Upgrade of land surface processes in JMA's operational global NWP model

14 Jan. 2020（Tue.） 11:30 – 11:45

30th Conference on Weather Analysis and Forecasting (WAF)
/26th Conference on Numerical Weather Prediction (NWP)

Takashi NABETANI [1], T. Tokuhiro [2], C. Matsukawa [1], and H. Yonehara [1]

1: Numerical Prediction Division, Japan Meteorological Agency

2: Climate Prediction Division, Japan Meteorological Agency

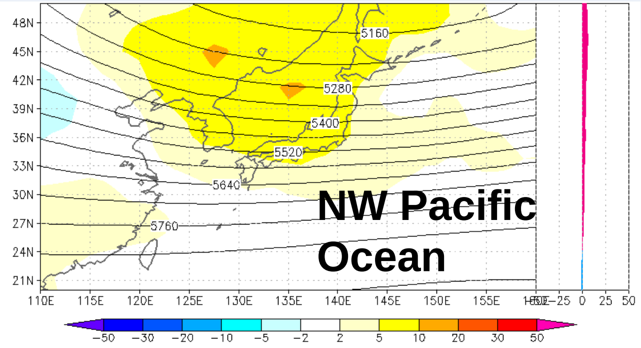
Contents

- Next upgrade plan of GSM (Global Spectral Model)
- Land surface processes in GSM
  - Configuration
  - Biases
  - Changes
    - Changes for winter low-level “cold bias” in high latitudes
    - MEs of T (2m) against SYNOP obs. and radiosondes
- Summary & Future works

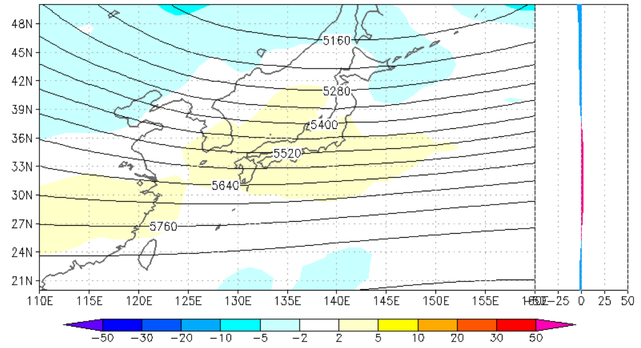
Next upgrade plan of GSM

- **GSM**
  - GSM (Global Spectral Model; JMA 2019) is the operational global NWP model at JMA.
  - The purposes are weather forecast, typhoon forecast, and provision of boundary conditions to the regional models around Japan.
- **Target**
  - Update of physical processes to improve forecast of geopotential height at 500 hPa in NH and mitigate biases of the surface variables.
- **Contents**
  - Drag processes => improve the geopotential height
  - Land surface processes => mitigate the biases of the surface
  - Radiation and cloud processes in polar areas

CNTL

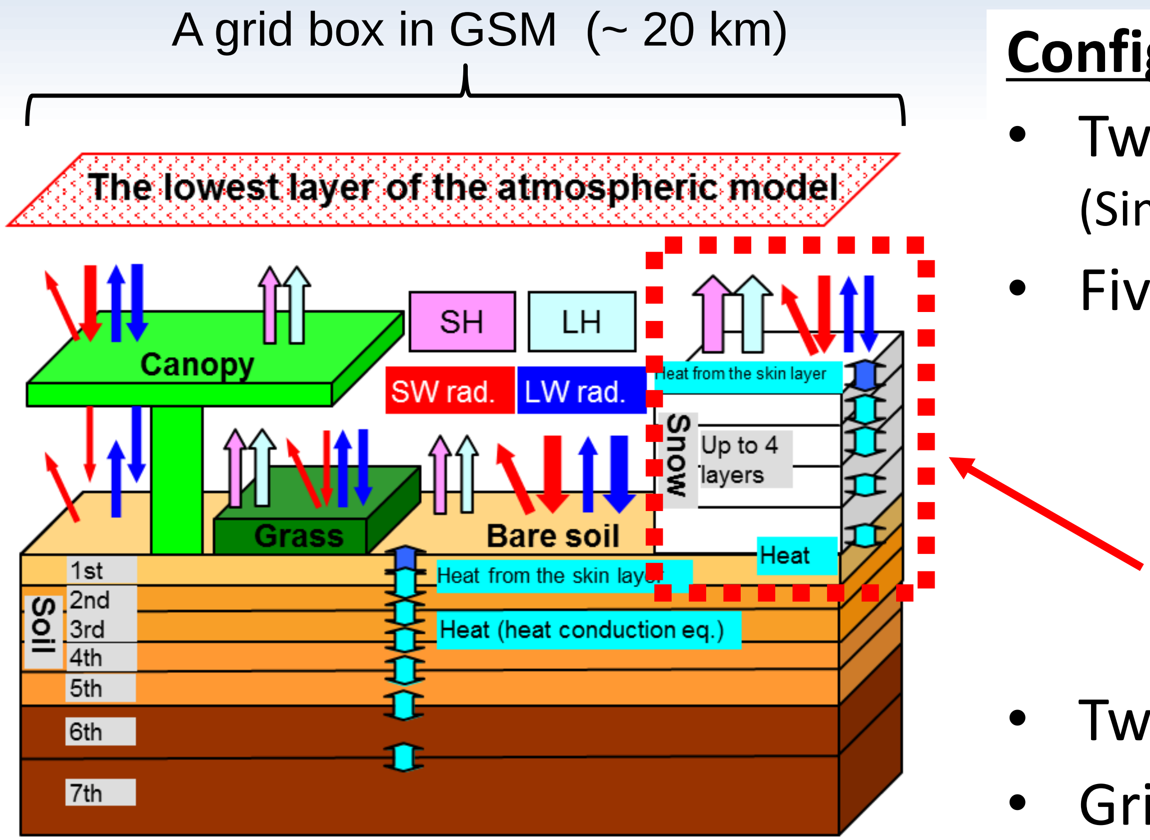


TEST



MEs of geopotential height at 500 hPa against anl. around NW Pacific Ocean
（Dec. 2017 – Feb. 2018, T+48 h）

Land surface processes in GSM



Configuration

- Two-layer energy balance scheme based on SiB (Simple Biosphere; Sellers et al. 1986; Sato et al. 1989)
- Five components:
  - Canopy
  - Canopy air space
  - Ground (grass and bare soil)
  - Snow
  - Soil
- Two tiles (snow-covered/snow-free)
- Grid boxes are isolated

In summary, the processes calculate heat, water, etc. for vegetation, snow and soil to provide lower boundary conditions of fluxes to the atmospheric model.

