Snow developments in ORCHIDEE

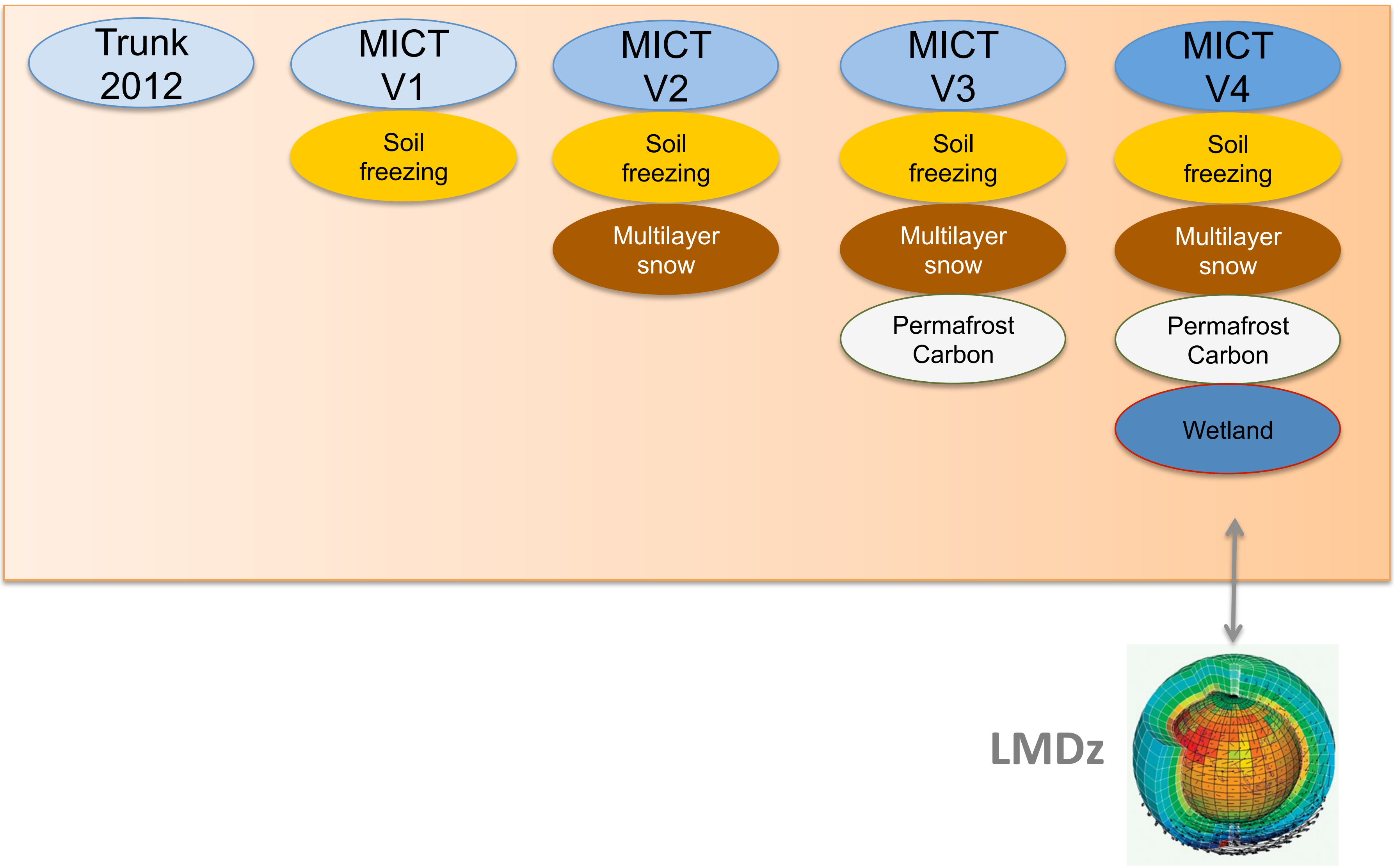
Tao Wang, C. Ottlé, A. Boone, P. Ciais, E. Brun, S. Morin, S. Dantec-Nédélec, etc..

LSCE – CNRM

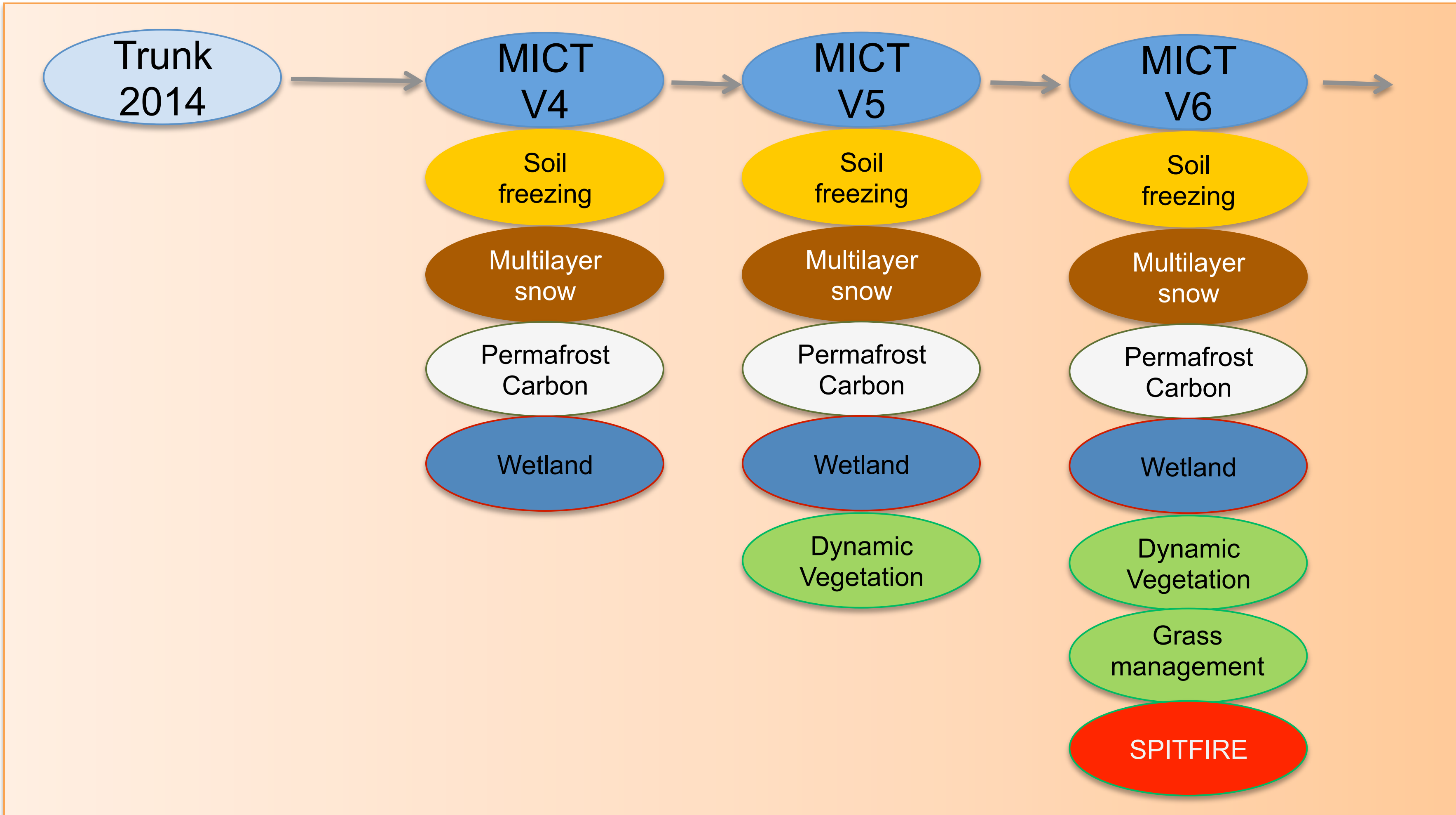
Recent developments to better represent high latitudes in ORCHIDEE MICT

- New snow model (Wang et al., 2013)
- New soil freezing/thawing model (Gouttevin et al., 2012)
- Soil carbon processes added (Koven et al., 2012, 2013)
- Wetlands and thermokarsts added (Ringeval et al., 2011)
- Water isotopes added (2 layer hydrology, Guglielmo, et al.,)
- New vegetation maps developed (Ottlé et al., 2013, ESA-CCI team, Mc Bean et al.,)

