数値モデルと衛星シミュレータによる連携研究

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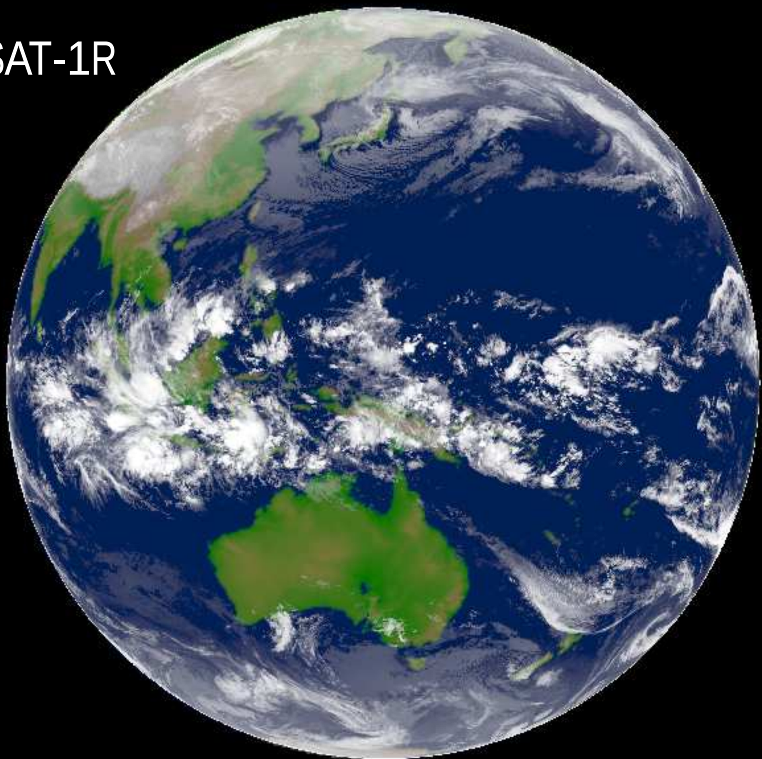
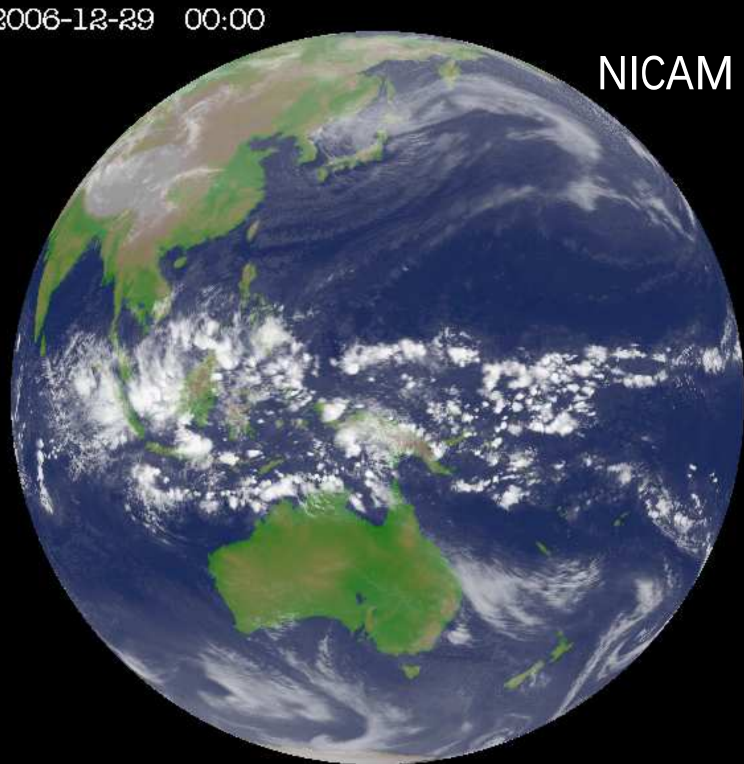
MTSAT-1R





NICAM

Miura et al. (2007,Science)

平成27**年**3**月**27**日** (**金**) 13:30～17:30 **開催場所：気象庁講堂**

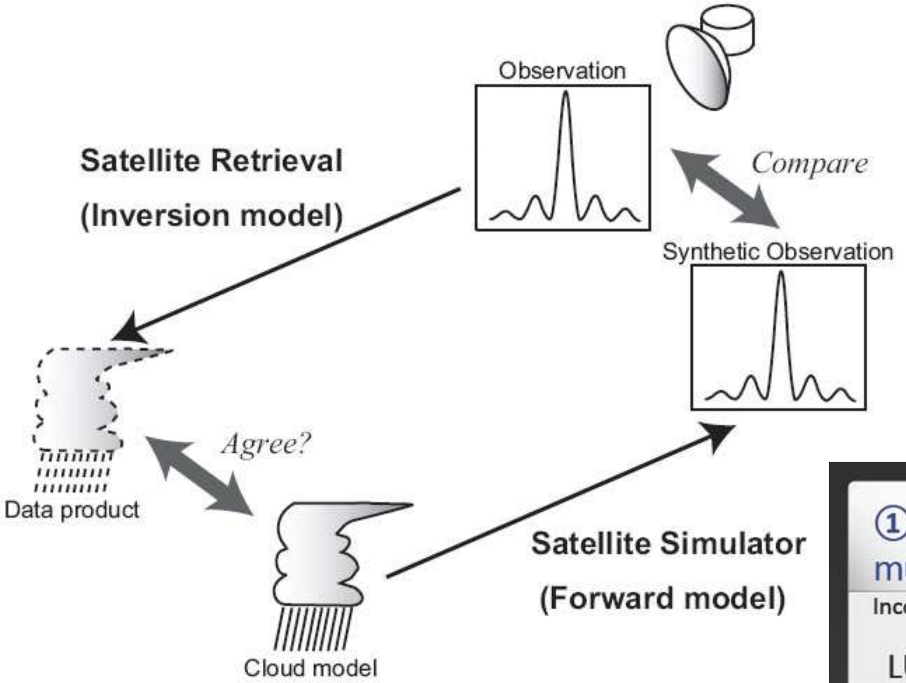
テーマ：「数値予報を用いた衛星観測シミュレーション」

http://pfi.kishou.go.jp/modelkenkyukai2014.html

内容

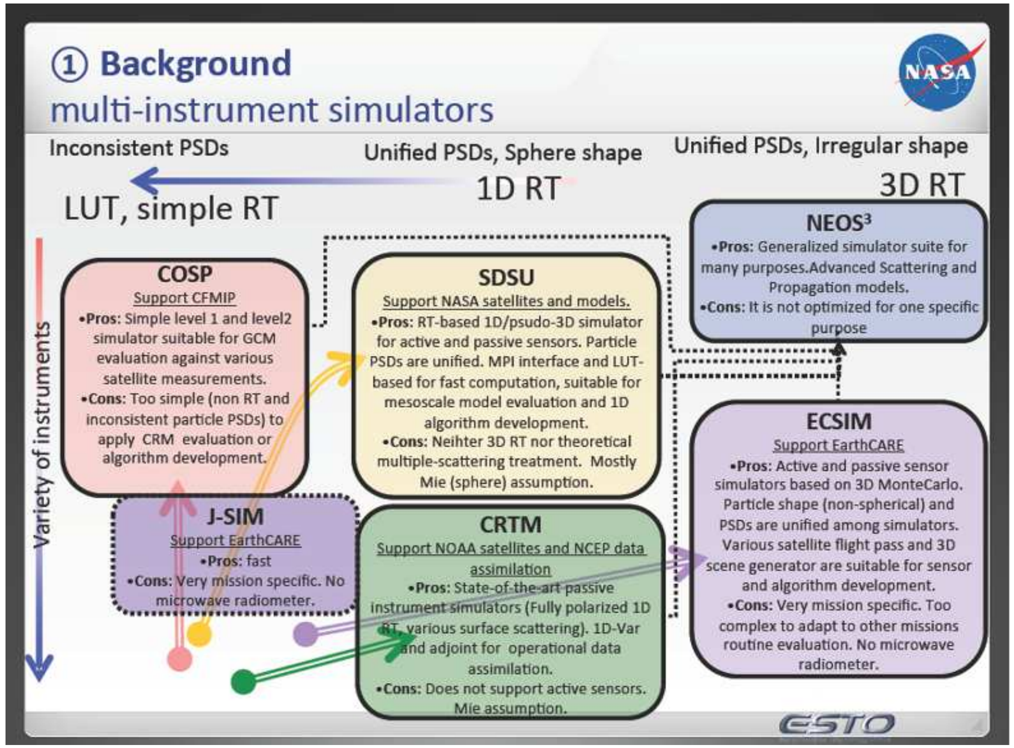
- *衛星シミュレータとは*
  - Joint-Simulator
- *数値モデルと衛星シミュレータとの連携研究*
  - NICAM**雲微物理スキームの改良**
  - **衛星データを用いたデータ同化**：NICAM-LETKF
- *今後の展望*

衛星シミュレータとは?



Masunaga et al. (2010, BAMS)

Simone Tanelli et al. (SPIE2012)



Joint Simulator for Satellite Sensors

- Simulate EarthCARE observations from Cloud Resolving Model (CRM) outputs.
- Built on Satellite Data Simulator Unit (SDSU) (Masunaga et al. 2010, BAMS), specifically NASA Goddard-SDSU (NASA-open source http://opensource.gsfc.nasa.gov/projects/G-SDSU/index.php)
- Target: validation and improvement of aerosol-cloud microphysical schemes in cloud resolving models
  - Has an universal interface that can be applied for various cloud microphysical outputs
    - For Global CRMs as well as regional CRMs.

      e.g., NICAM, WRF, GCE, etc.
  - Provide diagnosis tools and data set

EarthCARE Active SEnsor Simulator (EASE)

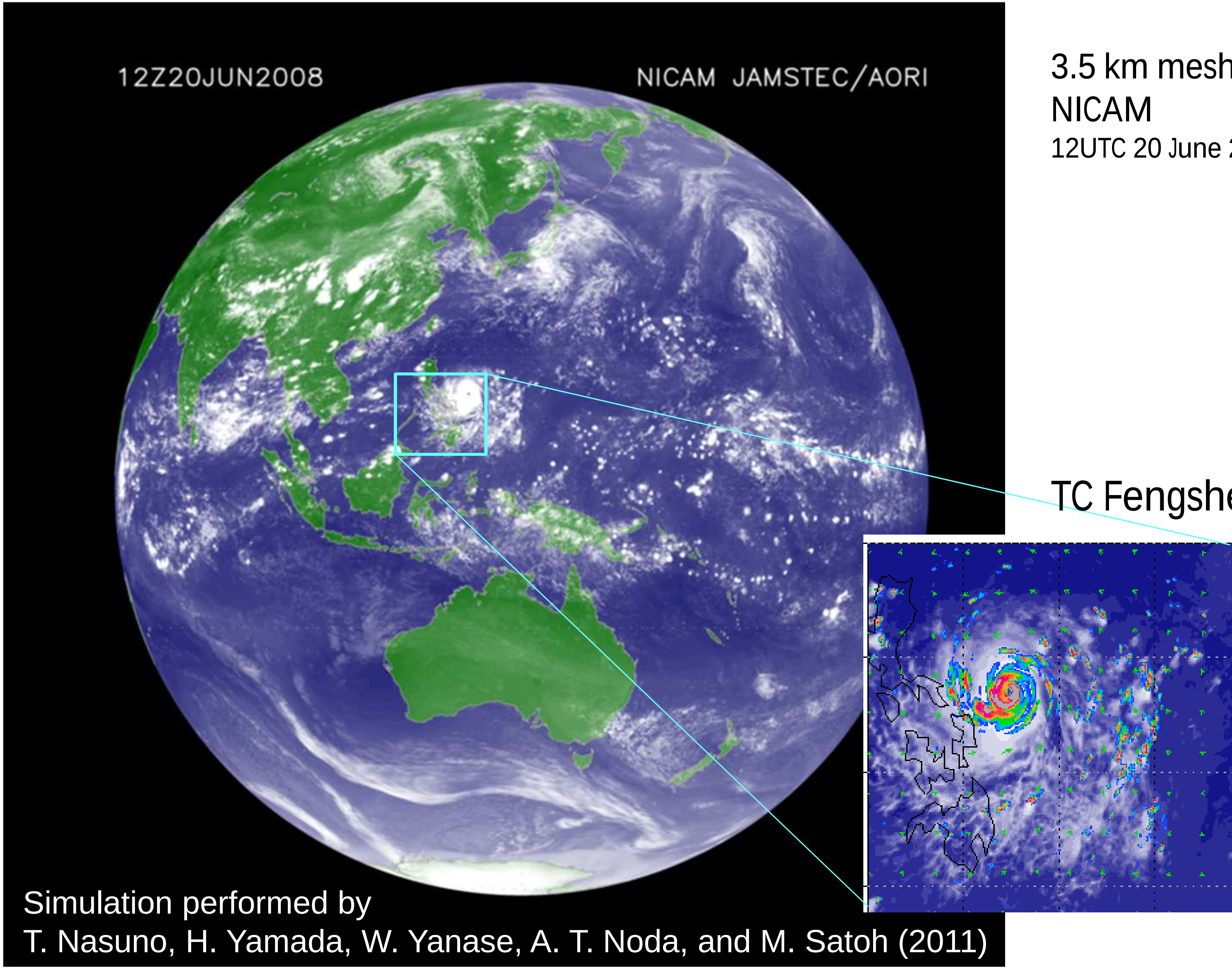
Okamoto et al., 2007, 2008 JGR, Nishizawa et al., 2008 JGR

J-simulator available by requests; see
http://www.eorc.jaxa.jp/EARTHCARE/about/jointsimulator_j.html
https://sites.google.com/site/jointsimulator/home_jp

数値モデルと衛星シミュレータの連携研究

- 数値モデルと衛星データの比較･検証
- 数値モデルの改良
- データ同化

3.5 km mesh
NICAM
12UTC 20 June 2008



TC Fengshen

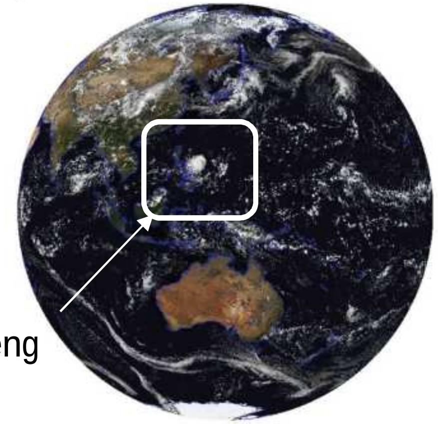
Simulation performed by
T. Nasuno, H. Yamada, W. Yanase, A. T. Noda, and M. Satoh (2011)

NICAMシミュレーションへのJoint-simulator の適用例

Hashino et al. (2013, *J. Geophys. Res.*)

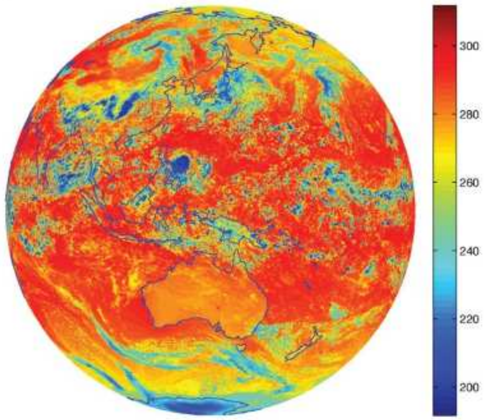
a) **可視** 0.62 μm

Background: Blue Marble: Next Generation, NASA

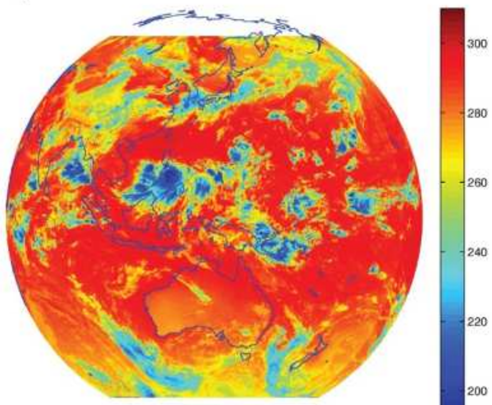


台風Fengsheng

b) **赤外** 10.8 μm TB [K]

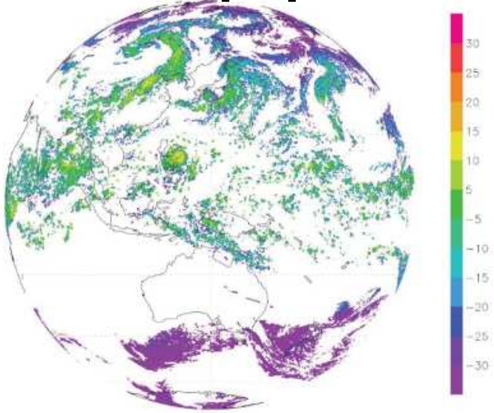


c) **赤外（観測）** 10.8 μm TB [K]

