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Improvement of a Stratocumulus Scheme for Mid-latitude Marine Low Clouds

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Model Physics in the JMA-GSM

Clouds: PDF scheme by Smith (1990)

Convection: Arakawa-Schubert scheme (Pan and Randall 1998)

No specific treatment for shallow convections

Turbulence: Mellor & Yamada (1974, 1982) Level 2

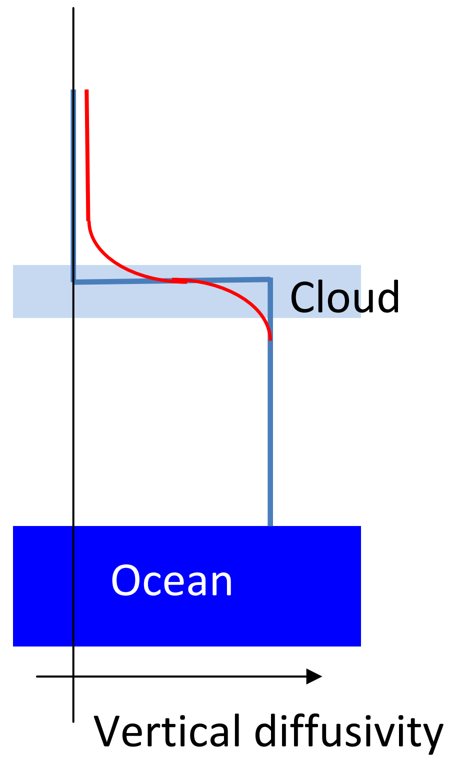
No Non-local effect
No cloud top entrainment

+

- Vertical smoothing of vertical diffusivity
- Background vertical diffusivity

+

Stratocumulus: Kawai & Inoue (2006) (+RH condition)



The JMA-GSM has a serious longstanding issue that shortwave radiation reflection is too little in mid-latitudes.

