QPE / Rainfall Rate

June 19, 2013

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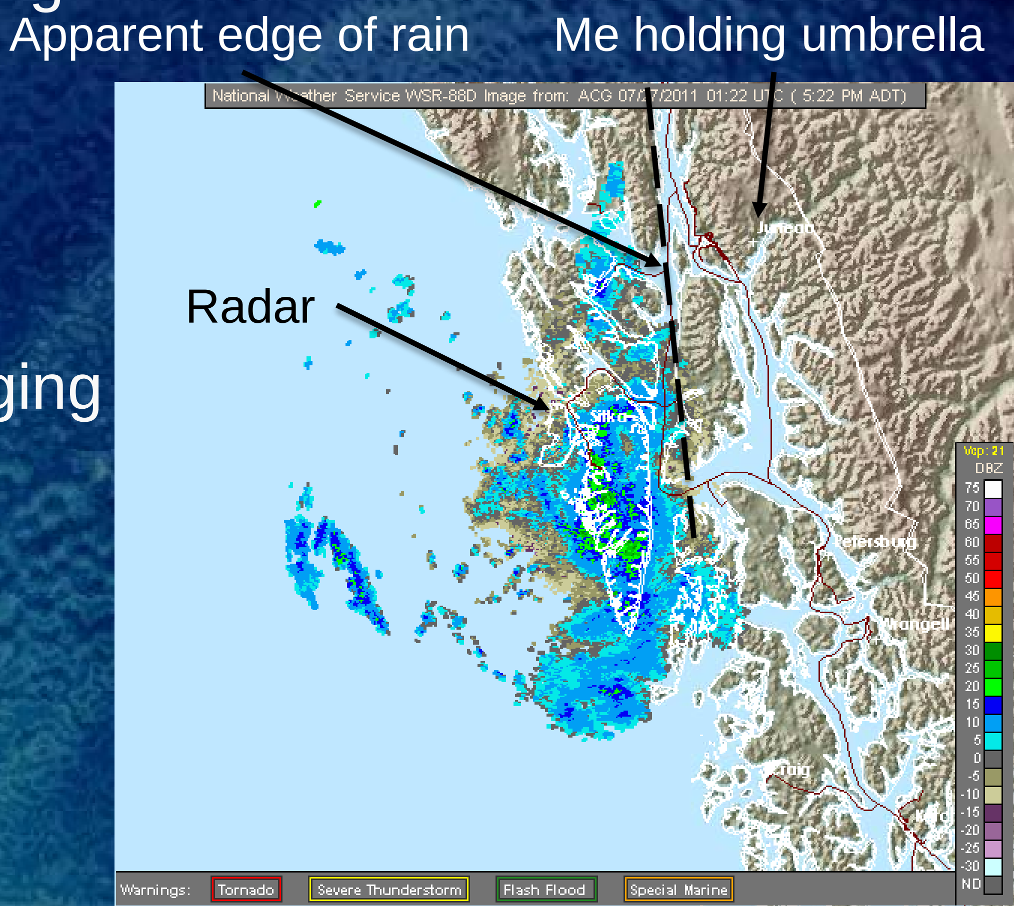
Outline

- Background
  - » Motivation
  - » Satellite QPE Basics
- The “Full” GOES-R Rainfall Rate Algorithm
- The Current-GOES version of the algorithm
  - » Differences from the “full” version
  - » Validation
  - » Recent examples
- Next Steps

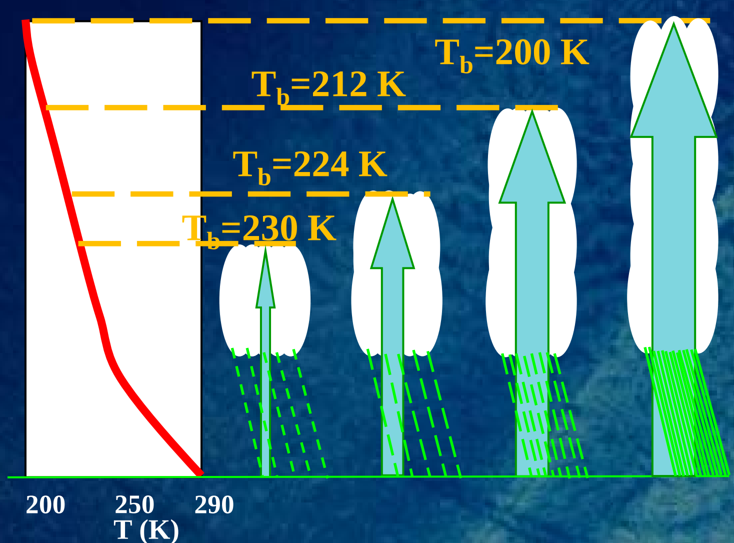
Motivation

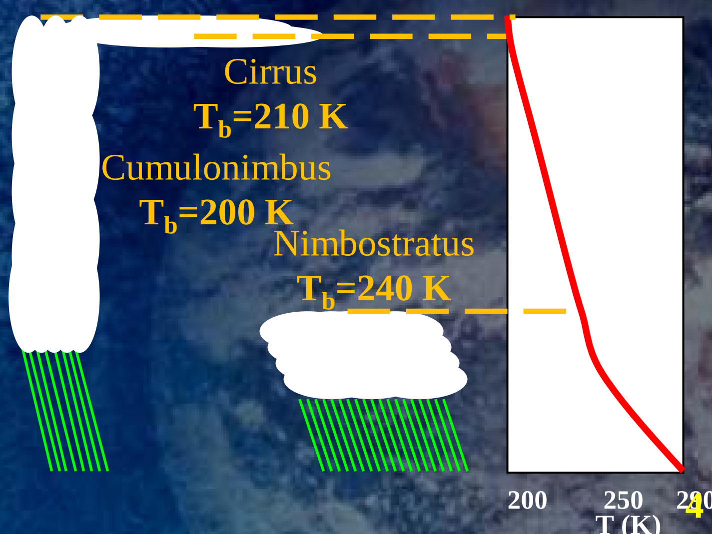
- Radar is highly valuable, but provides incomplete coverage due to
  - » Beam block
  - » Beam overshoot
  - » Radar unit placement
- This is particularly challenging in regions with complex terrain.



Satellite QPE Basics: IR

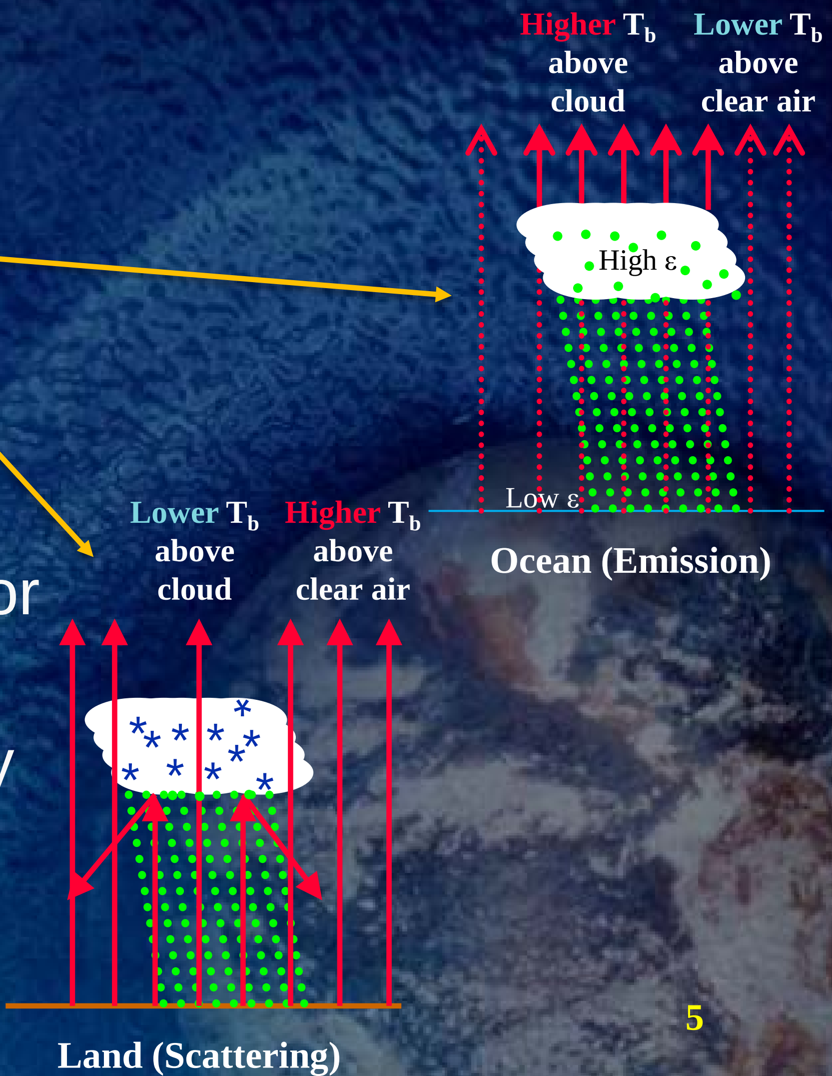
- IR-based algorithms retrieve rain rates based on cloud-top brightness temperatures:
  - » Cold tops→strong upward moisture flux→heavy rain
  - » Warm tops→weak / no upward moisture flux→light / no rain
- Works well for convective rainfall; poor assumption for stratiform rainfall





