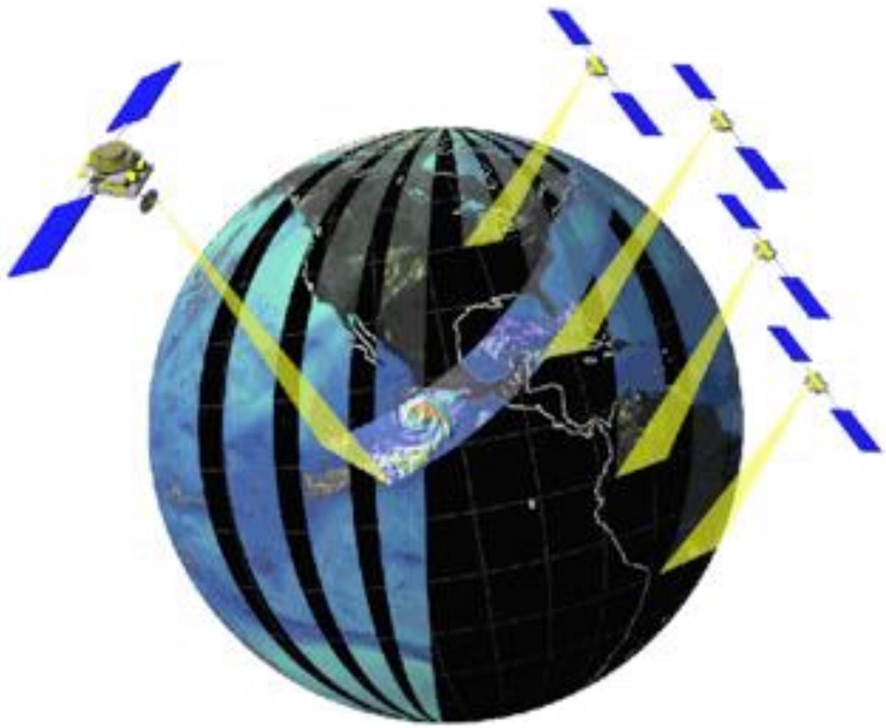
Projected Advances in the Remote Sensing of Precipitation



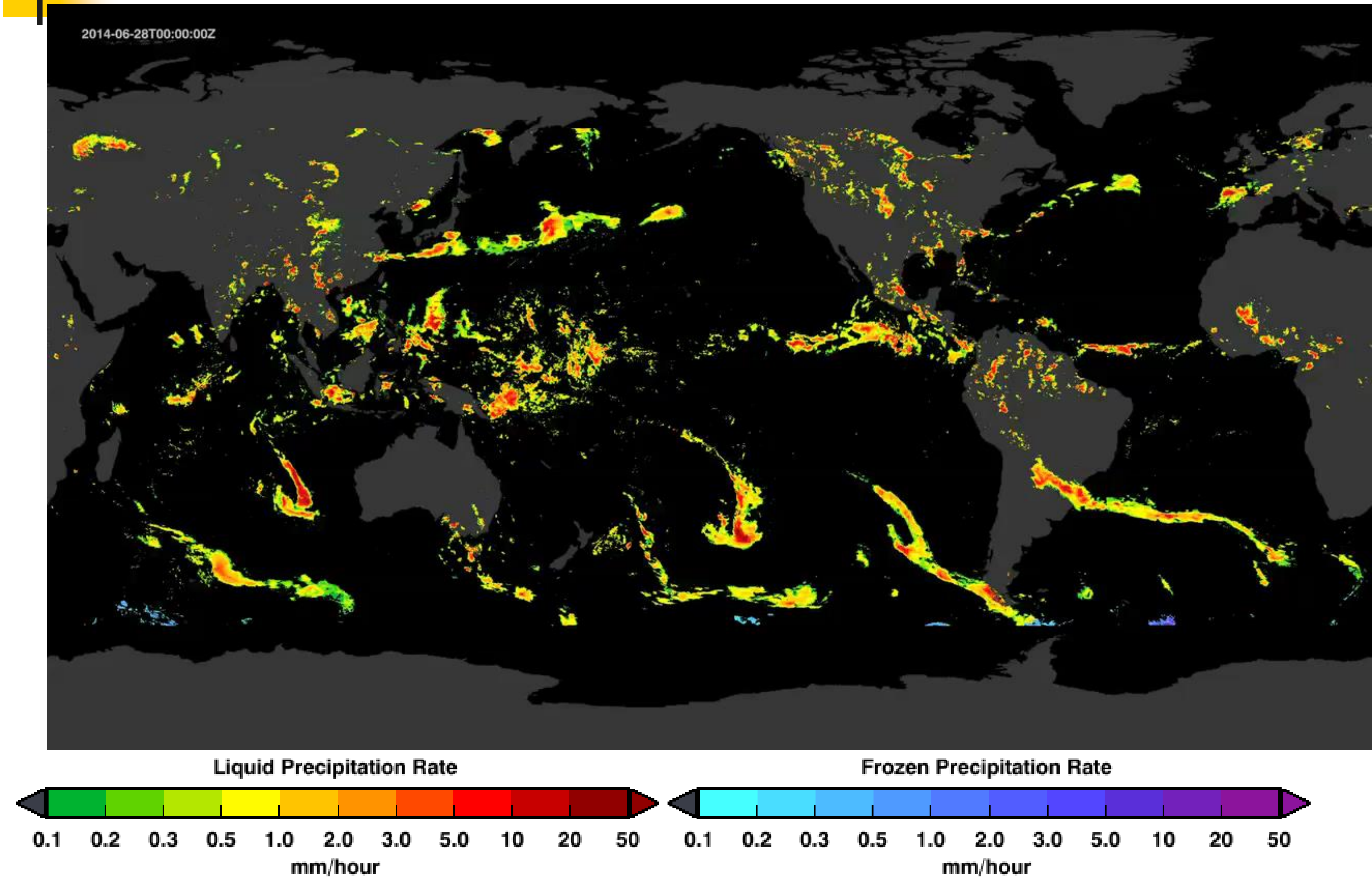
Christian Kummerow
Dept. of Atmospheric Science
Colorado State University

Colorado State University

Satellite inspired hydrology in an uncertain future:
a H SAF and HEPEX workshop
25-28 November, 2019

Multi-Satellite Precipitation Data

(30 min, 10km by 10km)



Overview

- Where we are today
- Potential advances with available data
- Advances in satellite sensors that can be predicted with confidence
- Advances in algorithms that are coming
- Advances beyond the current horizon

IMERG Data Sets

Multiple runs for different user requirements for latency and accuracy

- "early" – 4 hours
- "late" – 12 hours
- "final" – 2 months

Time intervals are half-hourly and monthly (Final only)

0.1° global CED grid

- PPS will provide subsetting by parameter and location
- initial release covers 60° N-S

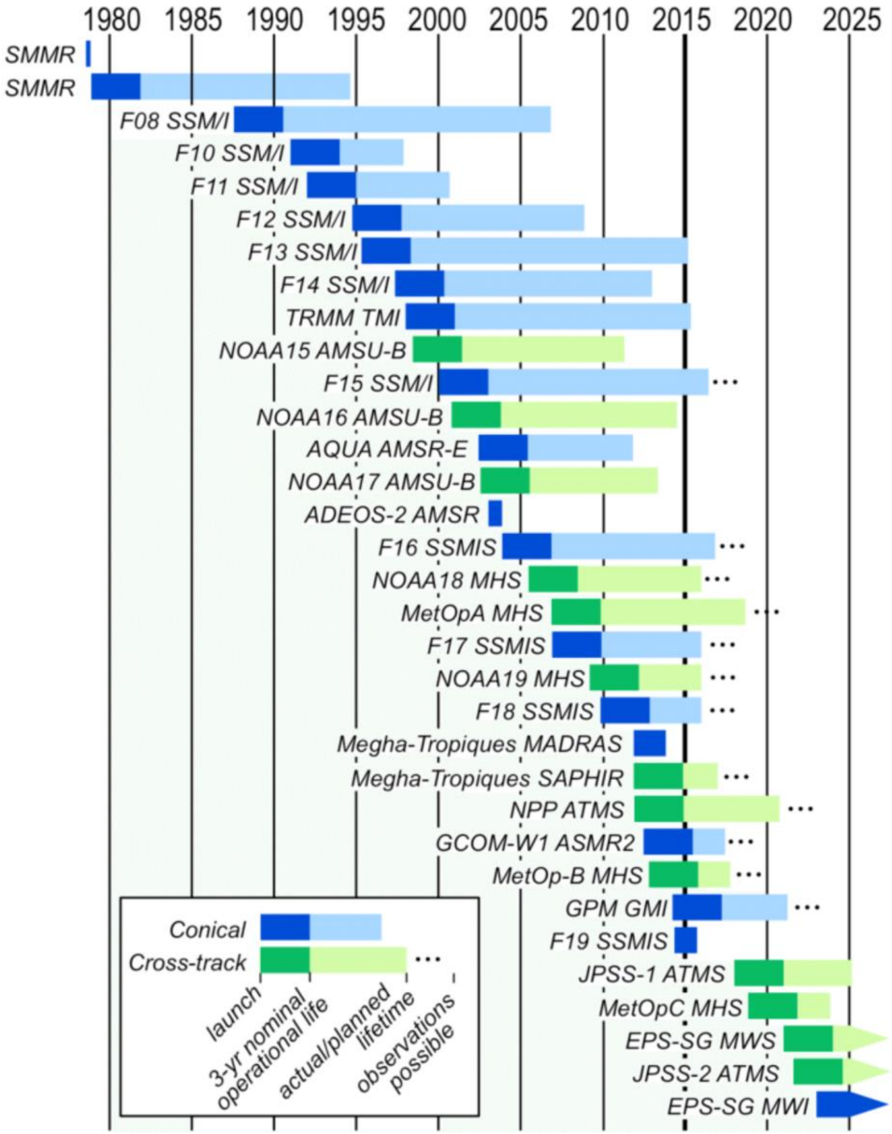
Multiple data fields in each file

User-oriented services

- interactive analysis (GIOVANNNI)
- alternate formats (KMZ, KML, TIFF WRF files, …)
- area averages (coming soon)

	Half-hourly data file (Early, Late, Final)
1	*Calibrated multi-satellite precipitation*
2	*Uncalibrated multi-satellite precipitation*
3	*Calibrated multi-satellite precipitation error*
4	PMW precipitation
5	PMW source identifier
6	PMW source time
7	IR precipitation
8	IR KF weight
9	*Probability of liquid-phase precipitation*

