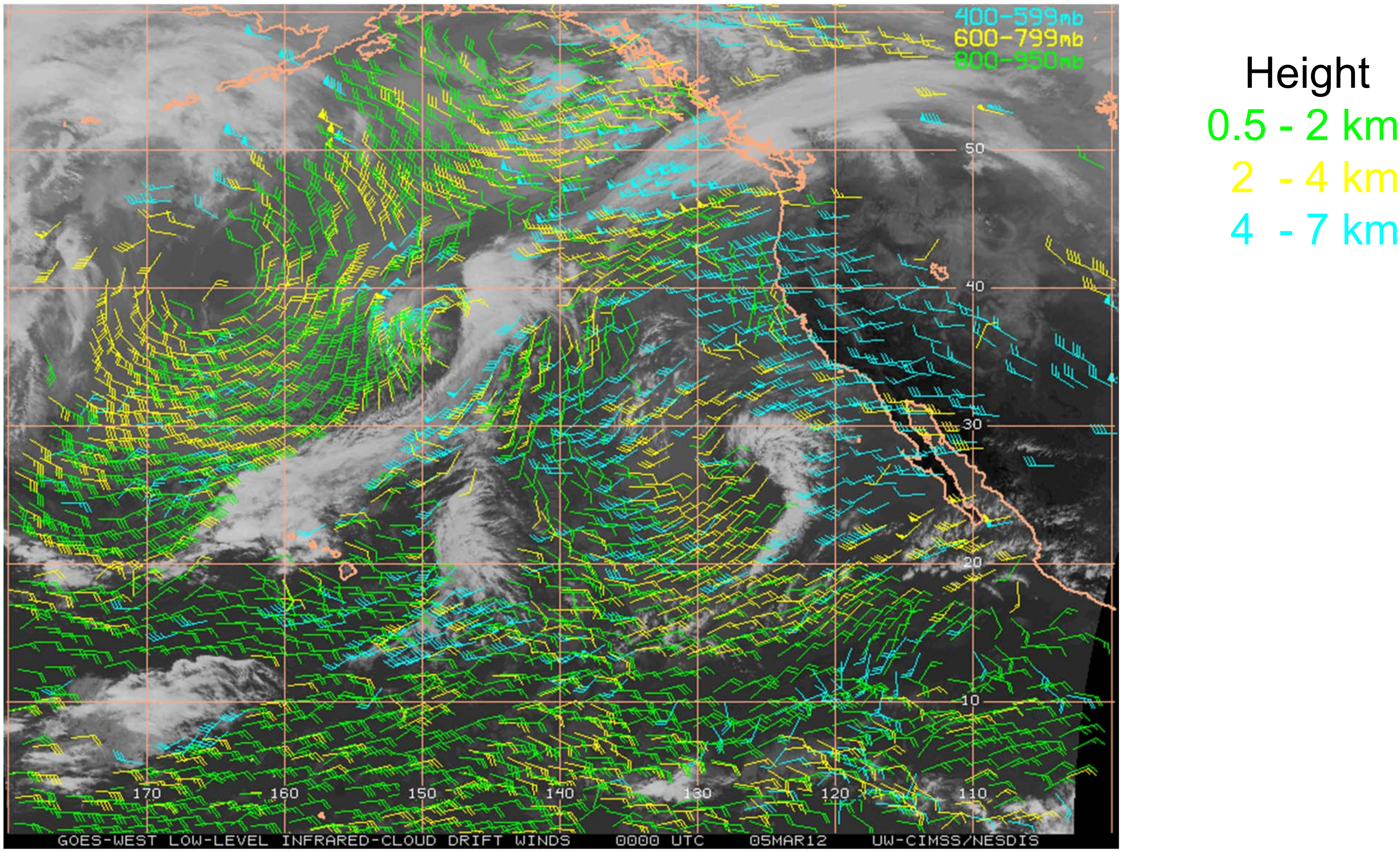


Displacement vectors

Atmospheric Winds

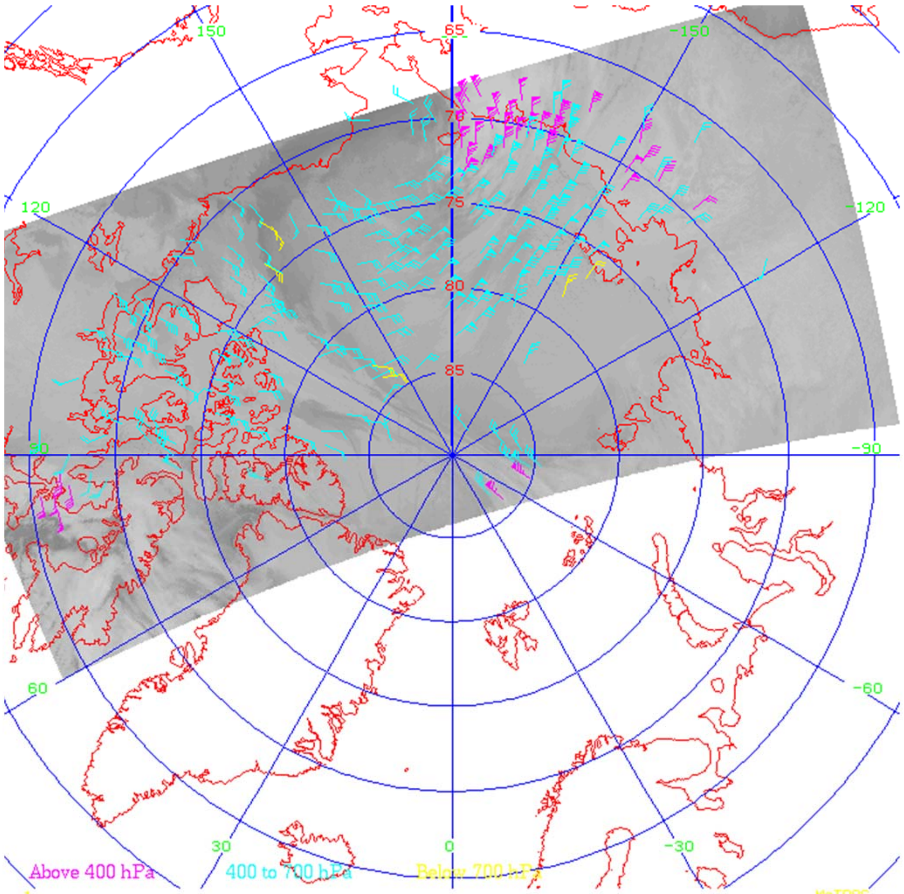


- Example of wind vectors derived from geostationary satellite data in the infrared spectral band



Polar Winds

- Polar-orbiting satellites provide frequent views over the polar area. This feature is used to generate wind vectors in high-latitude area with polar orbiting satellite data



Example of wind vectors derived from AVHRR data during one day

Other atmospheric parameters derived from satellite data

- Identification of fog
- Atmospheric dust and aerosols
- Volcanic plumes
- Ozone

Summary

- **Precipitation**
- Can be derived from observations in the infrared and microwave
- Infrared observations are best to use with convective clouds. They provide estimates of rainfall amount at high spatial resolution.
- Microwave retrievals are more universal and accurate due to more physical background. However they provide only instantaneous rain rates at coarser spatial resolution
- **Winds**
- Are derived primarily from infrared observations using cloud motion
- Can be derived over the whole globe (geostationary and polar orbiting satellites)
- Winds can be derived at different altitudes