Satellite QPE Basics: MW

- MW-based algorithms retrieve rain rates based on:
  - » Enhanced emission at low frequencies by cloud water
  - » Enhanced backscattering of upwelling radiation by cloud ice
- Emission over land only; significant detection problems for low-ice clouds over land
- Algorithms are calibrated mainly for the tropics (TRMM)



Other Satellite QPE Issues

- Primary interest is in rainfall rates at ground level; satellites detect cloud-top (IR) or cloud-level (MW) characteristics.
- Thus, no direct accounting for:
  - » Orographic effects
  - » Subcloud evaporation of hydrometeors
  - » Subcloud phase changes (e.g., snow to rain / sleet)
- Some algorithms (e.g., Hydro-Estimator) attempt to account for these effects using NWP model data

Implications for Satellite QPE Users

- Satellite rain rate estimates perform best for convective precipitation—as well as and sometimes even better than (single-pol) radar ***without*** gauge correction (Gourley et al. 2010)
- Satellite rain rate estimates still perform very poorly for stratiform precipitation—in fact, NWP model forecasts are often more skillful than satellite QPE in higher latitudes during the cool season
- Satellite QPE has value, but users need to be aware of its limitations to maximize its usefulness

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Rainfall Rate Requirements

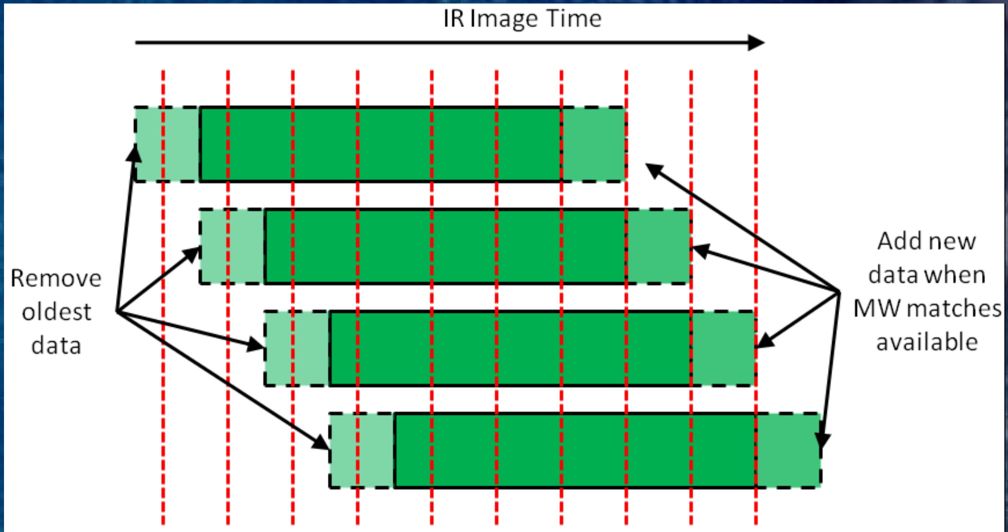
- Estimates of instantaneous rainfall rate…
  - » …every 15 minutes
  - » …at the full ABI pixel resolution (2 km at nadir)
  - » …with a latency of less than 5 minutes
  - » …over the entire full disk
    - – but with accuracy guaranteed only within 70º LZA and / or less than 60º latitude, whichever is less
  - » …with an accuracy (bias) of 6 mm/h and a prevision (68th percentile of absolute error) of 9 mm/h, measured for pixels with a rain rate of 10 mm/h.

Rainfall Rate Description

- MW-derived rain rates are used to calibrate an algorithm based on IR data:
  - MW-derived rain rates are the most accurate but not available continuously; only IR provides rapid refresh
  - Objective: optimal calibration for a particular geographic area, cloud type, and season.
- Two calibration steps:
  - Rain / no rain separation via discriminant analysis
  - Rain rate retrieval via regression
- Calibration is updated whenever new MW data become available

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 combined MW (MWCOMB) dataset



Calibration: Cloud Types

- Divide pixels into three 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 $T_{8.5}-T_{11.2}\geq-0.3$
  - » Type 3 (“cold-top convective cloud”): $T_{7.34}\geq T_{11.2}$
- Divide pixels by each latitude band (60-30ºS, 30ºS-EQ, EQ-30ºN, 30-60ºN).
- Maintain separate matched data sets for each class (3 cloud types x 4 latitude bands = 12 classes)

Calibration: GOES Predictors

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

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

(Note that these predictors were selected from a much larger initial set)

Calibration: Nonlinear Predictor Transformation

- Since the relationship between the IR predictors and rainfall rates are most likely nonlinear, regress all 8 predictors against the rainfall rates in log-log space to produce 8 additional nonlinear rain rate predictors; i.e.,

$$y = \alpha (x + \gamma)^{\beta}$$

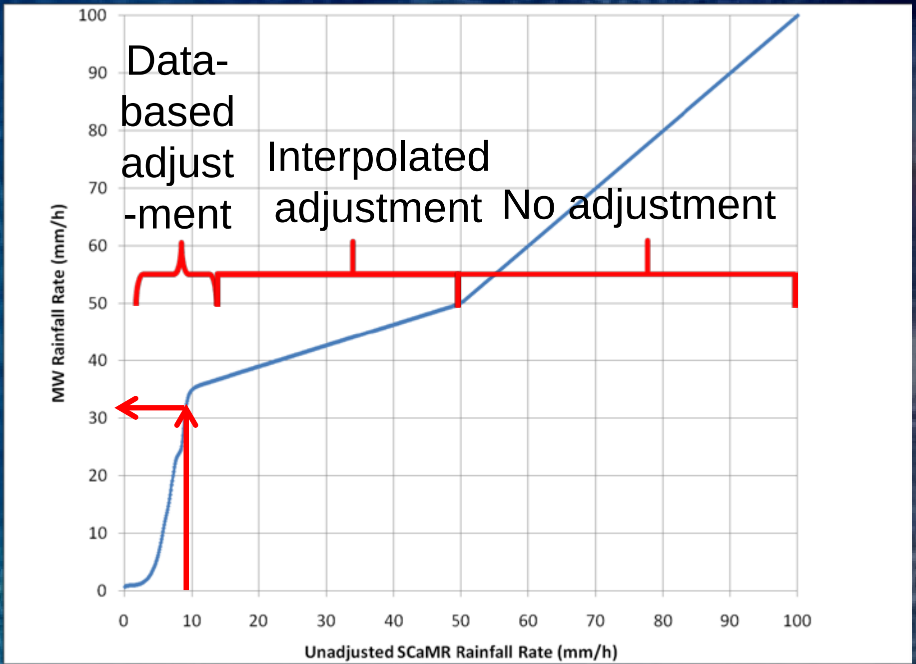
(the intercept γ is determined via “brute force”)

