Recent activities for fixing compensating errors in parametrisation schemes of the JMA operational global model

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Outline of my talk

- GSM (Global Spectral Model) as the operational NWP model at JMA
- Long-standing biases in GSM
  - Although biases differ from model to model, it could be useful to show how we face the problem.
- Recent upgrades of GSM with facing error compensation problems
- Examples of fixing compensating errors
- Summary

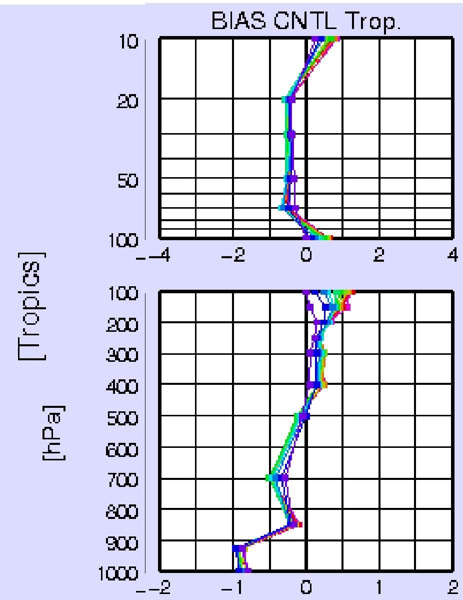
JMA Global Spectral Model (GSM)

- JMA's operational global model since Mar. 1988
  - For short to medium range forecasts (also for one-month and seasonal forecasts)
  - For Typhoon track forecasts
  - Input for other NWP systems (regional, dispersion, and wave models etc.)
- Covering wide time and spatial scales.
- Used in both deterministic (~20km) and ensemble forecast systems including DA systems.
- A number of improvements and source code-restructuring have been carried out for 28 years.
  - However, several long-standing biases exist

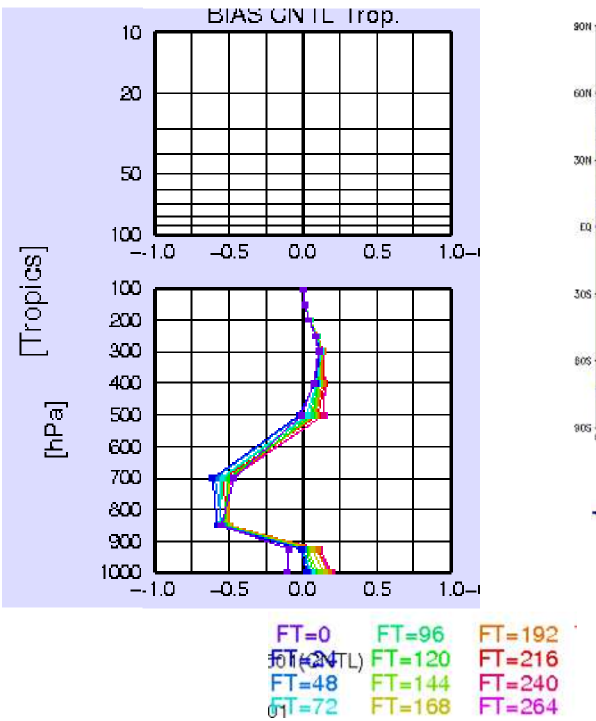
Background of the recent development: Long-standing biases in GSM

Mean errors against radiosondes over the Tropics

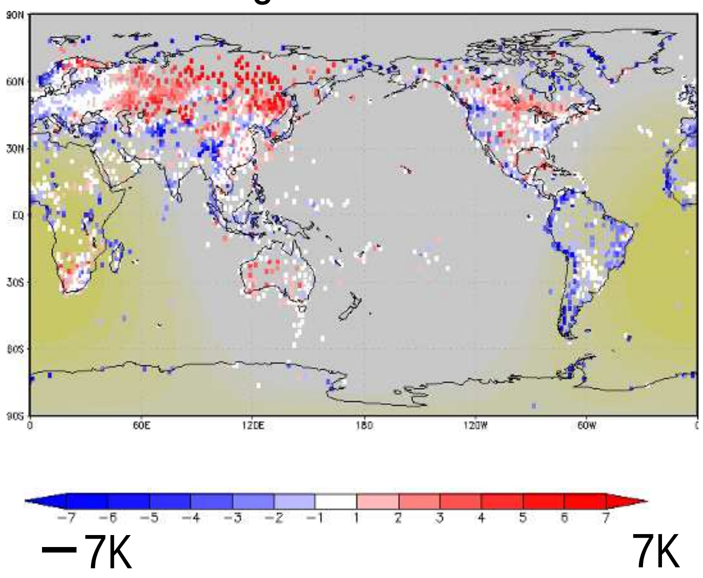
Temperature (K)



