TRMM PR Version 7 Algorithm

(1) Issues in V6 and needs for V7
(2) Changes in V7
(3) Results
(4) Future Issues

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Issues in V6

• Possible underestimation of rainfall rates (especially over land)
  – Underestimation likely from comparisons with TMI, AMeDAS, and Ground-based radar

• Dependence of the rain estimates (vertical profiles, rainfall rates, rain accumulations, etc.) on the incidence angle
  – Possible causes of the dependence
    • Dependence of the observable altitude on the incidence angle
    • Dependence of 2A21 PIA estimates on the incidence angle
    • Incomplete correction of the effects of beam mismatch after the altitude change
**Monthly rain over ocean (mm/month)**

**Version 6 1998-2005**

(John Stout)

<table>
<thead>
<tr>
<th></th>
<th>2A25</th>
<th>2A12</th>
<th>2B31</th>
<th>(\frac{(2A12-2A25)}{2A25}) (%)</th>
<th>(\frac{(2B31-2A25)}{2A25}) (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 35°</td>
<td>76.5</td>
<td>81.0</td>
<td>84.4</td>
<td>5.9</td>
<td>10.3</td>
</tr>
<tr>
<td>± 20°</td>
<td>90.8</td>
<td>96.4</td>
<td>102.6</td>
<td>6.2</td>
<td>13.0</td>
</tr>
<tr>
<td>± 10°</td>
<td>114.6</td>
<td>124.1</td>
<td>129.2</td>
<td>8.3</td>
<td>12.7</td>
</tr>
</tbody>
</table>

2A25: Estimated Surface, not Near Surface  
2A12: Narrow Swath  
2B31: Near Surface  

AWM (Area Weighted Mean) = \(\sum_{\text{lat}} \frac{\text{Zonal Average (lat)} \times \cos (\text{lat})}{\sum_{\text{lat}} \cos (\text{lat})}\)
Major changes in Level 1

- **L1A**: Calibration coefficients on the B-side
- **L1B**: Improvement in the surface-clutter detection method
  - Extension of the area where SRTM30 data is used
  - Raising the clutterFreeBottom by 250 m due to the change in the threshold for the surface clutter
  - Introduction of a new category “inland water” in landOceanFlag
  - Change in binEllipsoid due to the change in geolocation tool kit
- **L1C**: No change
Major changes in 2A21

• Introduction of 5 types of PIA (Path-Integrated Attenuation to surface)
  – Temporal reference: increased spatial resolution
    • introduction of the reference data base with 0.1 deg. grid
  – Spatial reference: introduction of Backward reference
    • along-track: forward + backward
    • hybrid (only over ocean): forward + backward

• Reference curve is determined piecewise in the hybrid method
  – separated at incidence angle of 11 degrees
  – substantial decrease in the dependence of PIA on the incidence angle

• Introduction of the concept of distance from the reference point in the spatial reference method

• Introduction of effective PIA (PIA$_{eff}$) and its error estimate
Major changes in 2A23

- Small rain cells are classified as convective (effect is small).
- About 40% of non-isolated shallow rain cells are classified as convective (effect is large).
  - The percentage of convective rain increases by 7%.
- Rain is basically classified as stratiform if a bright-band is detected. An exception is introduced: If $Z$ is very large, rain is classified as convective even if a bright-band is detected. (This case happens very rarely.)
- If the storm top height is higher than 15 km, the rain is classified as convective. (The number is small, but some effects appear 3A25 statistics.)
- New sub-categories are introduced in rain type classification.
- The method for bright-band detection is improved.
  - GANAL is used to estimate 0 deg. C height.
    - 0 deg. C height increased by about 1 km from V6 method.
  - Introduction of a 2-dimensional spatial filter (reducing misjudgment)
Angle bin dependence of each rain-type count and that of BB count

Thin: V6
Thick: V7 OAT
Major Changes in 2A25

• Expected value to maximum likelihood value in estimating $\alpha$
• Adding 0.5 dB to PIA estimates over land from 2A21 to compensate the wetting effect
• Changed the assumed vertical profile of specific attenuation $k$
  ($\alpha$ in $k = \alpha Z_e^\beta$) (Changed the vertical profile of the mixing ratio of water to ice)
• Introduction of a new DSD model (Z-R relation)
• Changed the uncertainty of $\zeta$ ($\alpha$ and $Z_m$) in the Hitschfeld-Bordan attenuation correction method
• Introduction of NUBF correction
• Correcting the smearing of BB in off-nadir beams
From expected value to ML estimate

- Adjustment parameter $\varepsilon$ that adjusts $\alpha$ is selected in such a way that the PIA estimate by the H-B method matches with the PIA estimate by the SRT.
  - Errors in both $\text{PIA}_{\text{SRT}}$ and $\text{PIA}_{\text{HB}}$ are taken into account
  - Derive Likelihood function $L(\varepsilon)$ of $\varepsilon$
  - Estimate $\varepsilon$ by Maximum likelihood method
- Expected value of $\varepsilon$ depends on the entire distribution of PDF $P(\varepsilon)$
  - Tails of $P(\varepsilon)$ are not reliable
    - Tails change with the assumed distribution of $\alpha$
- ML estimates are immune to the tails of likelihood $L(\varepsilon)$
New vertical profile of specific attenuation $k$

- $\alpha$ in $k = \alpha Z_e^\beta$ changes substantially with the proportions of water and ice in precipitation particles.
  - PIA estimate by the H-B method depends on $\alpha$.
  - A change in $\text{PIA}_{HB}$ changes $\varepsilon$ when SRT is used.
  - A change in $\varepsilon$ changes the $Z_e-R$ relation, and hence $R$.

