Improving Snow Physics Processes in the KIM/Noah-MP Coupled Model

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Coupled Model Team

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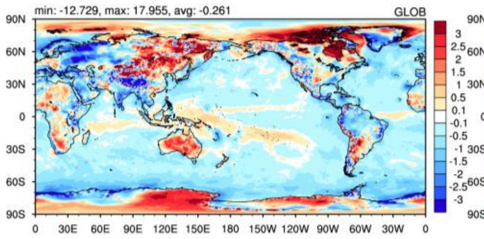
2024 Noah-MP International Workshop **(June 4, 2024)**

Cold bias in cold season over snow-covered

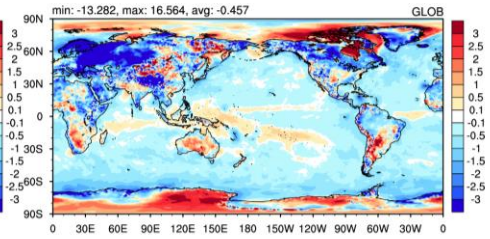
(ver.2023) KIM/Noah vs. KIM/Noah-MP 2017.01, 120-hr forecast (00UTC), 31-sample-average

- ✓ Cold bias in near-surface on snow-covered lands

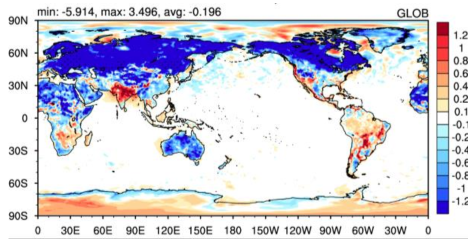
2-m temp.
Noah minus **IFS**



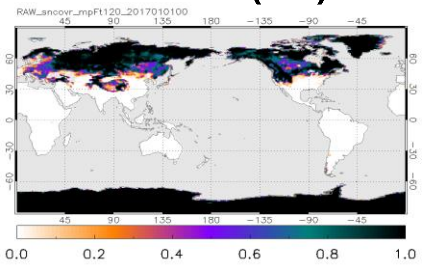
2-m temp.
Noah-MP minus **IFS**



2-m temp.
Noah-MP minus **Noah**

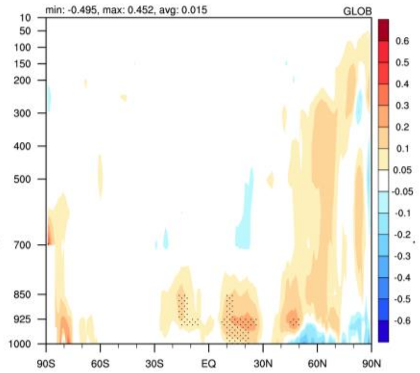


Snow cover fraction
Noah-MP (raw)

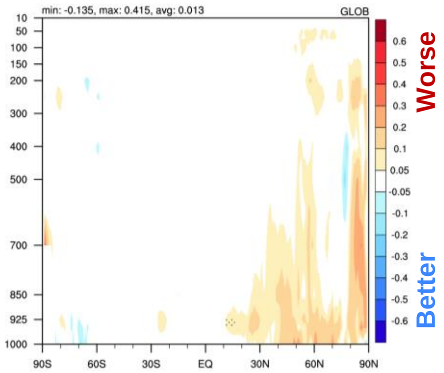


- ✓ Despite colder land surface, atmosphere is warmer (plausibly indicating weak vertical mixing)

Zonal-avg. temp.
Noah-MP minus **Noah**



Zonal-avg. temp.
RMSE diff
(Noah-MP minus **Noah)**



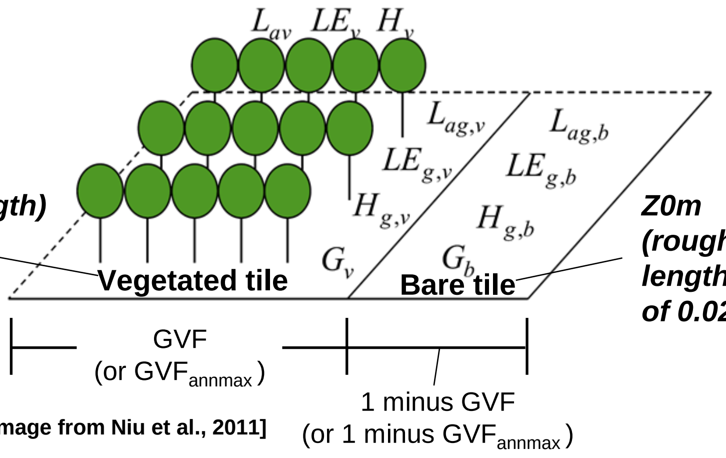
❖ Four modifications in Noah-MP

Target	***Description***	***Remark***
Sub-grid tile fraction	*Tiling fraction by LCT* (previously, it is by GVF)	
Snow thermal conductivity	*Constant of 0.35 W/m/K* (previously, determined by Verseghy (1991) scheme)	Using existing option
Snow cover fraction	*A scheme in Noah* (previously, Noah-MP embedded scheme (Niu and Yang, 2007))	
Snow albedo	The scheme in CLASS (Verseghy (1991) (previously, the scheme in BATS)	Using existing option

Two sub-grid tiles

1. Noah-MP has two tiles (**vegetated tile** and **bare tile**) in each grid: *energy balance calculated separately (except SW)*

Z0m (roughness length) for forest types of 1-2 m



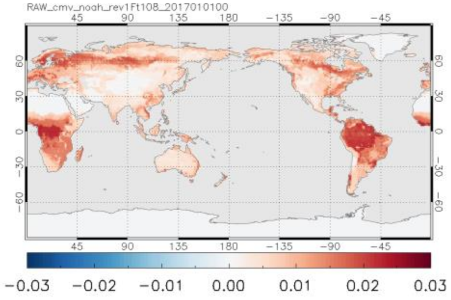
Z0m (roughness length) of 0.02 m

[The modified image from Niu et al., 2011]

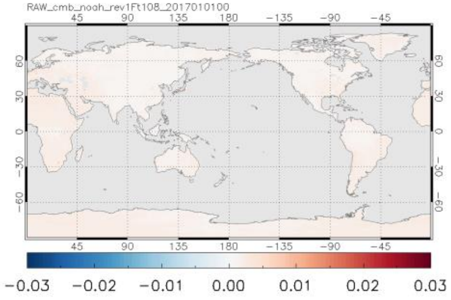
3. **Bare tile** is supposed to have exchange coefficients much smaller than **vegetated tile**

Exchange coefficient (CM) of Noah-MP in Jan.