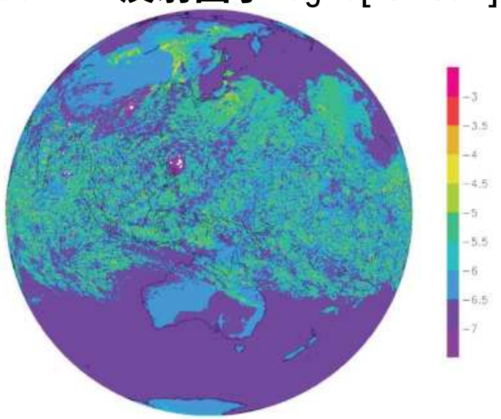


MTSAT (MRI, Japan; Chiba Univeristy, CEReS)+ globally-merged IR (CPC, NOAA)

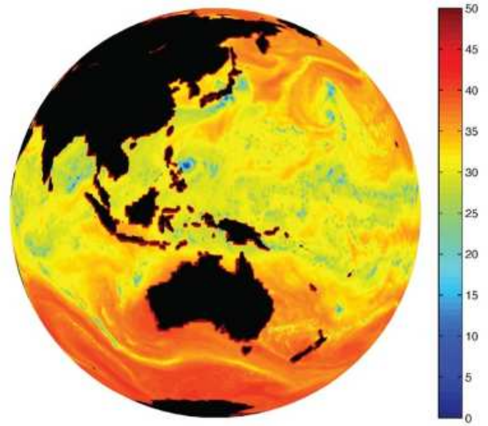
d) **雲レーダー（高度**10km)
94 GHz CPR [dBZ]



e) **ライダー（高度**14km)
532 nm **反射因子**Log10[1/m/str]

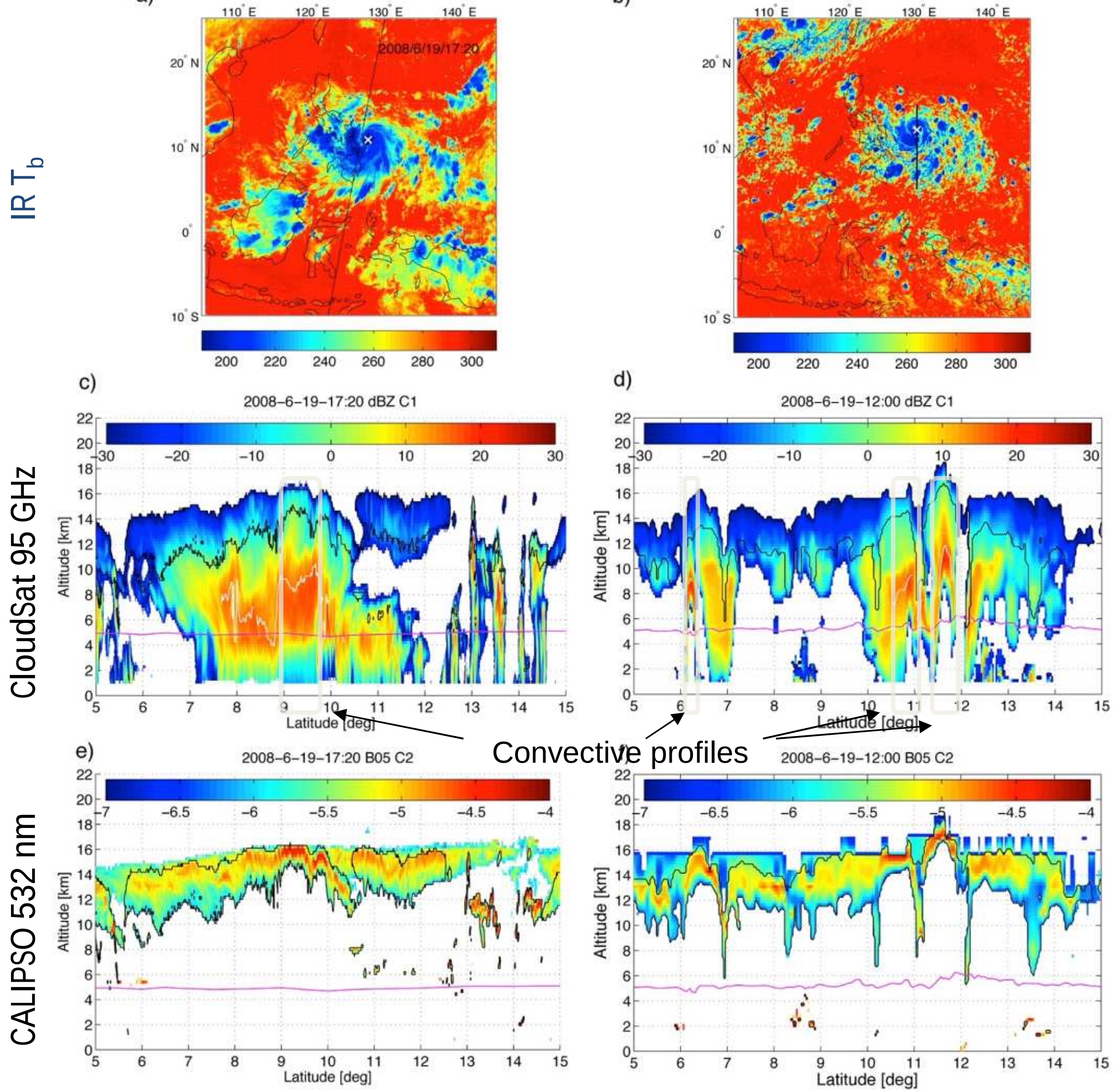


f) **マイクロ波** Pol diff for 19GHz



台風Fengshen の比較

観測　　数値シミュレーション



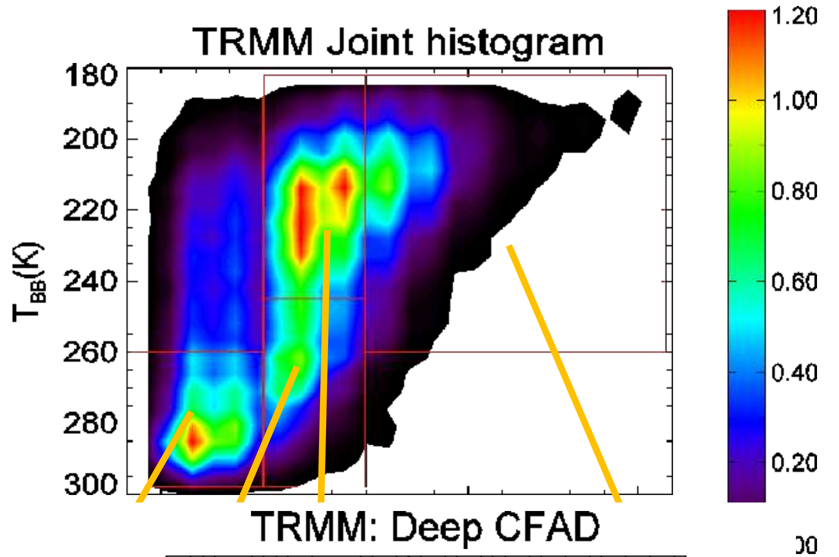
- Overlap regions of C1 and C2 mask (black lines) extends up to ~4 km both in OBS and NICAM.
- The altitude of multiple scattering onset (white lines, Battaglia et al. 2011) and high β_{532} suggest the convective profiles.
- Simulation: a lack of radar reflectivity found in the convective cores where water contents are high.
- Both of OBS and NICAM show the dark band.

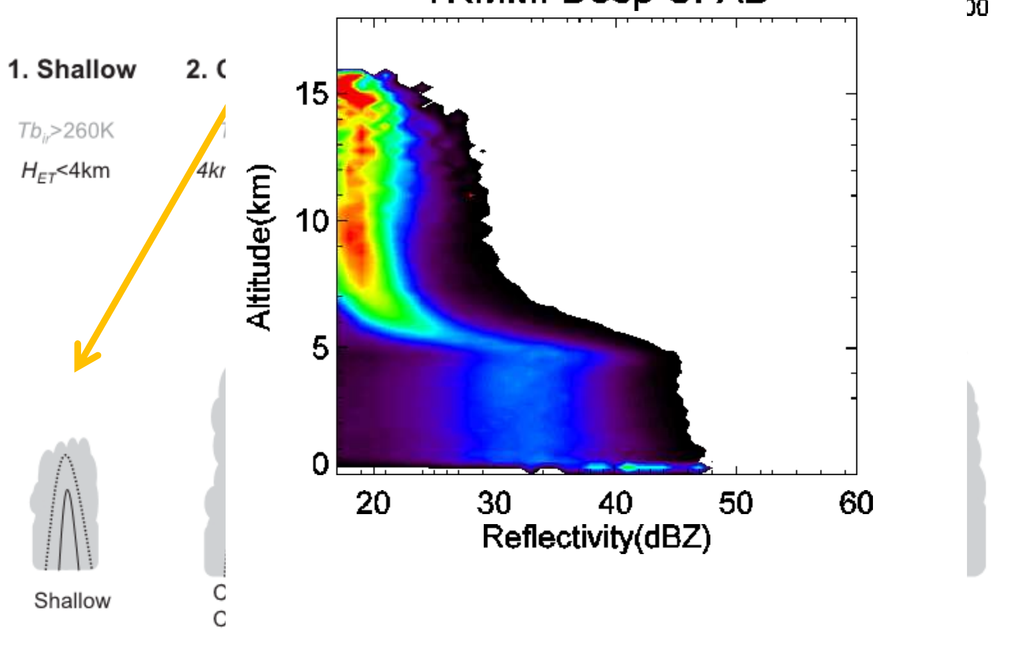
衛星データ･シミュレータを用いた雲スキームの改良

Roh and Satoh (2014, JAS)

T3EF: TRMM Triple-Sensor Three-Step Evaluation Framework (Matusi et al., 2009)

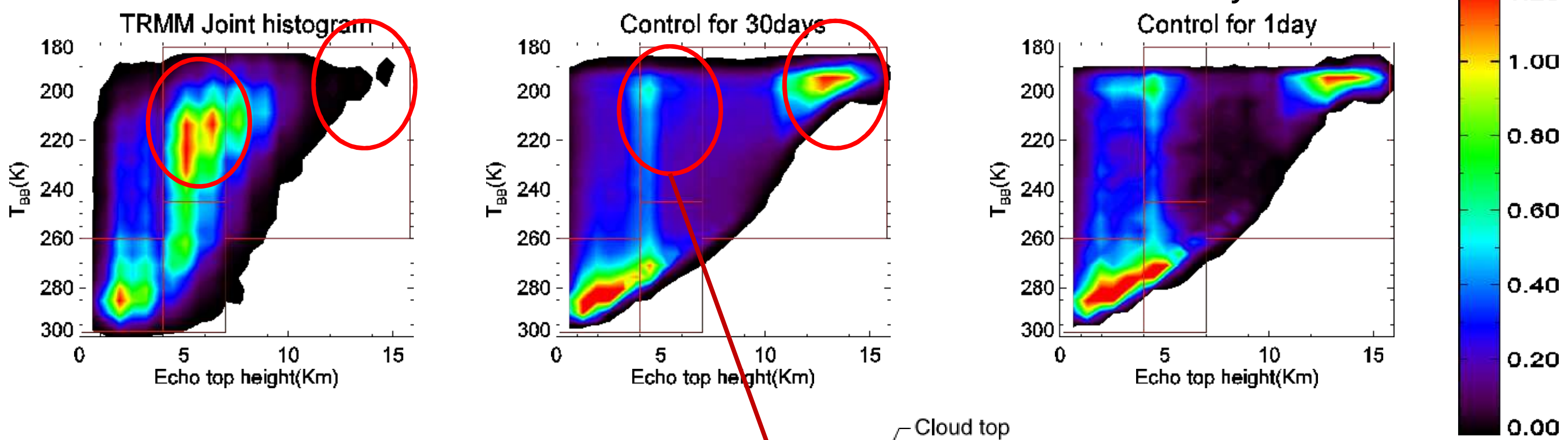
1) Creating joint diagrams of precipitating cloud types from collocated VIRS T_{bIR} and PR H_{ET}(Masunaga et al. 2005)
2) Constructing contoured frequency with altitude diagrams (CFADs) of PR reflectivity for each precipitating cl type
3) Constructing cumulative probability distributions of TMI PCT_{b85}.

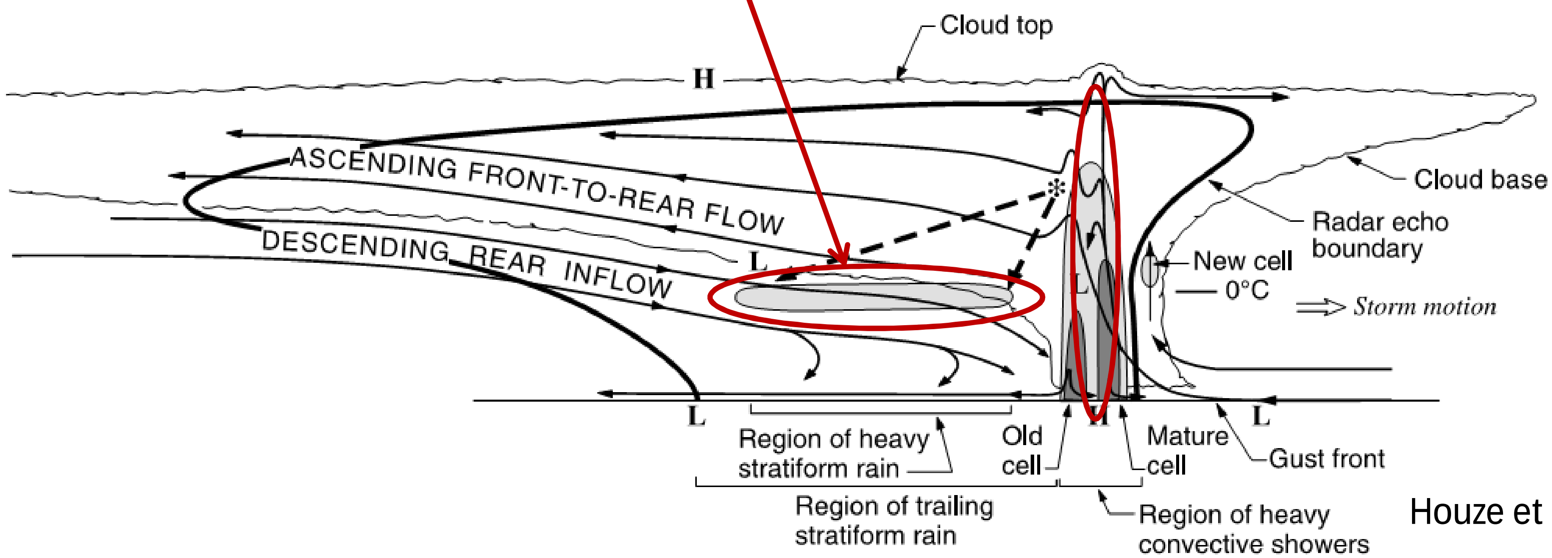




Joint histogram of echo top height and TBB

TRMM NICAM 1days run



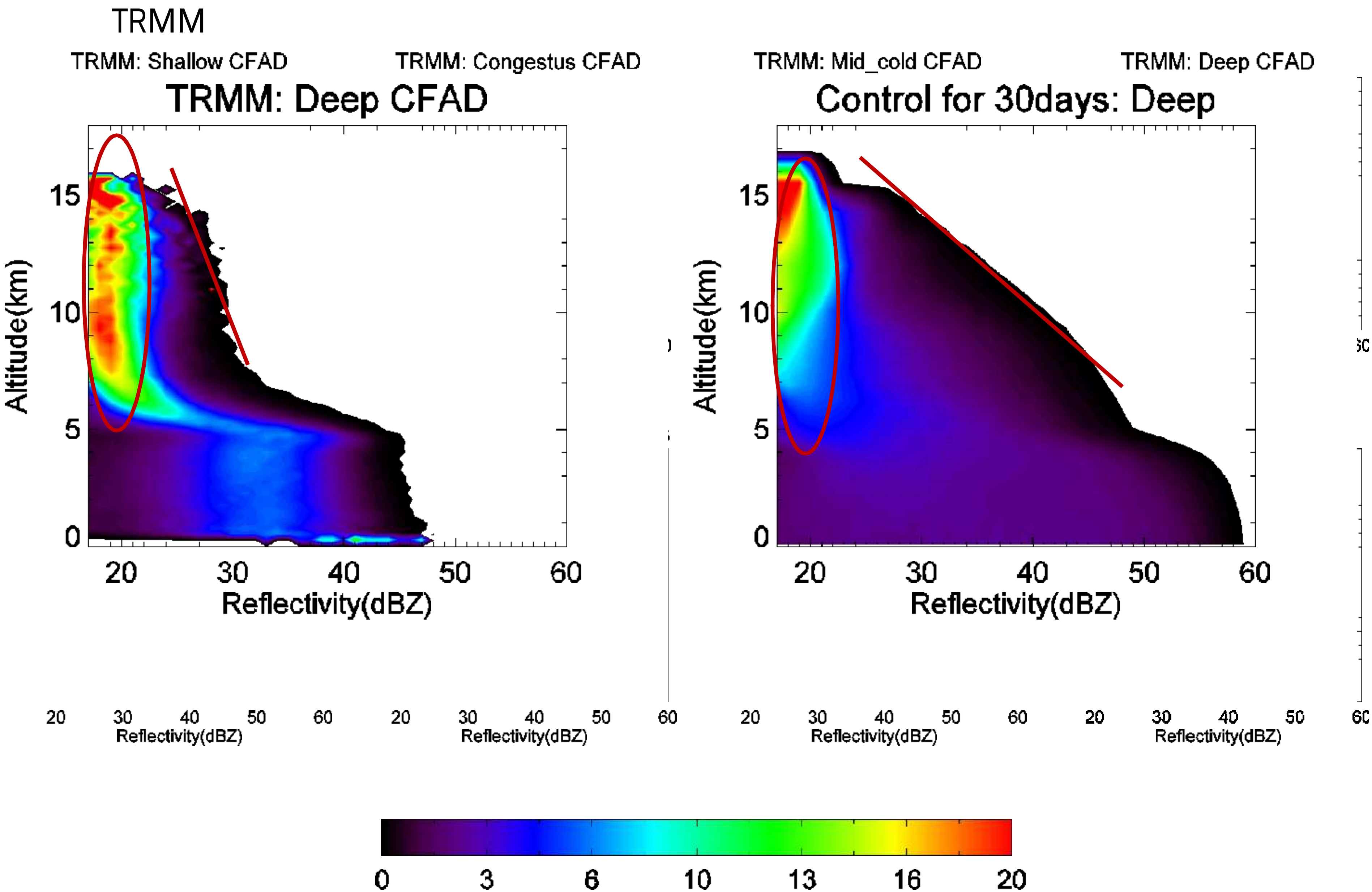


Houze et al. 2004

Stratiform Convective

1. Overestimation of frequencies over 12 km
2. Underestimation of stratiform precipitation

CFADs of each category



4. Modification of microphysics scheme

Brief description of modification and sensitivity tests

1. Common modifications

Saturation adjustment for cloud ice → Ice nucleation and ice deposition (Hong et al. 2004)