Evolution of high-latitude ORCHIDEE version

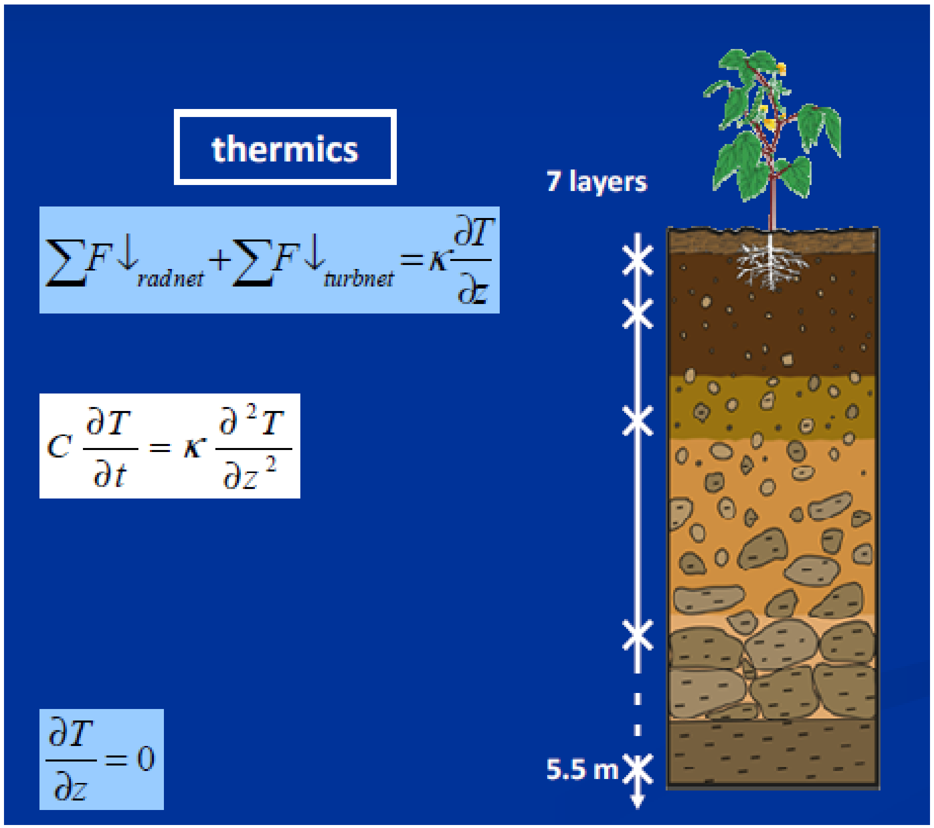


Evolution of high-latitude ORCHIDEE version

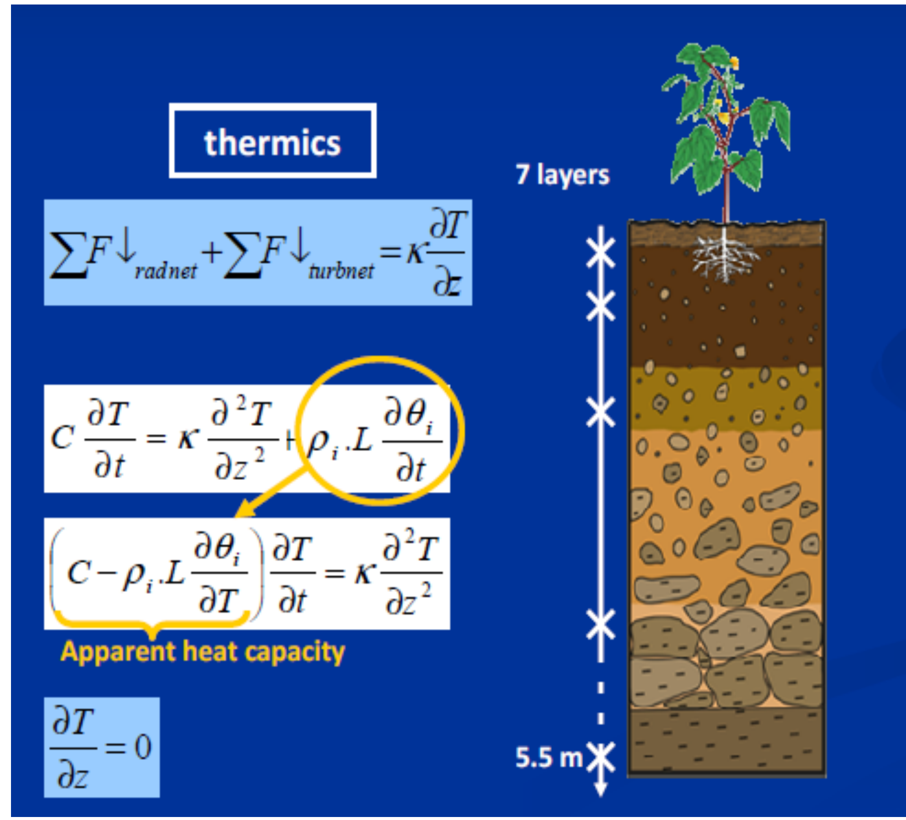


Soil freezing/thawing

Old feature



New feature

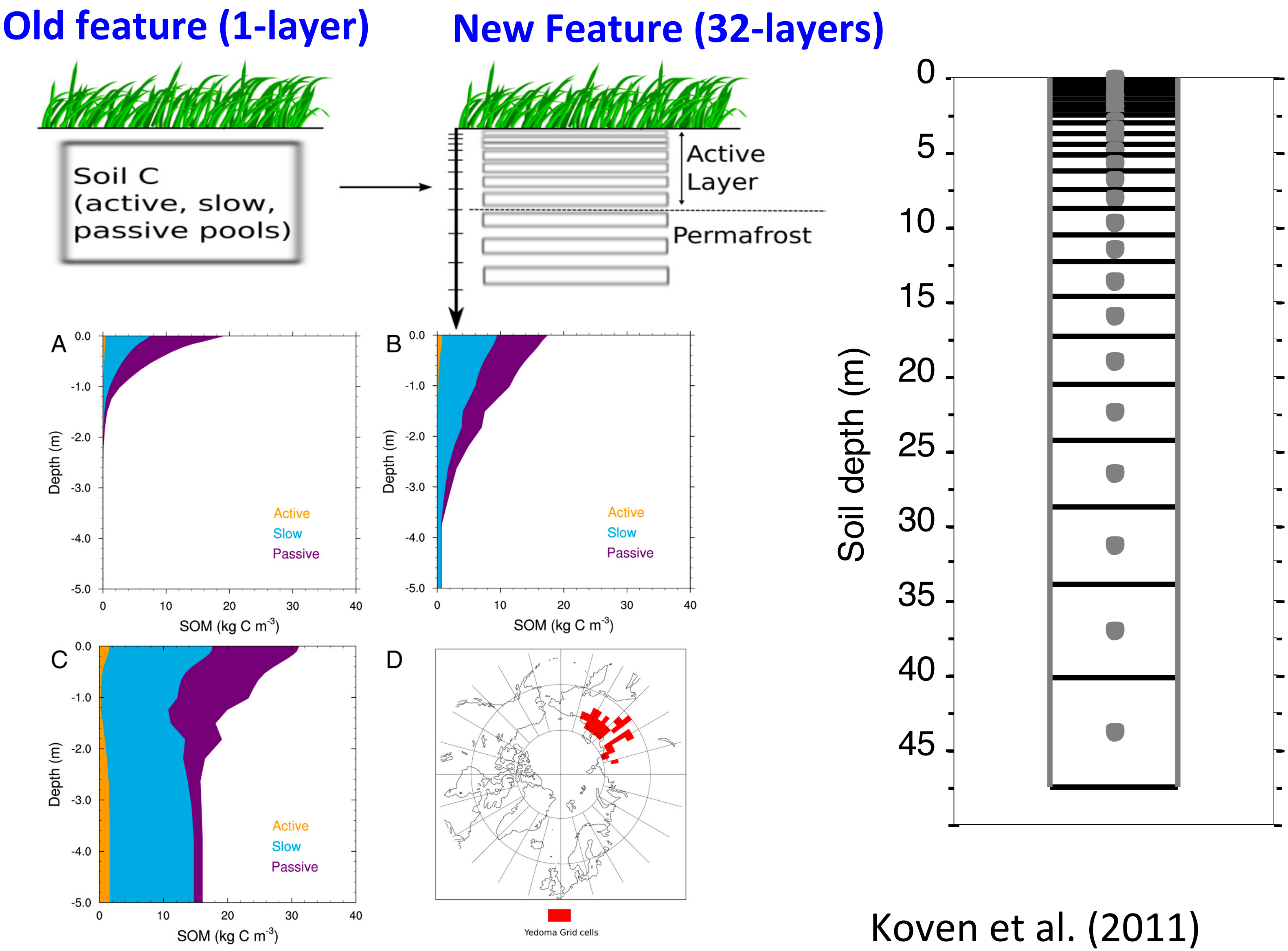


Gouttevin et al. (2012)

Layer n°	THERMAL MODULE *Depths of the layers boundaries (m)*		HYDROLOGICAL MODULE *Depths of the numerical nodes (m)*
	Default resolution	**Extended depth**	
1	0.043	0.043	0.0
2	0.129	0.129	0.00195
3	0.301	0.301	0.00586
4	0.646	0.646	0.0137
5	1.34	1.34	0.0293
6	2.72	2.72	0.0606
7	5.47	5.47	0.123
8		10.99	0.248
9		22.02	0.498
10		44.09	0.999
11		88.23	2

Table 2.3. Vertical discretizations of the thermal and hydrological modules in the default configuration, and in the extended-depth configuration (thermal module only).

