Remote sensing of precipitation extremes

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Introduction

What to discuss ?

Understanding and predicting weather and climate extreme

- Question 1 out of 8 key scientific questions:
  How can we improve the collation, dissemination and quality of observations needed to assess extremes and what new observations do we need? *(GEWEX:GHP and GDAP)*

- Many of extreme events are directly related to precipitation: flood, drought, hurricanes, ice storms, land slide

- IPCC SREX report (2012): Climate *Extremes*, or even *a series of non extreme* events, in *combination with social vulnerabilities* and exposure to risks can produce climate related disasters

Introduction

Remote sensing and ground observation should help us capture the following precipitation features

- ***Intensity,***
- ***Duration and sequence,***
- ***Frequency***
- ***Phase : Snow/rain***

These features are critical for our analysis of **extreme events** (e.g., drought, flood, Tropical storms, etc.) and **climate change**

Requirements for Precipitation Products:

- Higher spatial and temporal resolution
- Better quality
- More quantitative uncertainties.

Solution/Strategy: Include all available sensors as long as they satisfy the requirements

❖ **REMINDER** : Hydrologic estimates are as good as precipitation information

Observation tools

1) Rain gauges

Pros:
- "True" measurement of rain

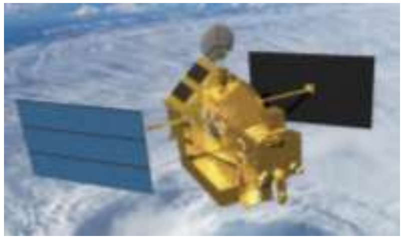
Cons:
- No coverage over oceans or remote regions
- Point measurement not representative of area
- Wind=> underestimation

2) Ground Radars

Pros:
- Excellent space and time resolution
- Estimation in real time

Cons:
- Poor coverage over oceans or remote regions
- Blockage (mountainous region)

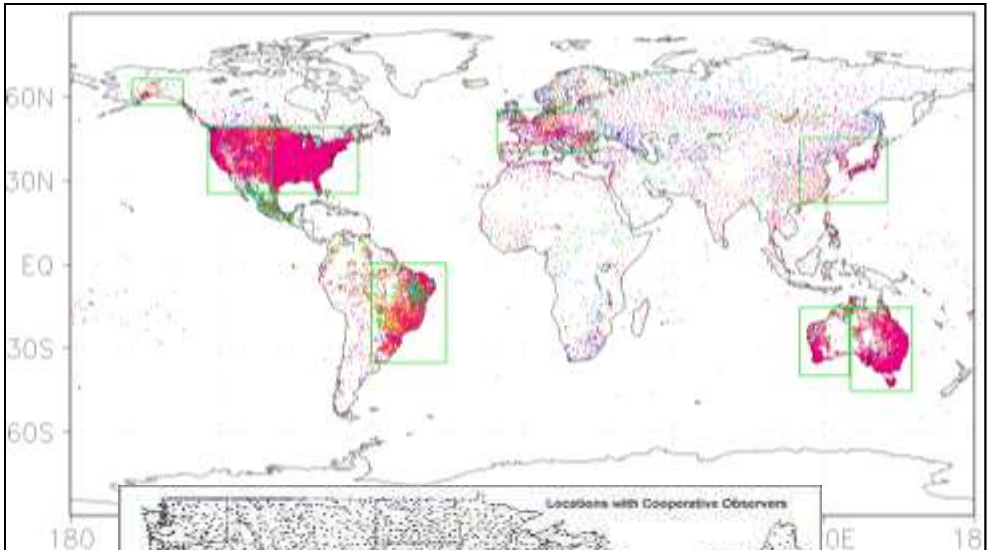
3) Satellite

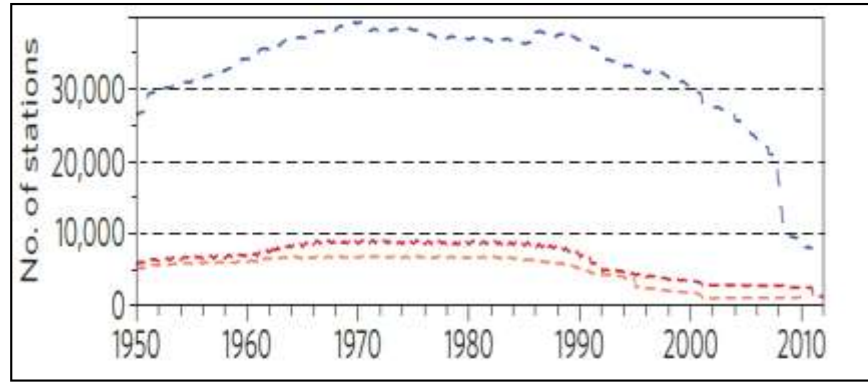


Pros:
- Global coverage
- Near real time

Cons:
- Expensive
- Needs long term planning

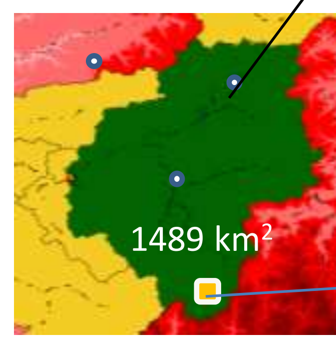
Ground observations are not sufficient





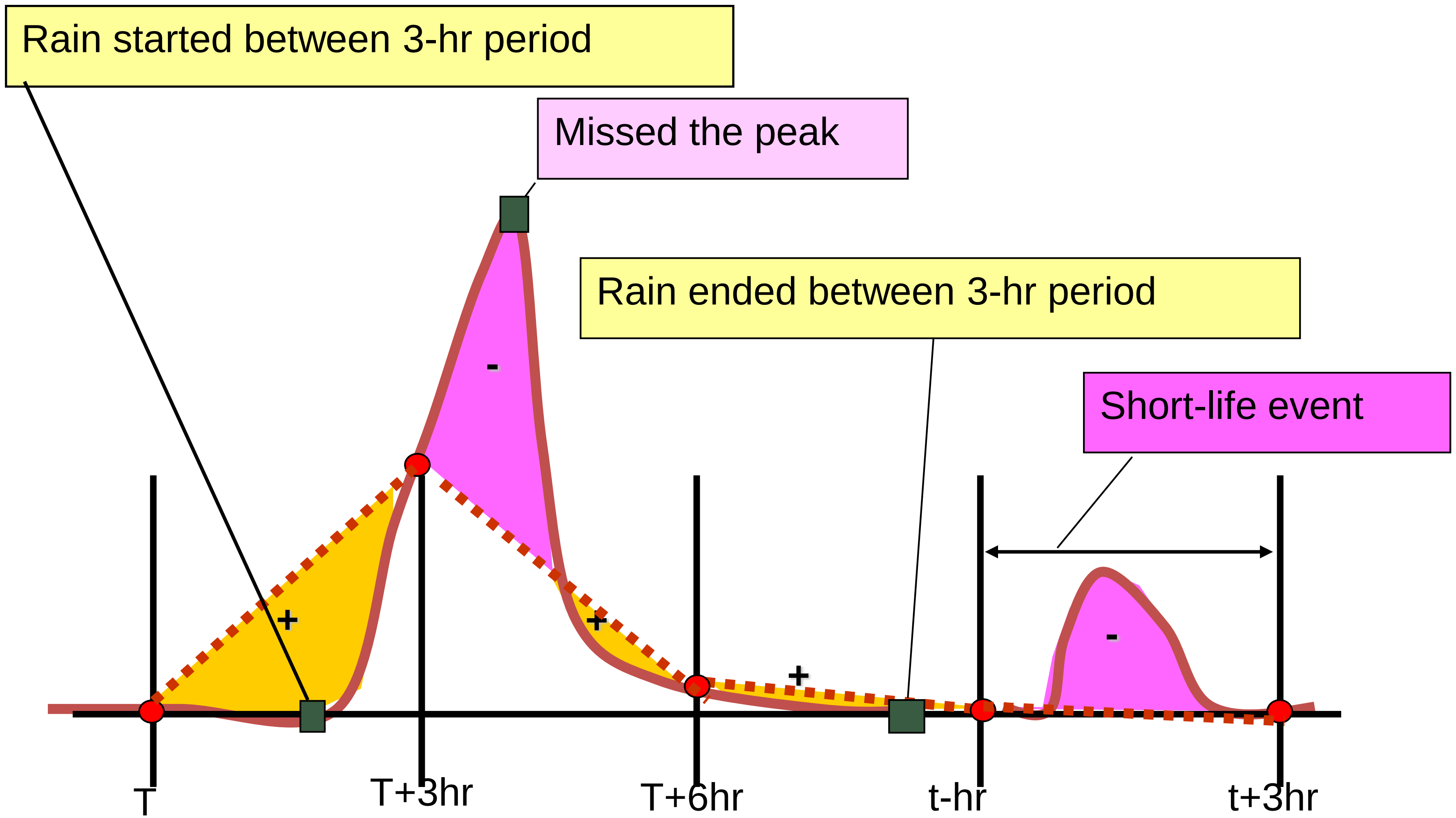
Gauge observations are not enough !

Mid-size watershed



Mid-size university

Interpolation of 3-hour Precipitation



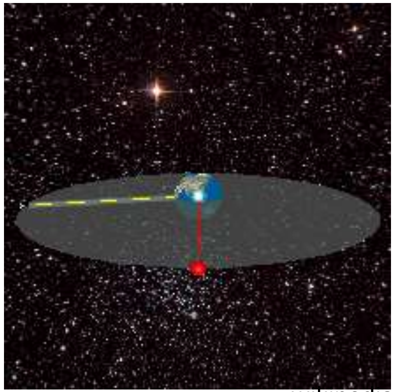
From Kuolin Hsu

Satellite/sensor types:

There are 3 main types of sensors used for precipitation retrieval:

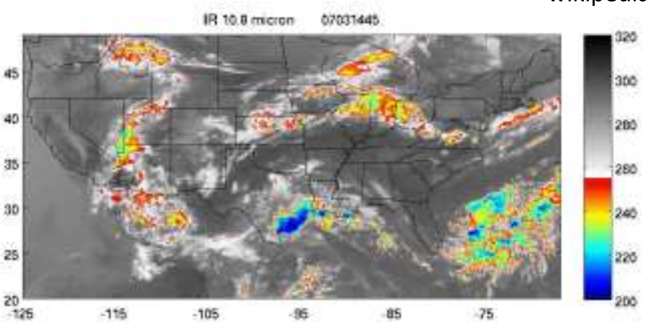
1) Visible/Infrared images often from Geostationary satellites

GOES/GOES-R
METEOSAT



wikipedia

Pros:
- Good temporal and spatial resolution (30 min, 4 km)
- very good coverage
- Observations go back to 1979



Cons:
- Receives mostly cloud–top information
- Indirect estimation of precipitation.