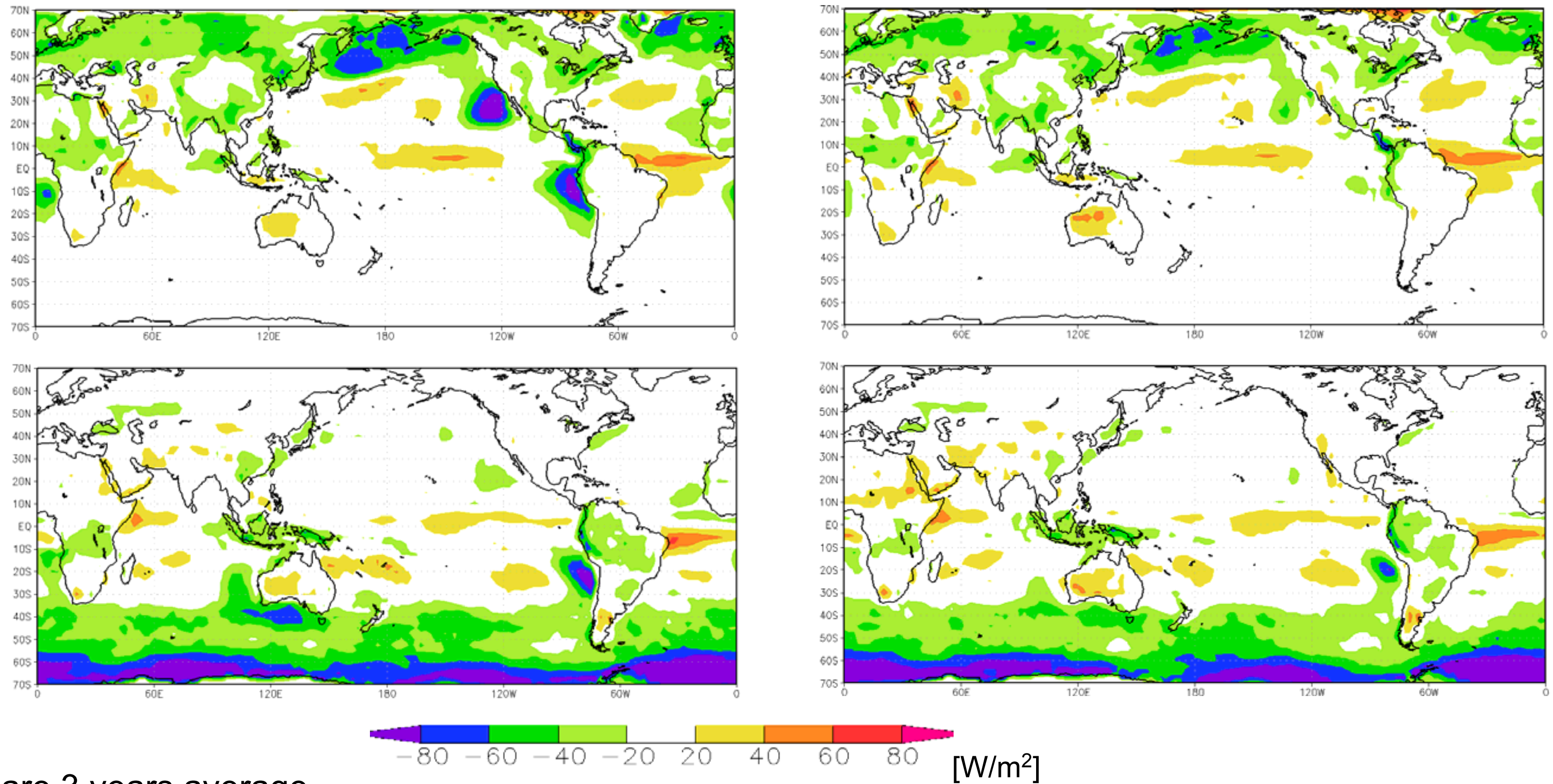
Bias of TOA upward shortwave flux

Without Sc scheme

Operational Sc scheme

Jul.

Jan.



All results are 3 years average (1987-1989) for each month

Similar in JRA(Japanese Re-Analysis) data...

Of course, because of too little (especially low-level) clouds...

Sc scheme developed in 2009

LTS Sc scheme

(1). Lower troposphere is stable.

$$LTS(=\theta_{700}-\theta_{surf})>20[K]$$

(Klein & Hartmann (1993))

(2). Layer near surface is not stable. (To guarantee the existence of a mixed layer.)

⬇

Cloud top mixing is completely suppressed.

- Stop vertical smoothing of vertical diffusivity.
- Background vertical diffusivity is almost zero.

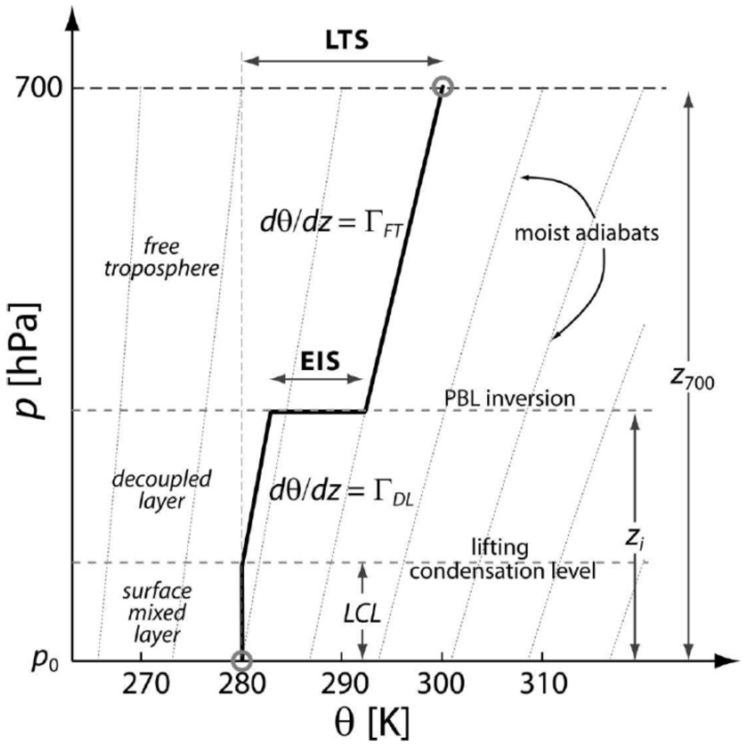
→ The intrusion of dry air from the cloud top is prevented.

→ BL is moister, and clouds are formed and not destroyed.