Specific humidity (g/kg)



2014Jan/2mTemp (12UTC)
ME ag. SYNOP



- Warm bias in the upper troposphere
- Cold bias in the lower and mid troposphere

- Dry bias in the mid troposphere

- Warm bias in the night time over the land

Obstacles to improvement

After the previous major upgrade (Tl319L40 to Tl959L60) in 2007,
we had suffered from …

- Compensating errors
  - Although a new physically sensible scheme (or methods, bug fixes, etc) were implemented, performance would not always be better. The new scheme could reveal hidden errors in other schemes.
- Minor treatment or not-well-documented patches
  - just written down as "correction", "adjustment“, "exception“ or etc… in source code
  - These may sound trivial, but sometimes critical for the model's performance
  - Sometimes compensate (or hide) essential problems in parametrisation schemes.

These problems had prevented us from further improvement, implementing new schemes and disentangling systematic errors in GSM.

Recent upgrades (relevant to parametrisation) in GSM with tackling the obstacles

- Mar. 2014 (GSM1403)
  - With increase of vertical levels from 60 to 100 (a topmost level raised from 0.1hPa to 0.01hPa)
- Mar. 2016 (GSM1603) the biggest upgrade in a recent decade
- May 2017 (GSM1705)

In these upgrades, improvement of convection, cloud, radiation, stable boundary layer, sea & land surface, sea ice treatment and subgrid gravity wave schemes reduced the long standing biases in GSM in a physically more sensible way.

Most of these upgrades were revision or overhaul of the existing schemes.
However, the improvement to the model's performance is significant.

Strategies and Tactics

- To understand which process compensates (or hides) errors in others
  - Hierarchical tests from Single Column Models (SCMs), Case studies, data assimilation cycles and to long-term integration
  - More "package testing" (synthesizing individual improvements) to diagnose interaction between processes
  - More discussion between modelers beyond each expertise
    - (e.g.) Encourage parametrisation developers familiarise themselves with other parametrisation schemes, dynamics, DA and/or model diagnostics etc...
  - A common verification package "DPSIVS" ,of the modelers, by the modelers, for the modelers, helps us (*see Takafumi Kanehama (JMA)'s poster*) speed up the development cycles

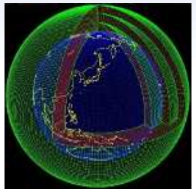
Strategies and Tactics

- To overhaul existing parametrisation schemes by
  - Making formulation and its discretisation as clear and physically / mathematically sensible as possible
  - reviewing source code between developers, documentation including discretisation , refactoring source code and etc...

Behind the long-standing biases

Revealed that *essential problems are masked by accumulated error compensations*

The biases we had actually looked at were at the surface layer (top of the box in the right side)



Treatment in the model
(corresponding to the right boxes)

- Inflating the cloud PDF width depending on convective mass flux

- Artificial vertical re-distribution of detrained cloud ice from the convection scheme (influence temperature through the cloud radiation)
- Too fast ice and snow fall speed and its time-step dependency (influence temperature through the cloud radiation)
- Artificial energy correction

- Lack of important processes (terms) in the convection scheme (due to computational cost problems)
  - precipitation conversion
  - Snow melting

Biases we had looked at

- Error compensation (2)
  - Mitigate insufficient mid-level cloud.
  - Reduce the cold bias
  - Enhance the dry bias (seen in verif.)

- Error compensation (1)
  - Over-compensation which results in cold and dry biases in the mid-troposphere
  - Leave the insufficient mid-level cloud problem unsolved

“Root” of errors in the formulation of the convection scheme.
These would have resulted in warm bias , and insufficient mid-level cloud.