Satellite/sensor types:

2) Microwave only on Low-Earth-Orbiting (LEO) platform

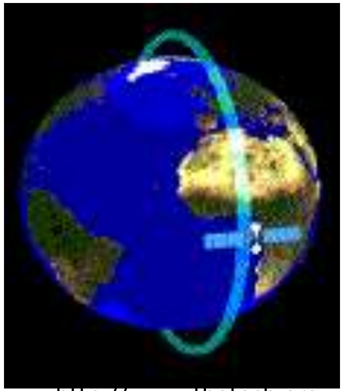
Pros:

- Respond more directly to hydrometeors and penetrates into cloud
- More accurate estimates

The first MW sensor (SSMI) came in 1987.

Cons:

- low temporal and spatial resolution (~5-50km)
- Heterogeneous emissivity over land
- (e.g., problem with warm rainfall over land)



http://www.thetech.org

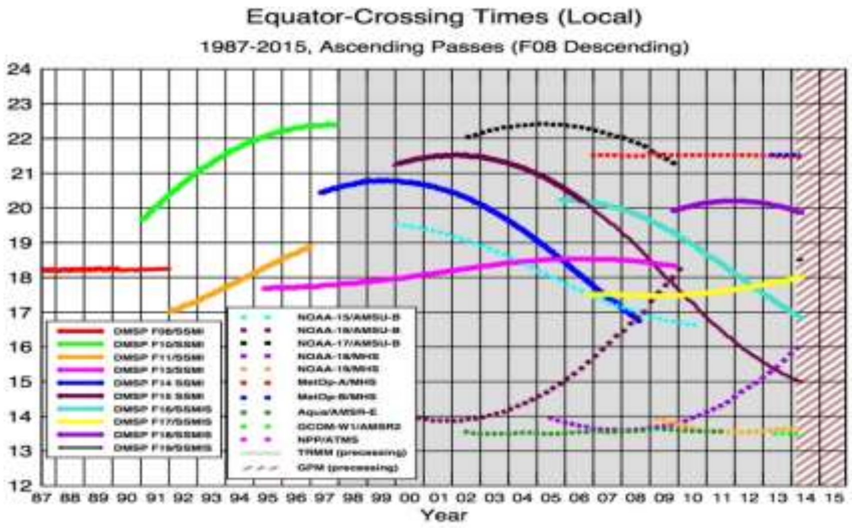
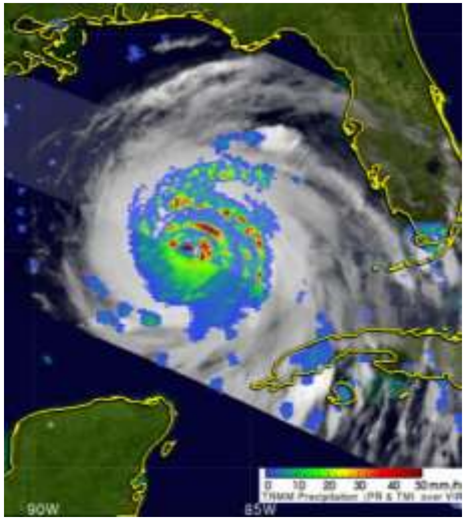


Image by Eric Nelkin (SSAI), 27 May 2014, NASA/Goddard Space Flight Center, Greenbelt, MD.

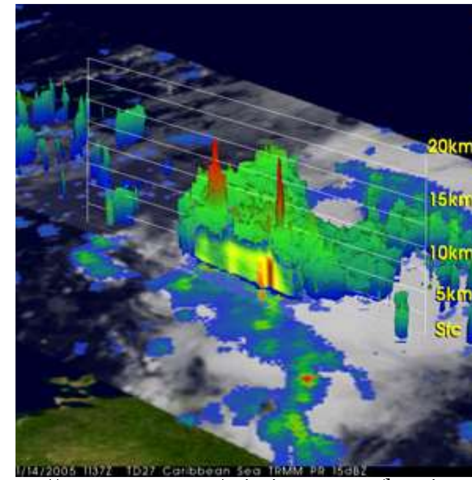
GMI-GPM
TMI-TRMM
SSMIS-DMSP
AMSU/MHS-NOAA
AMSR-GCOM
AMSRE-AQUA
ATMS-NPP
SAPHIR- **Megha-Tropiques**



So far there is no MW on geostationary platform.

Satellite/sensor types:

3) Radar: only on Low-Earth-Orbiting (LEO) platform



http://www.nasa.gov/mission_pages/hurricanes/archives/2005/h2005_gamma.html

<u>Pros</u>:
- Considered as the most accurate
- Good space resolution

<u>Cons</u>:
- Very Poor temporal resolution (several days repeating time)

TRMM PR (1997-2014)

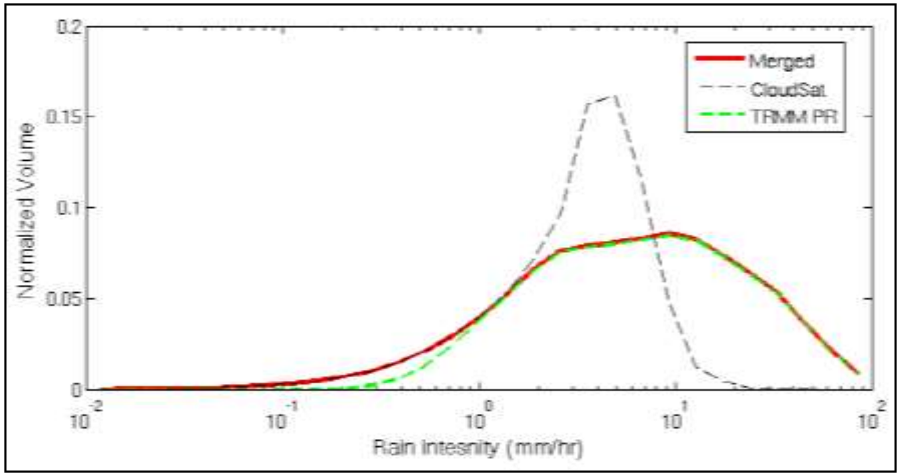
GPM DPR (since 2014)

CloudSat (since 2006)

So far there is no radar on geostationary platform.

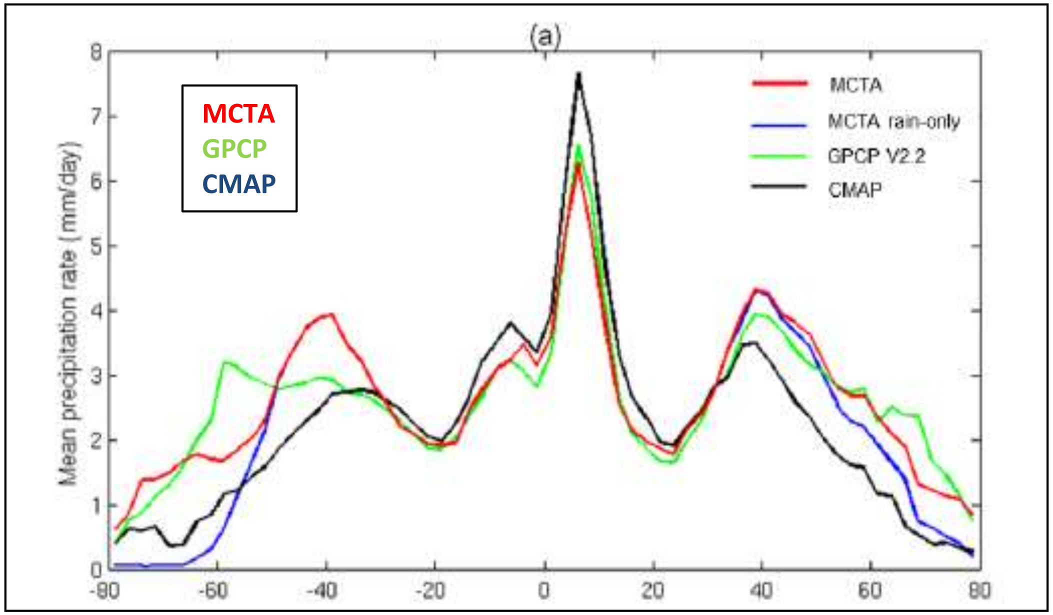
Advanced/new observation to update climate record

1) our climate records are often based on old instruments (consistency)
2) Better quality instruments exist and will continue to come
3) How can we use advanced/new instrument to improve climate records?