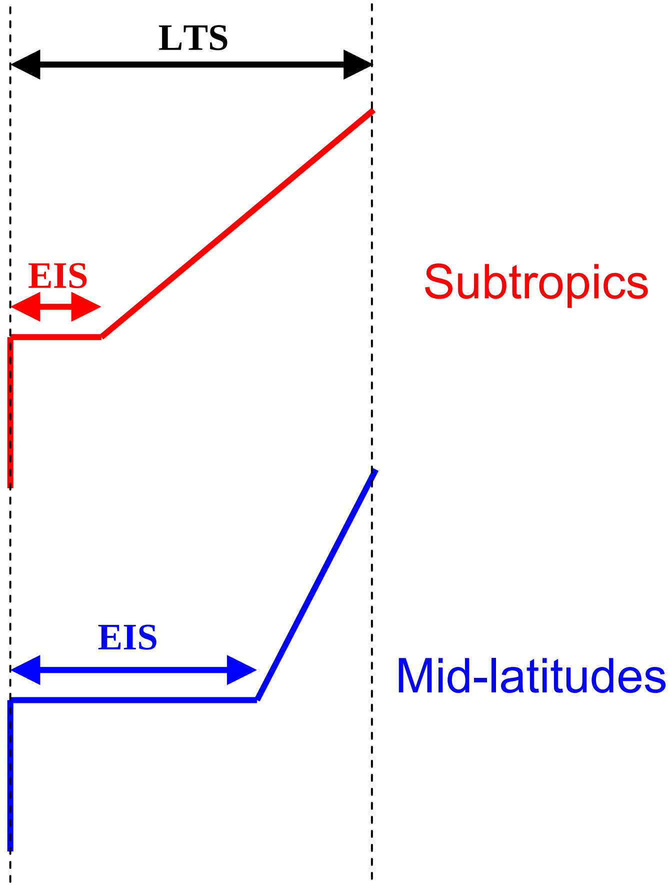
- In this version (Sc scheme V2 in Kawai (2012, SOLA)), vertical structure of clouds are better than the operational version.
- But the mid-latitude low clouds are almost the same as the operational version.

LTS □ EIS

EIS (Estimated Inversion Strength (Wood & Bretherton 2006))



Copied from Wood and Bretherton (2006)



* If LTS is utilized as this kind of condition, the model could be inappropriate to use for climate change simulation...

Use EIS as a substitute for LTS in condition (1) for the LTS Sc scheme.

CTE Sc scheme

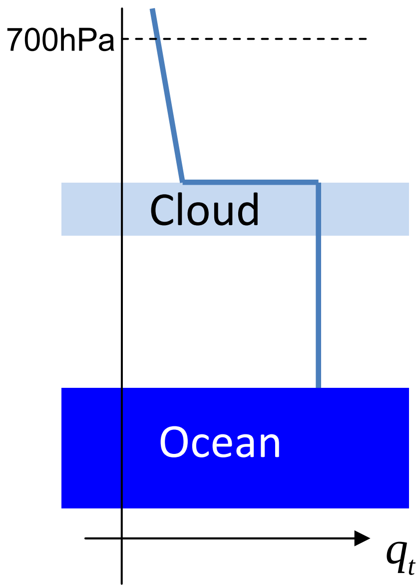
When EIS is used, mid-latitude low clouds are increased. But it was not enough compared to observation. Think further...

Criteria for no Cloud Top Entrainment Instability (Δ_{EZ} is the gap at the inversion)

$$\Delta_{EZ}\theta_e > k\frac{L}{c_p}\Delta_{EZ}q_t$$

Roughly assume that q_t below inversion is close to q_t near surface, and q_t above inversion is close to q_t at 700hPa. Coefficient $C_{\Delta q}$ (≤1.0, e.g. 0.8) is multiplied because actual q_t gap at the inversion is presumably smaller than that.

$$\Delta_{EZ}\theta_e > k\frac{L}{c_p}(q_{700} - q_{surf})C_{\Delta q}$$



Using potential temperature,

$$\Delta_{EZ}\theta + (1-k)\frac{L}{c_p}(q_{700} - q_{surf})C_{\Delta q} > 0$$

Use EIS as a potential temperature gap

$$EIS - (1-k)\frac{L}{c_p}(q_{surf} - q_{700})C_{\Delta q} > 0$$

CTE Sc scheme

As a substitute for condition (1) in LTS Sc scheme:

$$\theta_{700} - \theta_{surf} > 20[K],$$

Use the criteria for CTEI:

$$EIS_{CTE} = EIS - (1-k)\frac{L}{c_p}(q_{surf} - q_{700})C_{\Delta q} > 0.$$

In addition,

- To ensure the existence of inversion,

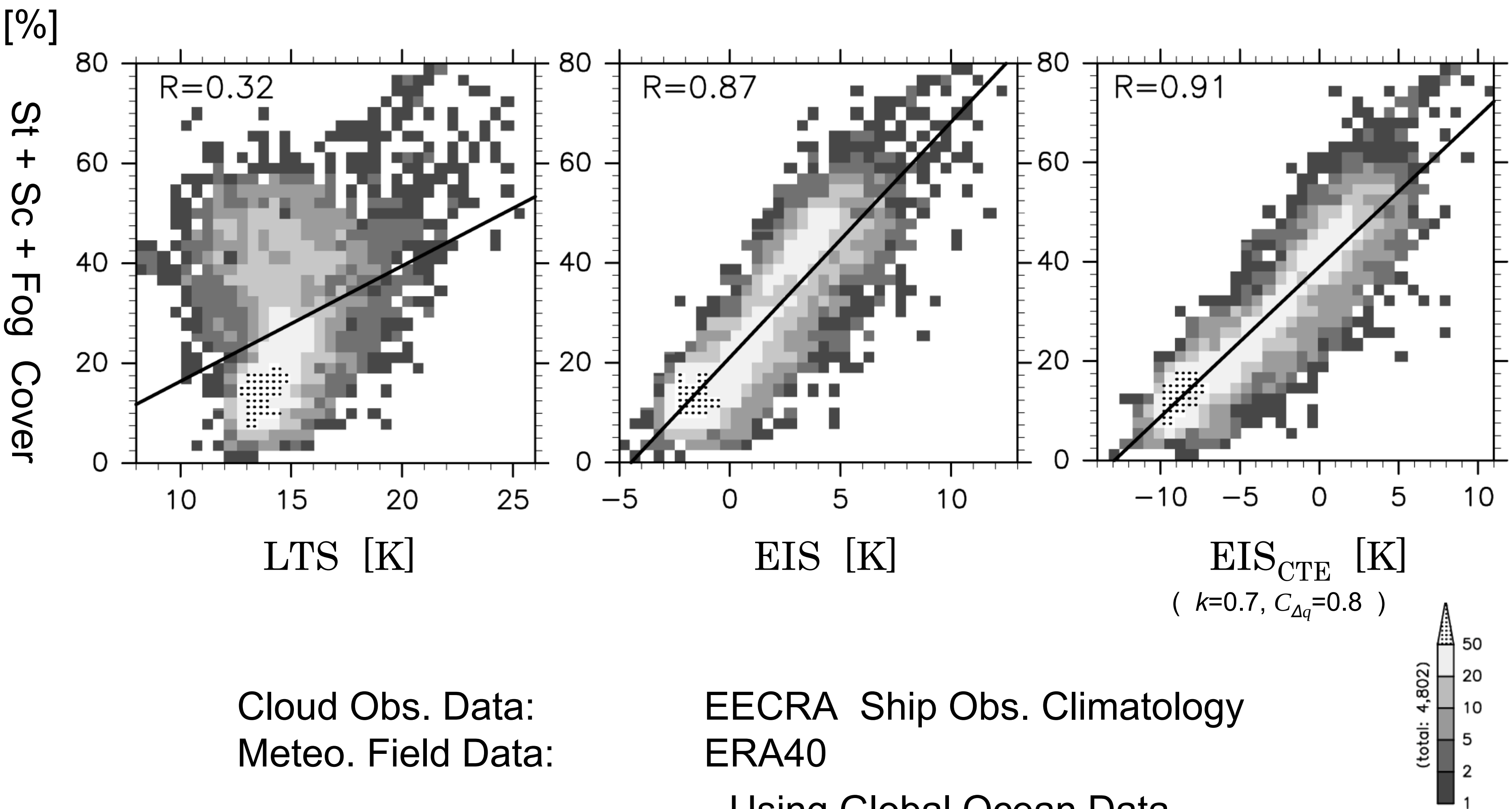
$$EIS > 3[K]$$

- The following condition is added to the condition (2) in the LTS Sc scheme, which ensures the existence of mixed layer.

$$RH_{surf} > 60[\%]$$

Supports from Observation...

LTS/EIS/EIS_{CTE} – Low cloud Cover relationship

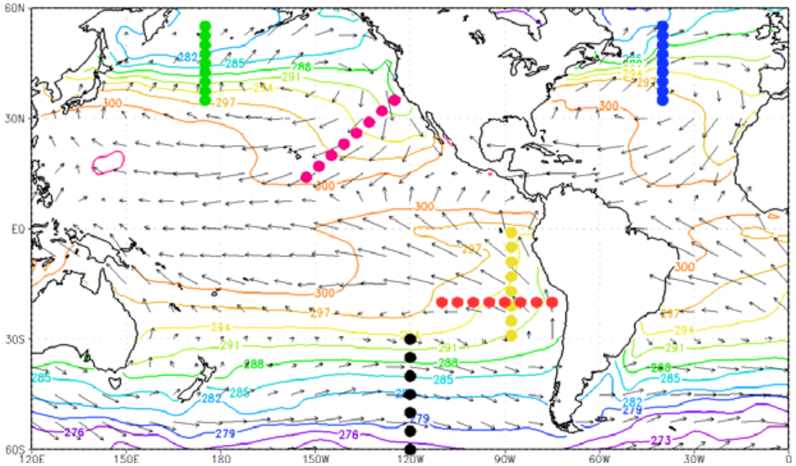


Cloud Obs. Data: EECRA Ship Obs. Climatology
Meteo. Field Data: ERA40

Using Global Ocean Data

EIS_{CTE} has good correlation with low cloud cover, at least, comparable to EIS.

