Development and validation of the ORCHIDEE snow model using SNOWMIP sites and two SWE products (GlobSnow and CMC)

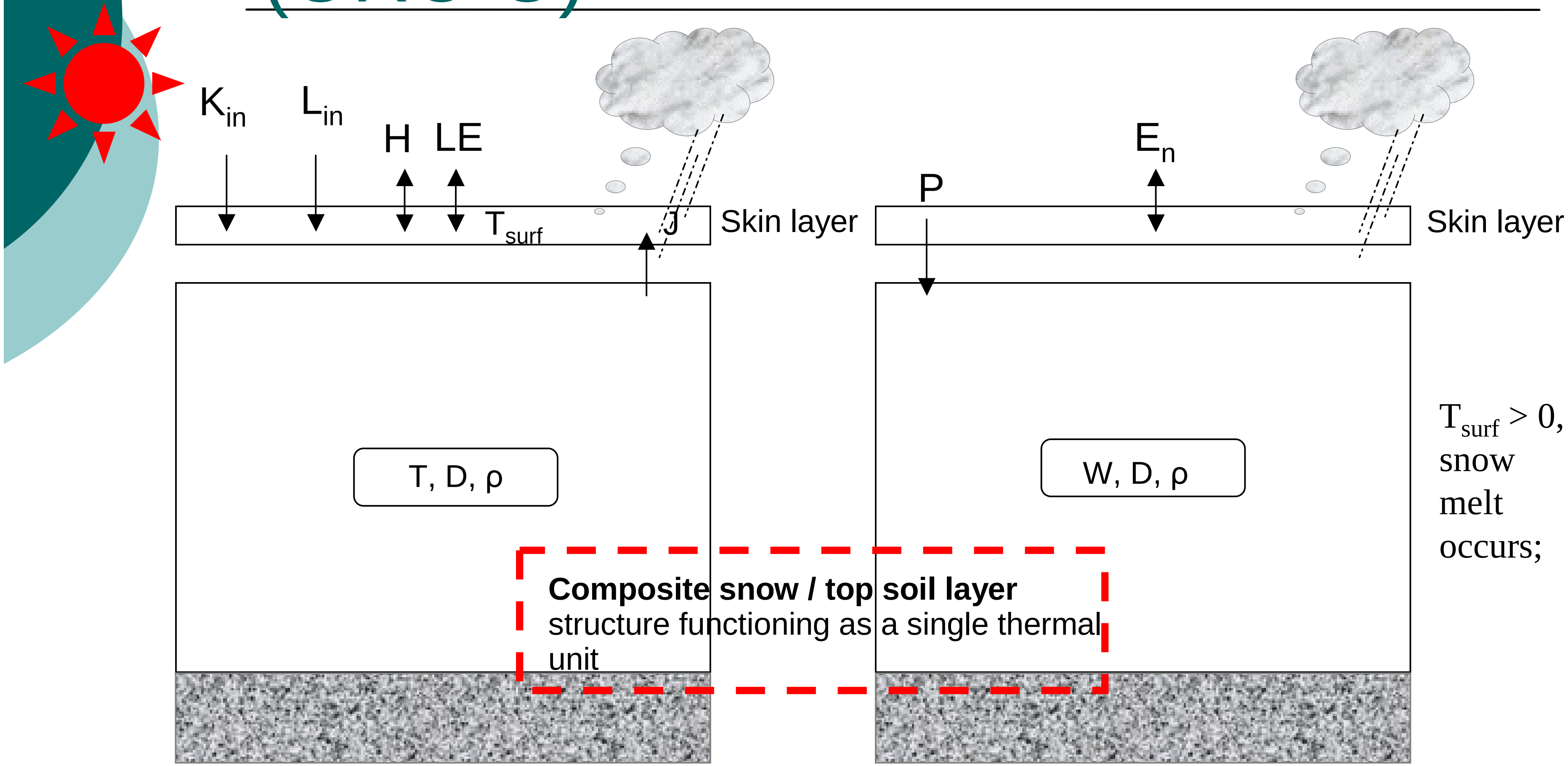
Tao Wang, Catherine Ottlé, Philippe Ciais, Gerhard Krinner, Aaron Boone, Samuel Morin

