TRMM PR Version 7 Algorithm

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

PR Algorithm Team & JAXA/EORC

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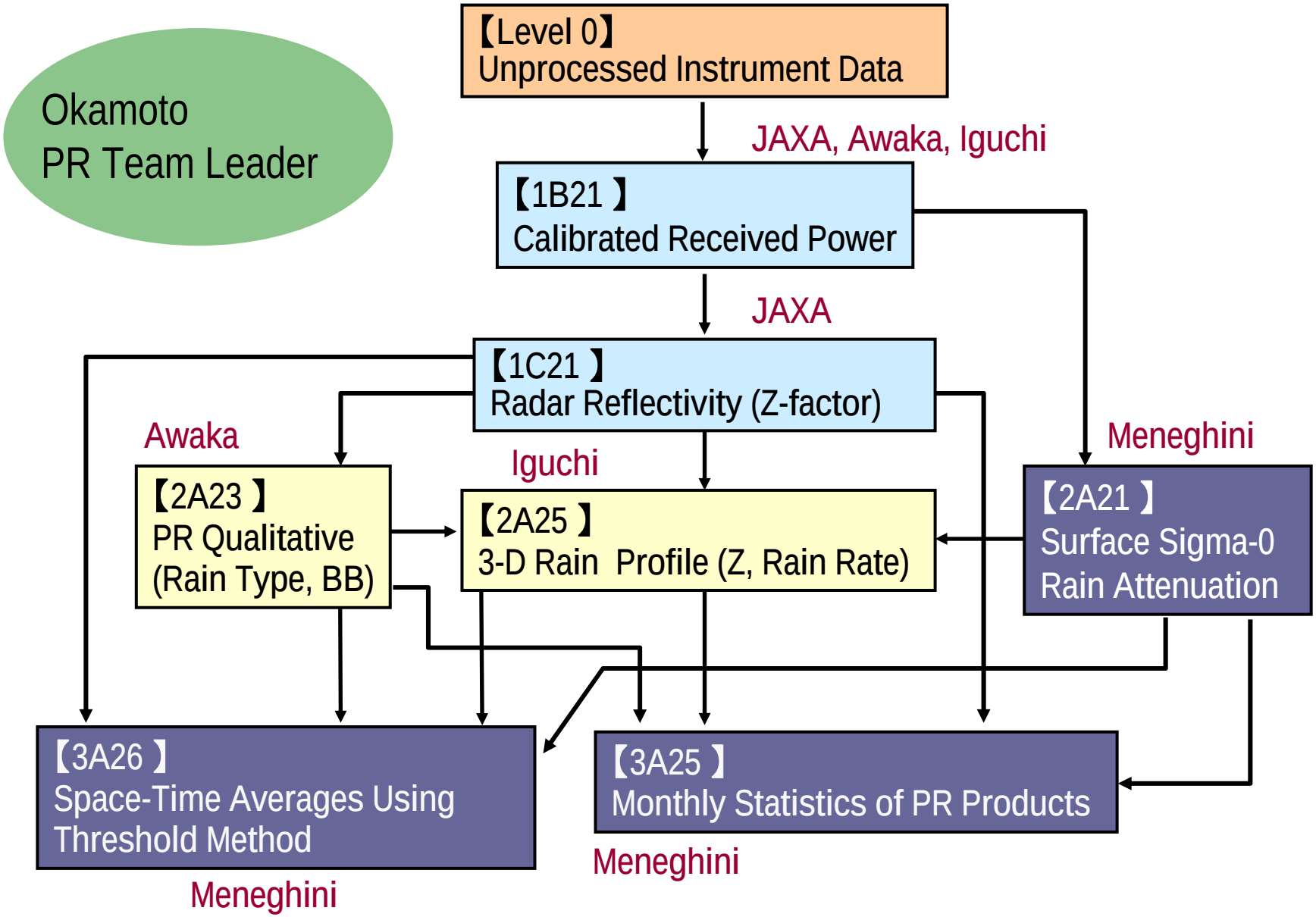
TRMM Precipitation Radar Algorithm Flow