Vertical carbon representation + deep permafrost carbon

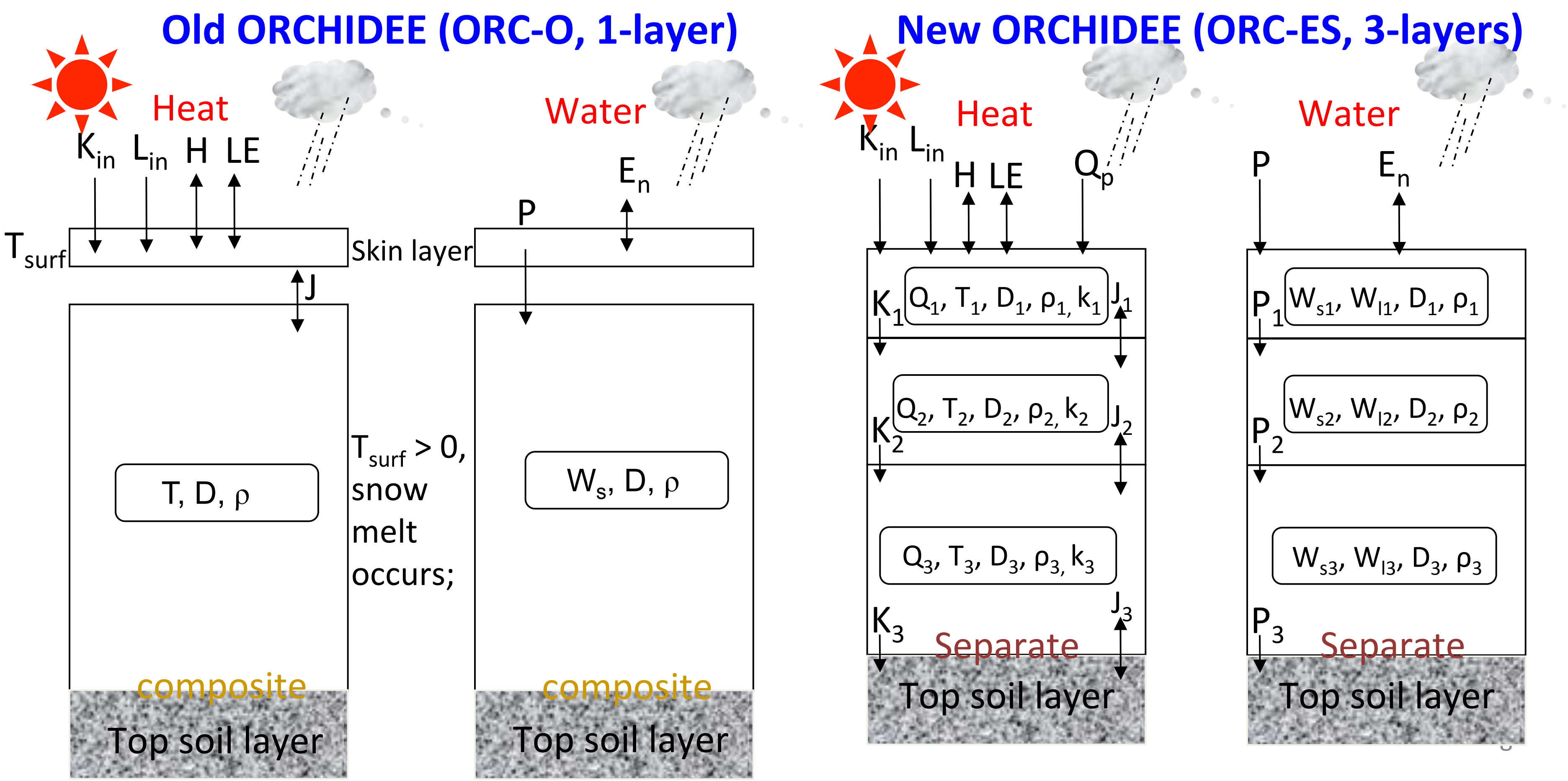


Koven et al. (2011)

ORCHIDEE Snow developments (Wang et al., 2013)

ISBA-ES (Boone et al.,)

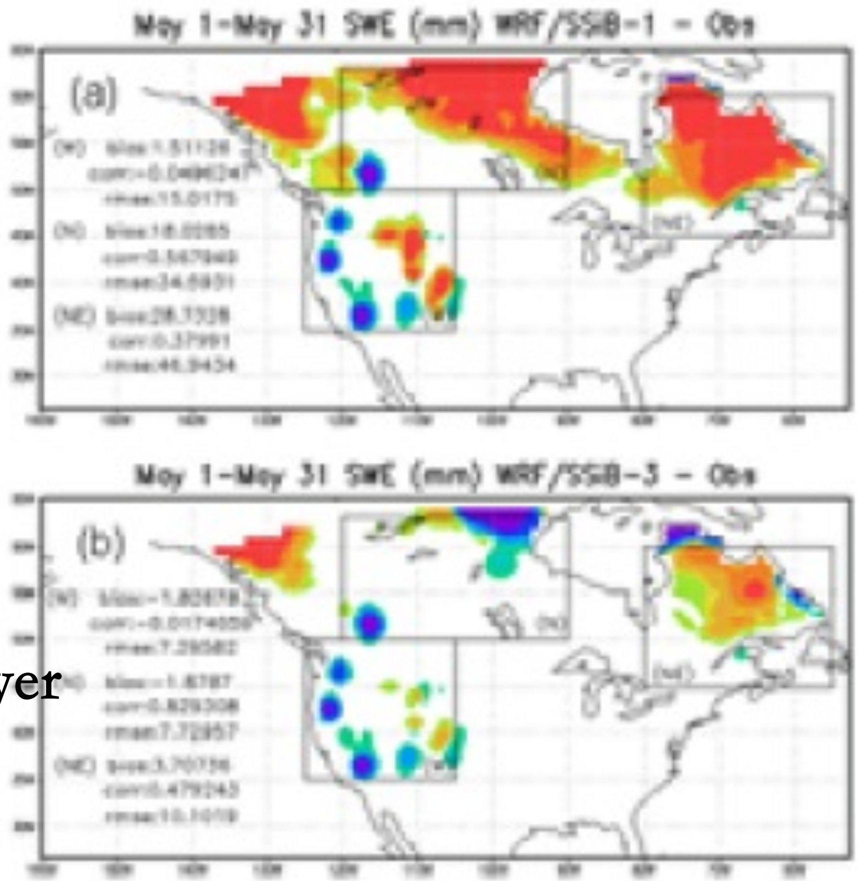
- ✓ Single layer **vs.** Three layers
- ✓ Composite **vs.** Separate snow structure
- ✓ Snow density(ρ) and snow thermal conductivity (k) (constant **vs.** variable)
- ✓ Thawing and refreezing processes (no **vs.** yes)
- ✓ Water flow between layers (no **vs.** yes)
- ✓ New snow albedo parametrization
- ✓ Snow impacts on roughness length



Main features of new snow module

- multiple-layer snow

Single layer



Multiple-layer

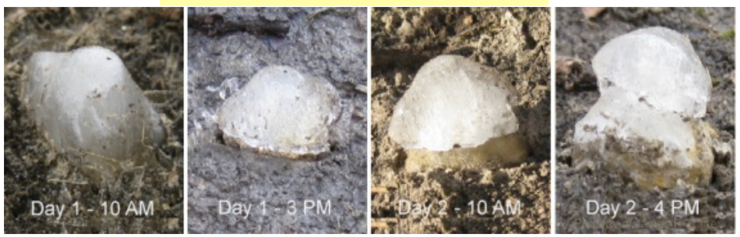
Waliser et al. (2011)

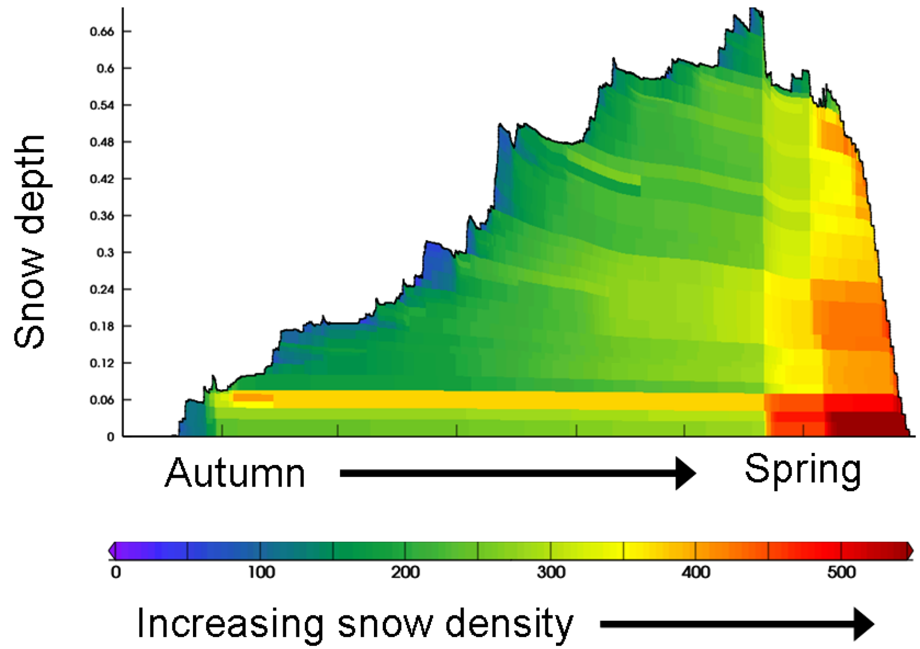
- Single-layer underestimate snow melt

Main features of new snow module

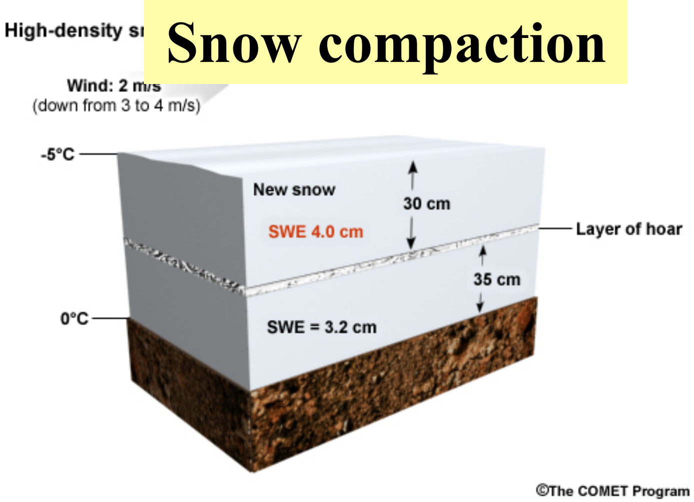
- freezing-thaw process and snow compaction (leading to spatio-temporal variation in snow density)

