GOES-R era Precipitation Products – Plans, Potential Enhancements and the Future NESDIS Enterprise Precipitation Vision

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And contributions from several colleagues including:

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N-Y. Wang[3], P. Meyers[3], R. Adler[3],P. Xie[4],R. Joyce[4], B. Rabin[5]

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[2]NOAA/NESDIS/OSD, Silver Spring, MD

[3]Cooperative Institute for Climate & Satellites (CICS), Univ. of Maryland, College Park, MD

[4]NOAA/NWS/NCEP, College Park, MD

[5]NOAA/NSSL and CIMSS, Madison, WI

Outline

- Role of Satellites
- Current/planned GOES (-R) baseline algorithms
  - Hydroestimator
  - Self-Calibrating Multivariate Precipitation Retrieval (SCaMPR)
- Latest on Passive Microwave Products
  - New missions/sensors
  - Snowfall rates
- Future vision
  - Potential products/enhancements
  - GPM era/NOAA Precipitation Enterprise

Role of Satellites for Precipitation Applications…stating the obvious but..

- Satellites are particularly useful where ground measurements are:
  - Not taken or missing
    - Examples – Sparse rain gauges and data delivery failure (maybe caused by an extreme rainfall event)
  - Of questionable quality
    - Examples – radar missing offshore rain; radar beam blockage in mountains
  - Not possible
    - Example – Open ocean

- NESDIS provides operational satellite products of hydrological parameters for each individual satellite it operates.
  - GOES – visible and IR based, rapid update
  - POES – passive MW, 3 satellite, 4 hour global coverage

- NOAA also utilizes satellite assets from other agencies like NASA, DoD, EUMETSAT and JAXA

NOAA Hydrological Satellite Products

Not necessarily 100% all inclusive…

Geostationary (Regional, rapid update)	Low Earth Orbiting (Global, 3-6 hourly)
Visible, IR and WV loops	Visible, IR and microwave imagery
Rain Rate	Rain and Snowfall Rate
Total Precipitable Water – TPW (cloud free)	TPW (all weather; ocean only in some cases)
Snow and Ice Cover	Snow cover/water equivalent/ice concentration
	Soil Moisture
Blended Products (R2O and O2R)	
Blended TPW (with LEO, GPS Met and GEO data) and Rain Rate (LEO)	
Ensemble Tropical Rainfall Potential (eTRaP)	
NOAA CPC Cloud Morphing Product (CMORPH)	
Other products emerging…GOES-R and JPSS programs	

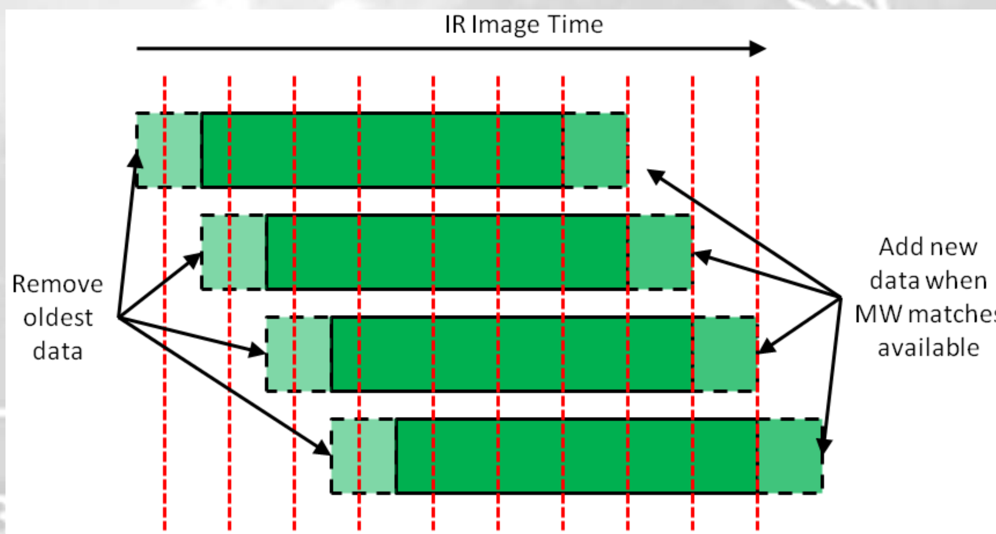
GOES-R Algorithm Overview - SCaMPR

Bob Kuligowski
NESDIS/STAR

- The GOES-R Rainfall Rate algorithm will produce estimates of instantaneous rain rate every 15 min on the ABI full disk at the IR pixel resolution (~ 2 km) with a latency of less than 5 min from image time.
  - Primary focus is operational flash flood forecast support
- The rain rates will be derived from the ABI IR bands, calibrated against rain rates from MW instruments.
- This will allow the rapid refresh and high spatial resolution of IR data from GEO while attempting to capture the accuracy of MW rain rates from LEO.
- A version of this algorithm modified for current GOES has been running in real time since August 2011 in support of GOES-R Proving Ground activities.

Calibration: Matched MW-IR Data

- Start with a rolling-value matched MW-IR dataset with 15,000 pixels with rates of at least 2.5 mm/h, which is updated whenever new MW rain rates become available.
  - MW rain rates are from the CPC (P.Xie) combined MW (MWCOMB) dataset



Calibration: Cloud Types

[Two types for current GOES; three types for GOES-R]

- Divide pixels into ~~three~~ two types:
  - ~~Type 1 (“water cloud”): $T_{7.34}<T_{11.2}$ and $T_{8.5}-T_{11.2}<-0.3$~~
  - ~~Type 2 (“ice cloud”): $T_{7.34}<T_{11.2}$ and $T_{8.5}-T_{11.2}\geq-0.3$~~
    - (No 8.5 µm on current GOES; combined into 1 type: $T_{6.7}<T_{11.0}$)
  - Type ~~3~~2 (“cold-top convective cloud”): ~~$T_{7.34}$~~ $T_{6.7}\geq T_{11.2}$
- Divide pixels by each latitude band (60-30ºS, 30ºS-EQ, EQ-30ºN, 30-60ºN).
- Maintain separate matched data sets for each class (~~3~~2 cloud types x 4 latitude bands = ~~12~~8 classes)

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cics-md

Calibration: GOES Predictors

- Use data from ~~5 ABI~~ 2 GOES bands (~~6.19~~, 6.7, ~~7.34, 8.5~~, 11.2, ~~12.3~~ µm) to create a total of ~~8~~4 predictors:

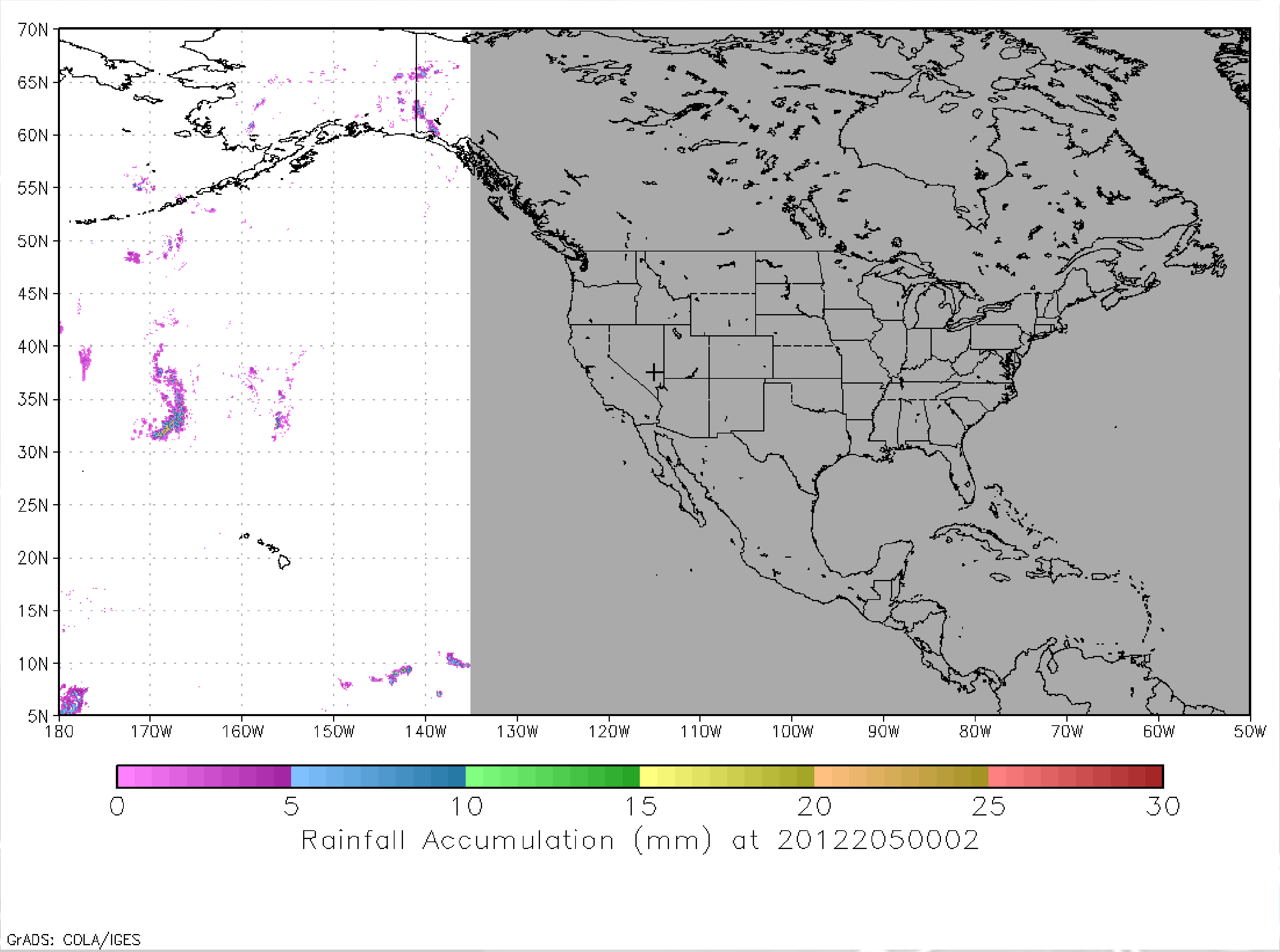
$\cancel{T_{6.19}}$ $T_{6.7}$	$\cancel{T_{8.5} - T_{7.34}}$
$S = 0.568 - (T_{min,11.2} - 217\ K)$	$\cancel{T_{11.2} - T_{7.34}}$ $T_{11.2} - T_{6.7}$
$T_{avg,11.2} - T_{min,11.2} - S$	$\cancel{T_{8.5} - T_{11.2}}$
$\cancel{T_{7.34} - T_{6.19}}$	$\cancel{T_{11.2} - T_{12.3}}$