Microwave Radiometers



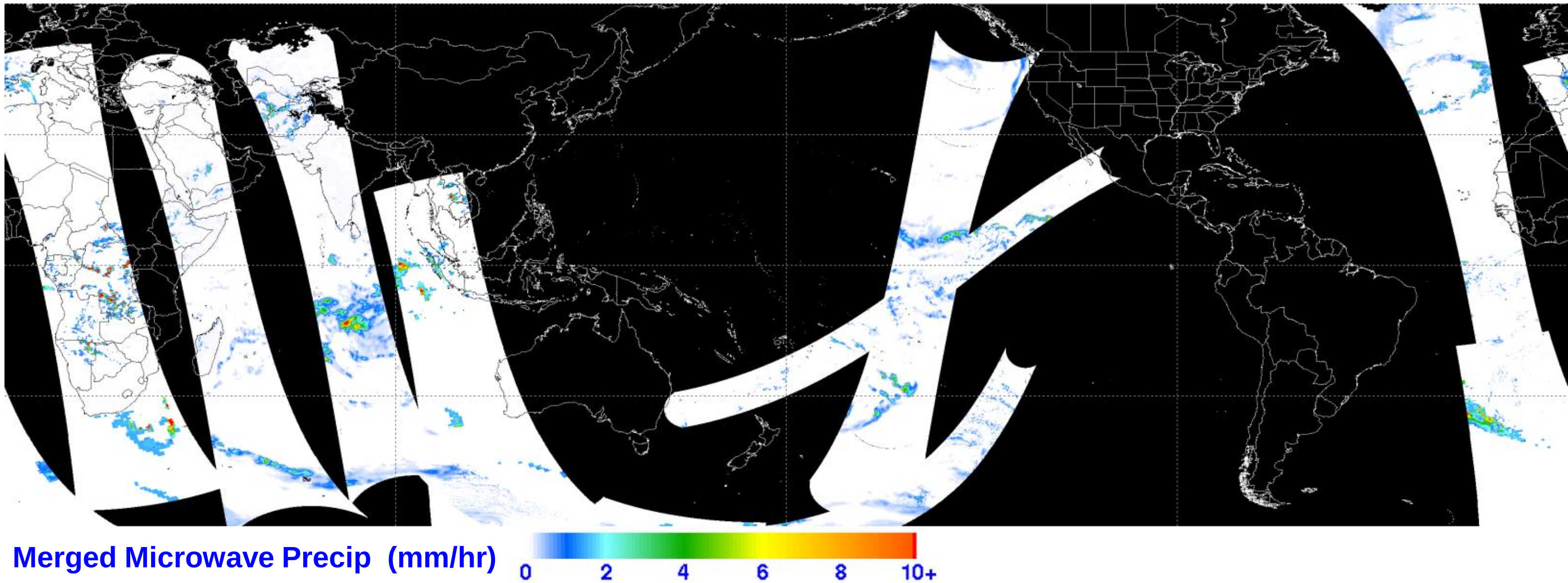
from Chris Kidd

IMERG Data Fields

1430-1500Z 3 April 2014

Microwave precip

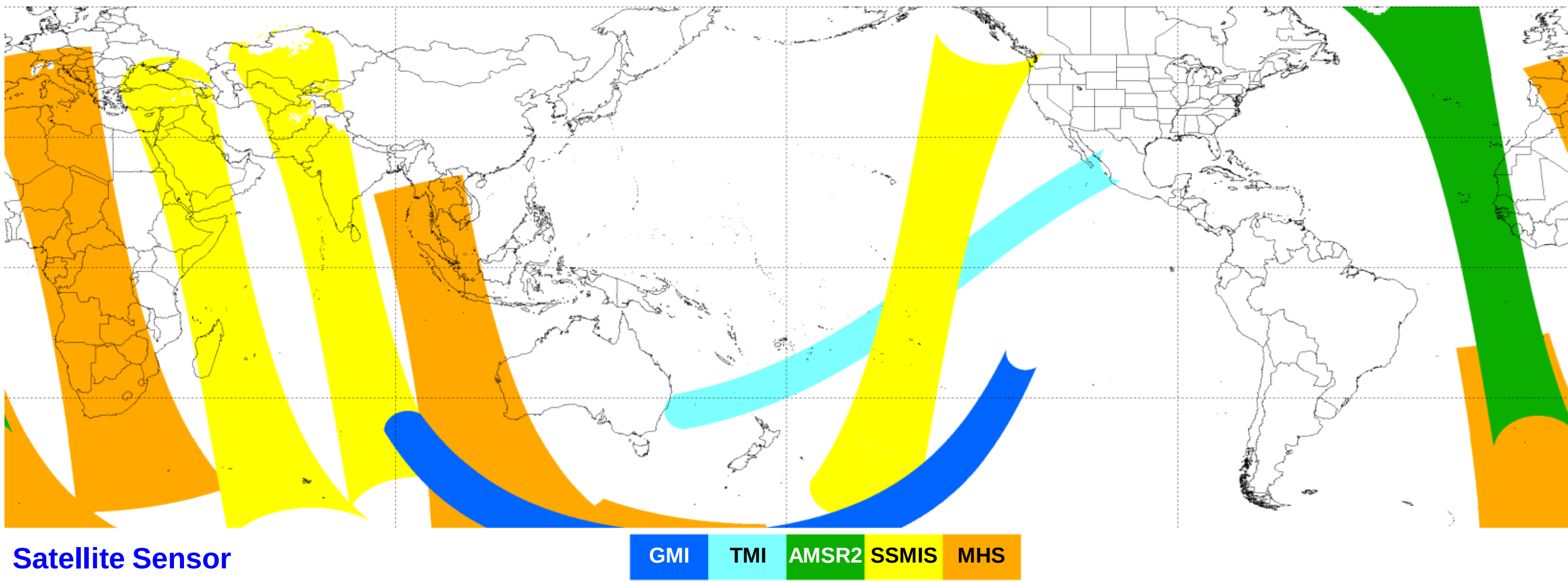
data collected in the half hour, with <u>dropouts due to snow/ice</u>



Source

microwave sensor contributing the data;

selected as imager first, then sounder



IMERG Data Fields

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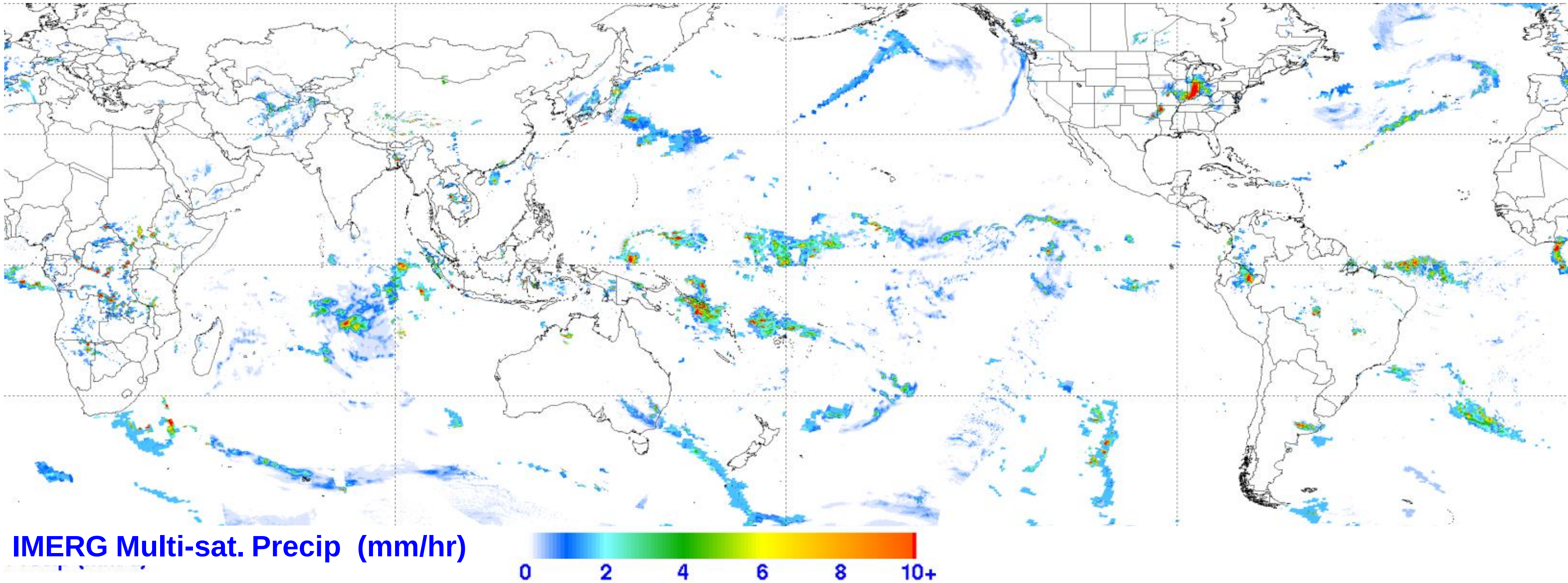
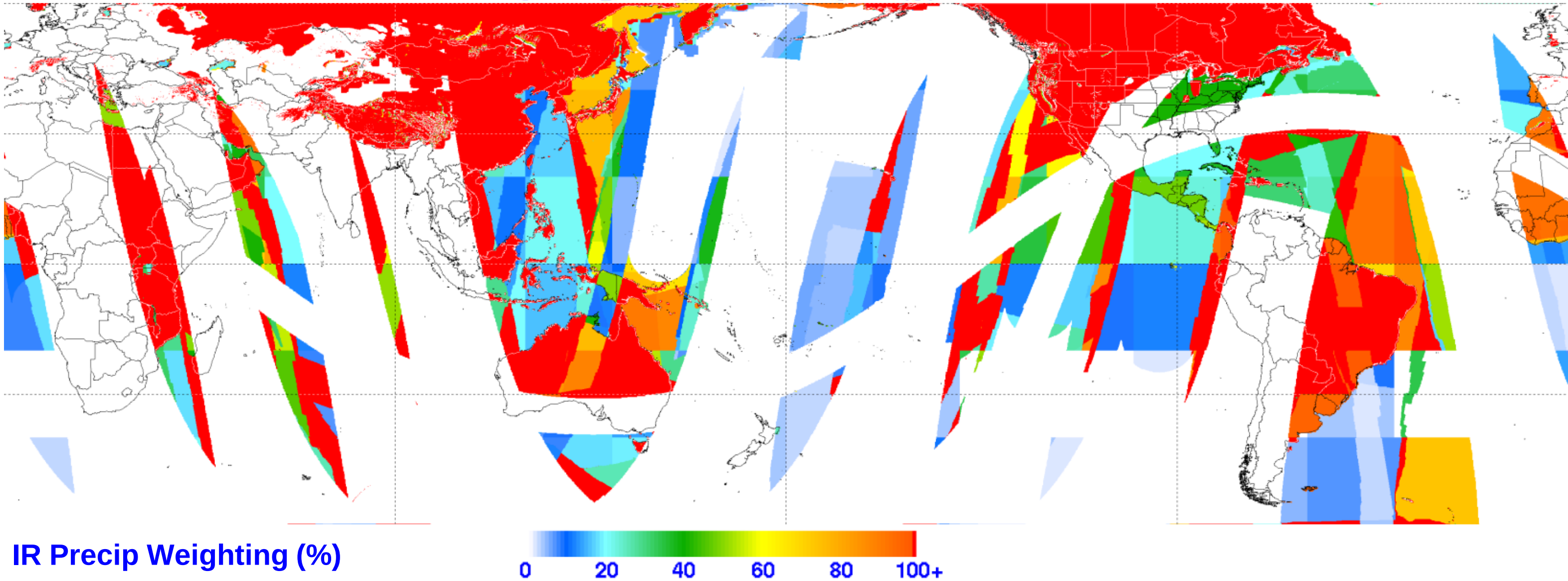
IMERG

"Early" IMERG field: forward morphed microwave, Kalman filter with IR data



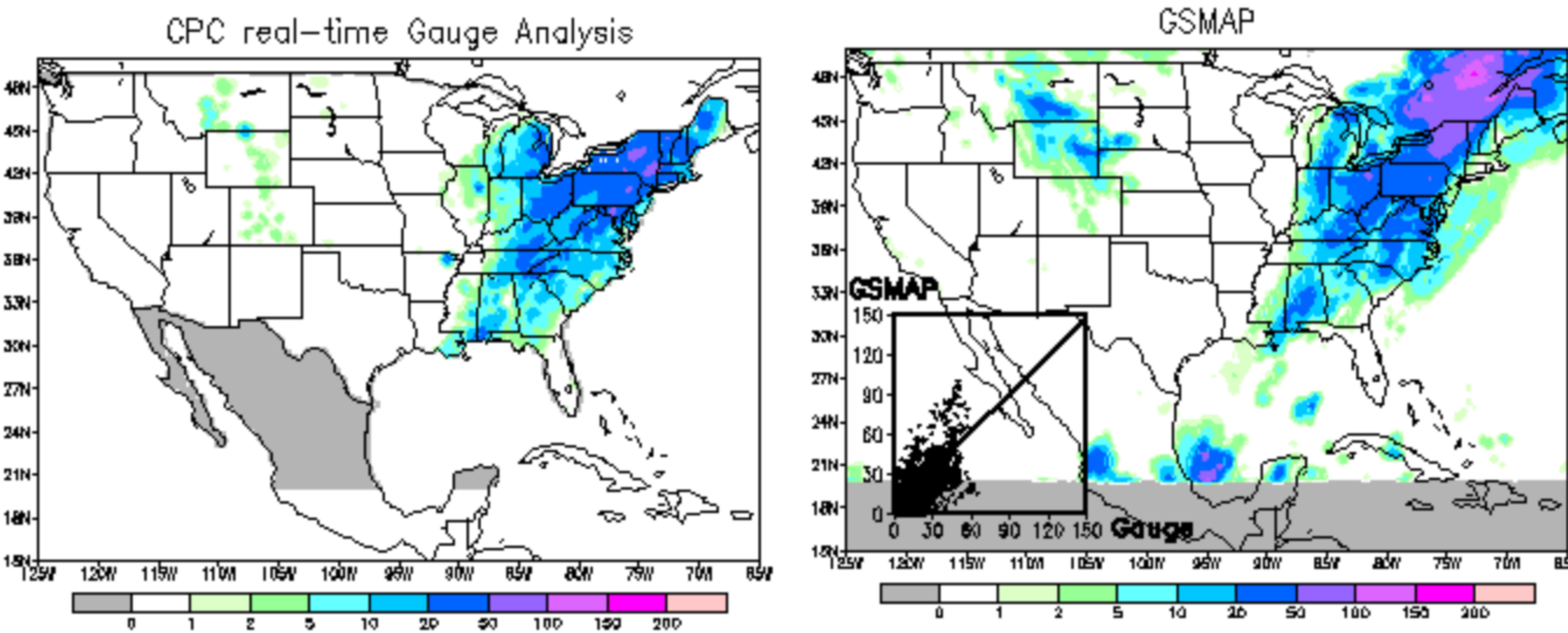
IR Weighting

weighting of IR in the Kalman filter step



Satellite Gauge Network Comparisons

13Z 31Oct2019 thru 12Z 01Nov2019
Data on 0.25 deg grid (UNITS are mm/day)