Biases related to the land surface processes

Bias1 winter low-level “cold bias” in high latitudes

- Change(a) changing diagnostic formula for fraction of snow coverage
- Change(b) introducing multi-layer of patchy snow

=> presented hereafter

Bias2 summer nighttime “warm bias” of the surface temperature in dry area

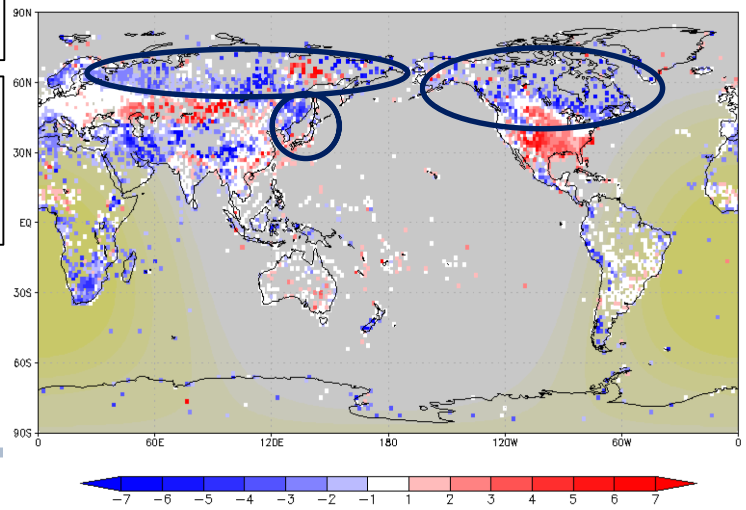
Bias3 summer “wet bias” of the surface temperature in Europe

Bias4 summer “shortage” of upward shortwave radiation at the surface in desert

T (2m)

ME
against SYNOP
Jan. 2018 T+120 h

Bias1 cold bias



Changes for winter low-level “cold bias” in high latitudes 1/2

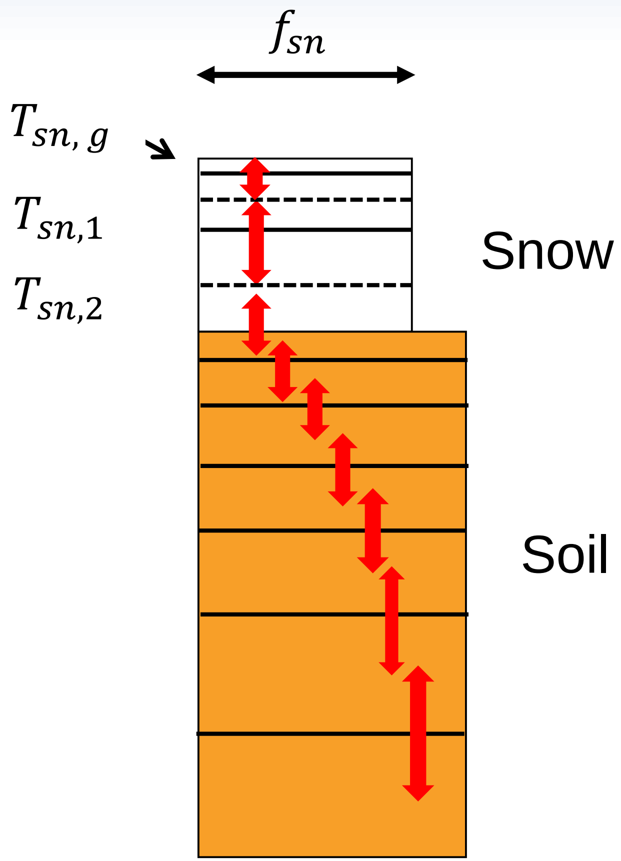
・ Effects of snow on the surface

Snow lowers the surface temperature by the following effects:

① increase of the surface albedo

② decrease of heat conductivity（insulation effect）

③ decrease of heat capacity



In GSM, the effects of snow are reproduced while the presence of snow is represented as fraction of snow coverage f_{sn} in each grid box.

In transition area from snow-covered to snow-free, a choice of formula for the fraction has a large impact on the surface temperature forecast and overestimation in the current formula is related to the “cold bias” in high latitudes.

The results of changing the formula and the multi-layer will be shown.

Changes for winter low-level "cold bias" in high latitudes 2/2

○Expose the soil and increase sensible heat

(a). Changing the formula as almost smaller one derived by using satellite observations.

The effects of snow decrease and the surface temperature warms up.

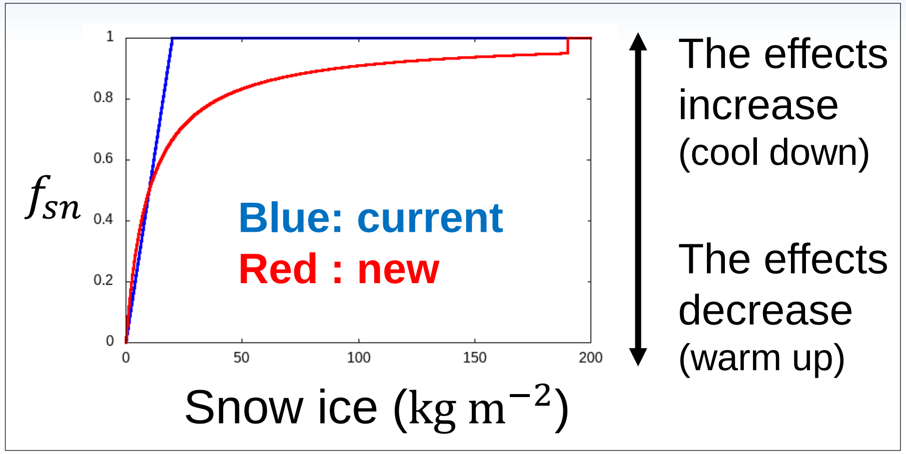
current: $f_{sn} = \frac{M_{sn}}{20} < 1$ (Sellers et al. 1986)

new: $\rightarrow$ $f_{sn} = \frac{z_{sn}}{z_{sn} + 0.01\frac{\rho_{wtr}}{\rho_{sn}}}$ (Roesch et al. 2001)

$\approx 0.05\ m$

(M_{sn}: snow ice ($\mathrm{kg\ m^{-2}}$), z_{sn}: snow depth (m))

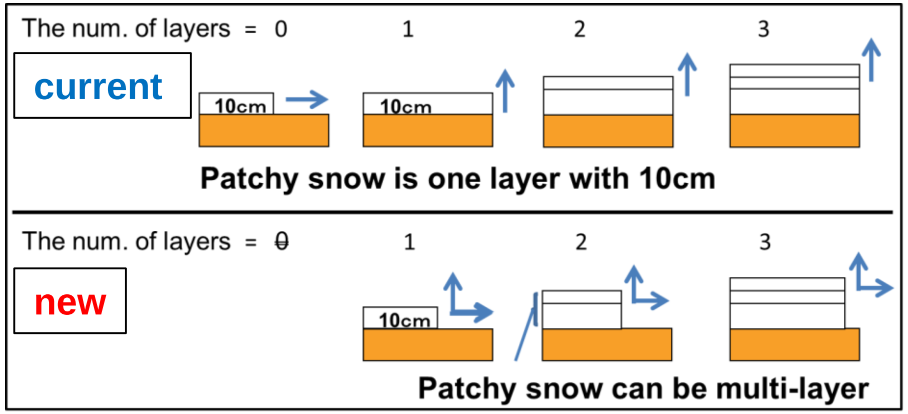
The current formula produces large fraction among various formulae.



(b). Also, multi-layer of patchy snow is introduced

In the current model, multi-layer of snow is considered only when the surface is fully-covered by snow ($f_{sn} = 1$) and the snow depth exceeds a certain threshold.

