Problem of Cloud Overlap in Radiation Process in JMA Global NWP Model

Ryoji Nagasawa

Climate Prediction Division/Japan Meteorological Agency
E-mail: r-nagasawa@met.kishou.go.jp

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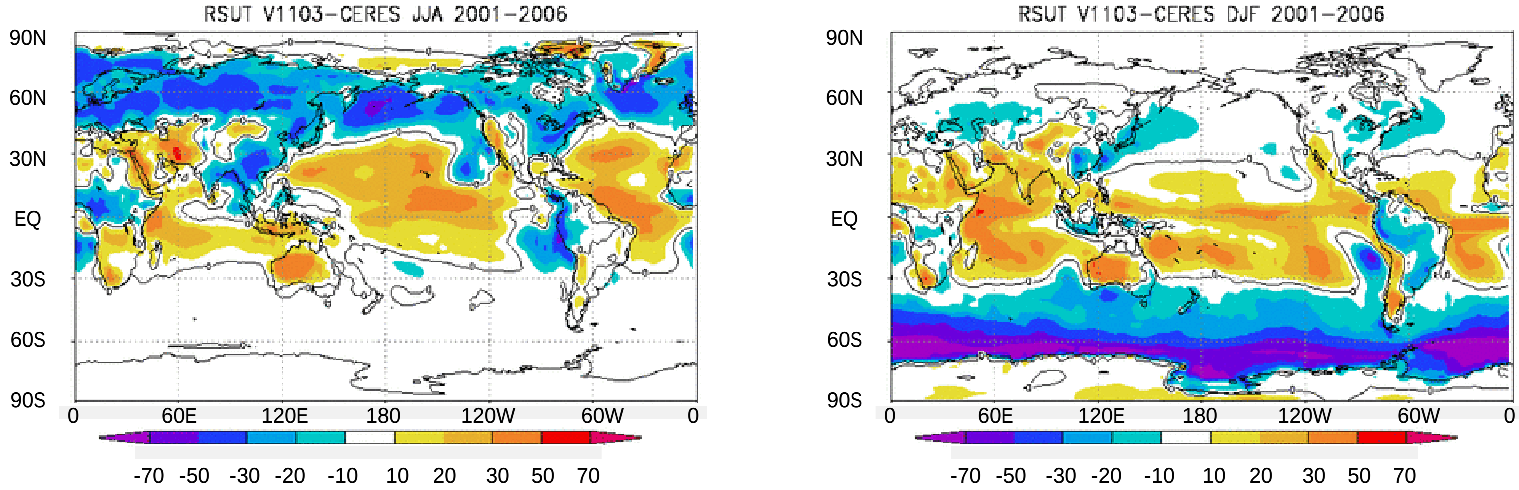
Introduction

Upward SW radiation flux at TOA (JMA GSM − CERES) (Wm^{-2})

JJA (2001–2006) DJF (2001–2006)



JMA GSM tends to be optically thicker (thinner) in the tropics (extratropics) for SW radiation flux compared with observation.

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One of the causes is an insufficient treatment of cloud overlap in the SW radiation calculation.

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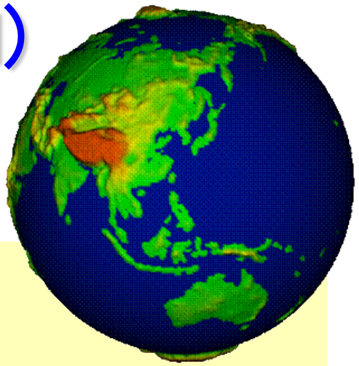
In this presentation, improved method to treat better cloud overlap in SW radiation calculation is presented.

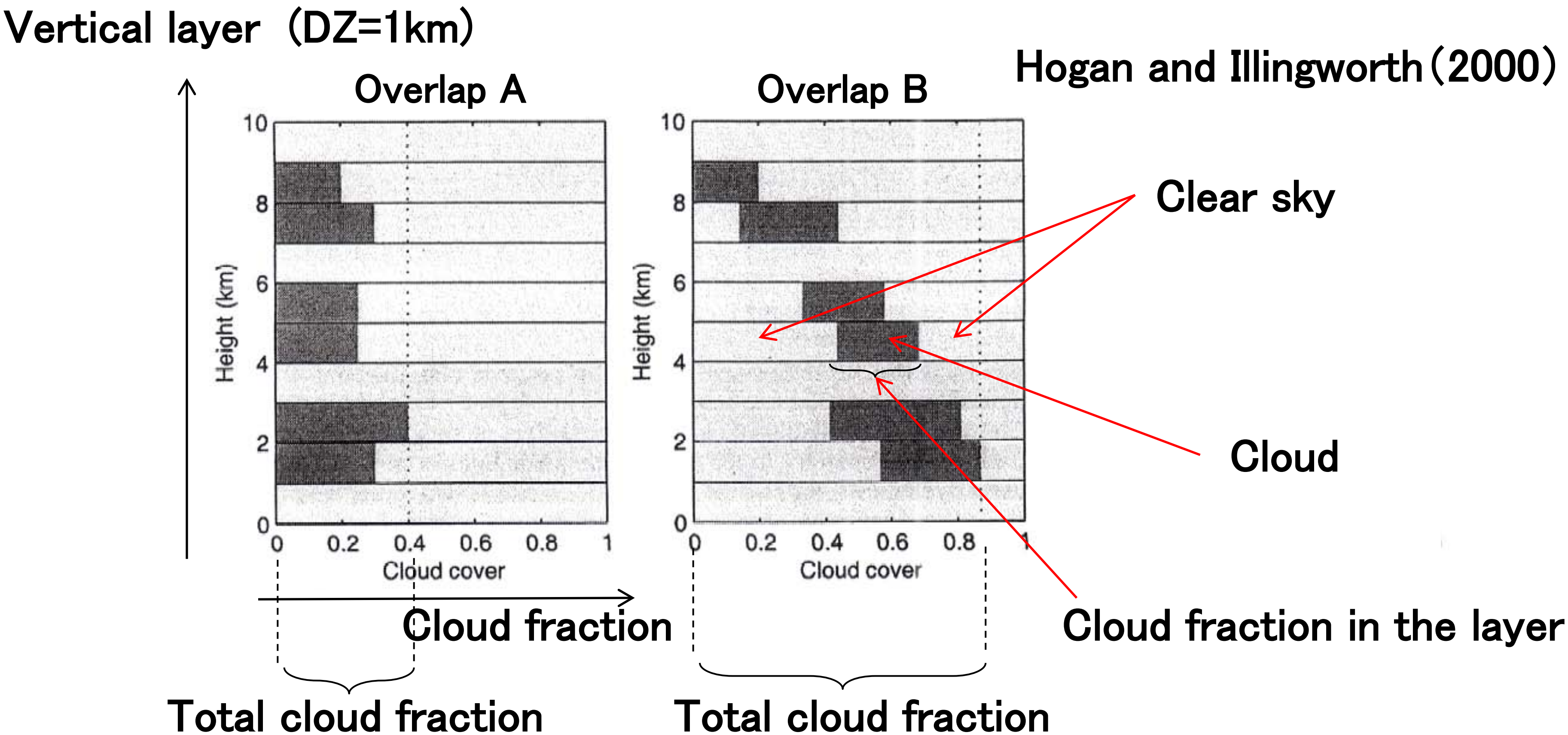
Overview of JMA Global NWP Model (JMA GSM)



ex. 1-month EPS (GSM1103)

AGCM	JMA GSM (JMA Global Spectral Model)
Horizontal resolution	TL_r159 (110km) (Reduced Gaussian Grid)
Vertical layers	60 (model top is 0.1hPa)
Basic equation	Primitive
Numerical techniques	Spectral in horizontal, finite differences in vertical
Cloud process	Smith (1990)
Cumulus convection	Prognostic AS with mass flux type middle level convection
Cloud radiation	Kitagawa (2000)
Clear sky radiation	Yabu et al. (2005) (based on Chou et al. 2001)
Boundary layer	Mellor-Yamada level-2
Gravity wave drag	Iwasaki et al. (1989)
Land surface	Simple biosphere model (SiB) (Sellers et al. 1986)

Overview of cloud overlap



Cloud fraction stands for inhomogeneity in horizontal grid in a coarse resolution model.