Turn off collection terms of snow and ice by graupel (Lang et al. 2007)

2. Size distributions

A. Snow → Selection → B. Graupel → Selection → C. Rain

A. Snow

1) Parameterizations of size distributions
2) Sensitivity tests of density effects

B. Graupel

1) N_{0G}
2) Sensitivity tests of Mass-dimension relationship

C. Rain

1) MP distribution
2) Zhang et al. 2008 method
3) The combined method

To investigate effects of size distribution on T3EF framework in the same scheme

Modification 1

1) Common modifications

- Turn off : accretion of graupel with snow (Lang et al., 2007)

  graupel + snow → graupel

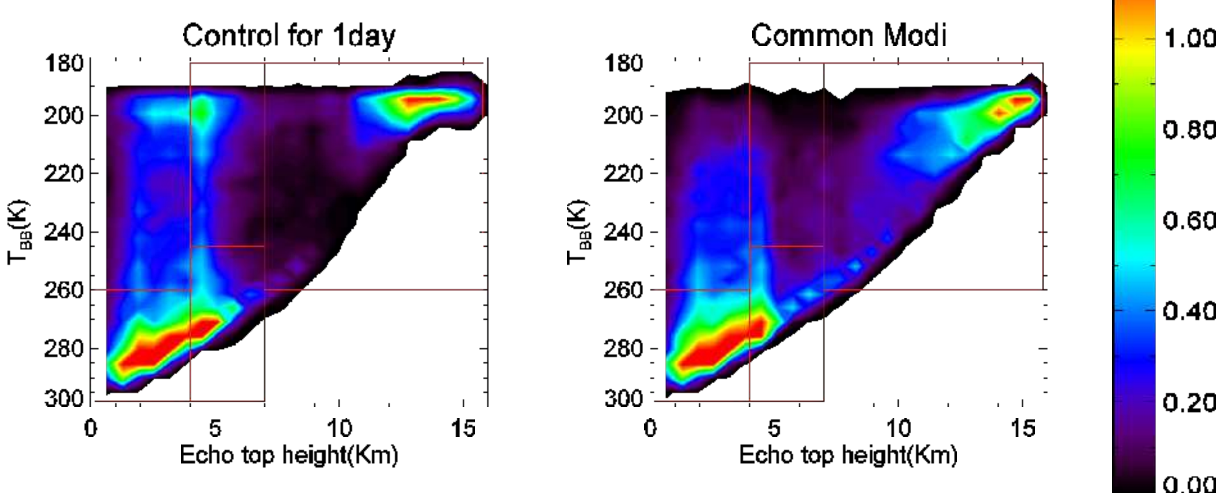
- Turn off : accretion of graupel with ice (Lang et al., 2007)

  graupel + cloud ice → graupel

(Excessive amounts of graupel are reproduced by single moment microphysics scheme. (Lang et al., 2007; Li et al., 2008; Matsui et al., 2009))

- Saturation adjustment → ice nucleation based Fletcher et al. (Hong et al. 2004)
- Introduction to depositional growth of cloud ice (Hong et al. 2004)

Control | Applied by upper changes



2A Snow

2A) Parameterization of snow size distribution

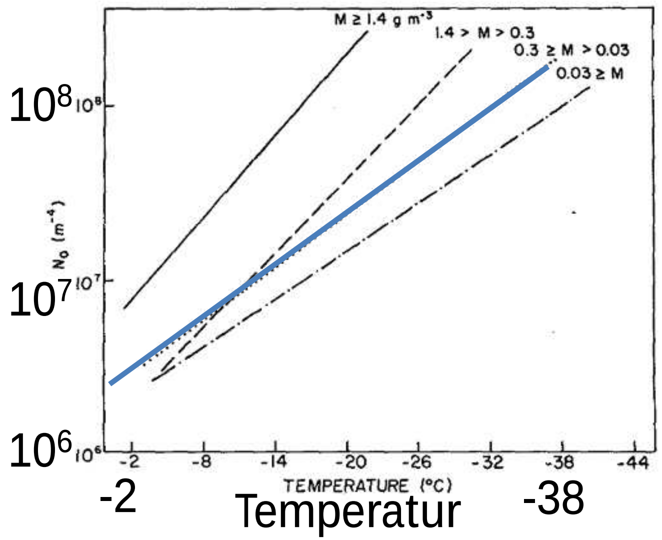
- Parameterization of N_0 using temperature (Hong et al. 2004)

  - Houze et al. 1979

  - $N_{0S} = 2 \times 10^6 e^{-0.12 \times T}$

  - negative exponential distributions

  - m(D) ∝ D^3

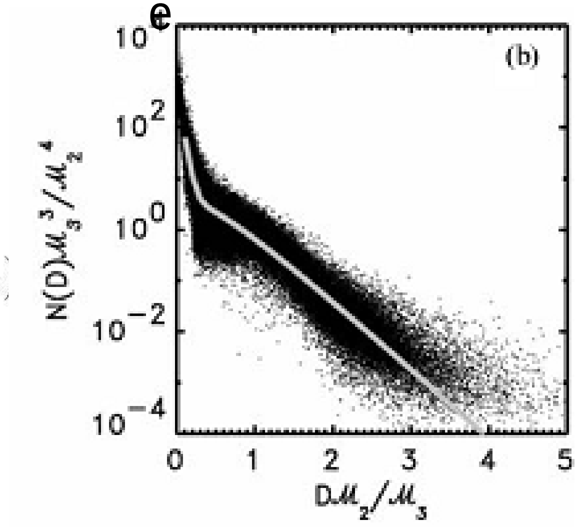


- Parameterization of moments using temperature and ice water content (Thompson et al. 2008)

  - Field et al. 2005

  - bimodal size distribution

  - m(D) ∝ D^2



$$N(D) = \frac{M_2^4}{M_3^3} 490.6\exp(-20.78 x_{23}) + 17.46 x_{23}^{0.6357} \times \exp(-3.290 x_{23})$$

Exp. dist. Gamma dist.

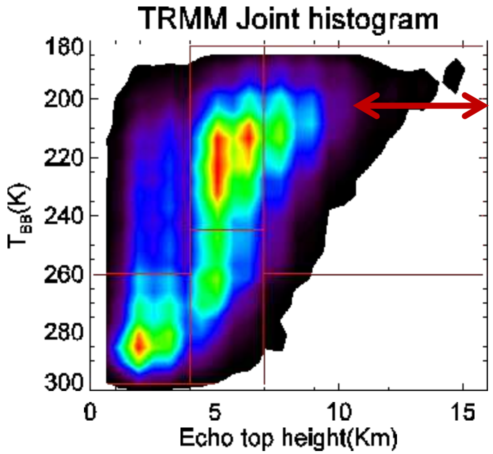
$$x = D(M_i/M_j)^{1/(j-i)} \qquad M_n = \int_0^\infty D^n N(D)dD$$

$$M_n = a(n, T_c) M_2^{b(n,T_c)}$$

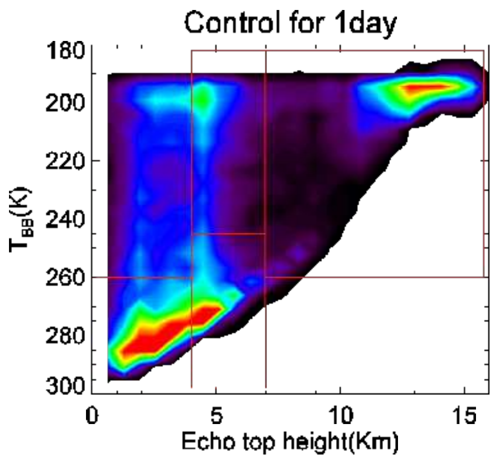
2A Snow

Sensitivity tests of snow size distribution - Histograms

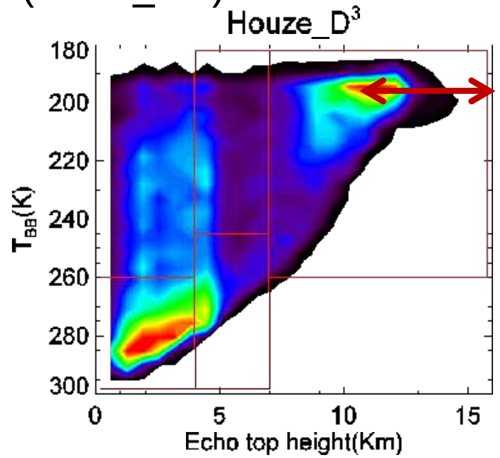
TRMM



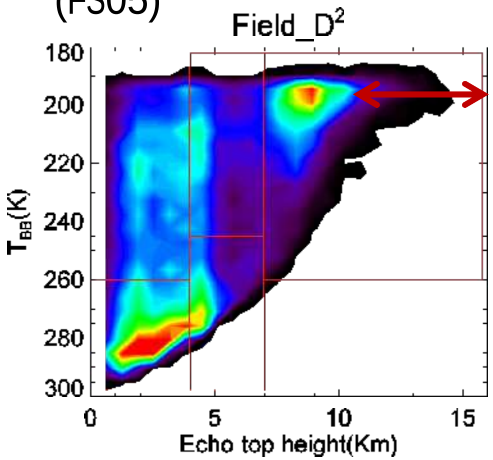
Control Run

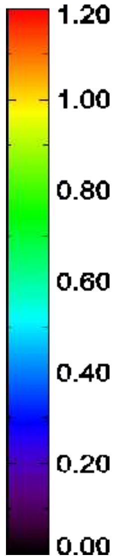


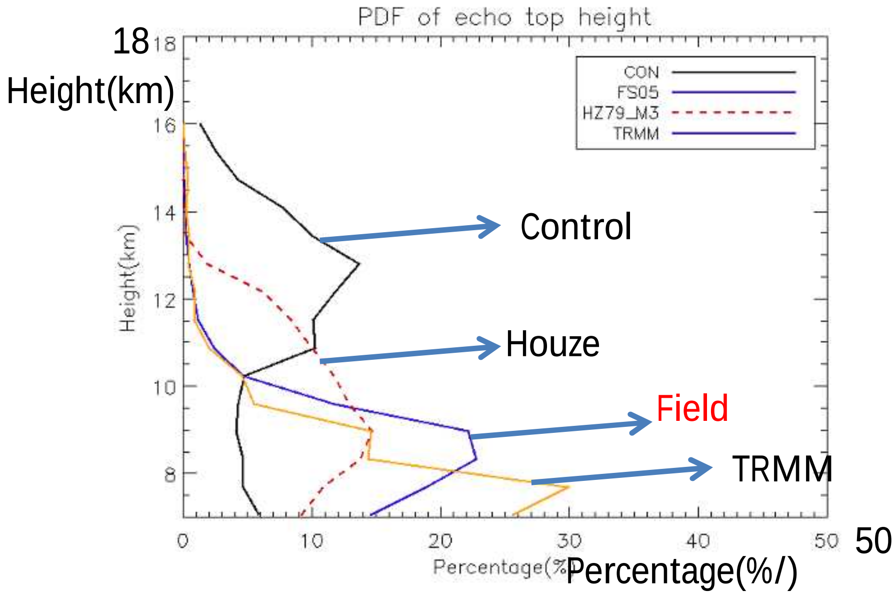
Houze 1979, Fixed density (HZ79_M3)



Field 2005, Flexible density (FS05)