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

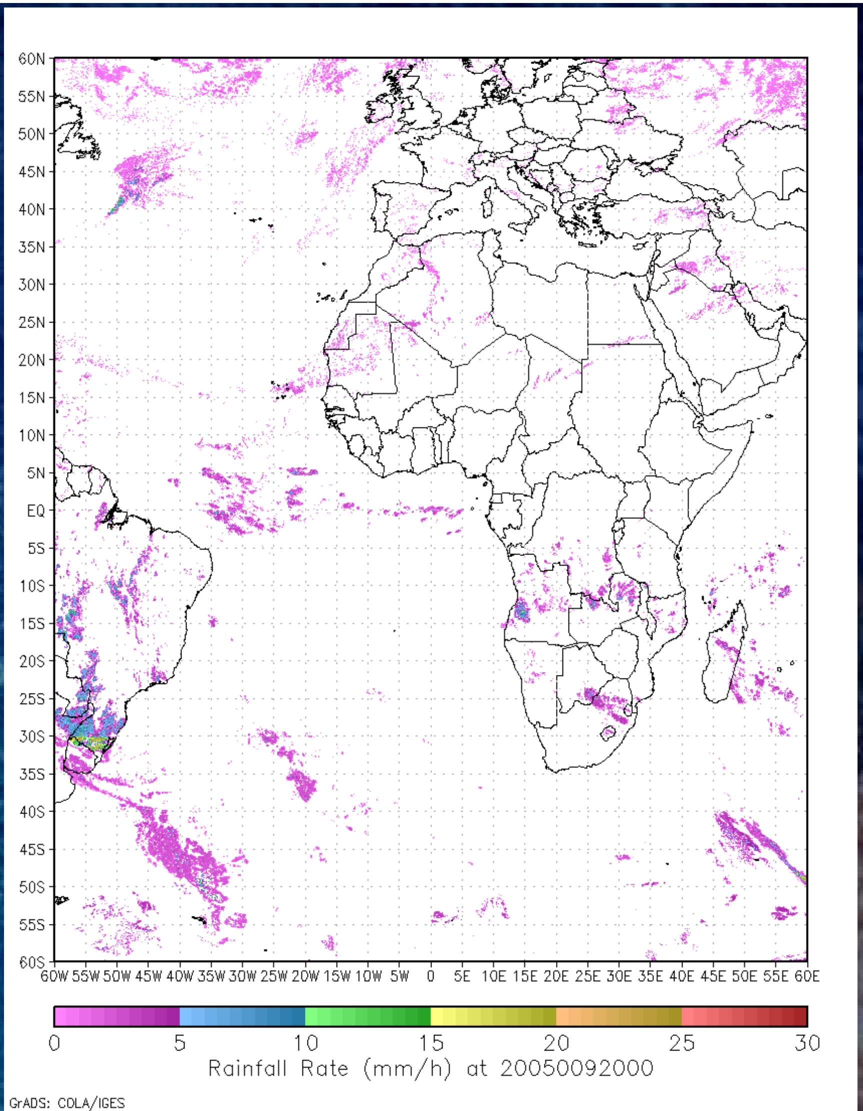
Calibration: Distribution Adjustment

- After calibration, match the CDF of the retrieved rain rates against the CDF of the target MW rain rates
- Use the result to adjust the retrieved rain rates to match the target rain rate distribution.



Example Rainfall Rate Output

- The GOES-R Rainfall Rate algorithm was developed using METEOSAT SEVIRI as a proxy; hence development and validation have been performed over Europe and Africa.
- Example retrieved from SEVIRI data on 9 January 2005.



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Rainfall Rate

- A simplified version of the GOES-R Rainfall Rate algorithm has been running on current GOES since August 2011 to support GOES-R Proving Ground activities and algorithm validation efforts:
  - » Coverage: both GOES-W and -E, covering 165ºE – 15ºW and 60ºS – 70ºN
  - » Temporal resolution: same as routine GOES scan schedule. Composite (W+E) files of instantaneous rates are produced every 15 min, summed into totals for 1, 3, 6 hours on the hour and 1, 3, and 7 days at 12Z daily
  - » Latency: 10 min

Current Version vs. Full Version: Cloud Types

- 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)

Current Version vs. Full Version: GOES Predictors

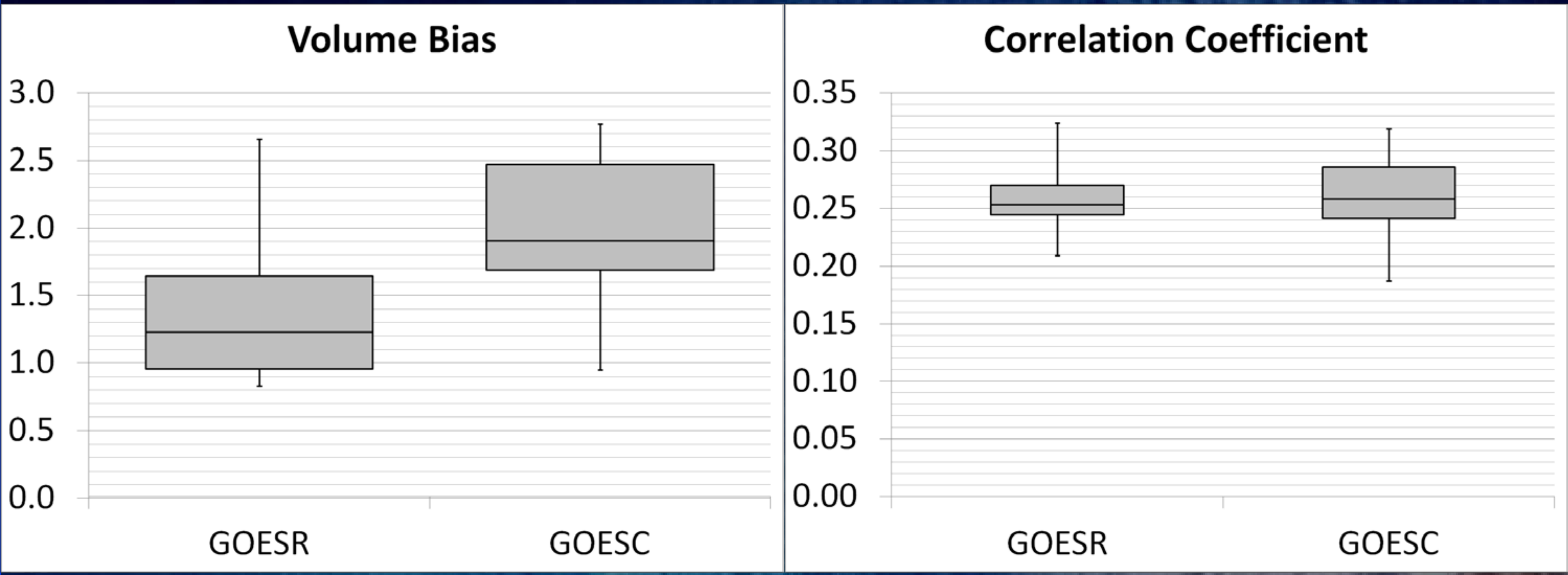
- Use data from ~~5 ABI~~ 2 GOES bands (~~6.19~~, 6.7, ~~7.34, 8.5~~, 11.2, ~~12.3~~ µm) to create a total of ~~8~~4 predictors:

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

  - » (Note that these predictors were selected from a much larger initial set)