Example:

- ❖ Merging CloudSat (capturing snowfall and light rainfall) with TRMM PR (capturing the most intense rainfall)
- ❖ Use the merged product to Revisit precipitation climatology products (GPCP and CMAP)

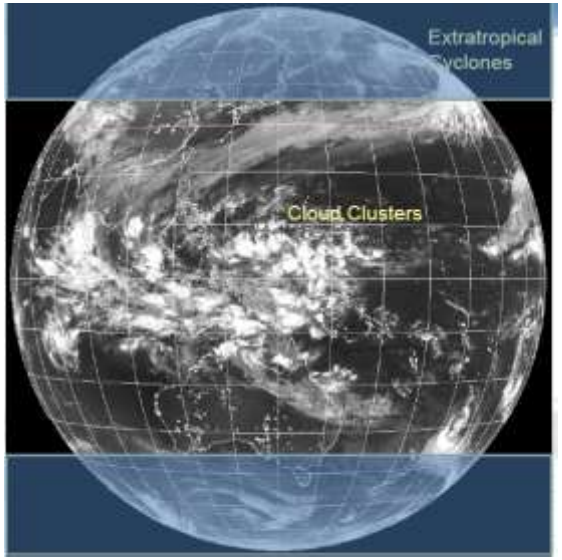


Behrangi et al. (2014)
J. of climatology

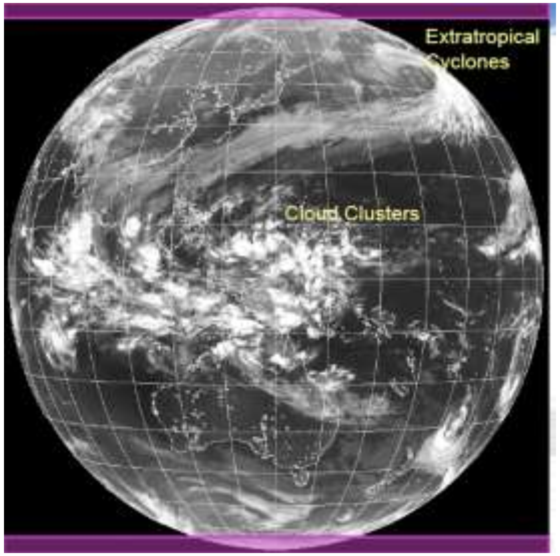
Recent missions

GPM: Moderate to intense precipitation (better than TRMM for light rain)

TRMM
35 S/N



Coverage: 57%

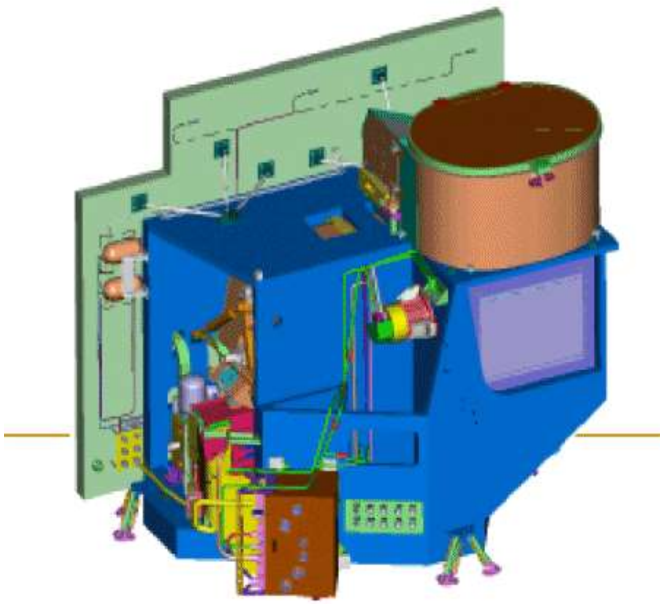


GPM
65 S/N

Coverage: 91%

Future missions

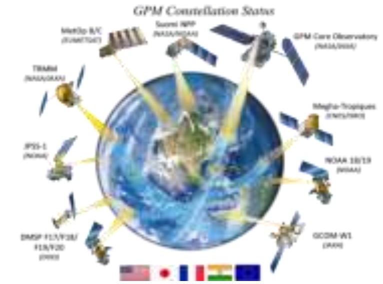
The ABI (Advanced Baseline Imager) *on Future GOES-R*

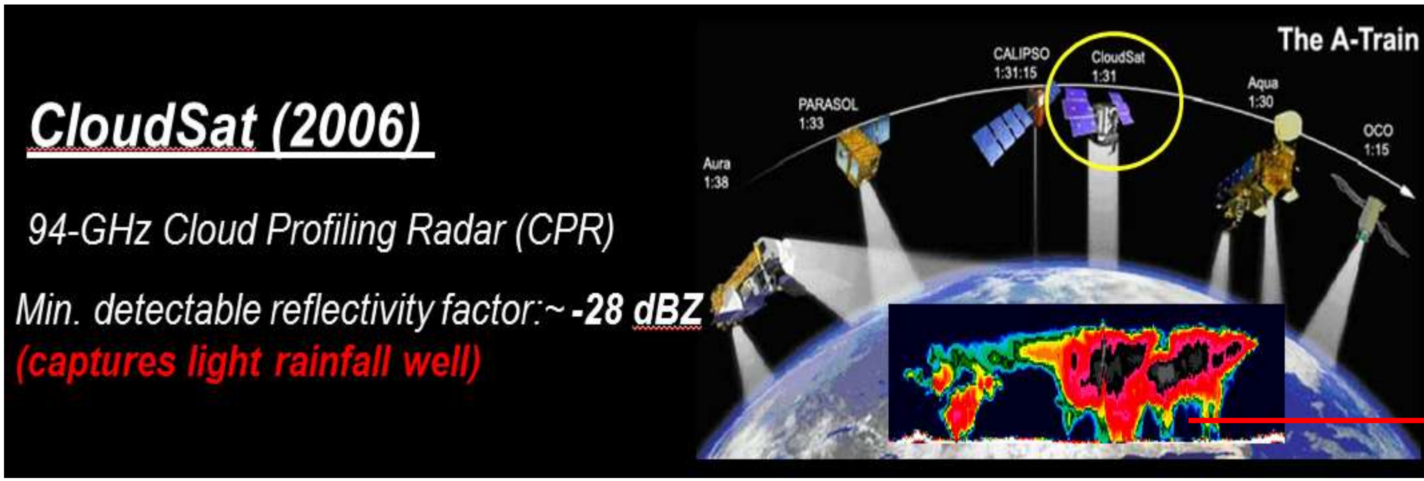


1-2km resolution global VIS/IR(16 bands) image every 15 min

Future missions

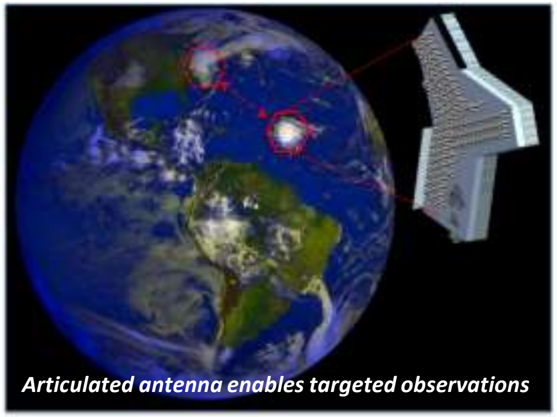
Light rainfall and snowfall

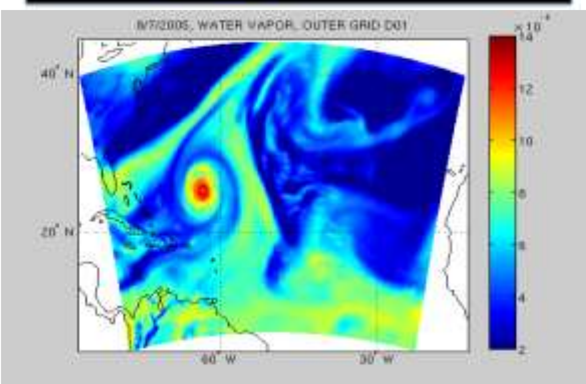


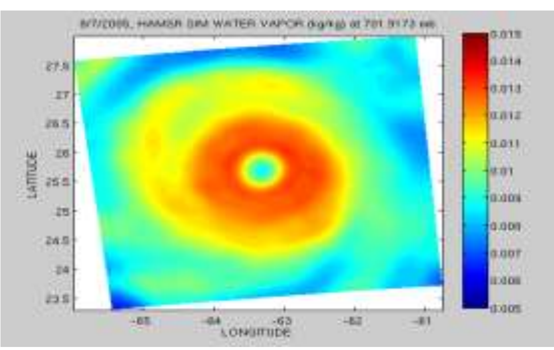


Signal Saturation

New concept missions to improve temporal res.

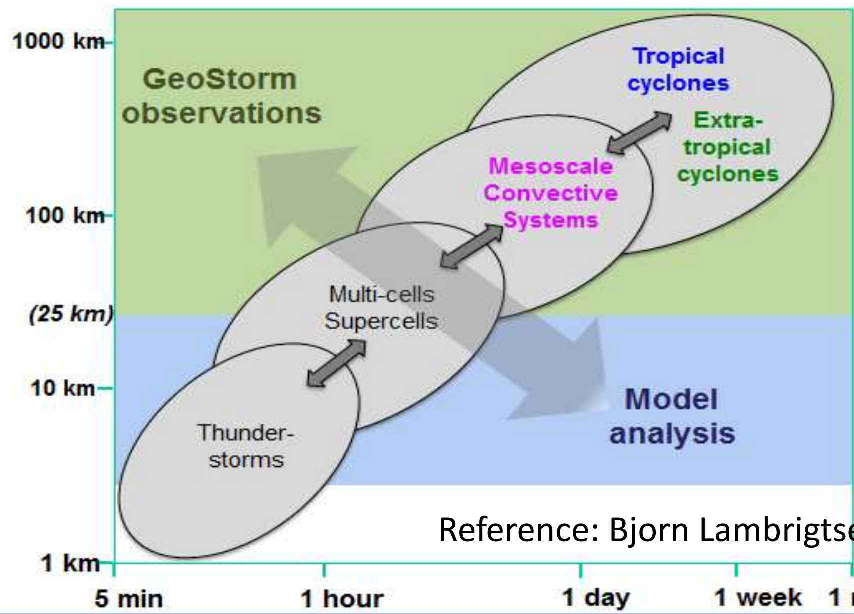






GeoStorm:

A GEOSTATIONARY MICROWAVE SOUNDER MISSION FOCUSED ON THE EVOLUTION OF SEVERE STORMS

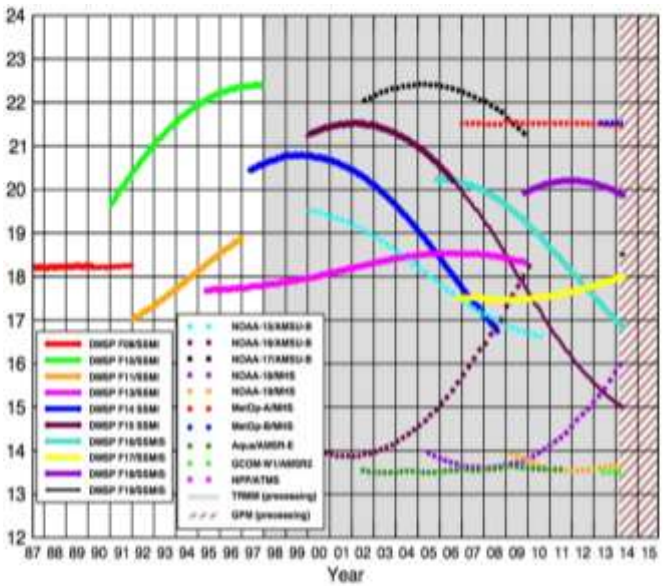


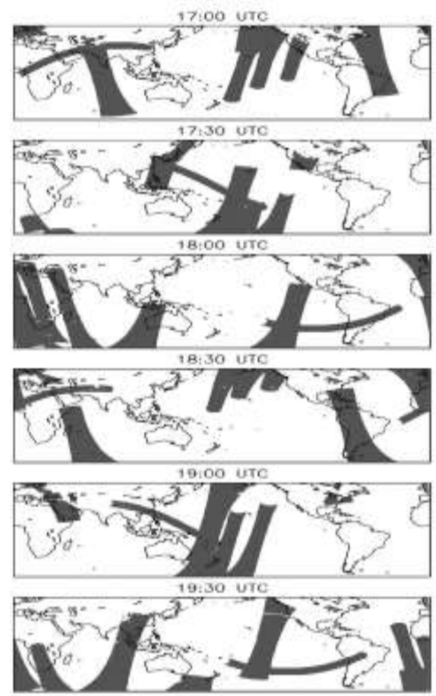
Reference: Bjorn Lambrigtsen (JPL)

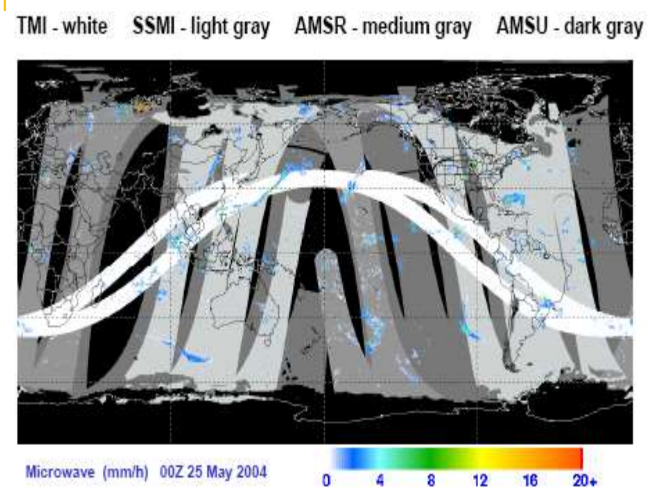
Great for process studies and life cycle/duration of storms

Temporal resolution: using multiple sensors

- Until having a geostationary microwave or radar, temporal res. of high quality precipitation from individual sensors remains poor
- Solution is to use combination of available good quality sensors
- With GPM we expect high quality observations almost every 3 hours (but depends on equator crossing time configuration)





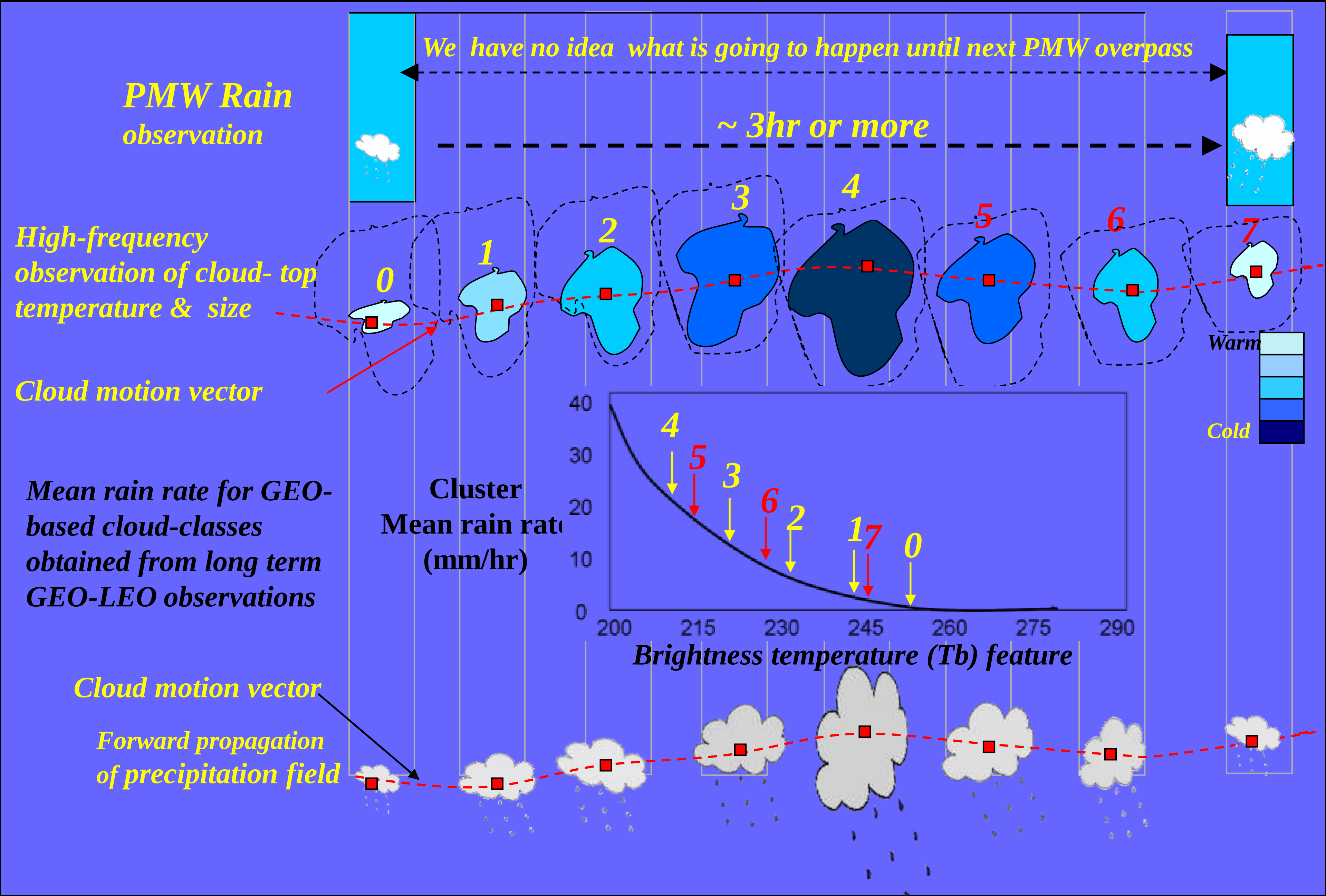


From Huffman et al. (2007)

One solution: Merged products (microwave and infrared)

Proposed method: REFAME

Rain Estimation using Forward Adjusted Advection of Microwave Estimates



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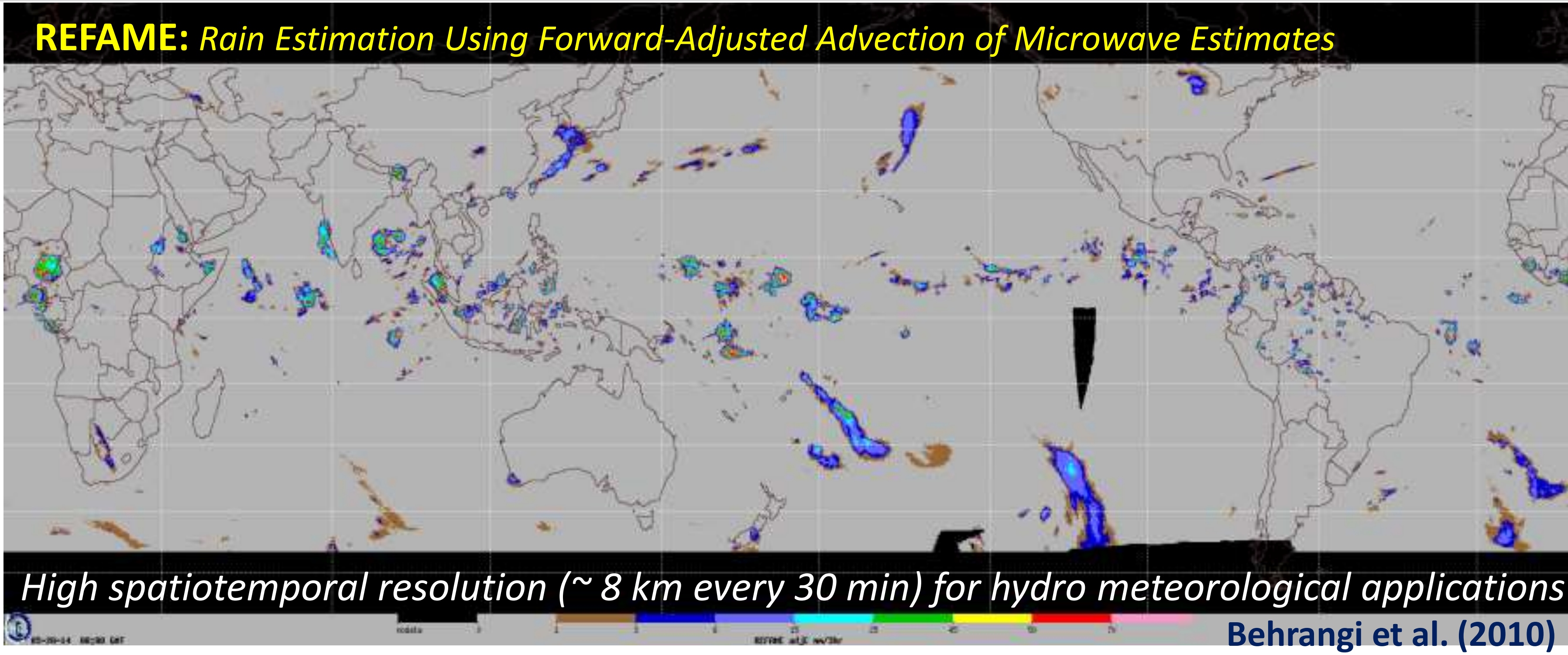
Pasadena, California