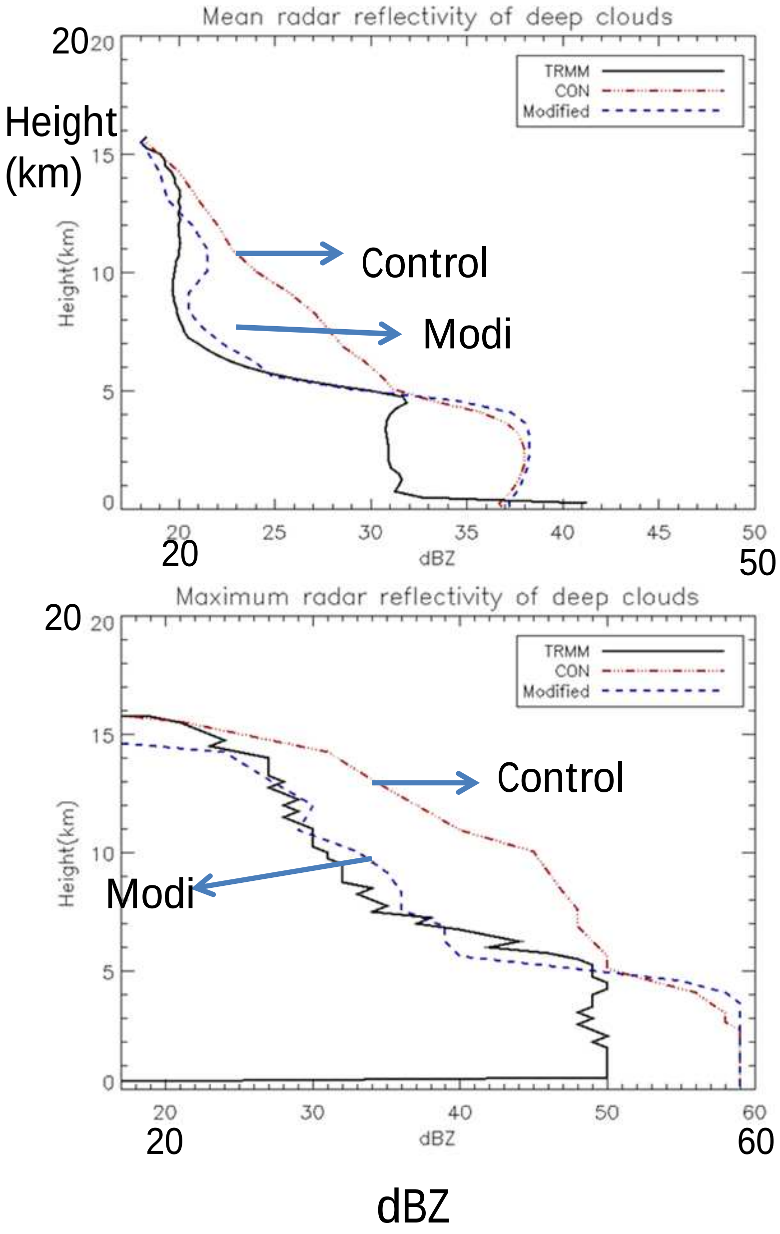


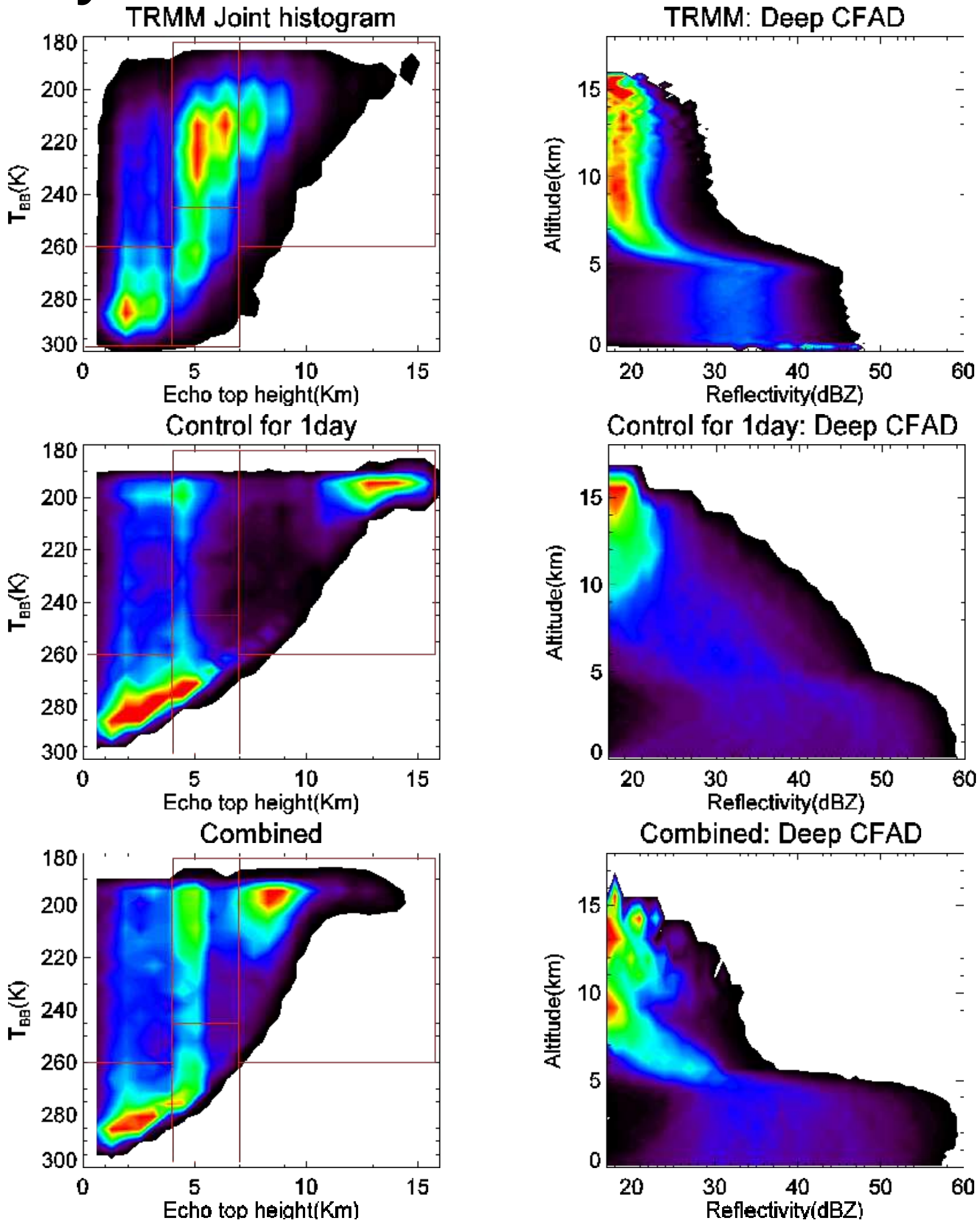




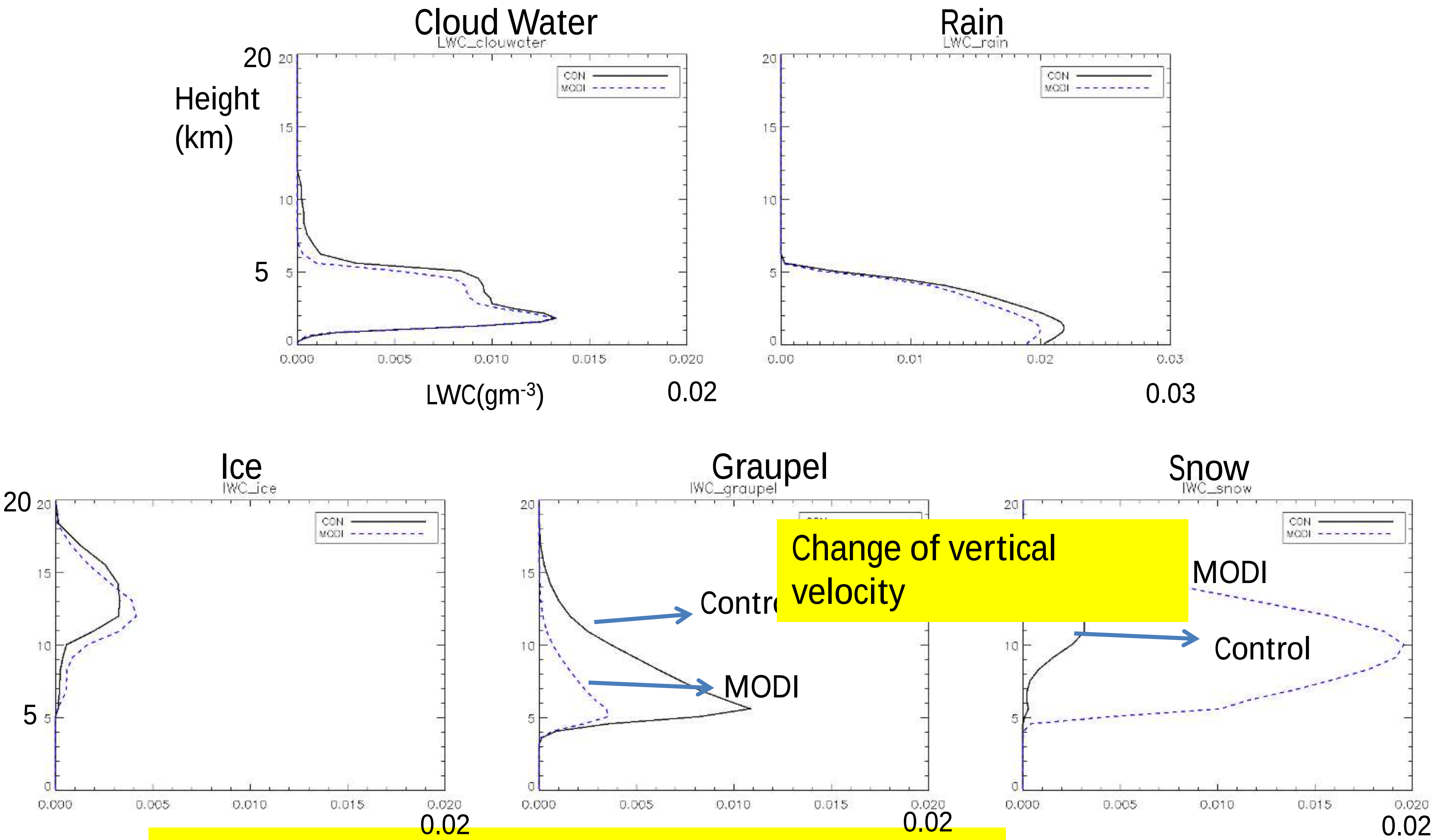
Total

Summary of results





Vertical distribution of LWC/IWC of average hydrometeor



The amounts of graupel decrease and the amounts snow increas in the modified simulation.

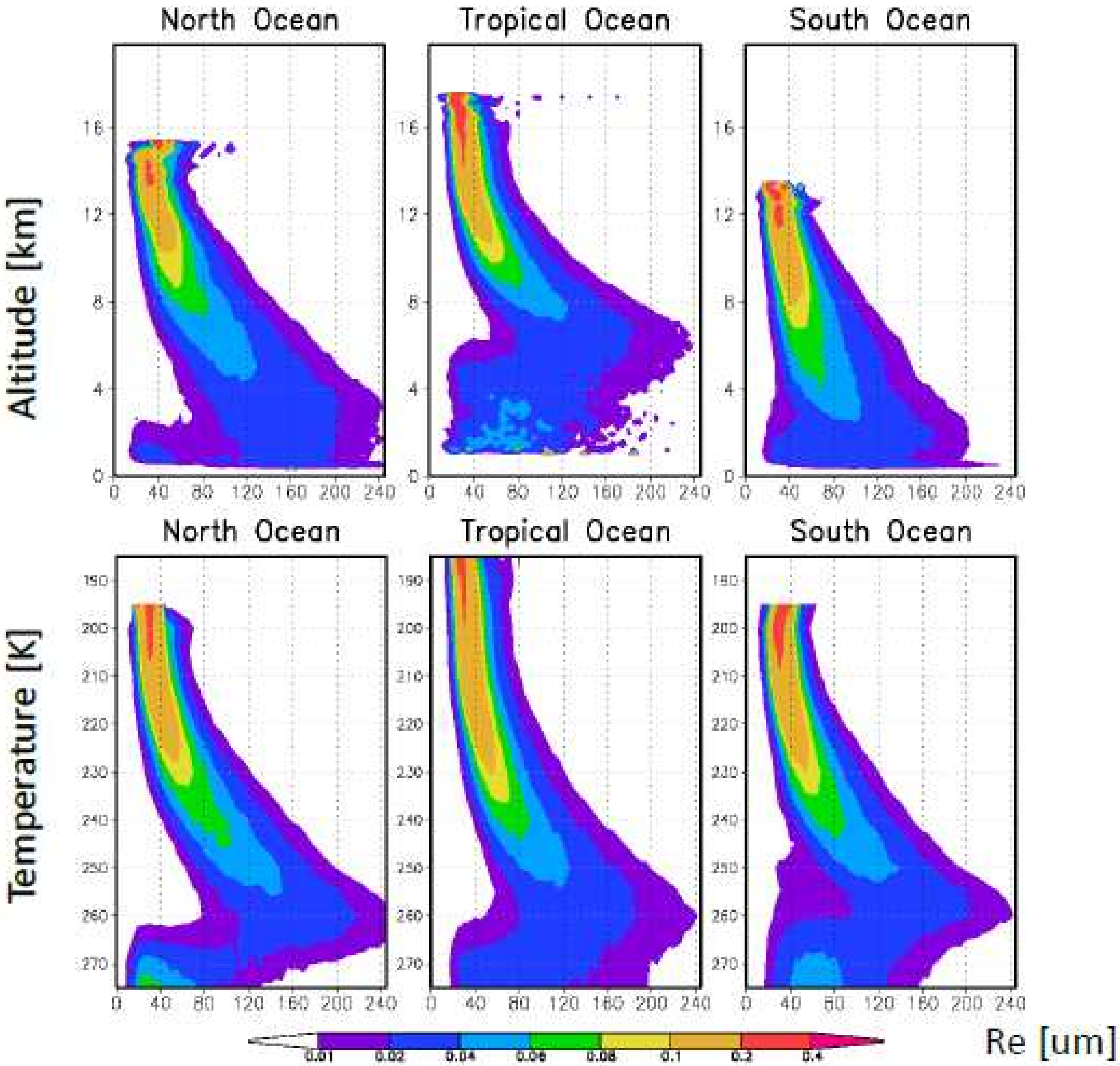
Cloud evaluation diagnosis

1. Contoured Frequency by Temperature Diagram (CFED)

2. BETTER (cloud-top beta-temperature radar-conditioned) diagram

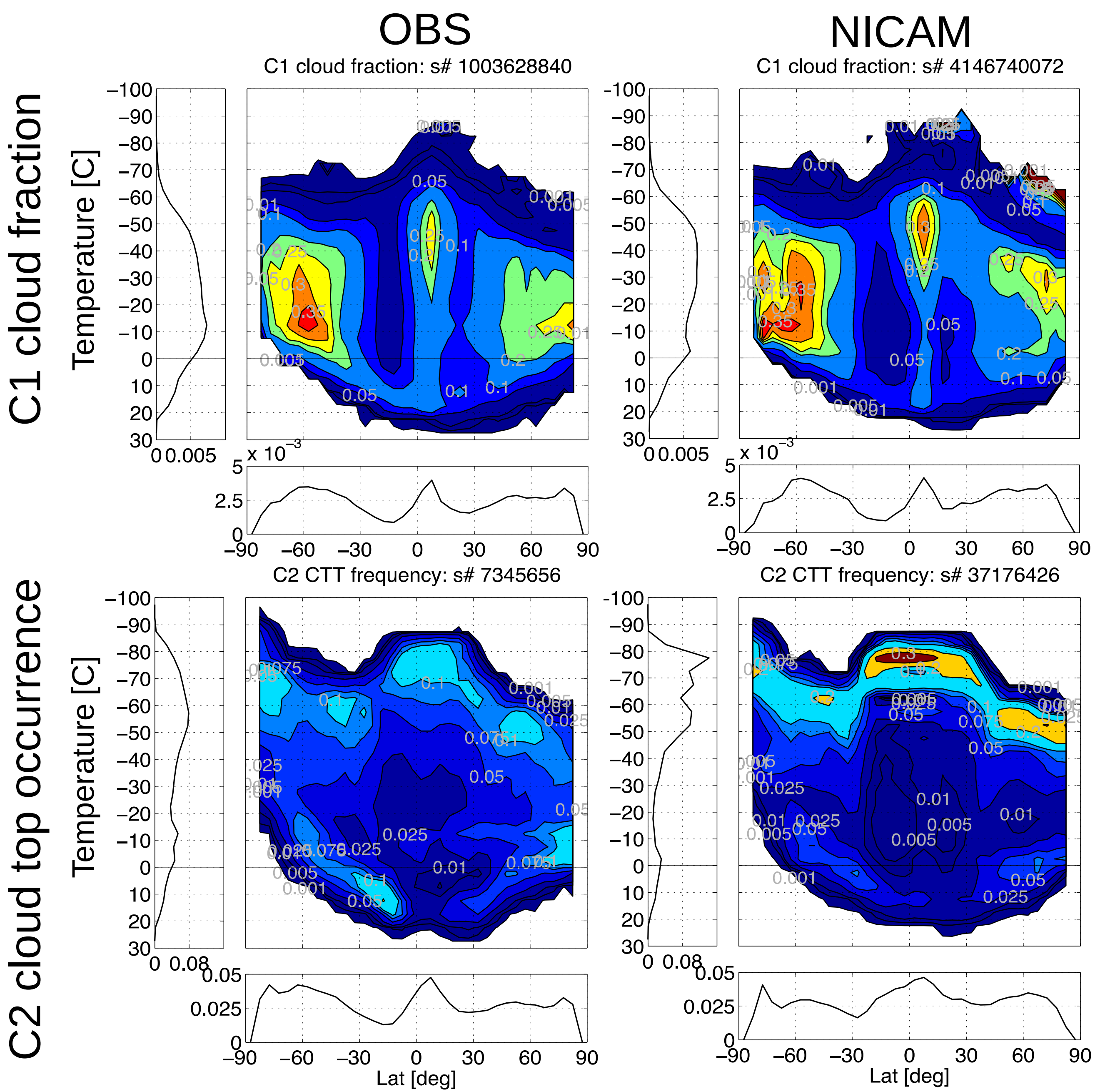
3. Cloud Classification & Cloud radiative forcing analysis

CFAD (obs) of Cloud Ice Effective Radius



CloudSat–CALIPSO merged dataset (CSCA-MD) [Hagihara et al. 2010, JGR; Okamoto et al. 2010]