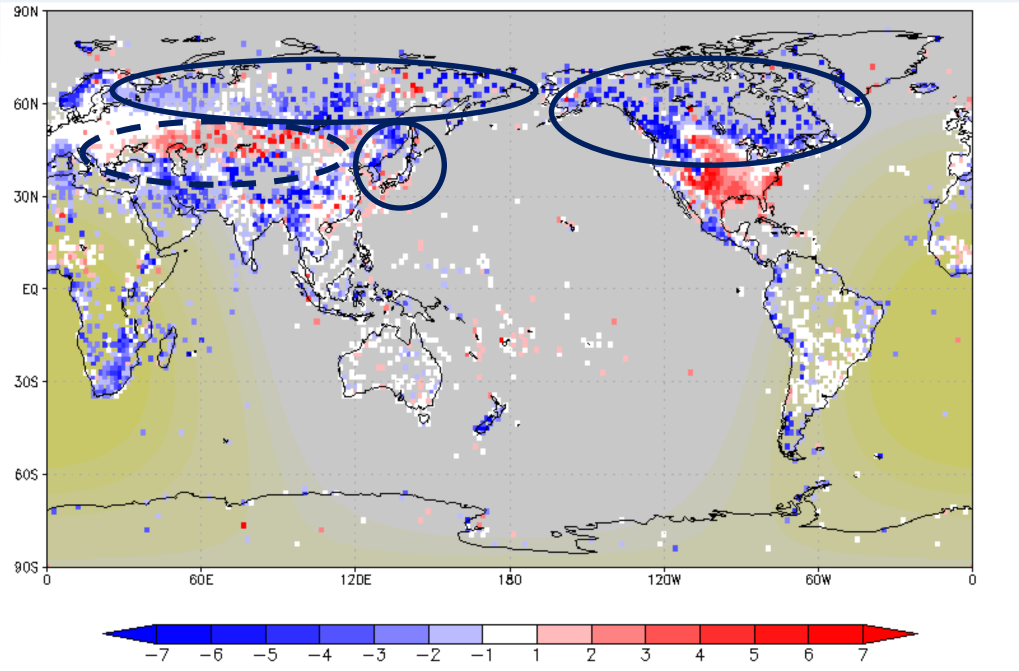
In the new model, it can be considered even with patchy snow ($f_{sn} < 1$).



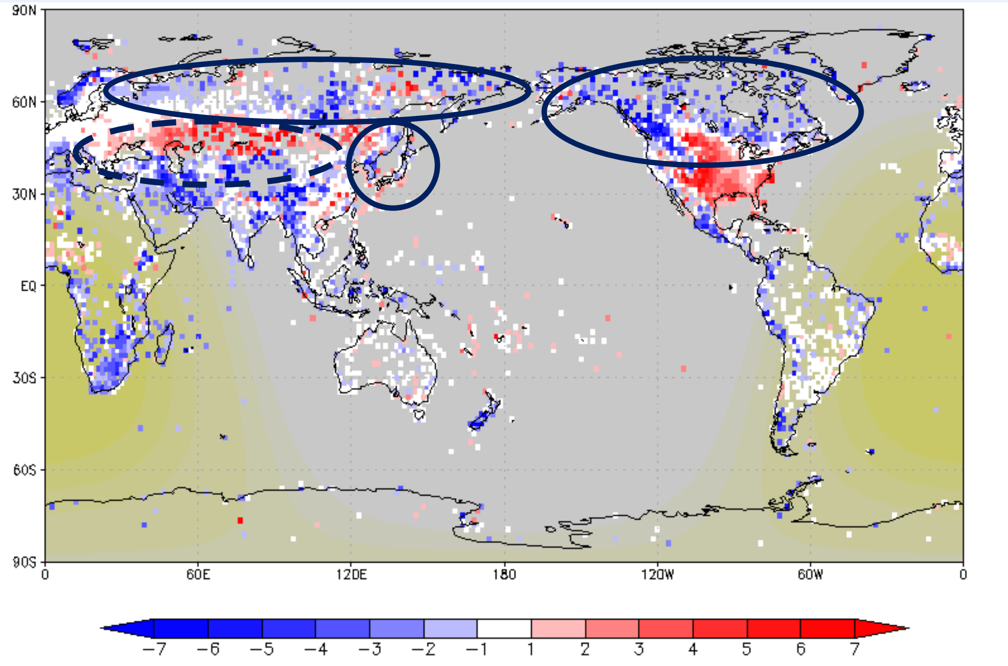
MEs of T (2m) against SYNOP obs. (Jan. 2018)

MEs of T (2m) against SYNOP T+120 h

CNTL (w/o changes for snow)



TEST



(Blue: cold, Red : warm, Yellow shade: solar rad. area)

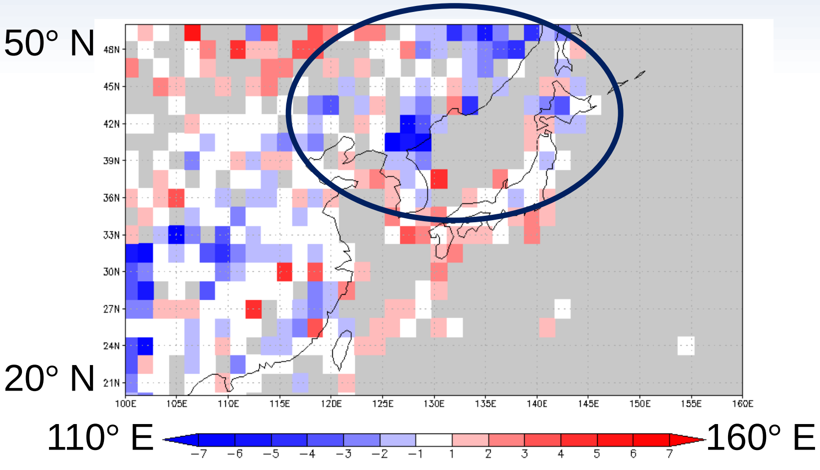
By changing the fraction of snow coverage and the multi-layer,
the winter low-level cold bias in high latitudes is mitigated,
although warm bias in Central Asia is slightly increased (dashed line circles).

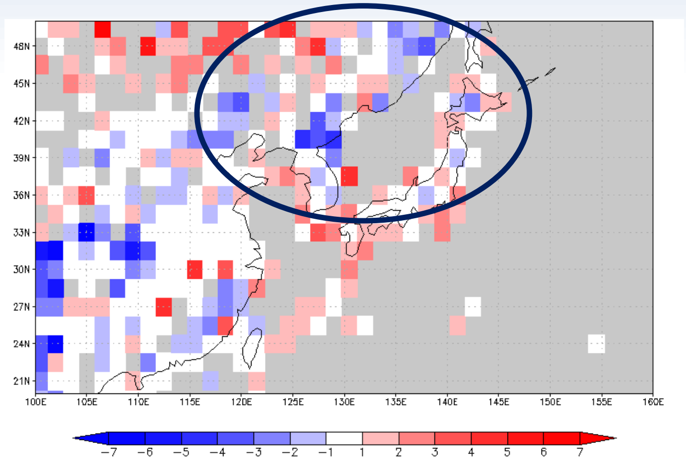
MEs of T (2m) against SYNOP obs. and radiosondes（Jan. 2018）

