Comparison of TRMM Rain Retrievals in challenging conditions

Daniel J. Cecil

NASA Marshall Space Flight Center

Daniel.J.Cecil@nasa.gov

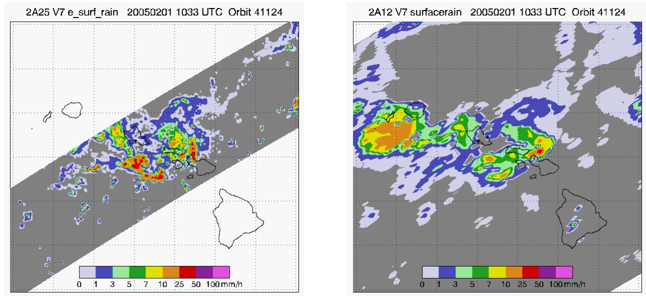
Introduction

This poster uses two very different types of rainfall patterns to examine the performance of TRMM Version 6 and Version 7 precipitation retrieval algorithms. This is particularly aimed at identifying strengths, weaknesses, and hopefully areas that can be improved in TRMM rain retrieval algorithms.

At bottom left, precipitation retrievals from intense mesoscale convective systems are examined. These have deep radar echoes and very low brightness temperatures due to scattering by large ice. Attenuation is a challenge for the radar algorithms, and the Bayesian algorithms are challenged by unusual combinations of brightness temperatures.

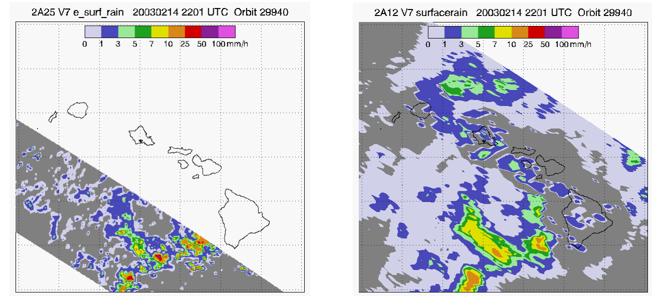
At right, suspicious retrieval values around the Hawaiian islands are examined. Most of the precipitation there is shallow, making it difficult for the passive microwave algorithms to detect much rain over land. The switch from ocean to coast to land algorithms for 2A12 produces artificial gradients in composited precipitation retrievals. The well-defined spatial patterns of rainfall (related to topography) makes it easy to spot some artifacts.

Hawaii Rain Retrieval Examples



Large rain event, strong convection near islands. 01 Feb 2005, 1033 UTC (12:33 AM HST)

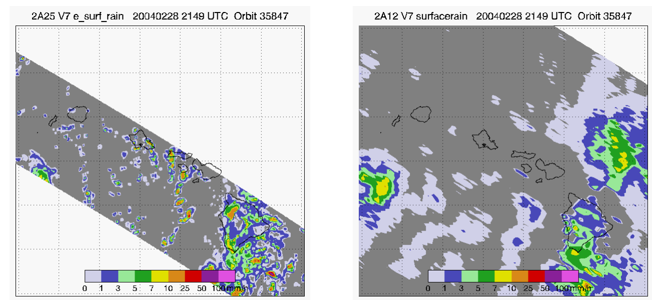
In this event the PR 2A25 and TMI 2A12 show very similar rain patterns. PR resolves higher rain rates on the small scale, while TMI paints moderate rain rates over a broader area. With strong, deep convection producing a robust ice phase, the TMI 2A12 handles the heavy rain near and over Molokai and West Maui better than the composite maps would suggest. This case is from February; deep systems suitable for TMI 2A12 over and near land are less common in August.



Gap in TMI 2A12-detected rain near islands. 14 Feb 2003, 2201 UTC (12:01 PM HST)

In the area where PR 2A25 and TMI 2A12 overlap, TMI 2A12 shows a much broader rain area. That is okay (intended, actually), because 2A12 version 7 includes a rain probability indicator. Much of the light rain area corresponds to a low (but non-zero) probability of rain actually falling.

More importantly, the outline of the 2A12 coast - ocean boundary shows up clearly in this example. For a large area surrounding the islands, 2A12 treats the scene as coast and the corresponding algorithm is unlikely to indicate rain. Land, coast, and ocean are actually three separate algorithms within 2A12.



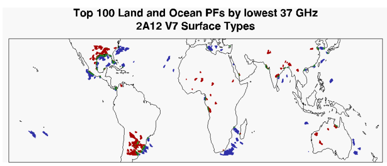
Partial gap in TMI 2A12-detected rain near islands. 28 Feb 2004, 2149 UTC (11:49 AM HST)

The coast-ocean boundary in TMI 2A12 is again evident, but this time TMI 2A12 does a good job representing the rain covering most of Hawaiʻi Island, and the heavier rain offshore near South Point.