	(G) gauge	(S) GSMAP
Number of points:	11314.	11314.
# points w/rain:	3129.	3035.
Mean rain rate:	4.21	4.35
Cond. rain rate:	15.25	16.17
Max. rain rate:	65.01	99.90

	G−S
Correlation:	0.829
Mean Absolute Error:	2.33
RMSE (mm/day):	5.93
RMSE (normalized):	1.41
Probability of Detection:	0.864

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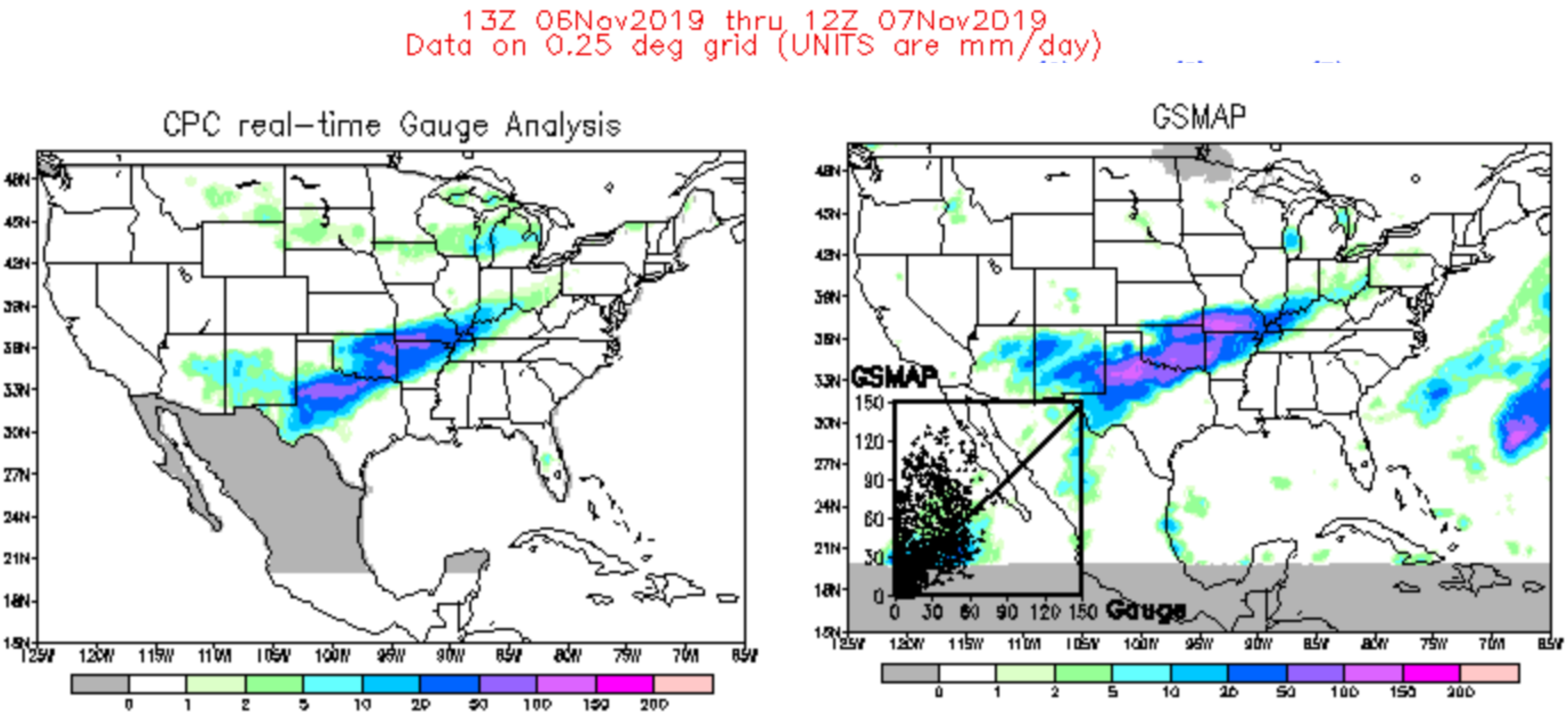

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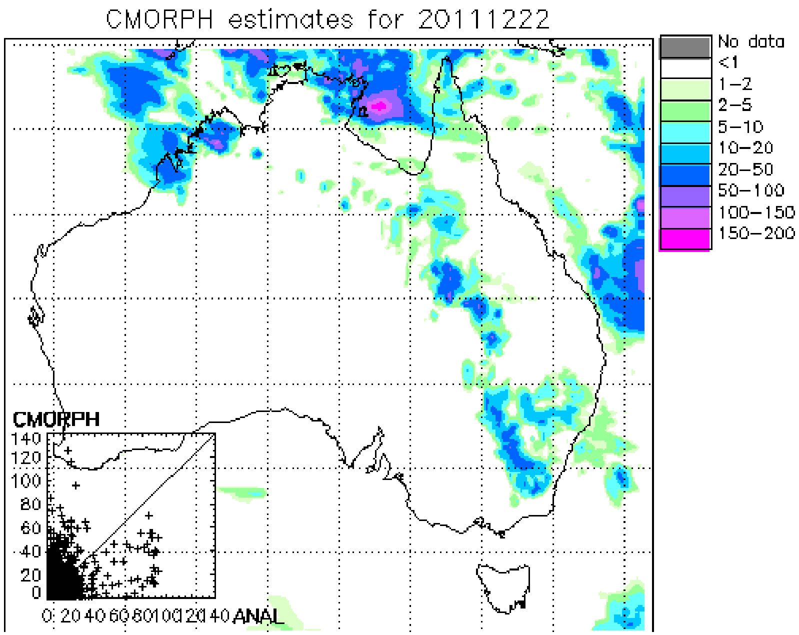
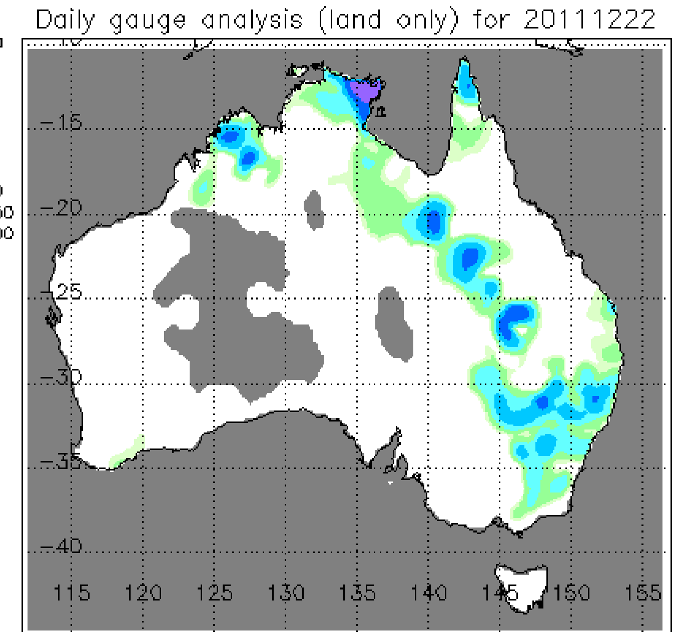




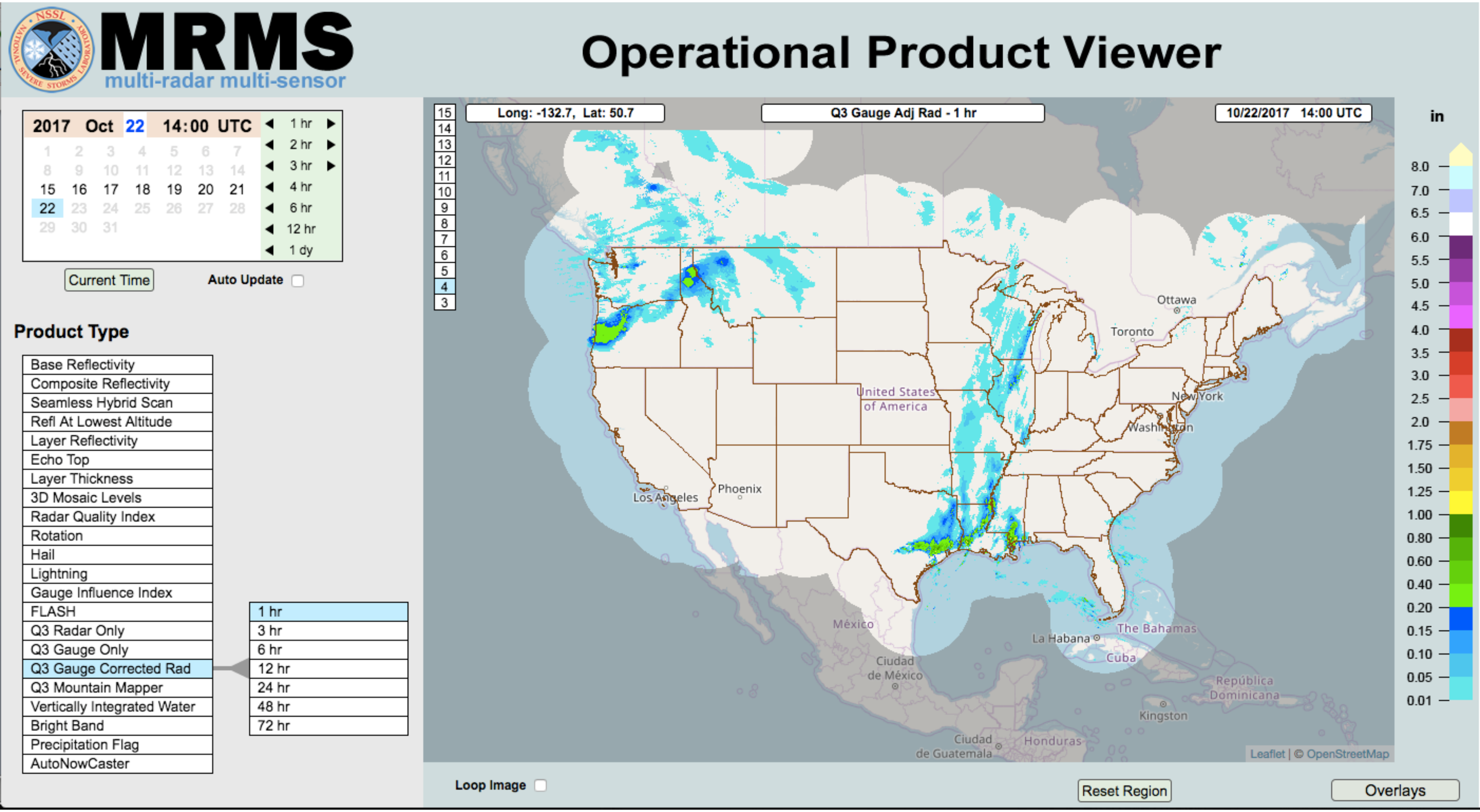
	Analysed	CMORPH
# gridpoints raining	2663	1883
Average rain	2.1	2.0
Conditional rain	7.8	10.6
Rain volume (mm*km^{2}x10^9)	14.3	13.7
Maximum rain	93.2	125.1

Mean abs error = 2.2
RMS error = 6.6
Correlation coeff = 0.500
Frequency bias = 0.707
Probability of detection = 0.555
False alarm ratio = 0.215
Hanssen & Kuipers score = 0.499
Equitable threat score= 0.379

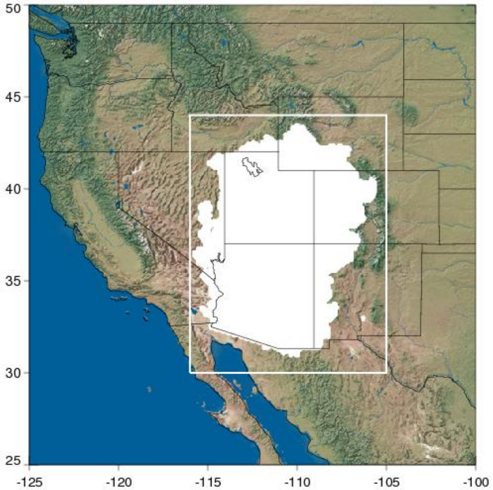
What else do we have?