CNTL **(w/o changes for snow)**

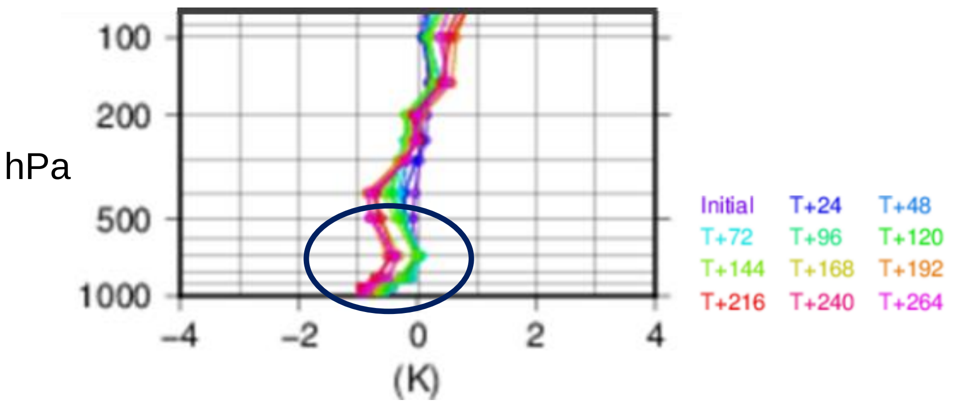
TEST

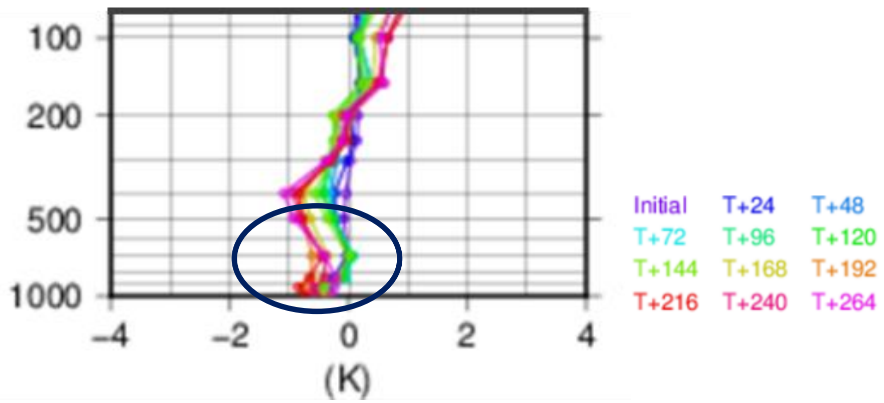
MEs of T (2m) against SYNOP T+120 h





MEs of T against radiosondes in Japan (20-50° N, 110-150° E)





- Around Japan, the cold bias is significantly mitigated.
- Any unfavorable influence on the atmosphere doesn’t seem to be indicated.

Summary & Future works

Summary

- GSM
  - JMA plans to upgrade GSM (JMA 2019) to improve forecast of geopotential height at 500 hPa in NH and mitigate biases of the surface variables.
- Land surface processes
  - The upgrade of the land surface processes consists of various changes including changes for snow.
  - Mitigation of the biases including winter low-level “cold bias” in high latitudes is confirmed.

Future works for the land surface processes

- Bare soil evaporation
  - Considering non-vegetated area with direct bare soil evaporation to the atmosphere.
- Fraction of snow coverage
  - Changing the diagnostic formula to mitigate the winter cold bias more.
- Tiling method
  - Representing the land with higher resolution than the atmospheric one.

References

- JMA, 2019: Outline of the Operational Numerical Weather Prediction at the Japan Meteorological Agency. 229pp, URL https://www.jma.go.jp/jma/jma-eng/jma-center/nwp/outline2019-nwp/index.htm

- Roesch, A., M. Wild, H. Gilgen, and A. Ohmura, 2001: A snow cover fraction parametrization for the ECHAM4 GCM. Climate Dyn., 17, 933–946.

- Sato, N., P. J. Sellers, D. A. Randall, E. K. Schneider, J. Shukla, J. L. Kinter III, Y-T Hou, and E. Albertazzi, 1989: Effects of implementing the simple biosphere model in a general circulation model. J. Atmos. Sci., 46, 2757-2782.

- Sellers, P. J., Y. Mintz, Y. C. Sud, and A. Dalcher, 1986: A simple biosphere model (SiB) for use within general circulation models. J. Atmos. Sci., 43, 505-531.

Bkup

Abstract

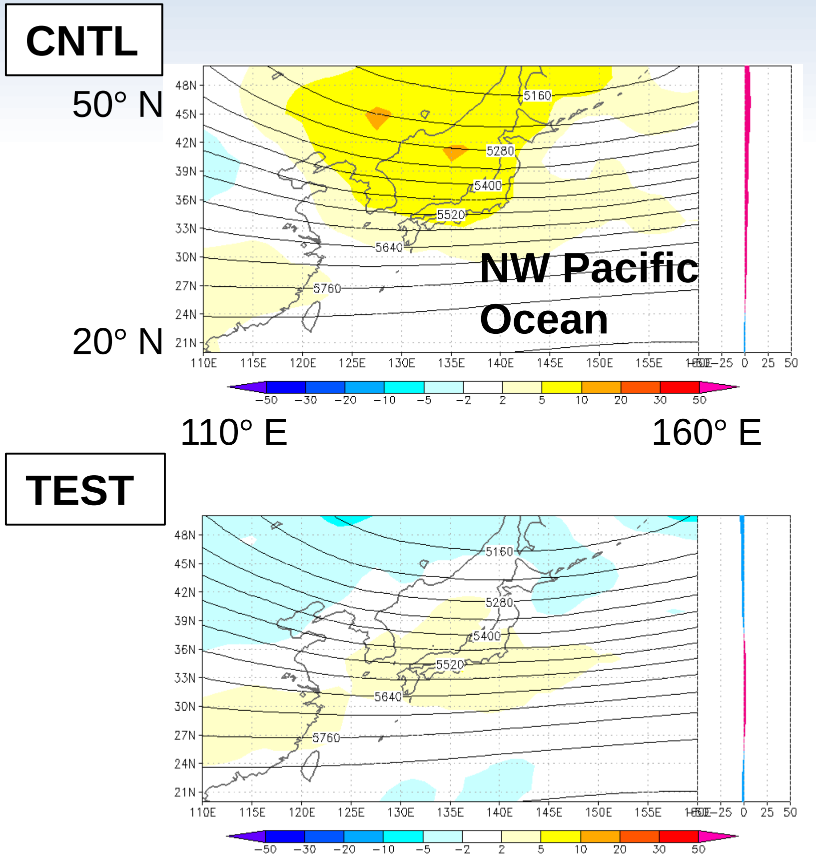
- The Japan Meteorological Agency (JMA) plans to upgrade its operational global NWP system by introducing a revised version of its Global Spectral Model (GSM; JMA 2019).
- The revision involves the refinement of various parametrized processes, including gravity wave, land surface, cloud, and radiation. In this presentation, we will show the changes and the impact experiment results, especially for the land surface processes.

- The upgrade of the land surface processes consists of various changes such as ones for diagnostic schemes of soil thermal conductivity and fraction of snow coverage to address several biases, which may be caused partially by the processes.