Vegetated tile

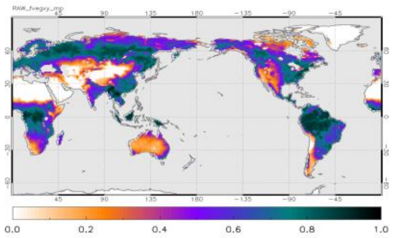


Bare tile



2. Every grids have a significant fraction of bare tile

GVF Green vegetation fraction

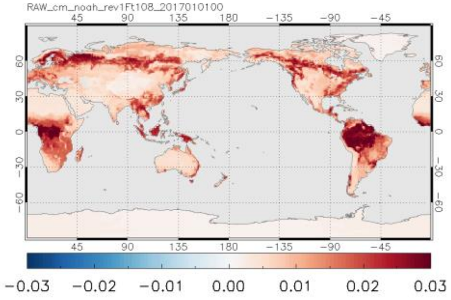


- ✓ Annual maximum GVF is recommended among physics option
- ✓ 10 % or more fraction of entire global grids are treated as bare land.

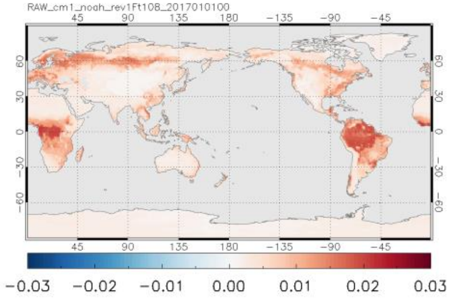
4. Smaller *CM* in Noah-MP than Noah is (partly) attributable to bare tile

Exchange coefficient (CM), grid representative

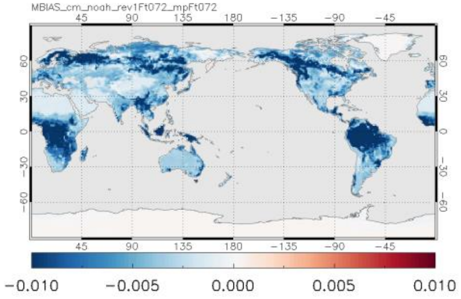
Noah



Noah-MP



Noah-MP minus Noah

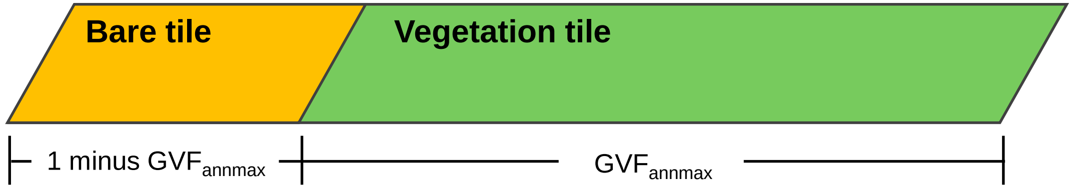


The variable determining the fraction of tiles

❖ What each tile represents: green or not vs. land cover type

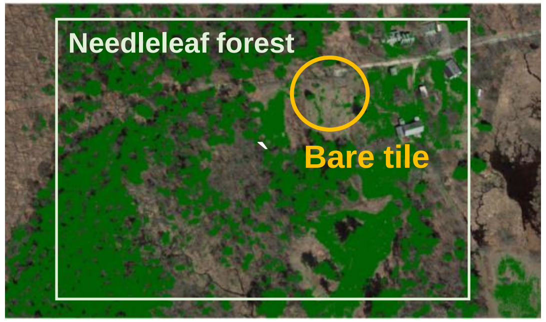
GVF: green vegetation fraction
LCT: land cover type

➢ ***Original Noah-MP (v5):*** GVF-dependent tile fraction



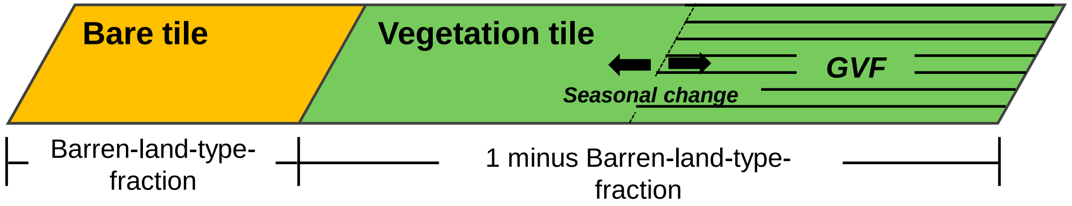
- ✓ *Open canopy surface within forest is assigned to bare tile separately*
- ✓ *Large discrepancy in turbulence between veg. and bare tiles*

Reference: GVF in Harvard forest April



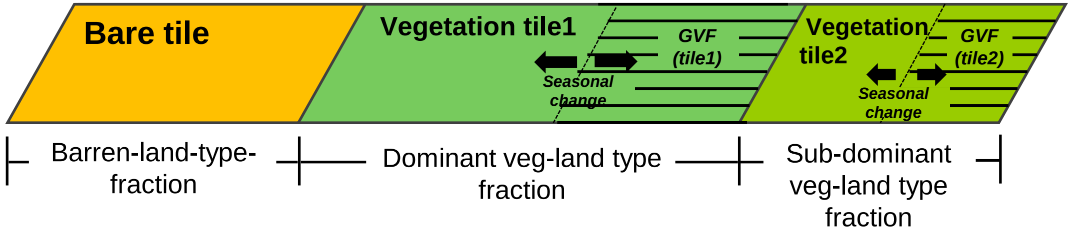
[Modified image from NOAA GVF ATBD v4]