- *Higher satellite spatial/temporal resolution*
- *Additional ground-based data sources*
- *More agile products*

1 Hour Rainfall – Radar/Gauge



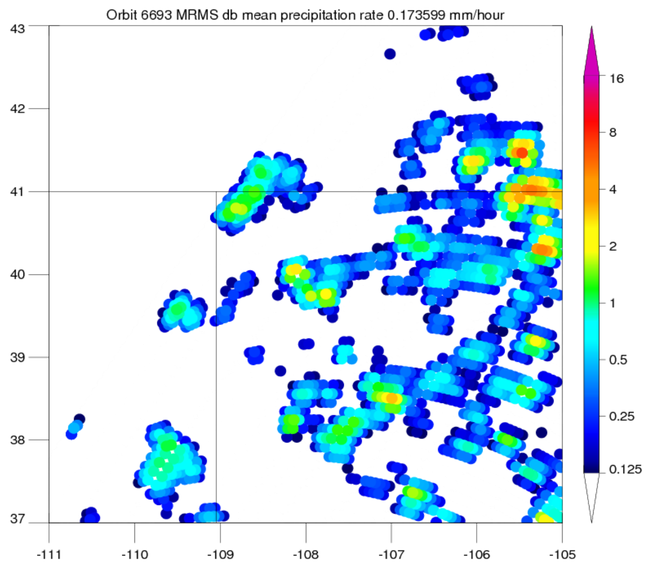
GPROF – **C**olorado **R**iver **B**asin



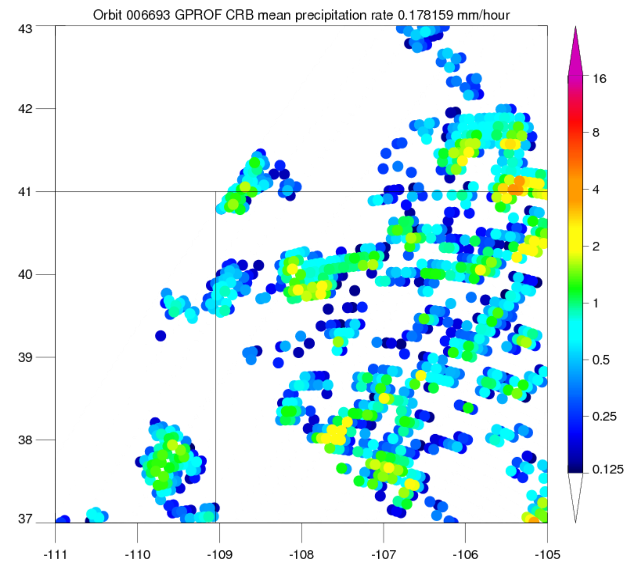
GPROF 2017 is trained against a global database
GPROF-CRB is trained with local precipitation only

GPROF 2017 is independent of gauge data
GPROF-CRB is bias adjusted to local gauge climatology

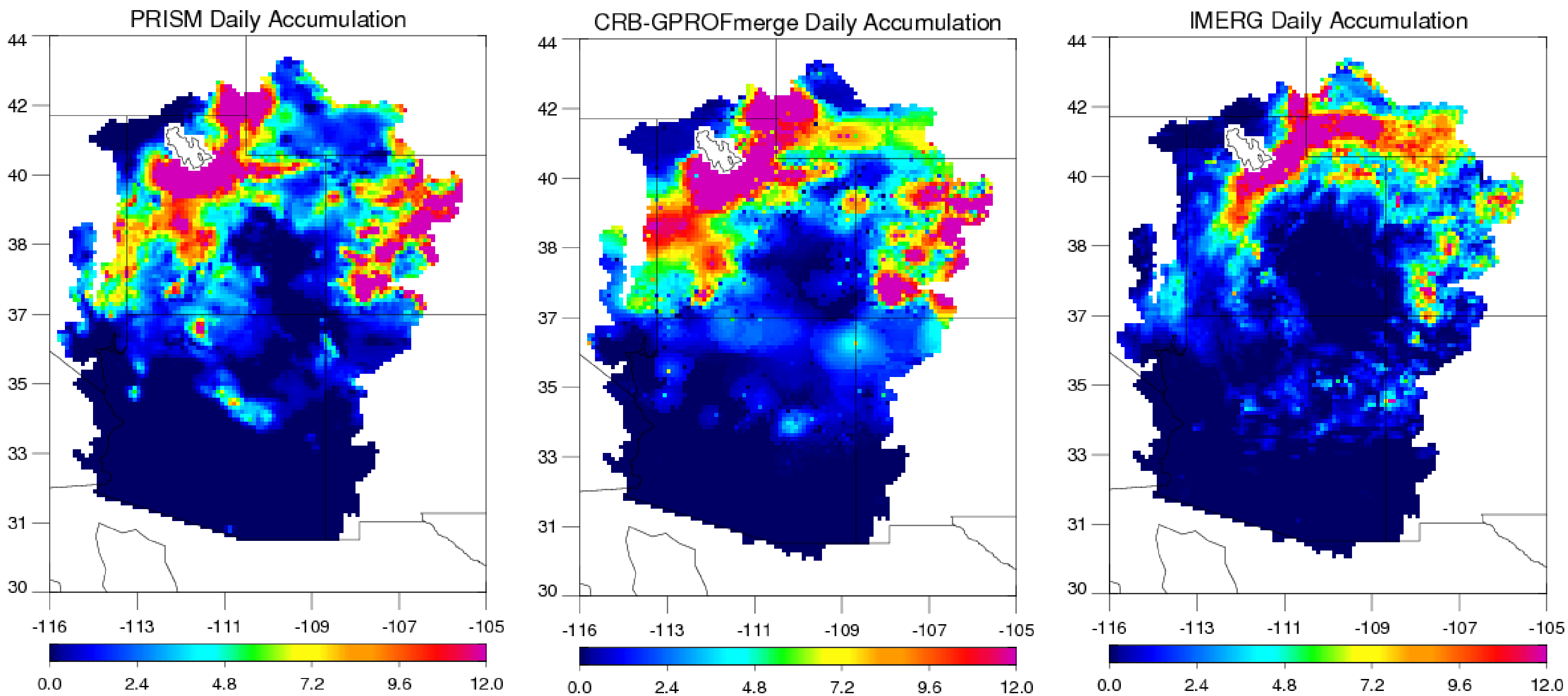
MRMS



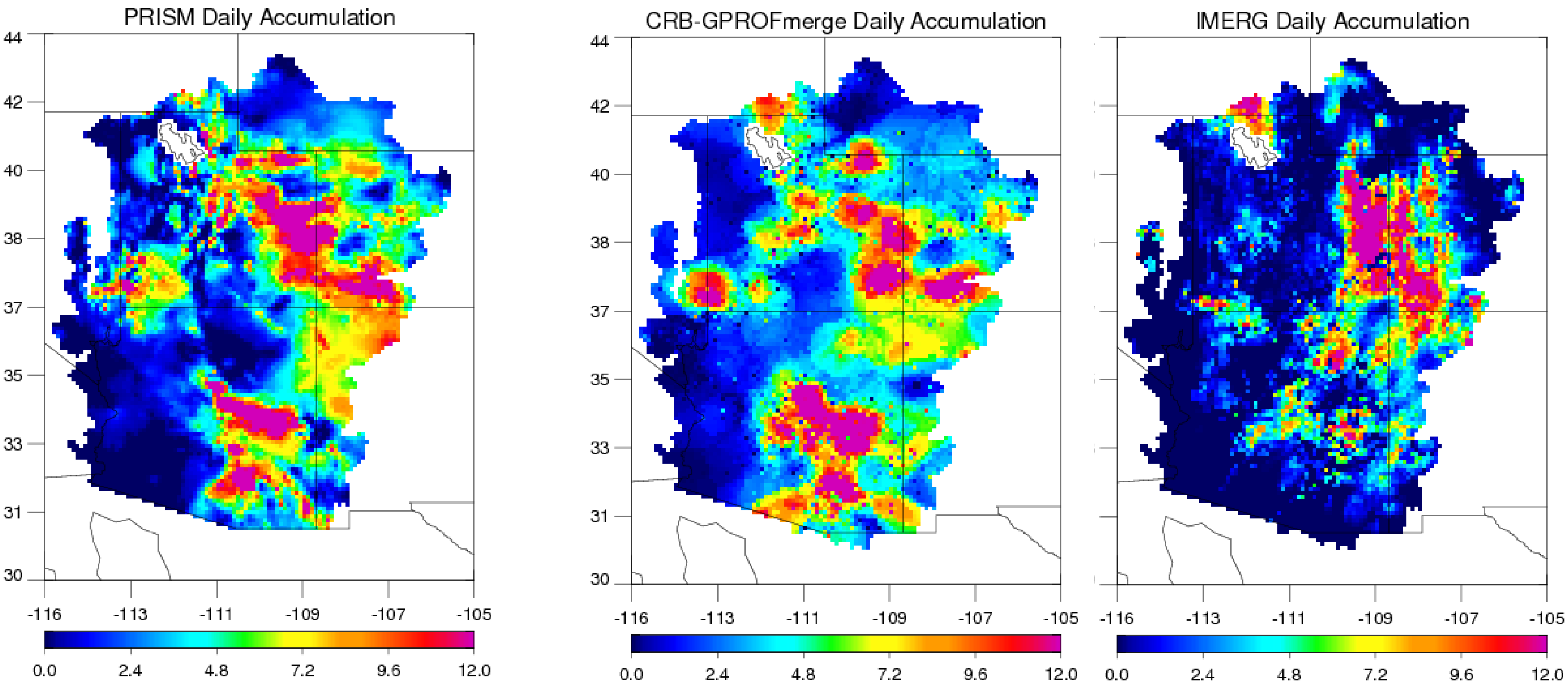
GPROF-CRB



10 May, 2015
The impact of more gauge data



14 December, 2015
The impact of more gauge data



Can we improve further?

- *Can we increase the spatial/temporal resolution?*
  Yes, GEO satellites now have full global coverage every 10 minutes, 2km. Some work is needed near scan edges.

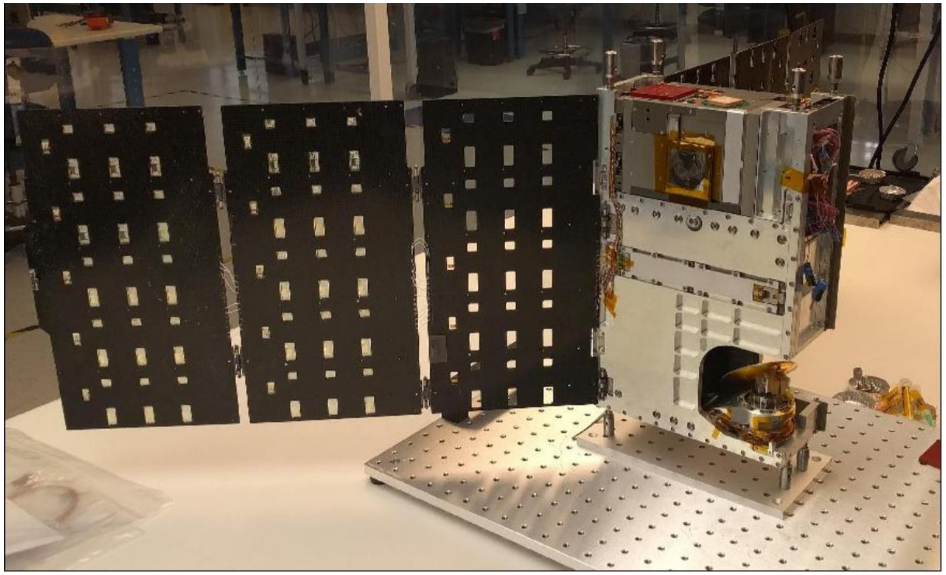
- *Can we add information?*
  Yes, many regions have additional data over the broadly available products. QC becomes an issue

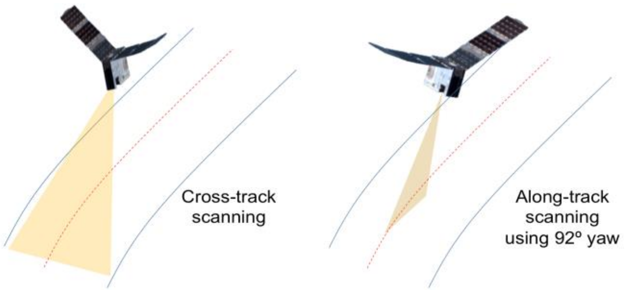
- *Can we make better use of our current products?*
  Yes, it is merely a matter of merging all available data for hydrologic applications (i.e. defined space/time scale). The current algorithms can all be adapted.