- The ratio of water is reduced above 0 degree C in convective rain.
  - 100% ice above -20 degrees C height

- Compared with V6, $\zeta$ and hence $\text{PIA}_{HB}$ decreased, and $\varepsilon$ increased.

- $R$ estimates decreased in light rain, but increased in heavy rain.

- The increase in $R$ in heavy rain is larger as the storm height increases.
**k profiles for Ze=40 dBZ**

0 degree C height is assumed at 5 km.

The lapse rate is assumed to be -6 degrees/km.

The assumed profile has been changed to the red line since ITE232. It was the solid line before the change (100% ice above the -15 degree level.)
New DSD model (Z-R relation)

• Z decreases by 0.5 dB in the new stratiform Z-R relation
  – R increases by about 8%

• New Z-R and k-Z relations based on a non-spherical rain drop model.
  – R decreases for heavy rain

• Two effects cancel each other in stratiform rain.
• R estimates slightly decrease in convective rain.
Re-evaluation of errors in $\zeta$ ($\alpha$ and $Z_m$) and PIA estimates by SRT

- Error in initial $\alpha$ is decreased
- Error in $Z_m$ is taken into account
- $\zeta$ depends on $\alpha$ and $Z_m$
- Assign the total error in $\zeta$ to $\alpha$ and $Z_m$
  - Reduced the adjustment of the DSD parameter that modifies the $R$-$Ze$ relation by $\text{PIA}_{\text{SRT}}$ slightly.
  - $R$ increases in regions where $\varepsilon$ is less than 1
Correction for NUBF effect

• Revival of the non-uniform beam filling correction
  – Corrected the error in NUBF correction formula in V5
  – Assume a Gamma distribution of $k$ in a horizontal plane
  – Assume vertical profiles are similar within a footprint
  – Deviation from similarity is regarded as a decrease in inhomogeneity
  – Use the coefficient of variation (CV) of PIA in 9 pixels on and around the IFOV
    • CV within the IFOV is estimated from the CV of the 9 pixels
    • Conversion factor tentatively used is half of the value derived for 2-dimensional case.

• → Rain estimates for (heavy) rain will increase
Correction of the smearing effect for a bright band at off-nadir

- At off-nadir observation, the apparent BB widens.
- The $k-Z_e$ and $Z_e-R$ relations used in the past versions do not take this effect into account.
- Effect of smearing is calculated for a standard case.
  - Effective $k-Z_e$ and $Z_e-R$ relations are calculated for each angle bin.
- The correction is not ideal yet.
- No smearing correction is applied unless a BB exists.
Major changes in Level 3

• 3A25
  – Known bugs were fixed
  – Introduction of new statistics
    • Mean and standard deviation of zeta
    • Regression coefficients between PIA and zeta

• 3A26
  – Known bugs were fixed
Summary of changes and their effects
(Only those that affect the rainfall estimates)

- Introduction of NUBF correction: increase in heavy rain
- Addition of 0.5 dB to PIA: increase in heavy rain over land
- 100% solid ice above -20 degree C: increase for high profile rain, but decrease in light rain
- Use of GANAL for 0 deg. C and change in the vertical model: (effect not clear)
- Introduction of non-spherical rain drop model: decrease
- New Ze-R relation for stratiform rain: increase
- Increase of convective rain cells: increase
- Change from expected value to ML estimate: increase in heavy rain

Note: Increase or decrease of the estimates depends on the structure of rain and other parameters, and cannot be judged in all cases.
Results of improvement

• Overall PR rain estimates have increased.
  Rain estimates
  – Increased over land, but remained about the same over ocean
  – Increased in high profile rain
    • especially over African continent
• Consistency with TMI and ground-base radar improved.
  – No change in AMeDAS comparisons
• Unnatural angle dependence over ocean disappeared.
• The reliability of the rain estimates is considered to be increased.
  – Improvement in rain model (drop shape model, 0 degree C height)
  – Improvement in the SRT: bias in PIA estimate decreased.
• A small number of new minor issues happened.
  – Misjudgment of clutter and rain
  – Handling the case in which rain echo disappears due to very large attenuation in heavy rain
Summary and issues

• The overall change in rain estimates is affected by the changes in 2A21 and 2A23 as well.
  – PIA estimates, classification, freezing height
• Rain estimates over ocean increases.
• Rain estimates over land is about the same as V6.
• Rain with a high storm height increased
• Adjustment of NUBF parameter and a bias in PIA by SRT over ocean may be necessary.
• Smearing correction routine needs to be improved.
Future Issues (preparations for V8)

• Detailed evaluation of V7
• Improvement in the correction of beam mismatch effect after the orbit change
  – A cause of underestimation in the latter half of the scan
  – We did not implement this correction in V7
• Remove exceptional errors that happen in extreme phenomena
• Improvement of the NUBF correction
• Improvement in smearing correction algorithm
• Improvement in the vertical profile model in surface clutter
• Improvement in the solid particle models and their vertical profile model
• Examination of the possibility to introduce the initial DSD models that depend on the region and rain system.