➢ ***KIM/Noah-MP (2024):*** LCT-dependent tile fraction



- ✓ GVF is used only for characterizing vegetation tile

➢ ***KIM/Noah-MP (2025, plan):*** One more vegetated tile



- ✓ *Sub-grid heterogeneity considered with LCT*

- ✓ Turbulent properties are influenced by surrounding surface structures

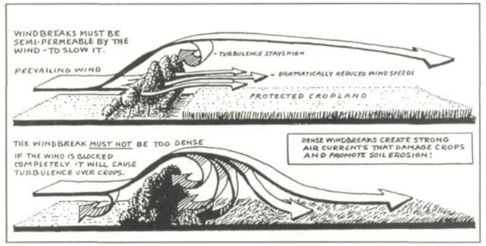


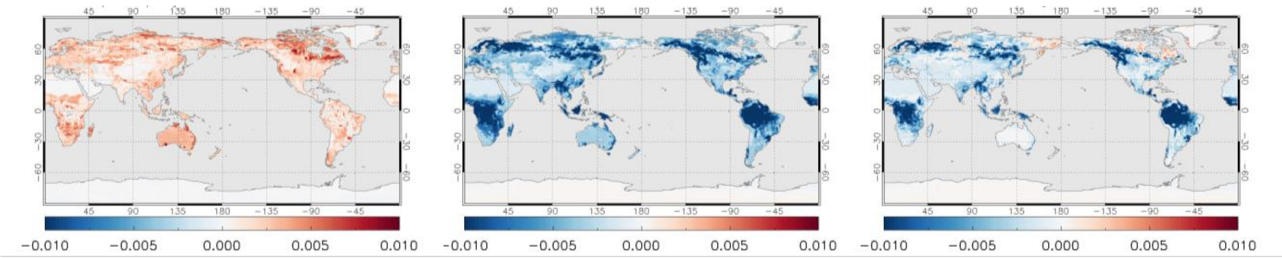
Figure 8.12 Windbreak design

[The Image from Tengnäs B. 1994]

Effects of tile fraction from GVF to LCT

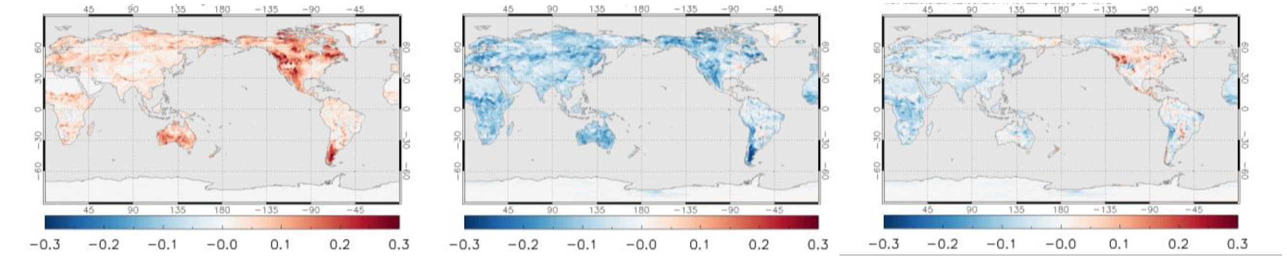
Exchange coefficient for momentum

Noah-MP minus **Noah-MP-w/oTile** | **Noah-MP-w/oTile** minus **Noah** | **Noah-MP** minus **Noah**



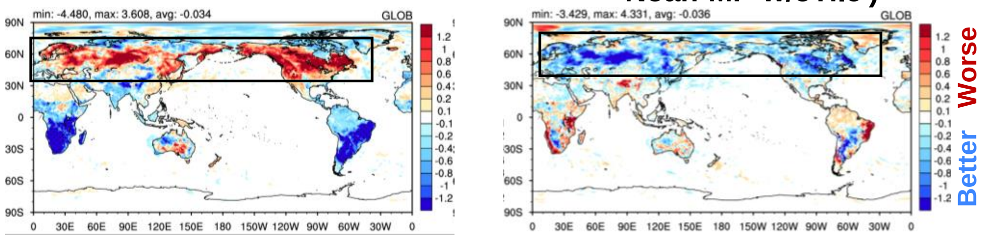
Friction velocity

Noah-MP minus **Noah-MP-w/oTile** | **Noah-MP-w/oTile** minus **Noah** | **Noah-MP** minus **Noah**



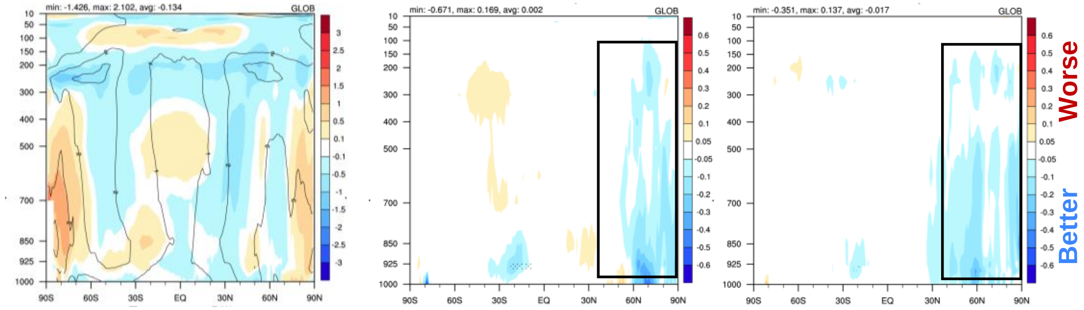
2-m temperature

Noah-MP-w/oTile | **RMSE diff. with ref. of IFS (Noah-MP** minus **Noah-MP-w/oTile)**