Behind the long-standing biases

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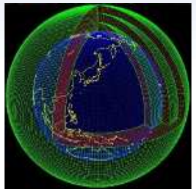

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How we revealed

- NWP cases
- DA cycles
- Long-term integration

- Unit tests (extracted from the model's actual source code)
- SCM tests
- Formulation & discretisation reviews
- Theoretical analysis
- NWP cases

- Formulation & discretisation review
- Unit tests
- SCM tests

To fix the long-standing biases

If we want to fix the essential problems (fix the problems from the *bottom*)......

Treatment in the model (corresponding to the right boxes)	Biases we would look at
• Inflating the cloud PDF width depending on convective mass flux	• Error compensation (2) • Mitigate insufficient mid-level clouds • *Enhance the cold and the dry biases*

• Artificial vertical re-distribution of detrained cloud ice from the convection scheme (influence temperature through the cloud radiation)
• Too fast ice and snow fall speed and its time-step dependency (influence temperature through the cloud radiation)
• Artificial energy correction
	• Error compensation (1)
	  • Over-compensation which would *enhance the cold and result in dry biases in the mid-troposphere*
	  • Leave the insufficient mid-level cloud problem unsolved

• *Implement the important processes* (terms) in the convection scheme
  • precipitation conversion in updraught
  • Snow melting
	Fix the "Root" of errors in the formulation of the convection scheme.
	• Result in the smaller cold bias than those in the older GSMs (but with insufficient mid-level cloud).

To fix the long-standing biases

We also need to correct the error compensation

Treatment in the model
(corresponding to the right boxes)

- Artificial vertical re-distribution of detrained cloud ice from the convection scheme (influence temperature through the cloud radiation)
- Too fast ice and snow fall speed and its time-step dependency (influence temperature through the cloud radiation)
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Biases we would look at

- Error compensation (1)
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Fix the "Root" of errors in the formulation of the convection scheme.

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@GSM1603

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Treatment in the model
(corresponding to the right boxes)

- *Implement the important processes* (terms) in the convection scheme
  - precipitation conversion in updraught
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Biases we look at

Fix the "Root" of errors in the formulation of the convection scheme.

- Result in the smaller cold bias than those in the older GSMs (but with insufficient mid-level cloud).

@GSM1705

... and to introduce new methods which mitigate the original biases in physically more sensible ways

Treatment in the model
(corresponding to the right boxes)

Biases we look at

- methods which consider the mid-level clouds relevant to convective clouds

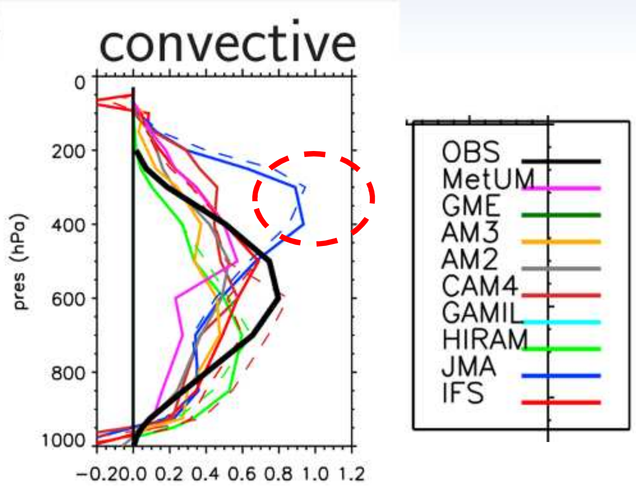
- Mitigation of the insufficient mid-level cloud problem

- *Implement the important processes* (terms) in the convection scheme
  - precipitation conversion in updraught
  - Snow melting (with the revision)

Fix the "Root" of errors in the formulation of the convection scheme.
- Result in the smaller cold bias than those in the older GSMs (but with insufficient mid-level cloud).

Essential problems in the GSM's convection schemes

- Lack of important terms in the formulation of the convection schemes in GSM
  - Precipitation generation from convective cloud condensate before reaching cloud top (requires an iterative calculation in the GSM's source code framework).
    - More ice cloud, snowfall and latent heat release in convective updraught which results in top heavy convective heating profile
  - Convective snow melting
    - Lack of the precipitation generation process during updraught generates a lot of snow at the cloud top and would bring too sharp cooling due to snowmelt around the freezing level.
      - Too dangerous to run the model stably !