Freeze-thaw





Snow compaction



Main features of new snow module

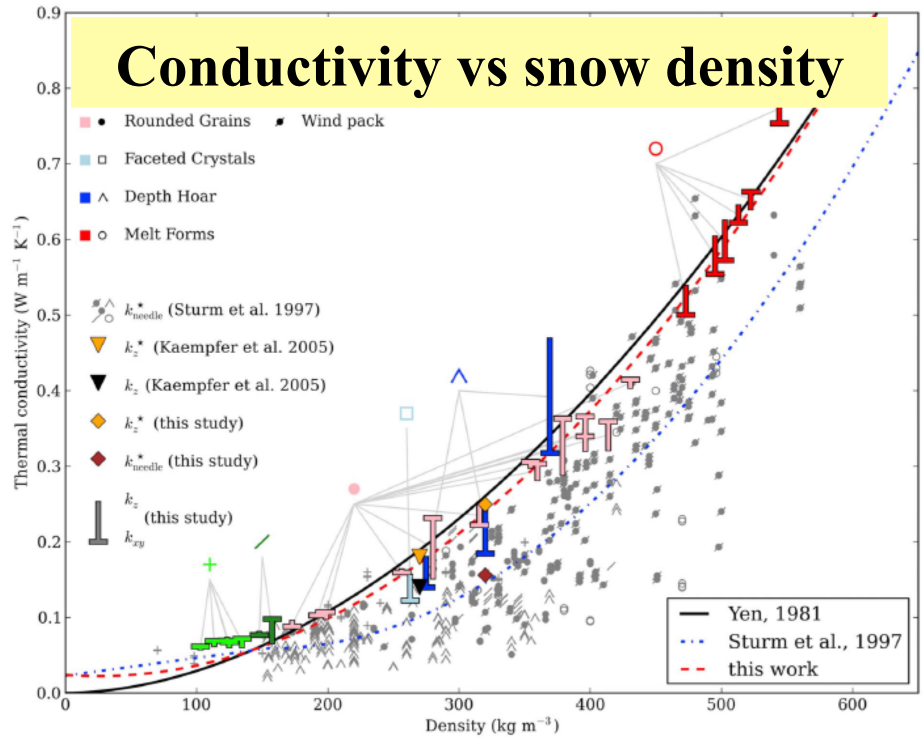
- snow thermal conductivity as a function of snow density and snow temperature

Snow thermal conductivity

$$\frac{\partial T}{\partial t} = \frac{\kappa}{\rho C_p} \frac{\partial^2 T}{\partial z^2}$$

Snow thermal capacity

Determine soil temperature and snow metamorphism



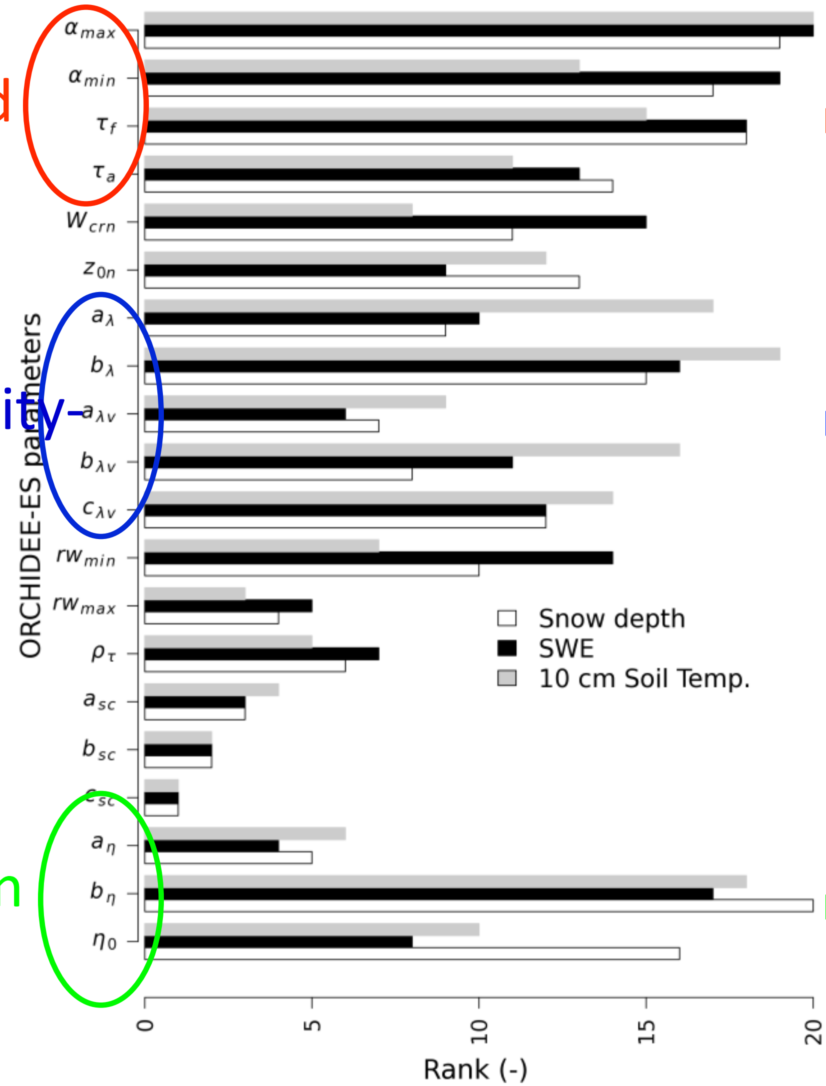
Sensitivity tests (Morris method)