Current Version vs. Full Version: Performance

5-9 Jan, Apr, Jul, Oct 2005 vs. TRMM PR over 60ºW – 60ºE

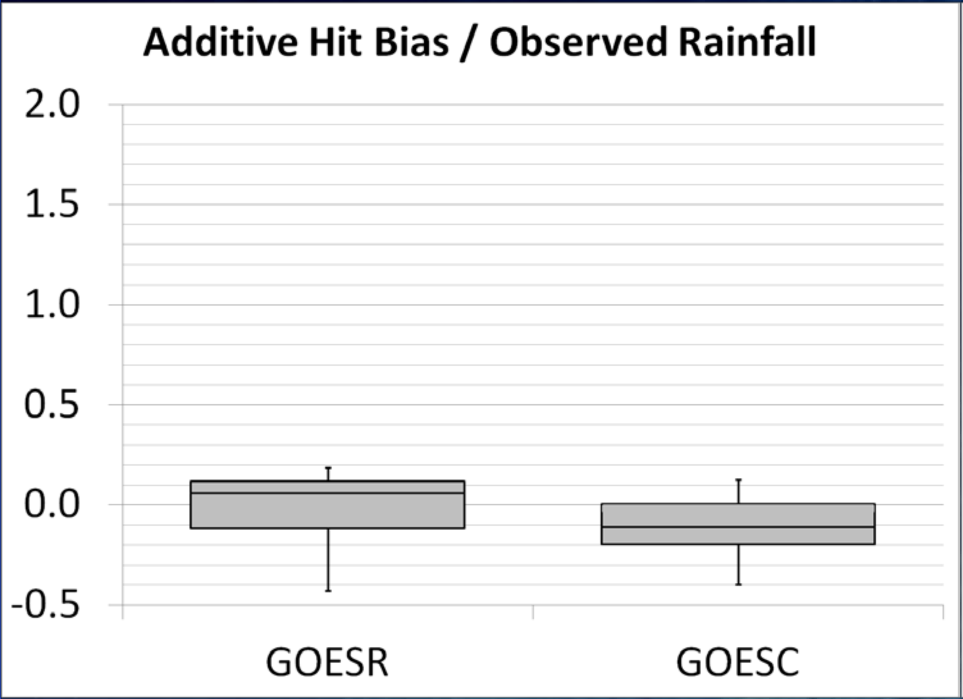


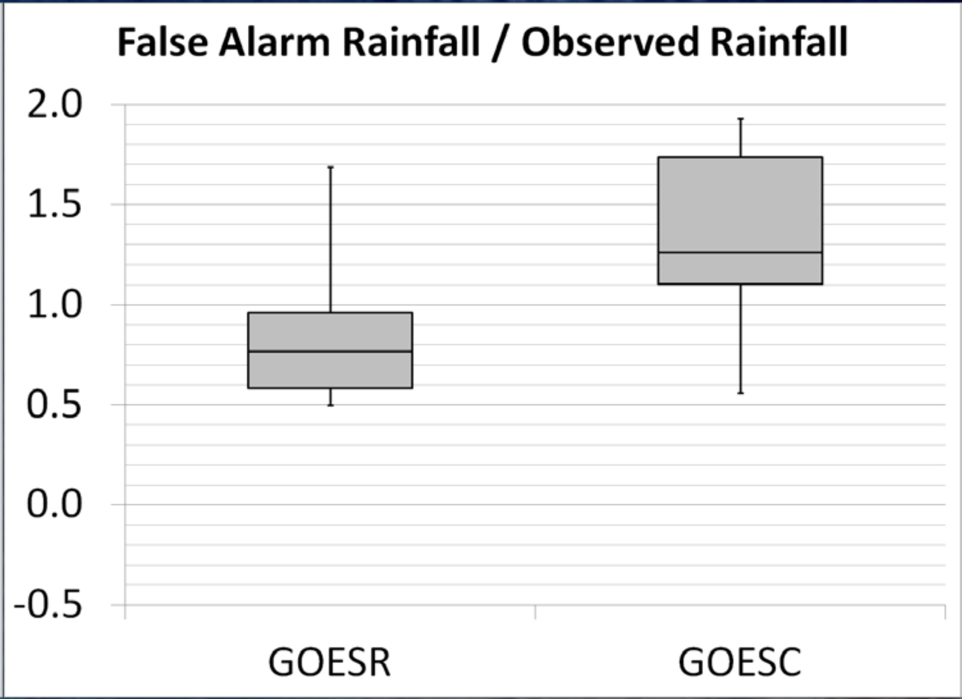
Current-GOES (GOESC) has stronger wet bias than full (GOESR)

Current-GOES (GOESC) has similar correlation to full version

Current Version vs. Full Version: Performance

5-9 Jan, Apr, Jul, Oct 2005 vs. TRMM PR over 60ºW – 60ºE



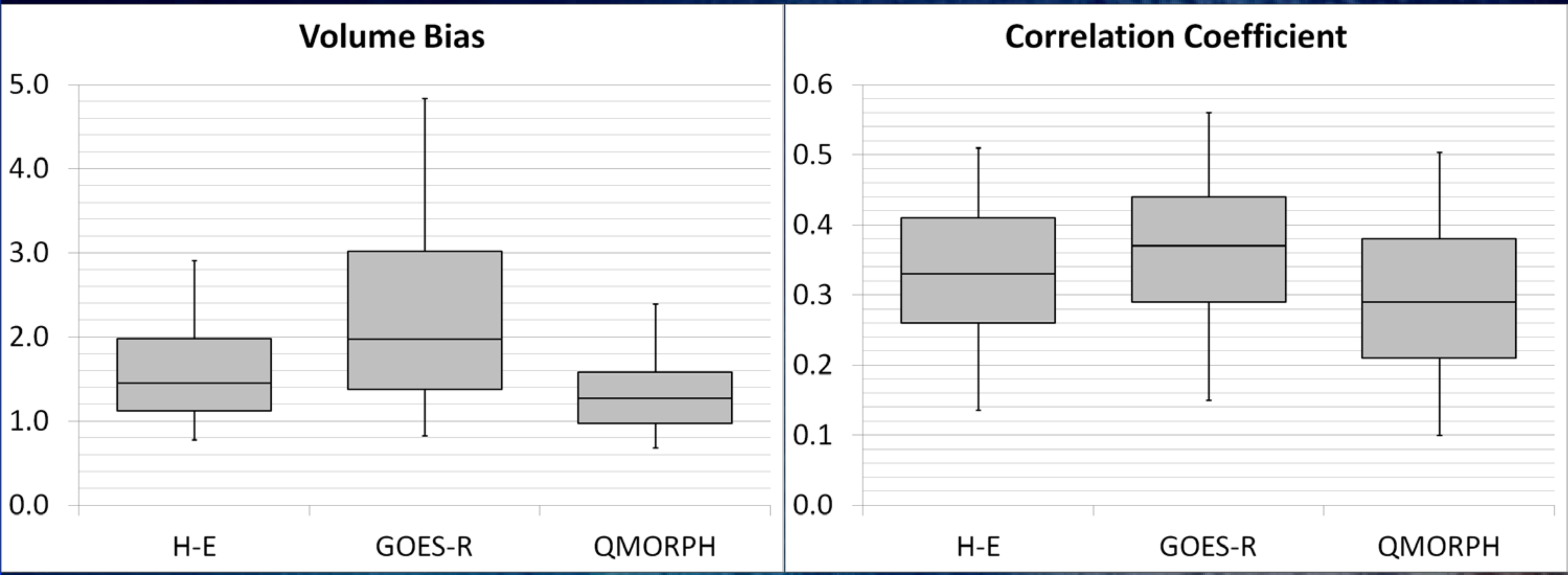


The current-GOES version is actually slightly drier than the full version for "hit" pixels…

…but significantly higher false alarms drive the strong wet bias in the current-GOES version

Current Version vs. Other Algorithms: Performance

15 May – 14 June 2013 vs. Stage IV over CONUS



Stronger wet bias than current operational Hydro-Estimator or CPC QMORPH, but…

…better correlation than either, even with a limited algorithm.