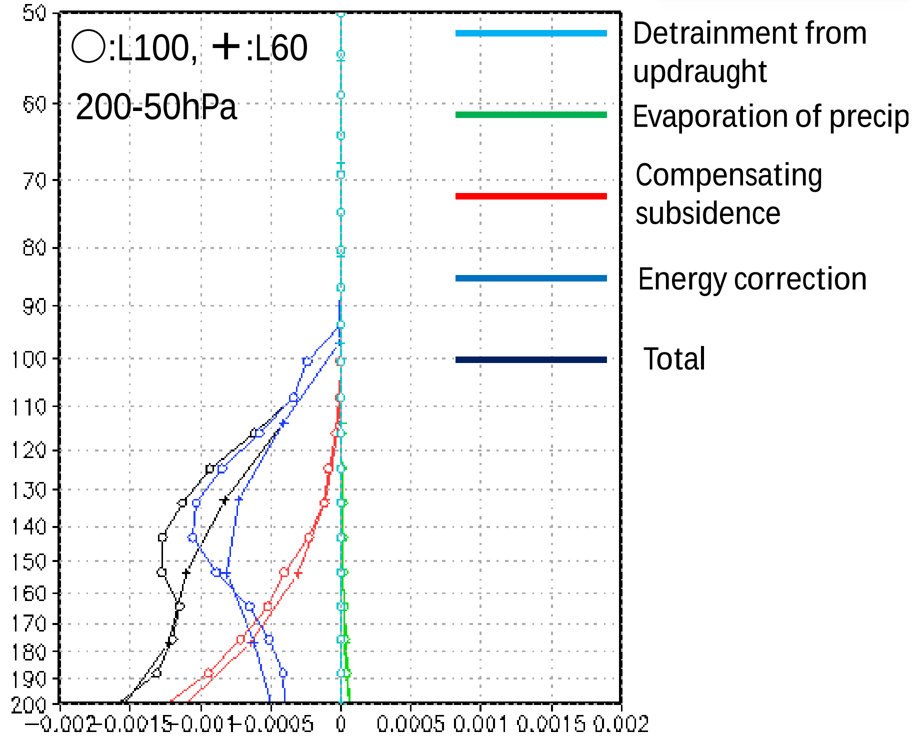
Lin et al. (2012)

Important to consider these terms although the computational cost is high.

Error compensation (1): Energy correction terms in the convection scheme

- Artificially corrects energy imbalance in a column coming from ice-phase precip. and numerics.
  - Imitating some aspects of a melting process, but these correction terms cools and dries (although the real melting process doesn't dry the atmosphere) the whole troposphere
  - SCM tests revealed that the correction term is dominant for moisture around the tropopause
    - "Correction" sounds trivial, but actually critical

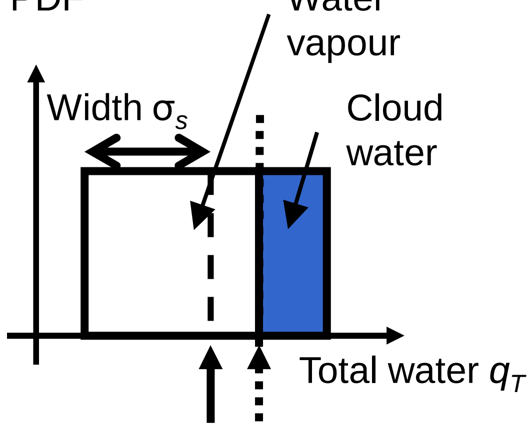
Decomposition of the moistening rate from the convection scheme in the TWP-ICE (Lin et al. 2012) SCM case



This energy correction is no longer needed if the precipitation conversion and snow melting processes are properly considered