ORCHIDEE-ES in Col de Porte

Albedo-related

Thermal conductivity-related

Snow compaction factors

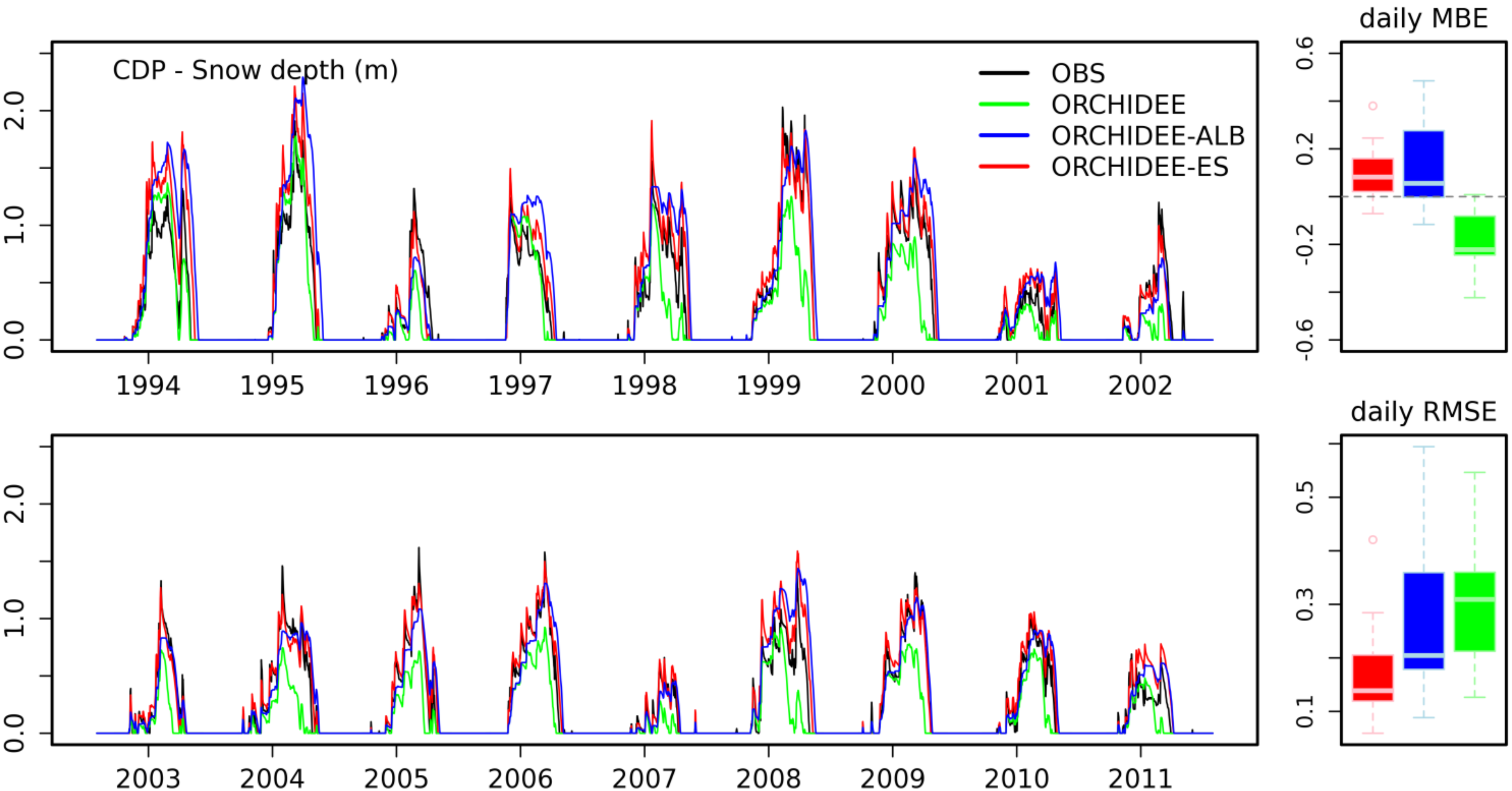


Most important

Very important for soil temperature simulation

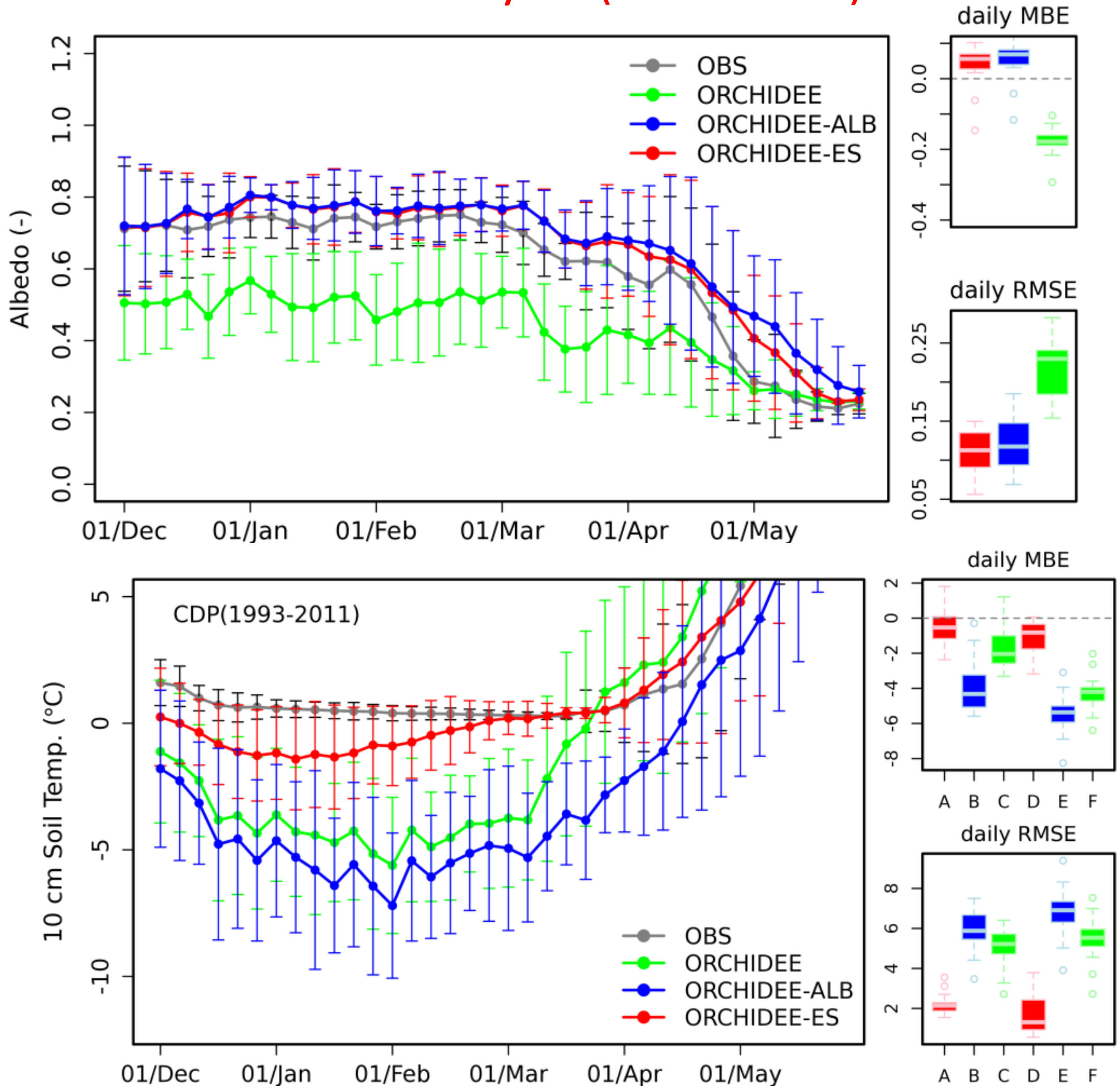
Very important for snow depth simulation

Evaluation results (CDP-snow depth)

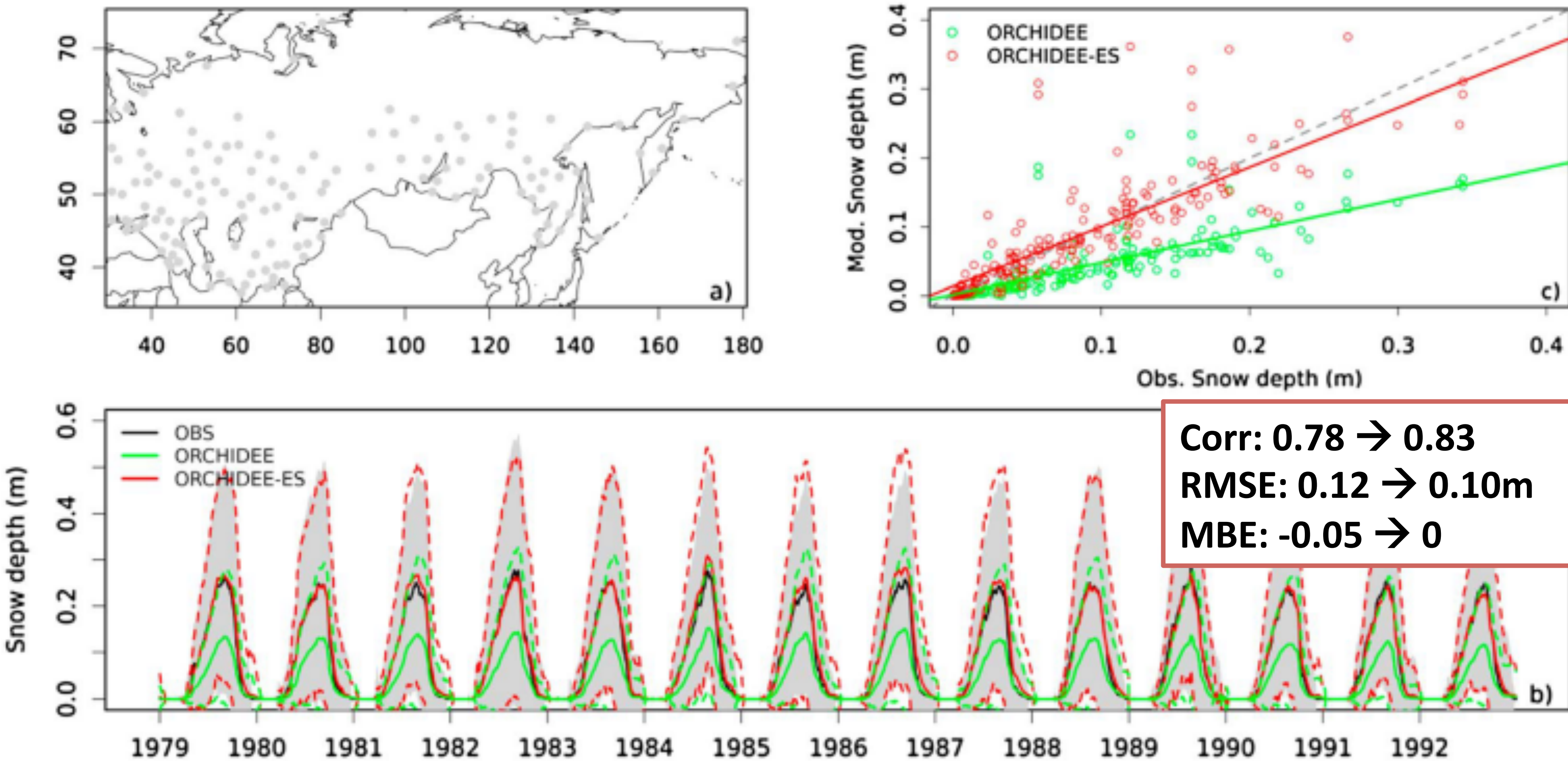


Wang et al., JGR, 2013

Evaluation results (Albedo and soil temperature), Col de Porte, mean seasonal cycle (1993-2011)



Evaluation results (Daily snow depth, density, SWE), Northern Eurasia, 165 stations HSDSD (1979-1992)



Corr: 0.78 → 0.83
RMSE: 0.12 → 0.10m
MBE: -0.05 → 0

Figure 10. (a) Spatial distribution of stations ($n = 165$) having at least 10 years with near complete (>360 days) year-round continuous snow cover; (b) mean daily snow depth comparison between observation and simulations across stations over the period 1979–1992. The gray region represents ± 1 standard deviation of mean daily observation. The dashed blue (or red) line represents ± 1 standard deviation of mean daily ORCHIDEE (or ORCHIDEE-ES) values; (c) the scatter plot of multiyear averaged (1979–1992) annual snow depth between observation and simulations across stations.

Wang et al., JGR, 2013

Validation over Siberia (Dantec-Nédélec et al.,)

- Orchidee versions comparison :
  - Standard Orchidee configuration
  - MICT-V3 version (with the soil freezing and better discretization of snow processes)

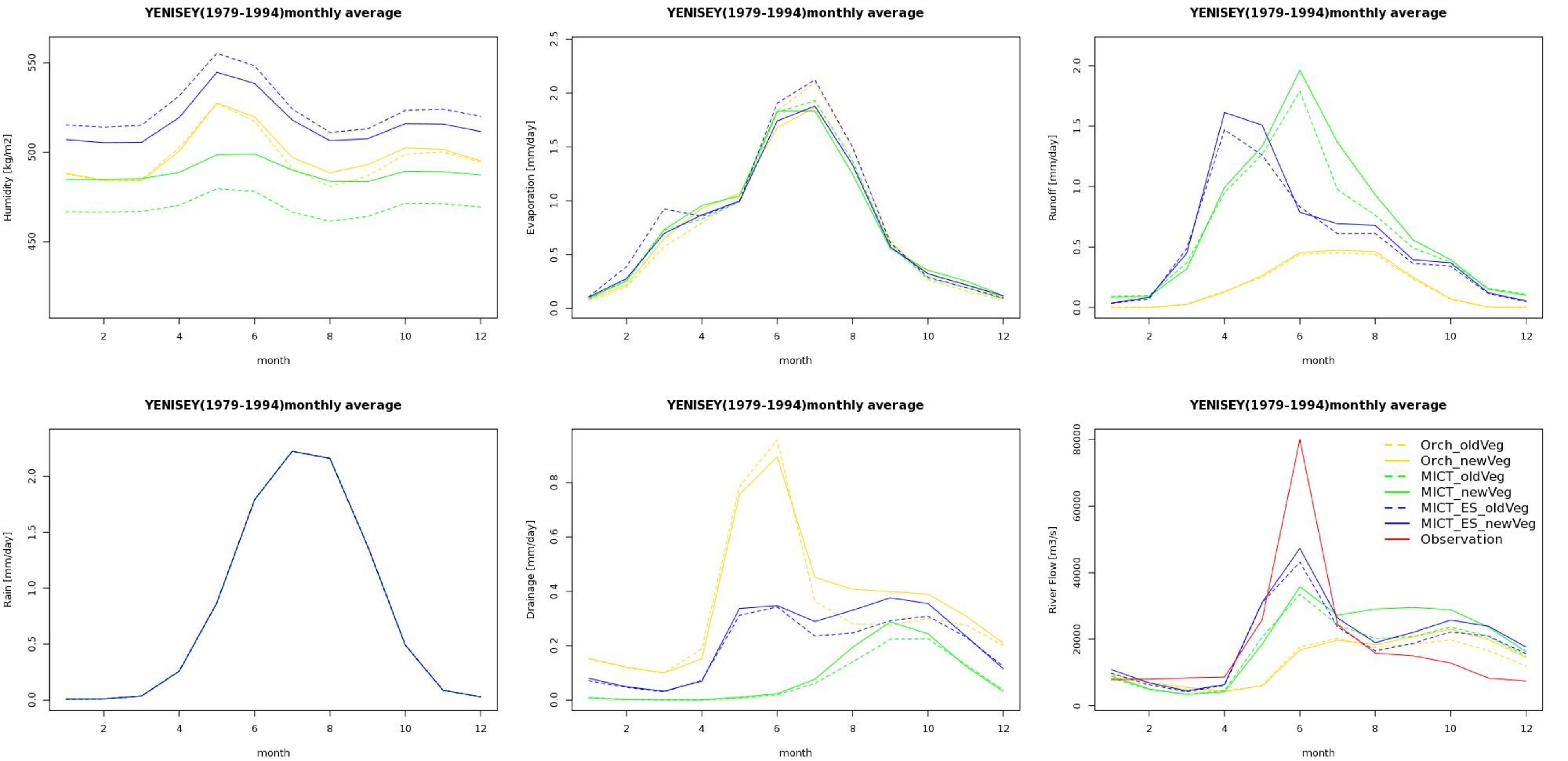
➢ Two vegetation maps : Olson et al (1983), Ottlé et al. (2013)