Meridional-Temperature distribution



NICAM

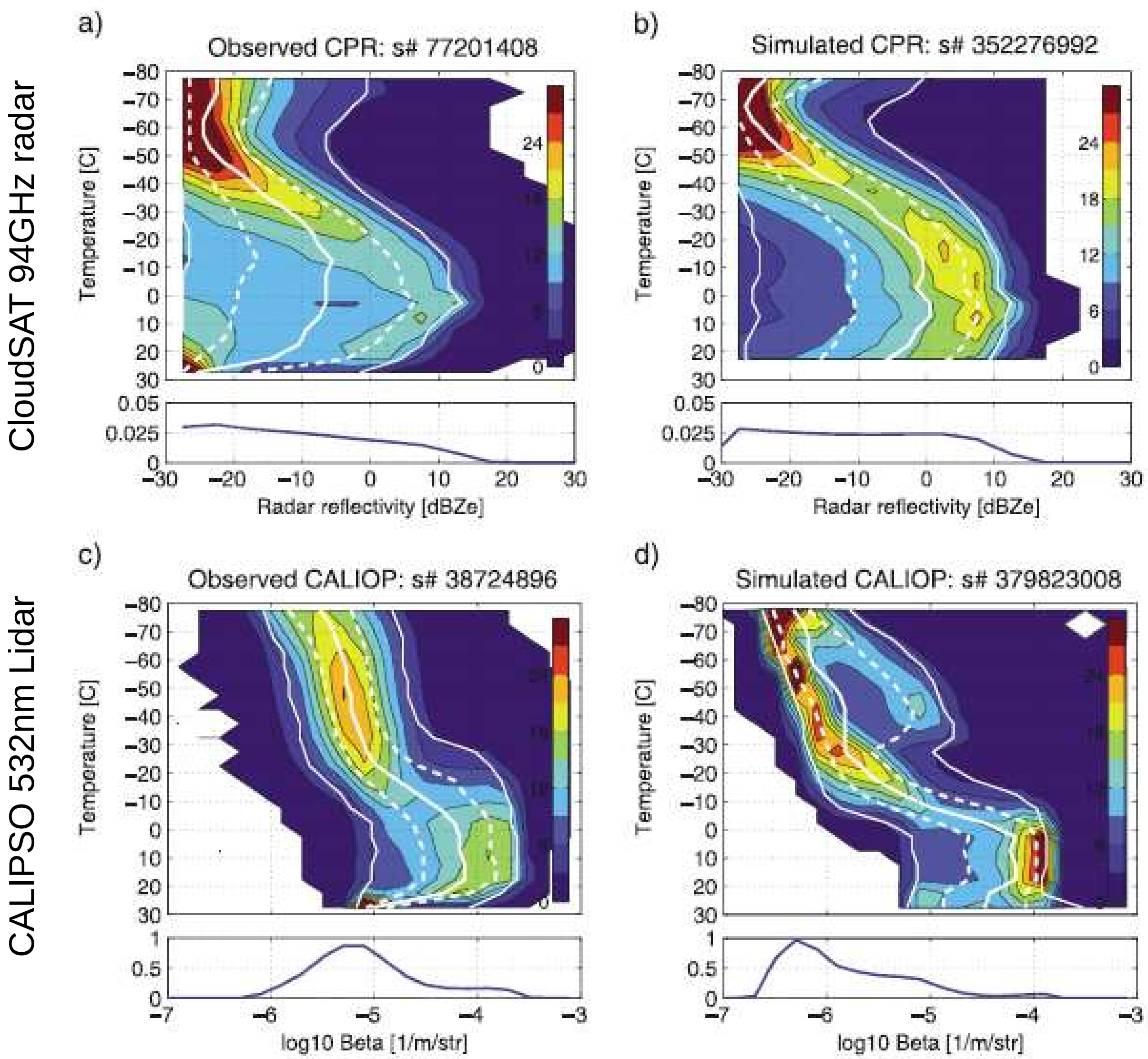
- C1 CF: generally good agreement with OBS (R=0.88).
- Captures the max CF in the tropics.
- Overestimates
  - ✓ high clouds at T < -30 ° C over most of the latitudes.
  - ✓ low-level clouds in high latitudes.
- Underestimates
  - ✓ subtropical warm clouds

Further info on cloud types

- C2 CTO: poor agreement with OBS.
- Captures the high and low clouds qualitatively.
- Misses middle clouds (-20 < cloud top T < -10C) in the tropics and northern mid latitudes.
- Polar stratospheric clouds are simulated.
- Higher relative occurrences of high clouds.

Global Contoured Frequency by tEmperature Diagram (CFED)

OBS NICAM



OBS

- one single dominant mode for a given T at T < -10C (z as vertical axis does not show it)

NICAM

- High occurrences of small dBZe especially at -60<T< -30 ° C.
- Overestimates the occurrence of 0 < dBZe' < 10 dB.
- The 95th quantile smaller at T < -40 ° C and -20 < T < 10 ° C.
- The 50th quantile larger at -35 < T < 0 ° C.

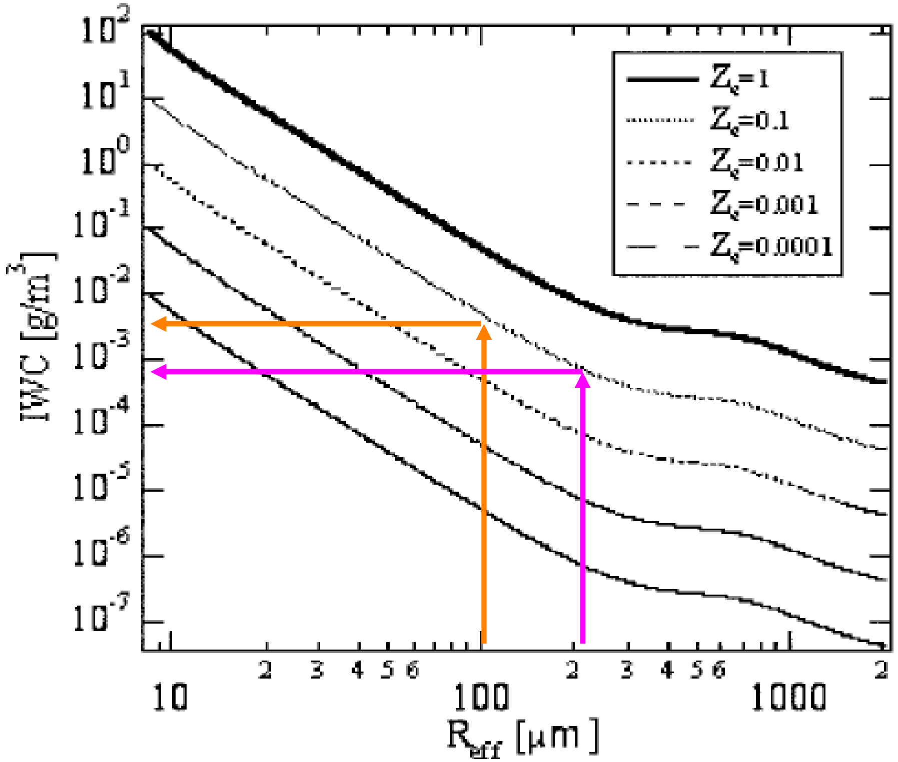
- Two modes exist for log10(β_{532}) at T < -40 ° C level.
- the 75th and 95th quantiles underestimated for liquid

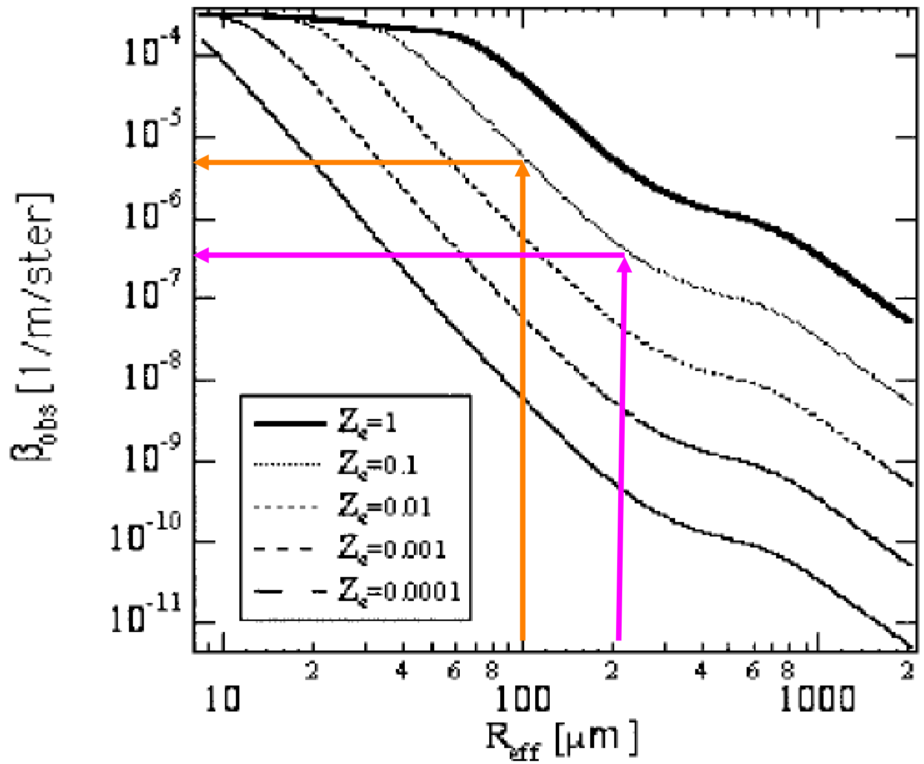
Contribution of each hydrometeor category

Cloud ice | Cloud droplets
Snow | Rain
Graupel

BETa-TEmperature Radar-conditioned diagram (BETTER)

Okamoto et al. (2003)   *Aim: obtain the relative information on size and IWC.*

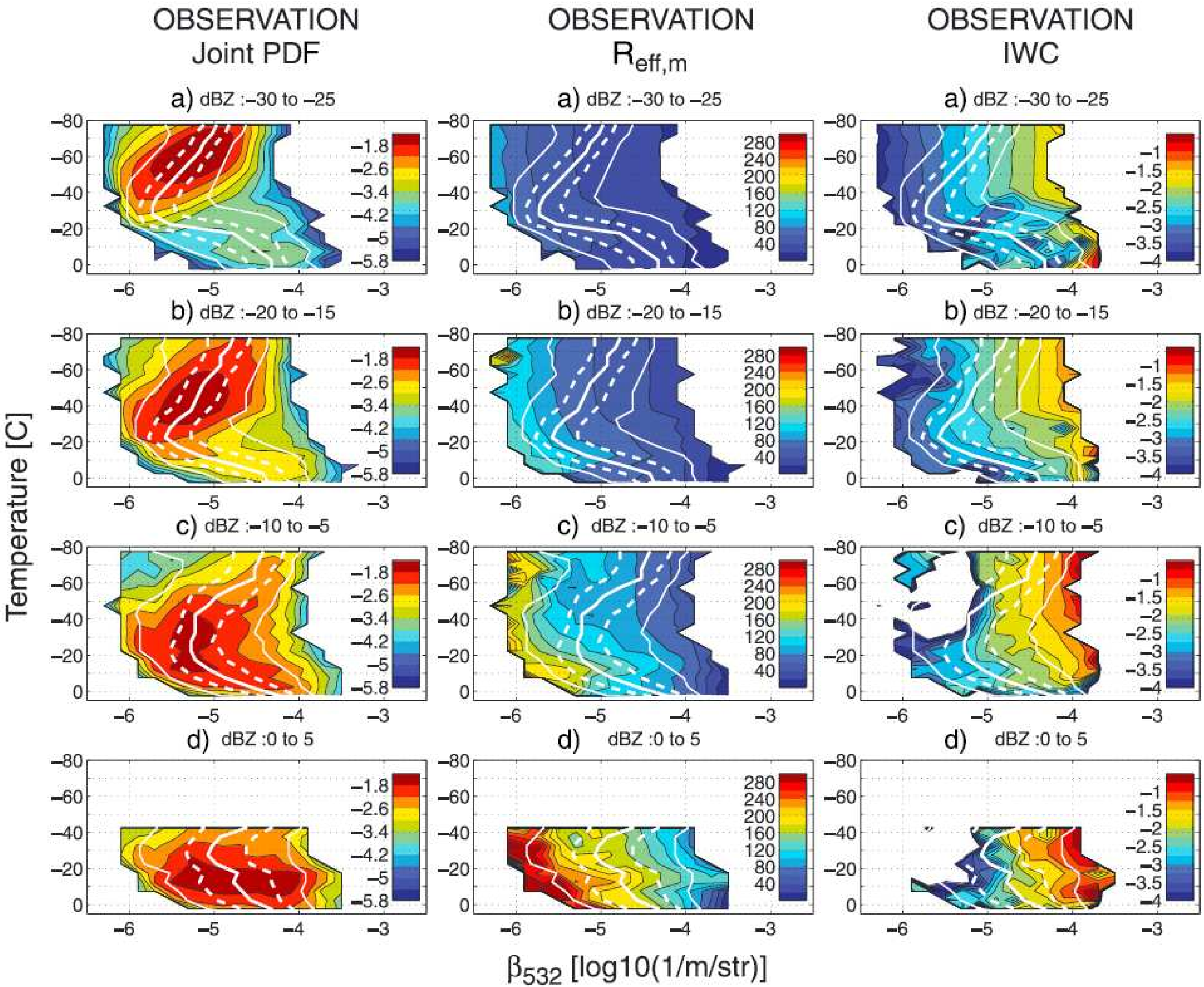




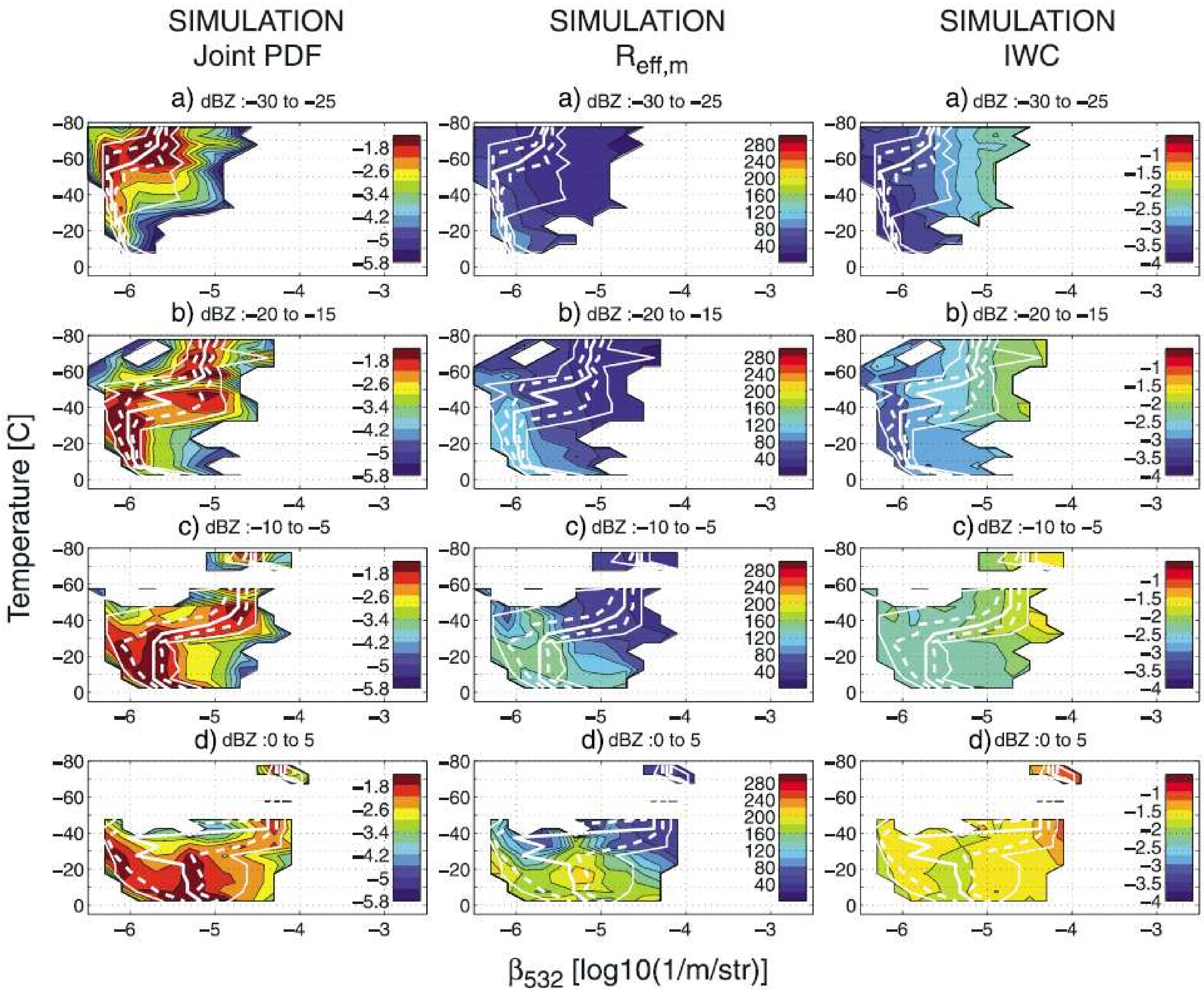
If Z_e are the same among two grid boxes, smaller R_{532} means larger $R_{eff,m}$ and smaller IWC

Assumption

Both the observation and simulation follow a similar R_{532} - $R_{eff,m}$ and IWC - $R_{eff,m}$ relationship for a given Z_e.