Error compensation (2): Inflating cloud PDF

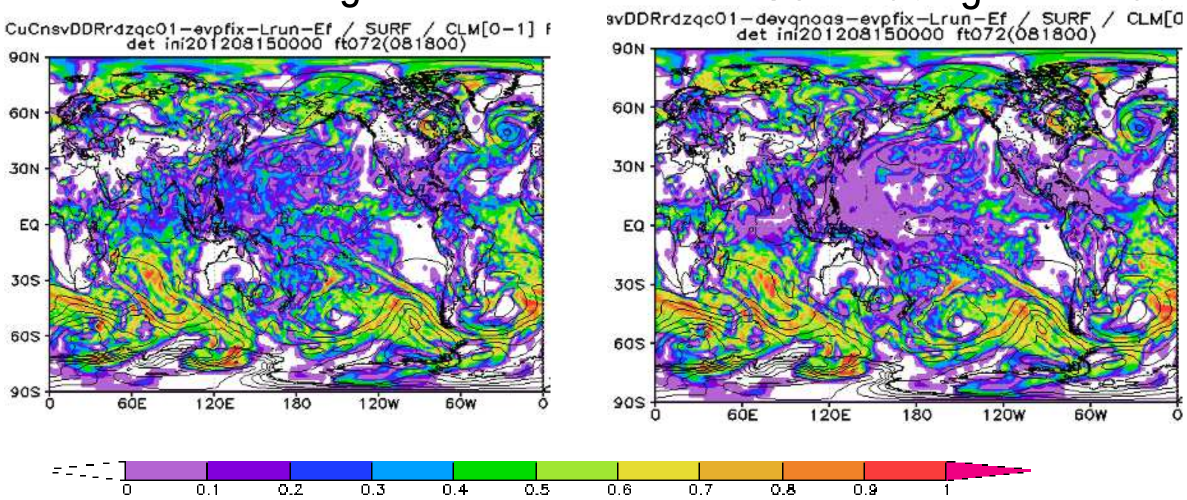
- Convective mass flux dependency of PDF width in the large scale cloud condensation scheme (A Smith(1990) type, but a top-hat shaped PDF is used.)
  - PDF becomes wider when the larger convective mass flux is calculated
  - More cloud condensation, hence more grid-scale precipitation
  - A kind of tuning, not in the original Smith's scheme, to create mid-level cloud



Midlevel cloud fraction (500hPa-800hPa)

w inflating PDF width

w/o inflating PDF width

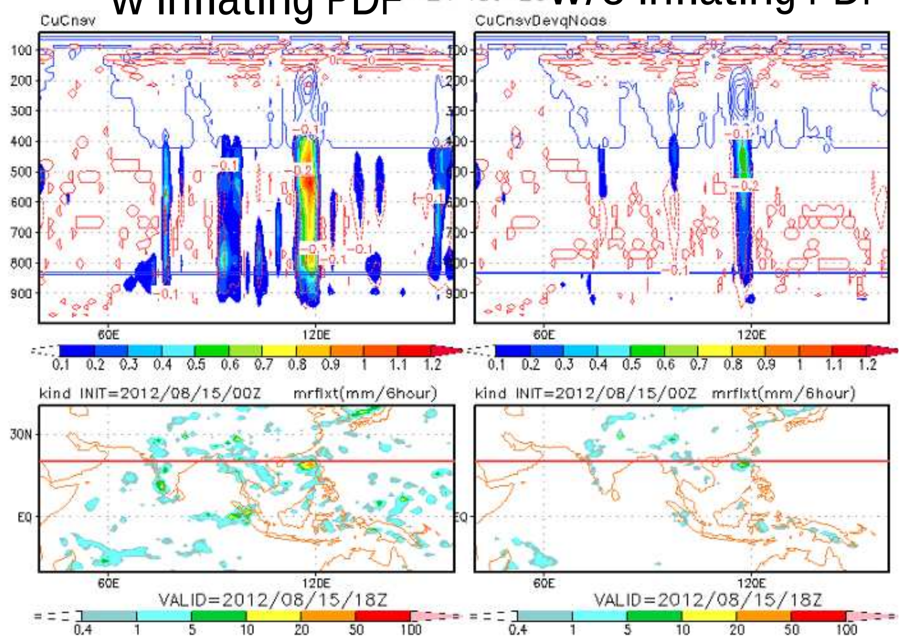


Side-effects of inflating PDF

- Dry biases
  - Condensation early-> conversion to rain by aggregation with convective precip. -> condensation again…
- Too many grid-point storms
- Distorted heating profiles
  - Latent heat release due to the condensation
  - Less need after fixing error compensation (1)