➢ Forcing data : WFDEI (1979-2009) : “WATCH Forcing Data methodology applied to ERA-Interim data”

➢ SPINUP : 200 years

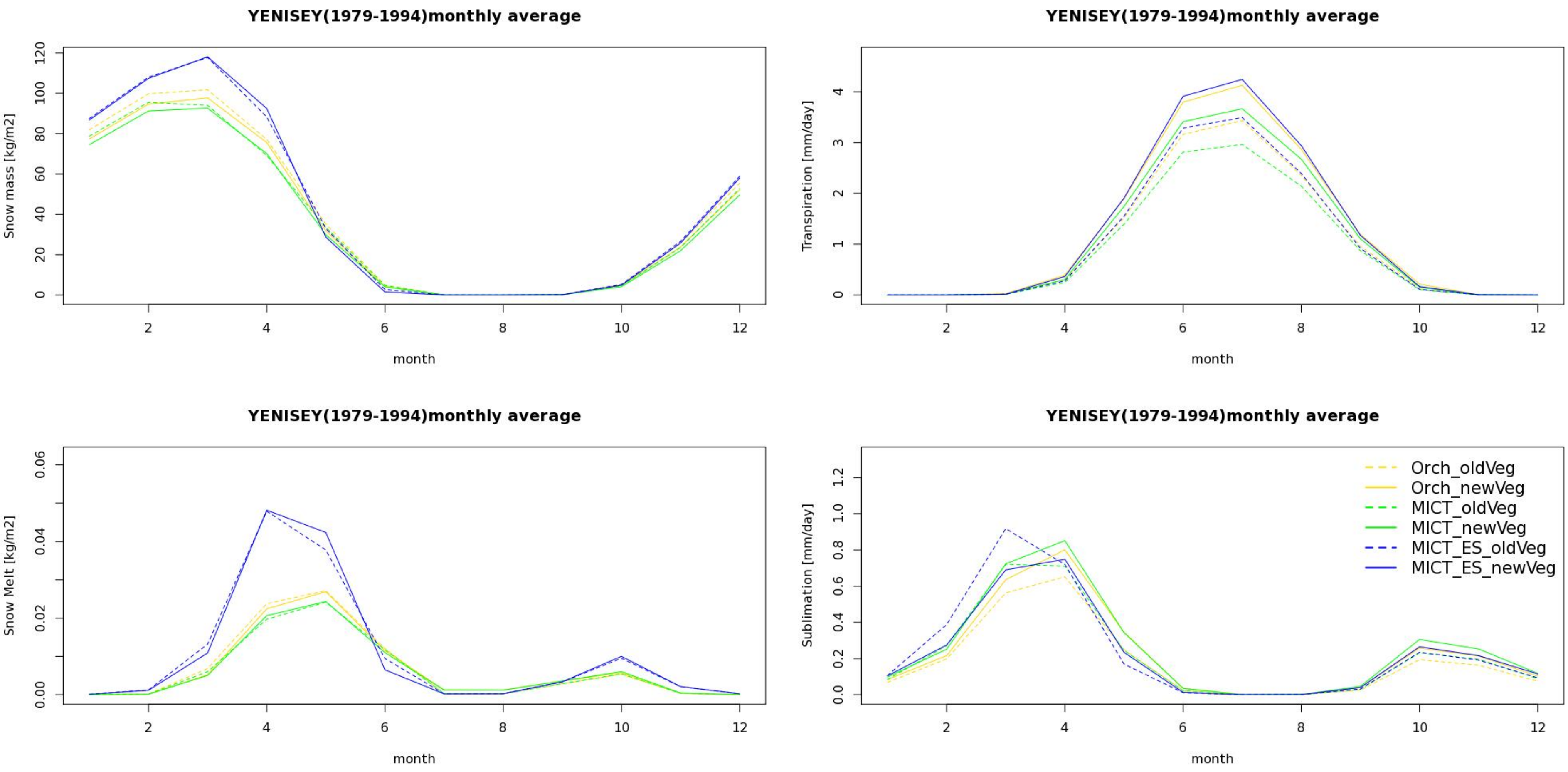
➢ 3 watersheds with different snow and permafrost conditi

Yenesei (1979-1994)



- Different initialization of soil humidity
- Slight Impact of vegetation map
- Strong impact of permafrost modeling on deep drainage and runoff, consequently on stream flows
- Significant impact of snow processes on the timing of drainage and runoff, better agreement with observations

Yenesei



- MICT_ES version : Strong impact of snow parameterization on snow pack evolution
- Insulating properties of snow → Higher soil temperature → Larger infiltration of snow melt in soil moisture and deep drainage → Larger transpiration in summer

