Preparation for space-based cloud radar assimilation

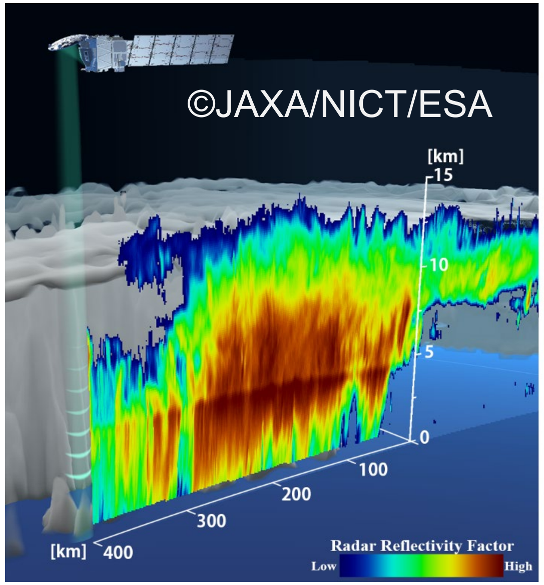
Kozo OKAMOTO[1], Masahiro HAYASHI[1], Masayuki NAKAGAWA[1], Gennosuke KIKUCHI[2], Takuji KUBOTA[3]

1: JMA/MRI, 2: Remote Sensing Technology Center of Japan, 3: JAXA/EORC

IPWG-11, Tokyo, 15-18 July 2024

Background and Objectives

- Cloud Profiling Radar (CPR)
  - CloudSat/CPR (28 Apr 2006)
  - Enhance our understanding of cloud process and improve NWP/climate models
- Assimilation of CPR
  - Limited studies
    - ← Small coverage, Challenges in model simulation and data assimilation processings
  - Promising results at ECMWF (Fielding & Janisková 2020; Janisková & Fielding 2020)
  - Unique info that passive obs does not have: Vertically resolved cloud/precipitation
  - EarthCARE/CPR will provide more accurate and new obs



- Objectives of this study
  - Investigate feasibility of assimilation of EarthCARE/CPR Ze in JMA's global system
    - Synergy with all-sky radiances of geo/polar IR sounders
  - Start with CloudSat/CPR

Outline

1. Examination of CPR Ze simulation
2. Sensitivity to frozen particle optical properties
3. Single cycle assimilation

Outline

1. **<u>Examination of CPR Ze simulation</u>**
2. Sensitivity to frozen particle optical properties
3. Single cycle assimilation

Model, Simulator and Observation

- Model: Global Spectral Model (GSM): JMA’s operational model (as of Dec.2019)
  - Horizontal spacing of 20km, 100 layers up to 0.01 hPa
  - Convection scheme：Prognostic Arakawa-Schubert → Convective clouds
  - Large-scale cloud: Smith scheme (Smith 1990, QJRMS) → Stratus clouds
  - Hydrometeor: total cloud (water+ice), rain flux, snow flux

- Simulator: RTTOV ver13.0
  - Calculate attenuated reflectivity factor (Ze), and its Jacobian
  - Hydrometer: cloud water, cloud ice, rain and snow (no graupel)
  - Set the same fraction for all hydrometeors

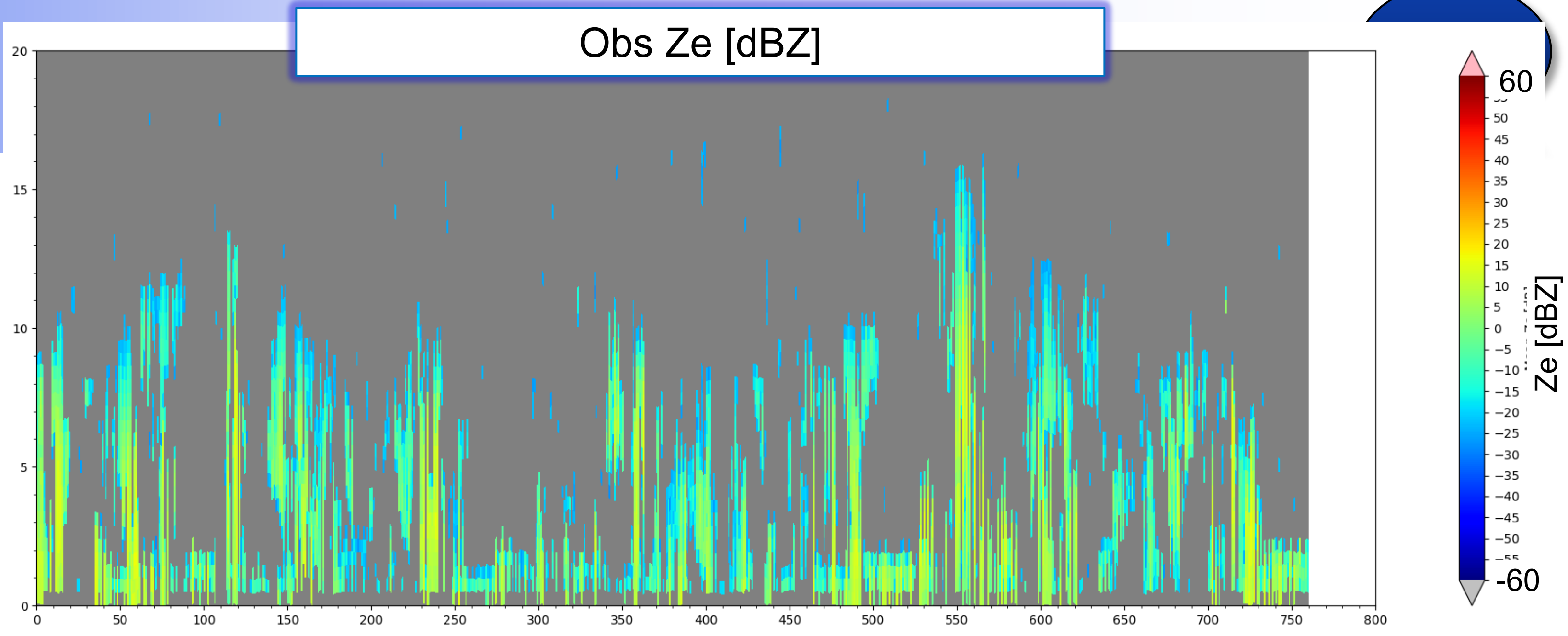
- Observations: CloudSat/CPR 2B-GEOPROF
  - Create super-ob (~55 km based on 4DVar inner-loop scale) by averaging reliable pixels
    - Select pixels over -30 dBZ and cloud_mask>=6
    - Vertically thin to every other one layer (~500 m), instead of averaging