Current Version vs. Other Algorithms: Performance

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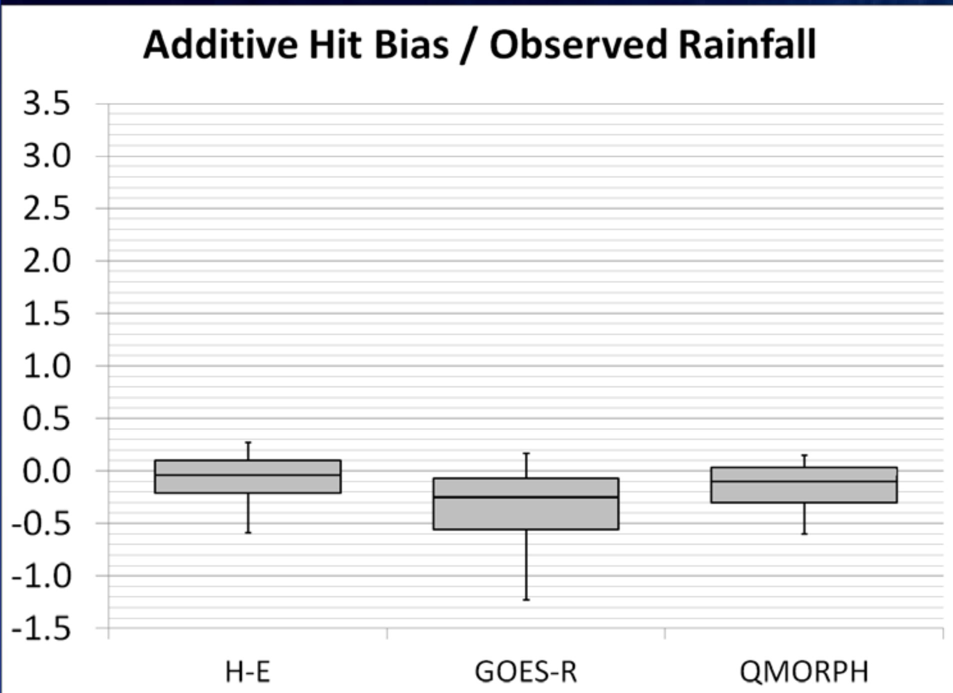
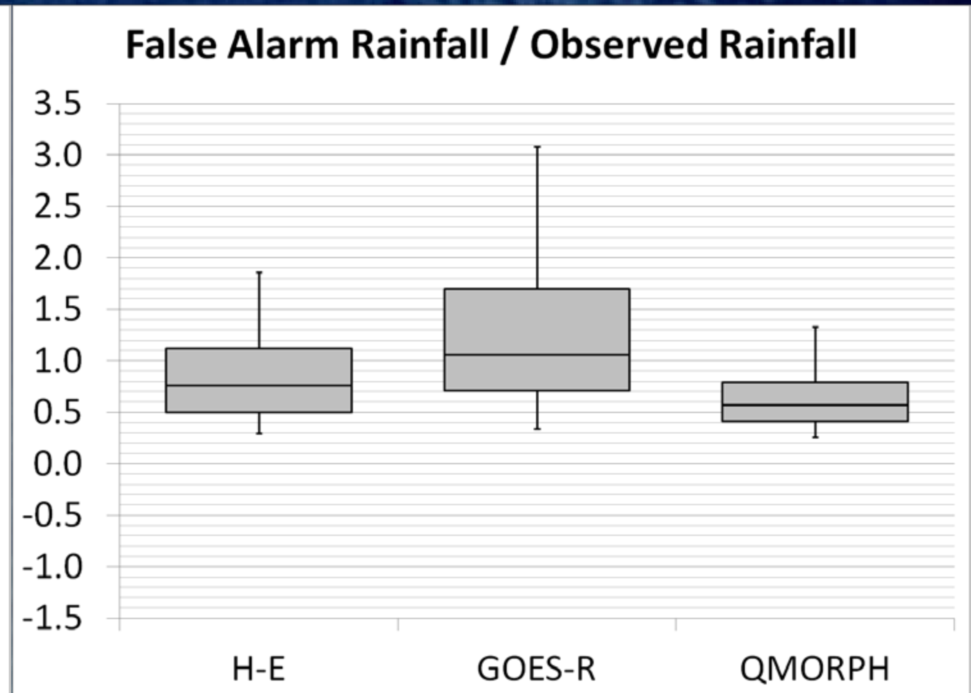
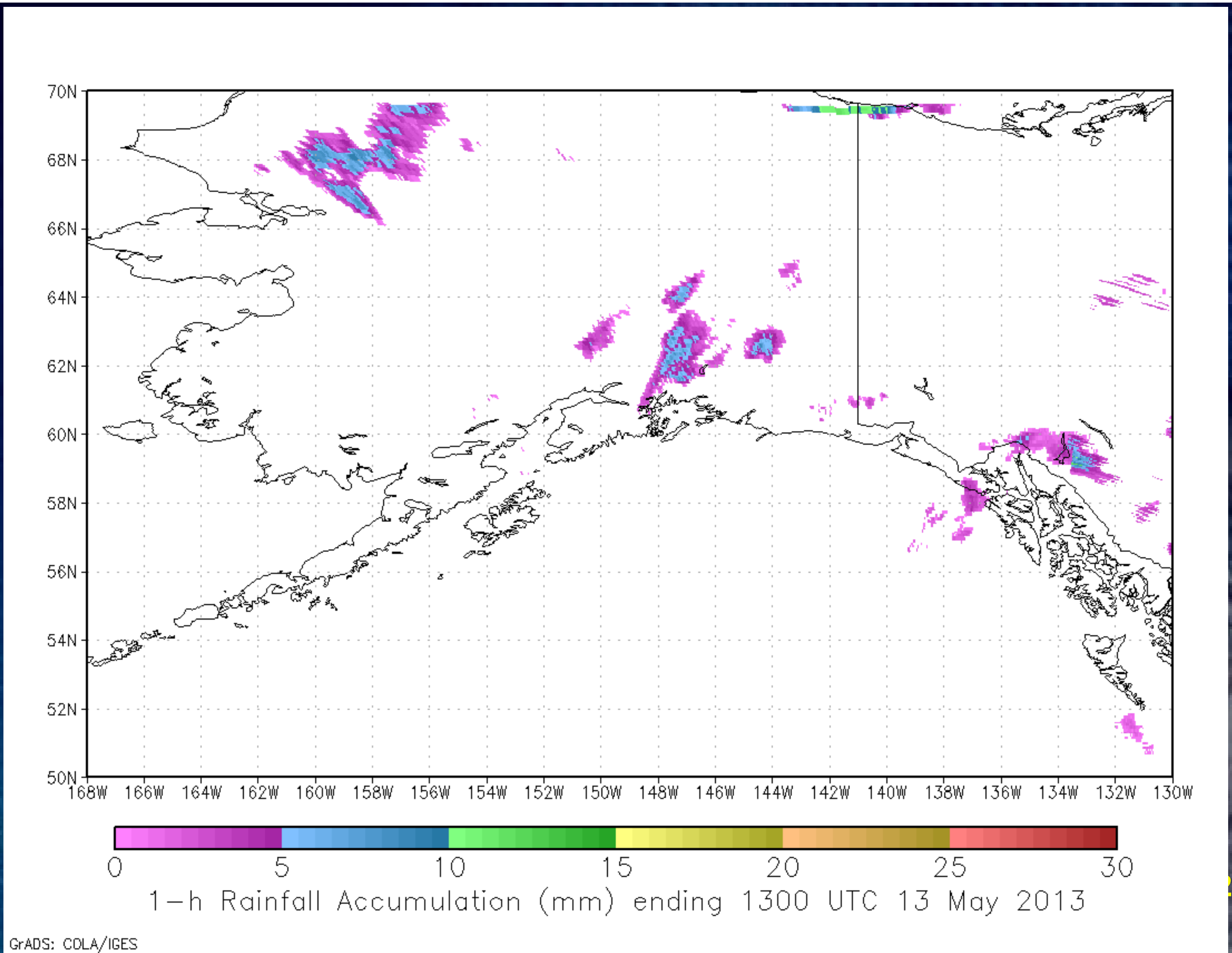




The GOES-R algorithm actually has a stronger dry bias than the H-E for "hit" pixels, but…