  - (Note that these predictors were selected from a much larger initial set)
  - Additional non-linear predictors are derived to account for non-linear relationships

Two Calibration Steps

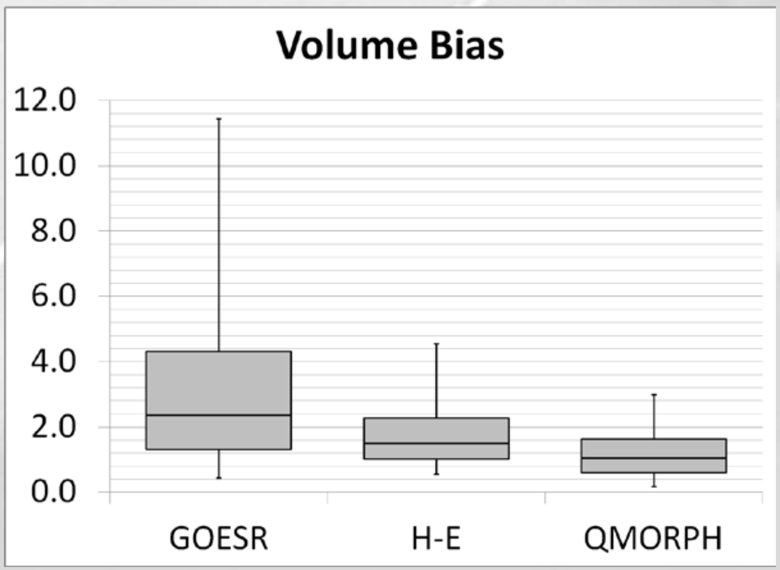
- Rain / no rain calibration using discriminant analysis and only linear predictors
  - Optimize Heidke Skill Score for up to 2 predictors
- Rain rate calibration using stepwise forward linear regression on all predictors (raining MW pixels only)
  - Optimize correlation coefficient for up to 2 predictors
  - Then make adjustments of the CDF’s between GOES and MW

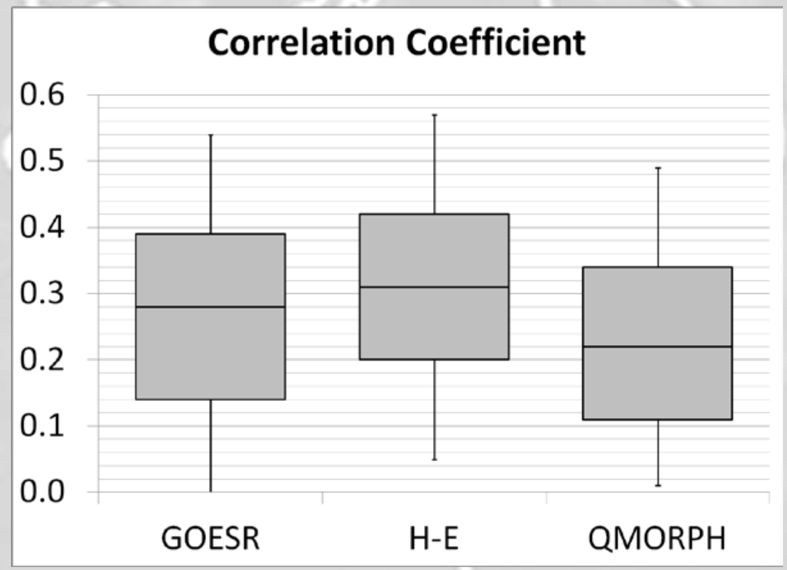
Example: 23 July 2012



Algorithm Performance: CONUS Version

- Comparison of CONUS (2-band) algorithm run on current GOES with H-E, validated against Stage IV/MPE 1-h totals
- Validation for 22 August 2011 – 1 September 2012



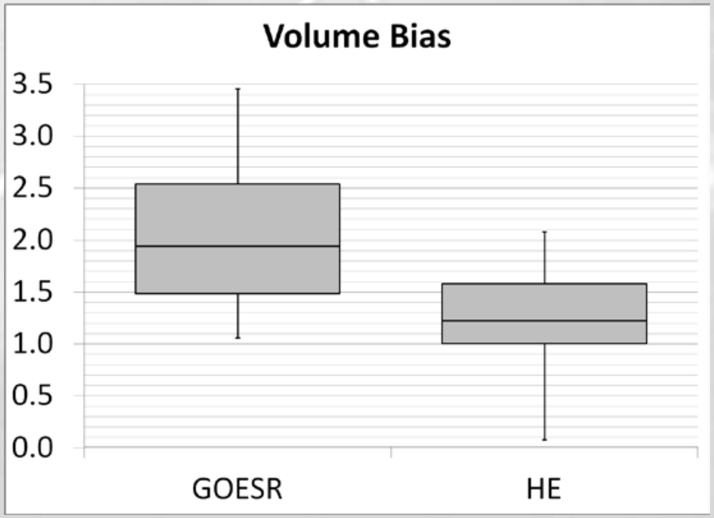


Significantly stronger wet bias than H-E

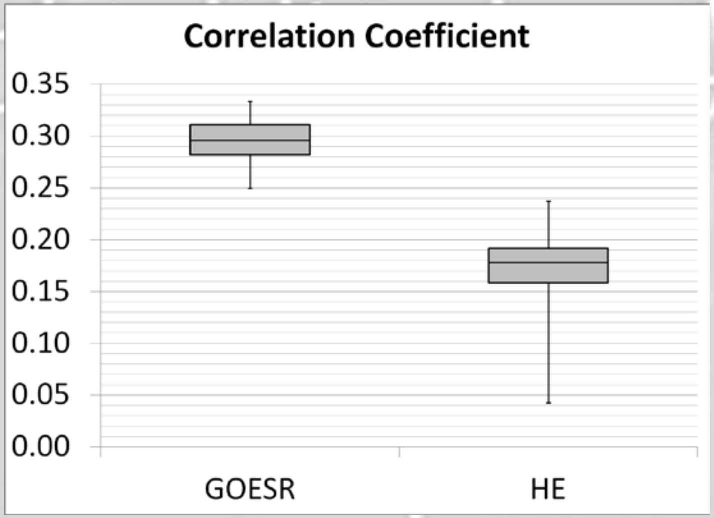
Slightly worse correlation coefficient than H-E

Algorithm Performance: Full Version

- Comparison of full (5-band) algorithm run on SEVIRI with H-E, validated against TMI instantaneous rates
- Validation for 6-9 January, April, July, October 2005



Stronger wet bias than H-E



Significantly better correlation than H-E

Future Plans for SCaMPR

- Determine and address the causes of the false alarms
  - Use the texture parameter of the H-E as a predictor to improve cirrus screening?
- Experiment with a model PW / RH adjustment to rain rates to account for moisture availability and subcloud evaporation of hydrometeors.
- Apply calibration coefficients derived by Zhanqing Li (UMCP) et al. to real-time GOES cloud property information and evaluate impact on warm-cloud light rainfall which typically IR and MW have difficulty detecting.
- Continue experiments with orographic rainfall modulation.

What are some new developments to look forward to in the GOES-R, JPSS and GPM era?

- GOES-R: GLM sensor, rapid updates/ABI
- JPSS: Snowfall rates, VIIRS/ATMS synergy, AMSR-2
- GPM: GMI/DPR, other constellation members
- Then lets put them all together!
- Then lets add in radar and gauges (next speaker)!

- I’ll show next some potential improvements
    - Convective precipitation
    - Winter season/snowfall

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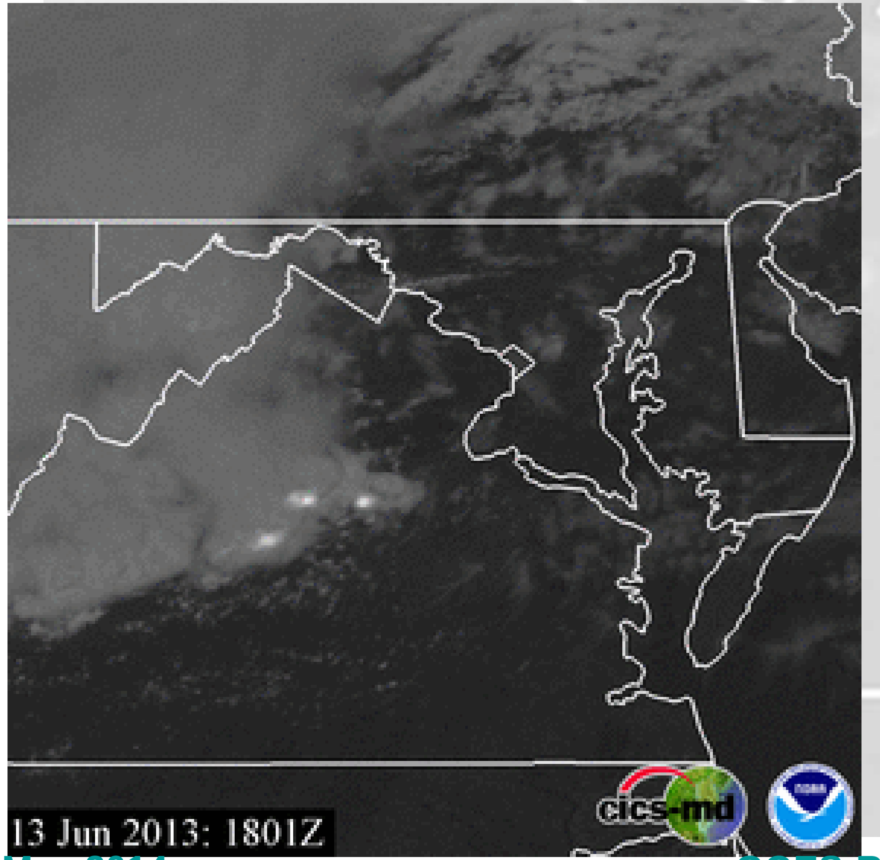
Patrick Meyers
Univ. of MD/CICS