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Result of radiation calculation depends heavily on adopted cloud overlap.

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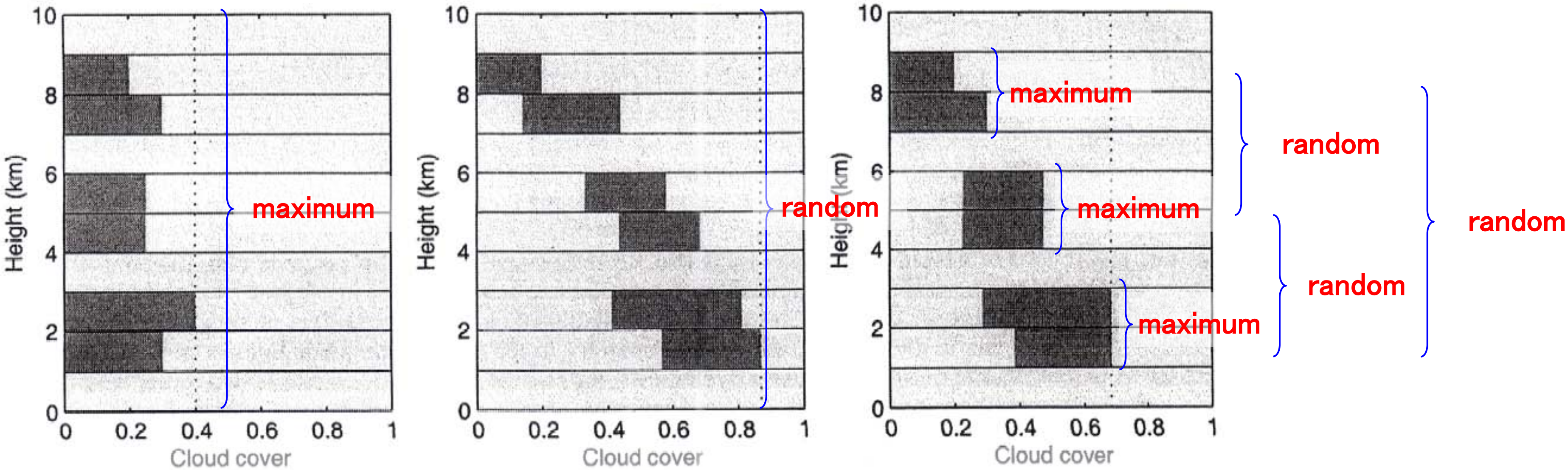
Various cloud overlaps are proposed in terms of computational cost and accuracy.

Major cloud overlaps

Hogan and Illingworth (2000)

Overlap A　　　　Overlap B



Maximum-Random overlap is better than the others.

Maximum overlap

$$CC_{ij} = \max(C_i, C_{i+1}, \ldots, C_{j-1})$$

Random overlap

$$CC_{ij} = 1 - \prod_{k=i}^{j-1} (1 - C_k)$$

Used in the SW radiation scheme

Maximum – Random overlap

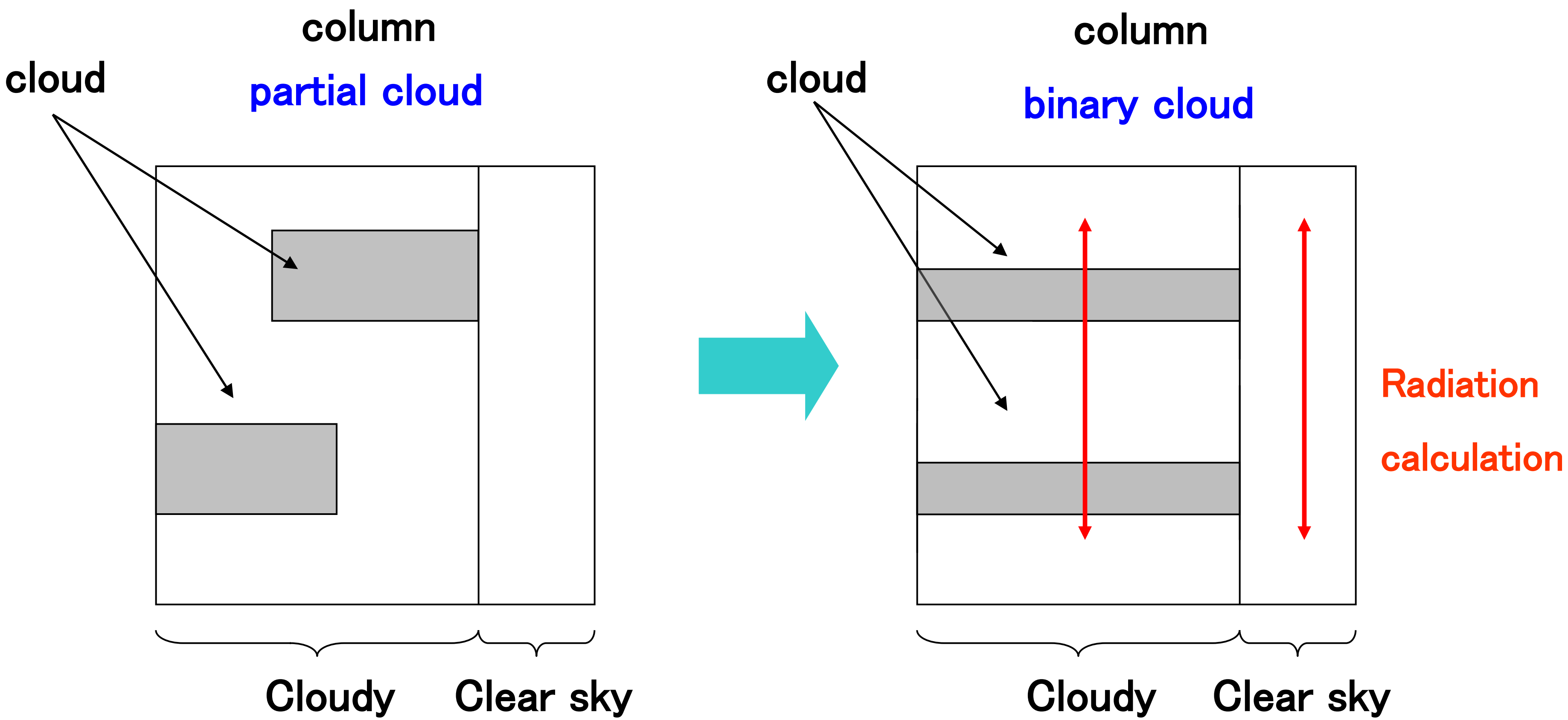
$$1 - CC_{ij} = (1 - C_i) \prod_{k=i}^{j-1} \frac{1 - \max(C_k, C_{k+1})}{1 - C_k}$$

Used in the LW radiation scheme

CC_{ij} Total cloud fraction between $i \sim j$ th layer

C_i Cloud fraction in i th layer

Current cloud overlap in SW (Kitagawa 2000)



Total cloud fraction (cloudy area) is determined by maximum-random overlap

Partial cloud is converted to optically thin binary cloud.