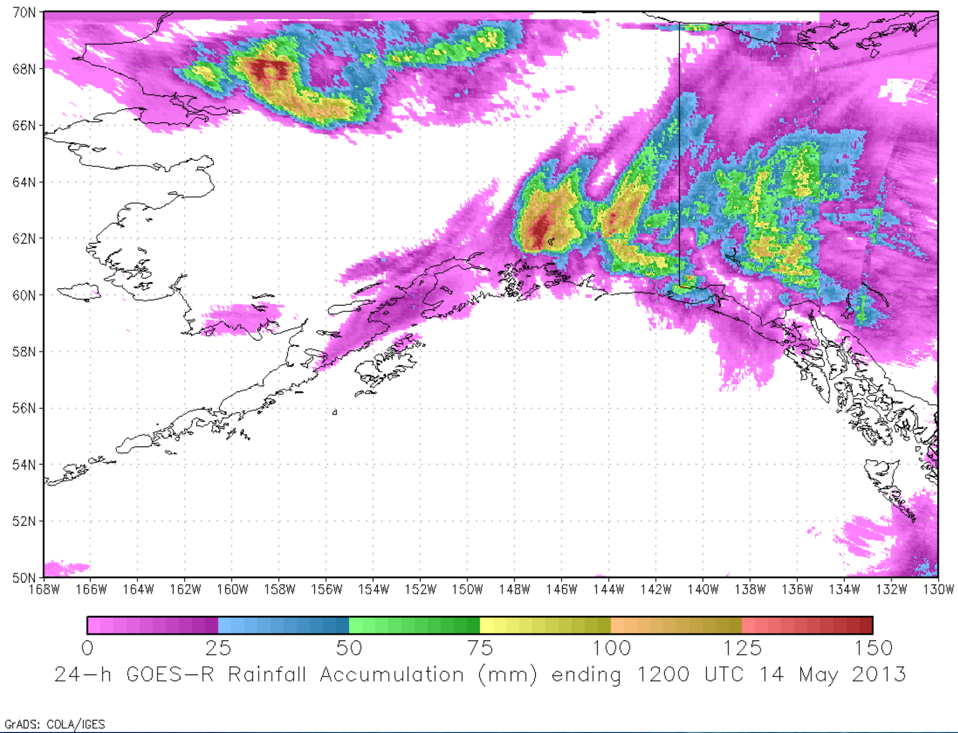
…false alarm rainfall leads to the overall wet bias in the GOES-R rain rates

24-h Loop of 1-h Rainfall Totals 13Z 13 May – 12Z 14 May 2013

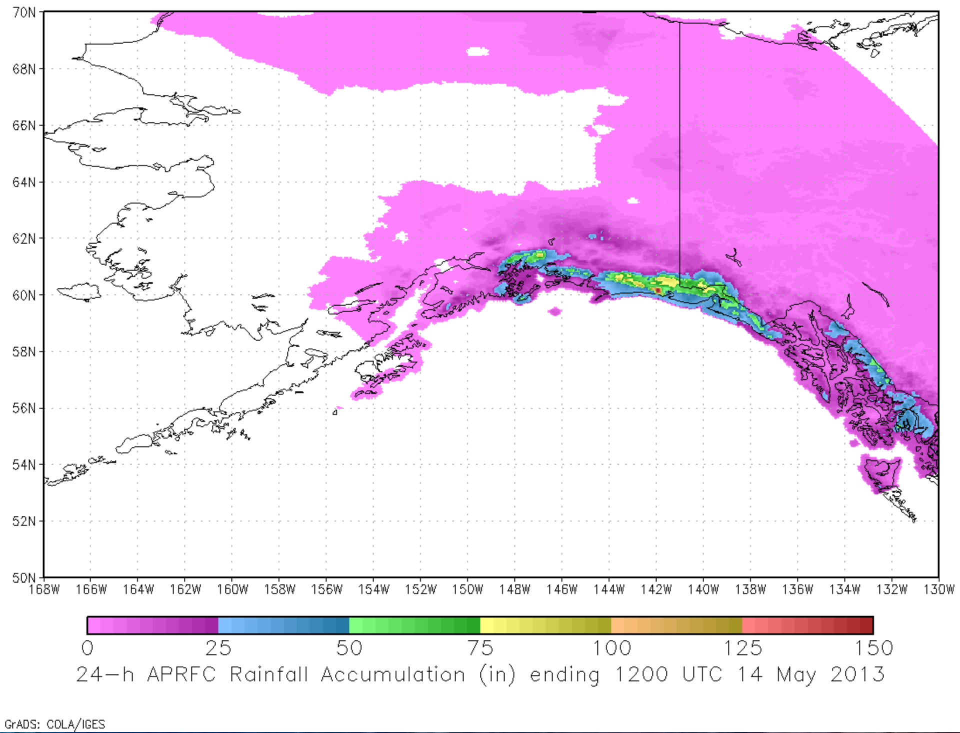


24-h Rainfall Totals 13Z 13 May – 12Z 14 May 2013

Satellite



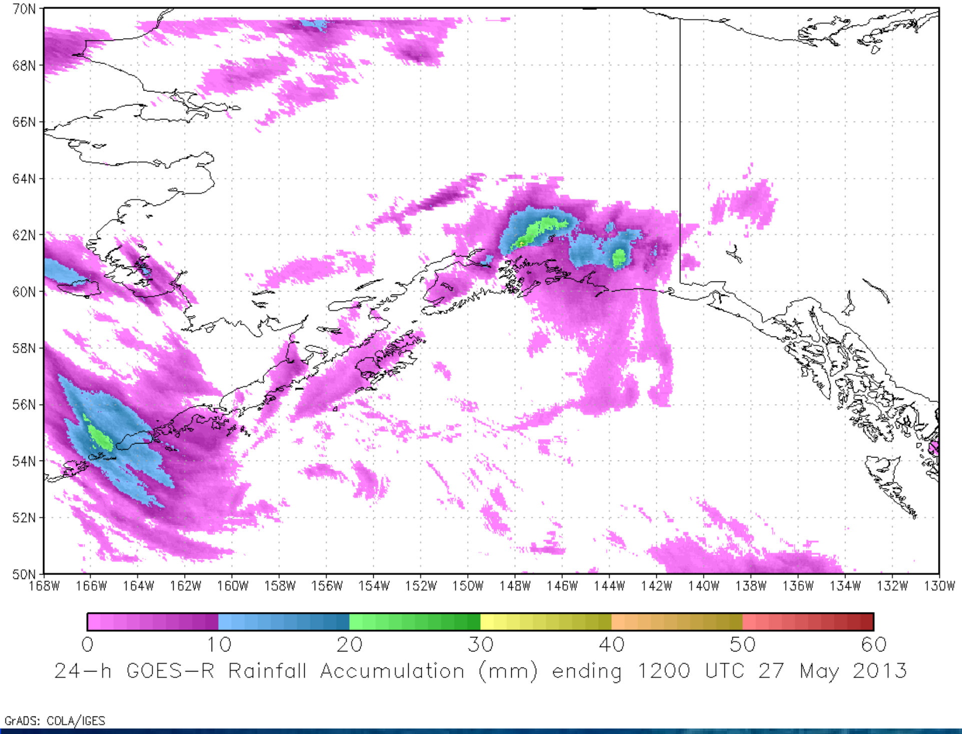
Mountain Mapper



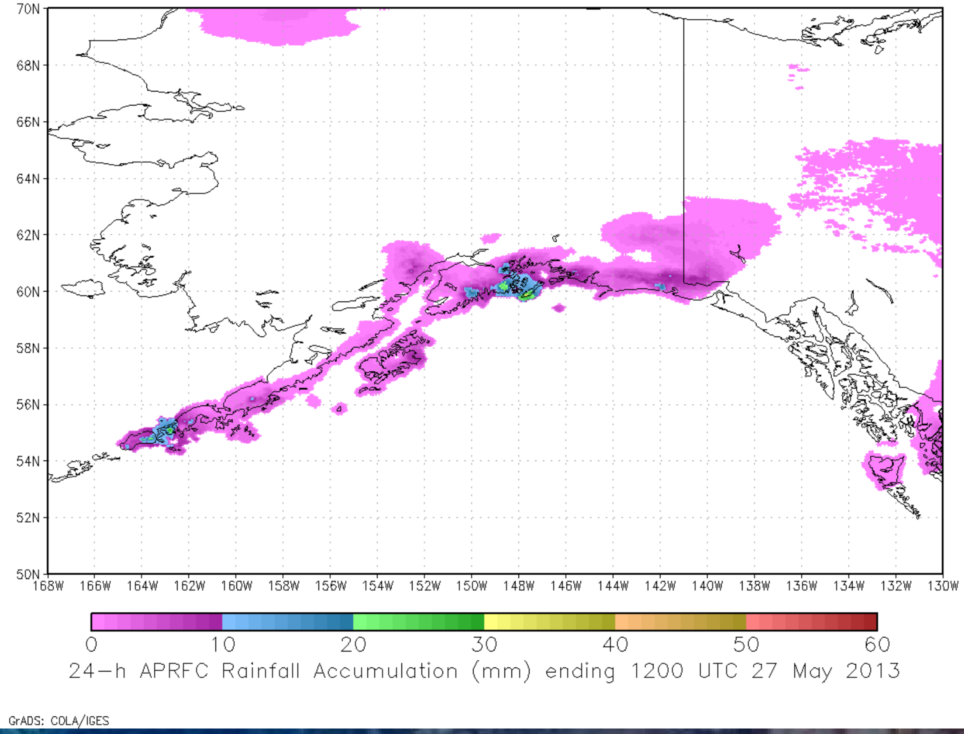
Source: http://aprfc.arh.noaa.gov/data/grib/qpe/