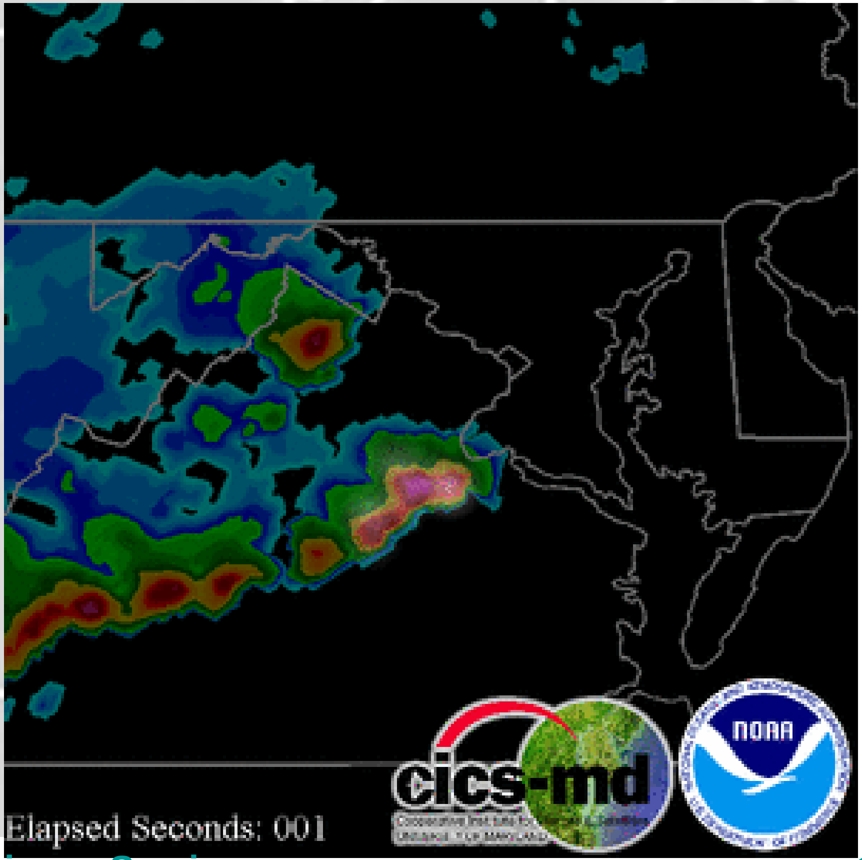
DCLMA Applications –

Showing the potential synergy from GOES-R ABI & GLM, and JPSS AMSR2

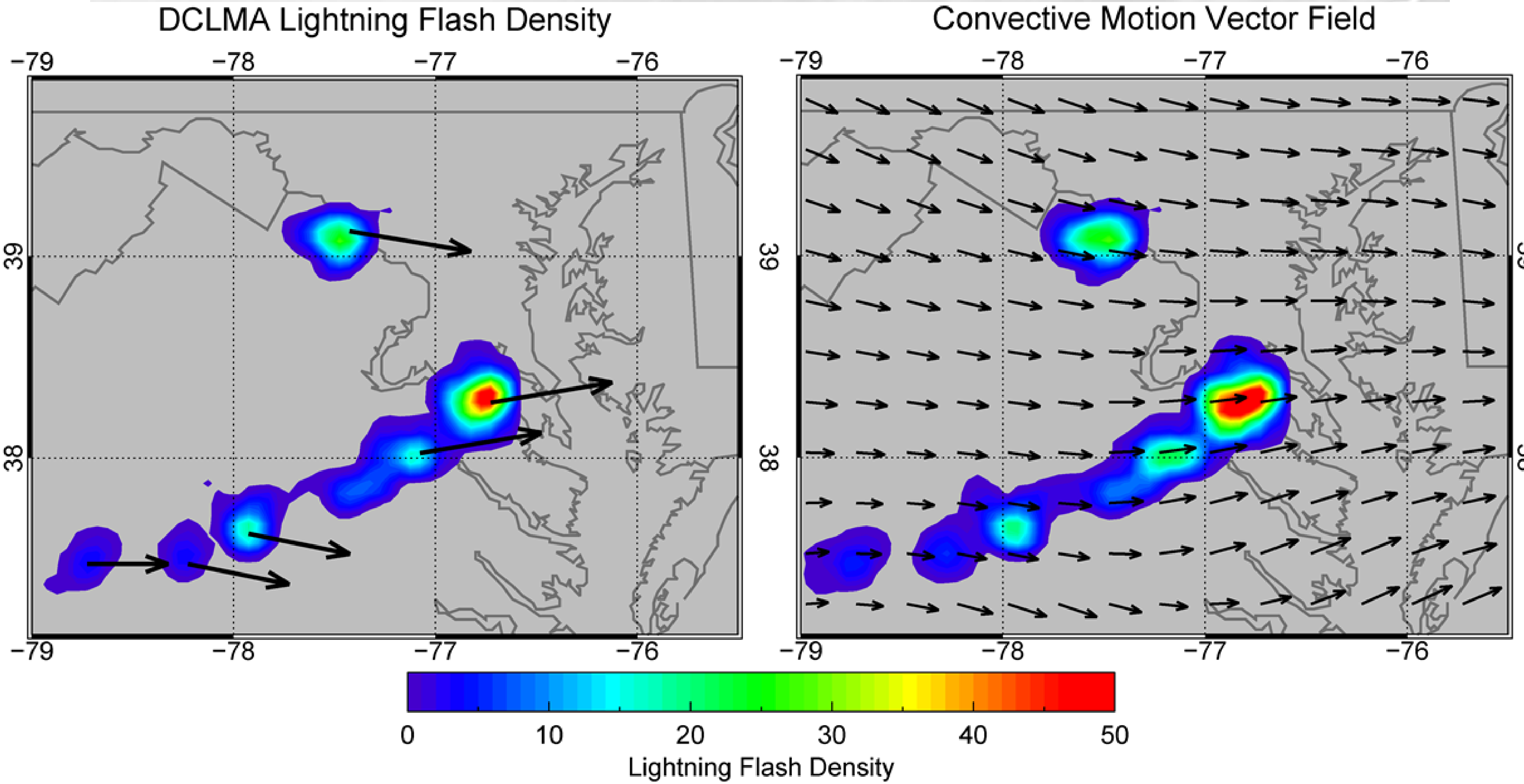
Minute Lightning Density with 2 Long-track Tornados



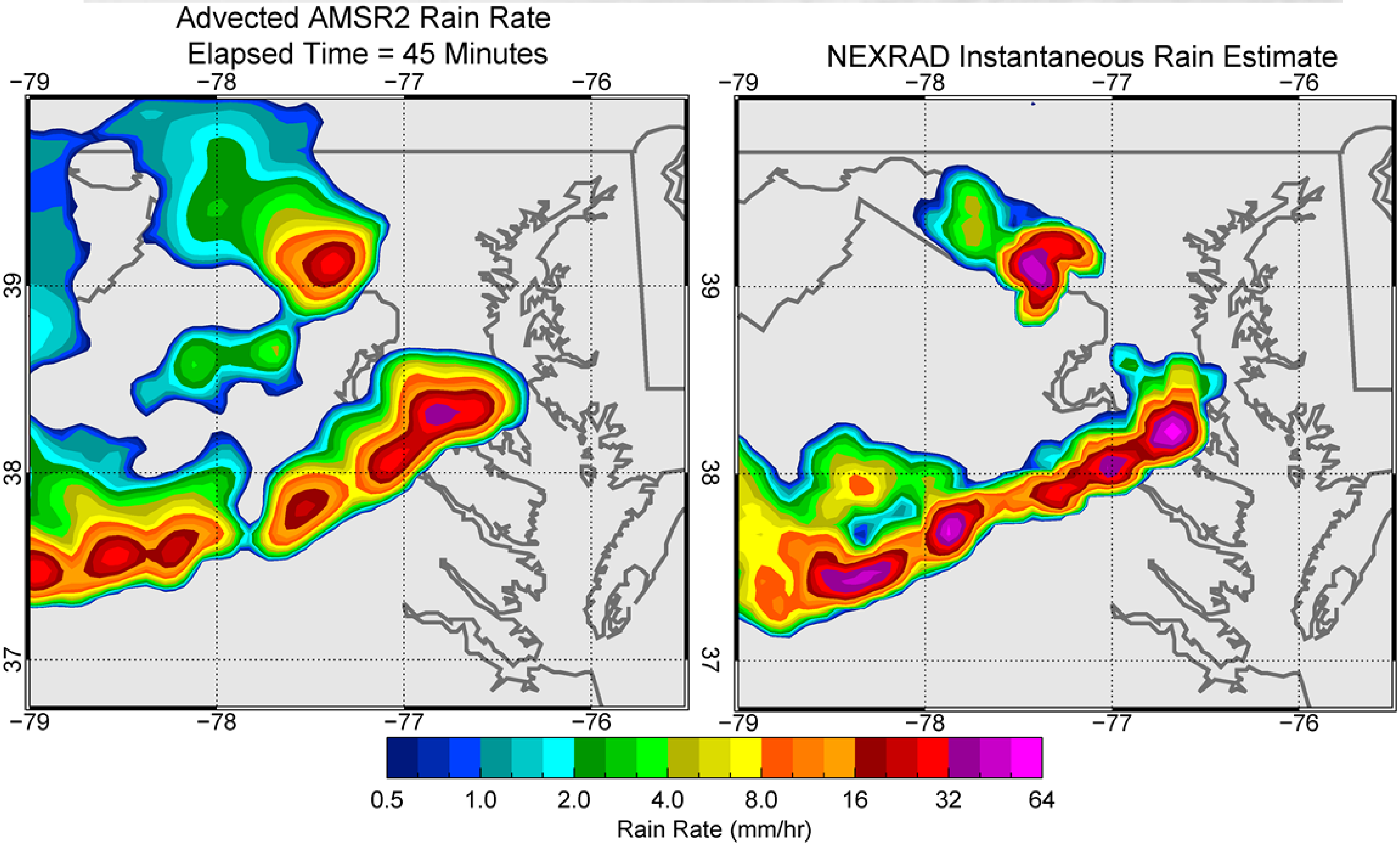
Lightning Flashes Each Second Overlaid on AMSR2 Precipitation