Zonal-avg temperature

MP-w/oTile minus IFS | **Noah-MP** minus **Noah-MP-w/oTile** | **RMSE diff. (Noah-MP** minus **Noah-MP-w/oTile)**



✓ The effects of this modification are…

- *Larger exchange coefficient and friction velocity approaching the benchmark model of KIM/Noah*
- *A mitigation of winter cold surface bias*
- *Colder continental troposphere with less RMSE (against IFS)*

Three experiments in this slide

Noah	KIM/Noah
Noah-MP	KIM/Noah-MP developed this year
Noah-MP-w/oTile	Same to MP-new, but not applied with tile fraction-related modification

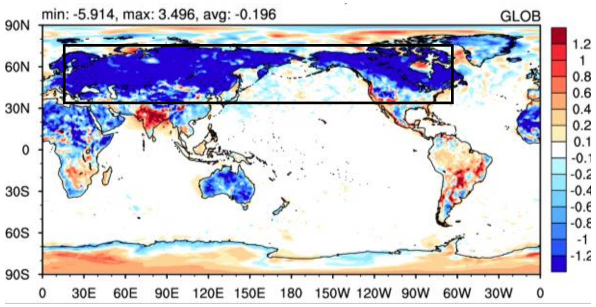
Cold surface, but warm soil

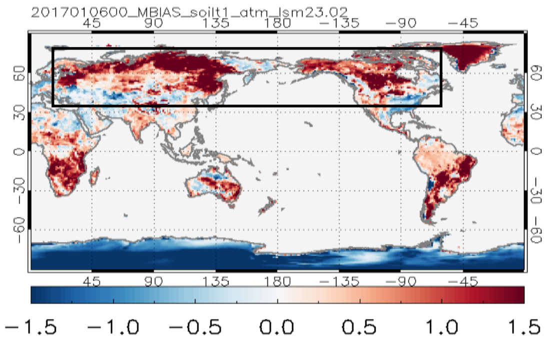
5-day forecast in Jan. 2017 with KIM/Noah and KIM/Noah-MP in ver.2023

- ✓ **Despite colder near-surface air temp., warmer soil temp. is found in Noah-MP for snow-covered, indicating snow insulation effects are too strong**

Noah-MP minus Noah

2-m temp. | **1st soil layer temp.**

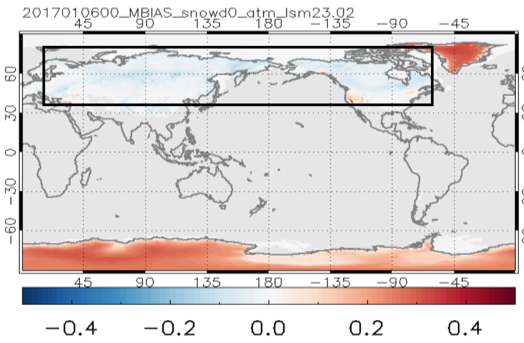


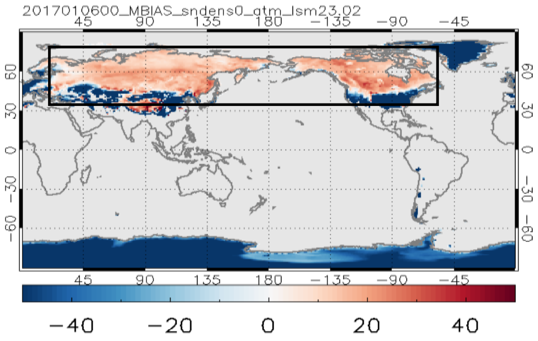


- ✓ **Noah-MP already has conditions of less snow insolation for the NH: *shallow* and *dense* snow layer**

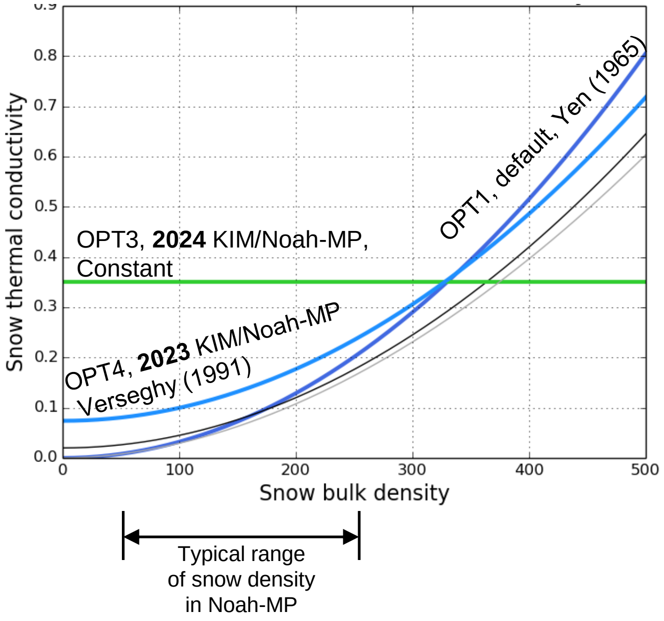
Noah-MP minus Noah

Snow depth | **Snow density**





- ✓ **Our decision**
  : to use an embedded option with higher conductivity
  - ➢ Lower the complexity (snow density-dependency not considered)



- ✓ *Advantage: apparently increasing conductance, more heat flux between soil and air, effectively reducing the cold bias in the NH*
- ✓ *Disadvantage: Seasonal and regional differences in conductivity cannot be considered*