24-h Rainfall Totals 13Z 26 May–12Z 27 May2013

Satellite



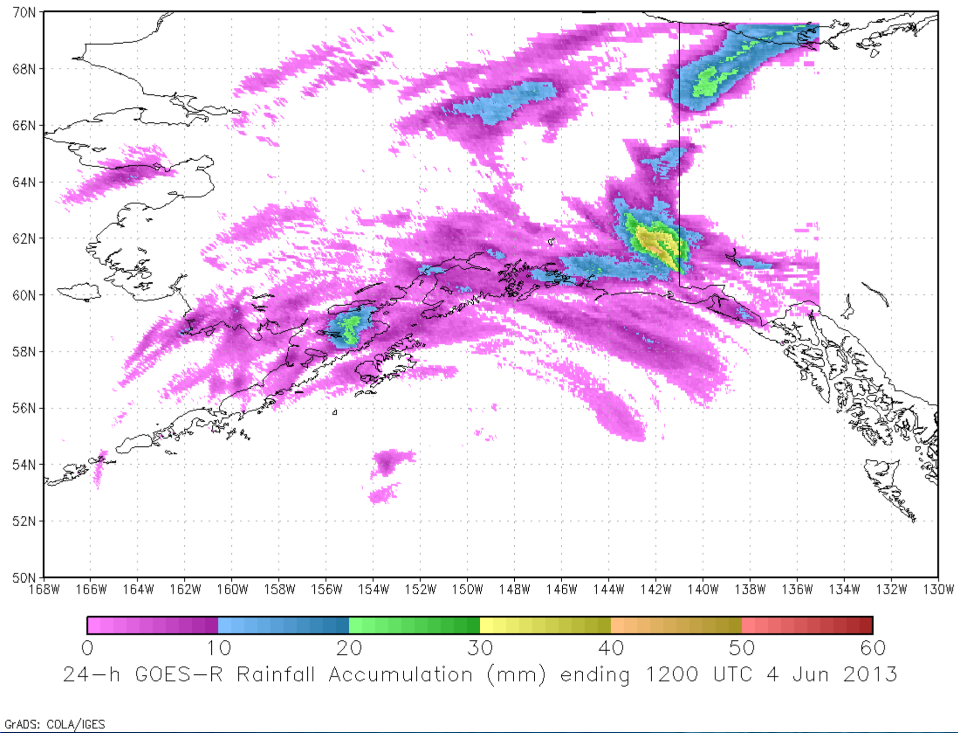
Mountain Mapper



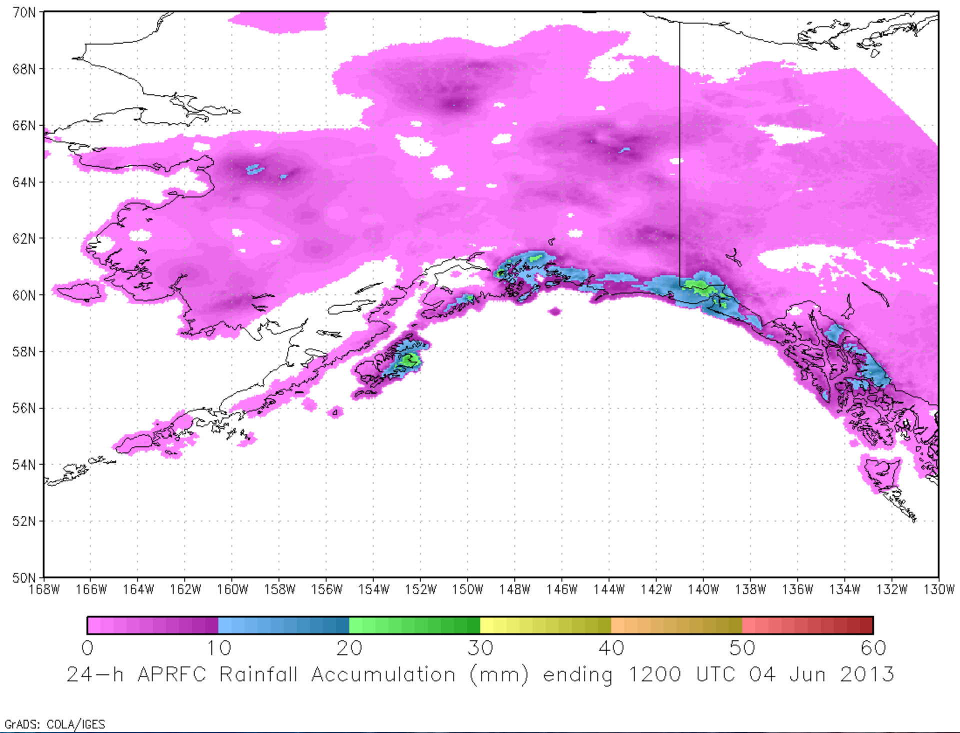
Source: http://aprfc.arh.noaa.gov/data/grib/qpe/