Motion Vectors from Lightning Density



Lightning-Advected Rain Rates from AMSR2

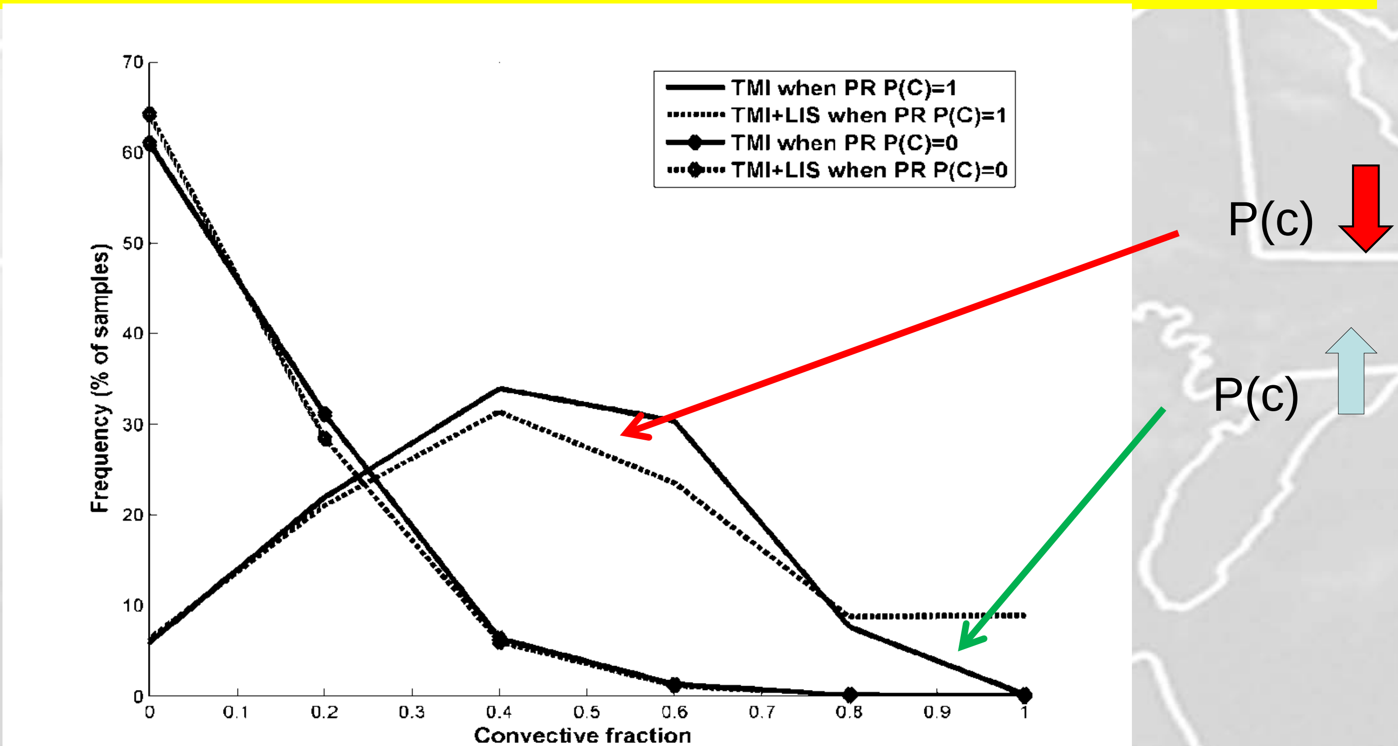


Combining GOES-R & GPM to improve MW input for GOES-R rain rates

Nai-Yu Wang, NESDIS/STAR and CICS-MD

Objective – Can lightning information (use LIS as proxy for GLM) improve stratiform/convective classification?

Lightning improves microwave convective-stratiform partitioning; reduces positive bias in MW rain rates – will improve training data used in SCaMPR



Wang, N.-Y., K. Gopalan, and R. Albrecht, 2012: Application of lightning to passive microwave convective and stratiform partitioning in passive microwave rainfall retrieval algorithm over land from TRMM, *Journal of Geophysical Research*, doi:10.1029/2012JD017812.

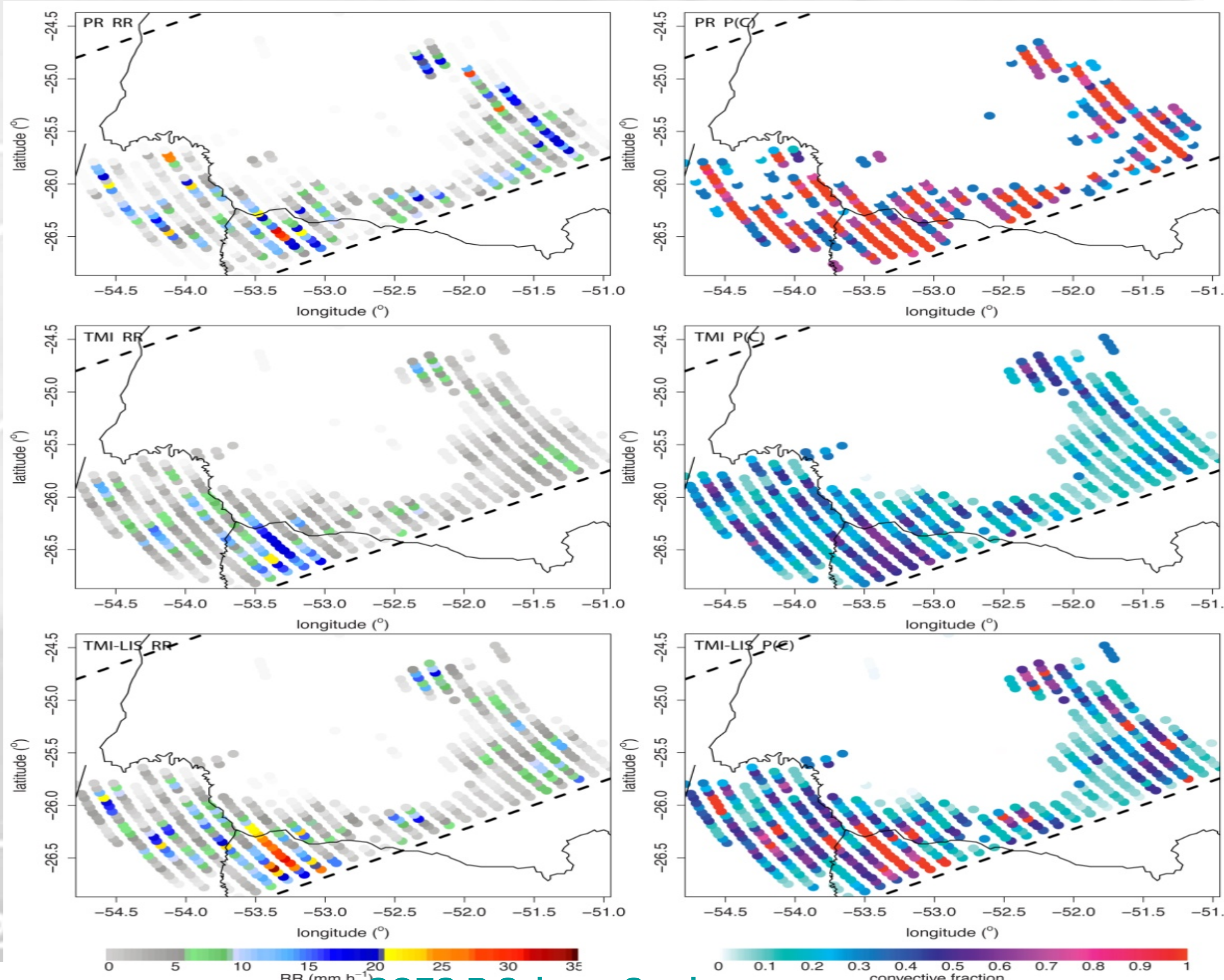
An Example from TRMM

Rain Rates | **Convective Fraction**

PR

TMI

TMI+LIS



A Combined IR and Lightning Rainfall Algorithm for Application to GOES-R Adler, Xu and Wang UMD/CICS

Goal: Develop and test a combined geo-IR and lightning rain algorithm for use with GOES-R [and also applicable with other types of lightning information]

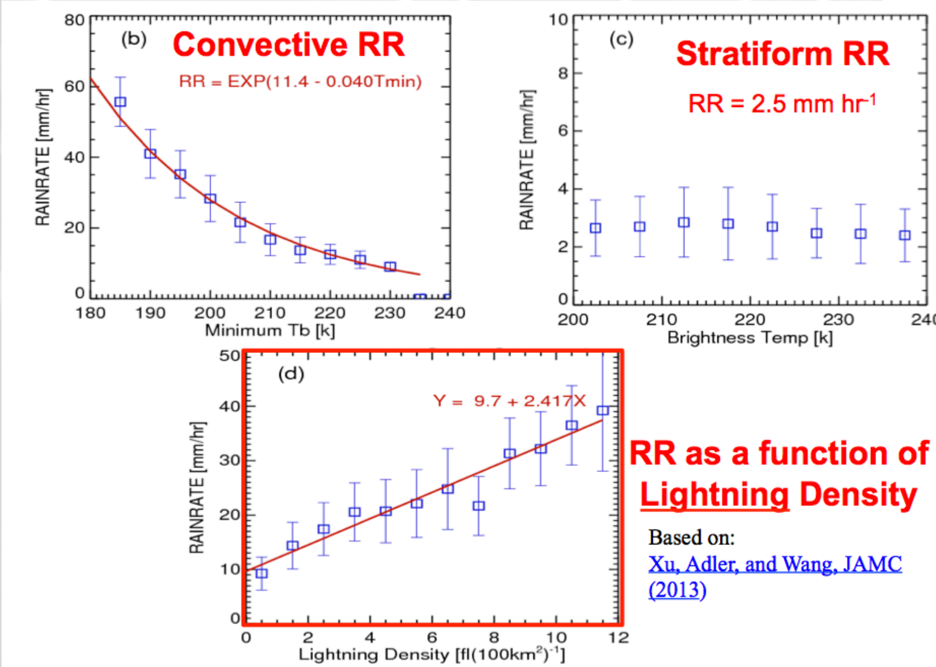
Approach

1. ***Utilize Tropical Rainfall Measuring Mission (TRMM) data (IR, Lightning, Passive Microwave and Radar) to develop and test an instantaneous rain estimation technique for use in deep convective situations.***