LSCE, Laboratoire des Sciences du Climat et de l'Environnement - FRANCE

CNRM-GAME, Centre National de Recherches Météorologiques

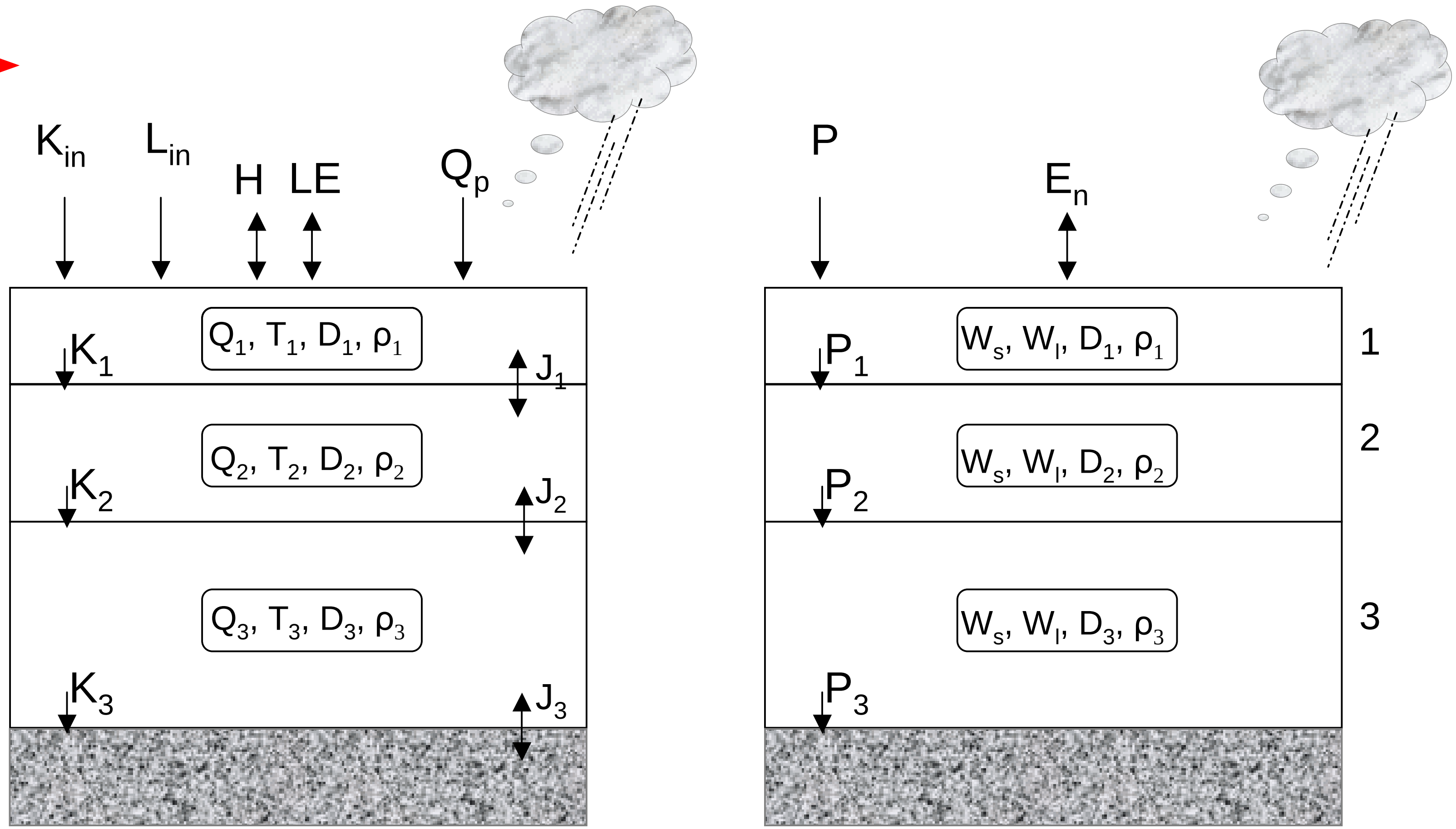
LGGE

Default ORCHIDEE snow model (ORC-O)



K_{in} (short wave radiation), **L_{in}** (longwave radiation), **H** (sensible heat flux), **LE**(latent heat flux), **J** (conduction heat flux), **W** (SWE), **D** (snow depth), **ρ** (fixed snow density, 330) , **P** (precipitation), **E_n** (evaporation), **T**(snow temperature), **Tsurf**(skin layer temperature)