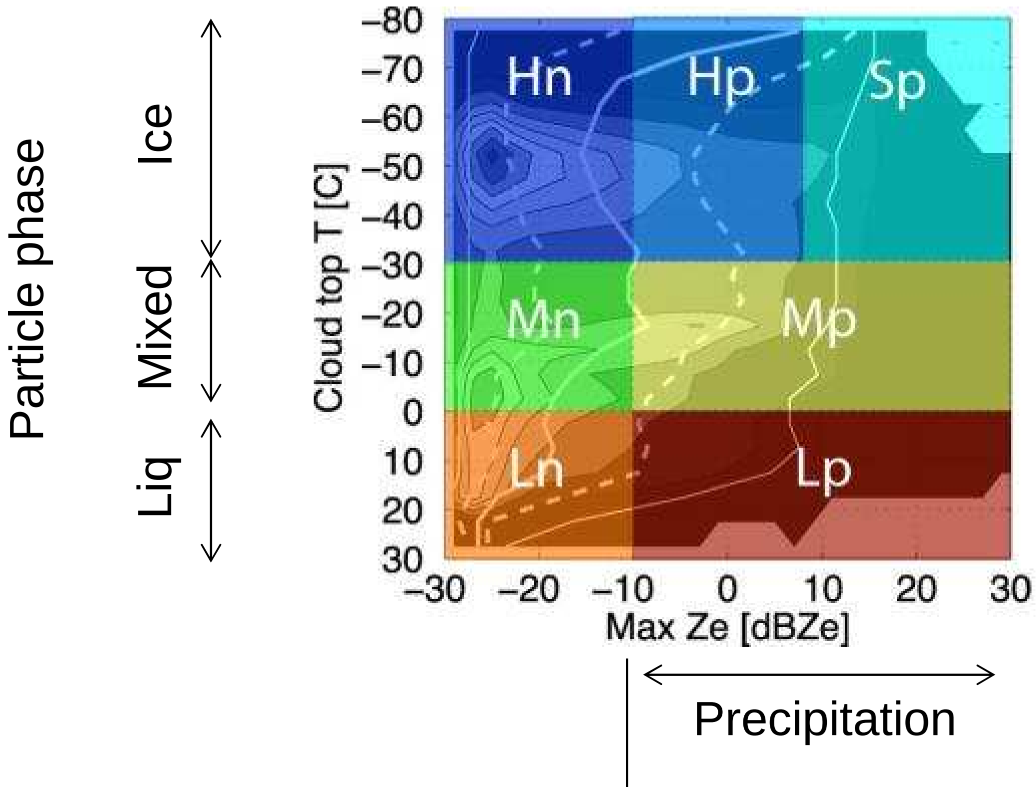
OBSERVATION
Joint PDF
OBSERVATION
$R_{eff,m}$
OBSERVATION
IWC
a) dBZ :−30 to −25
b) dBZ :−20 to −15
c) dBZ :−10 to −5
d) dBZ :0 to 5
Temperature [C]
β_{532} [log10(1/m/str)]

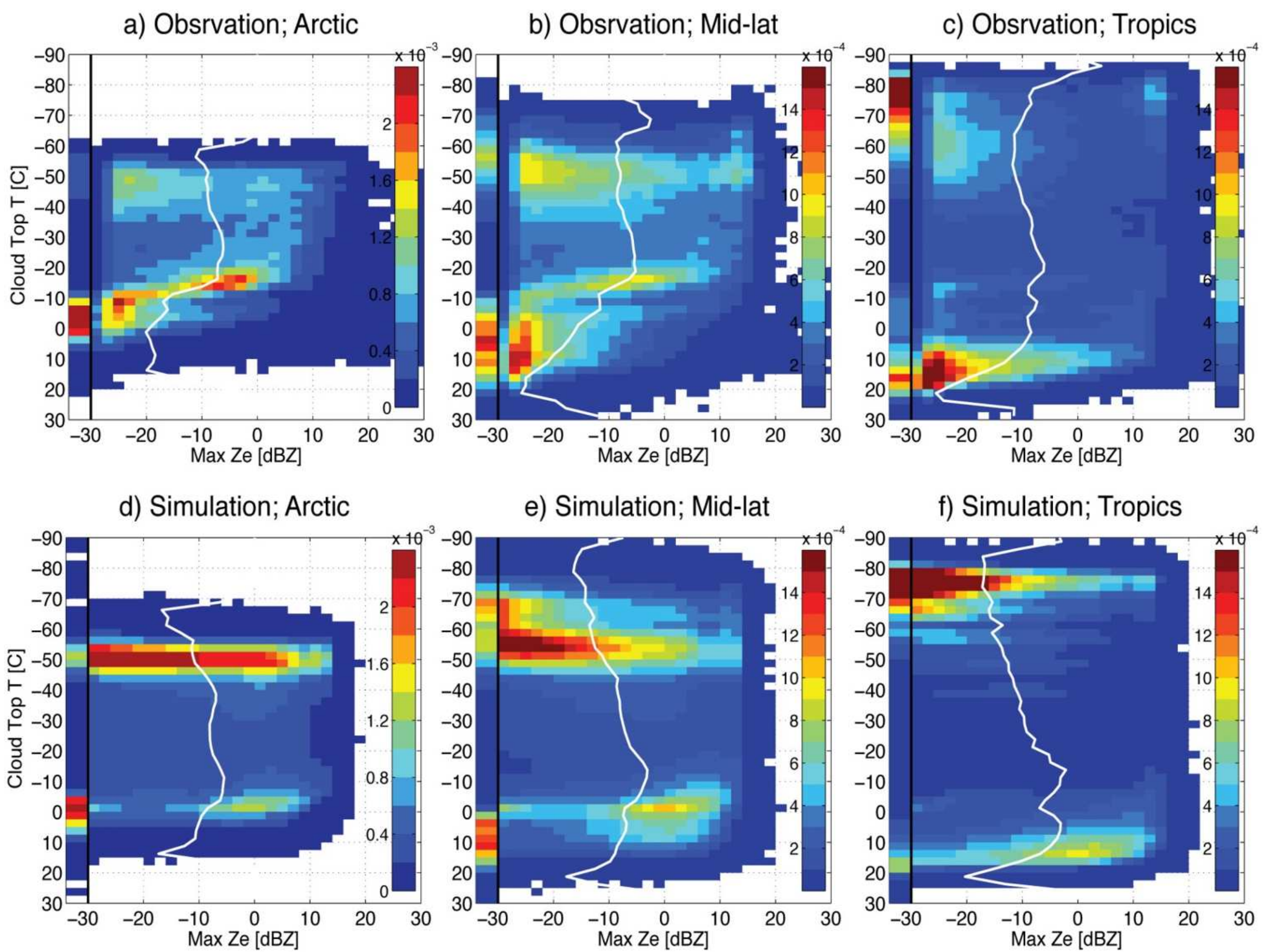

SIMULATION
Joint PDF
SIMULATION
$R_{eff,m}$
SIMULATION
IWC
a) dBZ :−30 to −25
b) dBZ :−20 to −15
c) dBZ :−10 to −5
d) dBZ :0 to 5
Temperature [C]
β_{532} [log10(1/m/str)]

気候モデルの雲放射強制の改善に向けて
Proposed cloud type diagram

Define Cloud Type by separating the domain of Cloud top T and max Ze into seven sub-domains. H: High, S: Storm, M: Mixed-phase, L: liquid. p is for precipitating, n is for non-precipitating.

Cloud Type Diagram

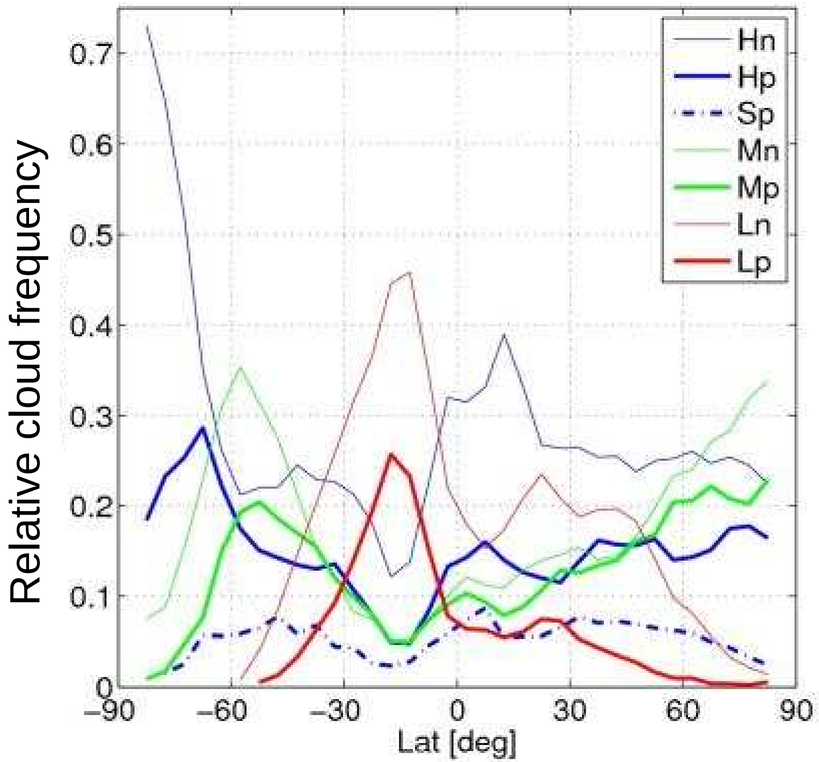




a) Obsrvation; Arctic
b) Obsrvation; Mid-lat
c) Obsrvation; Tropics
d) Simulation; Arctic
e) Simulation; Mid-lat
f) Simulation; Tropics
Cloud Top T [C]
Max Ze [dBZ]
x 10^-3
x 10^-4

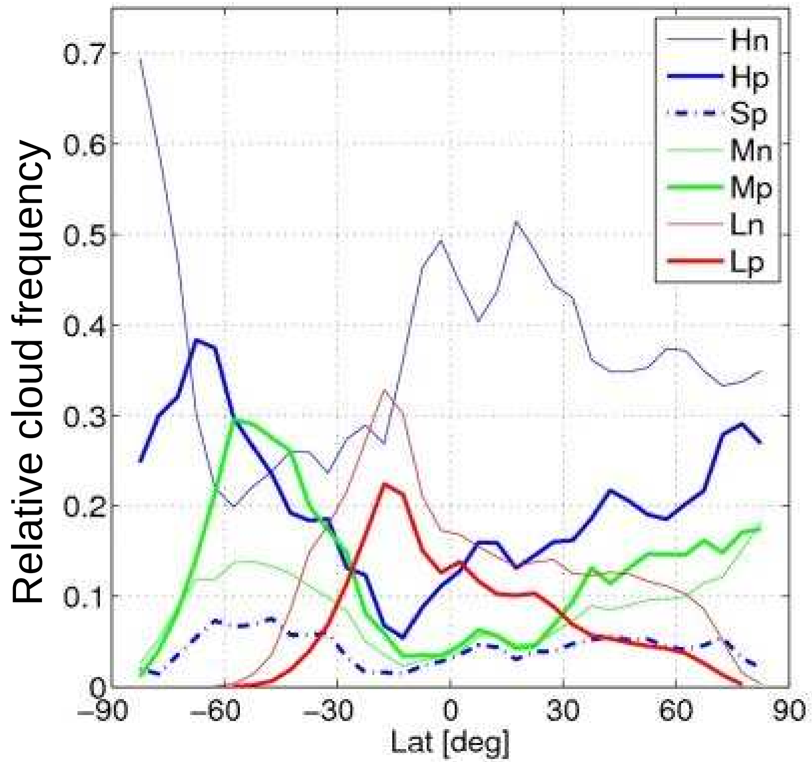
Zonal cloud occurrence by cloud type

OBS



- Hn dominate at Antarctic, Northern latitudes.
- Mn & Mp peaks at 60S and Arctic.
- Ln & Lp peaks at 15S.

SIM

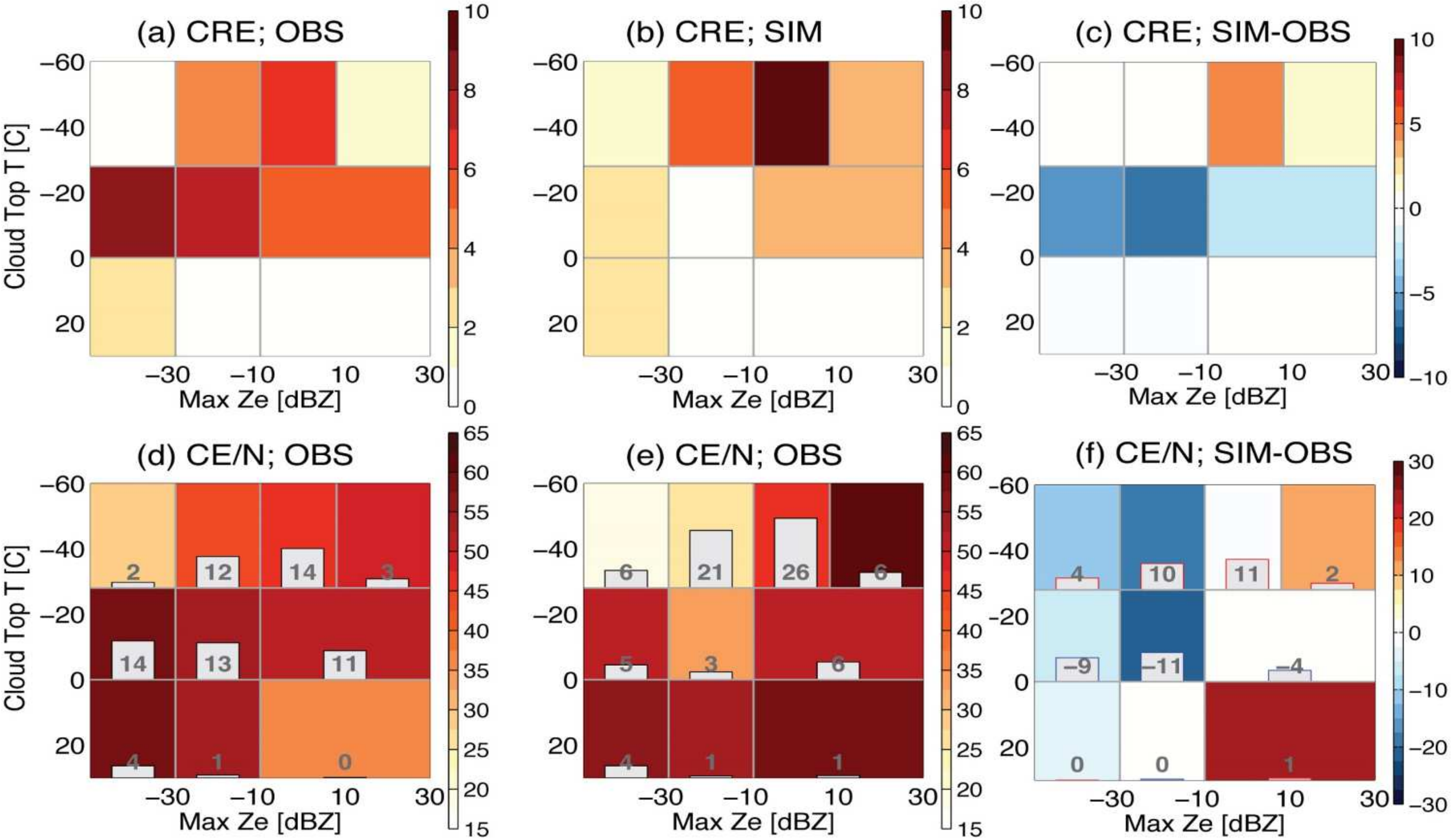


- Both of Hn and Hp are overestimated.
- Mp occurs more than Mn.
- Ln is underestimated.