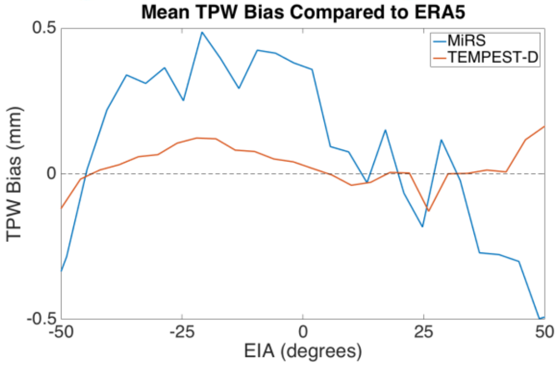
- What new sensors are coming?

Advances that are already here

TEMPEST-D

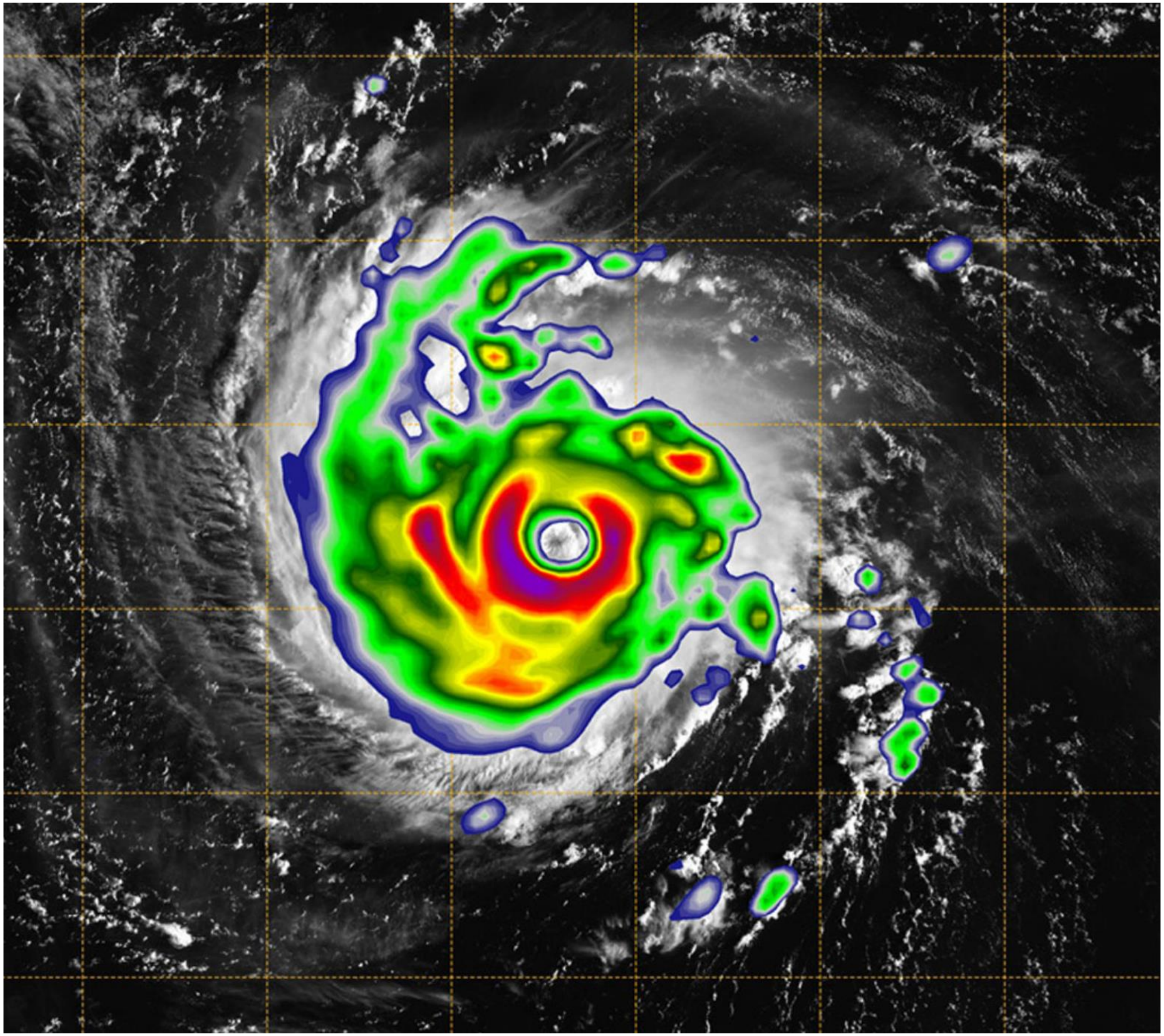






	TEMPEST-D	MHS
Channel Freq. (GHz)	87, 164, 174, 178, 181	89, 157, 183±1,183±3, 190
Mass	3.8 kg	63 kg
Power	6.5 W	74 W
Altitude	400 km	820 km
Resolution at Nadir	12.5 km (25 km at 87 GHz)	15.9 km
NEDT (K)	0.2, 0.3, 0.4, 0.4, 0.7	0.22, 0.34, 0.46, 0.40, 0.51
Integration Time	5 ms	18.5 ms

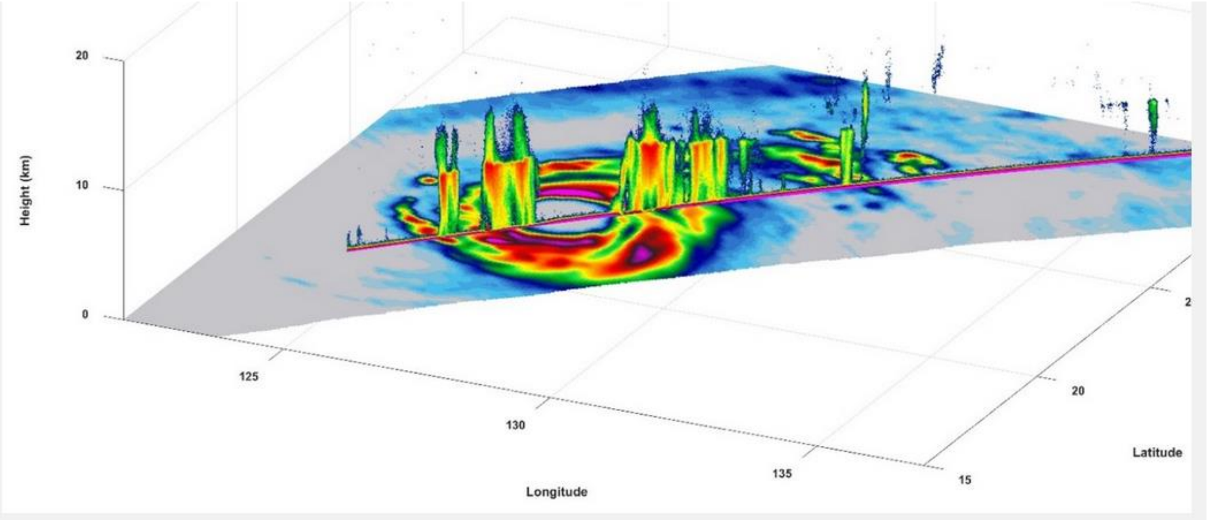
TEMPEST



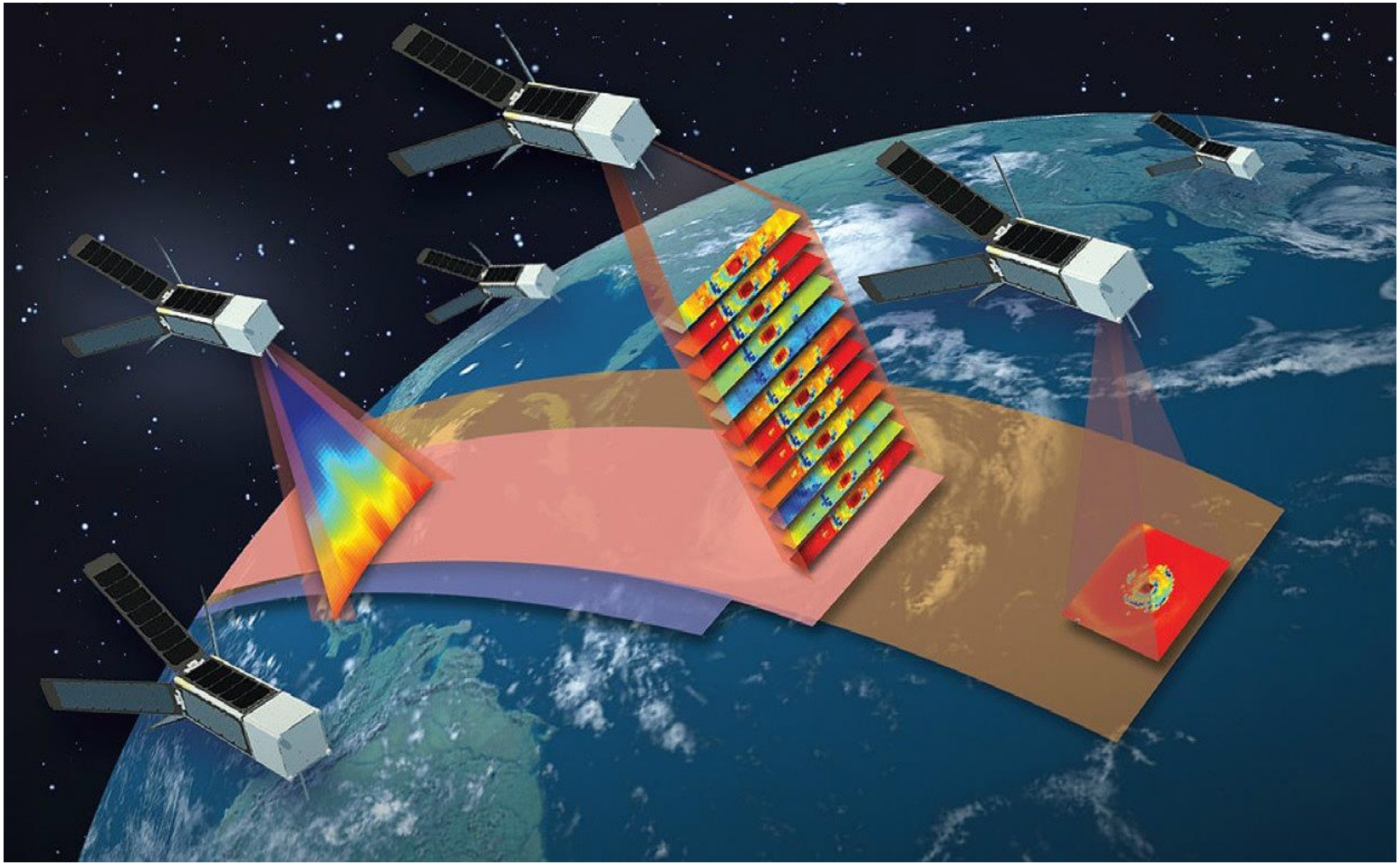
RainCube

RainCube	Value
Instrument	Ka-Band Radar
Frequency	35.75 GHz
Antenna	0.5m deployable
Footprint	<10 km
Vert. resolution	<250 m
Sensitivity	20 dBZ

Flight System	Value
Spacecraft mass	12 kg
Spacecraft volume	6U
Payload Power	Up to 35W
Payload Data	50 kbps
Payload duty cycle	25% transmit
Payload operation	1 full orbit



TROPICS



Constellation of 6 satellites
3U CuseSats

1 channel @ 89 GHz
7 channels at 118 GHz
3 channels at 183 GHz
1 channel at 220 GHz

25 km FOV at nadir @ 89 GHz

Decadal Survey – Designated Missions

Targeted Observable	Science/Applications Summary	Candidate Measurement Approach	Designated	Explorer	Incubation
Aerosols	Aerosol properties, aerosol vertical profiles, and cloud properties to understand their effects on climate and air quality	Backscatter lidar and multi-channel/multi-angle/polarization imaging radiometer flown together on the same platform	X		
Clouds, Convection, and Precipitation	Coupled cloud-precipitation state and dynamics for monitoring global hydrological cycle and understanding contributing processes including cloud feedback	Radar(s), with multi-frequency passive microwave and sub-mm radiometer	X		
Mass Change	Large-scale Earth dynamics measured by the changing mass distribution within and between the Earth's atmosphere, oceans, ground water, and ice sheets	Spacecraft ranging measurement of gravity anomaly	X		
Surface Biology and Geology	Earth surface geology and biology, ground/water temperature, snow reflectivity, active geologic processes, vegetation traits and algal biomass	Hyperspectral imagery in the visible and shortwave infrared, multi- or hyperspectral imagery in the thermal IR	X		
Surface Deformation and Change	Earth surface dynamics from earthquakes and landslides to ice sheets and permafrost	Interferometric Synthetic Aperture Radar (InSAR) with ionospheric correction	X		