24-h Rainfall Totals 13Z 10 June–12Z 11 June 2013

Satellite



Mountain Mapper



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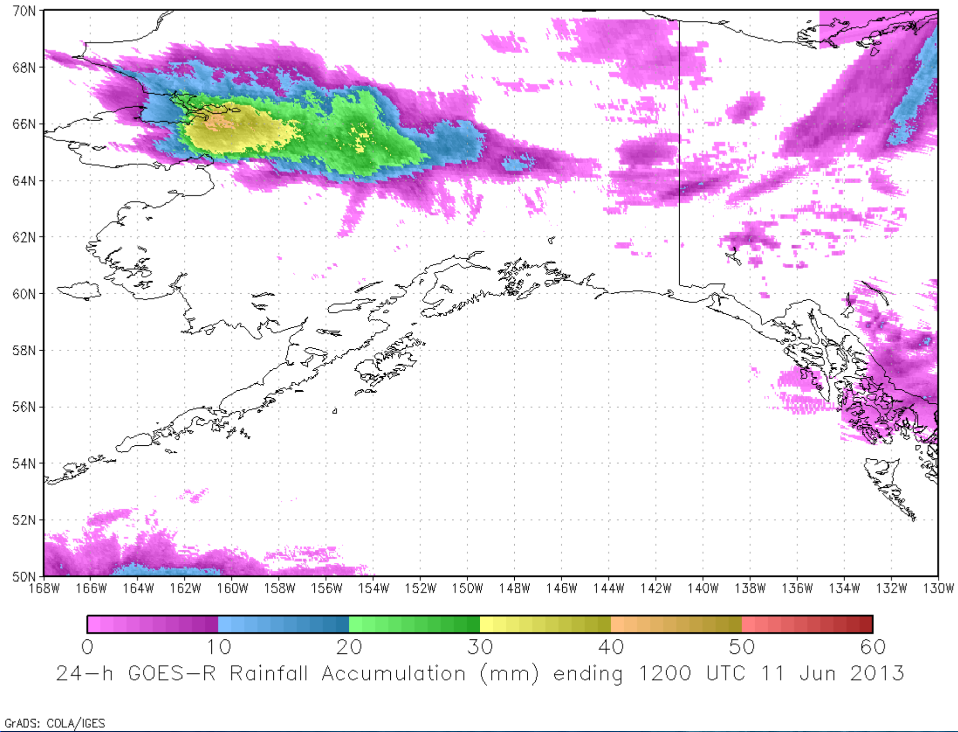
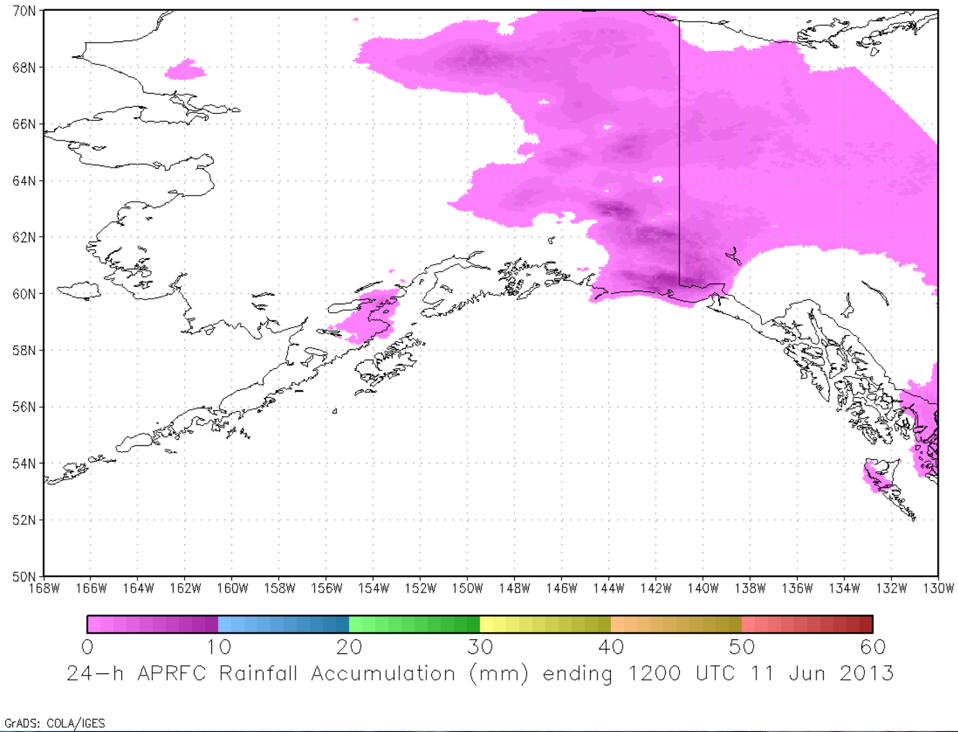
24-h Rainfall Totals 13Z 10 June–12Z 11 June 2013

Satellite



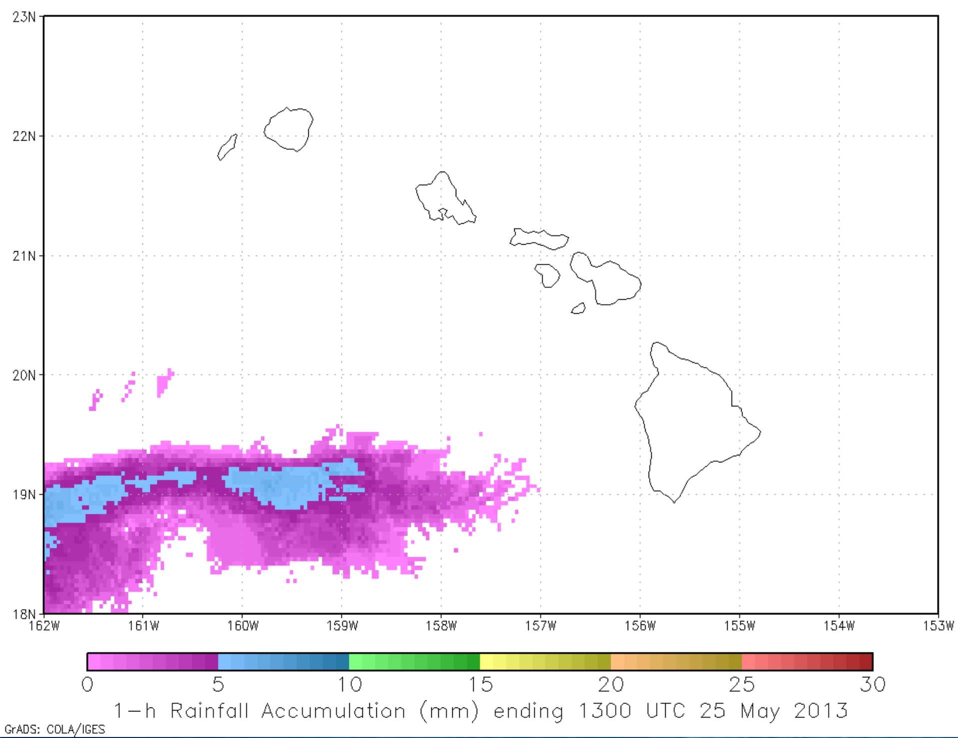
Mountain Mapper



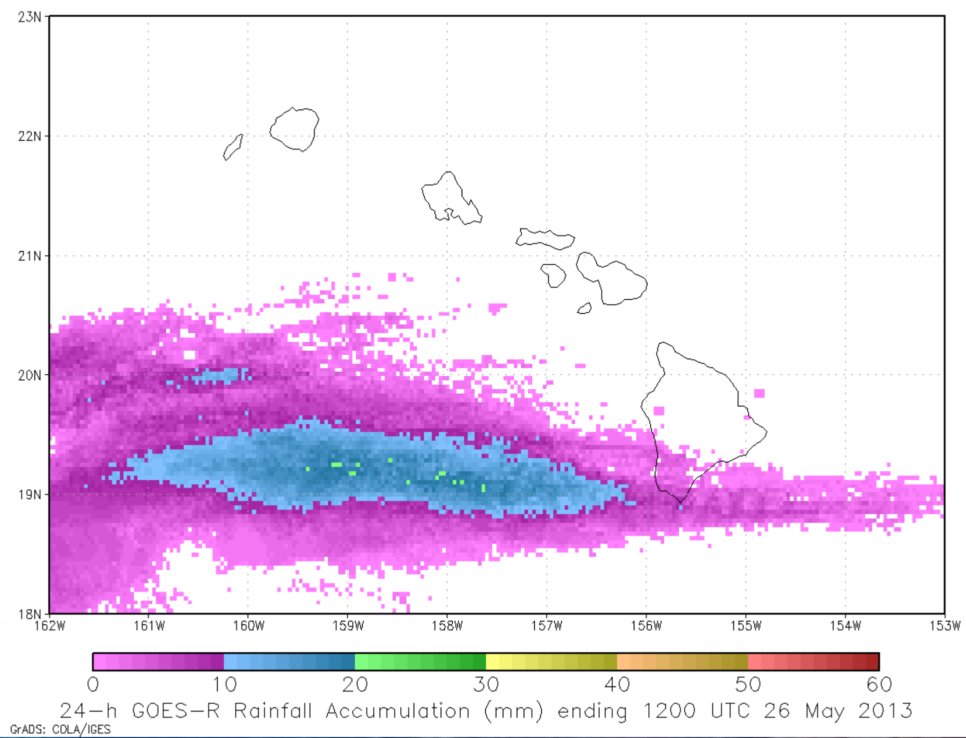
Source: http://aprfc.arh.noaa.gov/data/grib/qpe/

24-h Rainfall 13Z 25 May– 12Z 26 May 2013

1-h Loop



24-h Accumulation



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Rainfall Rate Next Steps

- The Rainfall Rate algorithm was delivered to the GOES-R System Prime contractor in September 2012 and is “frozen” except for bug fixes.
- “Deep-dive” validation of the algorithm is ongoing and has led to improvements.
- Primary focus at this time is to address the false alarms / wet bias—calibration shouldn’t allow it
- Future versions of the algorithm may include
  - A separate calibration for warm (stratiform) clouds based on retrieved cloud properties (optical thickness and ice / water path)
  - Adjustments for orographic effects
  - Adjustments for subcloud evaporation

Questions?