LTS/EIS/EIS$_{CTE}$ – Low cloud Cover relationship

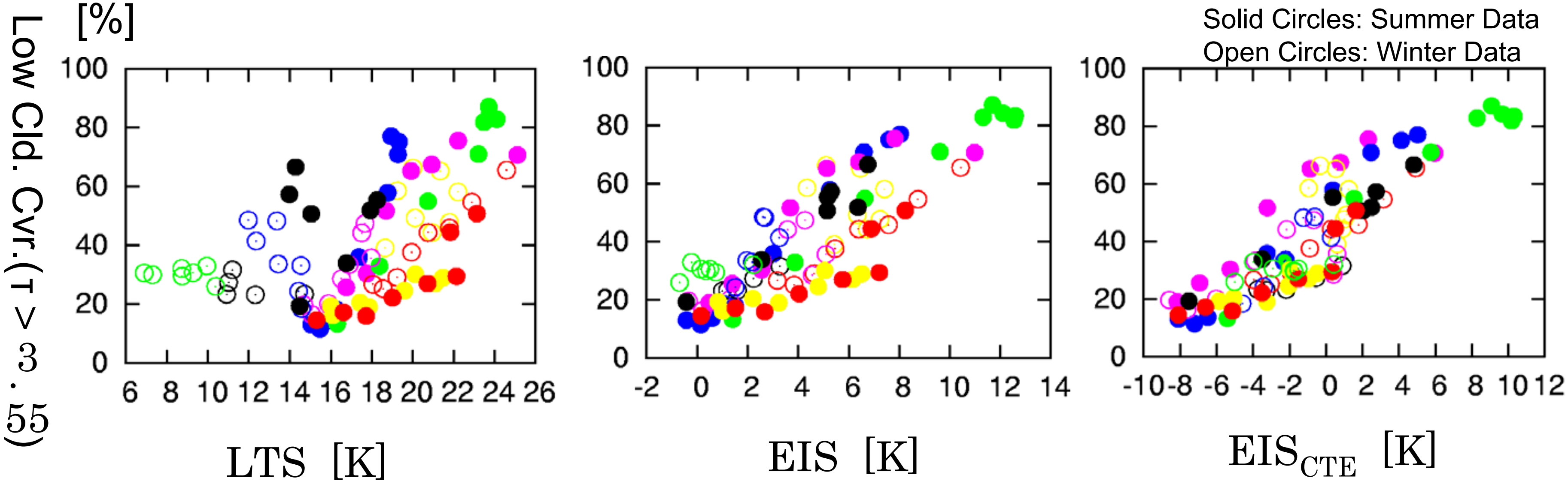


Background: SST & Surface Wind

Cloud Data :	ISCCP D1 Data
Meteor. Data :	ERA-Interim

- Low (below 680hPa) cloud cover in areas uncovered by upper or mid clouds is calculated.
- Data whose upper and mid cloud cover is less than 30% are used for the calculation.
- Jan. and Jul. mean data (1999-2001) is plotted.