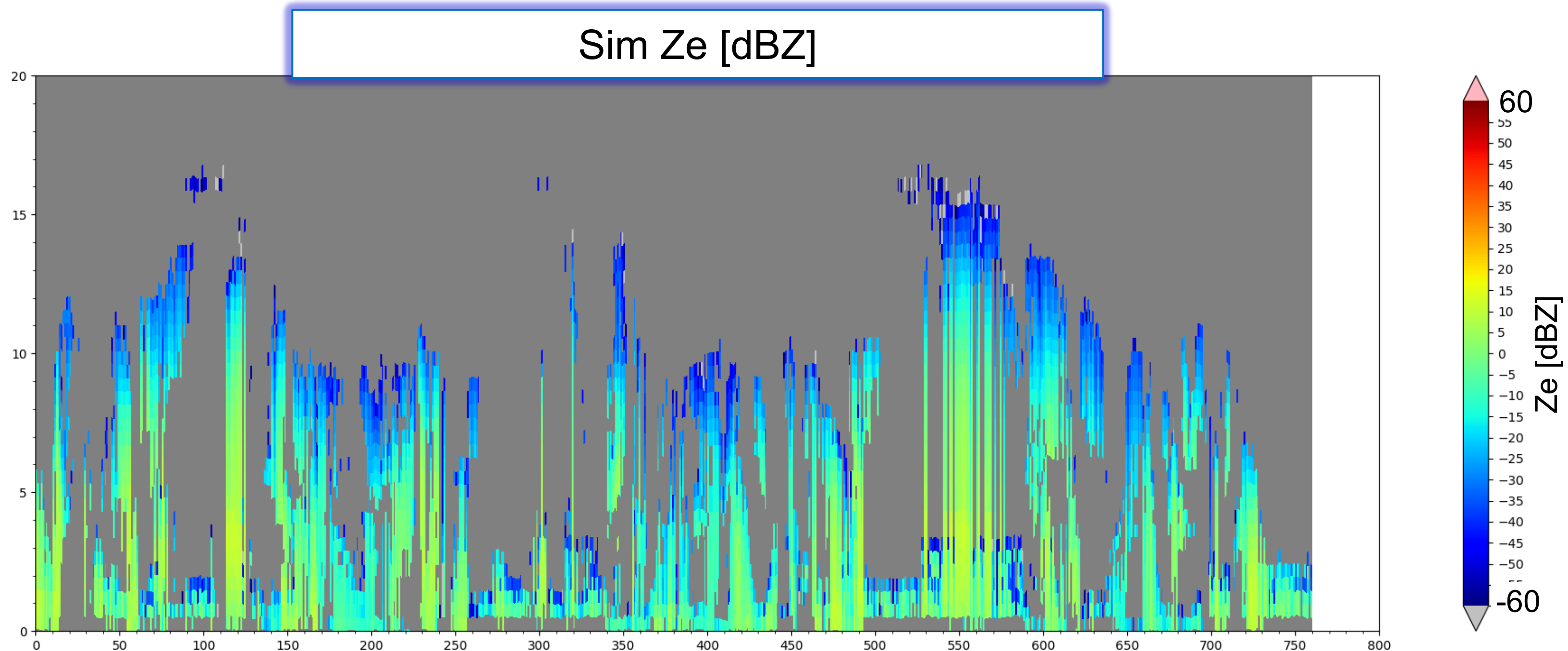
Quality Control (QC)

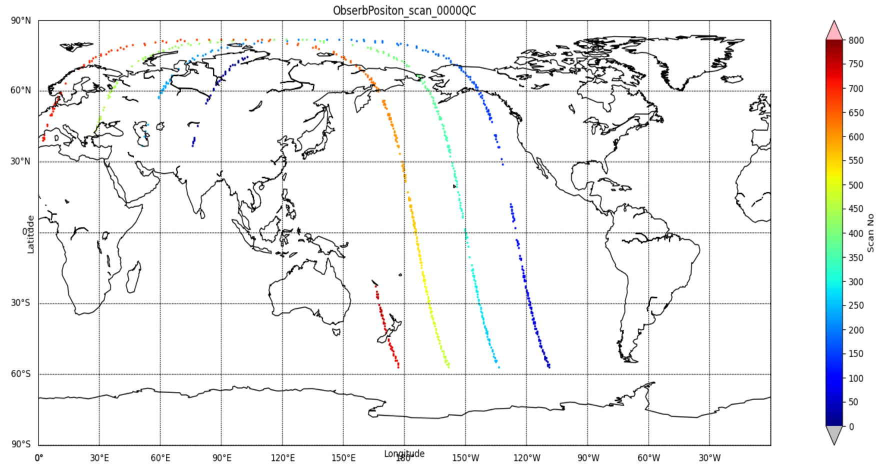
- Reliability
  - Both observed and simulated Ze ≥ -30 dBz
  - Cloud_mask ≥ 30
  - Higher than 1km in altitude to avoid ground clutter
- Homogeneity
  - Standard Deveiation < 20 dBZ, cloud fraction > 50 % and effective pixel number > 5
    - These statistics are calculated from effective pixels composing super-ob
- Consistency btw obs and sim
  - |Obs-Sim| < 24 dBZ