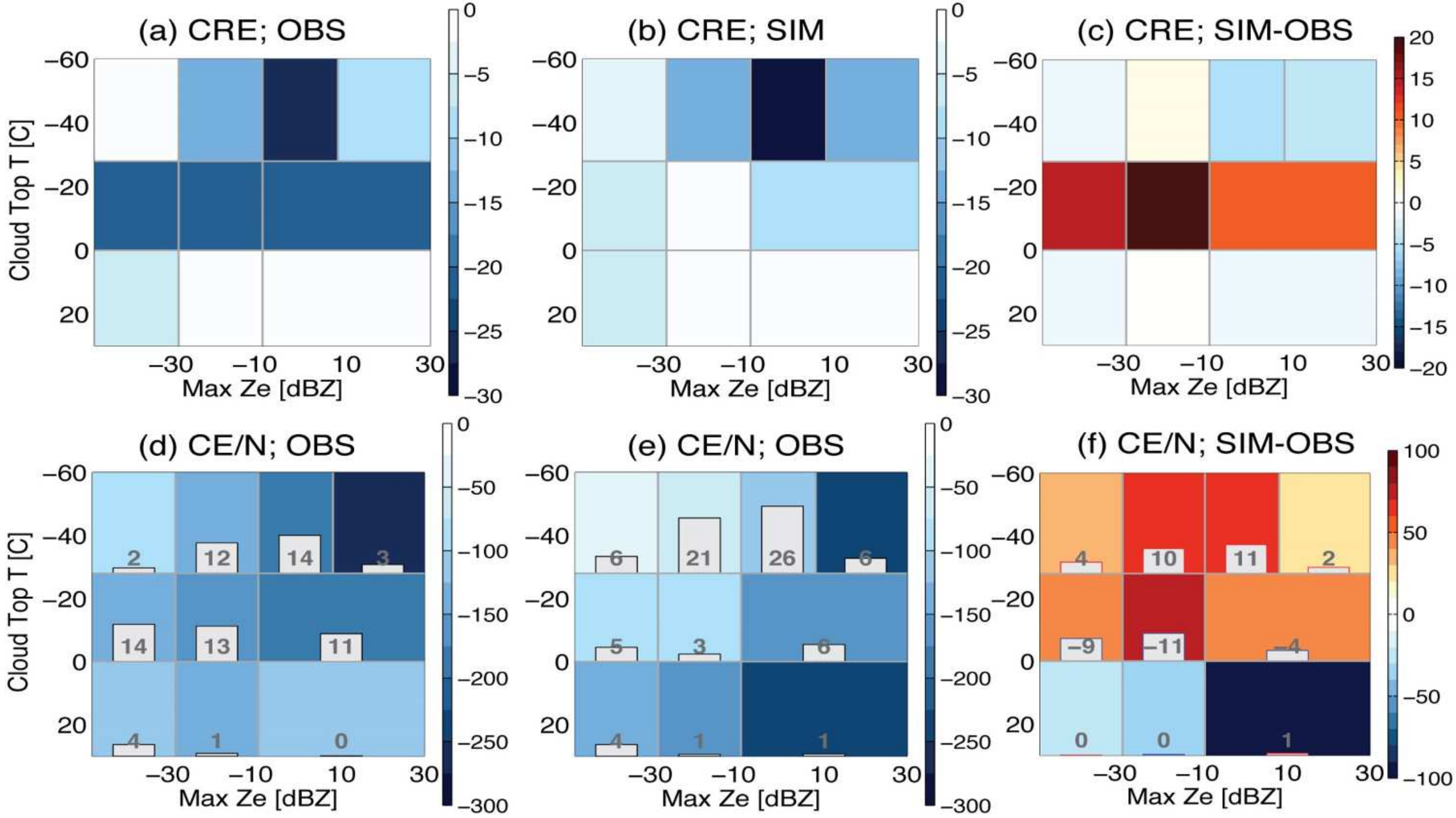
Long Wave Cloud Radiative Effects

over the Arctic band (65-82N)

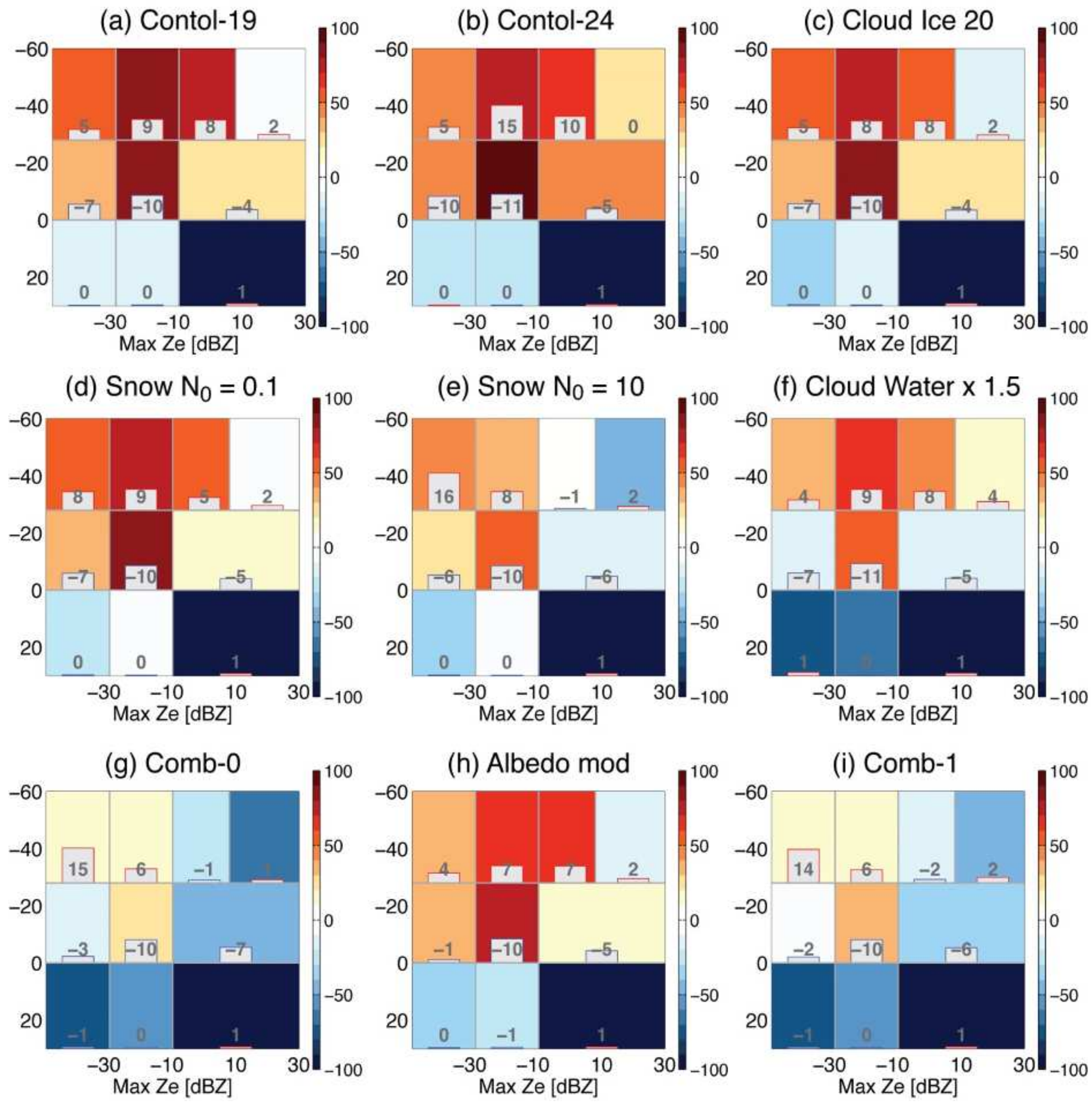
$$C = \sum_{i=1}^{10} C_i,$$
$$= \sum_{i=1}^{10} N_i \cdot CE_i,$$



Short Wave Cloud Radiative Effects over the Arctic band (65-82N)



Sensitivity to parameters of the forward models



shortwave surface downward flux and cloud fractions

Summary of the studies

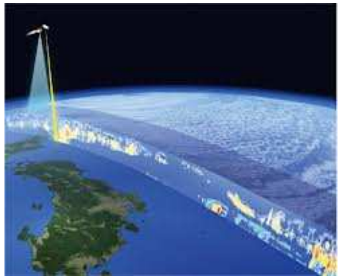
- Evaluation & improvement of cloud microphysics schemes, comparison and development
  - Hashino et al. (2013) Evaluating cloud microphysics from the NICAM against CloudSat and CALIPSO. J. Geophys. Res., 118, 7273-7293
  - Hashino et al.(2014) Evaluating Cloud Radiative Effects simulated by NICAM with A-train. in prep.
  - Roh and Satoh (2014) Evaluation of precipitating hydrometeor parameterizations in a single-moment bulk microphysics scheme for deep convective systems over the tropical open ocean. J. Atmos. Sci., 71, 2654-2673.
- Analyze and evaluate cloud changes associated with convective systems (tropical cyclones, extratropical cyclones, cloud clusters, MJOs)
  - Tropical cyclones (Yamada and Satoh, 2013 JCLI)
  - Cloud clusters & upper clouds (Noda et al. 2014, in review)
  - Extratropical cyclones (Kodama et al., 2014, GRL)

ポスト「京」重点課題 観測ビッグデータを活用した気象と地球環境の予測の高度化

(2)観測ビッグデータを活用した高度な同化手法と全球規模の災害を伴うイベントの高精度発生予測

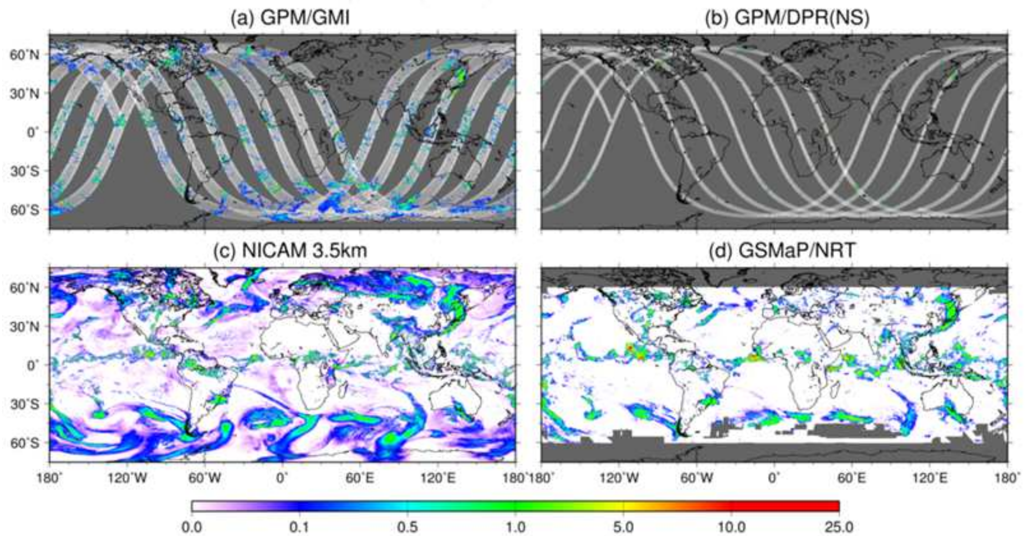
ブレークスルーの着目点：これまで使われてない新たな衛星データを大量に活用

GPMやひまわり8・9号などの新しい高頻度・高分解能データが利用可能になっている。



GPM衛星による降水観測データ

ひまわり8・9号による高頻度観測データ



GPMの観測データのフットプリント（上段）と数値モデルの降水域（下段左）と観測された降水域（下段右）。

ＧＰＭなどのこれまでに使われていない高頻度・高分解能の衛星データを、高度なデータ同化手法によって活用し、詳細な全球予報を得る。これにより、

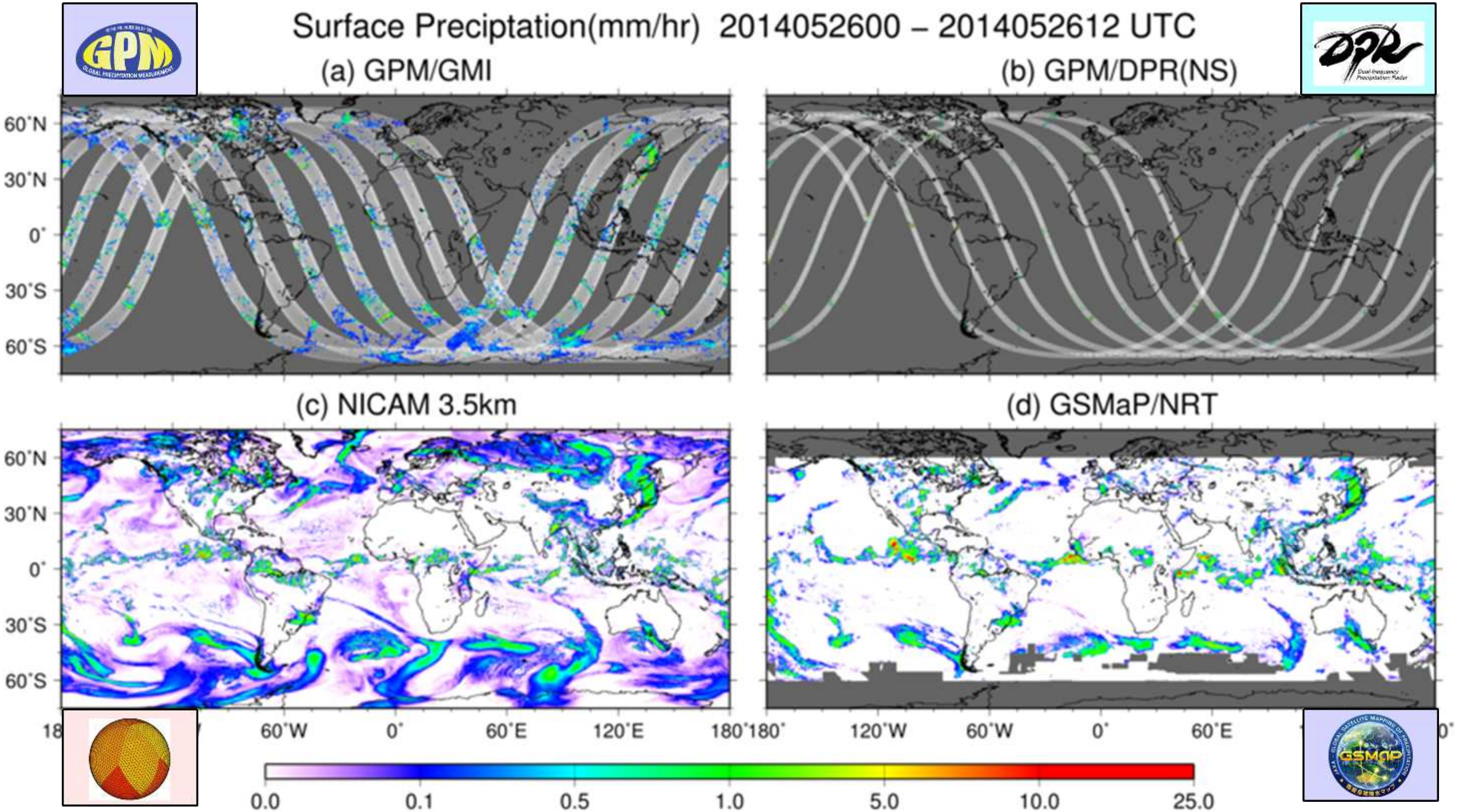
- 台風などの災害を伴う現象の発生に関わる理解の増進
- 予報技術の向上による人命と財産の保護

に貢献する。得られた全球予報を(1)「防災情報に資するための高精度予測」に利用し、予報精度向上の可能性を検討する。

これまで使われてない新しい衛星データの観測ビッグデータによって、全球規模の災害を伴うイベントの高精度な発生予測を達成・実現する。

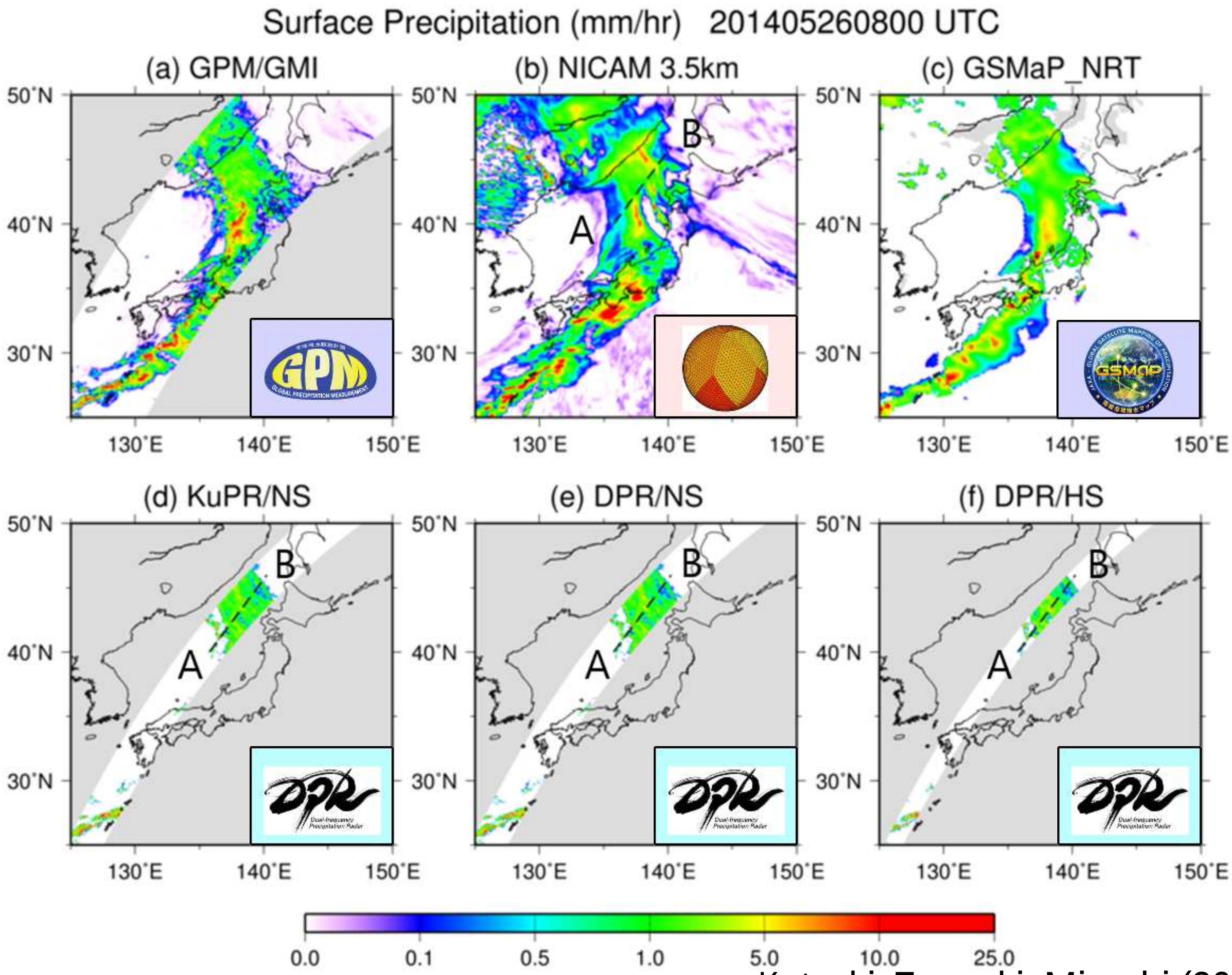
理化学研究所　計算科学研究機構　三好建正氏による

12-hour surface precipitation (mm h^{-1})