Solid Circles: Summer Data
Open Circles: Winter Data

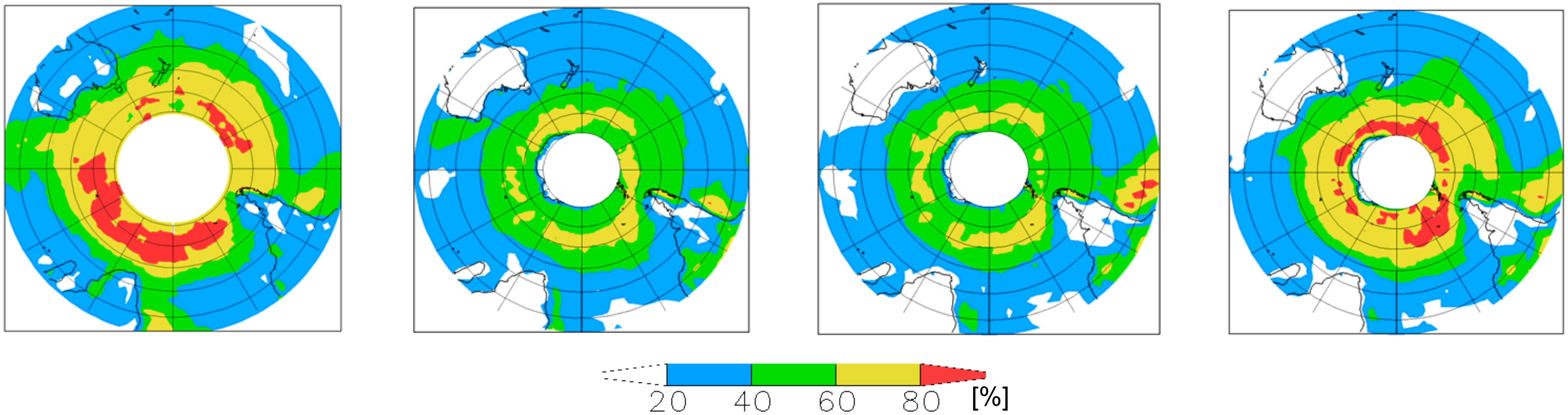


(k=0.7, $C_{\Delta q}$=0.8)

EIS$_{CTE}$ has good correlation with low cloud cover, at least, comparable to EIS.

Low Cloud Cover (Jan.)

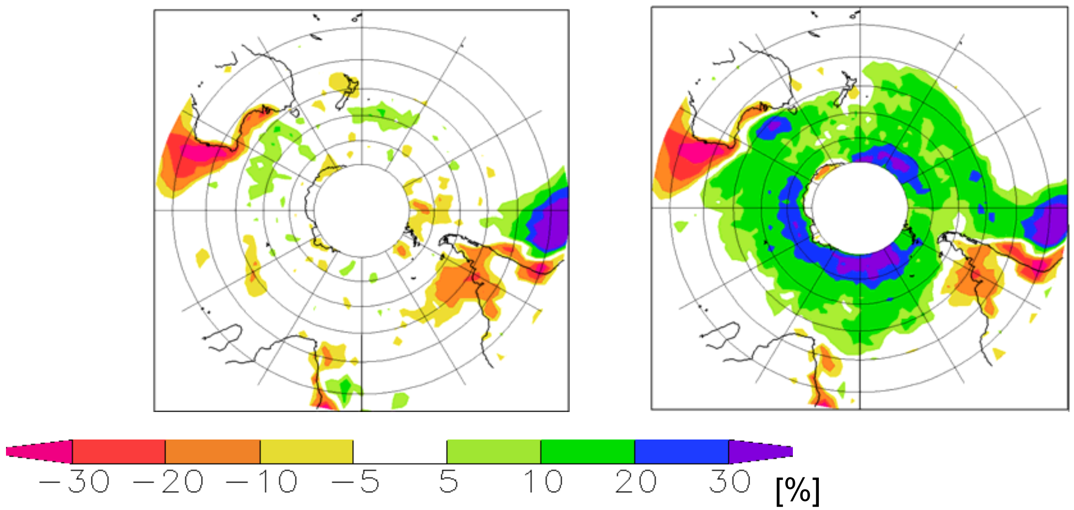
Obs. | Operational Sc scheme | LTS Sc scheme | CTE Sc scheme



Obs.:

Low cloud cover in areas uncovered by upper clouds (calculated using ISCCP data).