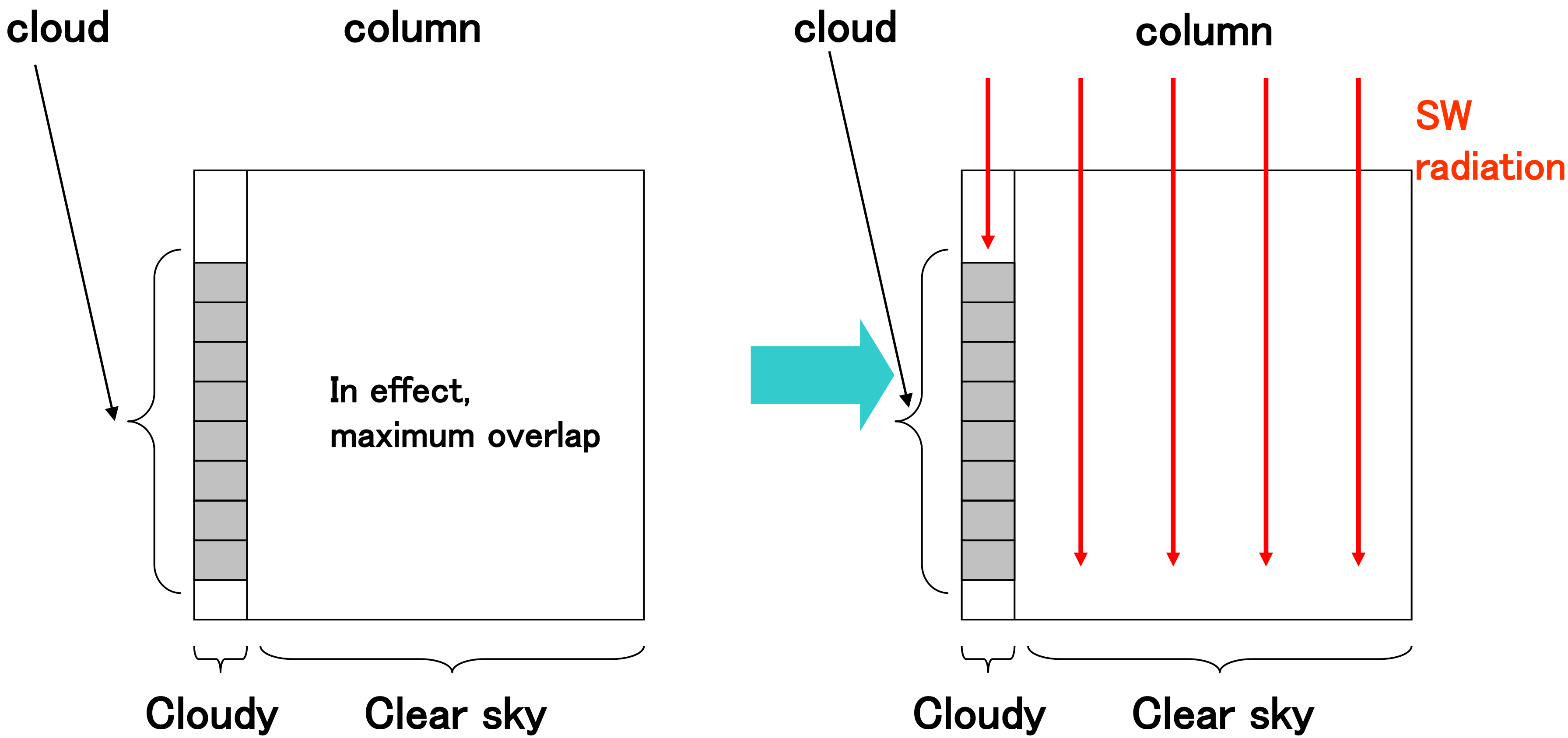
Radiation calculation of clear sky area and cloudy area is processed separately.

→ Inevitably random overlap is assumed in cloudy area.

→ Only 2 sub-columns are needed.

Problem of current cloud overlap in SW (Kitagawa 2000)

Case: only tower shaped cumulus exists where cloud fraction is small.



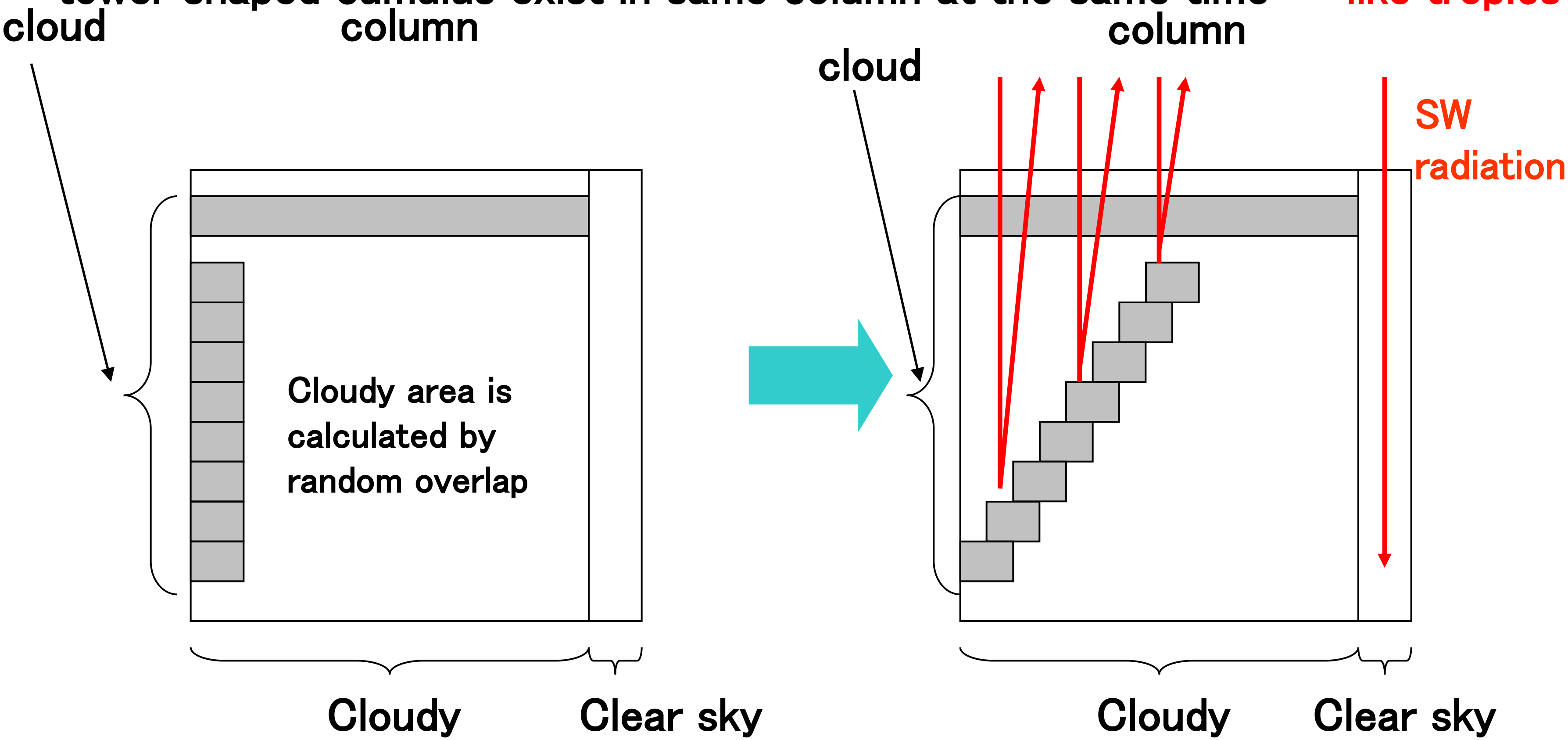
Total cloud fraction (cloudy area) is determined by maximum-random overlap.