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)

	2A25	2A12	2B31	(2A12-2A25) / 2A25 (%)	(2B31-2A25) / 2A25 (%)
±35°	76.5	81.0	84.4	5.9	10.3
±20°	90.8	96.4	102.6	6.2	13.0
±10°	114.6	124.1	129.2	8.3	12.7

2A25: Estimated Surface, not Near Surface

2A12: Narrow Swath

2B31: Near Surface

AWM(Area Weighted Mean) = $\sum_{lat} Zonal\ Average\,(lat) * \cos(lat) \Big/ \sum_{lat} \cos(lat)$

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

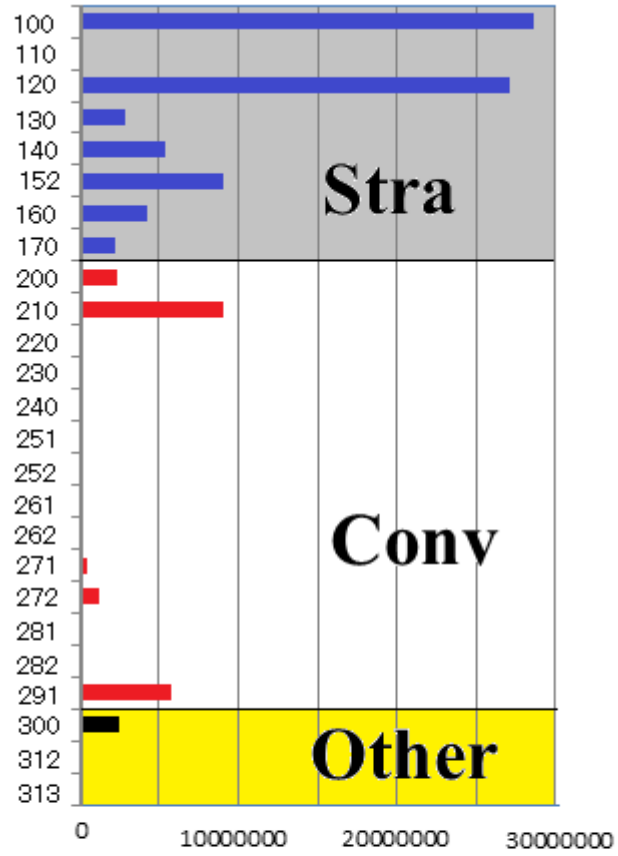
Major changes in 2A21

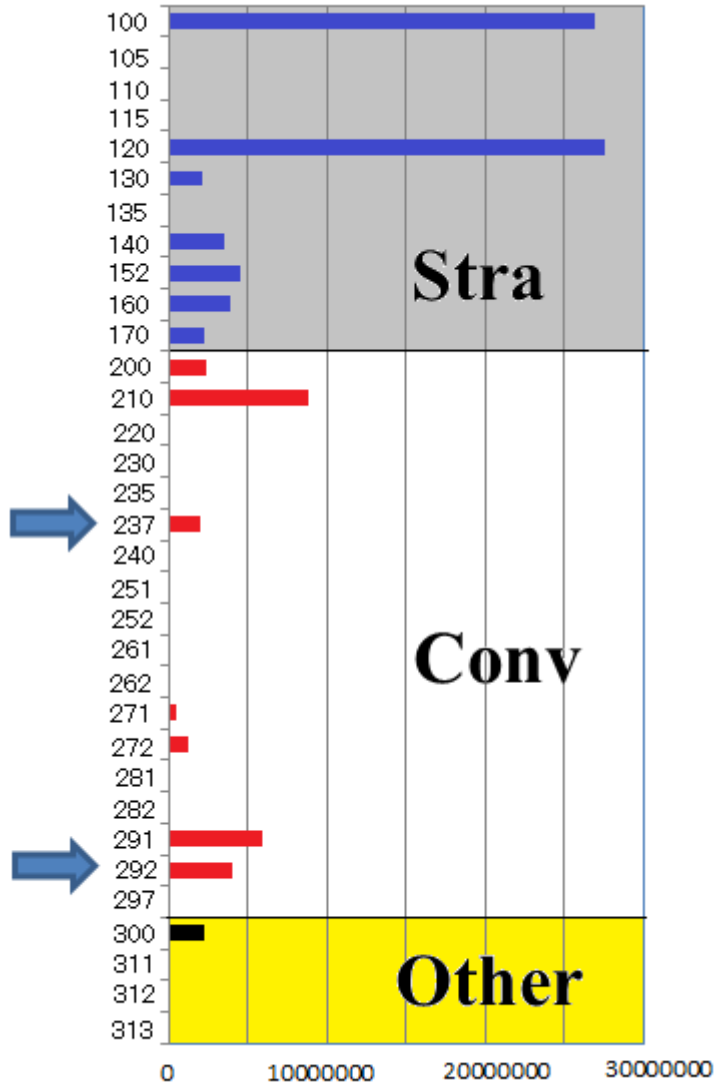
- Introduction of 5 types of PIA (Path-Integrated Attenuation to surface)
  - Temporal reference: increased spatial resolution
    - introduction of the reference data base with 0.1 deg. grid
  - Spatial reference: introduction of Backward reference
    - along-track: forward + backward
    - hybrid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