Example of obs and sim

- 18 UTC 9 – 03 UTC 10 July, 2018
- Before QC

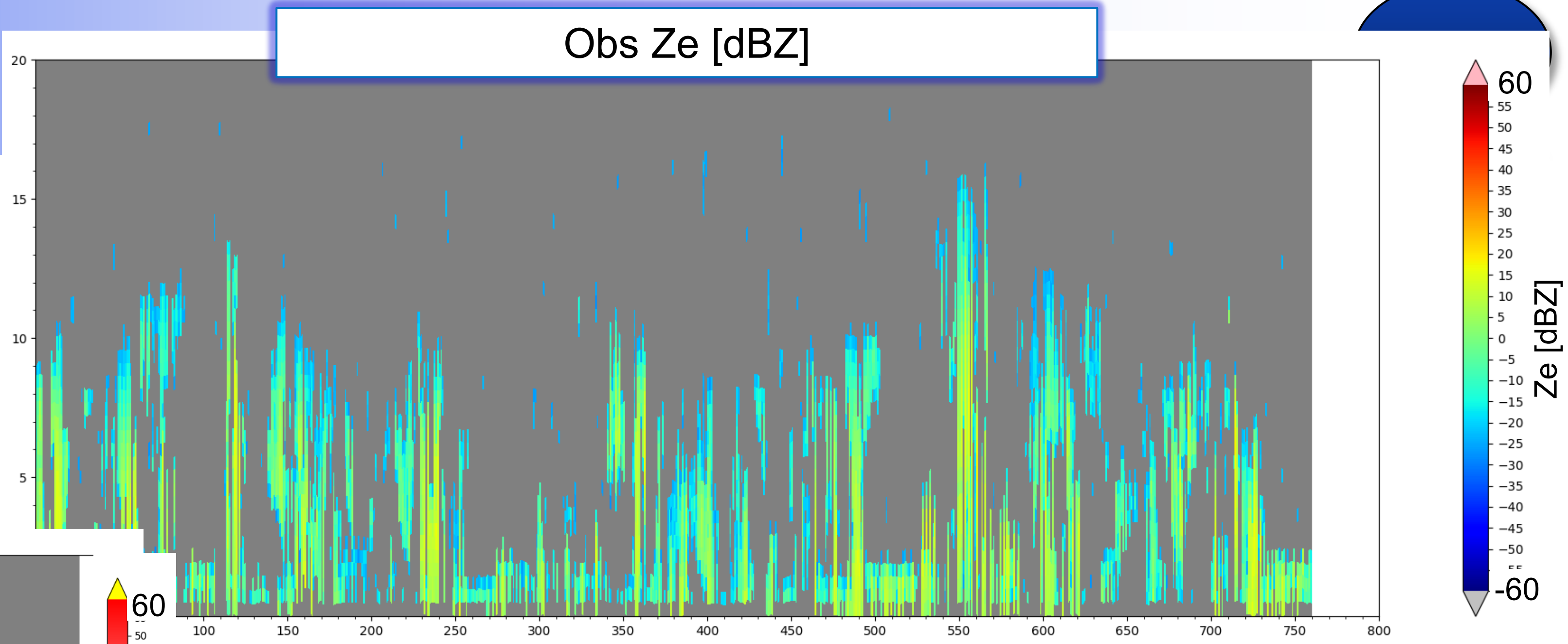


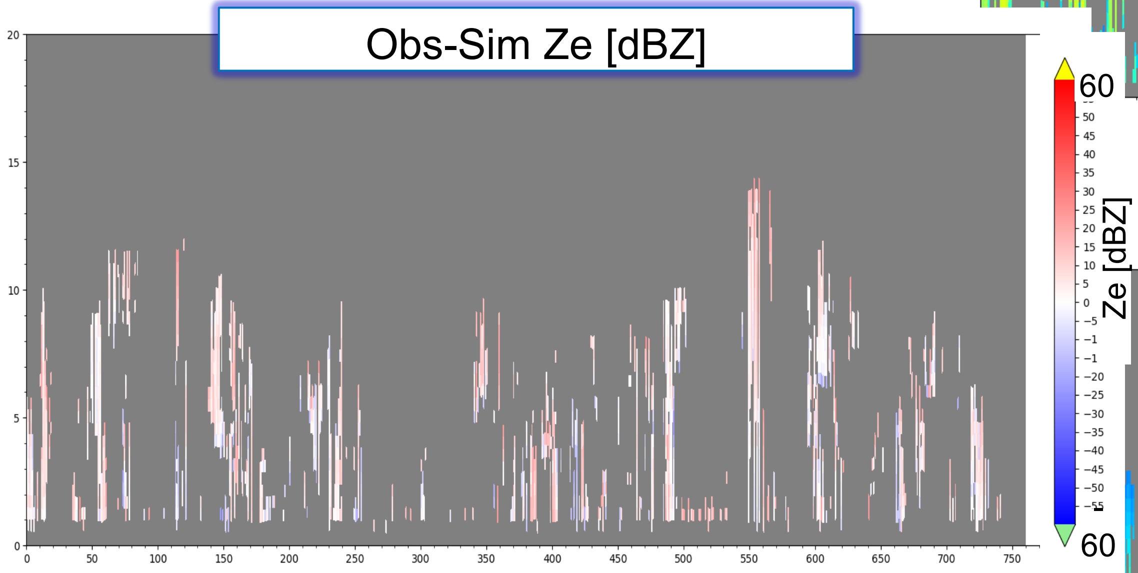


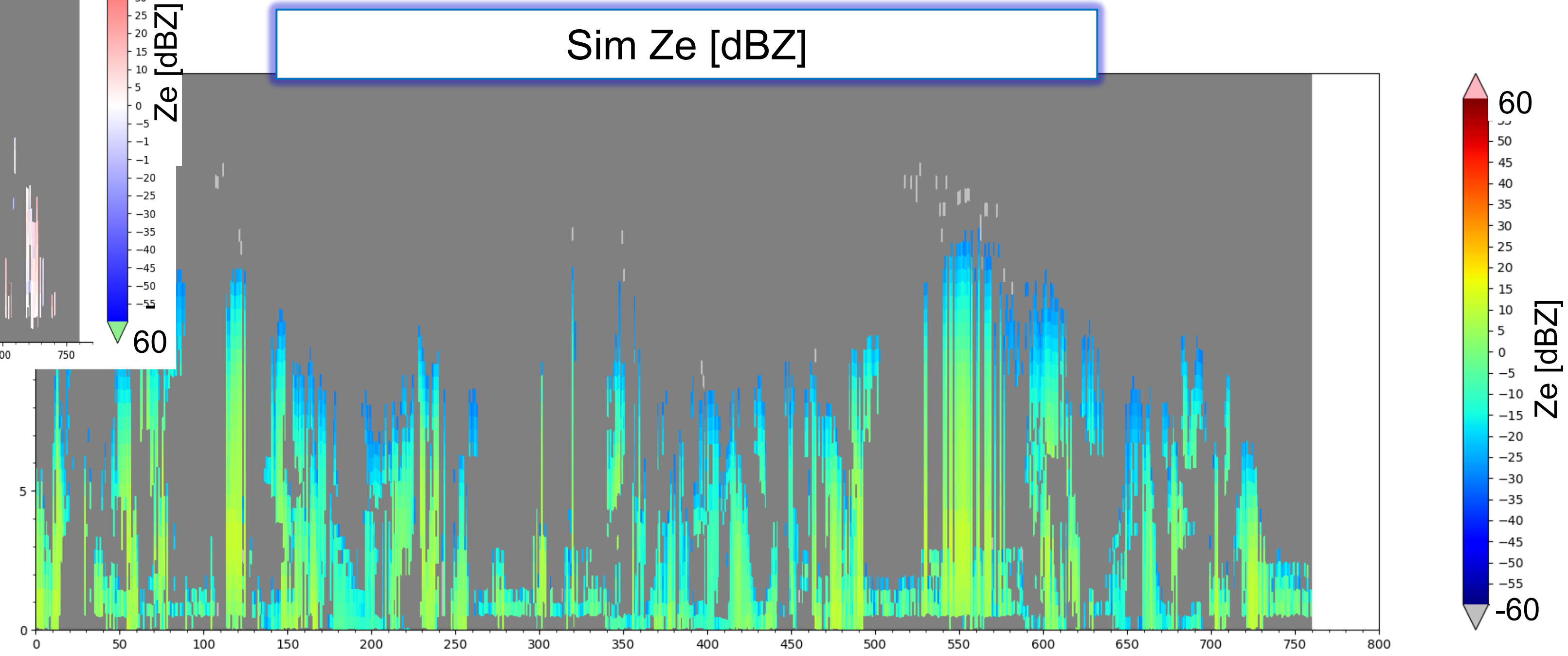


Example of obs and sim

- 18 UTC 9 – 03 UTC 10 July, 2018
- After QC

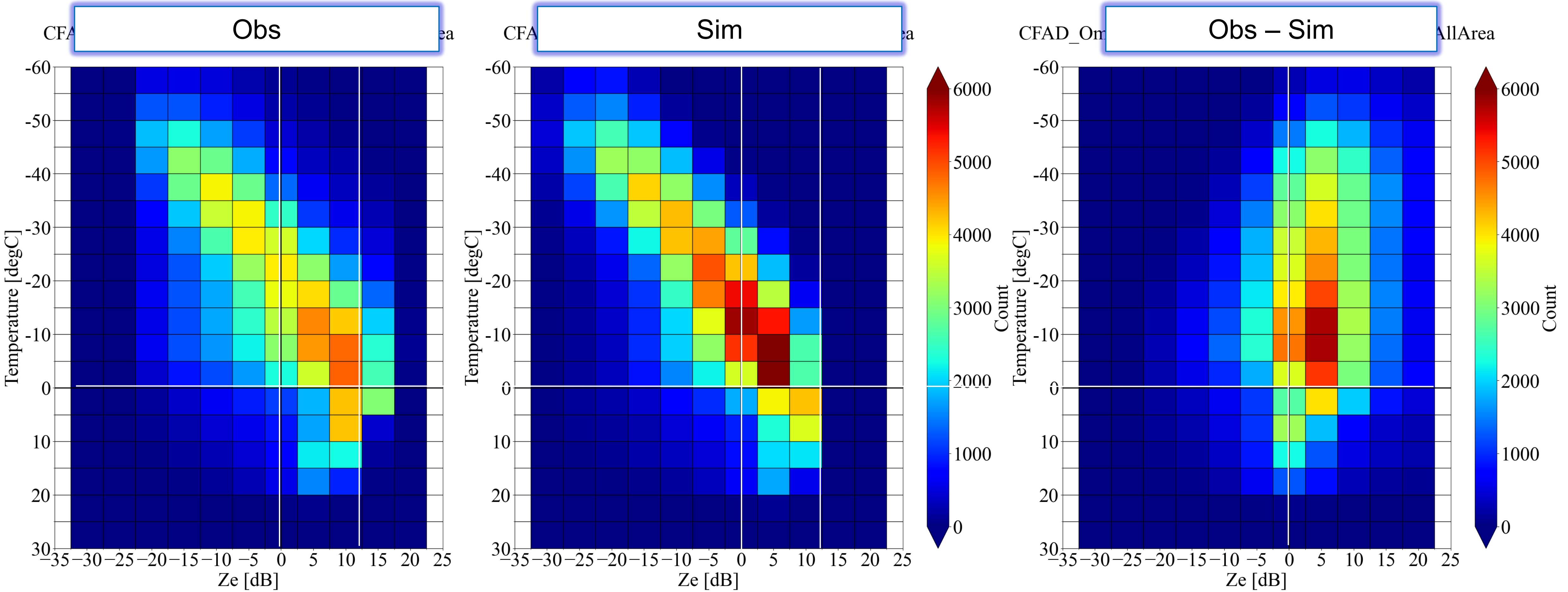






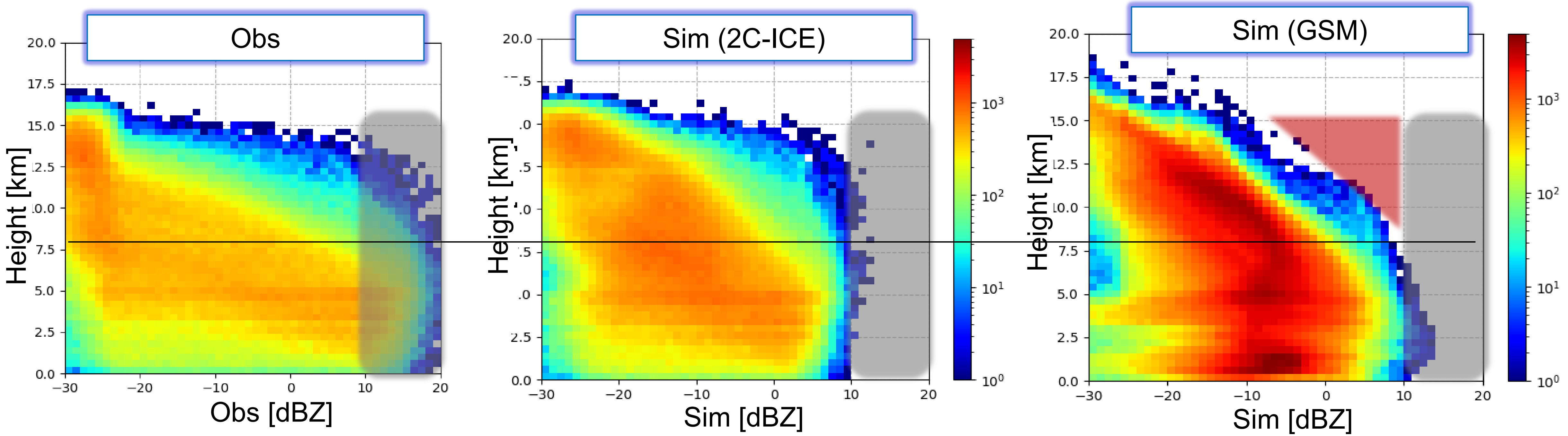
Number in Ze and temperature bins

- 10-31 July 2018
- Simulated samples are less variable and fewer in strong Ze
- → Positive Obs-Sim bias across a wide range of vertical layers



What caused underestimated sim or Obs-Sim>0

- Simulate Ze from 2C-ICE cloud products of CloudSat+CALIPSO, instead of GSM cloud (one month in August 2016)
- 2C-ICE simulation improves the agreement with obs but still underestimates Ze for Ze>10dBz
  - → RTTOV seems to underestimate Ze from clouds with large particle
- GSM simulation further underestimate Ze at higher altitude (>8 km)
  - → GSM significantly underpredict high clouds (Okamoto et al. 2021)

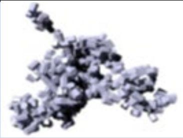
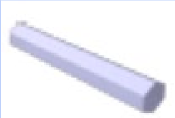
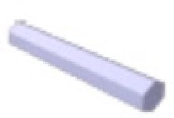


Outline

1. Examination of CPR Ze simulation
2. **Sensitivity to frozen particle optical properties**
3. Single cycle assimilation