LTS scheme − operat. scheme | **CTE scheme − operat. scheme**

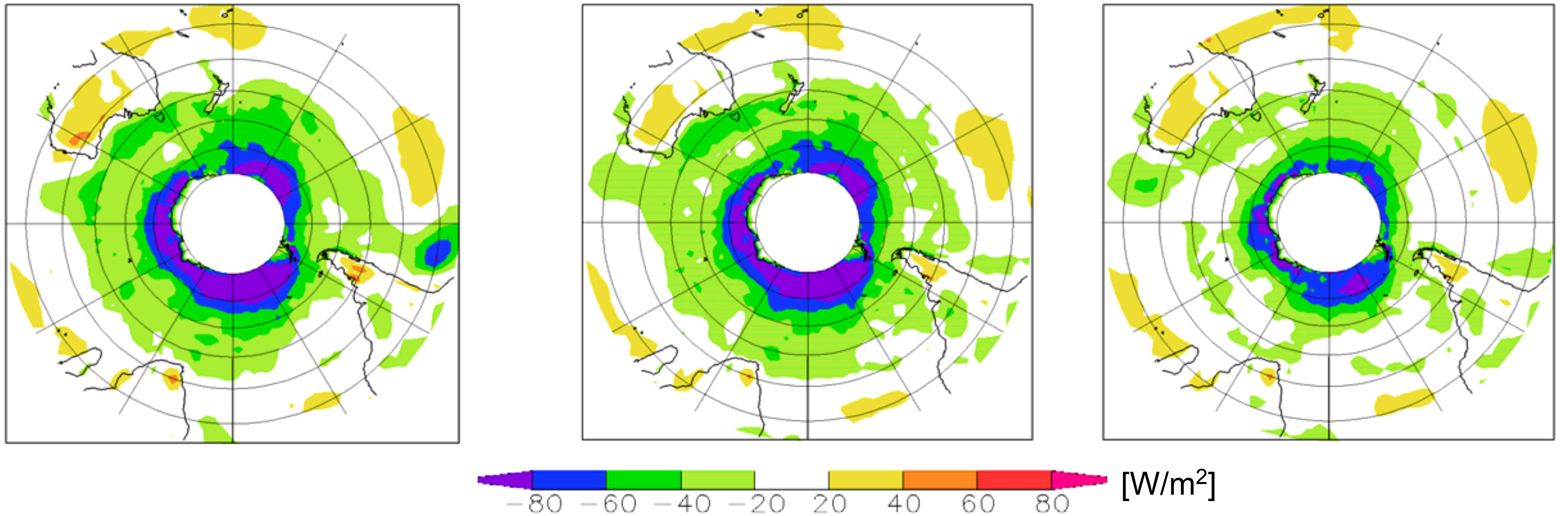


Low clouds in mid-latitudes were increased and closer to the obs.

Bias of TOA upward shortwave flux (Jan.)

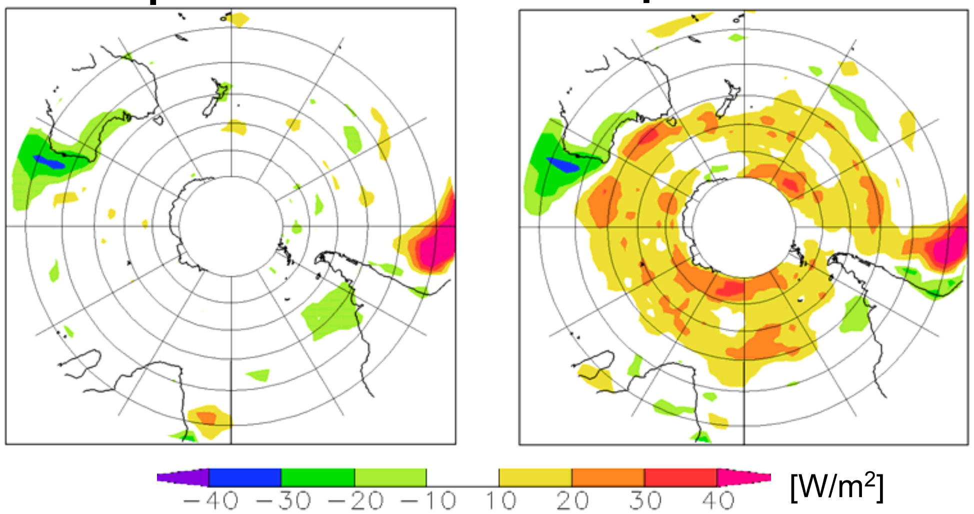
Operational Sc scheme | LTS Sc scheme | CTE Sc scheme