Merged products to increase temporal sampling



Several merged precipitation products exist

Near real-time/Application

(0.04/0.25 deg every 0.5/3hrs):

- **NASA TRMM 3B42**
- **NASA GPM IMERG**
- **CMORPH**
- **PERSIANN**
- **GSMaP**

Climatology/trend

daily/monthly (2.5deg and finer)

- GPCP
- CMAP
- CHIRPS
- PERSIANN CDR

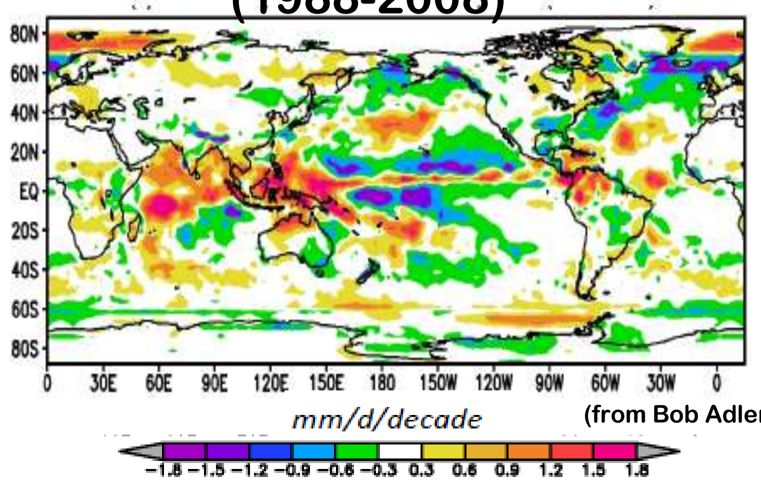
Climatology of precipitation extreme &variation

GPCP 95th percentile using 15 years of data

GPCP data :
- IR and MW (SSMI/S) -
1979- present
- 2.5X 2.5 deg. lat/lon

We can also look at number of days with precipitation rate is greater than certain rate.

Precipitation trends (1988-2008)



(from Bob Adler)

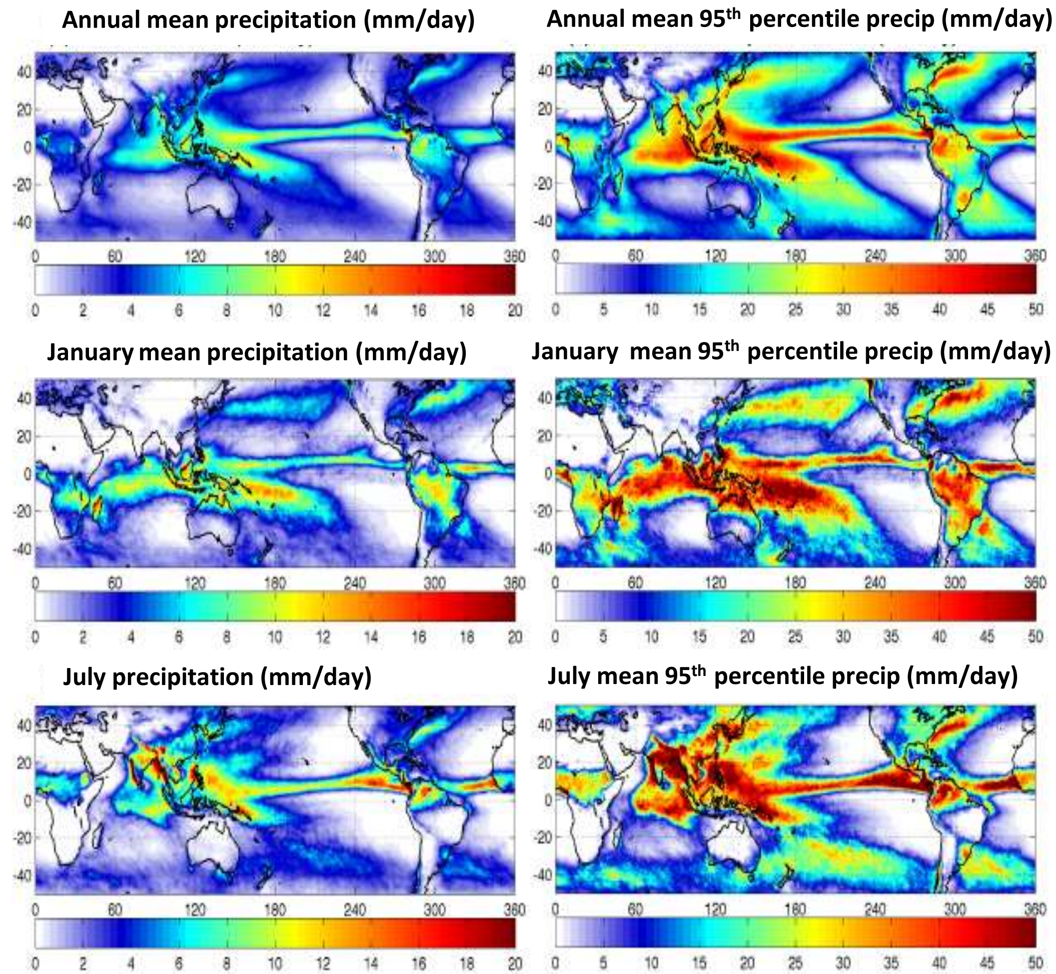
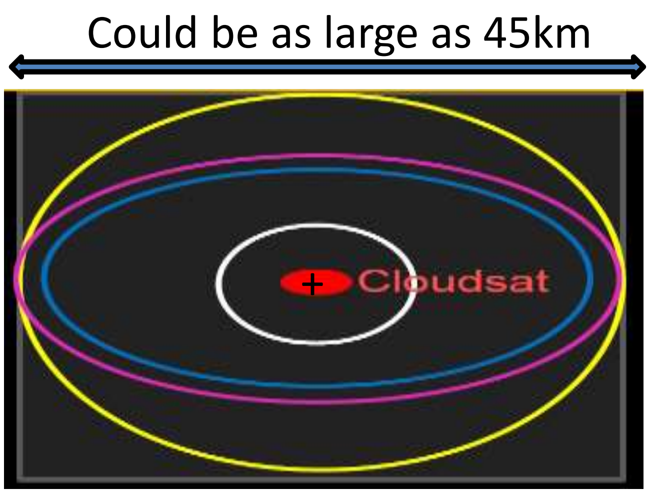


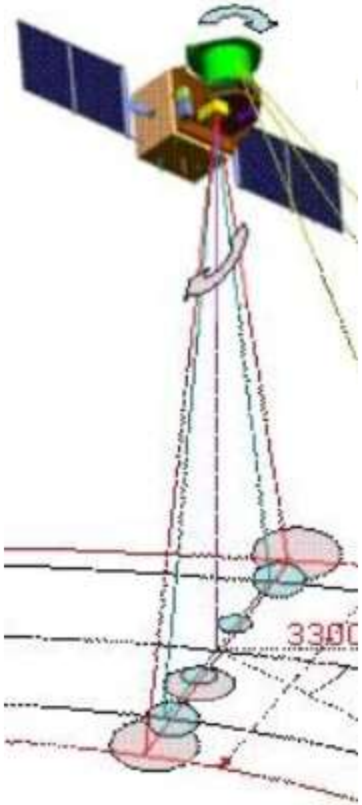
Image from Bob Adler

Importance of spatial resolution on precipitation intensity/frequency

Spatial scale is important for analysis of precipitation intensity and frequency:

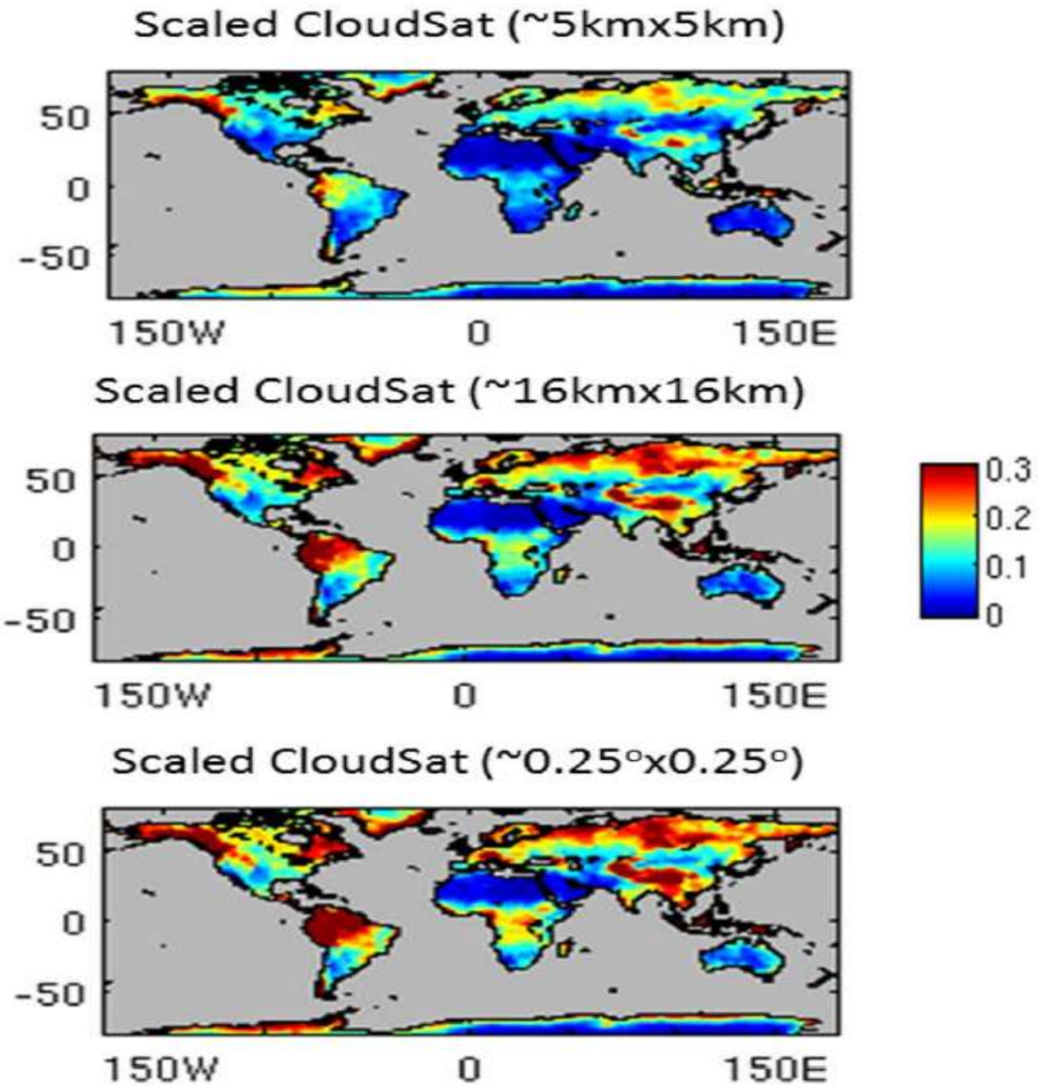
- Frequency of precipitation changes with footprint/FOV size
- Larger footprint can result in underestimation of extremes