Next upgrade plan of GSM

(with detailed explanation)

- GSM
  - GSM (Global Spectral Model; JMA 2019) is the operational global NWP model at JMA.
  - The purposes are weather forecast, typhoon forecast, and provision of boundary conditions to the regional models around Japan.
- Target
  - Update of physical processes to improve forecast of geopotential height at 500 hPa in NH and mitigate biases of the surface variables.
- Contents
  - Drag processes => improve the geopotential height
    - Sub-grid scale orographic processes
    - Non-orographic gravity wave processes
    - PBL scheme
  - Land surface processes => mitigate the biases of the surface
    - Bare soil evaporation, stomatal resistance, fraction of snow coverage, etc.
  - Radiation and cloud processes in polar areas
    - Sea ice albedo



MEs of geopotential height at 500 hPa against anl. around NW Pacific Ocean
(Dec. 2017 – Feb. 2018, T+48 h)

JMA's operational NWP systems

Global

Global Ensemble Prediction System (GEPS)
Coupled Prediction System (CPS)

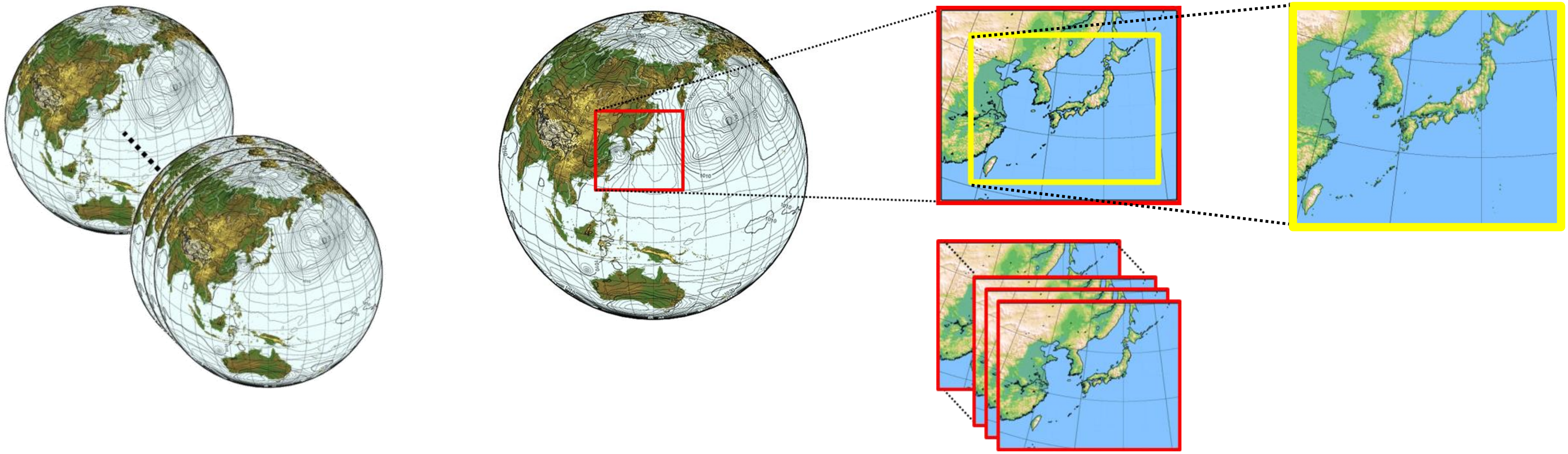
Global Spectral Model (GSM)

Meso-scale

Meso-Scale Model (MSM)
Meso-scale Ensemble Prediction System (MEPS)

Local

Local Forecast Model (LFM)



GEPS / CPS

Horizontal res. (upper: GEPS, lower: CPS)
- ~40km (- 18 days), ~55km (18 – 34 days)
- ~110km (atm. model)

Forecast range (GEPS)
- 2 ini./day 264h, 27mem.
- (depending on the day of the week)
- (when a typhoon coming, 2 ini./day added)

Forecast range (CPS)
- 1 ini./month 7months, 51mem.

GSM

Horizontal res.
- ~20km

Forecast range
- 3 ini./day 132h
- 1 ini./day 264h

MSM / MEPS

Horizontal res.
- 5km

Forecast range (MSM)
- 6 ini./day 39h
- 2 ini./day 51h

Forecast range (MEPS)
- 4 ini./day 39h, 21mem.

LFM

Horizontal res.
- 2km

Forecast range
- 24 ini./day 10h

Biases related to the land surface processes
(with detailed explanation)

Bias1　winter low-level "cold bias" in high latitudes

=>　presented hereafter

Bias2　summer nighttime "warm bias" of the surface temperature in dry area

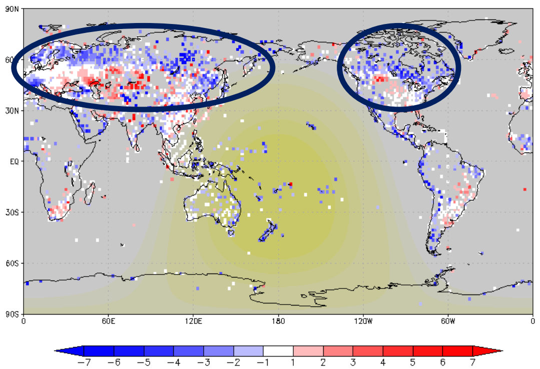
Bias3　summer "wet bias" of the surface temperature in Europe

Bias4　summer "shortage" of upward shortwave radiation at the surface in desert

Bias1 cold bias

T (2m)

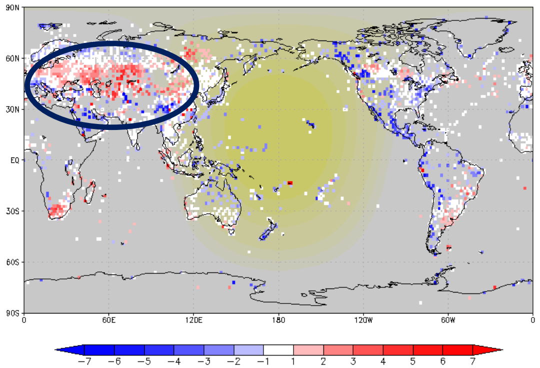
**ME
against SYNOP
Jan. 2018 T+132 h**



Bias2 warm bias

T (2m)

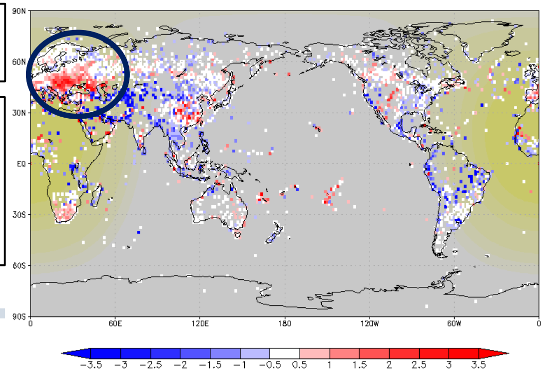
**ME
against SYNOP
Aug. 2017 T+132 h**



Bias3 wet bias

Q (2m)