Bias



LTS scheme − operat. scheme | **CTE scheme − operat. scheme**

Impact

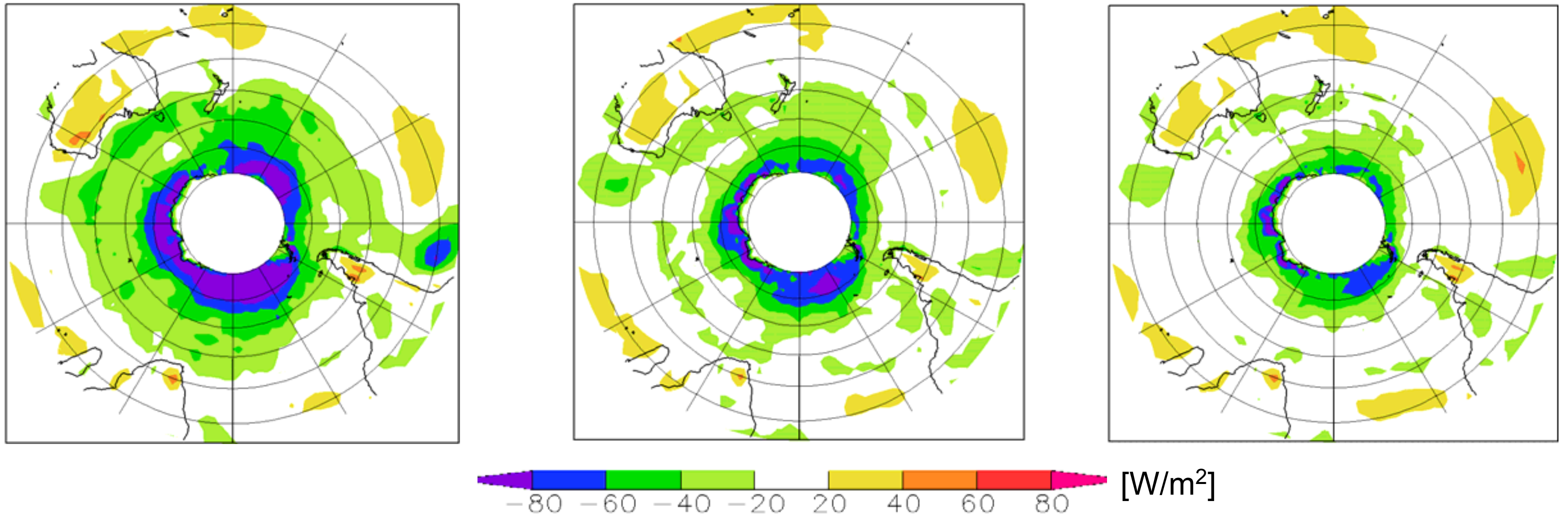


The SW flux error was reduced to some extent but substantial error still remains...

Bias of TOA upward shortwave flux (Jan.)

Operational Sc scheme | CTE Sc scheme | CTE Sc scheme & $q_{c,crit}$

Bias



Try to thicken the clouds optically.

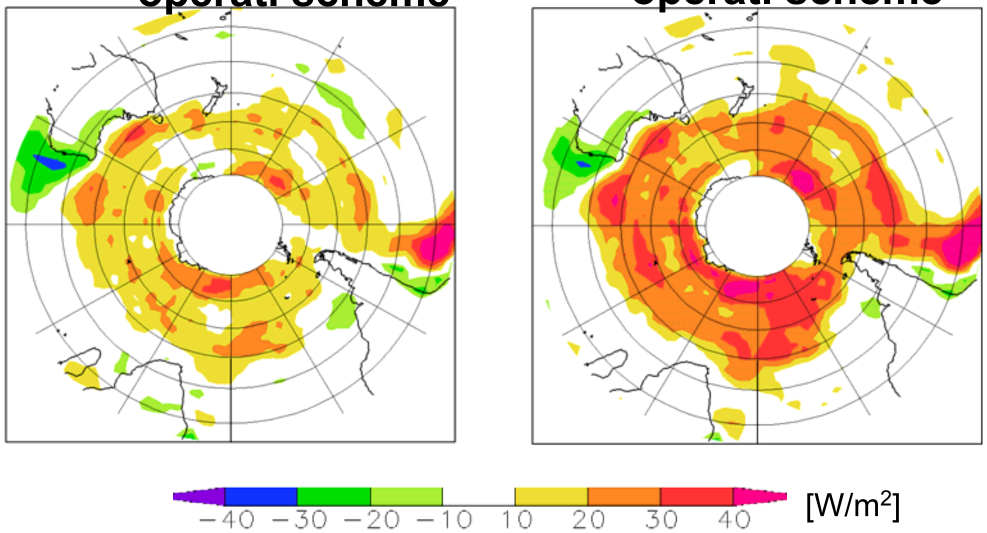
CWC threshold for autoconversion:

In the JMA-GSM, 0.1 [g/kg] for lowest model level, 0.2[g/kg] for below 800hPa, and 0.3[g/kg] for above it.

⇩

0.4[g/kg] for all levels

CTE scheme − operat. scheme | **CTE scheme & $q_{c,crit}$ − operat. scheme**



The SW flux error was reduced a lot.

Summary

- In the JMA-GSM, mid-latitude marine low clouds are not represented well.
  → Try to improve the Sc scheme.

- Excessive dry air intrusion (, and dissipation of cloud water) at the top of mid-latitude low clouds are successfully prevented using a condition (EIS_{CTE}) which determines the cloud top mixing. And mid-latitude clouds increased.
- In addition, CWC (, and cloud cover) was increased by suppressing the excessive conversion of CWC to precipitation.

→Large SW flux bias in mid-latitudes was improved (but there is still bias around 60S-70S).

Kawai (2013, CAS/JSC WGNE Research Activities in Atmospheric and Oceanic Modelling/WMO, 43)

Backup Slides

Operational Sc Scheme

This operational scheme (Kawai & Inoue, 2006) was developed for relatively coarse vertical resolution model to represent stratocumulus.

- Strong inversion layer just above the layer
- Not stable near the surface (→existence of ML)
- Apply this scheme only below 940hPa

- Determine the cloud cover as a function of inversion strength
- In-cloud CWC is proportional to saturation specific humidity:

- Suppress mixing at the top of the cloud layer