Intense Mesoscale Convective Systems

Cases are selected from TRMM Precipitation Feature database, based on having extremely low 37 GHz Polarization Corrected Temperatures

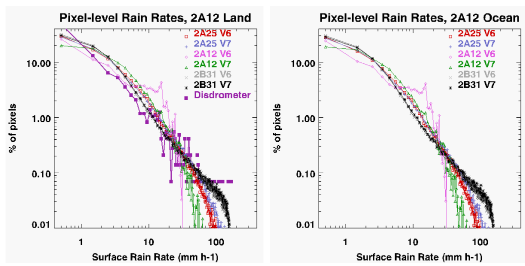
Top 100 cases over land (37 GHz < 135 K) and top 100 cases over ocean (37 GHz < 154 K)



Above: Locations of Intense MCS cases

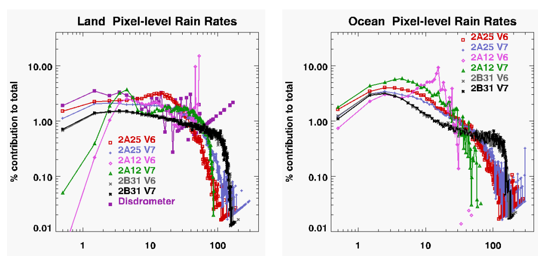
Below: Change (V7-V6) in total rain retrieved for these cases, and departure of the V7 algorithm from a mean of the six values from V6 *and* V7 2A12, 2A25, *and* 2B31.

V7 Product and Surface Type	Change from V6 to V7	Departure from mean
2A12 Ocean	15% less rain	23% less rain
2A12 Land	11% less rain	17% more rain
2A12 Coast	8% more rain	19% more rain
2A25 Ocean	18% more rain	4% more rain
2A25 Land	21% more rain	25% less rain
2A25 Coast	16% more rain	14% less rain
2B31 Ocean	4% more rain	22% more rain
2B31 Land	2% less rain	7% more rain



Above: Probability density function of pixel-level rain rates in intense MCS. Rain-rates from disdrometer measurements on intense convection days in MC3E experiment (Oklahoma) also plotted. TRMM and disdrometer (2DVD) distributions both include convective *and* stratiform rain components.

Below: Similar to above, but summing the contributions to total rainfall (i.e., weighting by rain rate).



Disdrometer rain rates (admittedly small sample) look more consistent with TRMM V7 rain rates than with V6, particularly for 2A12 land. 2A12 V6 had 10-20 mm / h rain rates too frequently, with hardly any rain rates exceeding 30 mm / h.

Want to examine this further, with larger set of disdrometer cases from variety of locations.

Hawaii Rain Retrieval Composites (next page)

1st Row: TRMM Precipitation Radar (PR) algorithm 2A25 Version 6 estimated surface rain. Version 6 composite lacks Aug 2011.

2nd Row: TRMM Precipitation Radar (PR) algorithm 2A25 Version 7 estimated surface rain.

The PR rainfall patterns match expectations well. Rain maxima generally located along and upwind of the eastern and northeastern coasts. The August maximum along the western coast of Hawaiʻi is also revealed. Prominent rain shadow during August, much less so during February. V6 and V7 very similar to each other. The most questionable feature is a strong local rain maximum along the south slope of Haleakala (Maui) in August, with greater magnitude in V7 than V6. Possibly a sampling artifact, or groundclutter? Or real???

3rd Row: TRMM Microwave Imager (TMI) algorithm 2A12 Version 6 surface rain. Version 6 composite lacks Aug 2011.

4th Row: TRMM Microwave Imager (TMI) algorithm 2A12 Version 7 surface rain.

Enormous rain amounts in the wrong place, on the Mauna Loa and Mauna Lea mountaintops and slopes (see bottom row). True rainfall maxima along and near coasts are missing. Rain enhancement over ocean about 100-300 km WSW of Hawaiʻi Island is captured. Rain greatly reduced where the algorithm designates the surface type as coast or mixed (marked by purple contour, including all major islands except the interior of Hawaiʻi Island. Coasts extend slightly further out from islands in V7. Anomalous rain on mountain tops reduced by accounting for "land ambiguous flag" in V7.