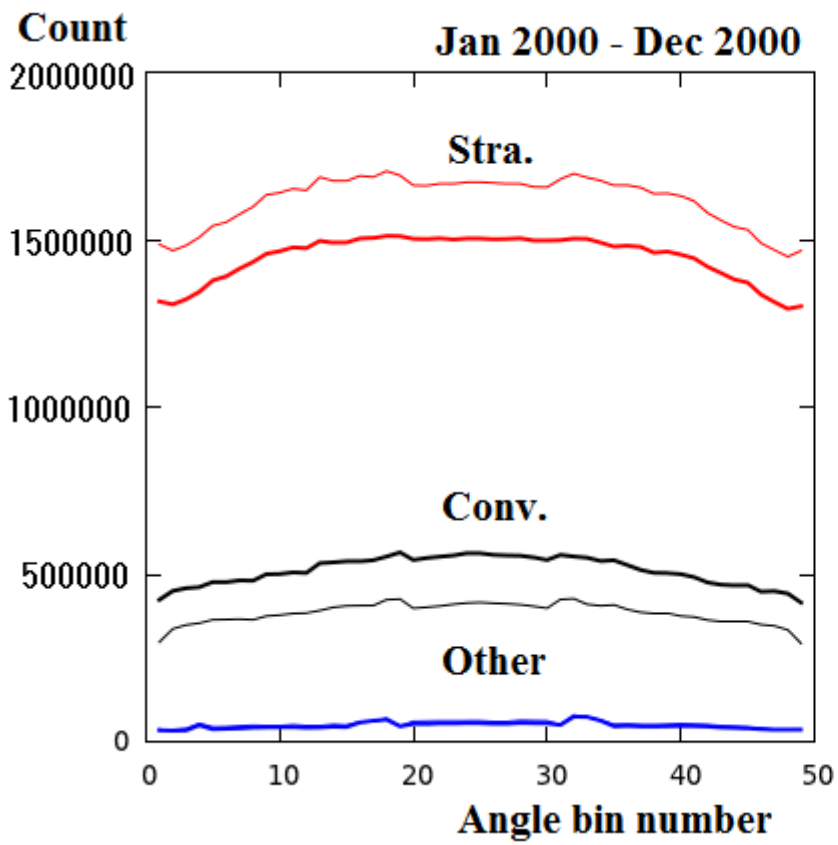
V6 **Jan 2000 – Dec 2000** **V7**

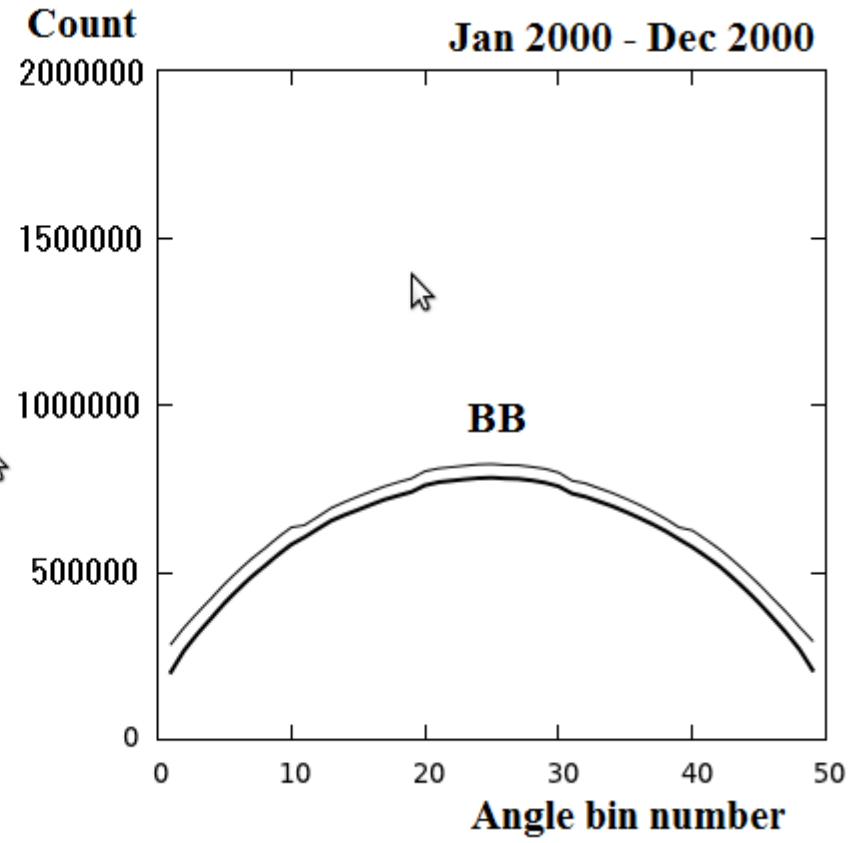




↓ 130 V:stra, H:other, with BB
↓ 140 V:other, H:stra, BB hardly expected
↓ 152 V:other, H:stra, shallow non-isolated

↑ 237 V:other, H:stra, small cell size
↑ 292 V:other, H:stra, shallow non-isolated





Thin: V6
Thick: V7 OAT

Angle bin dependence of each rain-type count and that of BB count

Major Changes in 2A25

- Expected value to maximum likelihood value in estimating α
- 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 (α 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 ζ (α and Z_m) in the Hitschfeld-Bordan attenuation correction method
- Introduction of NUBF correction
- Correcting the smearing of BB in off-nadir beams