Effects of increasing thermal conductivity

II. New schemes: *i) tile area with land cover type*
ii) snow thermal conductivity
iii) surface albedo

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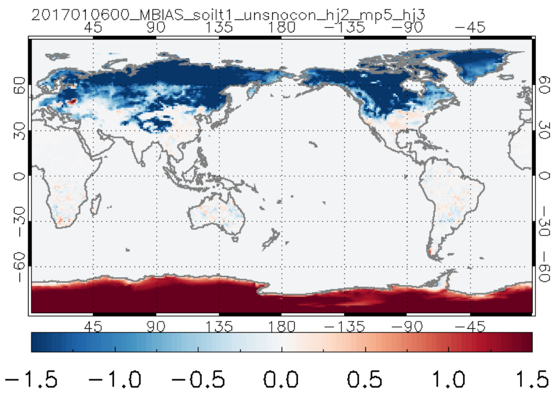
❖ More conductance and reduced cold bias in on surface and warm bias in soil in the NH

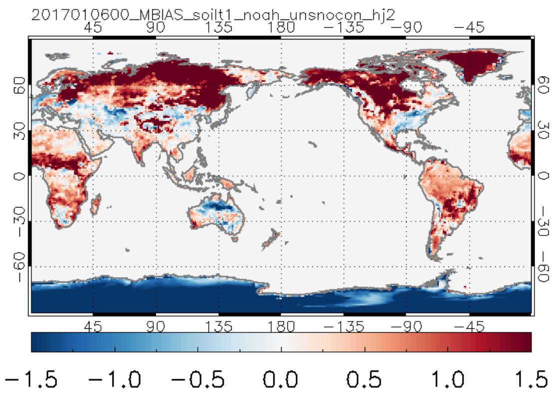
✓ Colder soil temperature in the NH approaching the benchmarking model of Noah

1st soil layer temperature

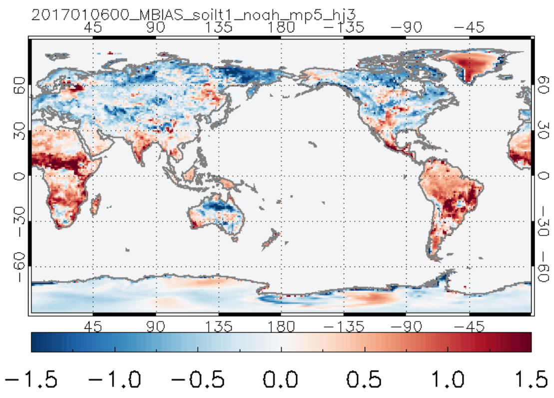
Noah-MP minus **Noah-MP-w/oCond**



Noah-MP-w/oCond minus **Noah**



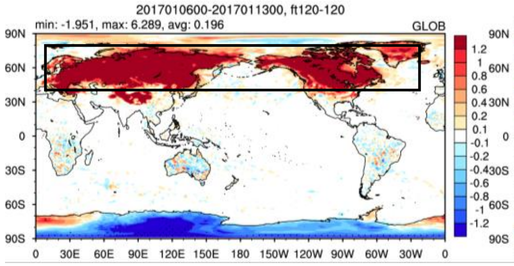
Noah-MP minus **Noah**



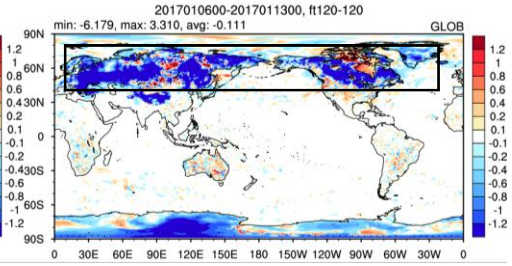
✓ Warmer near surface temperature in NH, transferring to lower troposphere

2-m air temperature

Noah-MP minus **Noah-MP-w/oCond**



RMSE diff. (ref. of IFS) :Noah-MP minus **Noah-MP-w/oCond**

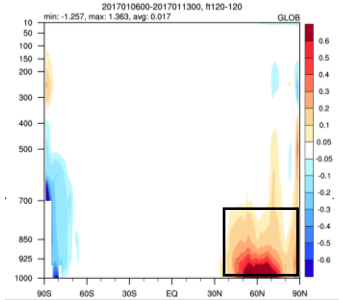


Worse

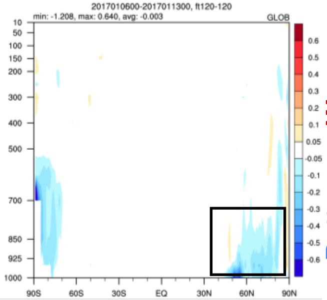
Better

Zonal-avg. air temperature

Noah-MP minus **Noah-MP-w/oCond**



RMSE diff. (ref. of IFS) :Noah-MP minus **Noah-MP-w/oCond**



Worse

Better

Three experiments in this slide

Noah	KIM/Noah
Noah-MP	KIM/Noah-MP developed this year
Noah-MP -w/oCond	Same to MP-new, but not applied with snow conductivity modification

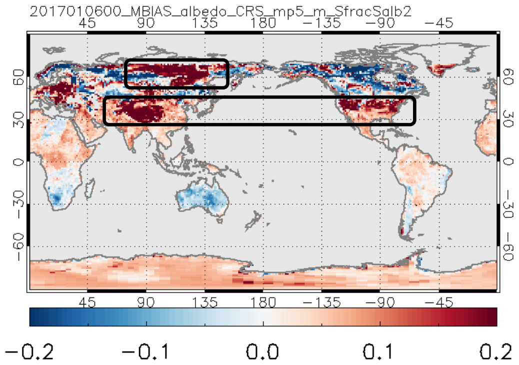
Snow albedo / snow cover fraction

5-day forecast in Jan. 2017 with KIM/Noah-MP in ver.2023

✓ **Overestimated surface albedo** on **marginally snow-covered** areas and in Siberia

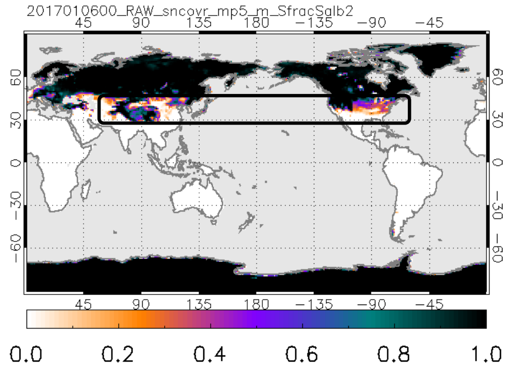
Surface albedo

Noah-MP minus Obs. Of CERES



Snow cover fraction

Noah-MP (raw)