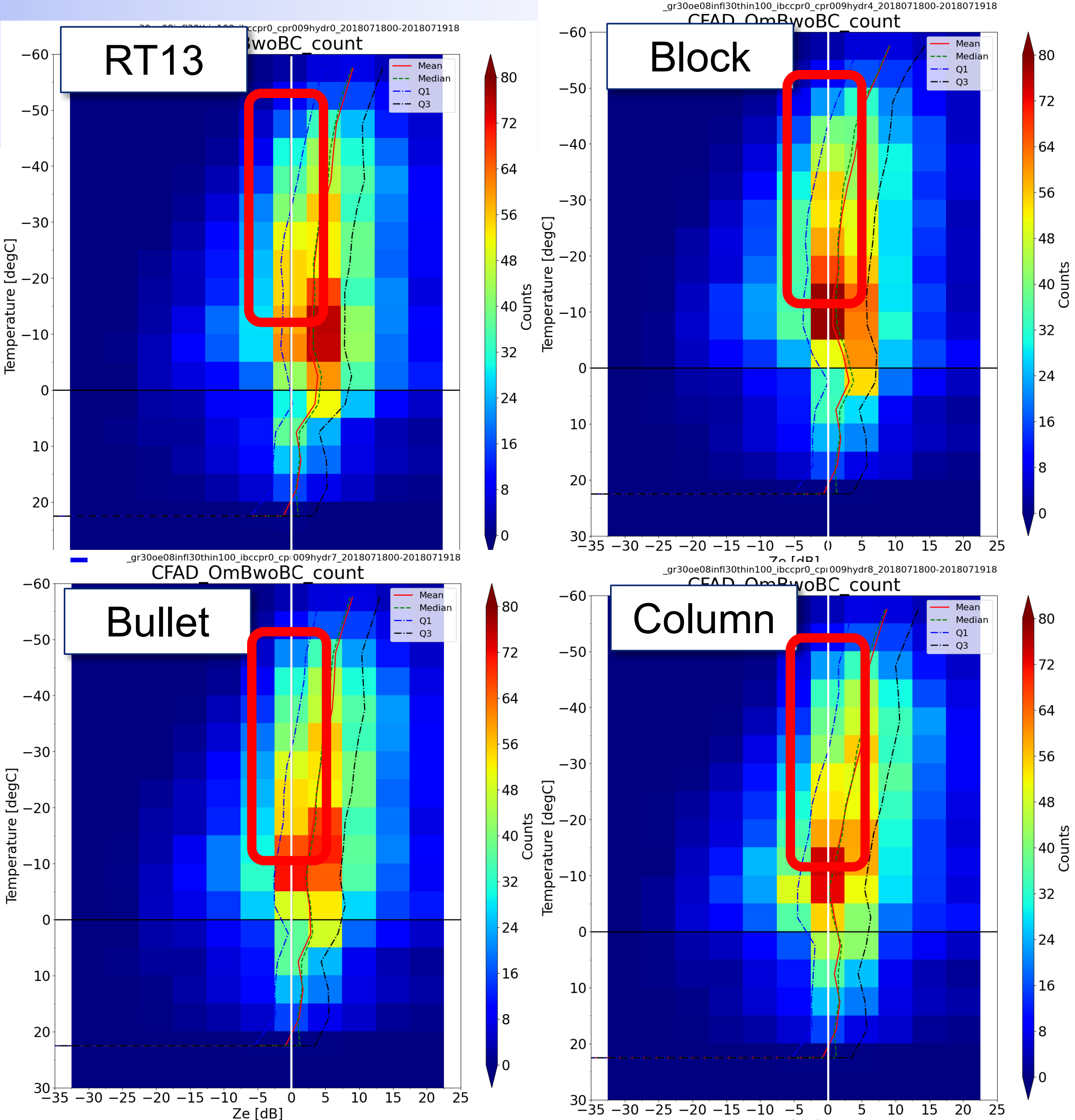
Test different particle shapes and PSDs in RTTOV hydrotable

- Extinction coefficients/SSA/asymmetry parameter/backscatter (reflectivity) are pre-calculated for hydrometeor, satellite, sensor, channel, temperature, and hydro water content
- Particle shapes from database of ARTS (Atmospheric Radiative Transfer Simulator; Eriksson2018)
- The default settings is defined based on Obs-Sim of SSMIS radiances at 19-183 GHz (Geer 2021, amt)

	snow	ice	Reference
Rt13 Default	ARTS large plate aggr Field2007 	ARTS large col aggr MGD(u=0,l=10^4) 	Geer (2021)
Block	ARTS block aggr Field2007 	ARTS large col aggr Field2007, Trop 	Geer (2021)
Bullet	ARTS 6-bullet rosette Field2007 	ARTS 6-bullet rosette MGD(u=0,l=10^4) 	Sato & Okamoto (2023)
Column	ARTS column type1 Field2007 	ARTS column type1 MGD(u=0,l=10^4) 	Sato & Okamoto (2023)

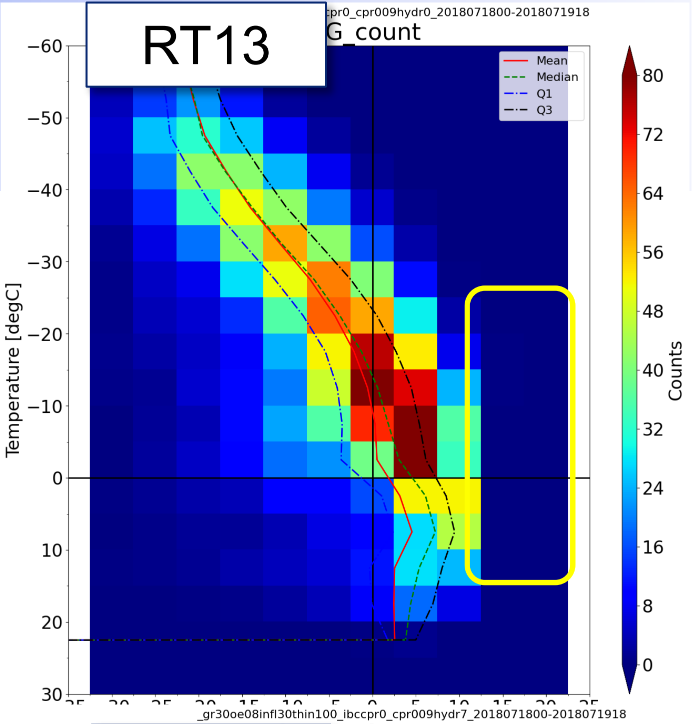
Number for obs - Sim

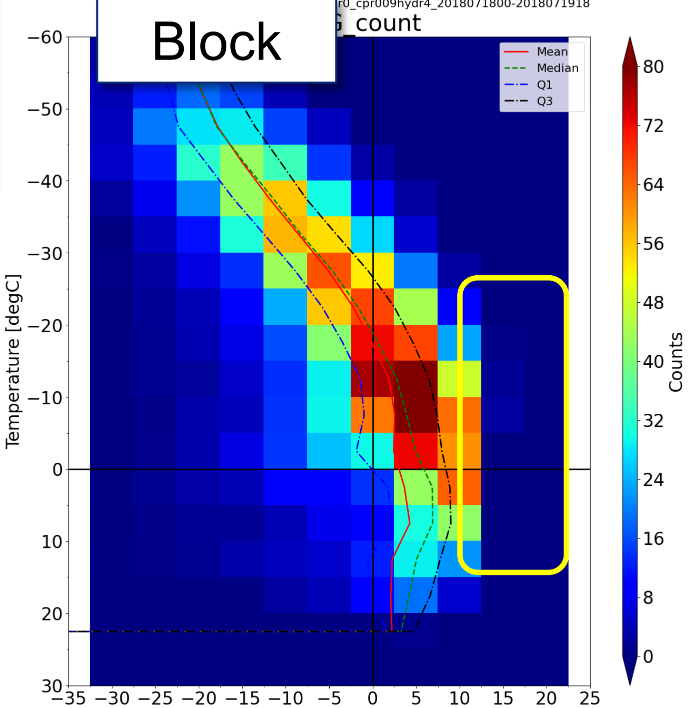
- Calculated from global data from 18 – 19 July 2018