Incident SW radiation flux to surface is large.

In the case, cloud is optically thin for SW radiation calculation.

Problem of current cloud overlap in SW (Kitagawa 2000)

Case: optically thin high level cloud where cloud fraction is large and tower shaped cumulus exist in same column at the same time → like tropics ?



Total cloud fraction (cloudy area) is determined by maximum-random overlap

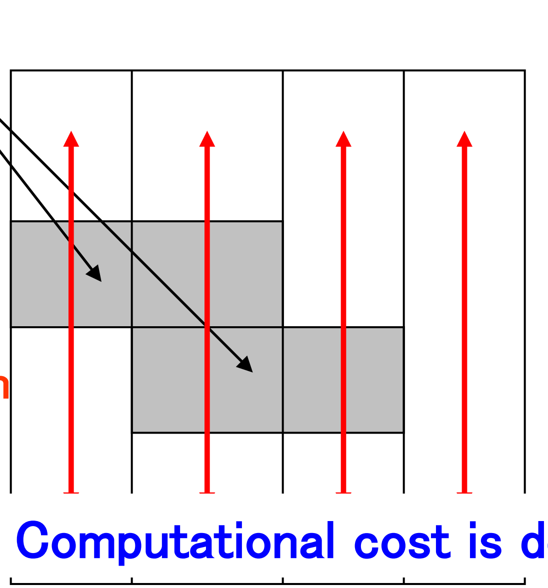
Incident SW radiation flux to surface is small.

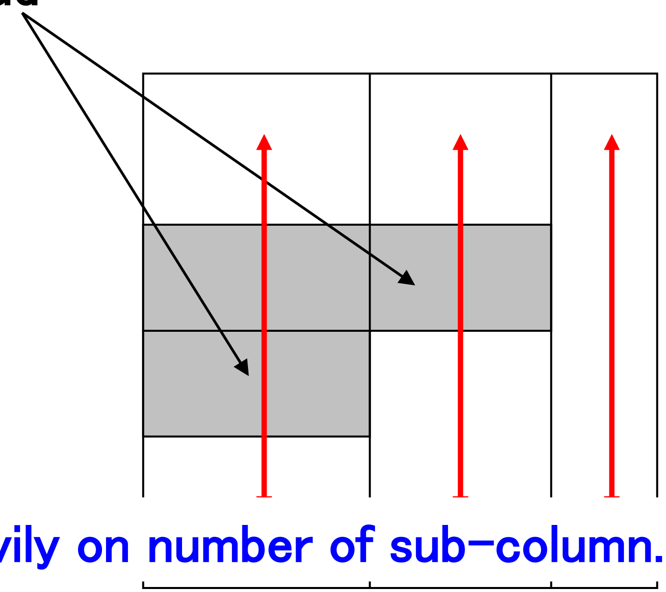
Radiation calculation is processed by random overlap in the cloudy area because of high level cloud, and optical thickness of tower shaped cumulus is overestimated.

The solution: ICA (benchmark)

Independent Column Approximation

Cloud overlap can be treated adequately, but computational cost is very expensive.





Computational cost is depend heavily on number of sub-column.

Cloud has vertical N layers.

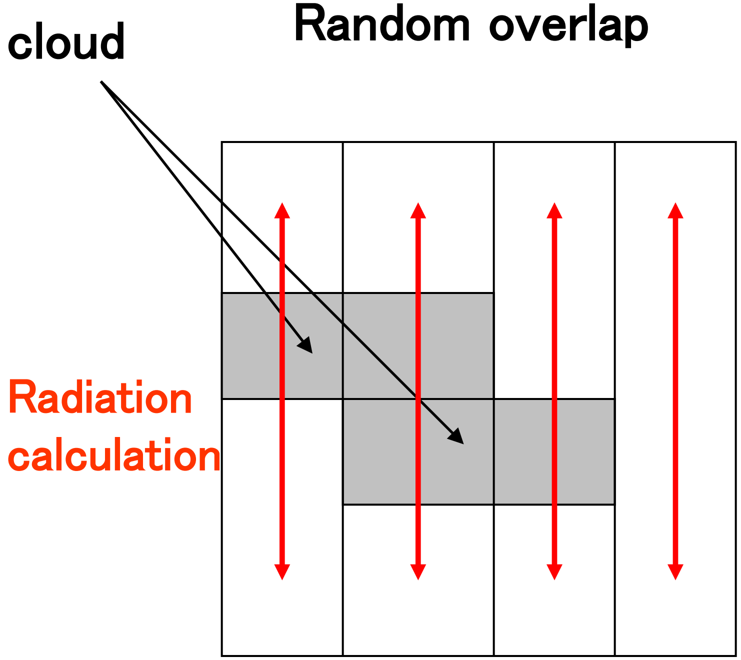
In case of random overlap, maximum number of sub-column is 2^N.

In case of maximum overlap, maximum number of sub-column is (N + 1).

It is important to reduce computational cost with less deterioration of accuracy of ICA.

Practical ICA: Collins (2001)

How to reduce computational cost with less deterioration of accuracy of ICA?



Cloud fraction = 1.0

Extracts

1. Ignore tiny cloud fraction.
2. Round cloud fraction to first decimal place (ex. 0.05).
3. Ignore narrow sub-columns whose contribution (width) is small.
4. Adopt broader 15 sub-columns whose contribution (width) is large. Ignore the others.

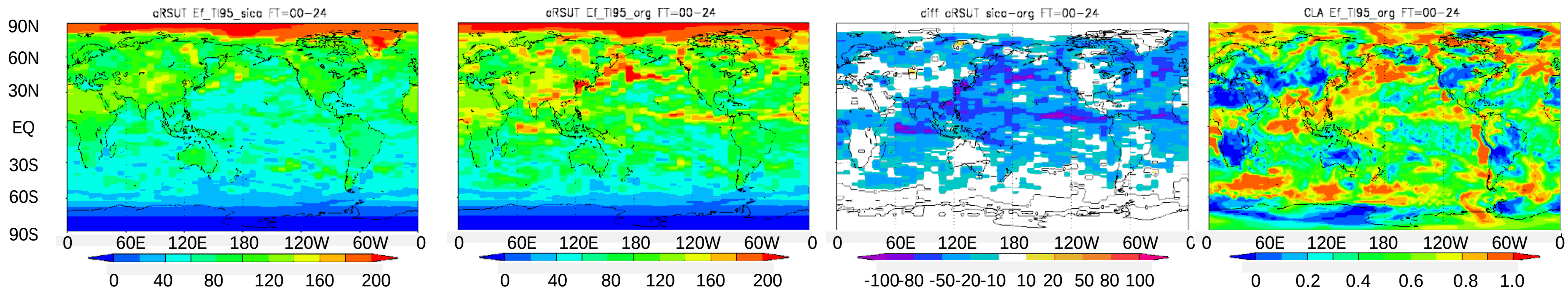
Above simplification parameters are determined by considering computational cost and accuracy.