Precipitation Frequency:

Impact of FOV size on Precipitation frequency



Other important factors have to be considered:

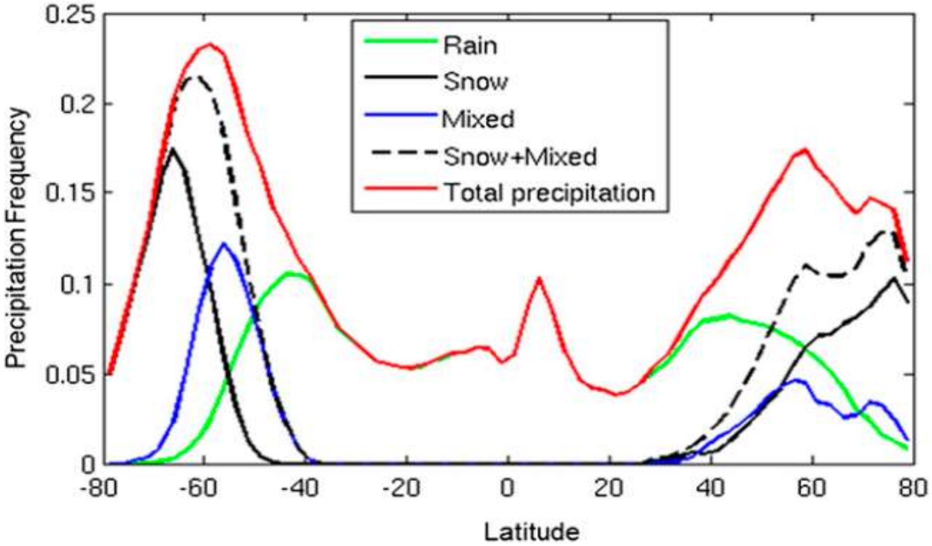
- Observation time
- Observation consistency
- Observation continuity
- …

Precipitation phase:

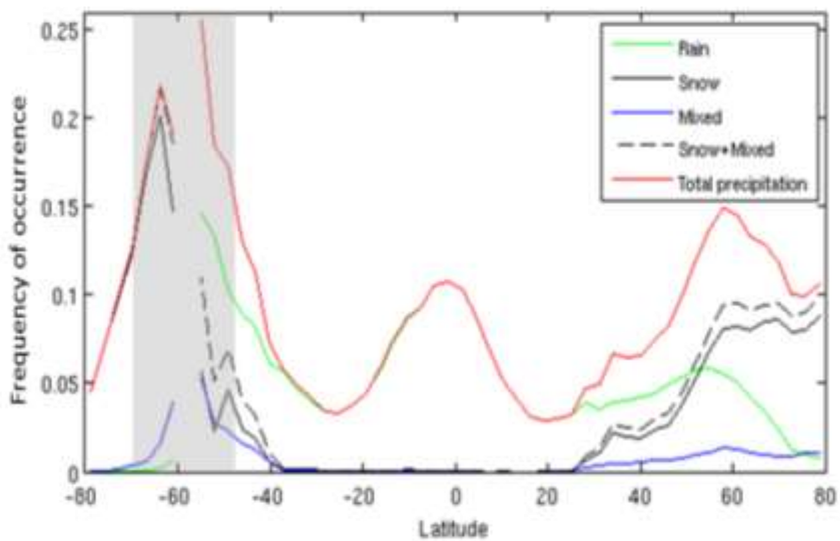
Zonal distribution of precipitation phase frequencies

(Based on CloudSat footprint observations for 2007–2009)

Ocean



Land

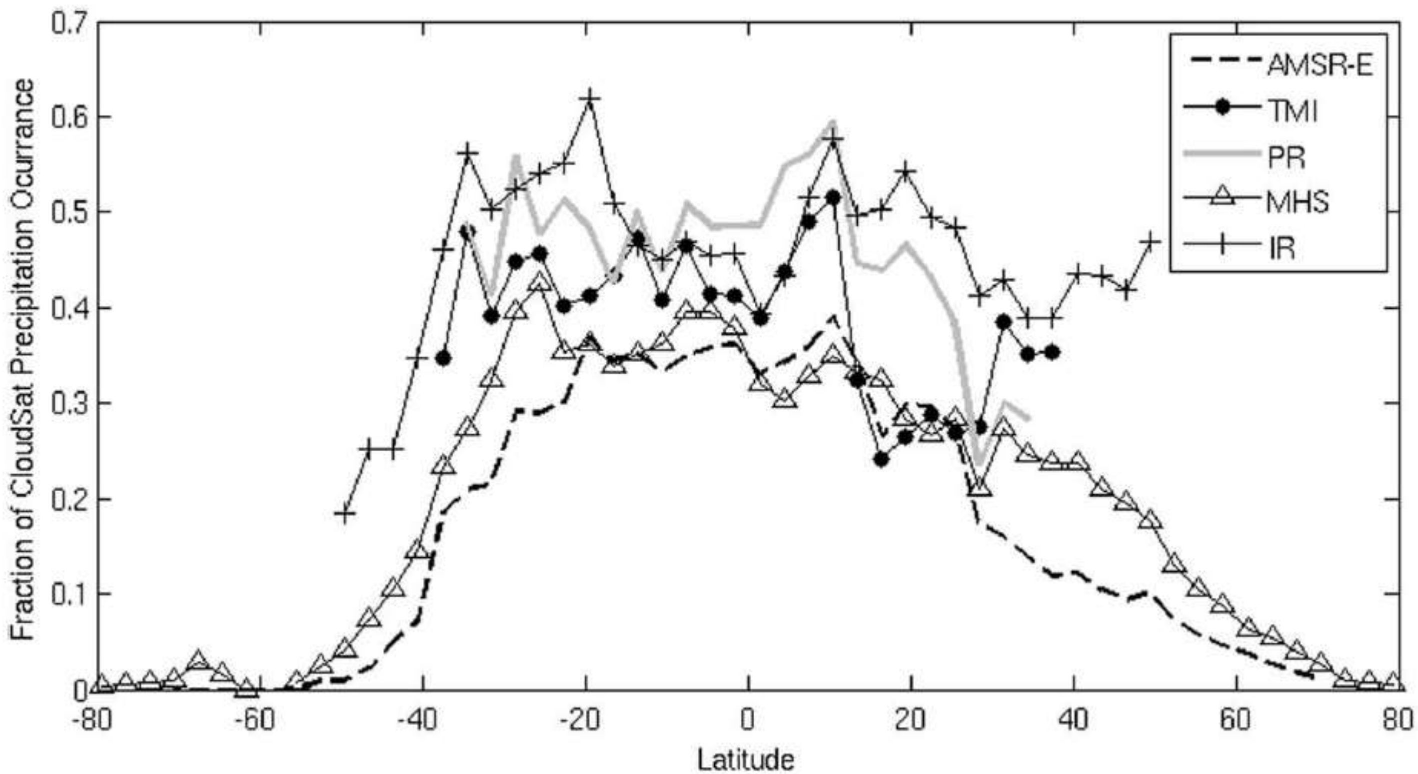


Behrangi et al. *WRR* (2014)
Behrangi et al. *J. of climate* (2014)

It is critical to be able to observe/estimate snowfall in high latitudes.

Precipitation Frequency

Missing a large fraction of precipitation occurrence in high latitudes

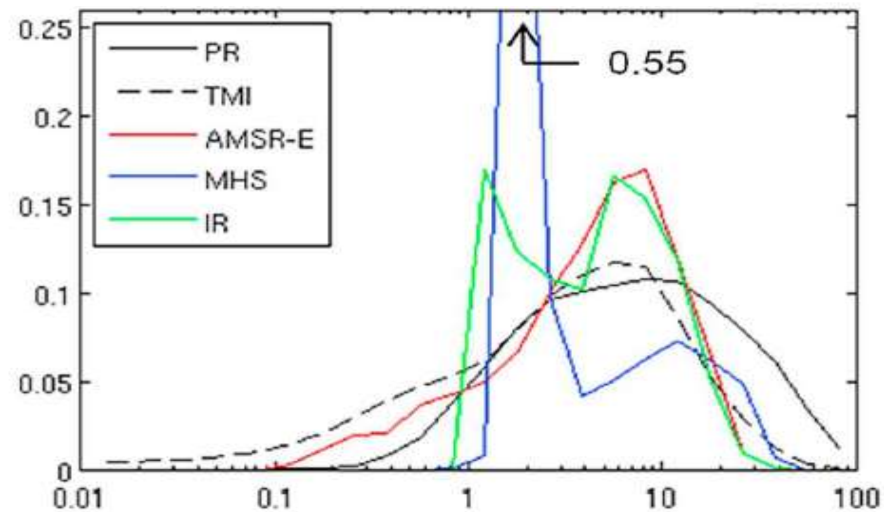


In latitudes higher than 60 deg. sensors capture less than 10% of precipitation detected by CloudSat.