LMDZ coupled simulations (Wang et al., 2015

Spinup
IPSL AR5
1901-1920

→

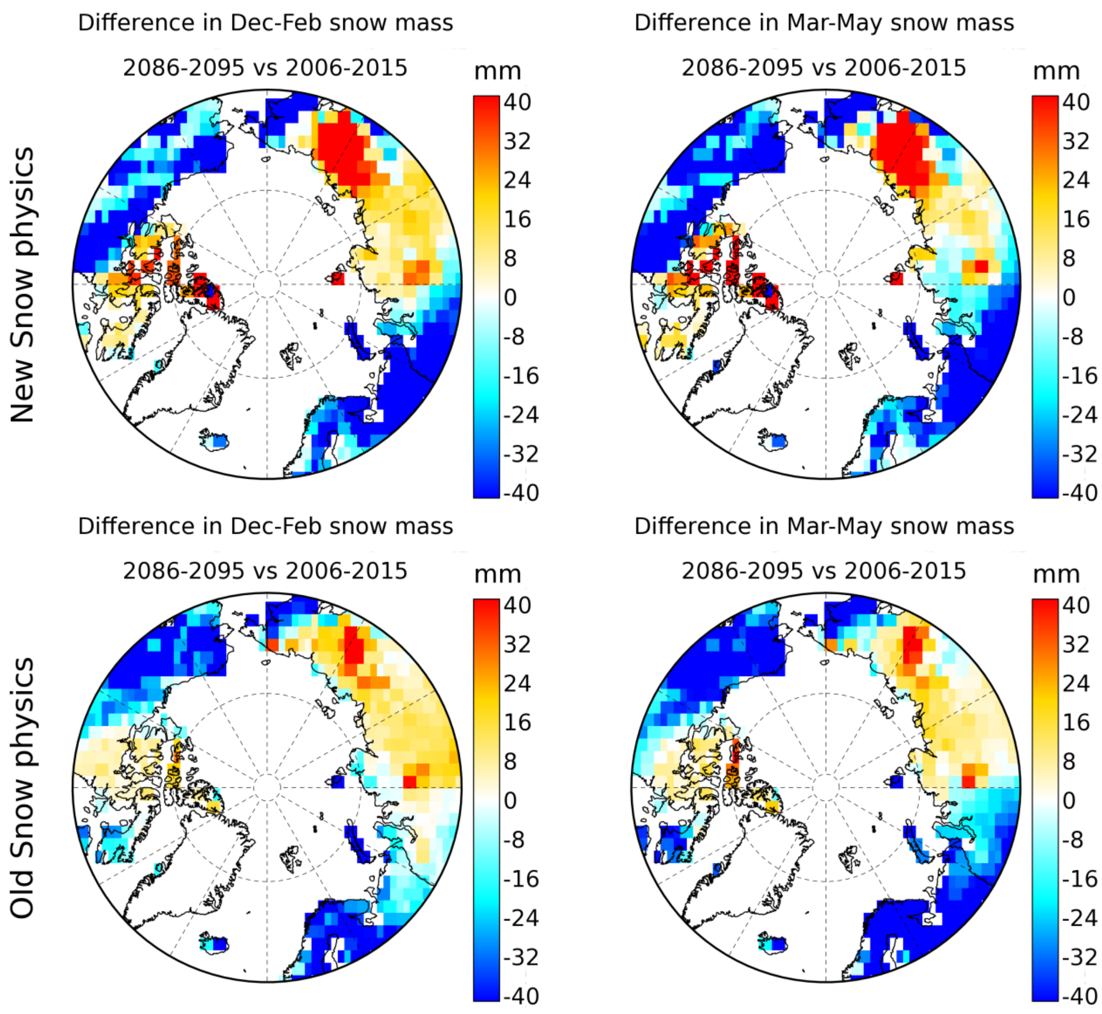
IPSL
1921-2005

→

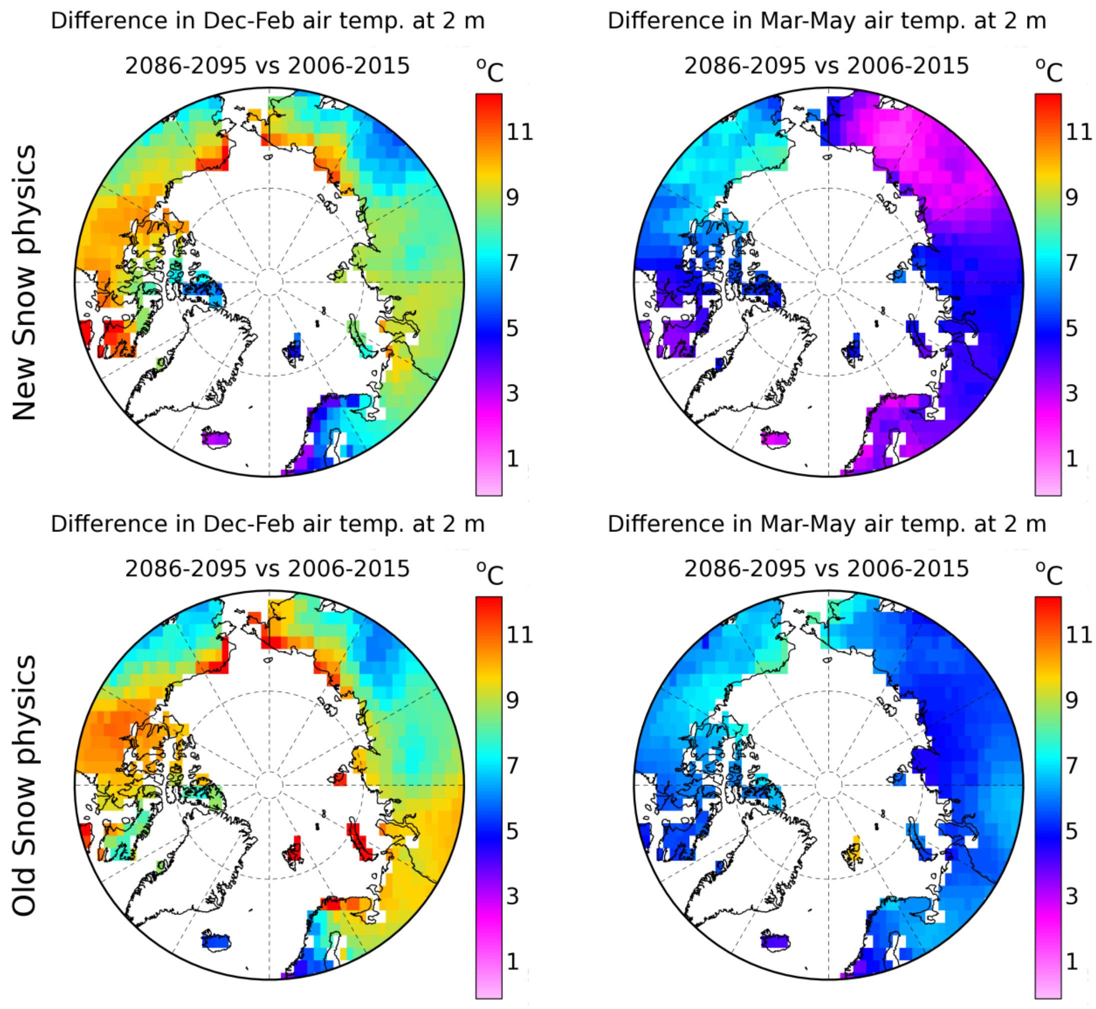
Coupled RCP 8.5
MICT V3 + LMDZ

IPSL AR5 RCP 8.5

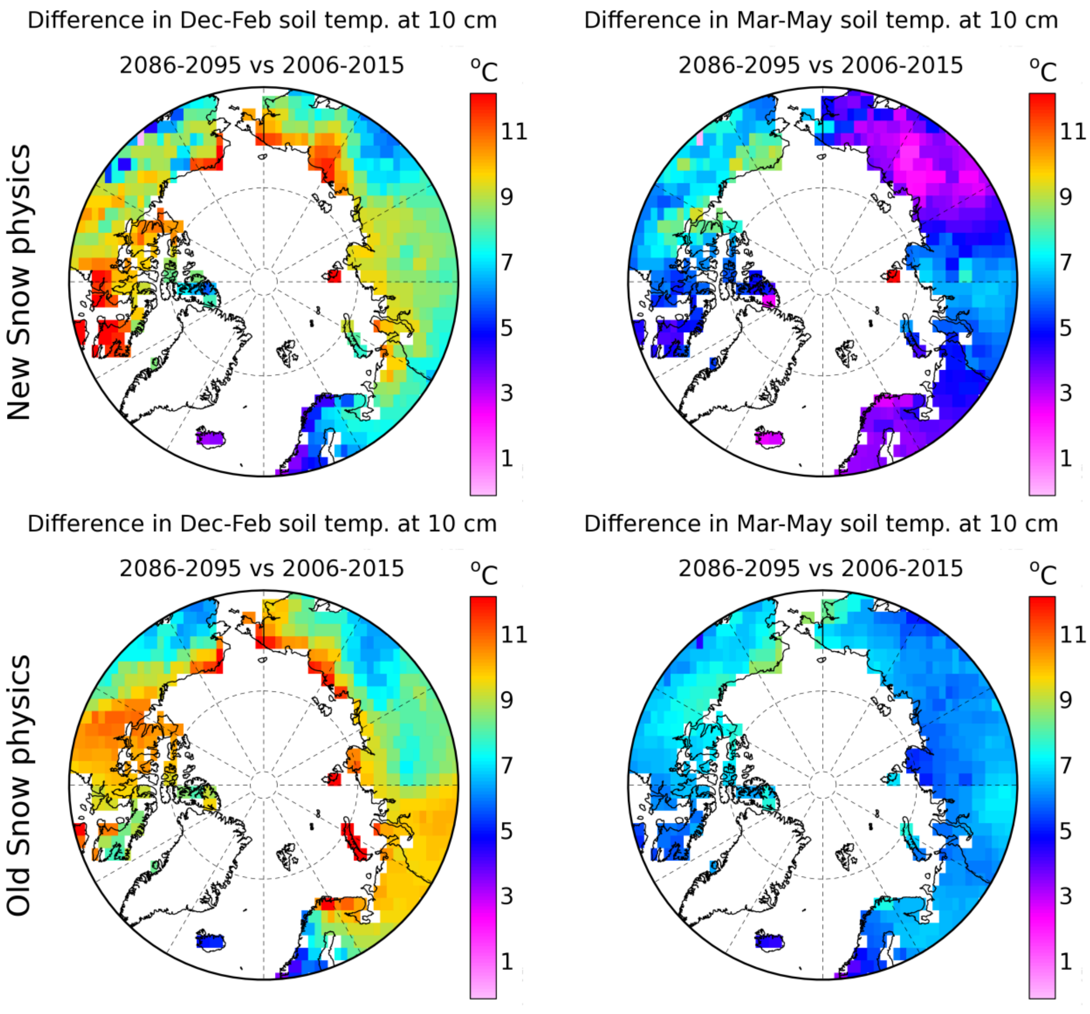
Changes in snow mass from LMDz-ORCHIDEE



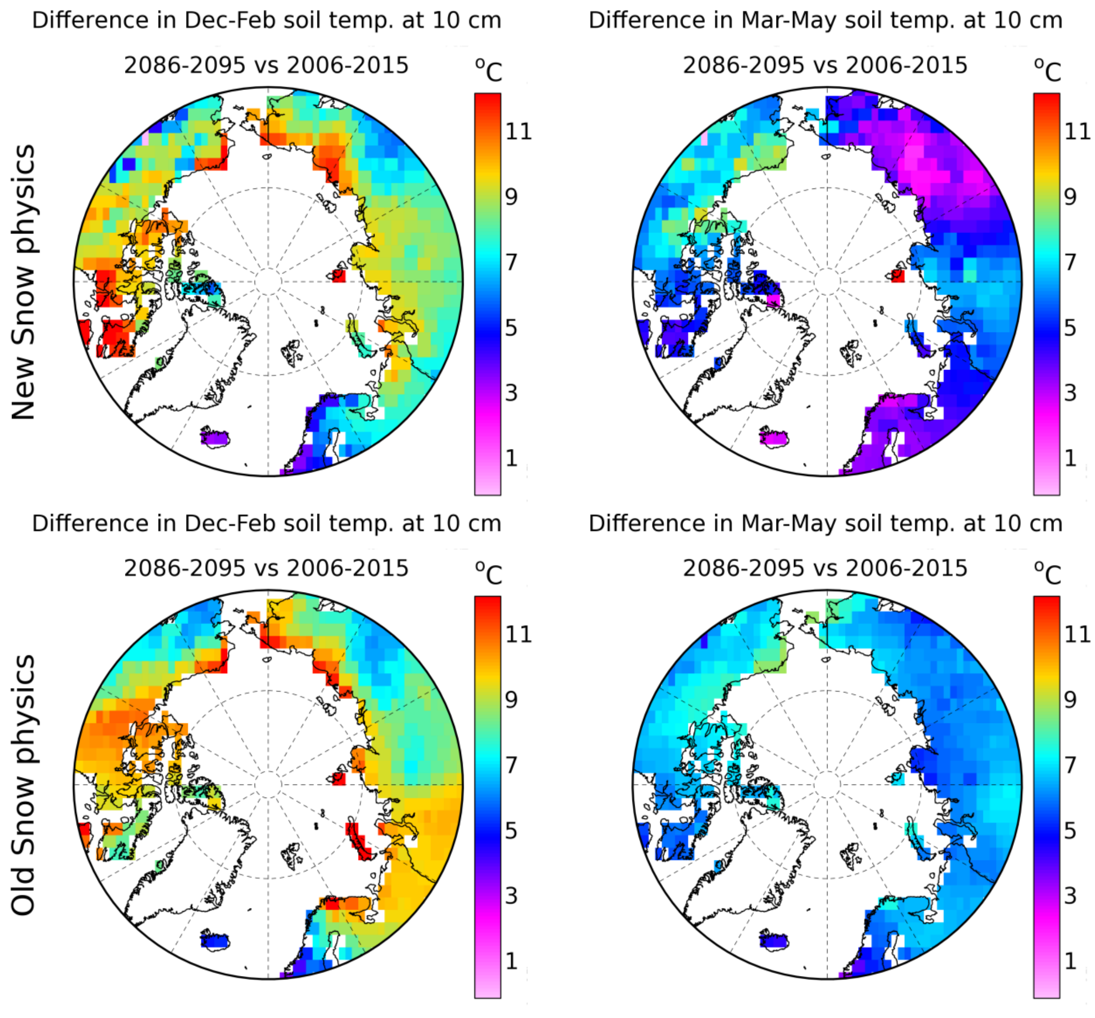
Changes in air temperature at 2 meters from LMDz-ORCHIDEE