2. ***Apply IR-based Convective-Stratiform Technique (CST; Adler and Negri, 1988). CST defines convective cores by T_b minima and adds stratiform rain through T_b threshold.***

3. ***Use Lightning flash rate as additional information to CST to detect new convective cores, eliminate incorrect IR-defined cores, and estimate convective core rainfall rates.***

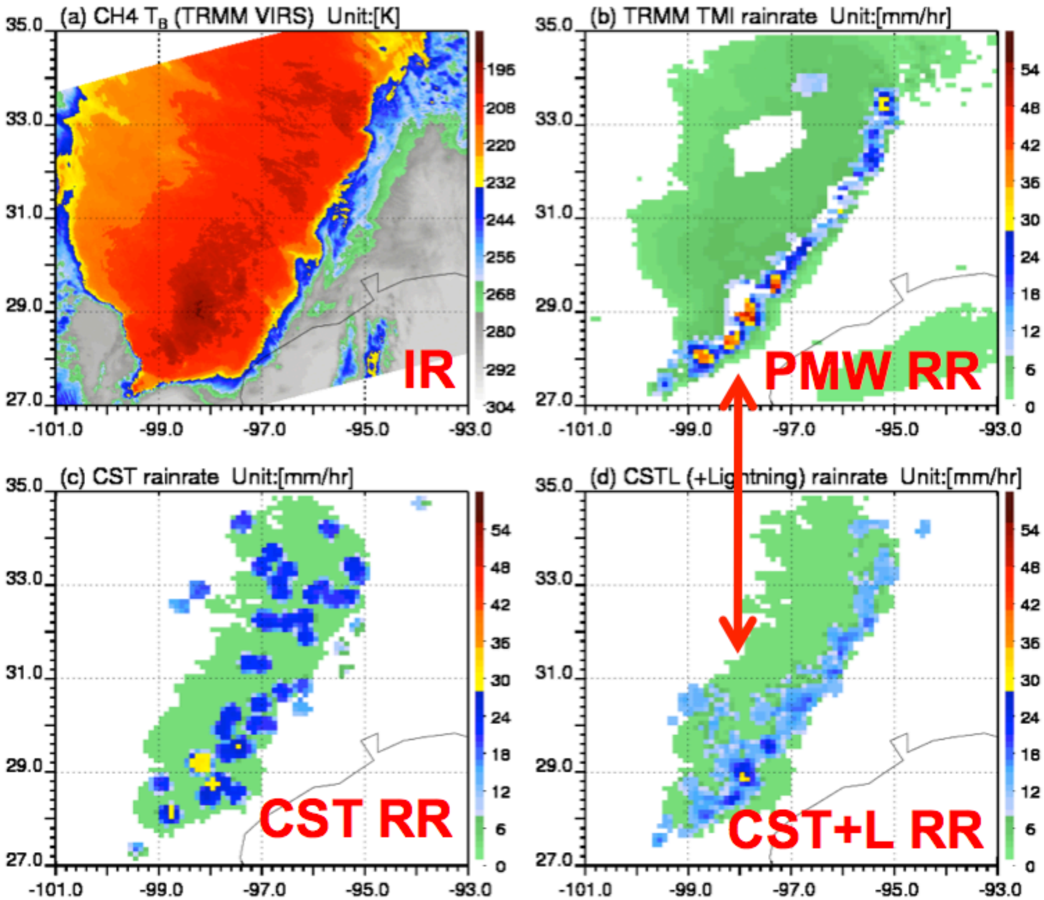
IR and Lightning Rainrate Functions



*Xu, Weixin, R. Adler, Nai-Yu Wang, 2014: Combining Satellite Infrared and Lightning Information to Estimate Warm-Season Convective and Stratiform Rainfall. J. Appl. Meteor. Climatol., **53**, 180–199.*

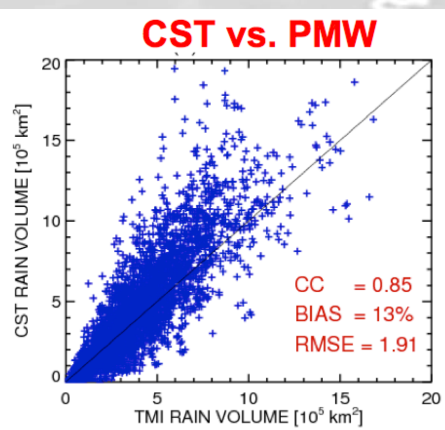
*Xu, Weixin, R. Adler, Nai-Yu Wang, 2013: Improving Geostationary Satellite Rainfall Estimates Using Lightning Observations: Underlying Lightning–Rainfall–Cloud Relationships. J. Appl. Meteor. Climatol., **52**, 213–229.*

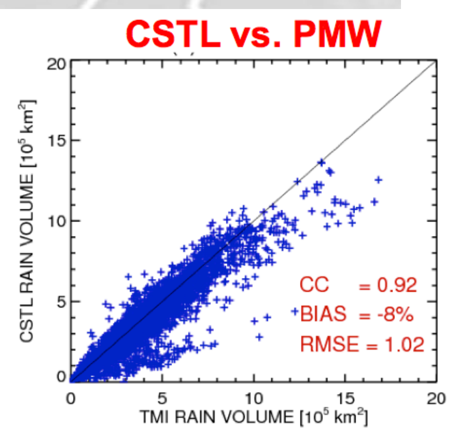
Evaluation of IR-only (CST) and IR+Lightning (CSTL)



Validation on independent TRMM PMW data indicate importance of lightning flash rate data to define convective cores not identified by IR and eliminate IR misidentified convective features (see example at left) providing a IR/lightning estimate of instantaneous rain rate much closer to what is estimated from simultaneous PMW

Statistics indicate significant improvement with addition of lightning information in terms of probability of detection and false alarms of convective cores and for rain rate estimates, e.g., over TRMM scenes 800x800 km² (at right).



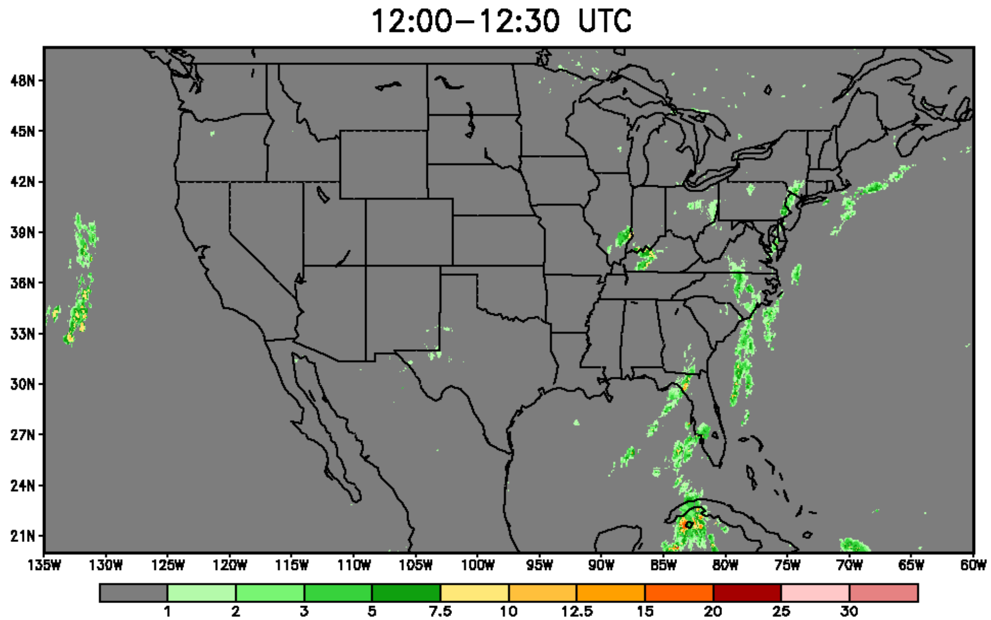


GOES-R Enhanced Regional CMORPH *and* Gauge-Radar-Satellite-Model Fused Precipitation Analysis

Pingping Xie & Robert Joyce

NOAA Climate Prediction Center

- Our GOES-R project aims to develop two sets of integrated precipitation products over the GOES-R domain:
  - A regional CMORPH with refined spatial resolution (2km), reduced latency (15-min) and improved accuracy through infusion precipitation estimates derived from GOES-R sensors and other LEO platforms
  - A gauge-radar-satellite-model fused analysis of hourly precipitation to cover the CONUS and its adjacent regions seamlessly for improved monitoring of weather and climate

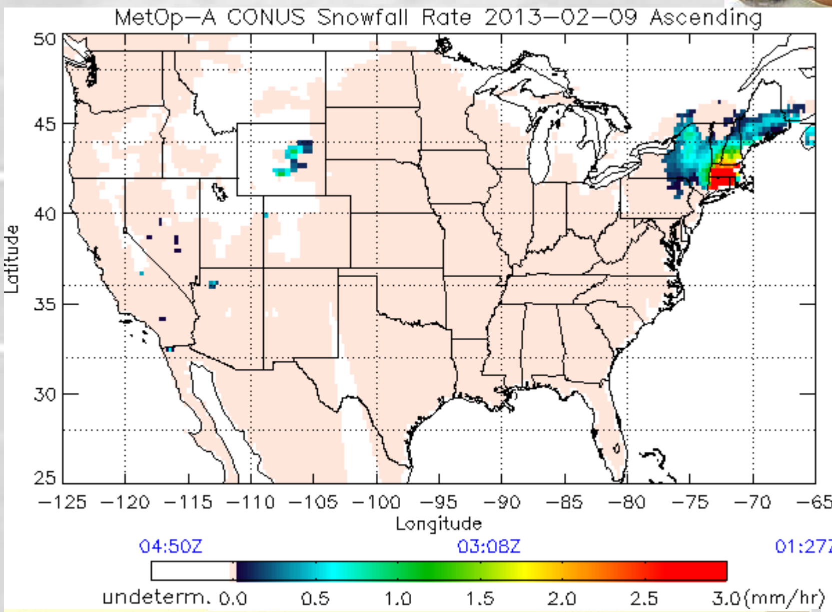


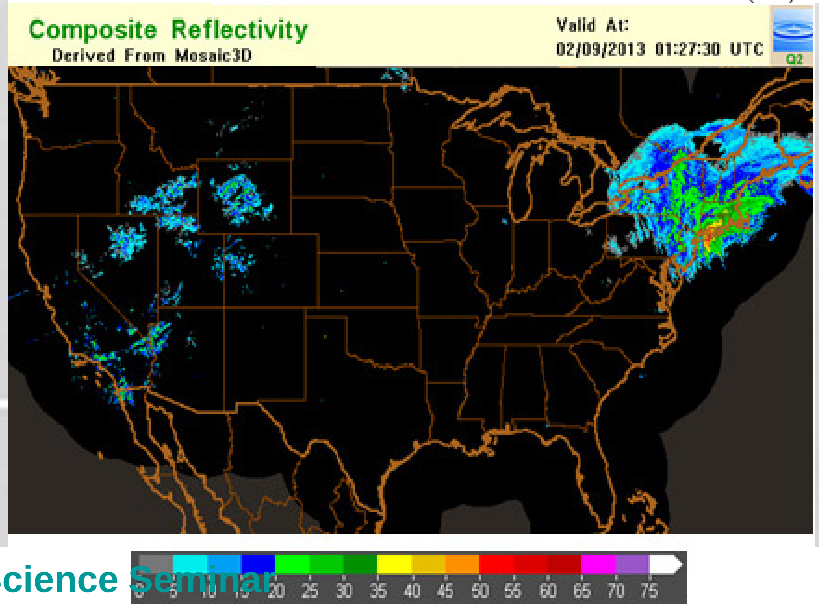
Synthetic GOES-R enhanced regional CMORPH precipitation estimates for July 1, 2013, produced on a 4km resolution using satellite PMW and GOES IR data available at a latency of 15 minutes.