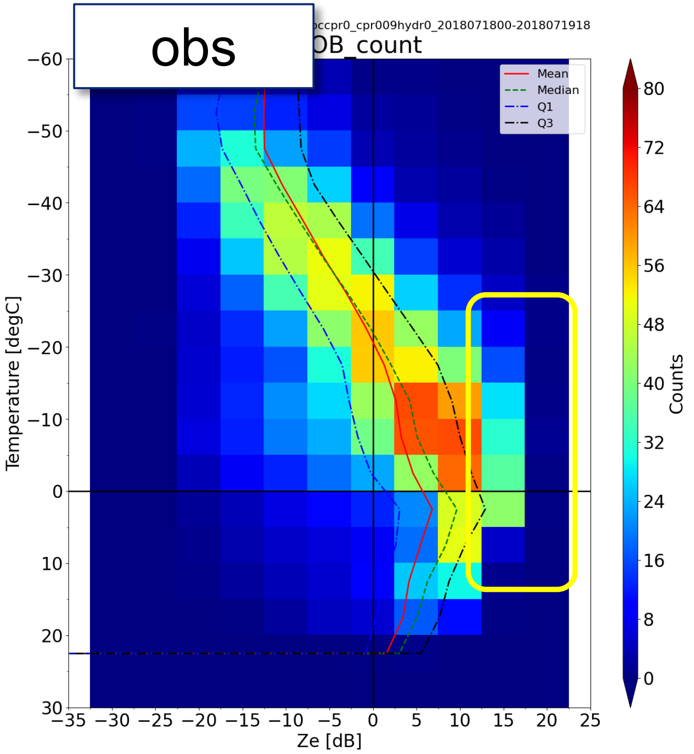


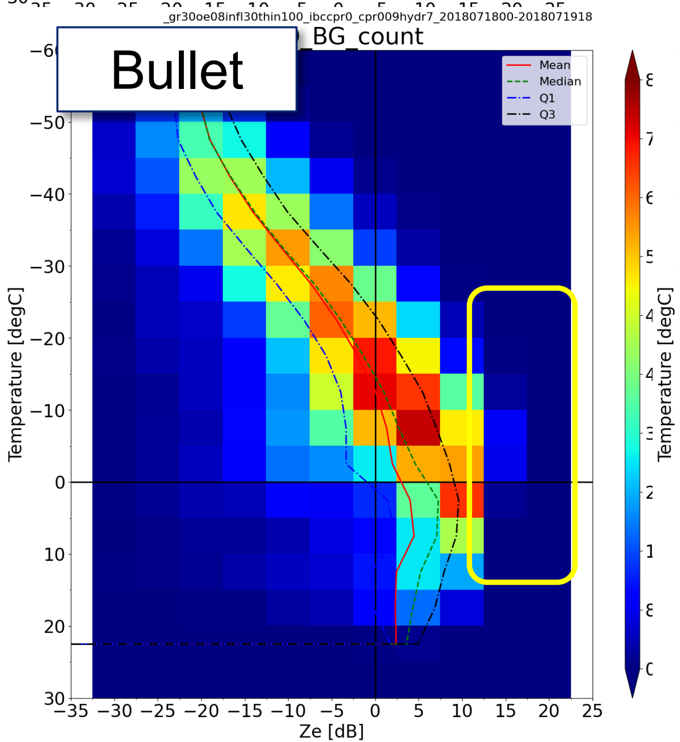
Number for obs & sim

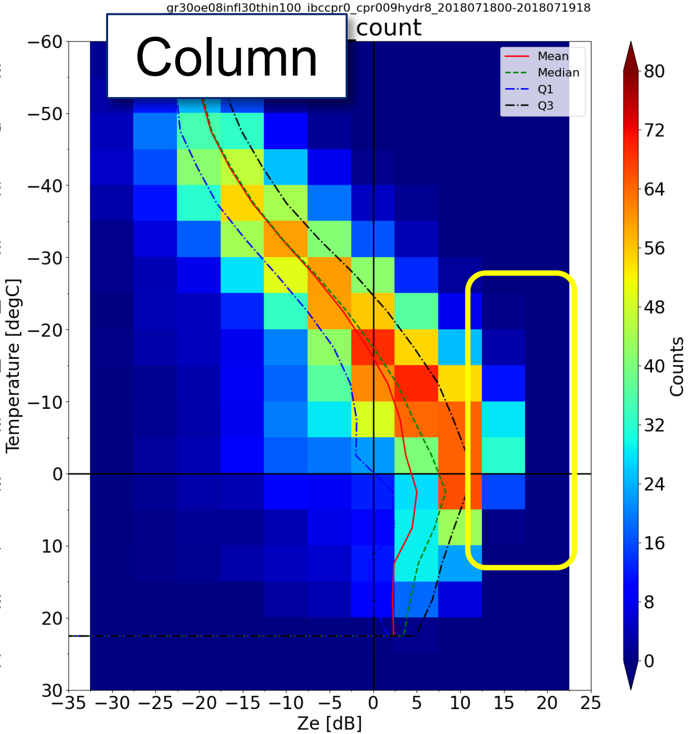
- Calculated from global data from 18 – 19 July 2018











Outline

1. Examination of CPR Ze simulation
2. Sensitivity to frozen particle optical properties

3. Single cycle assimilation

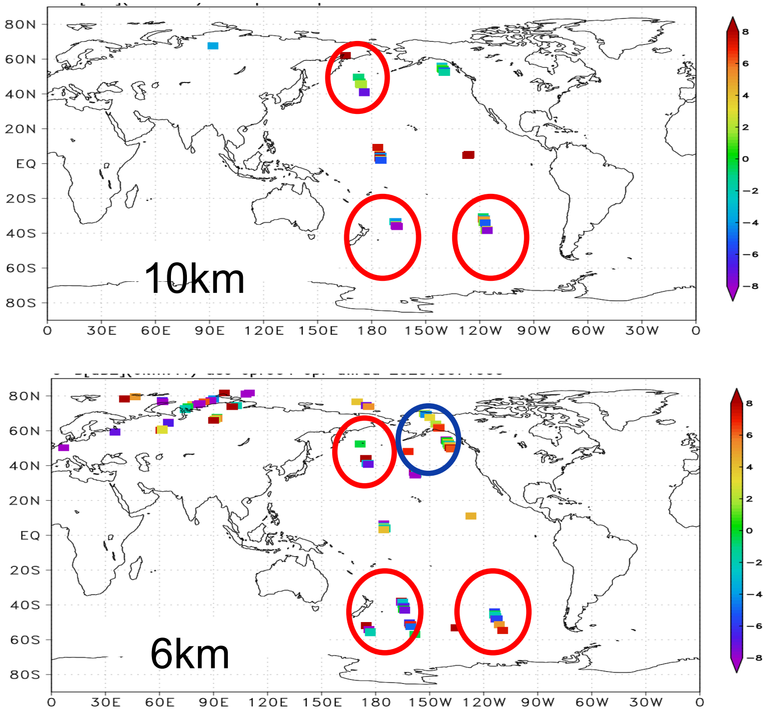
Data assimilation setting

- Assimilation system
  - Operational global DA system of JMA (as of Dec. 2019), and updated to RTTOV13
    - Hybrid-4DVar, Microwave all-sky radiance assimilation
- Obs Configuration
  - CNTL: Operational configuration, but replace Himawari-8/AHI clear-sky with all-sky
  - TEST: Add CloudSat/CPR Ze to CNTL
    - obs.error=24dBz (fixed, no inter-lev/horizontal correlation), 100km thinning
- Single cycle assimilation: 00UTC 10 July 2018