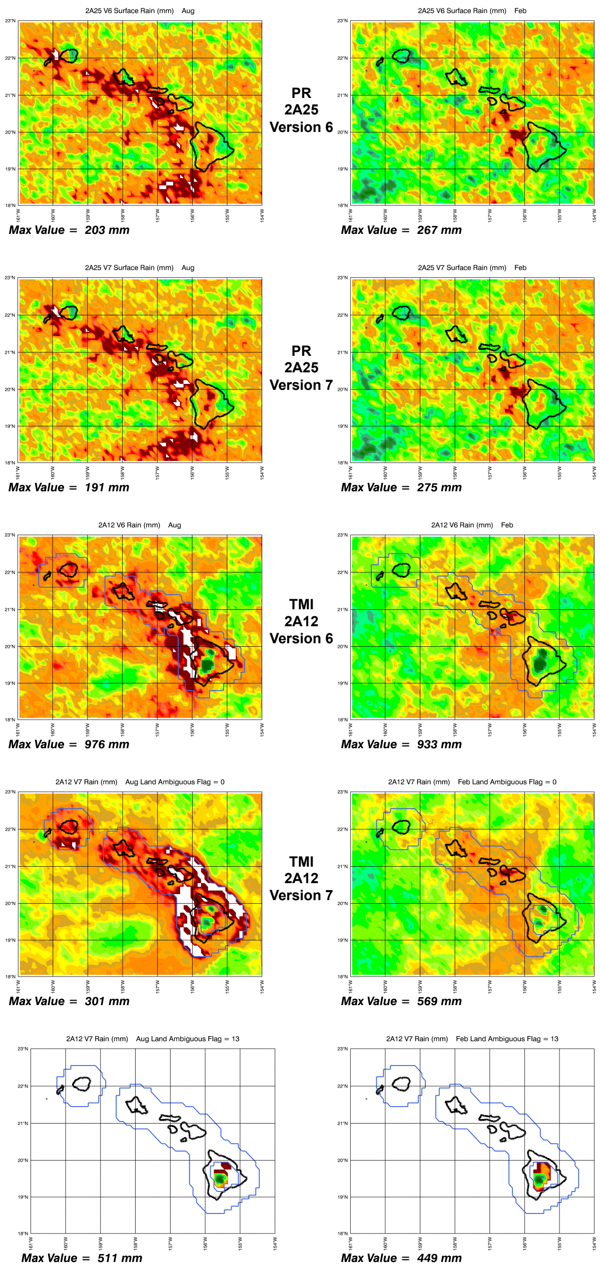
5th Row: TMI 2A12 Version 7 surface rain screened out by land ambiguous flag setting = 13. These are generally light instantaneous rain rates mostly around 2 mm h^{-1}, but they are assigned commonly overnight. Similar amounts for August compared to February suggest it is not a problem with the snow screen.

AUGUST 1998-2011

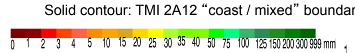
Expectations: dominated by trade winds; rain on the east and northeast sides of most islands, also along the west (Kona) coast of Hawaiʻi Island; prominent rain shadow to the west of the island chain

FEBRUARY 1998-2011

Expectations: similar areas of precipitation enhancement, but more rain everywhere from transient synoptic systems.



Solid contour: TMI 2A12 “coast / mixed” boundary



What the heck is going on with all that “rain” on Mauna Loa and Mauna Kea?

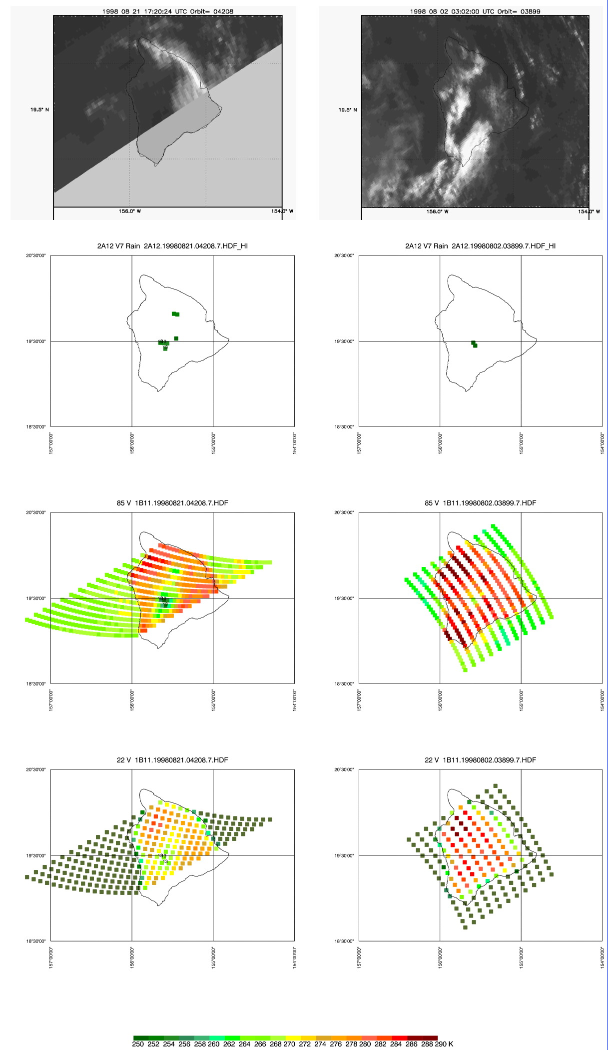
If these “rain” pixels are false alarms unrelated to rain and cloud, it should be easy to find visible imagery showing a clear sky instead of rain. But the cases where “land ambiguous” flags are set on these mountains almost always occur overnight. The 1998 08 21 17:20:24 UTC example (right) is a rare exception, just after sunrise. (Hawaiian Standard Time is about 10 hours behind UTC.) A few pixels are marked with the 2A12 land ambiguous flag value 13 (meaning ambiguous 21 V, with different scattering screens).