✓ **Snow albedo option changed in KIM/Noah-MP:**

CLASS scheme tends to have snow albedo lower than BATS scheme

Implemented year	Snow albedo option	Description
KIM/Noah-MP(2023)	BATS scheme (Yang et al., 1997)	• Snow aging with i) vapor diffusion, ii) freezing, iii) dirt and soot • Solar zenith angle-dependent
KIM/Noah-MP(2024)	CLASS scheme (Verseghy, 1991)	• Snow aging with time

✓ **Snow cover fraction: to be reduced by adoption of Noah scheme**

KIM/Noah-MP(2023)
: **Noah-MP embedded scheme** [Niu and Yang, 2007]

- ✓ *Two snow variable used (snow density, and snow depth)*
- ✓ *Two parameters with land cover type (LCT)-dependent*

$$f_{sno} = \tanh\left[\frac{h_{sno}}{F_{scf}\left(\frac{\rho_{sno}}{\rho_{new}}\right)^{m}}\right]$$

h_{sno}: Snow depth; m: LCT-dependent param.; ρ_{sno}: Snow density; F_{scf}: LCT-dependent param.

[Niu and Yang, 2007, He et al., 2019]

KIM/Noah-MP(2023)
: **WRF/Noah scheme**

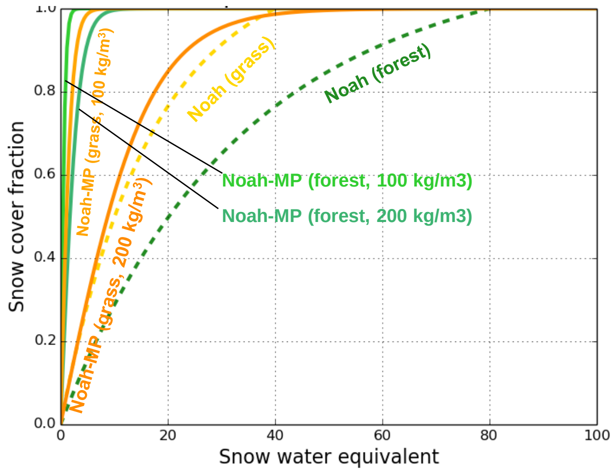
- ✓ *Only a single snow variable used (snow water equivalent)*
- ✓ *With two global parameters*

$$f_{sno} = 1 - [\exp(-2.6R_{SWE}) - R_{SWE} \cdot \exp(-2.6)]$$

$$R_{SWE} = \frac{SWE}{SWE_{max}}$$

SWE: Snow water equivalent

✓ *Noah scheme yields smaller snow cover fraction can be expected for typical snow conditions*

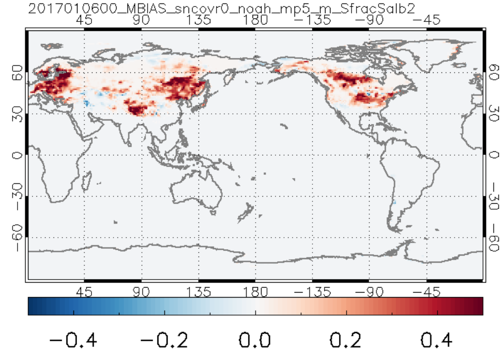


Snow albedo / snow cover fraction

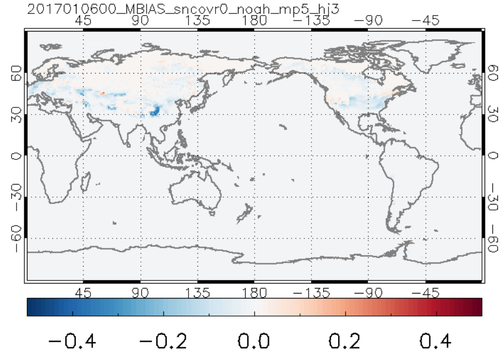
✓ Reduced snow cover fraction and surface albedo