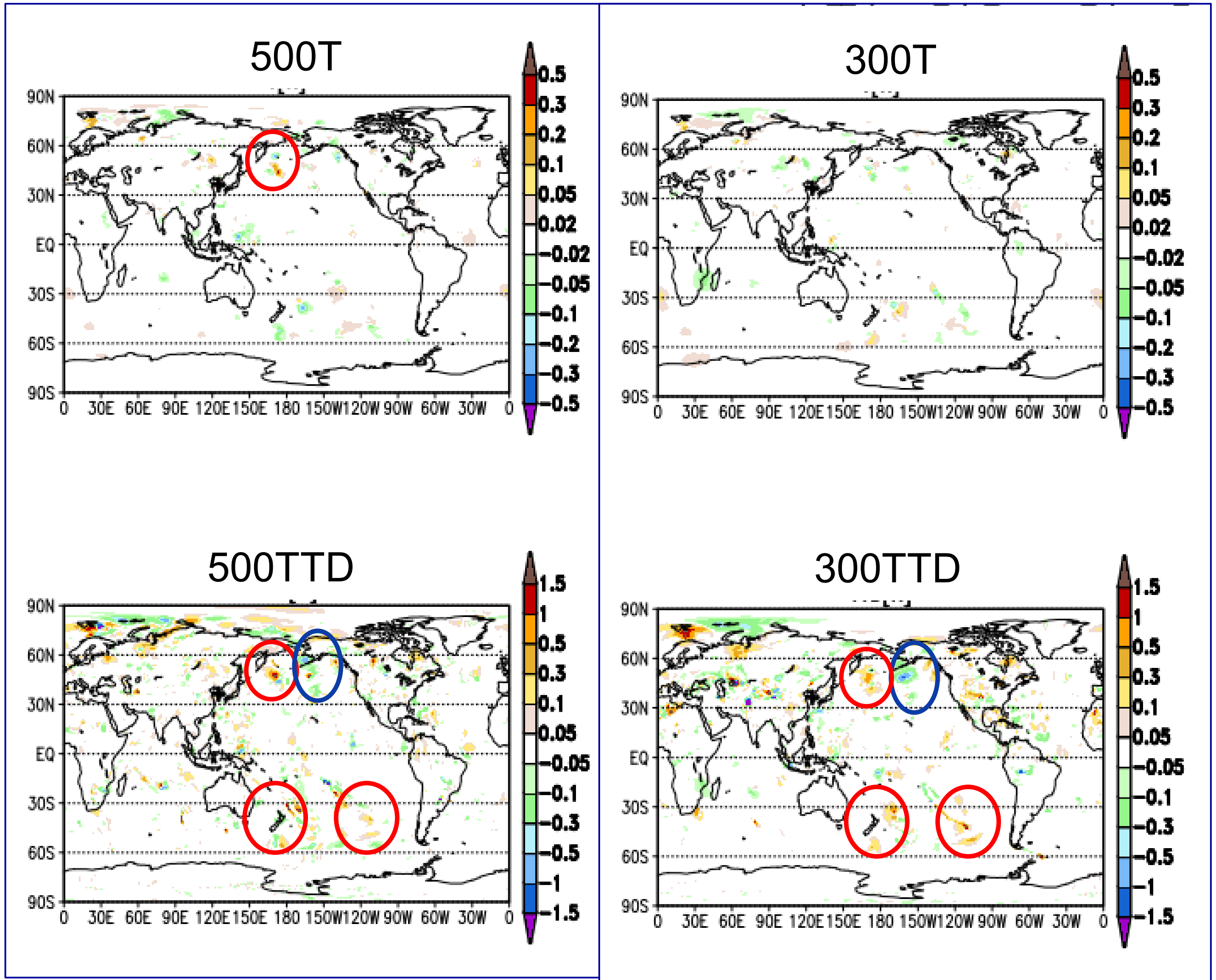
Single cycle assimilation impact

- Small number of obs assimilated: 300 profiles per analysis
  - Himawari all-sky rad > 11,000
- Analysis difference (impact) is very small

Obs-Sim of CPR Ze



Analysis difference of TEST and CNTL



Sensitivity of Ze w.r.t. humidity and cloud ice $\partial Ze/\partial X$

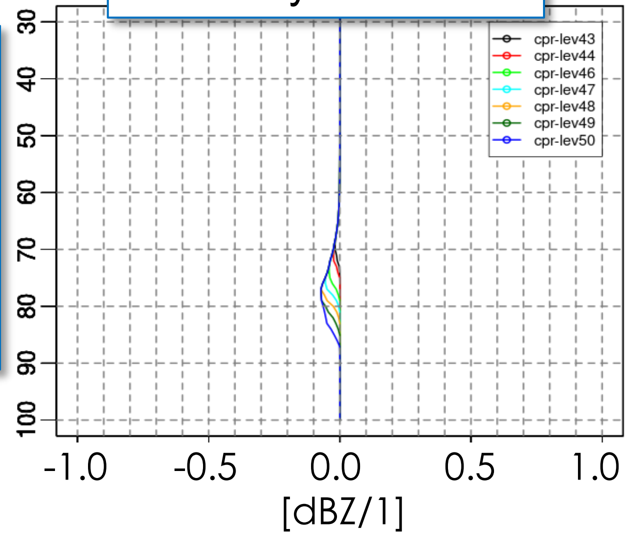
- Jacobian for Ze obs
  - 00 UTC 10 July, 2018 (75.5N,129.3E) 7 levels assimilated
  - $\partial Ze/\partial T$ & $\partial Ze/\partial Q$ are much smaller (than radiance Jacobian)
  - $\partial Ze/\partial C$ (C=cloud water, ice, fraction, rain & snow) are larger

- JMA's 4DVar does not directly analyze clouds
- → Propagate cloud-related obs information into analysis variables through a linearized model