The Future of Observations

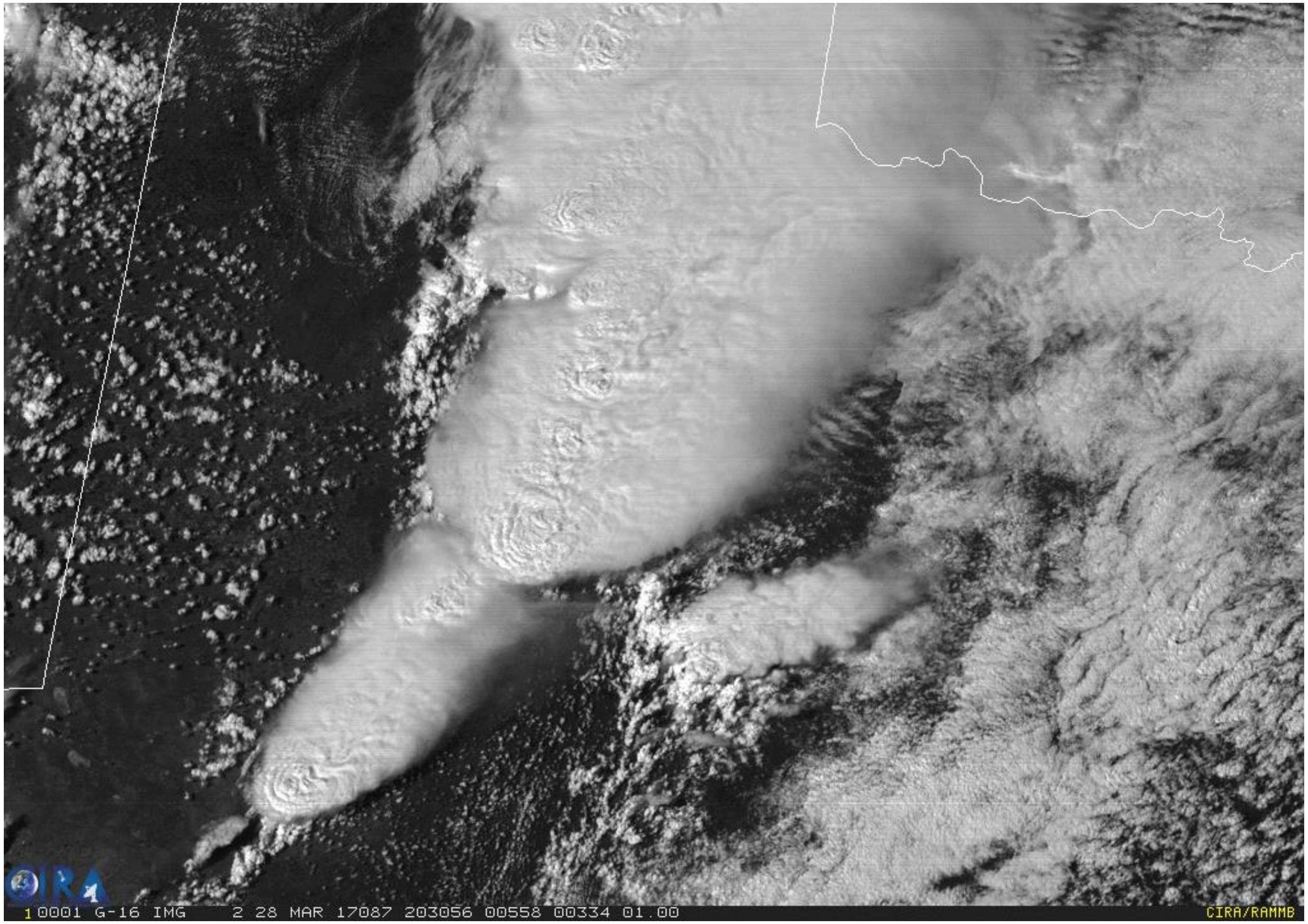
- *More satellites are coming. There will be some large sensors like we are used to, but the majority will be small and not last for very long.*
- *Microwave radiometers are on the 1-3 year horizon. Radars with wide coverage are a bit further behind.*
- *Satellites with good physics (GPM, EarthCare, NASA Cloud-Convection-Precipitation) can serve as a global calibration package.*

New Methods on the Horizon

- *Machine Learning*
- *Mch higher temporal resolution*
- *More model constraints on observations*

30-Second, 0.5 km Imagery

GOES-16 30-second band 2 imagery – west Texas – 28 Mar. 2017



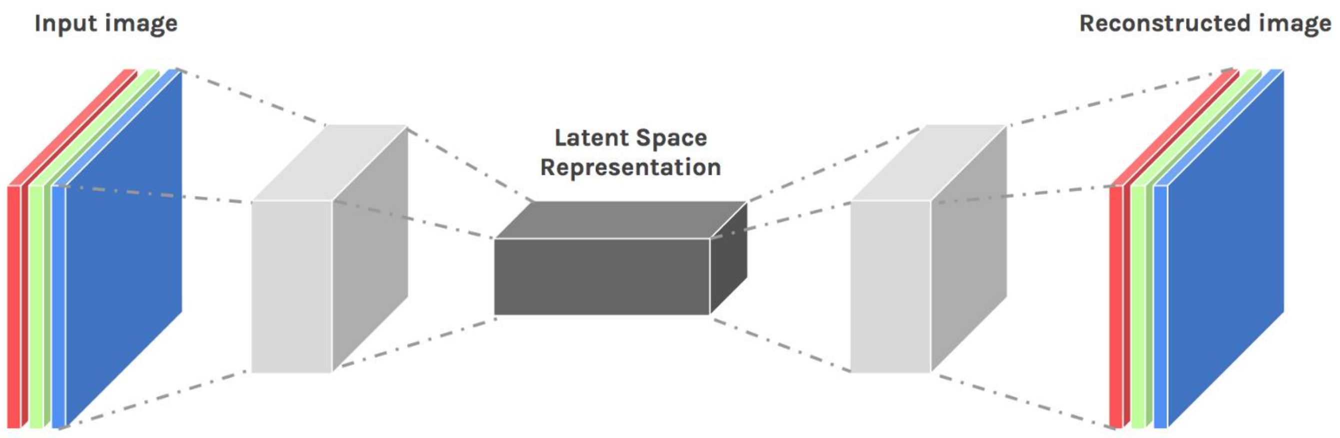
Detecting Convection from Rapid Imagery

Use image series (2 minutes apart) to classify clouds

- GOES-16 satellite Ch2 (0.65 µm) visible images (2-min interval)
- GOES-16 satellite Ch14 (11.2 µm) T_b images (2-min interval)

Use Machine Learning to relate

- Convective clouds (w. bright reflectance and bubbling cloud top) to PrecipFlag (Convective/Stratiform) from Multi-Radar/Multi-Sensor System (MRMS)