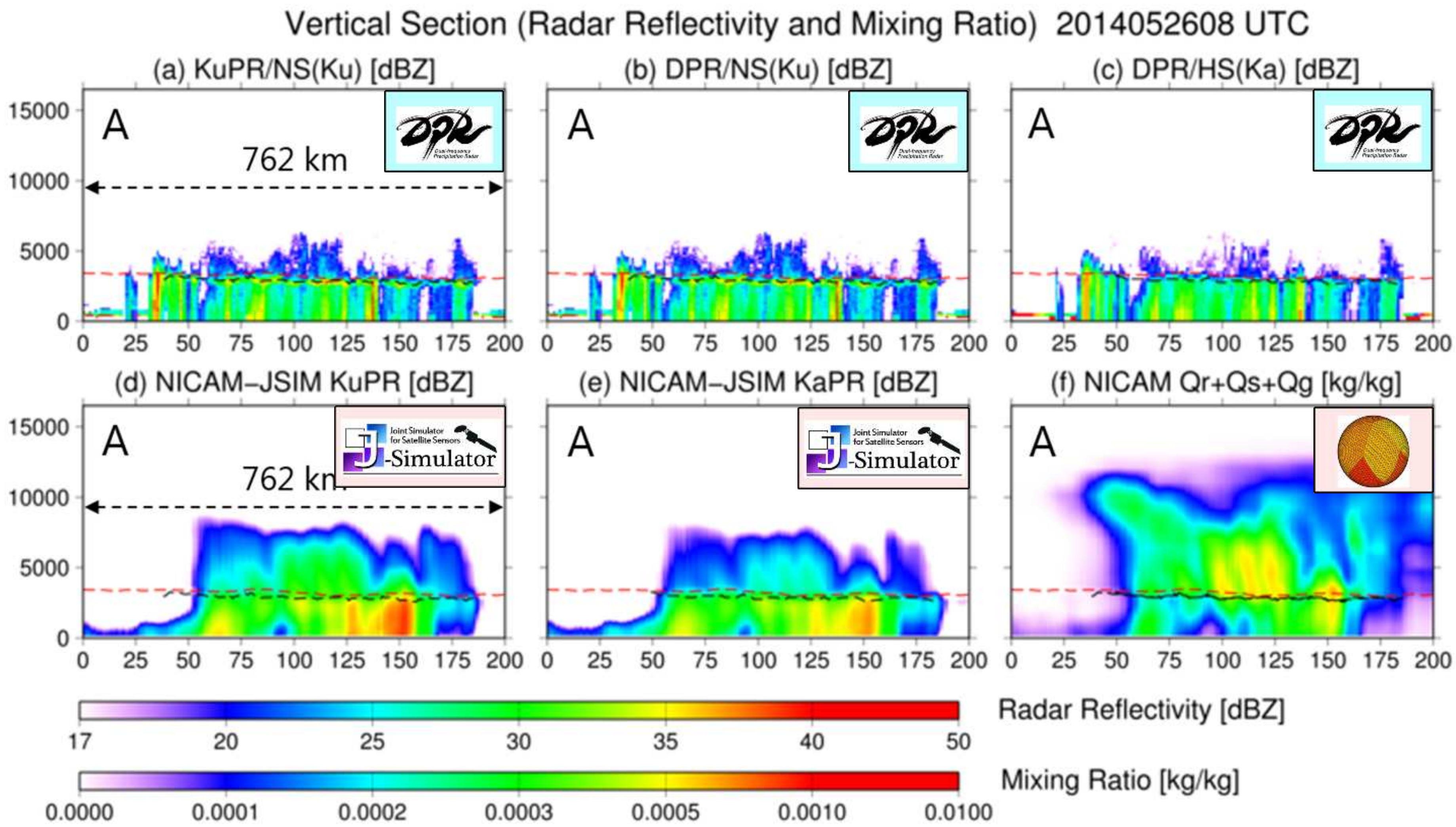
Kotsuki, Terasaki, Miyoshi (2014, SOLA)

Case 1: Surface Precipitation (Japan)



Kotsuki, Terasaki, Miyoshi (2014, SOLA)

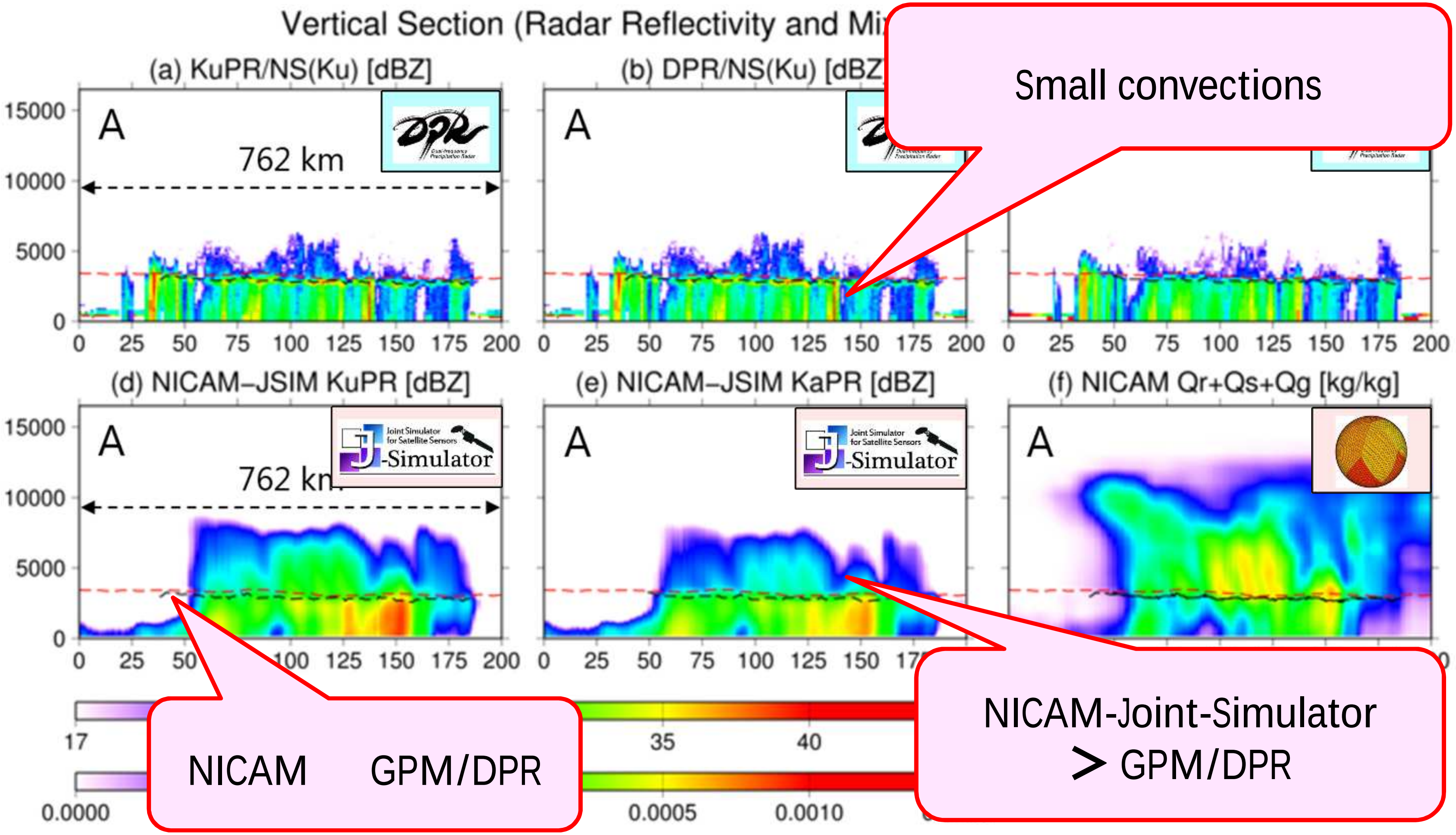
Case 1: Vertical Structure (Japan)



Kotsuki, Terasaki, Miyoshi (2014, SOLA)

- - - : GPM/DPR bright band height (m), - - -: NICAM 0℃ height (m)

Case 1: Vertical Structure (Japan)

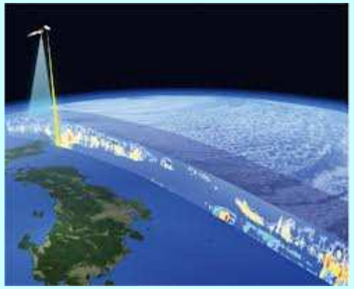


Kotsuki, Terasaki, Miyoshi (2014, SOLA)

- - - : GPM/DPR bright band height (m), - - -: NICAM 0℃ height (m)

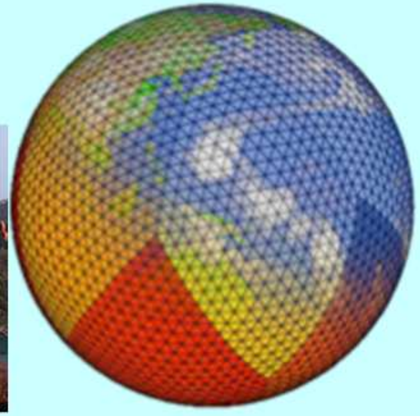
全球降水観測データ同化計画

TRMM/GPM



LETKF

NICAM



Local Ensemble Transform Kalman Filter *(Hunt et al. 2007)*

- 詳細な降水過程を含む全球モデルNICAMに、実用的なアンサンブルデータ同化手法LETKFを適用し、衛星による降水観測データを有効に活用するデータ同化手法を確立
- NICAM-LETKFによって解析される全球降水分布は、これまでのGSMaPとは異なる方法で推定された新たな全球降水マップとして期待

Terasaki, Sawada, Miyoshi (2015, SOLA)

降雨プロダクト GSMaP

http://sharaku.eorc.jaxa.jp/GSMaP/

次世代　GSMaP

■ 数値モデルによる同化を利用

　NICAMによる降水同化 dx<10km

■多用な衛星データの利用

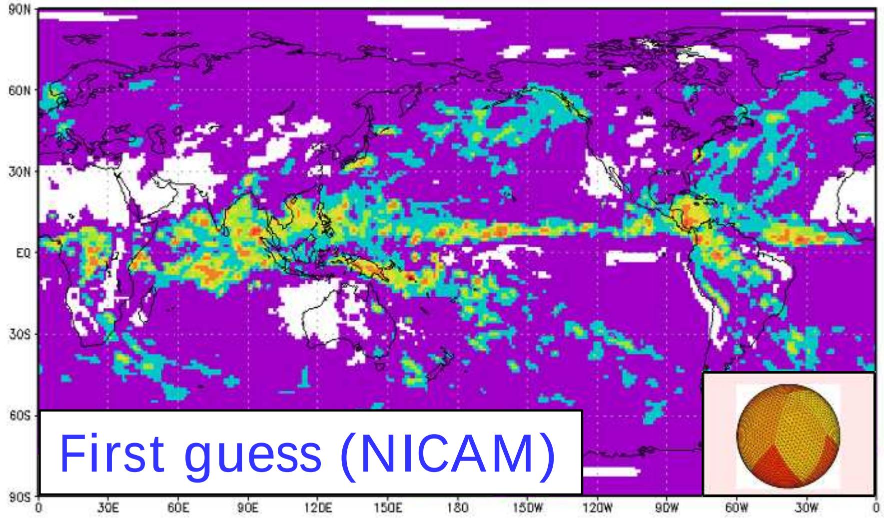
　Joint-Simulator

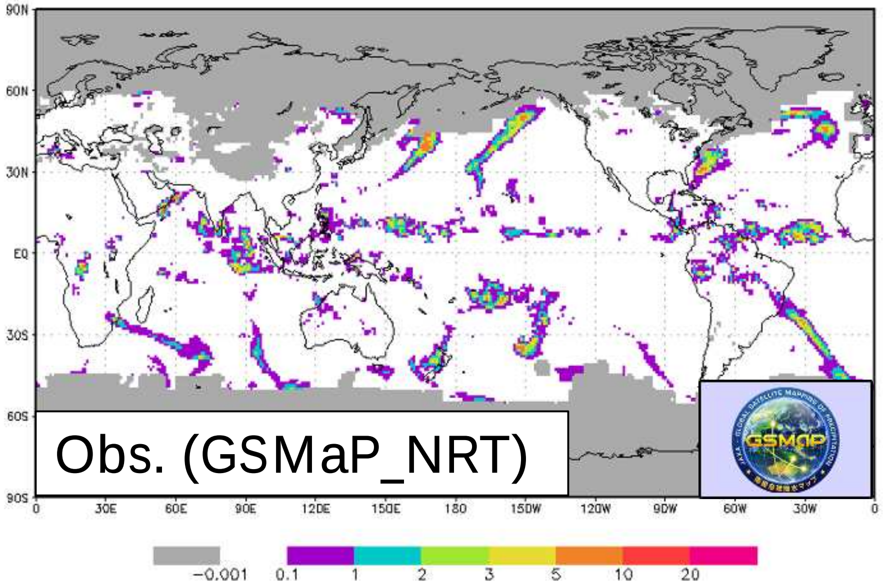
■雲･雪･降水粒子の4次元場解析

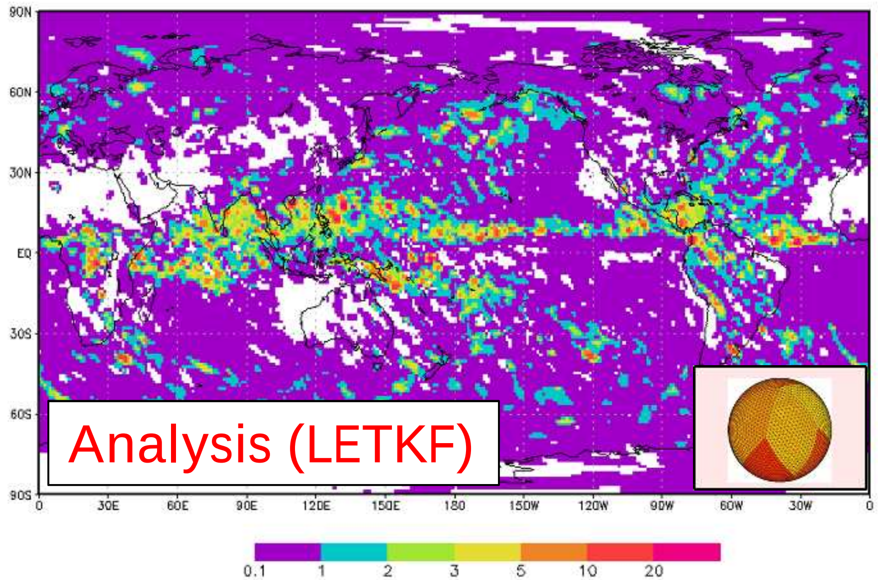
Some first results

Time: 2011 11/01 06UTC

6-hourly precipitation (mm/6hr)







After the first assimilation step

Kotsuki et al. (2015, in preparation)

今後の展望

- ***衛星観測データによる数値モデルの検証***
  - **多用な衛星データの利用**
  - Metrics, **優先度**
  - **雲･降水スキームの改良、シミュレーション結果の改善**
  - **雲･降水がよいモデルは大気大循環場もよいか？**

- ***今後の人工衛星データの利用について***
  - **雲･降雨データの同化** (TRMM, GPM, GCOM-W, EarthCARE)
  - NICAM-LETKF**による雲･雪･降水の**4**次元プロダクト**

    衛星シミュレータと高解像度全球非静力モデルによる雲･雪･降水の同化

    “Level 4” **の時代** = retrieval **が不要**
  - cf. NICAM-GsMAP, O(km) mesh global data