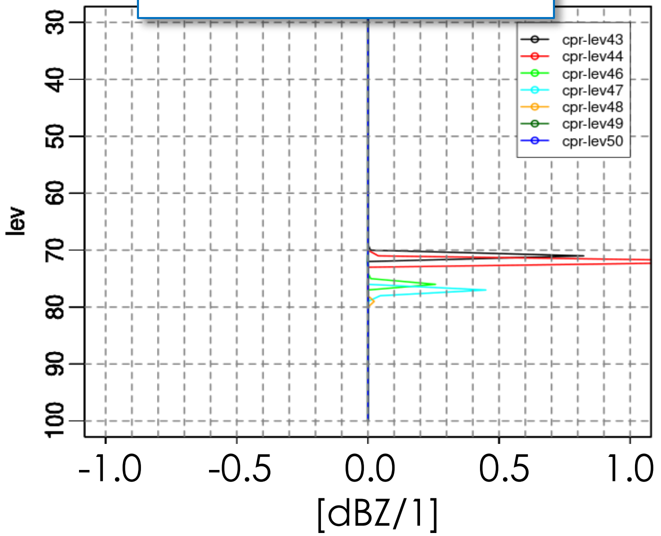
Vertical profile of Jacobian

CPR Ze

Humidity dZe/dlnQ

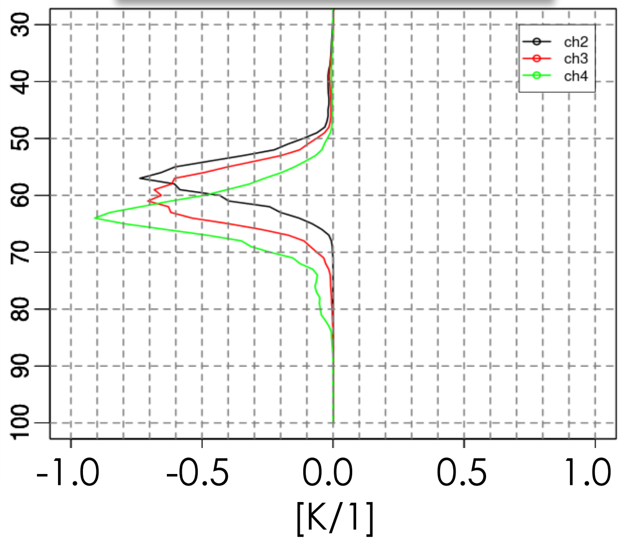


Cloud ice dZe/dlnCi

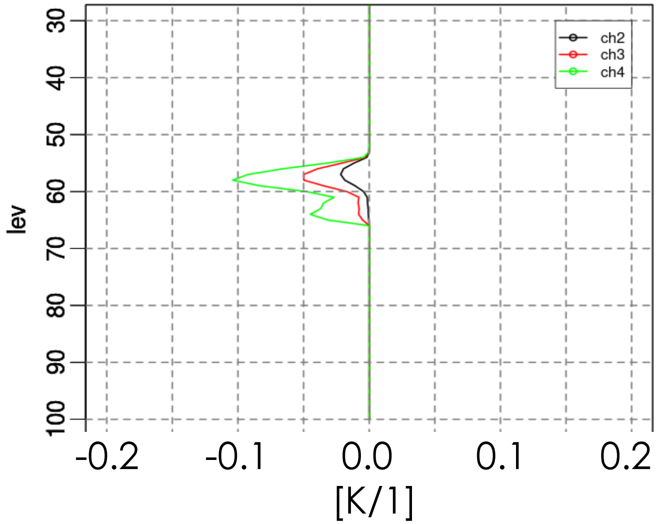


Reference: AHI radiance

Humidity dTB/dlnQ

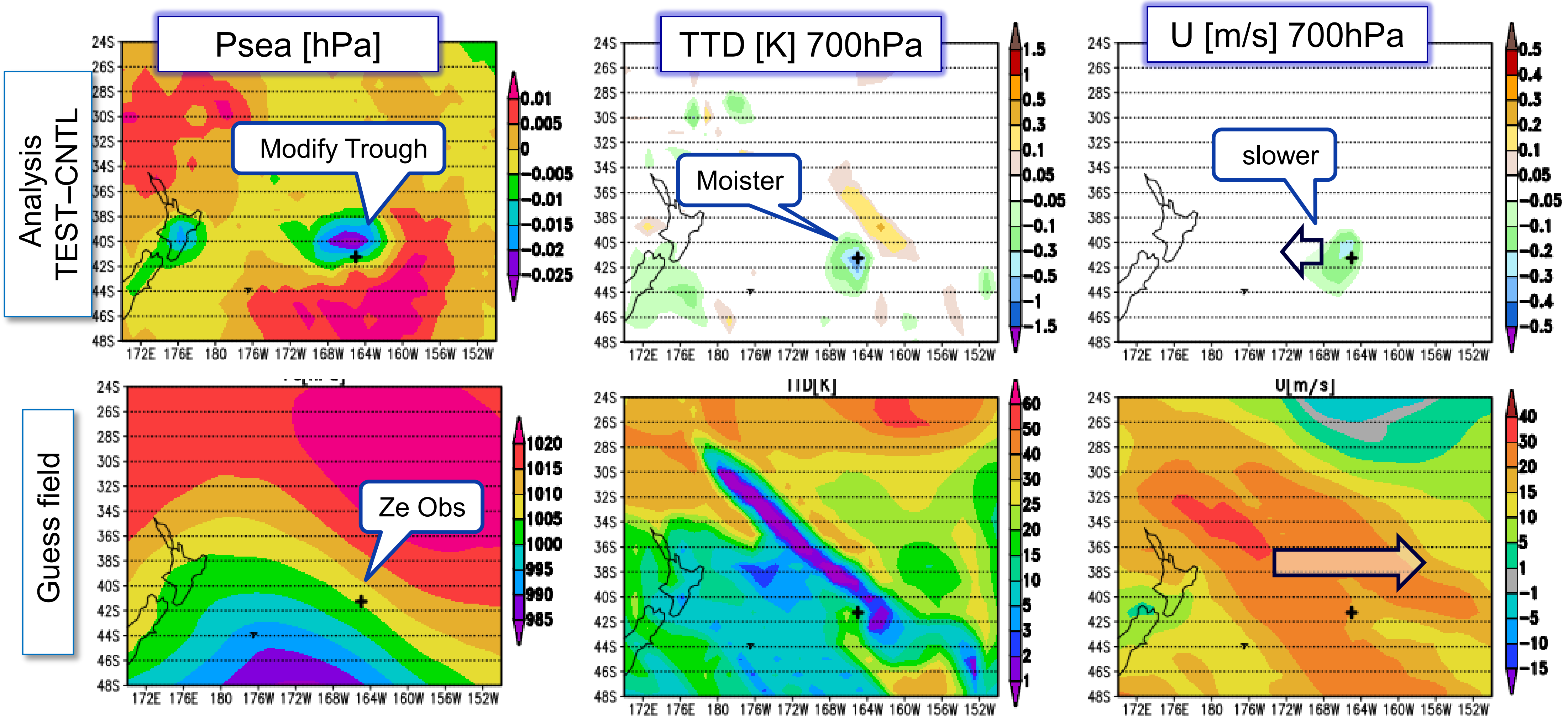


Cloud icedTB/dlnCi



Single obs assimilation impact

- Assimilate single profile of Ze with Obs-Sim>0 (insufficient cloud) at 15 levels
- Correct wind, pressure and humidity to slow down the moist belt passing eastward
  → Keep slightly higher humidity around obs location (→ Slightly increase clouds)



Summary

- Started the assimilation study of CPR Ze in JMA's global system
- JMA's global model (GSM) and RTTOV underestimate CloudSat/CPR Ze (Obs-Sim>0)
  - Insufficient high clouds in GSM
  - Weak scattering in RTTOV → Change PSD and shape of snow and ice
- Single cycle assimilation experiments showed analysis increments were reasonable in their direction but too small in magnitude

- Plan to continue these examinations and assimilation tests for EarthCARE/CPR