Pixels with unflagged “rain” tend to be more in the evening or morning. The 1998 08 02 03:02:00 UTC (around 5 pm HST) example at far right has a couple TMI pixels with 2A12 indicating rain at the Mauna Loa summit, where the VIRS visible channel shows a clear sky.

Over land, TMI 2A12 uses 19 and 21 GHz to predict 85 GHz brightness temperature, then computes a scattering index based on the departure of the observed 85 GHz from the predicted value (Wang et al. 2009 JMSJ). A colder observed 85 GHz generally suggests rain, with the upwelling radiation scattered by precipitation ice.

Alternatively, a cold mountain surface (in the absence of rain) would also have a low brightness temperature. Besides weak emission from the cold surface, there is a lack of column water vapor above the elevated surface. This contributes to substantially lower brightness temperature than the lower elevation surroundings.

The 21 GHz channel on TRMM has a footprint over 200 km^2, more than six times as large as the 85 GHz footprint. An 85 GHz footprint better resolves the radiometrically cold mountain, while the corresponding 21 GHz footprint includes a mix of radiometrically warm and cold scenes. The radiometrically cold mountain is easily confused for a rain signal.



The land ambiguous flag is correctly set more often for Mauna Loa than Mauna Kea, and almost always overnight instead of during the daytime. Perhaps this is because the nighttime cooling and the large horizontal extent of Mauna Loa make it more likely for the 21 GHz brightness temperature to decrease low enough to trigger this flag. This is seen by comparing the early morning versus late afternoon examples at right. Perhaps the greater emissivity of Mauna Loaʼs slopes (with more recent / more extensive lava flows) also factors in.

If a radiometrically cold mountain is the cause for these false rain detections, why doesnʼt the same thing cause big, noticeable problems for 2A12 elsewhere? Perhaps it does. But Mauna Loa and Mauna Kea are unusual in that they rise to ~4 km elevation, sloping down to sea level within tens of km horizontally. That promotes a large difference of emissions from the surface and overlying atmosphere over a short horizontal distance. The background scene for a ~200 km^2 21 GHz footprint is likely warmer here than around most other tall mountains.

Main issues for TRMM rain retrievals around Hawaii:

(This focuses on the negatives, in hopes of either spurring improvements in subsequent versions of the algorithms, or at least for the sake of knowing which rain estimates to take seriously and which to disregard.)

TMI 2A12 fails to detect most rain over the islands. Shallow rain clouds difficult for TMI to detect over land. Land algorithm relies on scattering by ice-phase precipitation particles, since the background emissivity is high.

TMI 2A12 estimates too much rain on the wrong parts of the Big Island. Hawaiʻi (Big Island) summits and slopes of Mauna Loa and Mauna Kea have anomalously high rain estimates from TMI, due to a mis-identification of land characteristics as precipitation. These areas are often flagged as ambiguous, but the flagged pixels are often accompanied by false rain detections nearby. They appear to be due to the TMI scattering algorithm mis-interpreting the cold 85 GHz brightness temperatures from the mountains (in the abscence of rain) for scattering by ice. The 21 GHz channel is used to characterize the background scene for the 85 GHz to compare against, but the 21 GHz footprint is much larger and might be washing out the signal of the colder, elevated surface.

TMI 2A12 fails to detect most rain *near* the islands. TMI 2A12 algorithm designates a buffer zone around the islands (wholly including the smaller islands) as a mix or coast, instead of being treated as land or ocean. These coast pixels are treated with a scattering-based algorithm suitable for typical land backgrounds, but with rain rates scaled down as an adjustment toward typical ocean values. This is a double whammy near Hawaii, since the rain is often shallow and difficult to detect with scattering-based algorithms.

TMI 2A12 and PR 2A25 both capture the rain shadow in the lee of the islands, and the subsequent rain enhancement ~100 - 300 km WSW of Hawaiʻi Island.

PR 2A25 limited by groundclutter in areas of sharp topography. Much of the rain is associated with orographic effects. PRʼs ~5 km footprint can cover large range of surface elevations. *But generally, PR depicts the expected rain patterns quite well.*

Acknowledgements:

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