Snow cover fraction

Noah-MP-w/oSnAlb minus **Noah**

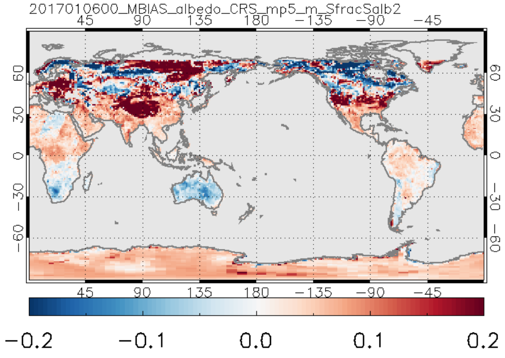


Noah-MP minus **Noah**

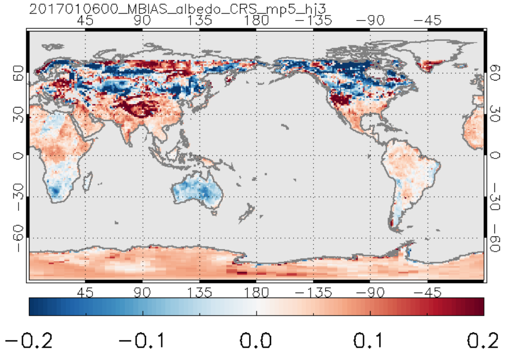


Surface albedo

Noah-MP-w/oSnAlb minus **Obs.(CERES)**



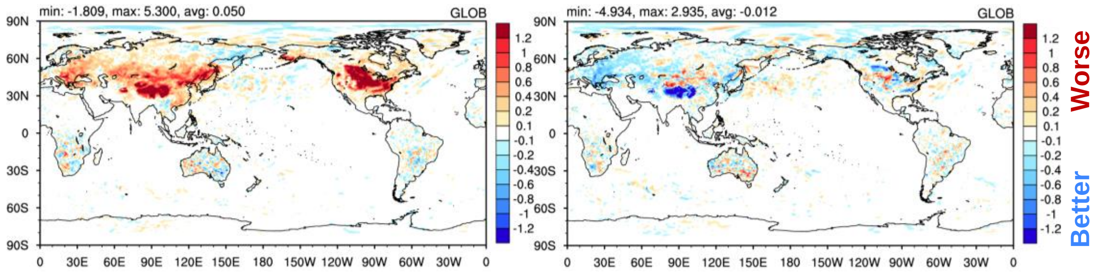
Noah-MP minus **Obs.(CERES)**



✓ Mitigated the near-surface cold bias

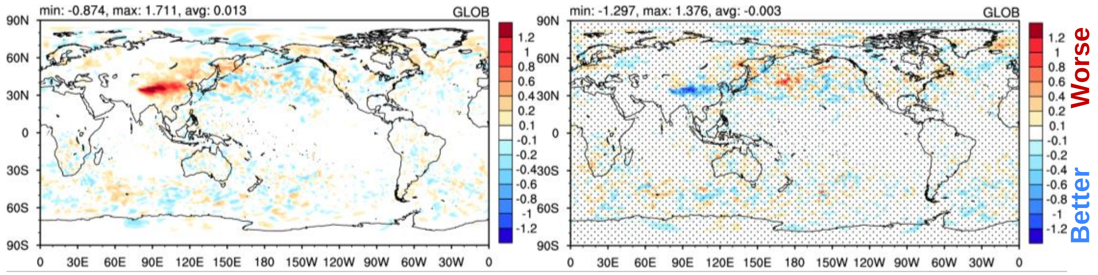
2-m temperature

Noah-MP minus **Noah-MP-w/oSnAlb** | **RMSE diff. with ref. of IFS (Noah-MP** minus **Noah-MP-w/oSnAlb)**



500 hPa temperature

Noah-MP minus **Noah-MP-w/oSnAlb** | **RMSE diff. with ref. of IFS (Noah-MP** minus **Noah-MP-w/oSnAlb)**



Three experiments in this slide

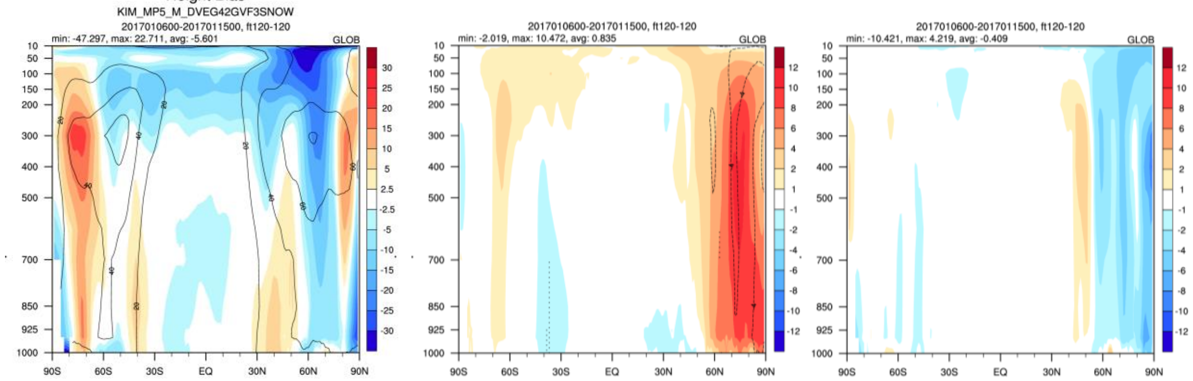
Noah	KIM/Noah
Noah-MP	KIM/Noah-MP developed this year
Noah-MP -w/oSnAlb	Same to MP-new, but not applied with the modifications on snow cover fraction and snow albedo

Conclusion: Addressing surface cold bias

Modifications are conducted for
i) tile fraction, ii) snow thermal conductivity, iii) snow fraction/albedo
Expecting appropriate i) exchange coefficient, ii) ground conductance, iii) surface albedo

500-hPa geopotential height

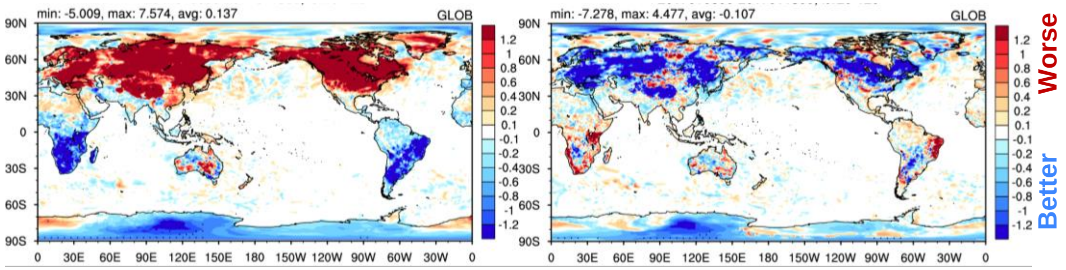
Noah-MP-w/o3fact Minus IFS | **Noah-MP** minus **Noah-MP-w/o3fact** | **RMSE diff. with ref. of IFS (Noah-MP** minus **Noah-MP-w/o3fact)**



✓ The high-latitude NH troposphere temperature and geopotential height are simulated better through largely a modification on the tile fraction