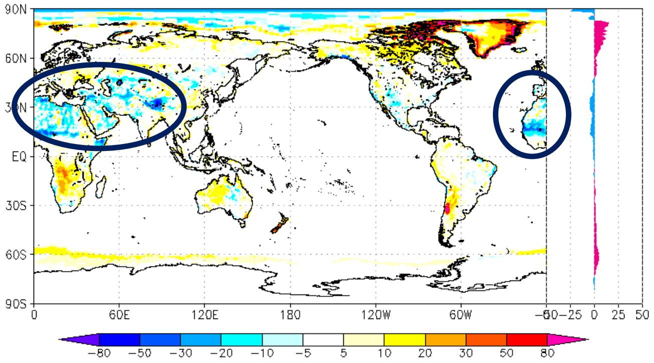
**ME
against SYNOP
Aug. 2017 T+120 h**



Bias4 shortage of SW

Upward SW radiation at the surface

**ME
against CERES
Aug. 2017**



Changes in the land surface processes
(with detailed explanation)

Bias1 winter low-level "cold bias" in high latitudes

- Changing diagnostic formula for fraction of snow coverage
- Introducing multi-layer of patchy snow

Bias2 summer nighttime "warm bias" of the surface temperature in dry area

- Changing a parameter of bare soil evaporation
- Changing a scheme of grass heat conductivity
- Increasing a ratio of grass coverage to canopy coverage

Bias3 summer "wet bias" of the surface temperature in Europe

- Partitioning a leaf to sunlit/shaded areas to increase stomatal resistance
- Changing soil moisture dependence to increase stomatal resistance

Bias4 summer "shortage" of upward shortwave radiation at the surface in desert

- Updating a parameter of desert albedo

Comparisons of fraction of snow coverage with satellite observations (Roesch et al. 2001)

- Diagnostic formula

$$f_s = \frac{S_n}{S_n + S_n^*}$$

where S_n is the water equivalent of snow in metres and S_n^* is the critical snow depth (=0.01 m).

- Comparisons

Various formulae

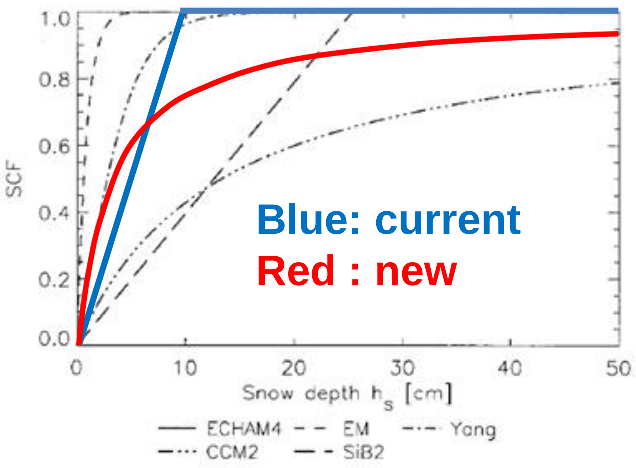


Fig. 1 Relationship between snow depth and snow cover fraction assuming $z_0 = 2$ cm (grass) and a snow density $\rho_s = 300$ kg m^{-3} using various parametrizations. EM: "Europa-Modell" (Edelmann et al. 1995); *Yang*: Yang et al. (1997); CCM2: 2nd version of NCAR climate model (Marshall et al. 1994); SiB2: Simple Biosphere Model (Sellers et al. 1996)

Satellite observations

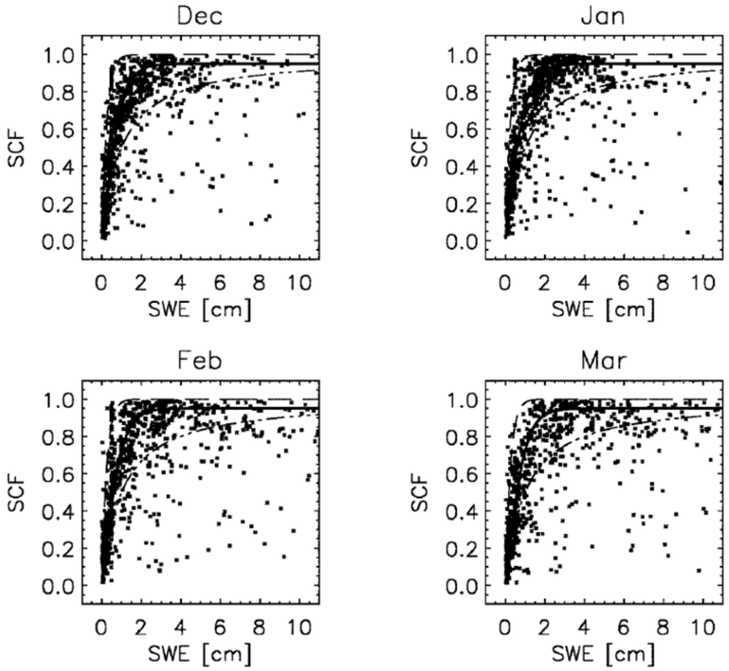


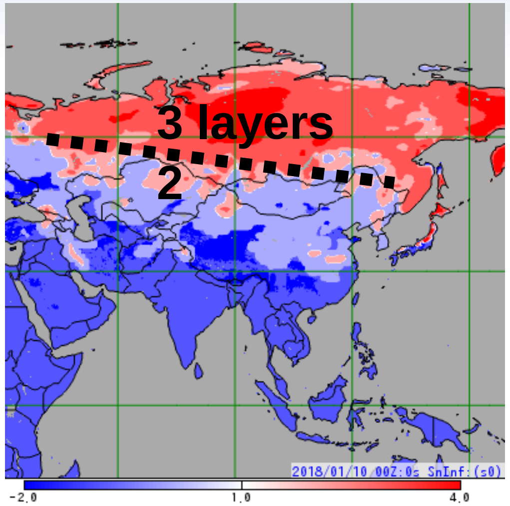
Fig. 3 SCF as a function of SWE in flat, non-forested T106 grid cells. SWE interpolated from USAF snow depth climatology; SCF from NOAA data (1973–1996). Curves are displayed for the new parametrization (*solid thick line*, Eq. 6), "Europa-Modell" (EM, *long-dashed*) and ECHAM (*dash-dotted*, Eq. 2)

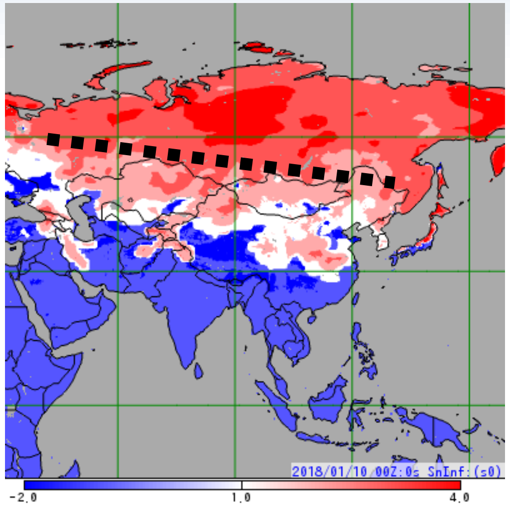
Maps of snow area（Jan. 2018）

CNTL (w/o changes for snow)