Precipitation fluxes (top) and precipitation (bottom) from the large scale cloud scheme

w inflating PDF   w/o inflating PDF



mm/6hour

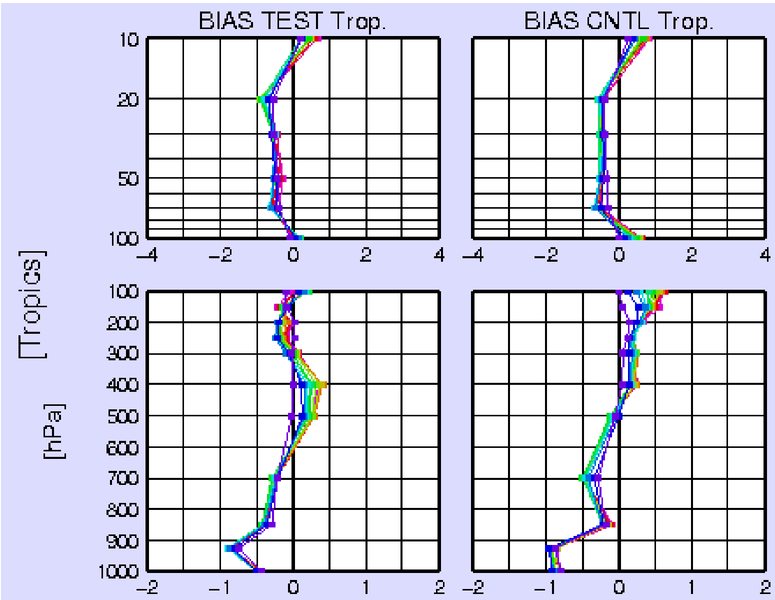
The inflation brings severe “side-effects” that overweighed its intended “benefit”

Reduction of the biases in GSM

Mean errors against radiosondes over the Tropics

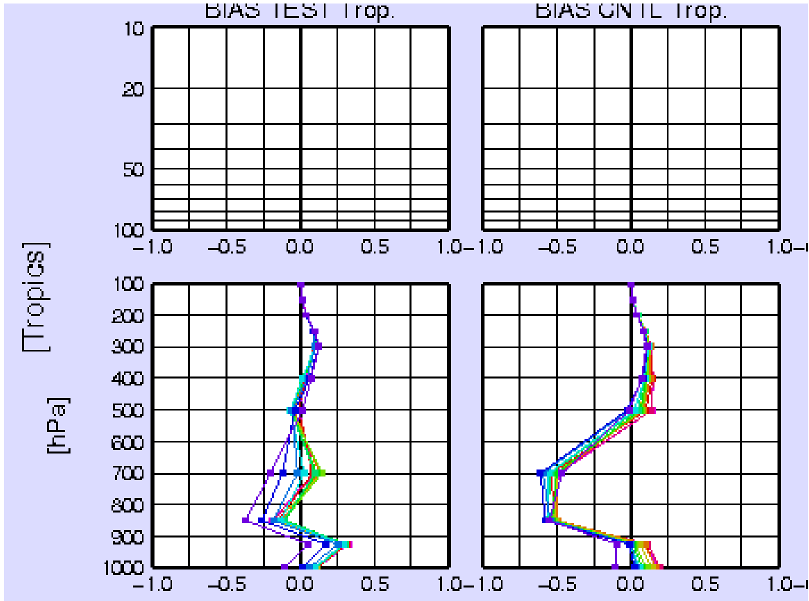
Temperature (K)

GSM1603 GSM1403



Specific humidity (g/kg)