2-m temperature

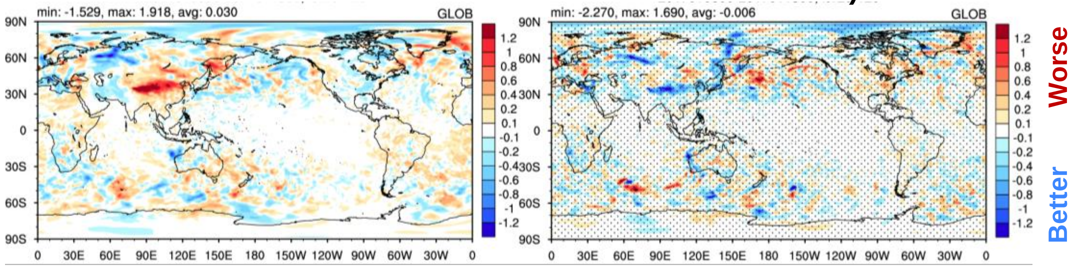
Noah-MP minus **Noah-MP-w/o3fact** | **RMSE diff. with ref. of IFS (Noah-MP** minus **Noah-MP-w/o3fact)**



✓ Surface cold bias mitigated significantly through largely a modification on snow thermal conductivity

500-hPa temperature

Noah-MP minus **Noah-MP-w/o3fact** | **RMSE diff. with ref. of IFS (Noah-MP** minus **Noah-MP-w/o3fact)**



✓ Mid-troposphere on the Tibetan cold bias mitigated through largely a modification on snow fraction/albedo

Three experiments in this slide

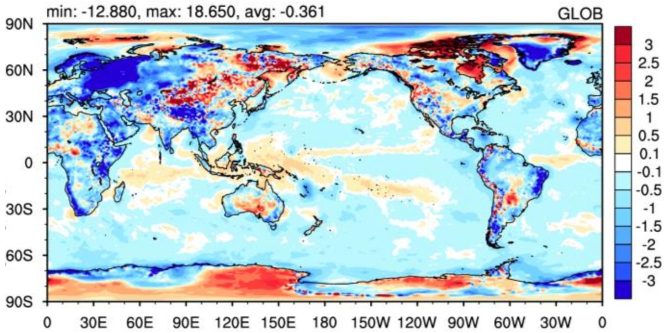
Noah	KIM/Noah
Noah-MP	KIM/Noah-MP developed this year
Noah-MP -w/o3fact	Same to MP-new, but not applied with the modifications introduced in this presentation, related to i) tile fraction, ii) snow thermal conductivity, iii) snow fraction/albedo

Remained issues

✓ ***Surface cold bias remained in Europe***

2-m temperature

Noah-MP(new) minus **IFS**

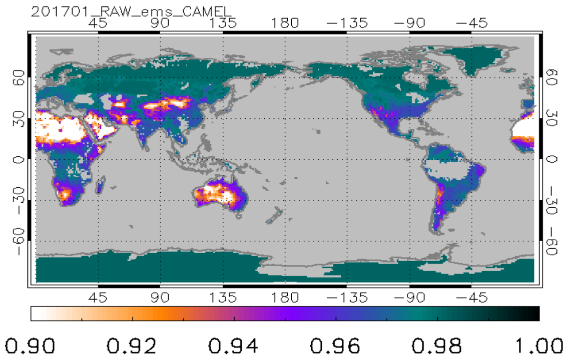


✓ ***Over-estimates of land surface emissivity over forest regions:***

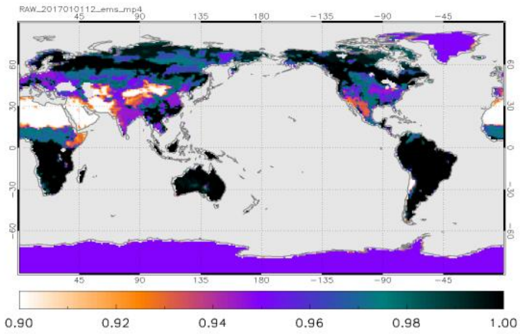
The correction would mitigate the remained cold bias in forest regions

Land surface emissivity

Obs. (CAMEL)



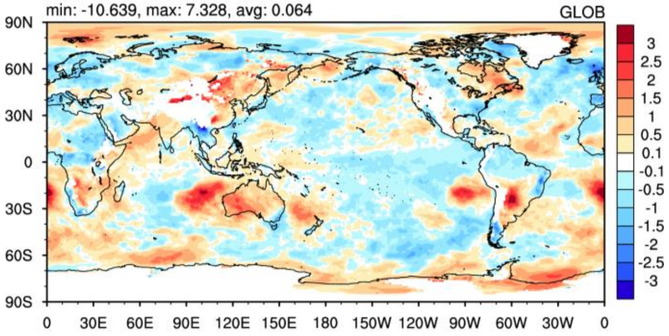
Noah-MP(new) (raw)



✓ ***Warm bias in lower troposphere in East Asia***

850-hPa temperature

Noah-MP(new) minus **IFS**

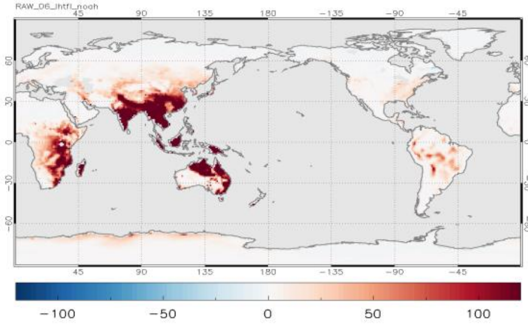


✓ ***Near-zero latent heat flux over snow covered:***

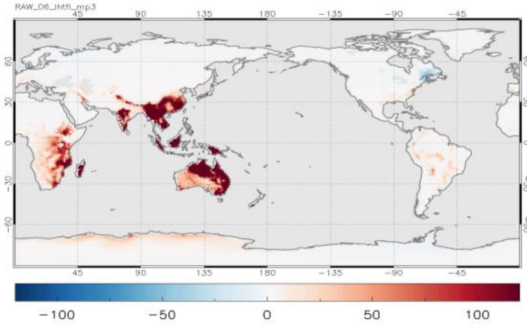
Realization of significant LH flux would contribute to the reducing the warm bias in the East Asia

Latent heat flux

Noah (raw)



Noah-MP(new) (raw)



Thank you