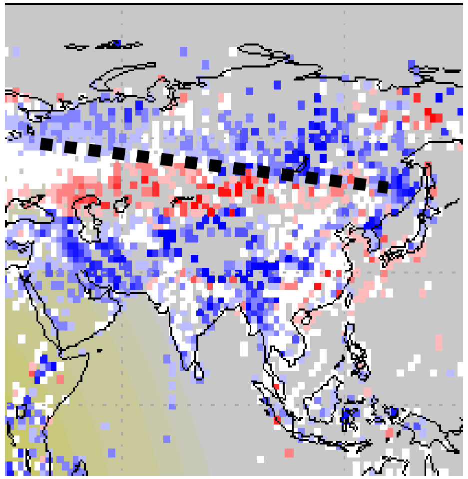
TEST

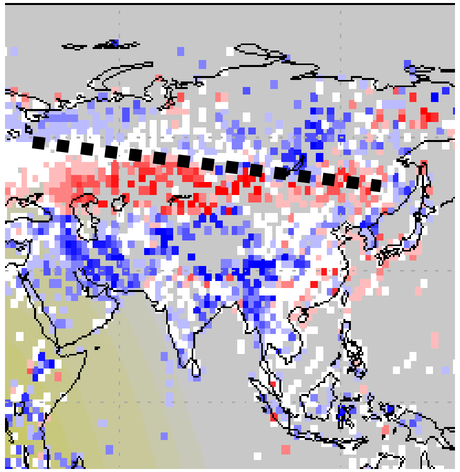
The number of snow layers
(Analysis at 00UTC, 10 Jan. 2018)





MEs of T (2m) against SYNOP T+120 h





Changes for summer nighttime “warm bias” of the surface temperature in dry area 1/2

○Decrease heat conductivity of soil skin layer

When soil moisture W decreases, the heat conductivity λ_{skin} decreases.

$$\lambda_{skin} = K_e \lambda_{sat} + (1 - K_e)\lambda_{dry} \quad (\lambda_{sat} > \lambda_{dry})$$

$$K_e = \begin{cases} W & \text{(with frozen soil)} \\ \log W + 1 \geq 0 & \text{(not with frozen soil)} \end{cases}$$

(a). Changing a parameter of bare soil evaporation E_{bs}

In the current model, two parameters are used to represent the bare soil wetness:
relative humidity of the soil skin layer α, evaporation efficiency β ($\alpha\beta$ method; Kondo et al. 1990).

In the new model, α is removed to increase the bare soil evaporation (β method; Lee and Pielke 1992).

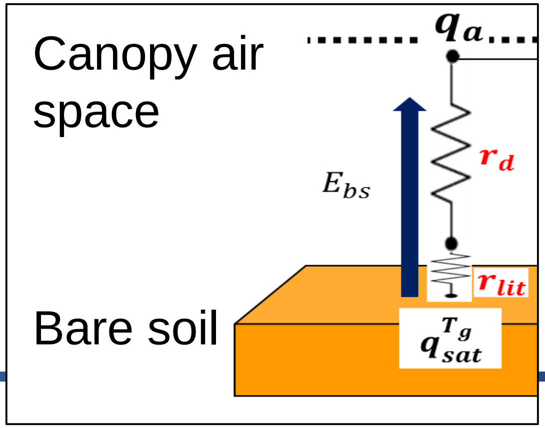
Relative hum.

Diff. of specific hum.
between canopy air space and the ground

$$E_{bs} = -\rho_{atm}\beta \frac{q_a - \cancel{\alpha} q_{sat}^{T_g}}{r_d + r_{lit}}$$

Evaporation
efficiency

Aerodynamic resistance
+ Litter layer resistance



Changes for summer nighttime "warm bias" of the surface temperature in dry area 2/2

(b). Changing a scheme of grass heat conductivity

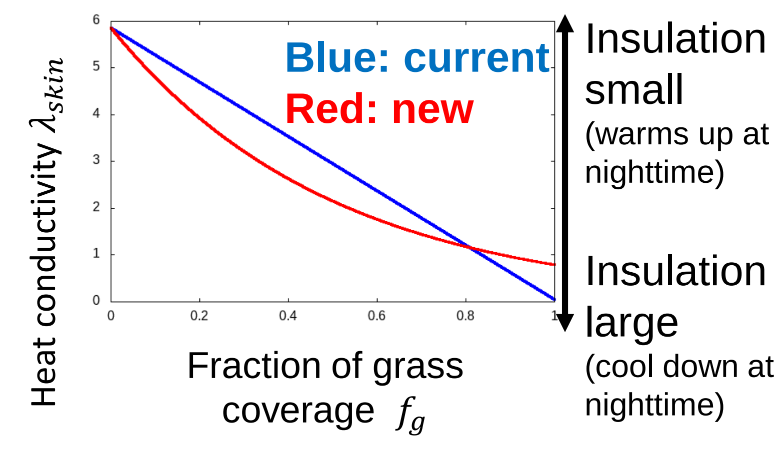
In the current model, fraction of grass coverage f_g is used to calculate heat conductivity of soil skin layer.

In the new model, the scheme is changed to almost decrease λ_{skin}.

$$\lambda_{skin} = \left(1 - f_g\right) \lambda_{sl,1} + f_g \, 0.05$$ (Farouki 1981; Oleson et al. 2010)

$$\rightarrow \lambda_{skin} = \lambda_{sl,\,1} \, e^{-2f_g}$$ (Ek et al. 2003)

($\lambda_{sl,\,1}$: heat conductivity of the first soil layer $[\mathrm{W\ m^{-1}K^{-1}}]$)