Precipitation intensity:

Precipitation radar from TRMM and GPM are critical to capture the intense tail of the precipitation histogram

Tropical ocean (36 S/N)



(mm/hr)

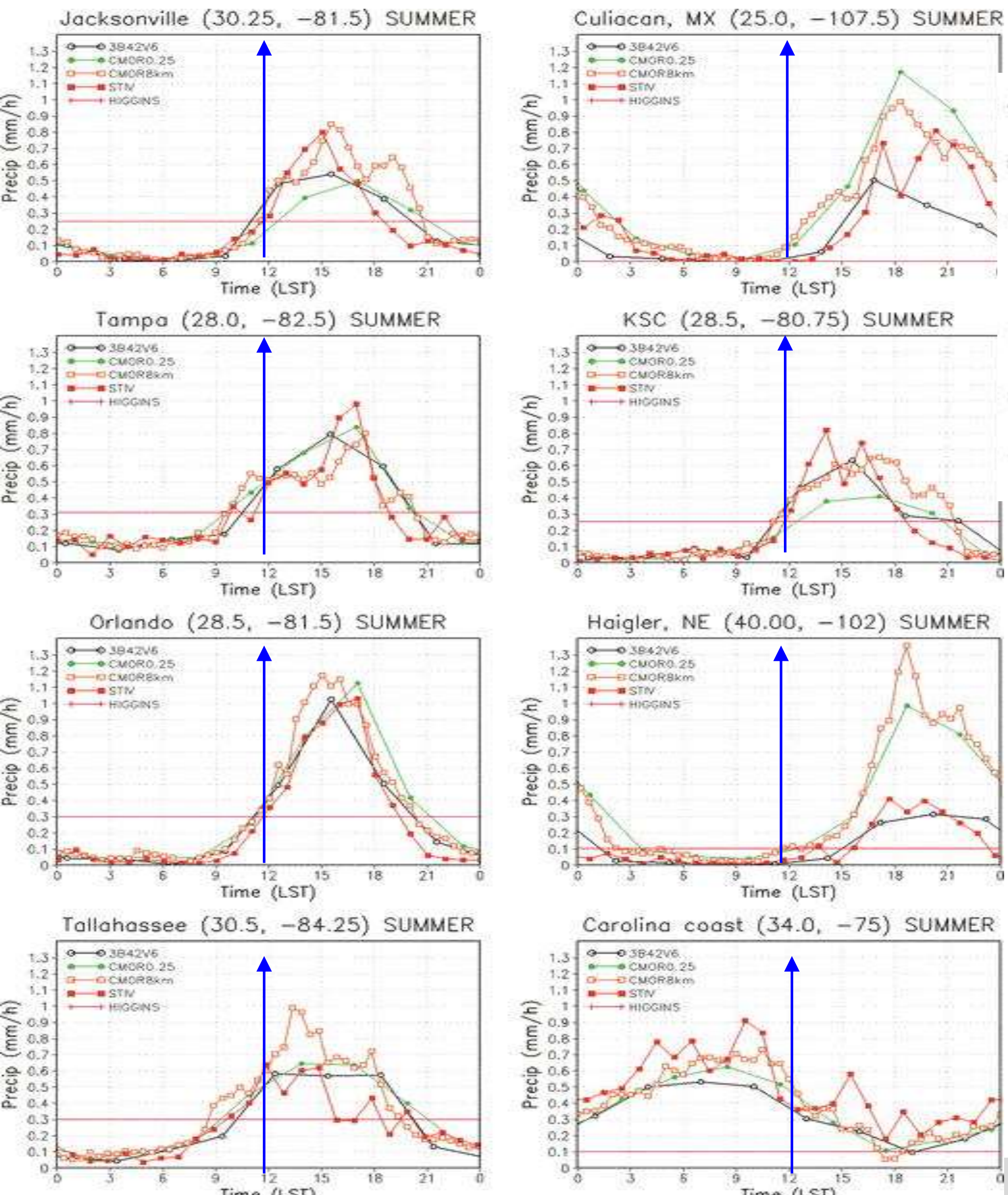
Many factors contribute to ability of PR or (GPM DPR) to capture extreme precipitation:

1. ***Measurement type***: At 13.8 GHz the signals barely saturate under heaviest precipitation
2. ***Footprint resolution***: The resolution of PR /DPR is about 5km.

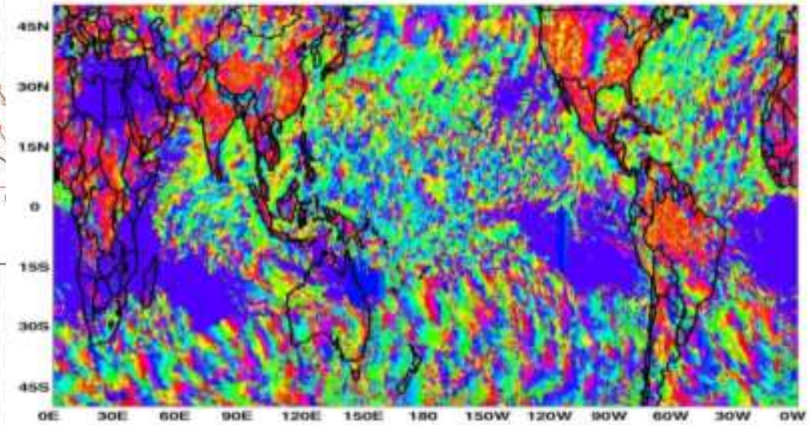
Over ocean, TRMM TMI resolution for ~22GHz channel is ~18x23 km).

<u>Recording</u> gauge observations likely can estimate higher precipitation rates, at least because they are point measurements. However, their accuracy and spatial representation have to be considered.

Diurnal cycle of precipitation:



Peak Hour of PERSIANN Diurnal Rainfall



From Kuolin Hsu

Local Time

00 03 06 09 12 15 18 21

$\underbrace{\text{06 09 12 15 18}}_{}$

Day-time hours

Climatology of daily precipitation time series at eight locations over CONUS (Tian et al., 2007)

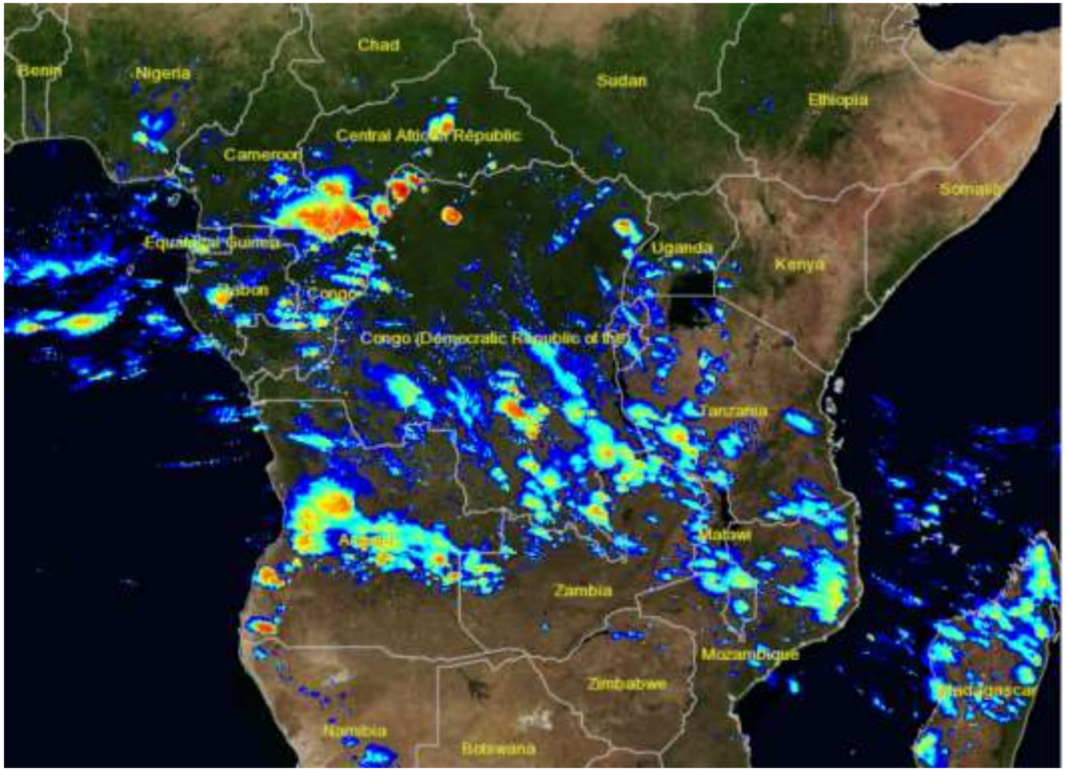
←

Time of observation is critical to study extreme precipitation !

<u>Models are not great at this.</u>

Extreme precipitation: regional consideration

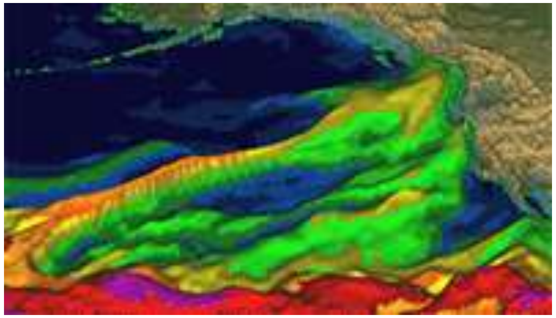
In many regions, major precipitation extremes are from convective systems and satellites often perform good in capturing intense precipitation from deep convective systems.