Developed ORCHIDEE (ORC-N) snow model (based on ISBA-ES)



$\mathbf{K_{in}}$ (short wave radiation), $\mathbf{L_{in}}$ (longwave radiation), **H** (sensible heat flux), **LE**(latent heat flux), **J** (conduction heat flux), **Q** (snow layer heat content), $\mathbf{Q_p}$(advective heat from rain and snow), **W** (snow layer SWE), $\mathbf{W_l}$ (snow layer liquid water content), **D** (snow layer depth), **ρ** (snow layer density) , **P** (precipitation), $\mathbf{E_n}$ (evaporation)

Snow albedo parameterization in ORC-O and ORC-N

ORC-O:

$$\alpha_g^{t+1} = \alpha_{\mathrm{ini}} + \tau_a \exp(-\frac{S_{age}^{t+1}}{5})$$

$$S_{age}^{t+1} = (S_{age}^{t} + (1-\frac{S_{age}^{t}}{50})\frac{\Delta t}{86400})\exp(\frac{-P_n}{W_{crn}})$$

α_{ini} is prescribed for each vegetation type

S_{age} is snow age

ORC-N (from ISBA-ES) for non-forested sites :

$$\alpha_g^{t+1} = (P_n \Delta t / W_{crn})(\alpha_{\max} - \alpha_{\min}) + (1-\omega_\alpha)[\alpha_g^t - \frac{\tau_a \Delta t}{86400}]$$

$$+\omega_\alpha[(\alpha_g^t - \alpha_{\min})\exp(\frac{\tau_f \Delta t}{86400}) + \alpha_{\min}]$$

$$(\alpha_{\min} \le \alpha_g \le \alpha_{\max}, \alpha_{\min} = 0.50, \alpha_{\max} = 0.85)$$

The weight ω_α is the ratio of snow liquid content to snow water equivalent in the surface snow layer.

Modifed Albedo scheme implemented in ORC-O (named as ORC-O-ALB) for non-forested sites:

$$\alpha_g^{t+1} = (P_n \Delta t / W_{crn})(\alpha_{\max} - \alpha_{\min}) + [\alpha_g^t - \frac{\tau_a \Delta t}{86400}](Tsurf < 273.15)$$

Dry snow

$$\alpha_g^{t+1} = (P_n \Delta t / W_{crn})(\alpha_{\max} - \alpha_{\min}) + [(\alpha_g^t - \alpha_{\min})\exp(\frac{\tau_f \Delta t}{86400}) + \alpha_{\min}](Tsurf = 273.15)$$

Wet snow

$$(\alpha_{\min} \le \alpha_g \le \alpha_{\max}, \alpha_{\min} = 0.50, \alpha_{\max} = 0.85)$$

New forest snow albedo parameterization in ORC-N (*Roesch et al., 2001, 2006*)

1) $\alpha_{for} = SVF\alpha_g + (1 - SVF)\alpha_{can}$

2) $SVF = e^{-0.5LAI}$ $SVF = e^{-1.5LAI}$

3) $\alpha_{can} = f_{snc}\alpha_{snc} + (1 - f_{snc})\alpha_{g\_c}$

f_{snc} = 0.5, No canopy interception processes

4) $\alpha_g^{t+1} = (P_n \Delta t / W_{crn})(\alpha_{\max} - \alpha_{\min}) + (1 - \omega_\alpha)[\alpha^t - \frac{\tau_a \Delta t}{86400}]$

$+ \omega_\alpha[(\alpha_g^t - \alpha_{\min})\exp(\frac{\tau_f \Delta t}{86400}) + \alpha_{\min}]$

$(\alpha_{\min} \le \alpha_g \le \alpha_{\max})$

Non-forested snow albedo scheme

2 + 5 locations, 6 variables

Data:

Col De Porte (CDP, 1994-1995)
Weissfluhjoch (WFJ, 1992-1993)
SNOWMIP2 (5 locations, open and forested)

Variables:

SWE

SD

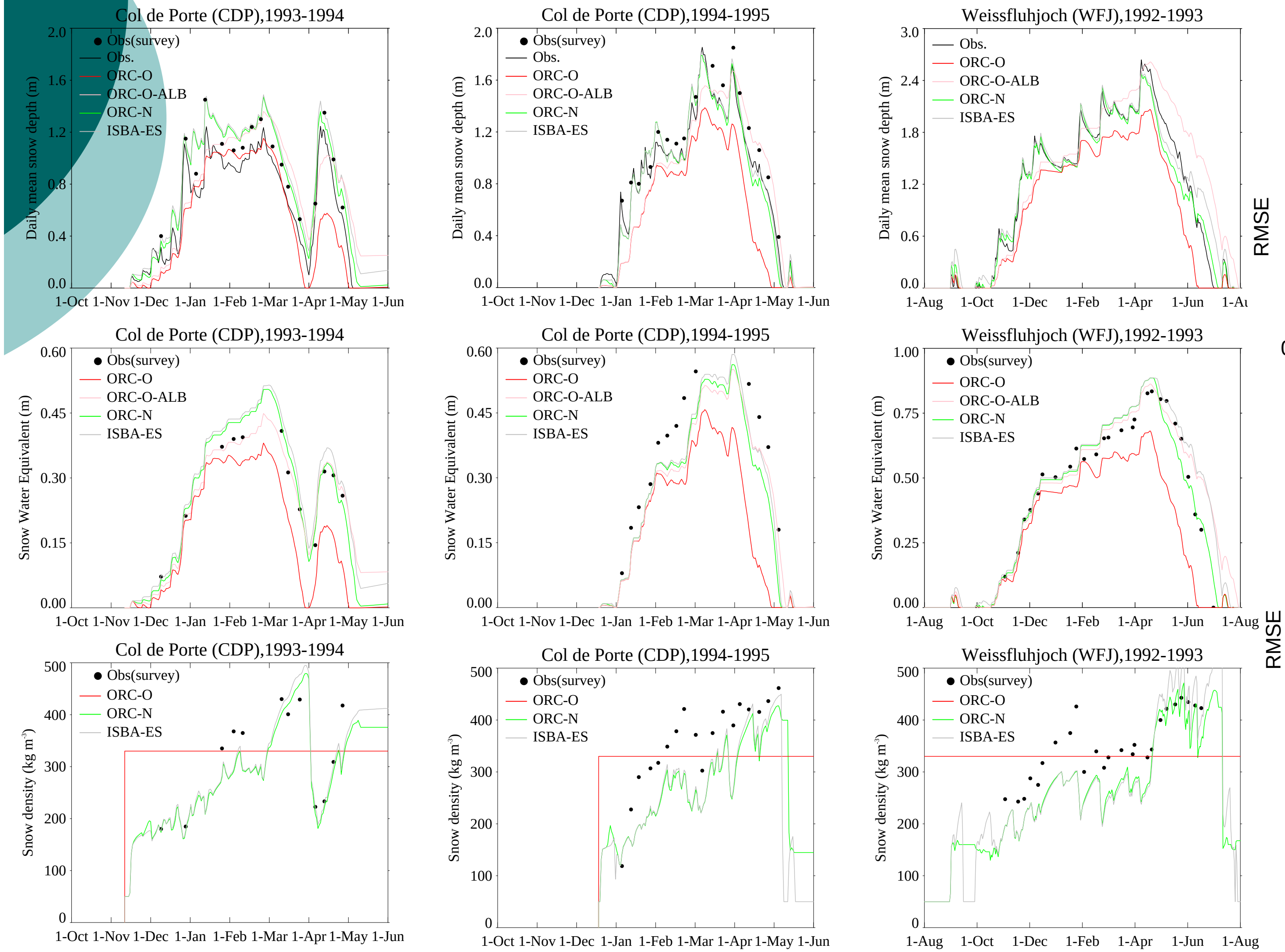
Snow density

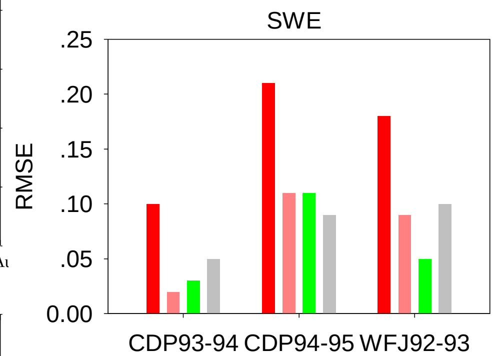
Surface temperature

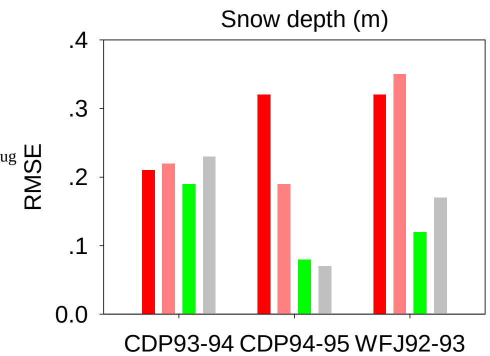
Snow albedo

Snowmelt runoff

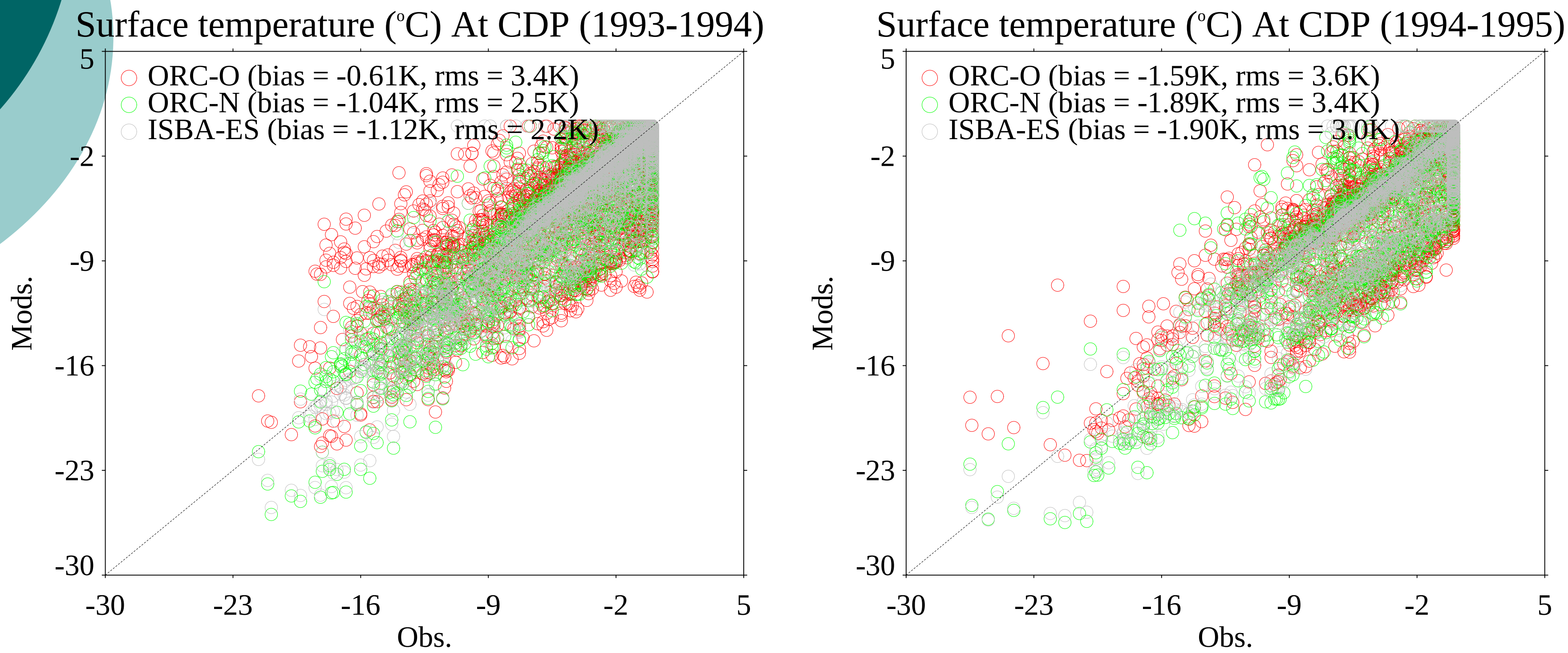