Impact of Collins(2001)

FT=0～24, 2009081012UTC Ini（TL95L60）

Upward SW radiation flux at TOA (Wm^{-2})　　　Total cloud fraction

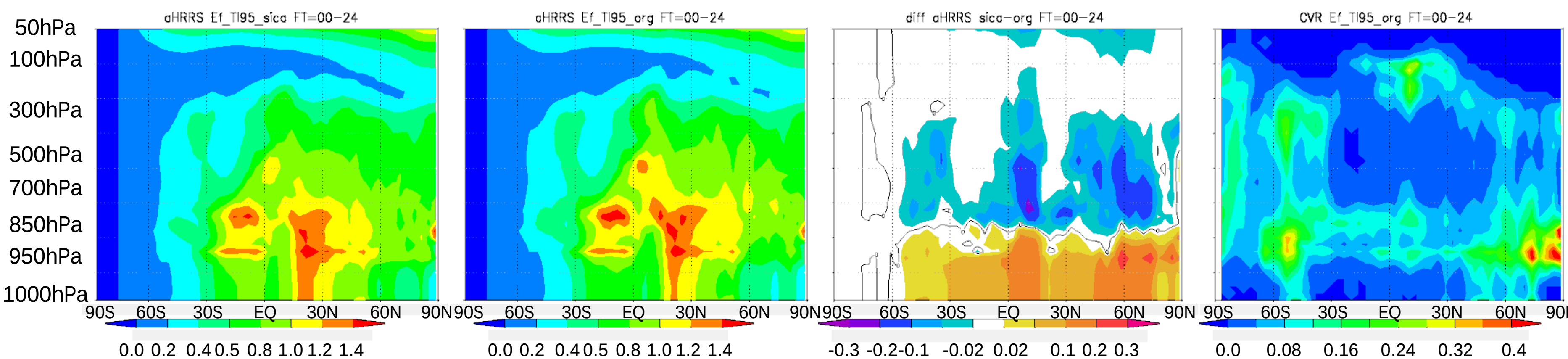
TEST（Collins 2001）　CNTL（Kitagawa 2000）　TEST – CNTL



Cloud in TEST is optically thin compared with that in CNTL by Maximum–Random overlap.

CPU time of TEST is not so large compared with CNTL. Mean)

TEST（Collins 2001）　CNTL（Kitagawa 2000）　TEST – CNTL



Implementation of maximum-random overlap decreases SW heating in middle troposphere and increases SW heating in lower troposphere.

Summary and plans

- ○JMA GSM tends to be optically thicker (thinner) in the tropics (extratropics) for shortwave radiation flux compared with observation.

- ○One of the causes is an insufficient treatment of cloud overlap in the shortwave radiation calculation.

- ○Practical ICA, improved method to treat better cloud overlap in the shortwave radiation calculation with small cost is tested. The method with maximum – random overlap decreases cloud optical thickness extensively.

- ○ Practical ICA has to be tested in many cases and appropriate parameters have to be fixed considering computational cost and accuracy.

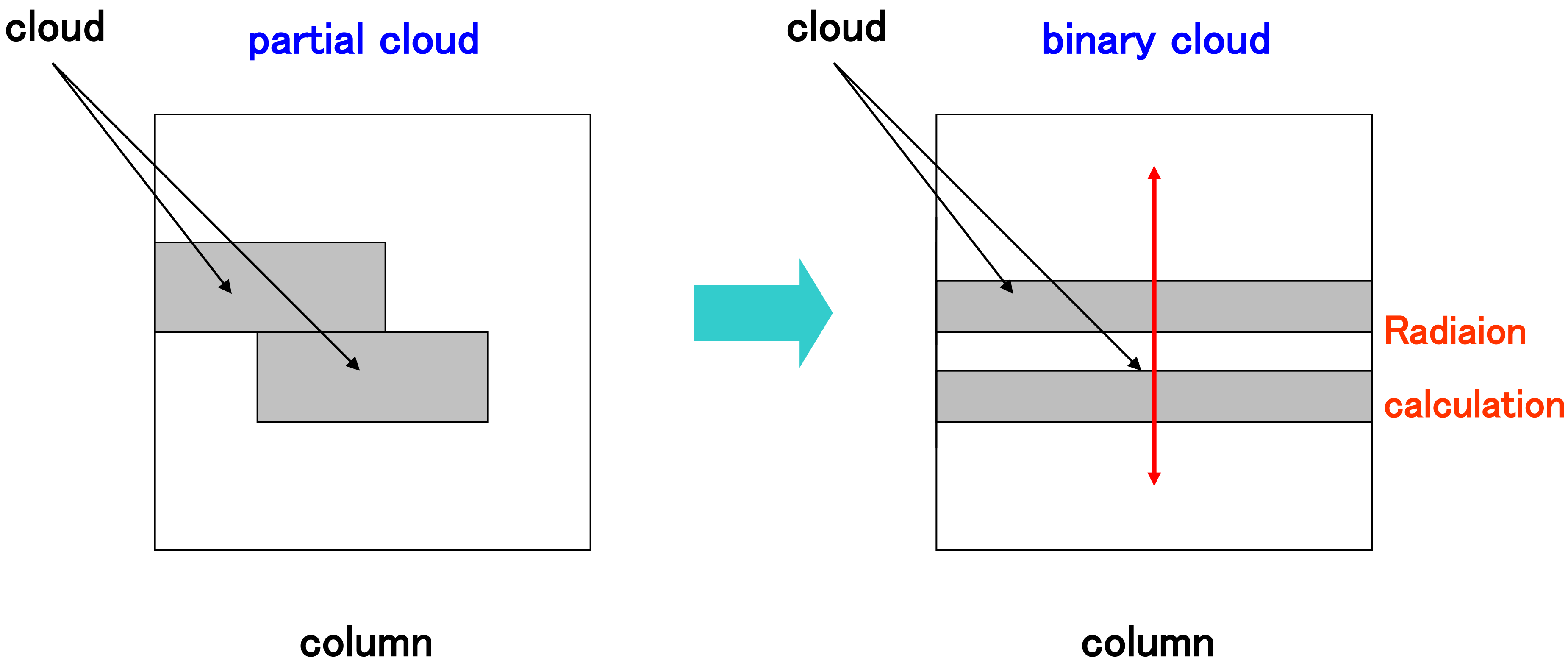
- ○ Description of cloud simulated by JMA GSM has to be improved.

Thank you for your attention

backup slides

Primitive method (Sugi and Tada 1988)

Computational cost is small but cloud overlap can not be treated adequately.

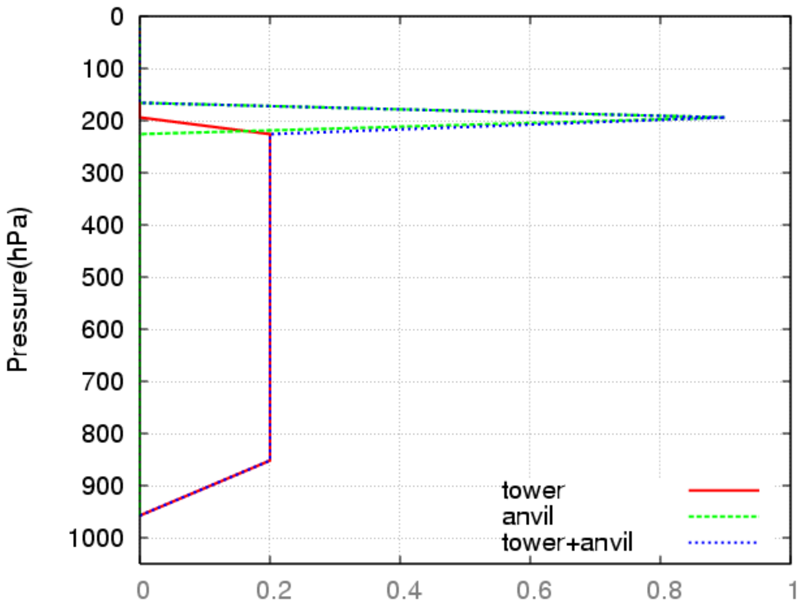


Input cloud is converted to optically thin cloud whose cloud fraction is 1.0 and then, radiation calculation is processed.