GSM1603 GSM1403



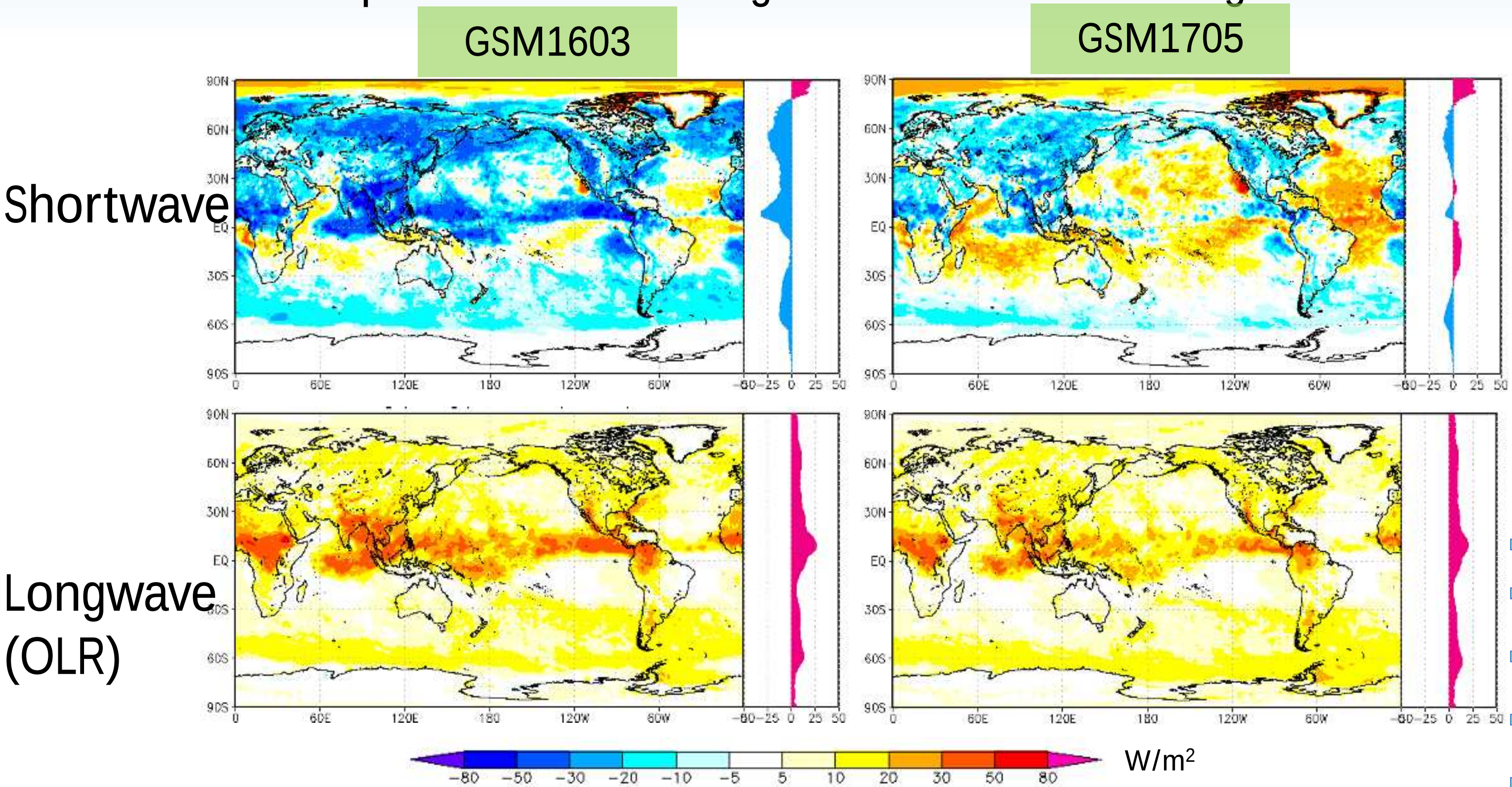
- Mitigated the warm bias in the upper troposphere
- Mitigated the cold bias in the lower and mid troposphere

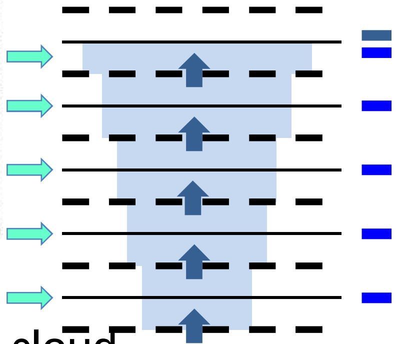
- Reduction of the dry bias in the mid troposphere

FT=0 FT=96 FT=192
FT=24 FT=120 FT=216
FT=48 FT=144 FT=240
FT=72 FT=168 FT=264

Coping with the insufficient mid-level cloud problem for the better radiation budget