MHS AND ATMS SNOWFALL RATES

Huan Meng, NESDIS/STAR

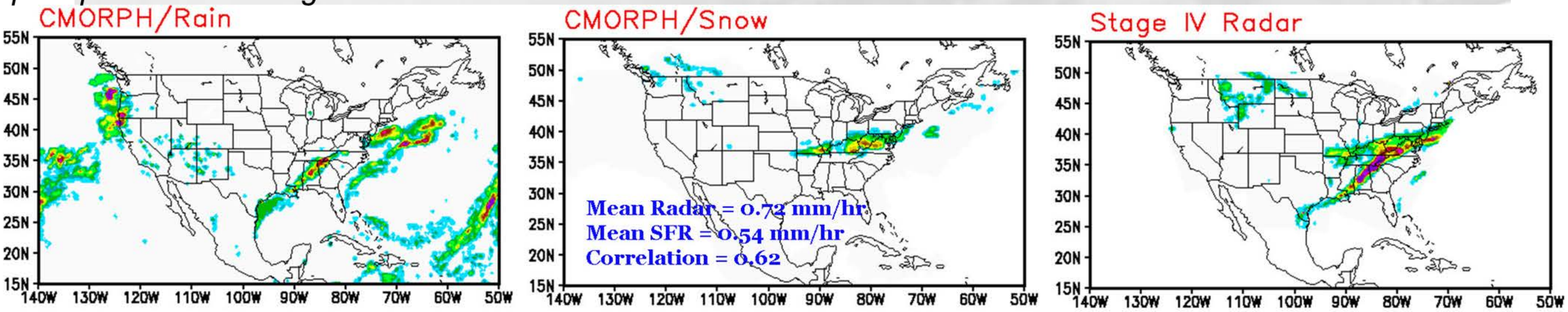
- Satellite retrieved water equivalent snowfall rate (SFR) over global land
- Uses measurements from passive microwave sensors, AMSU/MHS/ATMS
- AMSU/MHS SFR is operational at NESDIS with four satellites through MSPPS (N18, N19, MOA, MOB)
  - Up to 8 obs/day at a given location
- S-NPP ATMS algorithm being tested
  - Recent tests with DB significantly reduces latency
- Resolution: 16 km x 16 km at nadir
- Maximum snowfall rate: 5 mm/hr
- Validated against NMQ, StageIV, and gauge snowfall data

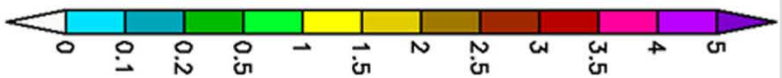




SFR Applications – CMORPH, GOES-R Cloud Properties

NCEP/CPC CMORPH blended precipitation product uses both ATMS and AMSU/MHS SFR for its winter precipitation analysis. In this snowfall event, the correlation coefficient between the CMORPH 3-hour precipitation and Stage IV reaches 0.62.

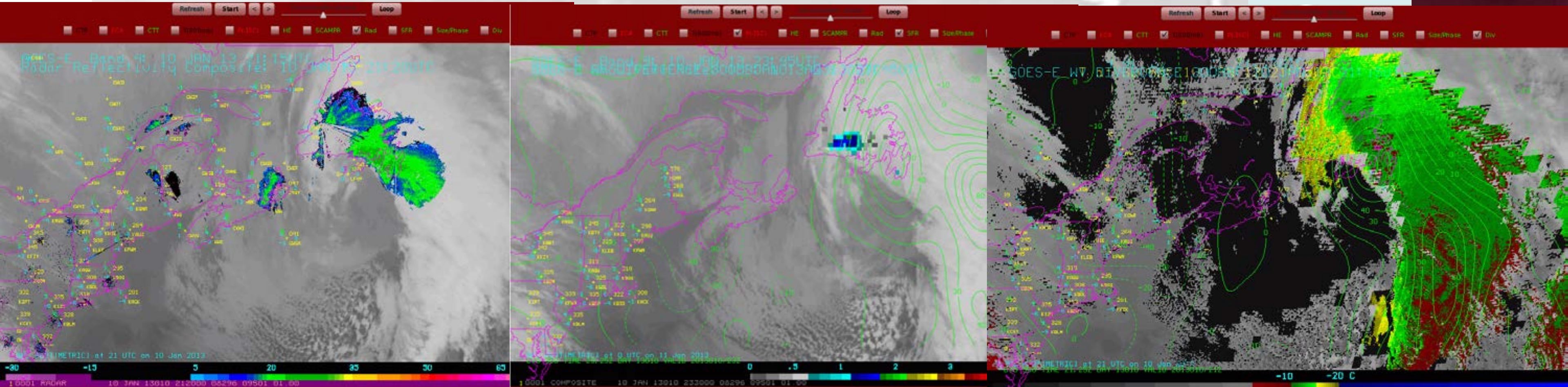




(Courtesy of P. Xie and R. Joyce)

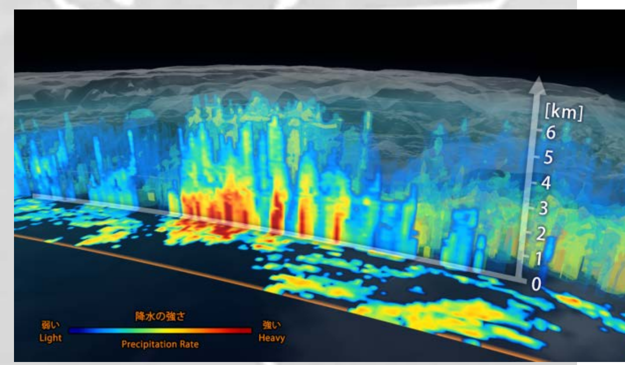
Some preliminary work by Bob Rabin indicates some qualitative agreement between the SFR and a GOES-R (proxy data) based dendritic growth product.

Bob Rabin
NOAA/NSSL
CIMSS



GPM (NASA/JAXA)

- Satellite and Sensor Status:
  - GPM Core – Feb. 27, 2014 (JAXA)
  - Primary sensors
    - GMI (NASA) – 13 channel (10-183 GHz) conically scanning radiometer (successor to TRMM TMI)
      - Enhancement for cold season precipitation
    - DPR (JAXA) – Ka/Ku band radar (successor to TRMM PR)
      - Dual frequency helps improve vertical structure of precipitation
      - Dual frequency improves sensitivity to lighter precipitation
  - NOAA has been receiving GMI data in test mode since March
    - JCSDA – BUFR
    - NESDIS/OSPO – native data on server
- GPM core serves as a calibration anchor for GPM constellation members
  - NOAA can exploit this capability for improved operational precipitation products
    - POES and JPSS
    - But also for GOES-R