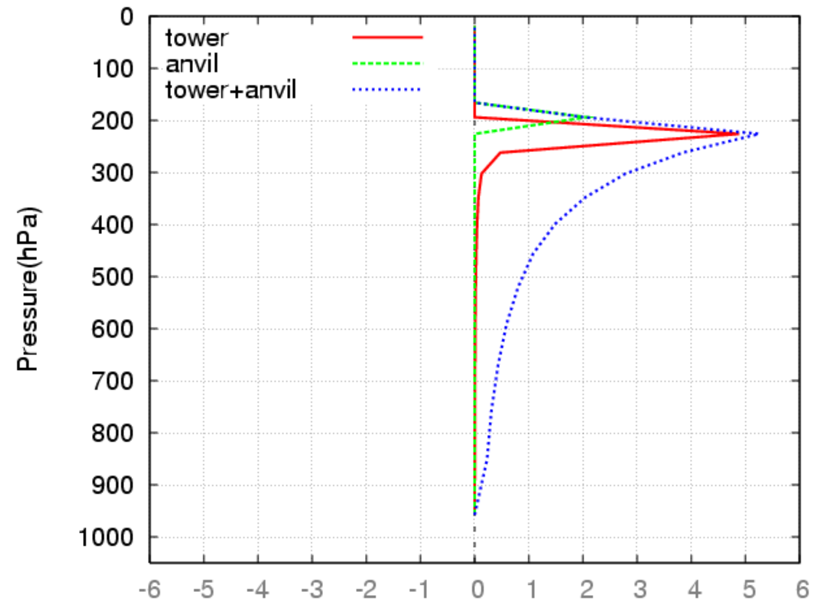
→ Inevitably random overlap is assumed. → only 1 sub-column is needed.

Example of problem
(results by vertical 1-dimensional model)

Vertical profiles of cloud fraction



SW radiation heating rate



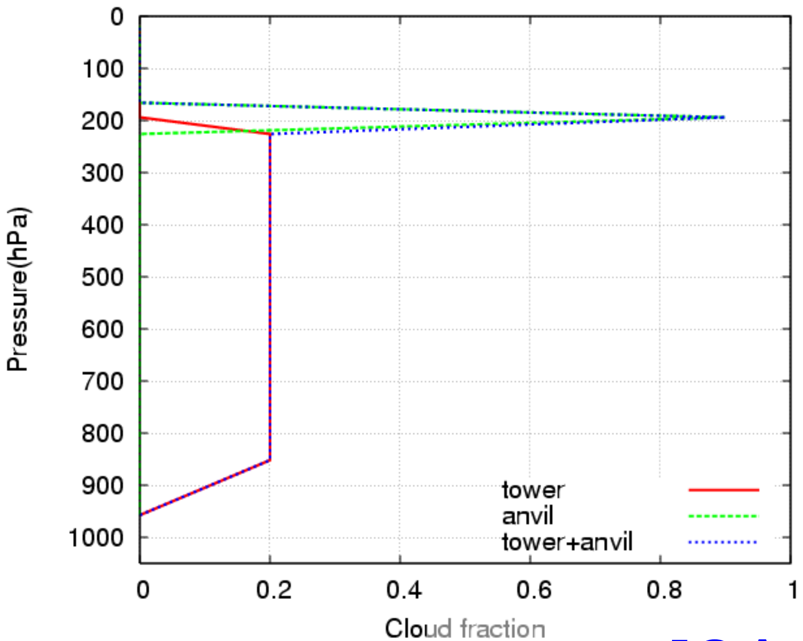
Optical thickness of tower shaped cumulus is overestimated

Table: SW radiation heating rate, cloud radiative forcing at surface, etc. by vertical 1-dimensional model

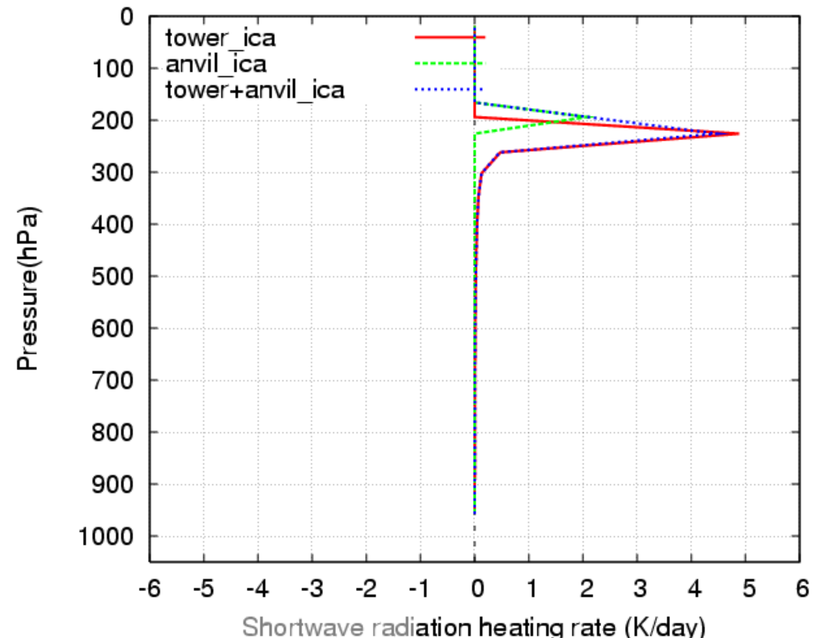
Settings of vertical profile of cloud fraction	tower	anvil	tower + anvil
Albedo at TOA	0.32	0.24	0.56
Amount of SW radiation absorption in atmosphere (Wm^{-2})	23.8	7.4	110.7
Cloud radiative forcing at surface (Wm^{-2})	133.9	41.2	444.6

Results by ICA
(results by vertical 1-dimensional model)

Vertical profiles of cloud fraction



SW radiation heating rate



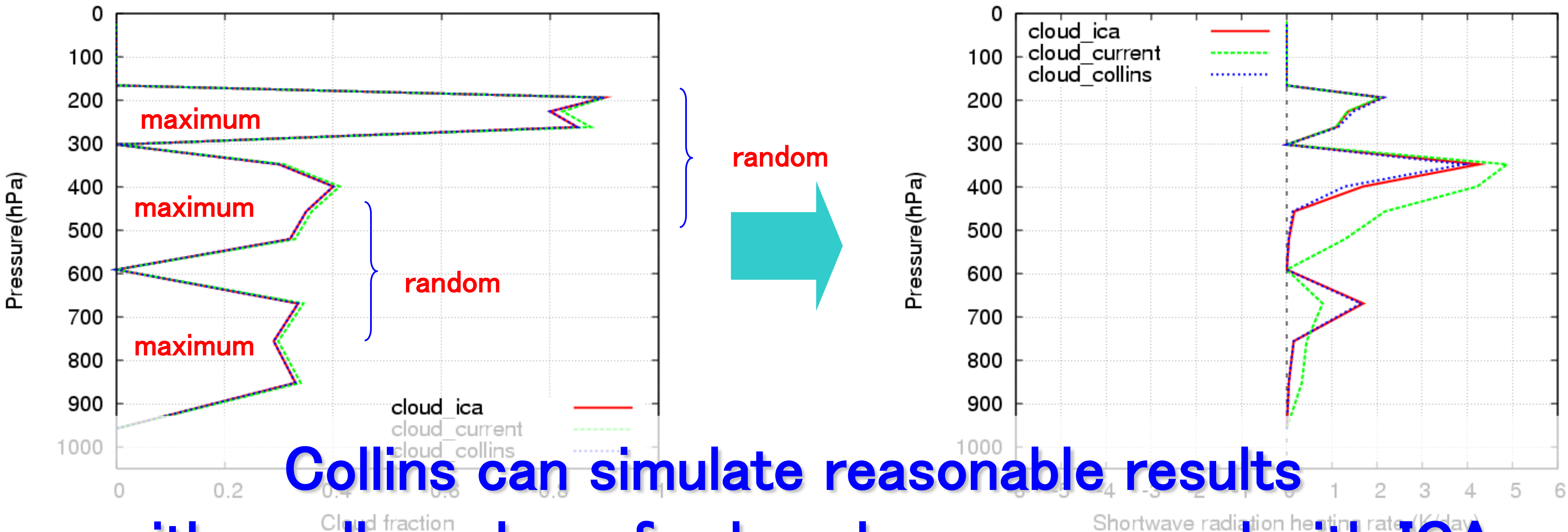
ICA operates well.