Changes in soil temperature at 10 cm from LMDz-ORCHIDEE



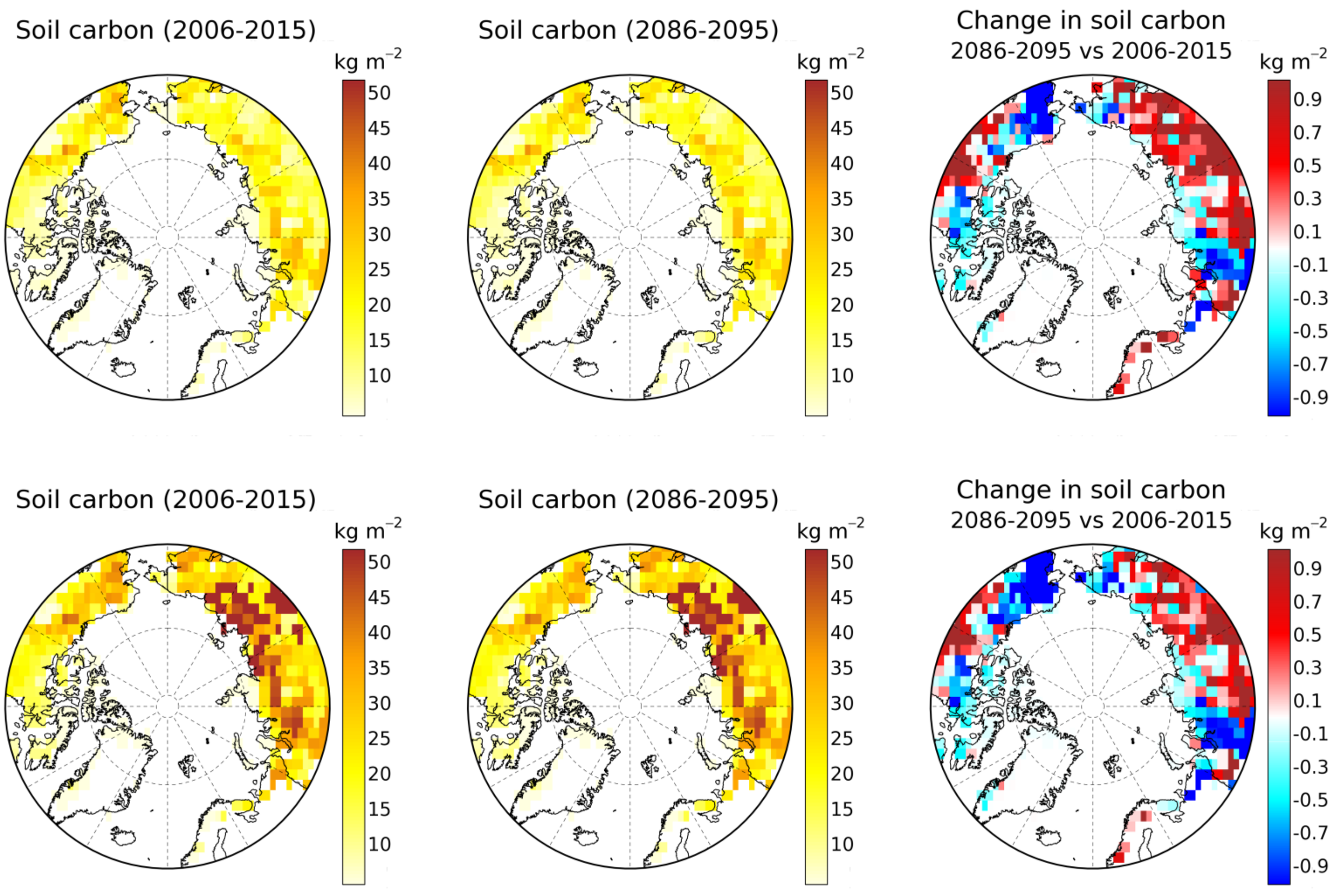
Changes in soil temperature at 10 cm from LMDz-ORCHIDEE



Changes in soil carbon from LMDz-ORCHIDEE

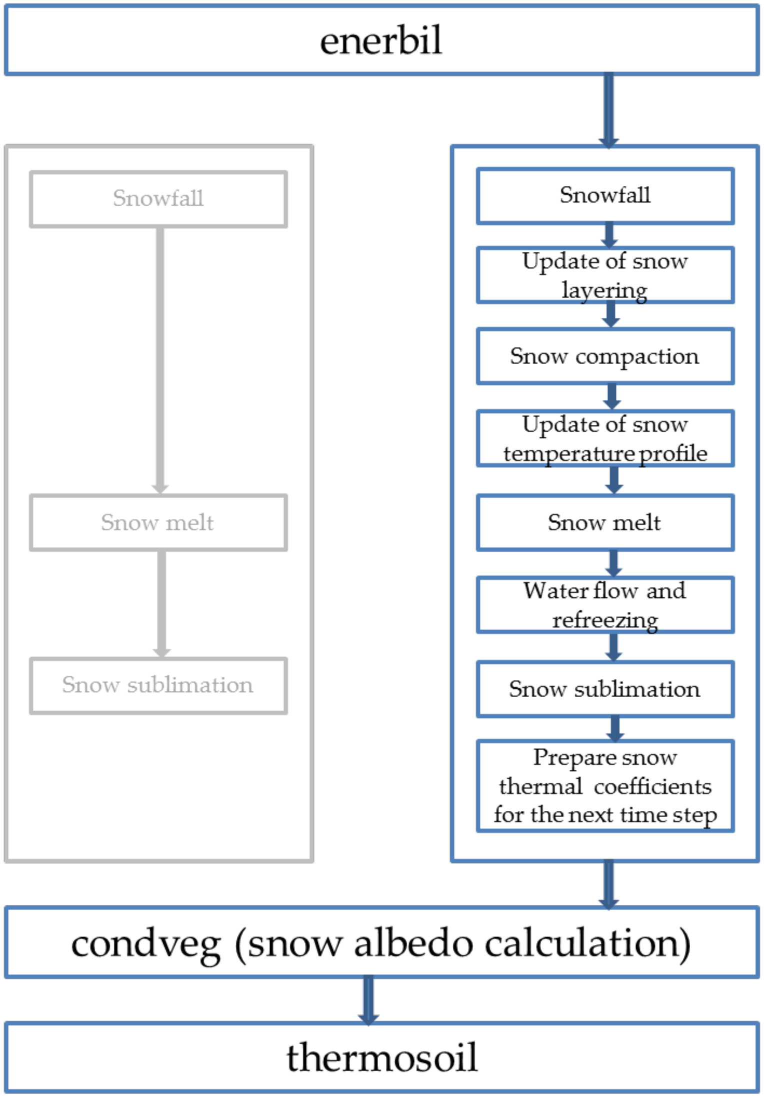
Soil Carbon change in the 21st century under RCP8.5

	2006-2015	2086-2095	Change
No permafrost Carbon			
Permafrost carbon			



Snow model implementation

- Organized in a separate block of modules (in MICT branch)
- Same philosophy as ORCHIDEE-old
- Snow fraction used only for surface albedo, snow cover the entire grid
- Implicit resolution but explicit representation of the energy budget at the snow-soil interface (soil-snow heat flux calculated using the soil temperature at previous time step)
- Snow temperature profile is calculated first neglecting phase changes and updated
- Water conservative, Energy ??



Procedure

- Snowfall mass and heat content are added to the uppermost snow layer. Snow density, depth, temperature and liquid water content are updated in the surface layer. Snowfall is assumed to have the same temperature as the uppermost snow layer upon reaching the surface, therefore the advective heat flux from snowfall can be neglected (in the surface energy budget).
- The snow thicknesses are reset and the vertical profiles of mass and heat are redistributed while conserving the total snow pack mass and heat
- Snow layer heat content, density and depth are used to diagnose Ts_i and Wl_i
- Compaction is calculated and ρ_i and Ds_i are updated. Snow mass and heat content are unaltered. Surface snow albedo and snow thermal conductivity are calculated
- The linearized system of equations is solved simultaneously with the soil temperature profile to estimate the preliminary profile of Ts_i and the surface flux at the soil interface (Gs_0)
- Phase changes, water flows and changes in liquid water storage are evaluated. Profiles of Ts_i, Wl_i, ρ_i and Ds_i are updated.
- The heat content Hs_i is updated from the profiles of Ts_i, Wl_i, ρ_i and Ds_i, and saved for the next time step along with the updated profiles of ρ_i and Ds_i. Snow surface fluxes, runoff and the heat flux at the snow/soil/vegetation interface are output.

Vertical discretization

- 3 snow layers
- 32 soil layers, up to 45m