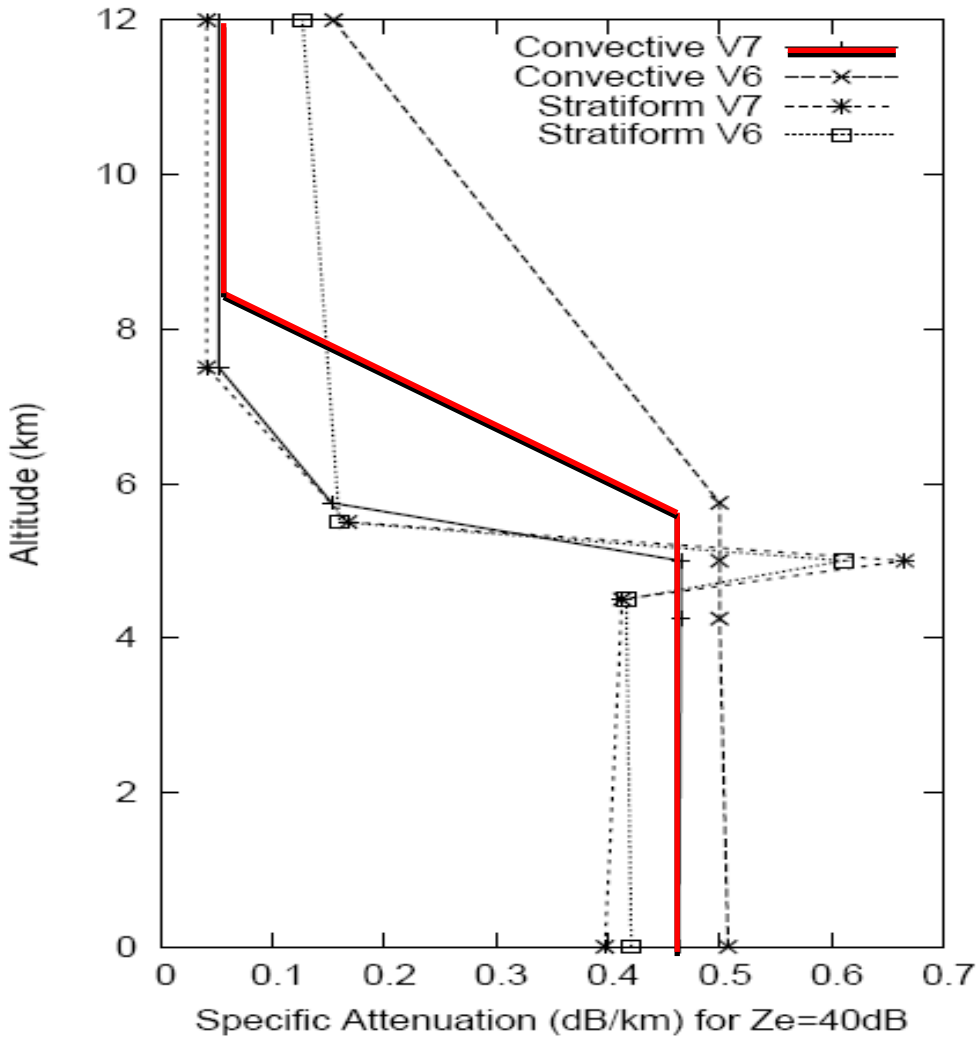
From expected value to ML estimate

- Adjustment parameter ε that adjust α 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 PIA_{SRT} and PIA_{HB} are taken into account
  - Derive Likelihood function $L(\varepsilon)$ of ε
  - Estimate ε by Maximum likelihood method
- Expected value of ε depends on the entire distribution of PDF $P(\varepsilon)$
  - Tails of $P(\varepsilon)$ are not reliable
    - Tails change with the assumed distribution of α
- ML estimates are immune to the tails of likelihood $L(\varepsilon)$

New vertical profile of specific attenuation *k*

- α 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 α.
  - A change in PIA_{HB} changes ε when SRT is used.
  - A change in ε 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, ζ and hence PIA_{HB} decreased, and ε 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 ζ (α and Z_m) and PIA estimates by SRT

$$\zeta(r) \stackrel{\text{def}}{=} 2q\beta \int_0^r \alpha_0(s) Z_m^\beta(s)\, ds$$

$$k_{\mathrm{P}} = \alpha_0 Z_e^\beta$$

- Error in initial α is decreased
- Error in Z_m is taken into account
- ζ depends on α and Z_m
- Assign the total error in ζ to α and Z_m
  - Reduced the adjustment of the DSD parameter that modifies the *R*-*Ze* relation by $\mathrm{PIA}_{\mathrm{SRT}}$ slightly.
    - *R* increases in regions where ε 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.