Table: SW radiation heating rate, cloud radiative forcing at surface, etc. by vertical 1-dimensional model

Settings of vertical profile of cloud fraction	tower_ica	anvil_ica	tower + anvil_ica
Albedo at TOA	0.32	0.24	0.35
Amount of SW radiation absorption in atmosphere (Wm^{-2})	23.8	7.4	29.5
Cloud radiative forcing at surface (Wm^{-2})	133.9	41.2	165.9

Results by Collins (2001)
(results by vertical 1-dimensional model)

Vertical profile of cloud fraction / SW radiation heating rate



Collins can simulate reasonable results with small number of sub-column compared with ICA

Table: setting of vertical profile of cloud fraction and SW radiation heating rate, cloud radiative forcing at surface, etc. by vertical 1-dimensional model

Treatment of cloud overlap	ICA	CURRENT	COLLINS
Albedo at TOA	0.58	0.62	0.56
Amount of SW radiation absorption in atmosphere (Wm^{-2})	73.3	114.9	68.6
Cloud radiative forcing at surface (Wm^{-2})	417.0	499.7	390.5
Number of sub-column	80	2	15

Horizontal resolution of JMA Global NWP Models

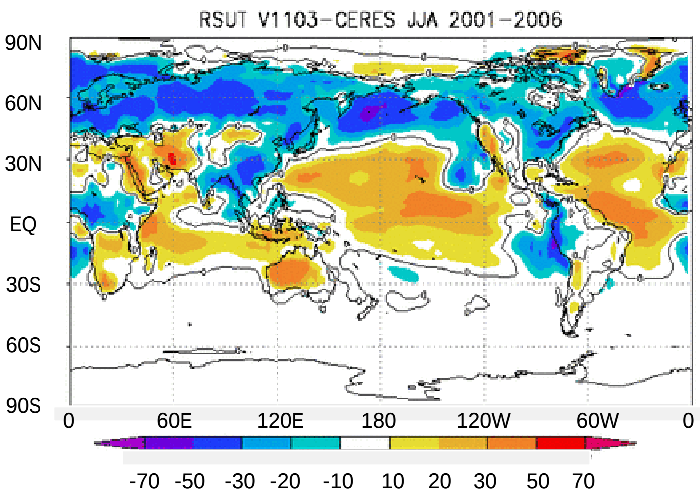
○Short-range forecast model	DX=20km	deterministic
○Weekly EPS	DX=60km	51 members
○Typhoon EPS	DX=60km	11 members
○1-month EPS	DX=110km	50 members
○3-month EPS	DX=180km	51 members
○Warm/Cold Season EPS	DX=180km	51 members

Horizontal resolution is too coarse to remove cloud overlap assumption.

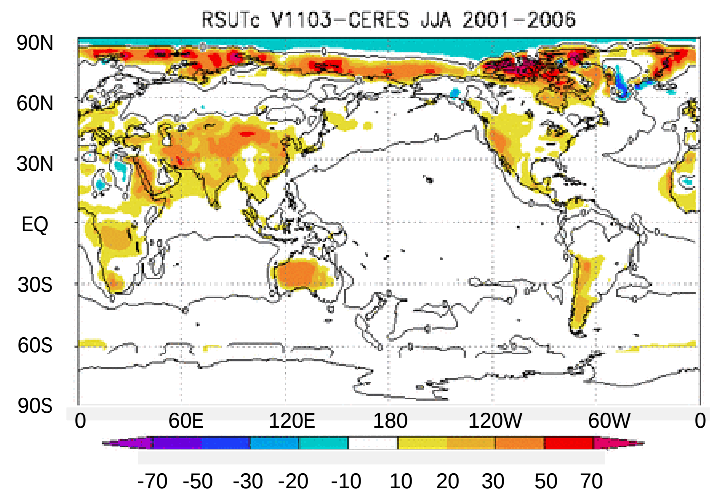
Upward SW radiation flux at TOA(Wm^{-2})

JJA (2001–2006)

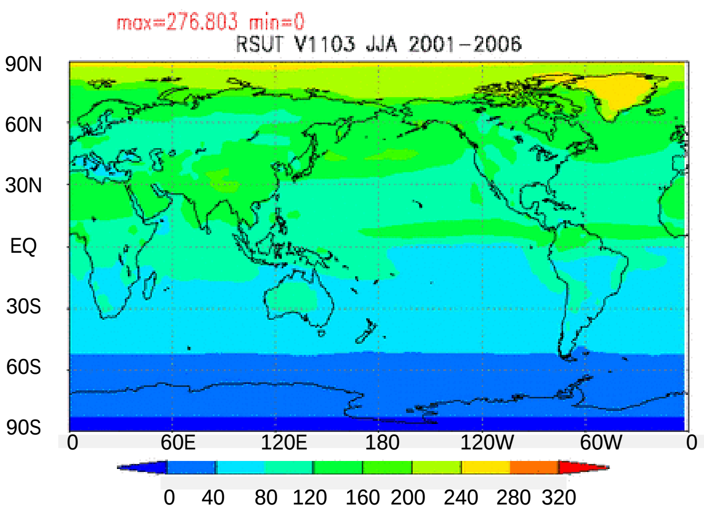
JMA GSM − CERES



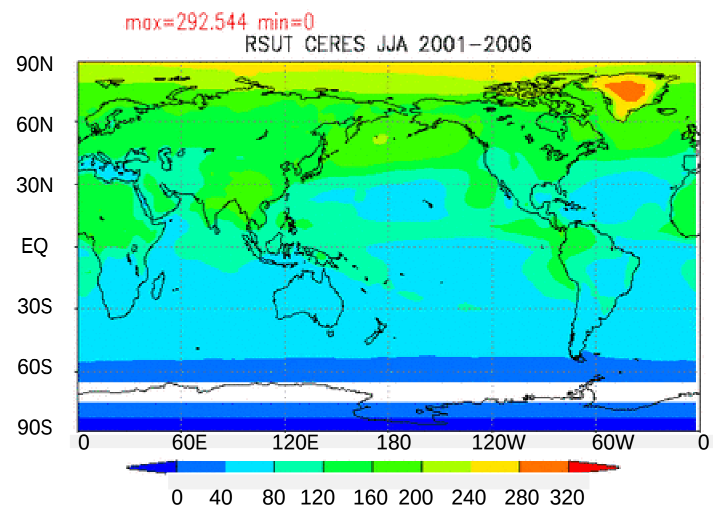
JMA GSM − CERES (clear sky)



JMA GSM



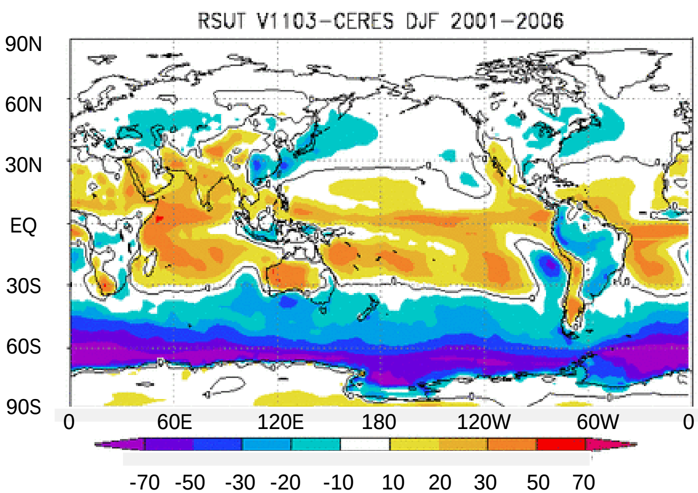
CERES(Obs)