More Mission Details at:
http://www.nasa.gov/mission_pages/GPM/main/

The GPM Constellation at Work

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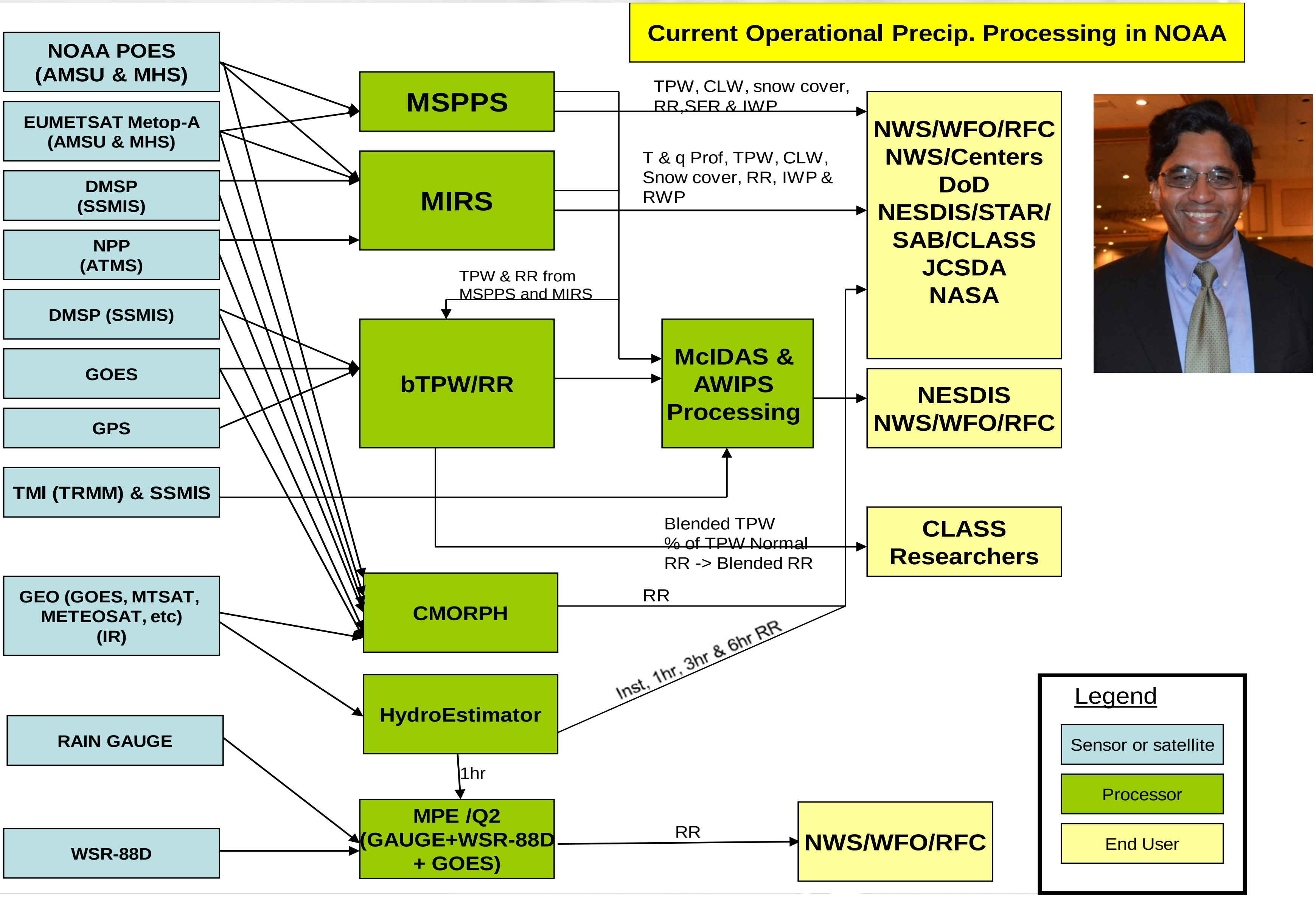
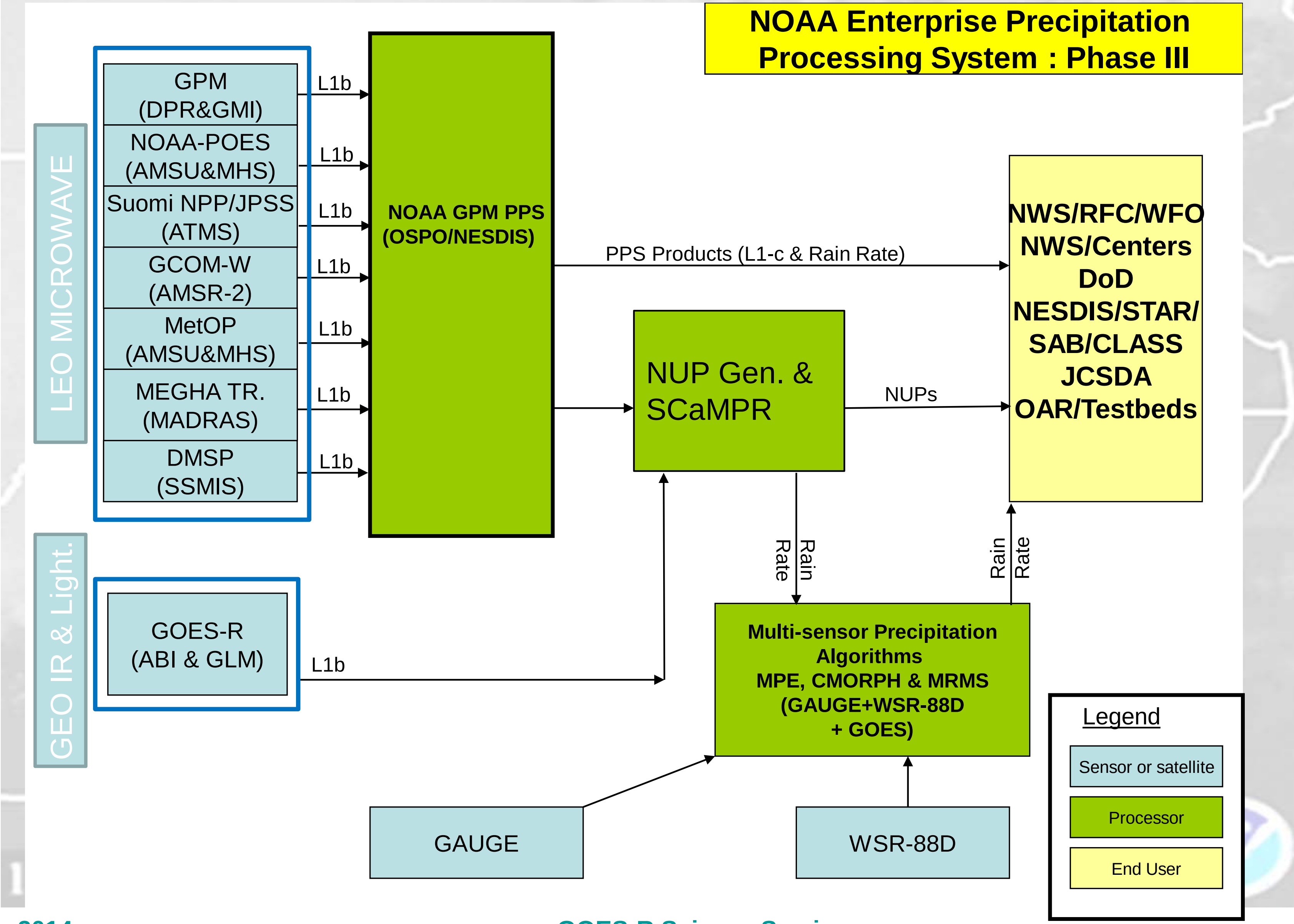
Courtesy of NASA

Current – Satellite Precipitation at NOAA

Provided by C. Kondragunta, NESDIS/OSD



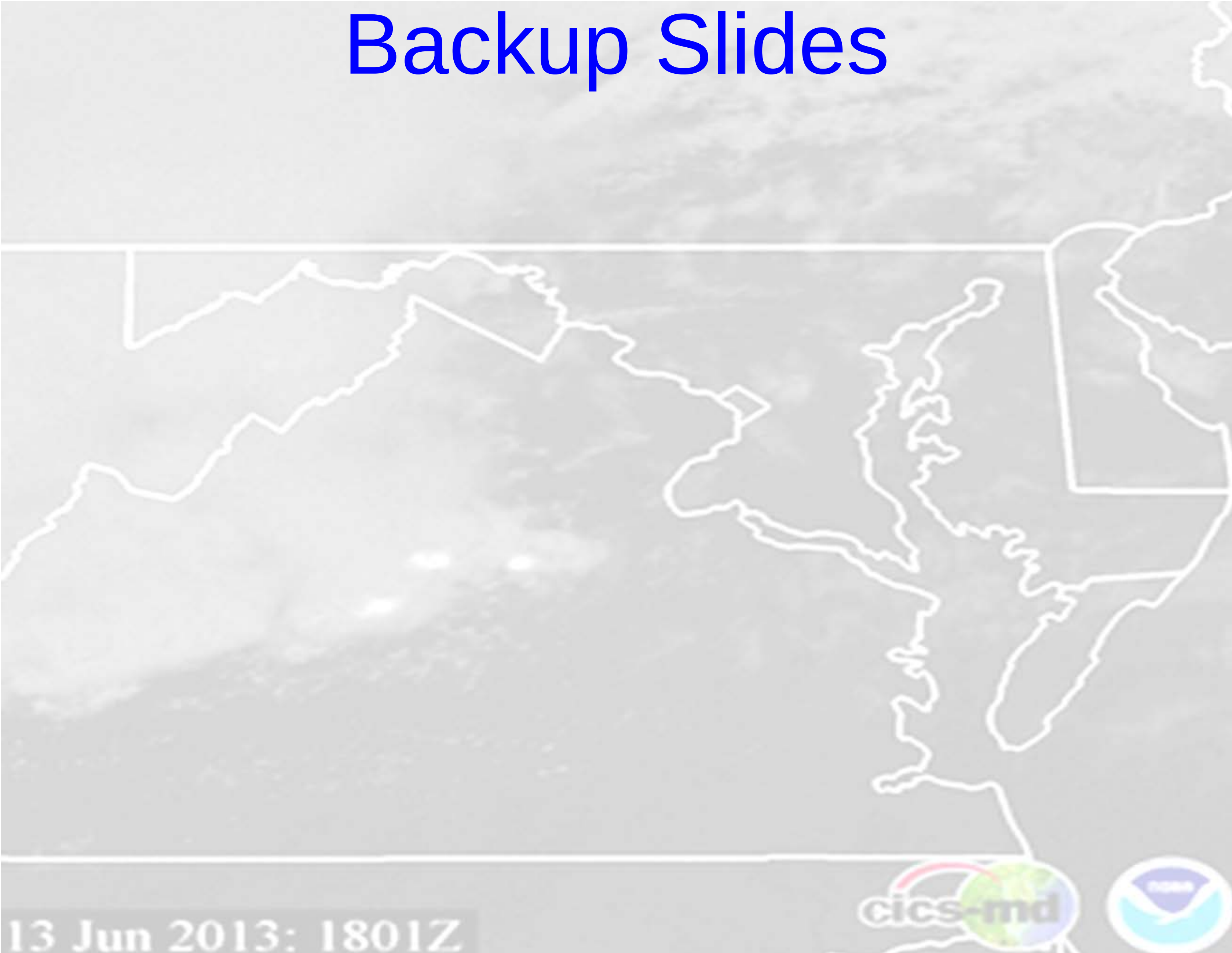
Future – Precipitation Enterprise Concept