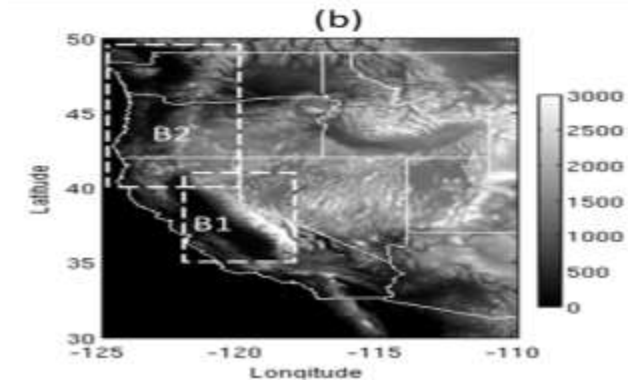


However, not every extreme precipitation is from deep convective systems

Extreme precipitation: regional consideration

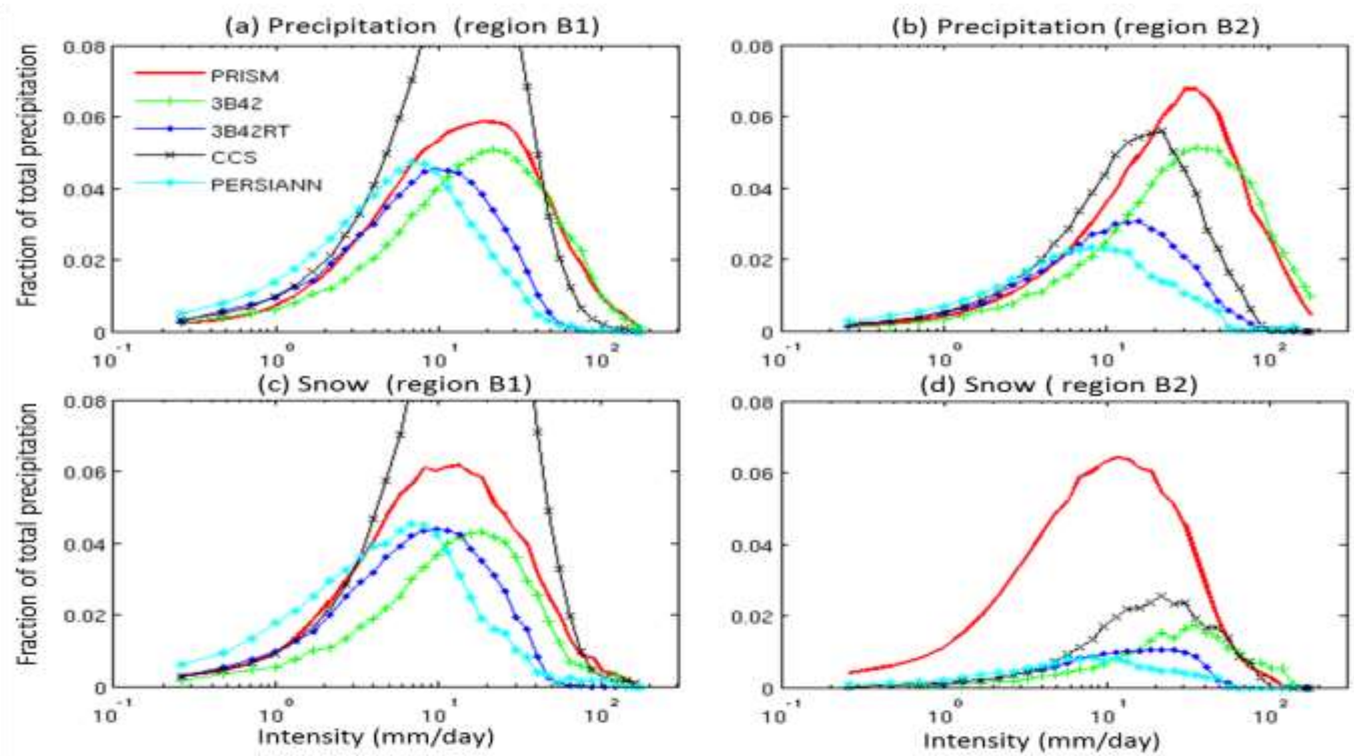
Atmospheric rivers





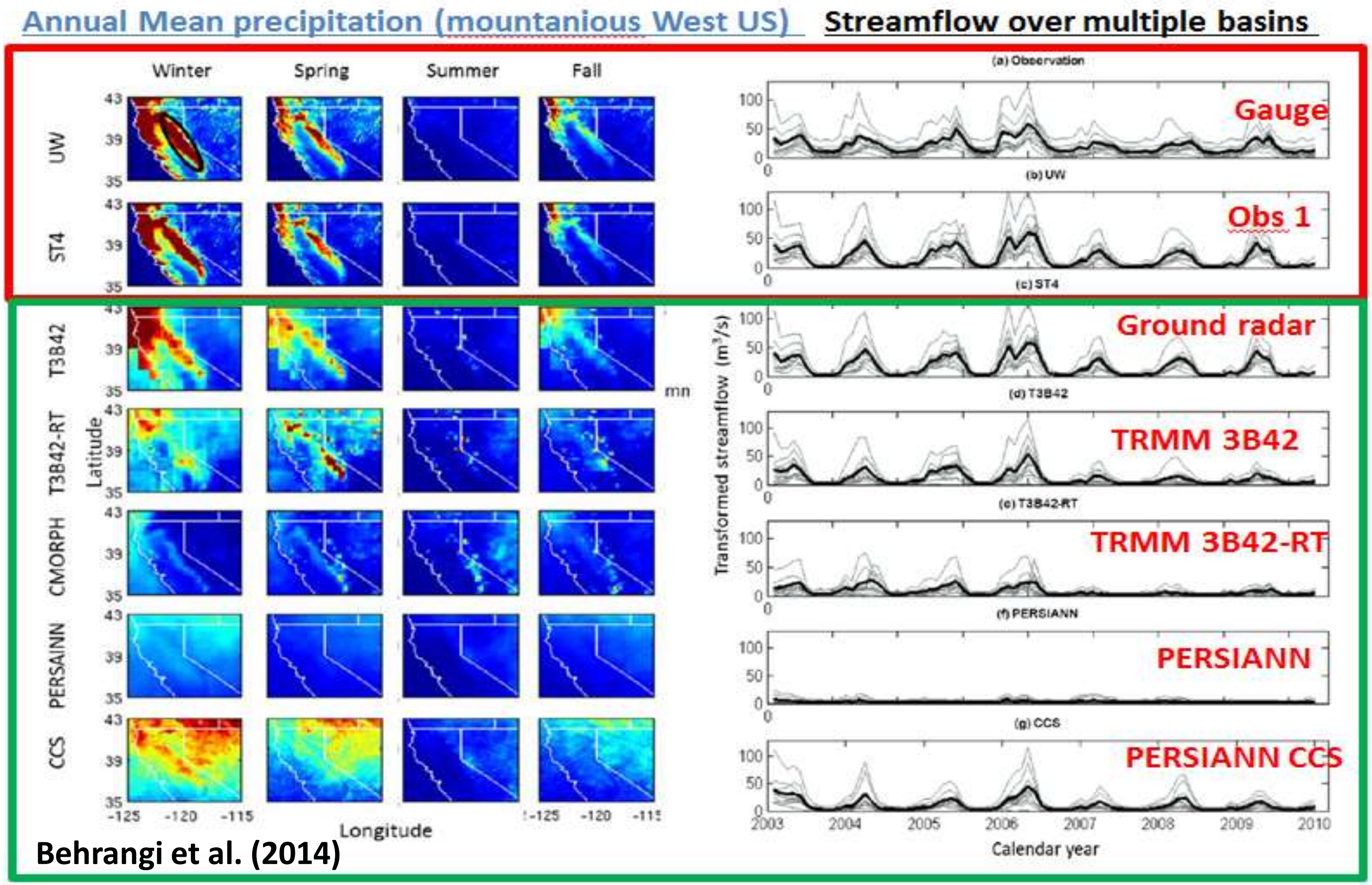
western US

Image of AR OROGRAPHY



Behrangi et al. (2015)
To be submitted to JHM

Extreme precipitation in western US:



Capturing mountainous precipitation is difficult but critical for water resources, flood, and drought analysis.

Summary and concluding remarks

For analysis of Extreme precipitation from satellite we need to consider several points:

- Analysis of precipitation extremes should be done regionally: Type of precipitation and the ability of sensors to measure different types of precipitation vary regionally and seasonally.
- Because of their areal coverage, satellite observations are great for comparison and evaluation of models (there is no point to grid issue like that exists in ground stations)
- Capturing very intense and very light tails of precipitation PDF remain challenging. Currently TRMM PR and GPM DPR are the best sources for estimation of intense rain. CloudSat is the best for light rainfall and snowfall. Both have very poor temporal res.
- Merged precipitation products are important for many studies.
- Significant fraction of precipitation (mainly light rainfall and snowfall) are missed , especially at higher latitude where the missed precipitation (volume and frequency can exceed 50 %). This can impact drought analysis and calculation of duration and frequency of precipitation.
- Extreme precipitation can include warm rainfall (rainfall from clouds below freezing level) and snowfall. Both are not well captured by current instruments.
- Challenges in capturing very light and very intense tails of precipitation can impact monitoring and prediction of Drought and Flood (important topics for GDAP and GHP)
- *etc. will discuss in breakout sessions*

Summary and concluding remarks

NEEDS: To capture extremes we need great:

1) Temporal resolution (need sub daily. How far can we go ? Hourly?)
2) Spatial resolution
3) Great sensitivity across the entire precipitation range
4) Full sampling (can not rely on interpolation)
5) Long-term data for climate analysis
6) Consistent observations (instrument type, observation time, quality control)
7) Requirements to advance/evaluate models

Challenges:

1) Mismatch in the spatial scale and observation time (e.g., point/grid and instantaneous/accumulation observation)
2) Interpolation method
3) Tradeoff between sampling, resolution, consistency, long-term record, etc.
4) How new and high quality observation can help revisit our climate records

Doable action-items/ requirements and plan for future:

1) Data requirements within and between existing observations of extremes (e.g. *in situ* and remote sensing, existing and future datasets)
2) What are our future needs ? (BREAKOUT GROUPS)
3) Requirements to advance/evaluate models

Thanks !

<u>**Contact info:**</u>

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