SWE, SD, Snow density at CDP and WFJ



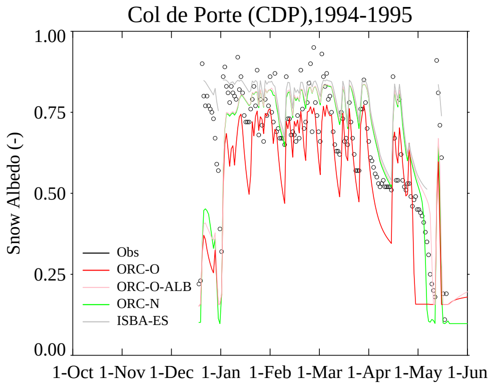


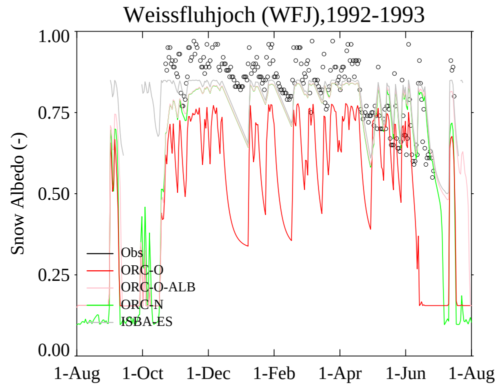


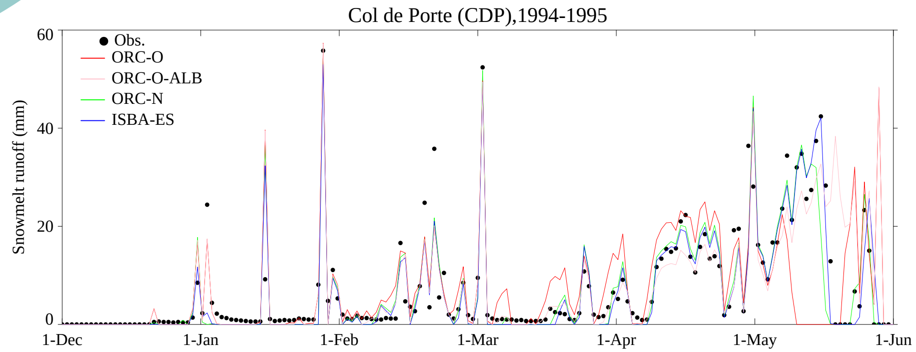
Snow surface temperature (CDP)