Mean errors of upward short and long wave radiation fluxes against CERES at TOA (Aug. 2015)





*Considering convective cloud towers ("stems" of convection) in the cloud radiation scheme (instead of the mass flux-dependent PDF in the cloud condensation scheme)
*Refinement of optically effective radius for liquid cloud water
contribute to the improvement of SW radiation in GSM1705

Another example for benefits of "package testing" in GSM1603

- A new land surface scheme (improved SiB, iSiB)
  - Physically more sensible than the older scheme.
  - But a warm bias (tuning) in the older land surface scheme had hidden an atmospheric model's error for a long time (>10years) in GSM
    - Shortage of downward LW radiative fluxes at the ground was the essential problem.
  - Improvement of the cloud ice fall scheme, upgrade of the sea-ice treatment, and emissivity of soil and snow for long wave radiation in GSM1603 helped us introduce the new land surface scheme

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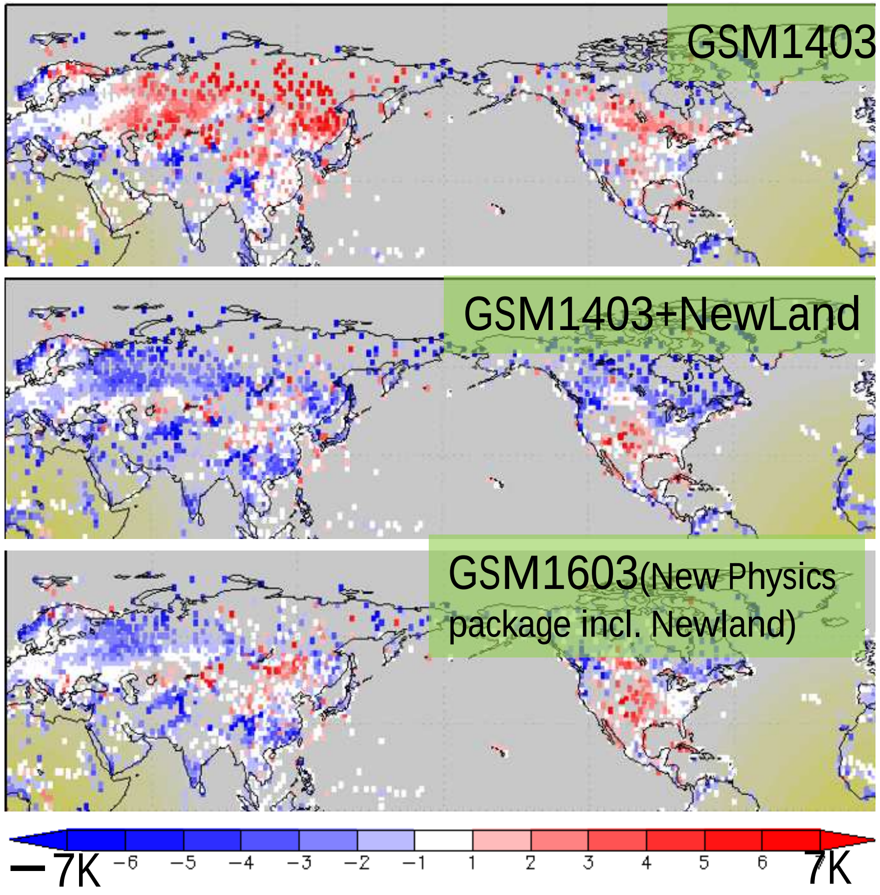

Summary

- Parametrisation schemes in GSM were upgraded several times in recent years.
  - Convection, cloud, radiation, boundary layer, land and sea surface... almost all of the parametrisation schemes are revised.
  - reduced several long-standing biases from which we had suffered.
- The keys for the improvement were
  - Efforts on revealing and fixing compensating errors.
    - Face error compensation in the model.
    - Detect which problems are essential and/or which are compensations .
    - Hierarchical testbeds, common verif./eval. tools and discussion beyond each expertise help our efforts.
  - Understand and overhaul the schemes in detail, rather than replacing them with something new as black boxes.
  - A number of package tests to diagnose interaction between processes