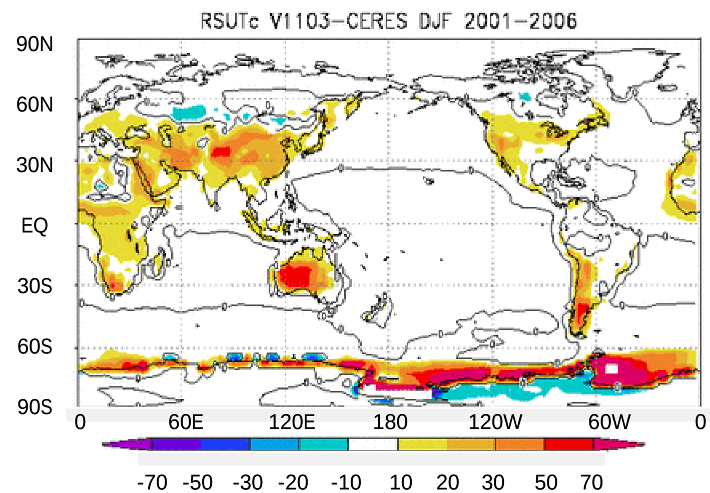
Upward SW radiation flux at TOA(Wm^{-2})

DJF (2001–2006)

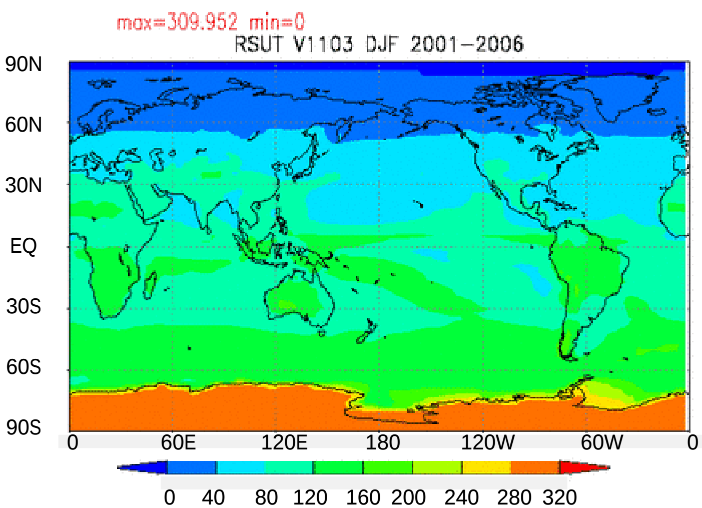
JMA GSM – CERES



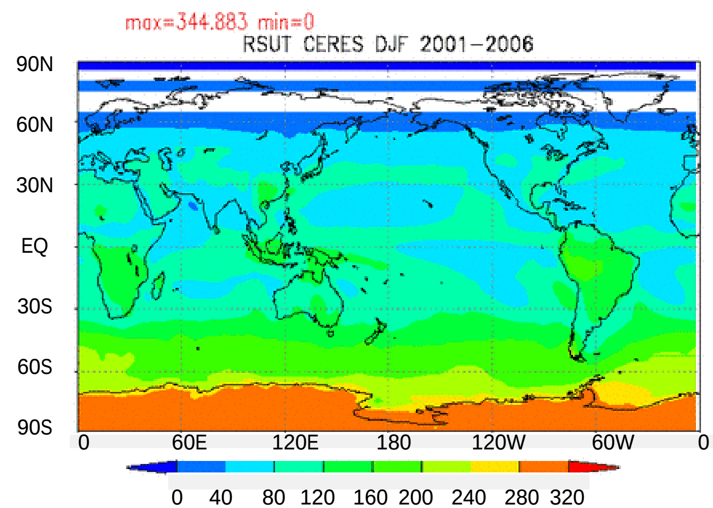
JMA GSM – CERES (clear sky)



JMA GSM



CERES (obs)



Impact of Collins (2001)

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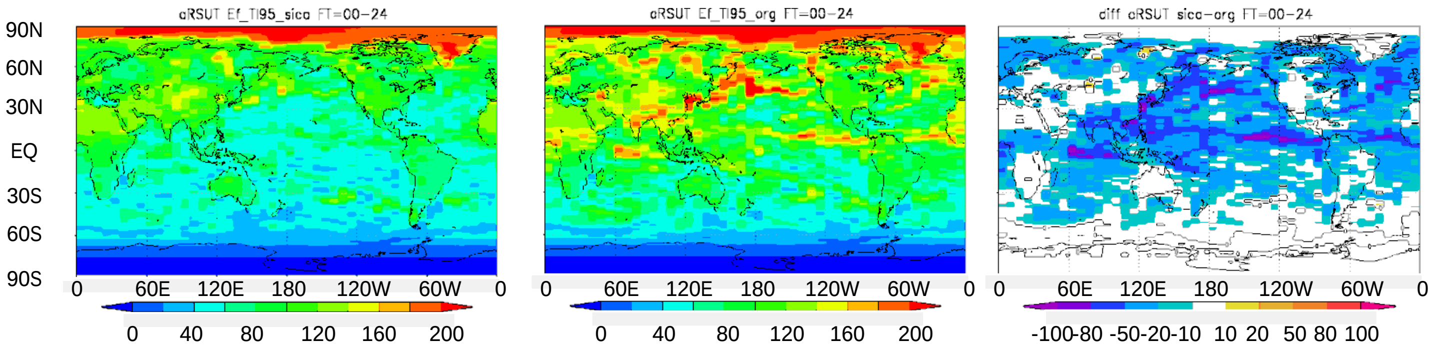
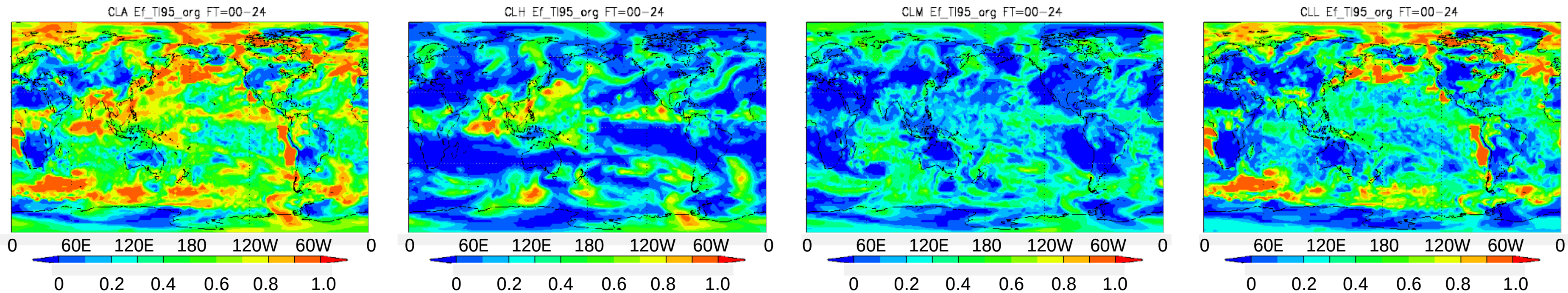
Upward SW radiation flux at TOA (Wm^{-2})

TEST(Collins 2001) CNTL(Kitagawa 2000) TEST-CNTL



Cloud in TEST is optically thin compared with that in CNTL by Maximum-Random overlap.

Total cloud fraction | Upper level cloud fraction | Middle level cloud fraction | Low level cloud fraction



Cloud fraction simulated by JMA GSM tends to be partial.