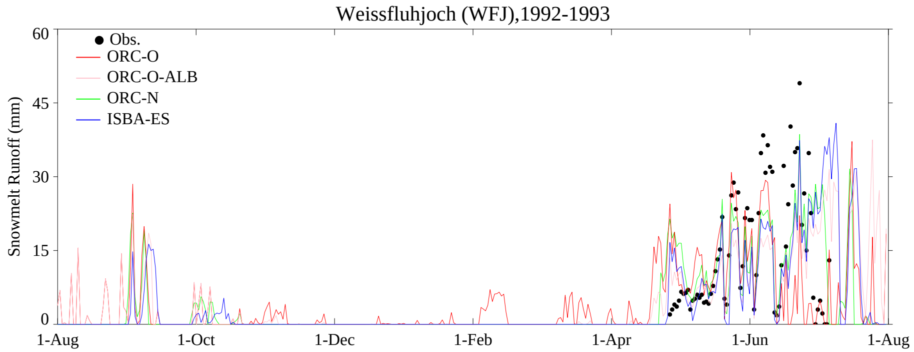


Snow Albedo and snowmelt runoff





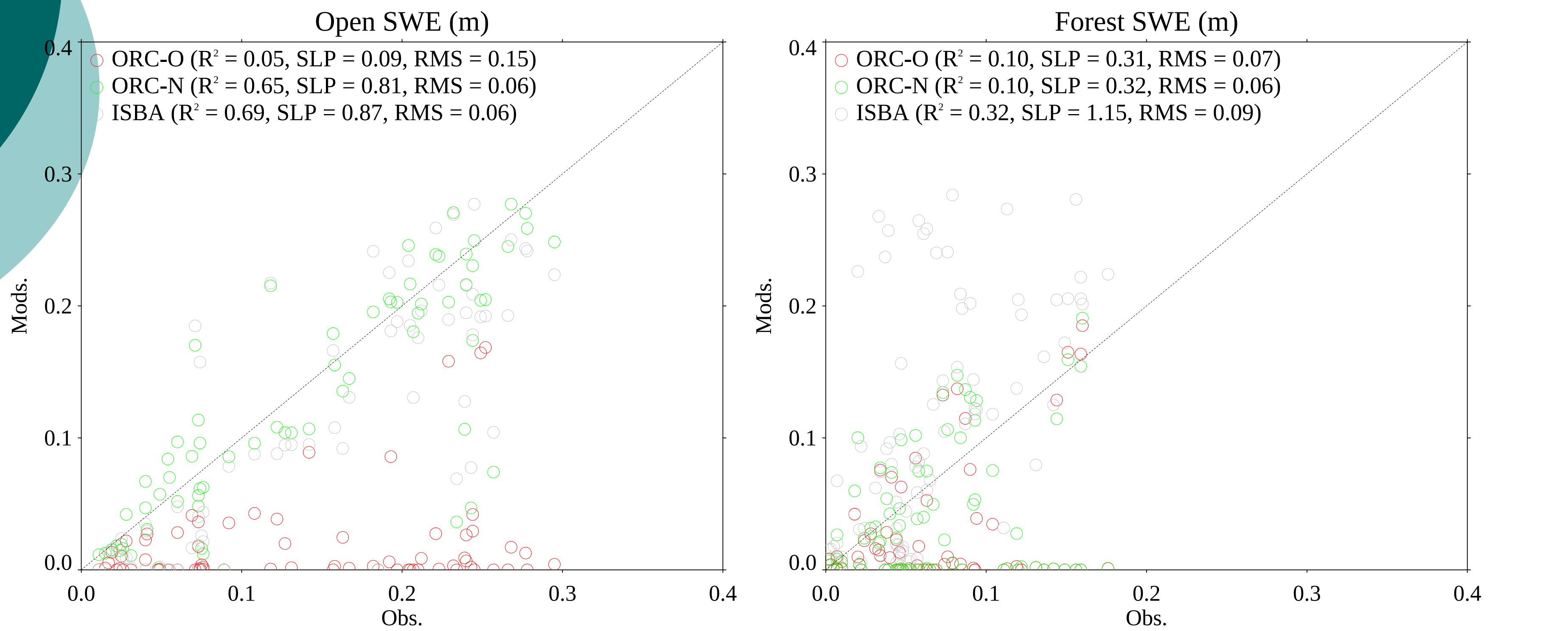




Snowmelt runoff comparison

Site	Model	MB	ME	RMSE
CDP94-95	ORC-O	**1.04**	**0.15**	**10.07**
	ORC-O-ALB	**1.05**	**0.49**	**7.81**
	ORC-N	**0.93**	**0.74**	**5.53**
	ISBA-ES	**0.91**	**0.81**	**4.74**
WFJ92-93	ORC-O	**0.76**	**-0.02**	**12.57**