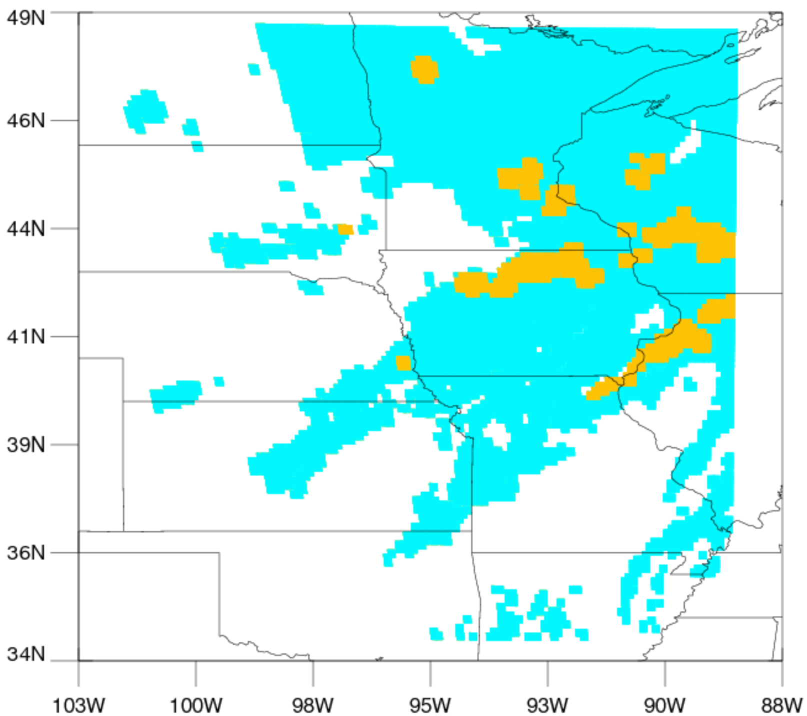


auto-encoder

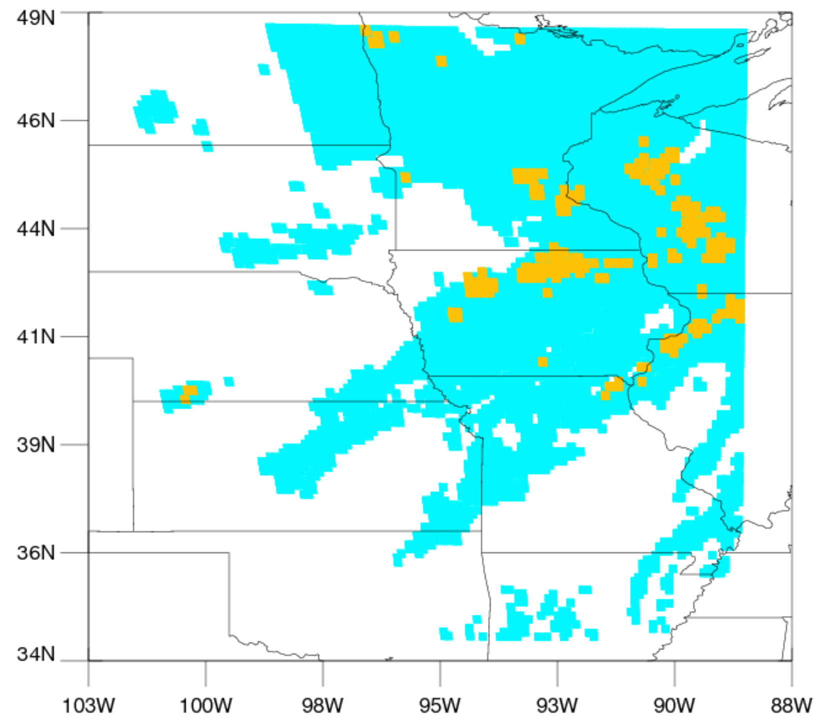
Detecting convections from rapid imager

Blue: Non-convective
Yellow: Convective

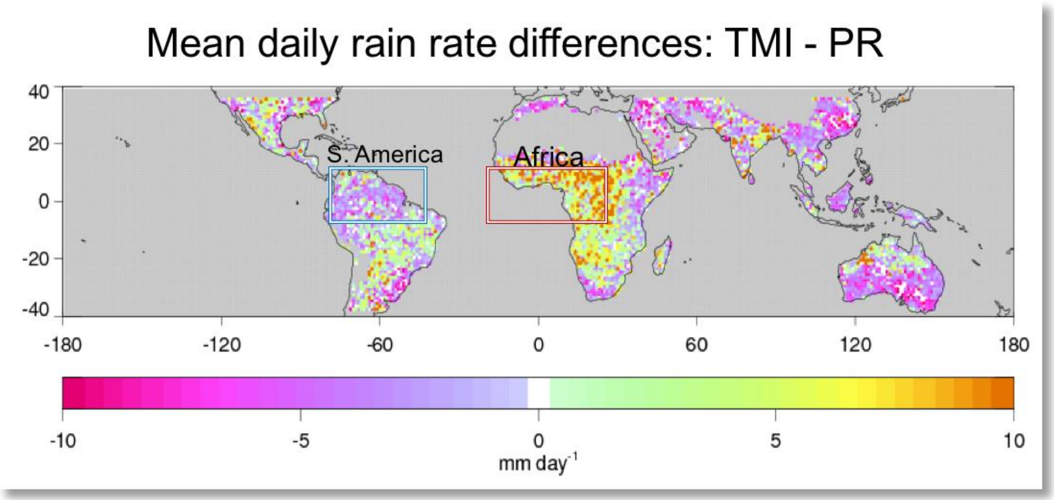
Truth from MRMS



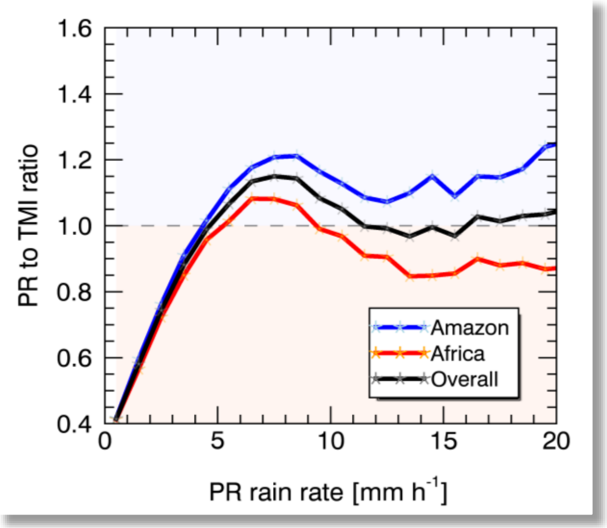
Predicted

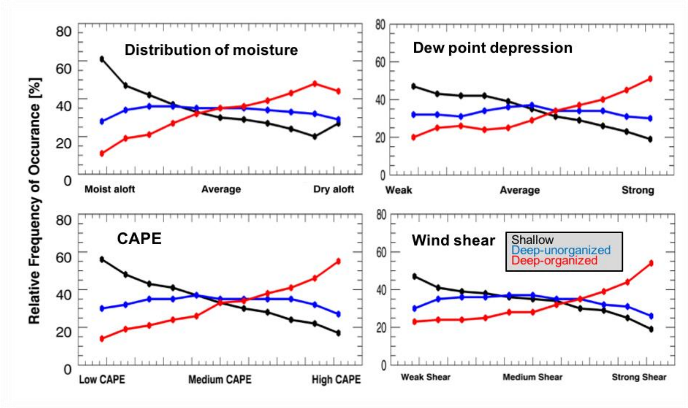


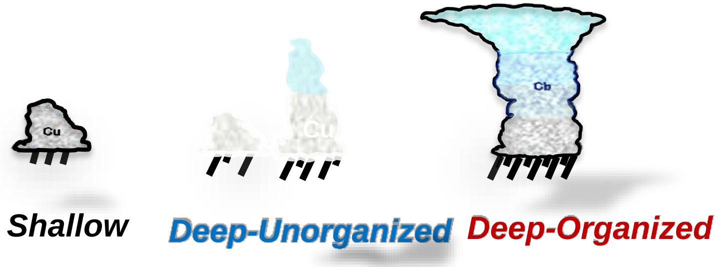
Using Model Fields to constrain retrievals



Regional bias vs. rainfall rate

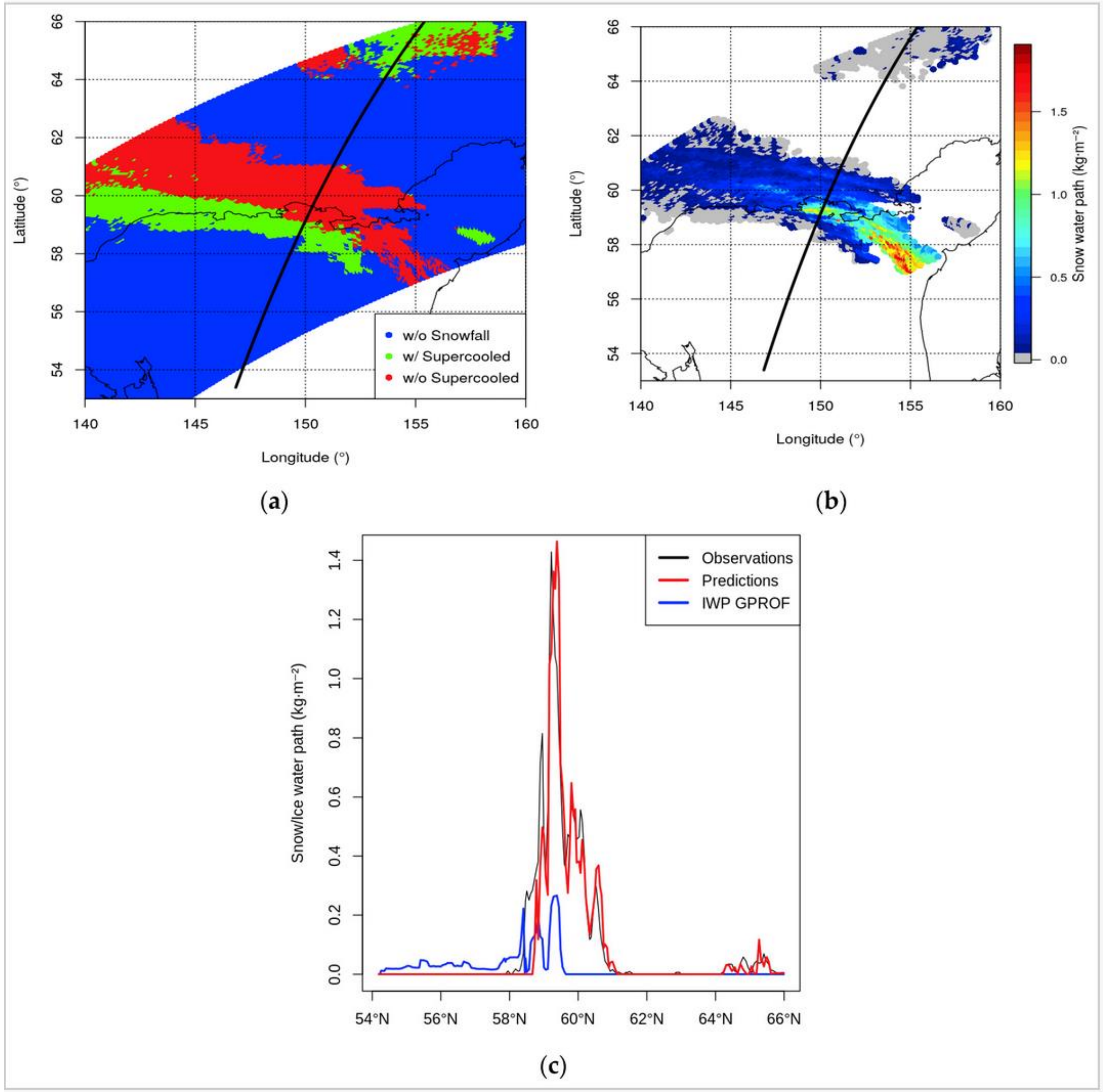






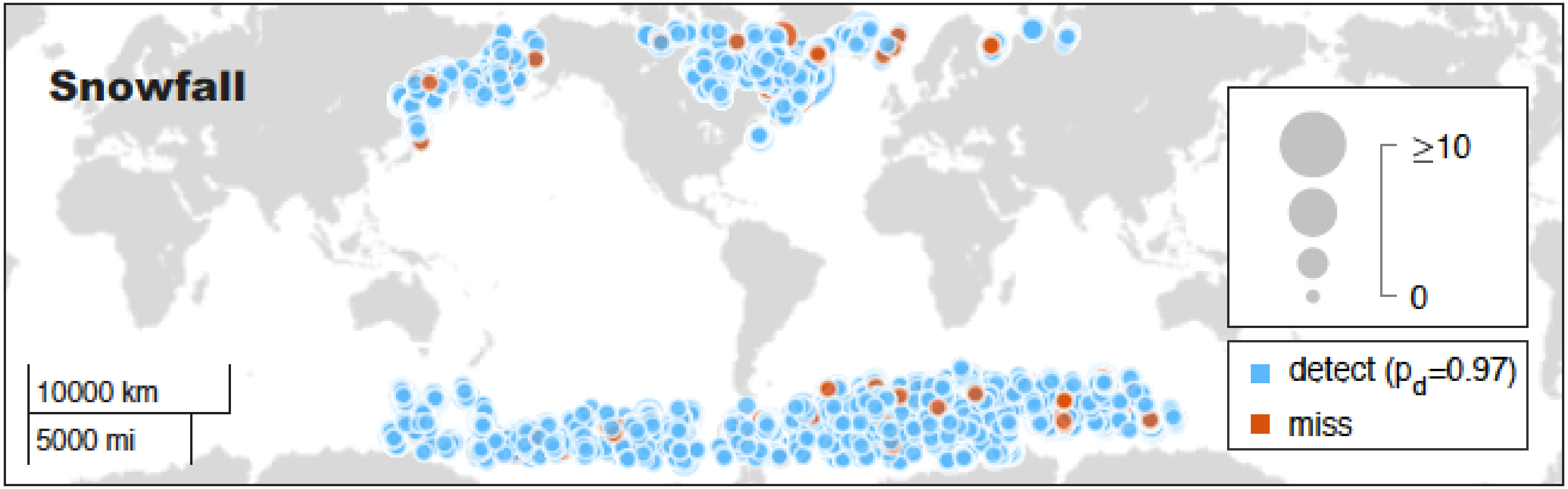
SLALOM

A random Forest Approach to Snowfall Detection



Snowfall Identification

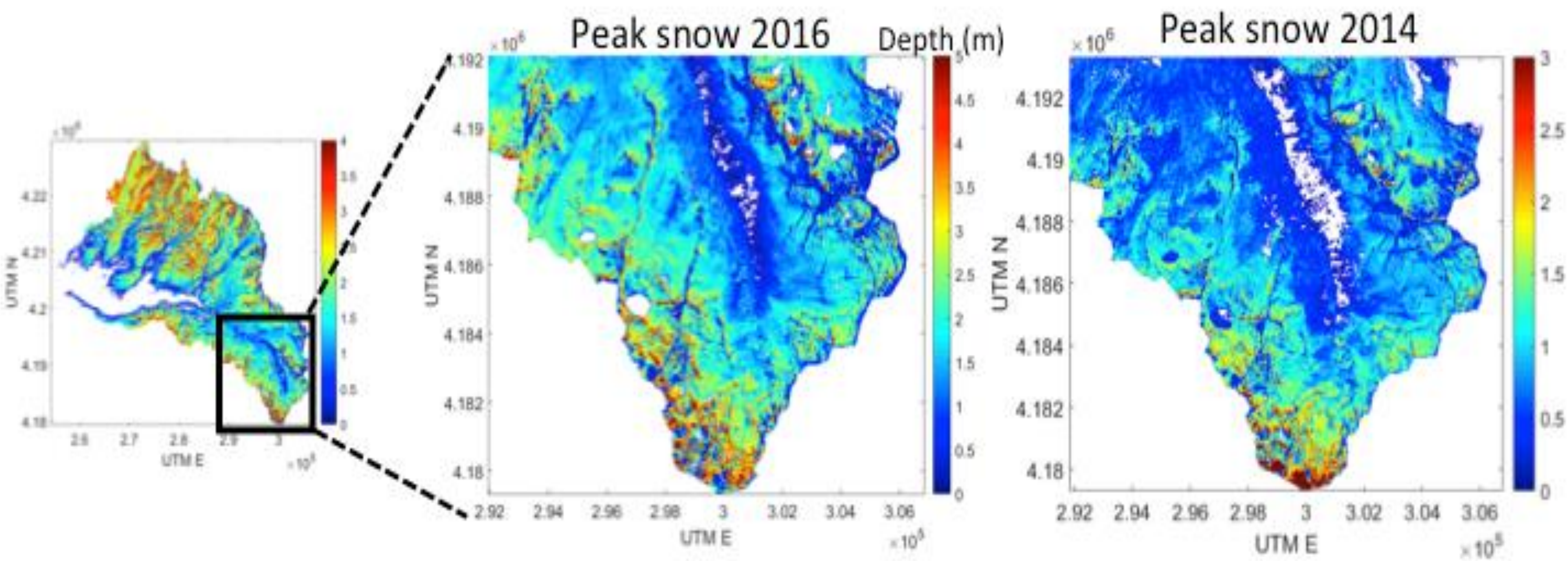
Metric Learning



Entejab, A. et al., , 2019: Metric Learning for approximation of Microwave Channel Error Covariance: Application for Satellite Retrieval of Drizzle and Light Snowfall . IEEE Transactions on Geoscience and Remote Sensing.