Summary and Future

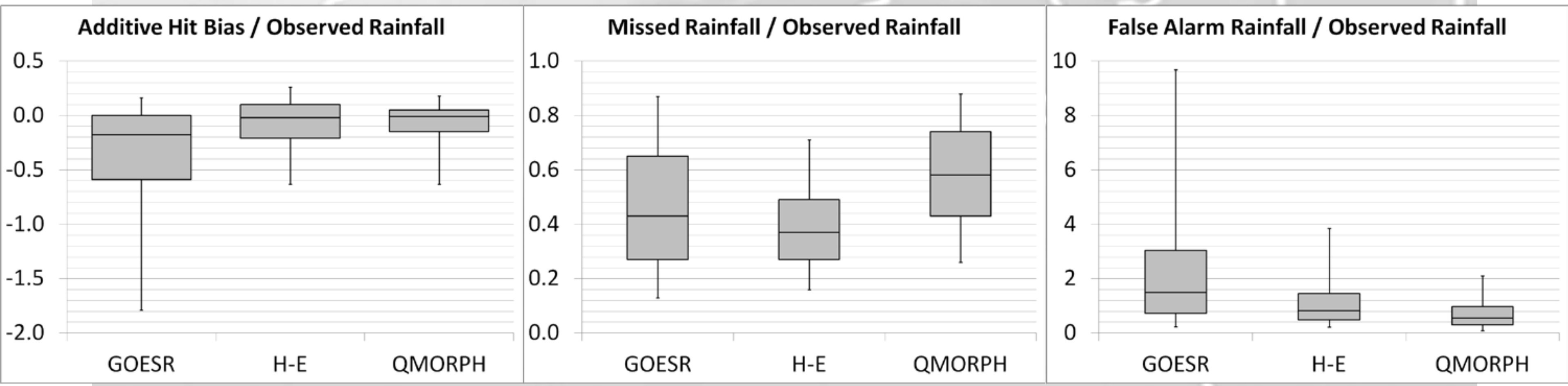
- Exciting times ahead in the satellite precipitation field
  – GOES-R
    - Improved spatial, temporal and spectral resolution via ABI
    - New capabilities – GLM
  – JPSS (and related missions)
    - Improved spatial and spectral resolutions via CrIS, ATMS and VIIRS
    - Expanded use of direct broadcast reduces data latency for JPSS
- Need to leverage non-NOAA assets for improved products
  – NASA GPM (and JAXA GCOM)
  – New, improved capabilities expected on EUMETSAT missions
  – Can we start to exploit China, Korea, etc?
- Enhance synergies with GOES-R, JPSS and other broad-based NOAA programs
  – Including radar and gauge programs
- ENTERPRISE Solution
  – Better products delivered to users!

Backup Slides



Algorithm Performance: CONUS Version

- Comparison of CONUS (2-band) algorithm run on current GOES with H-E, validated against Stage IV/MPE 1-h totals
- Validation for 22 August 2011 – 1 September 2012

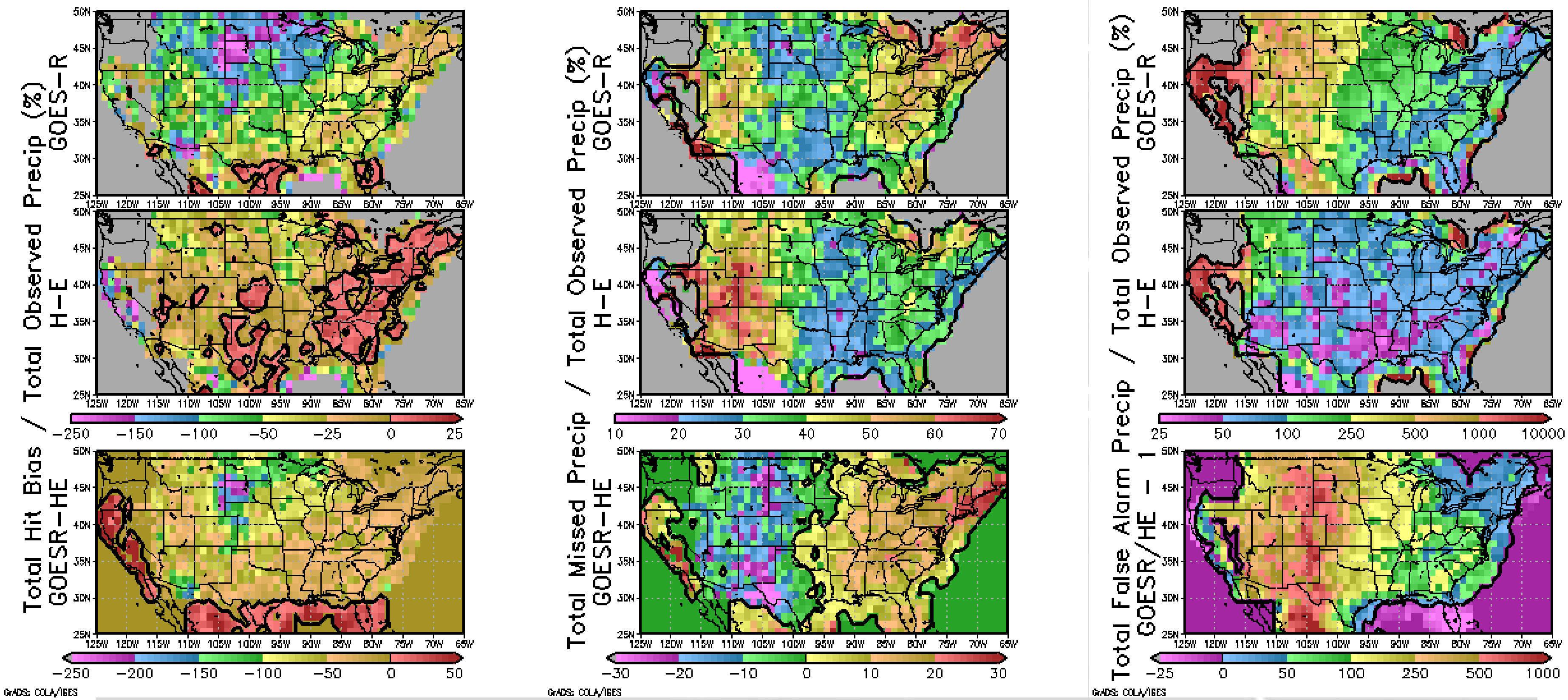


Stronger dry bias compared to H-E for "hit" pixels

Slightly more missed rainfall than H-E

Significantly more false alarm rainfall than H-E

Algorithm Performance: CONUS Version



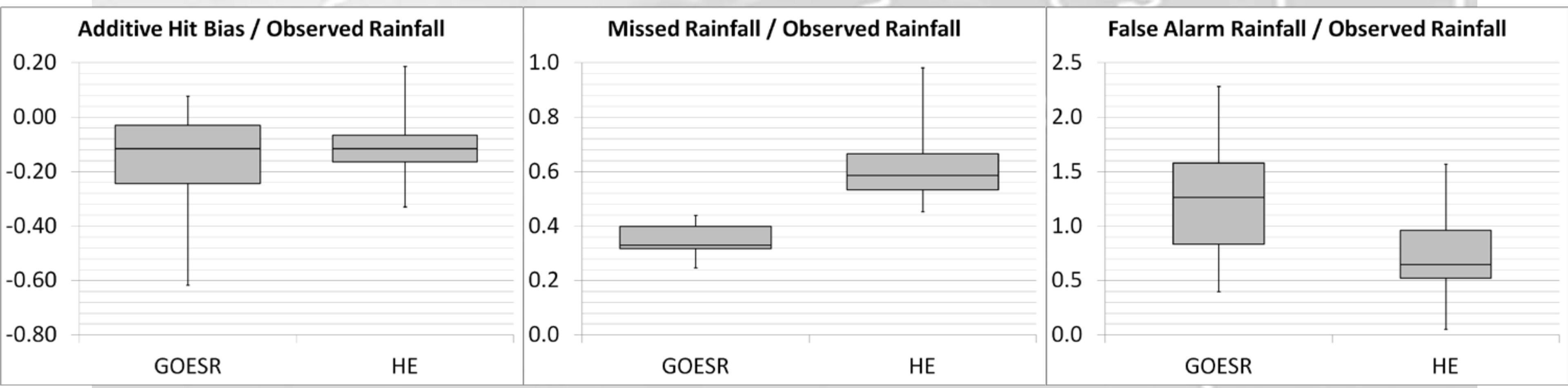
Much stronger dry bias for "hit" pixels than H-E over northern Plains

Less missed rain than H-E over western US; more missed rain over eastern US

Much more false alarm precip than H-E over western US

Algorithm Performance: Full Version

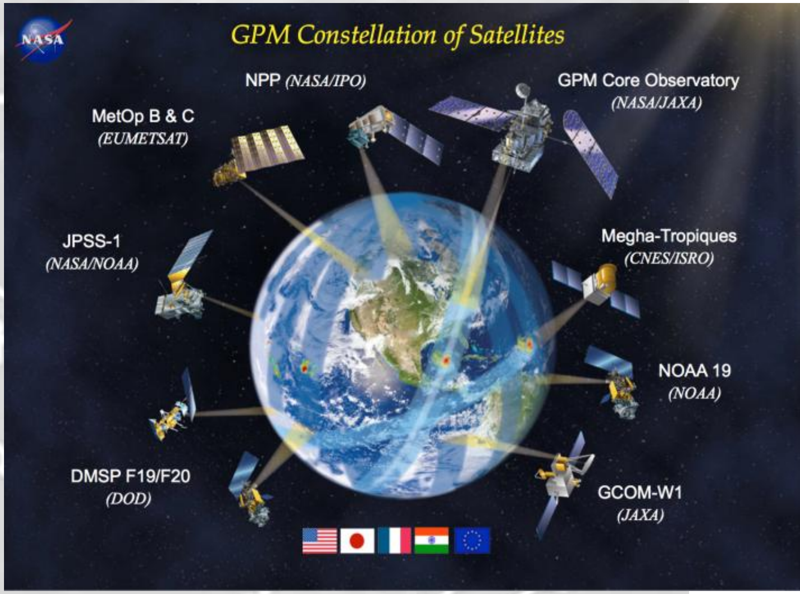
- Comparison of full (5-band) algorithm run on SEVIRI with H-E, validated against TMI instantaneous rates
- Validation for 6-9 January, April, July, October 2005



Similar slight dry bias to H-E for “hit” pixels	Significantly less missed rainfall than H-E	More false alarm rainfall than H-E

The Global Precipitation Measurement (GPM) Mission

- GPM is “ripe” for R2O; why?
  - Precipitation Processing System (PPS)
    - NASA- Precip. Research Focus
    - NOAA – 24 x 7 Operations Focus
      - NOAA Unique products – TPW, OWS, AWIPS, …
    - Prototype system to
      - Reduce “stove pipes “ and system maintenance cost
      - Anchor for multi-satellite precipitation products
        - » GOES and LEO
      - Anchor for multi-sensor precipitation products
        - » Satellite, radar, gauges
  - L1C (Inter-calibrated radiances)
    - Ideal for climate related activities
    - May benefit NWP data assimilation



GPM Core Satellite Launch Feb 2014