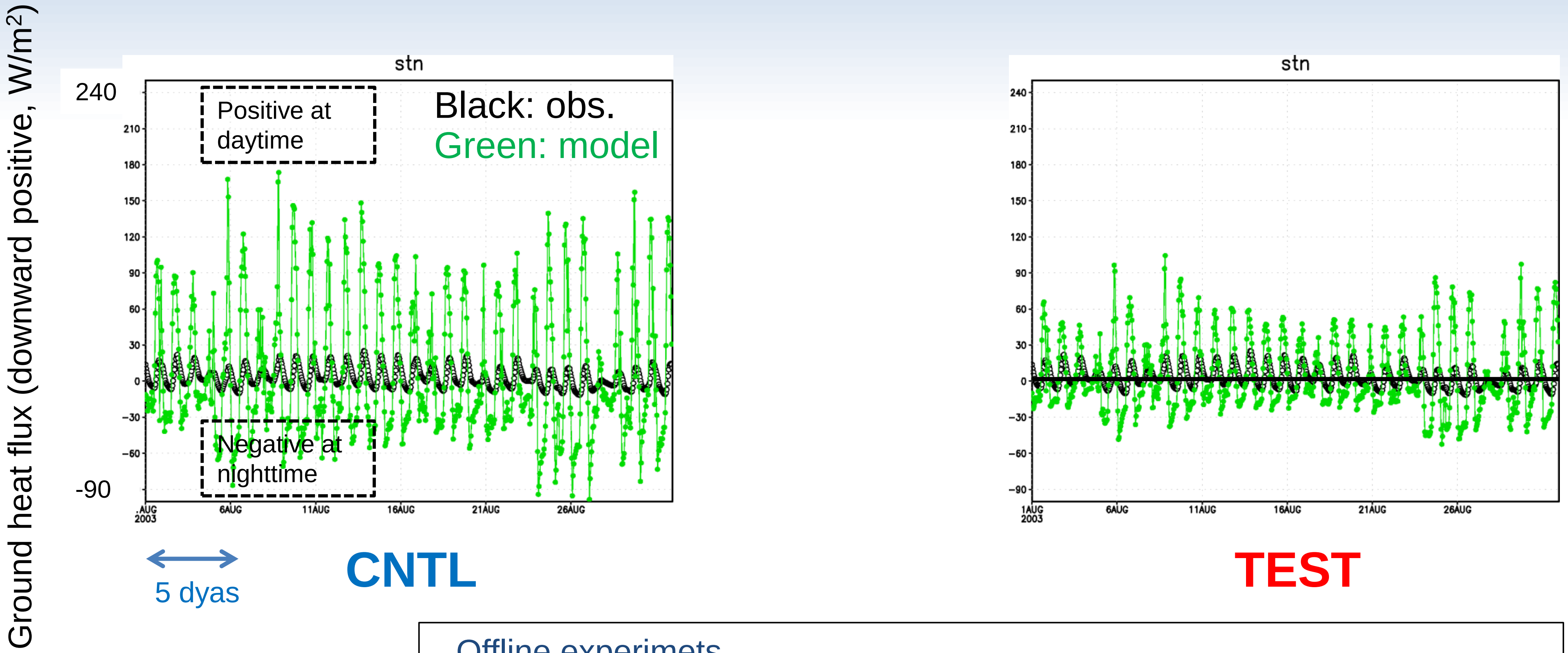


(c). Increasing a ratio of grass coverage to canopy coverage

In the current model, fraction of canopy and grass coverage are calculated using some datasets of vegetation fraction.

In the new model, fraction of canopy coverage is decreased and fraction of grass coverage is increased to increase the heat conductivity

Offline experiments using CEOP dataset



Offline experimets
Cite: ⑰BERMS Old Jack Pine (evergreen needle - leaved tree), Canada
Period: 2003/08

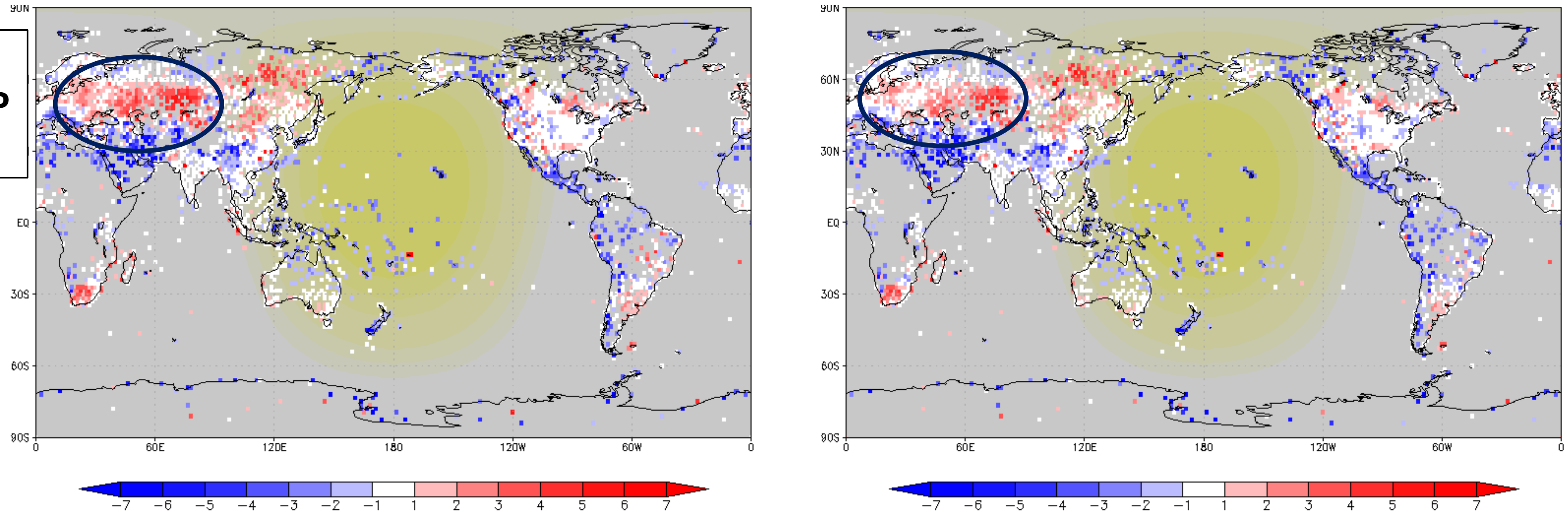
By decreasing the heat conductivity λ_{skin},
overestimated diurnal amplitude of the ground heat flux is mitigated.

MEs of T (2m) against SYNOP obs. (Aug. 2017)

MEs of T (2m) against SYNOP T+132 h

CNTL **(w/o changes for snow)**

TEST



(Blue: cold, Red : warm, Yellow shade: solar rad. area)

By changing the heat conductivity,
the "warm bias" of the surface temperature in dry area is mitigated.

Summary & Future works
(with detailed explanation)

<u>Summary</u>

- GSM
  - JMA plans to upgrade GSM (JMA 2019) to improve forecast of geopotential height at 500 hPa in NH and mitigate biases of the surface variables.
- Land surface processes
  - The upgrade of the land surface processes consists of various changes including change of the diagnostic formula for fraction of snow coverage.
  - Mitigation of the biases including winter low-level “cold bias” in high latitudes are confirmed.

<u>Future works for the land surface processes</u>

- Bare soil evaporation
  - Considering non-vegetated area with direct bare soil evaporation to the atmosphere.
  - Matching with “soil moisture analysis” planned to be introduced.
- Fraction of snow coverage
  - Changing the diagnostic formula to mitigate winter low-level cold bias in high latitudes more and to match with “snow depth analysis” planned to be upgraded.
- Tiling method
  - Investigating the representation of the land with higher resolution than the atmospheric one.

Future works for the land surface processes
(with detailed explanation)

- Bare soil evaporation
  - Considering the non-vegetated area with direct bare soil evaporation to the atmosphere not via canopy air space.
  - Modifying the schemes to match with “soil moisture analysis” planned to be introduced.
- Fraction of snow coverage
  - Changing the diagnostic formula to mitigate winter low-level cold bias in high latitudes more and to match with “snow depth analysis” planned to be upgraded.
- Tiling method
  - In the current model, a one grid box corresponds to a one vegetation type.
  - Investigating the representation of the land with higher resolution than the atmospheric one.
- Representation of lake
  - In the current model, the lake surface temperature is calculated as the sea surface temperature with the same latitude corrected with elevation.
  - Refine the representation of lake to improve the lake surface flux.

References for Bkup slides

- Ek, M. B., K. E. Mitchell, Y. Lin, E. Rogers, P. Grunmann, V. Koren, G. Gayno, and J. D. Tarpley, 2003: Implementation of Noah land surface model advances in the National Centers for Environmental Prediction operational mesoscale Eta model. J. Geophys. Res., 108, 8851.

- Farouki, O. T., 1981: The thermal properties of soils in cold regions. Cold Regions Sci. and Tech., 5, 67-75.

- Kondo, J., N. Saigusa and T. Sato, 1990: A parameterization of evaporation from bare soil surfaces. J. Appl. Meteorol., 29, 383-387.

- Lee, T. J. and R. A. Pielke, 1992: Estimating the soil surface specific humidity. J. Appl. Meteorol., 31, 480-484.

- Oleson, K. W. et al. 2010: Technical Description of version 4.0 of the Community Land Model (CLM). NCAR Technical Note 478, NCAR. 257pp.