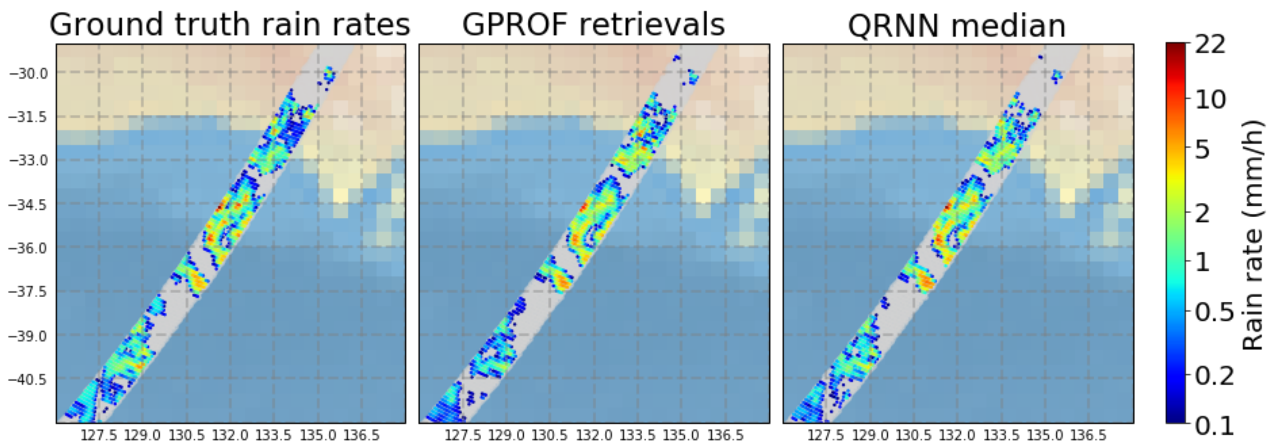
Using Historical Snow Depth Information

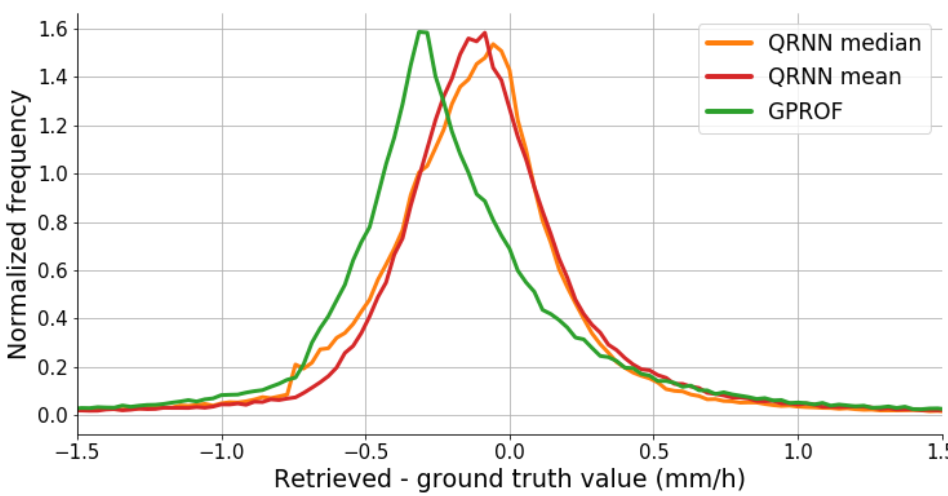
w. model analysis to detect weather pattern

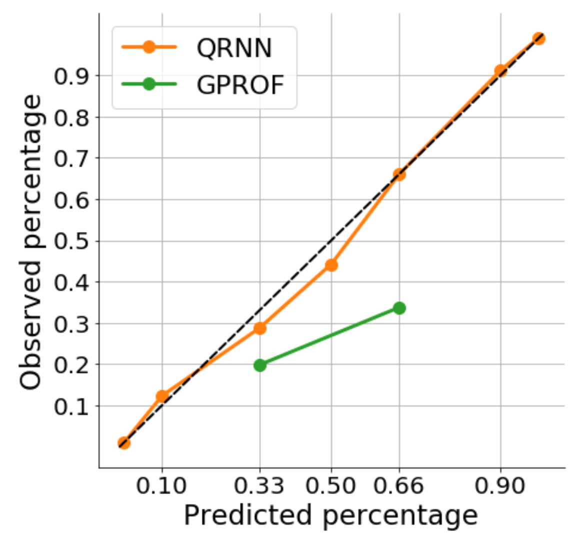


Snow depth measured by aerial lidar at 3-m resolution over the Tuolumne River basin in the Sierra Nevada, California. To date, over 48 lidar collections have occurred between winters 2013 and 2019, spanning the driest year (2015) and the wettest year (2017) on record. Patterns of snow accumulation are remarkably consistent (Pflug et al. 2019).

Quartile Regression Neural Networks







Pfreundschuh, S., et al., : A neural network approach to estimate a posteriori distributions of Bayesian retrieval problems, J. Atmos. Meas. Tech., 2018

State of the Art

- Radars are quite good at rain/snow profiles, microwave radiometers have less information and IR sensors even less.

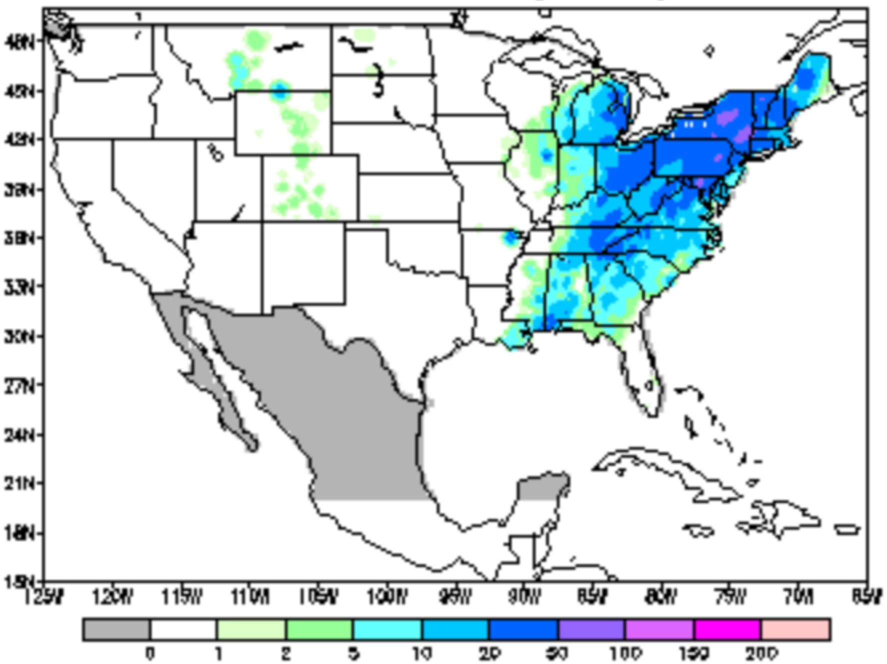
- We need to supplement information content to get more accurate results. Models need to be better coupled to exploit their information content.

- Merged products must know uncertainties of individual components or make somewhat arbitrary assumptions

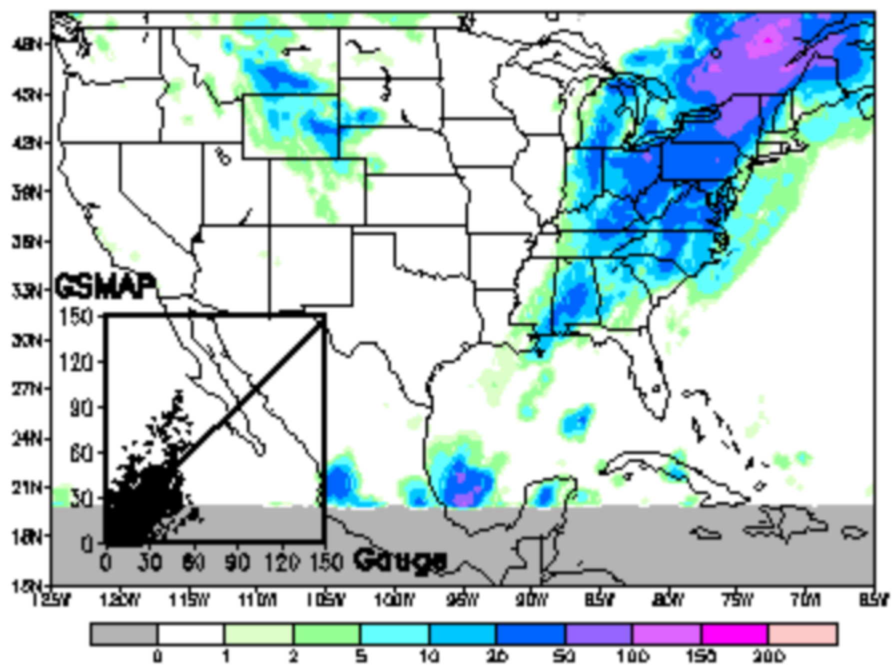
Satellite Gauge Network Comparisons

13Z 31Oct2019 thru 12Z 01Nov2019
Data on 0.25 deg grid (UNITS are mm/day)

CPC real-time Gauge Analysis



GSMAP



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13Z 06Nov2019 thru 12Z 07Nov2019
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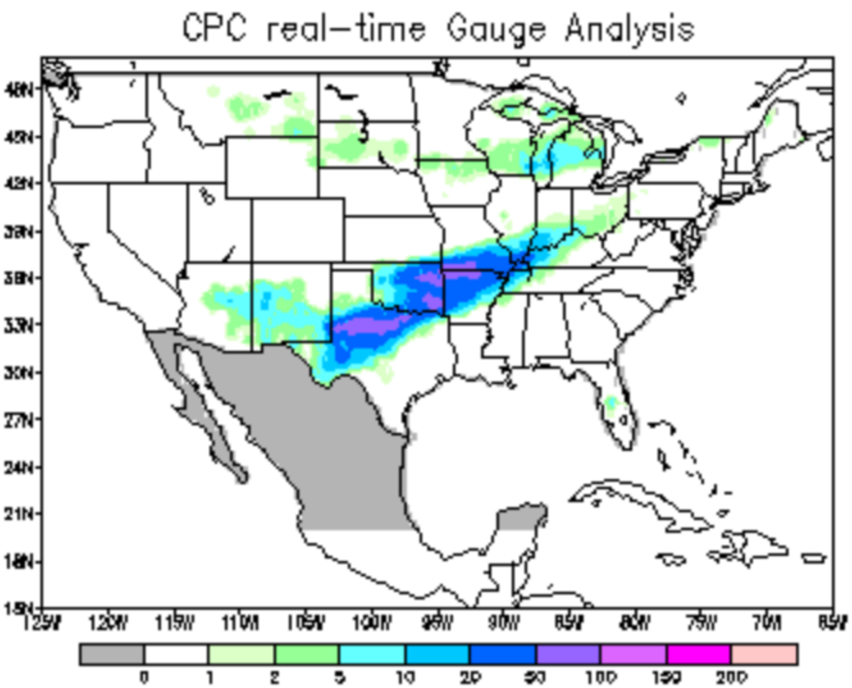

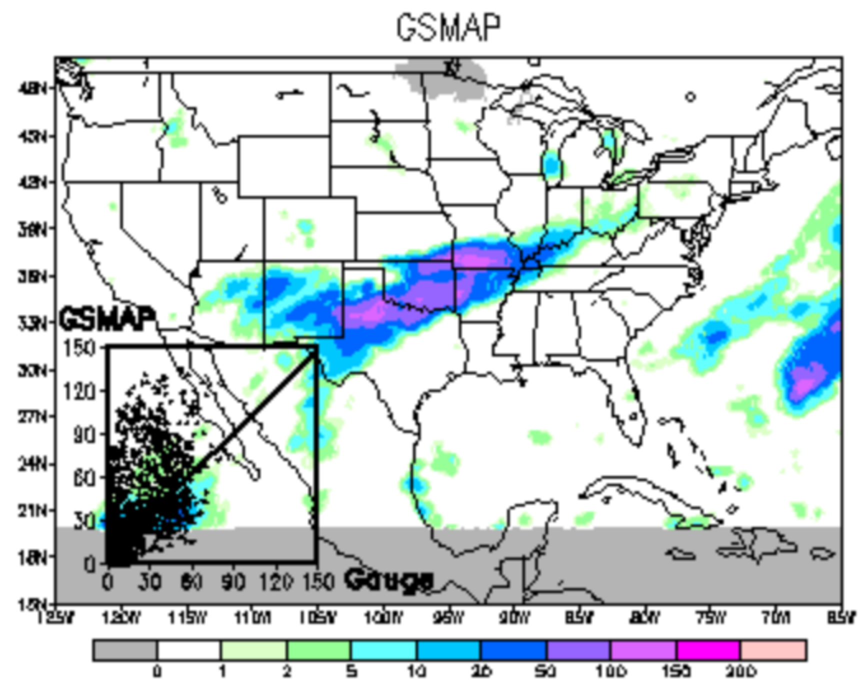

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~~Precipitation Validation~~
Predicting Precipitation Uncertainty

Status: We currently carry out enormous amounts of "validation" activities. We never ask "where else" or "when else" do these results apply?

Hypothesis: We can define "regimes" based on todays state-of-the-art analyses (e.g. ERA-5) for which validation statistics should be comparable. Can use GPM, EarthCare, (A)CCP or in-situ observations to verify.

Benefit: Knowing uncertainties everywhere is the foundation of all "Merged" products.

Merged Products

- Gauges
- Local networks
- Radars
- Cellular communications
- Polar orbiting satellites
- Geostationary clouds
- Model Output

N product families & lots of products within each family. As agencies try to produce customized products for the user community, they keep adding rainfall products. Soon we will drown in them.

What if we stopped making products until a user specifies what they needed? Products on demand!