	ORC-O-ALB	**0.81**	**0.14**	**11.54**
	ORC-N	**1.01**	**0.29**	**10.49**
	ISBA-ES	**0.92**	**0.01**	**12.38**

SNOWMIP2 sites (open and forested sites)

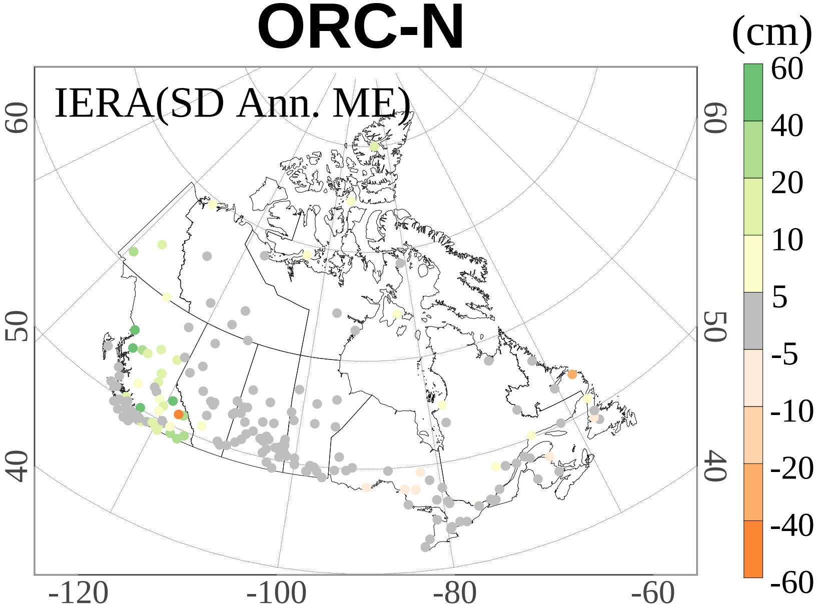


Only parameterizing the albedo scheme in the forested sites is not enough!! Needing another energy layer to resolve the snow dynamics under the canopy

ERA-Interim forcing (1999-2009)

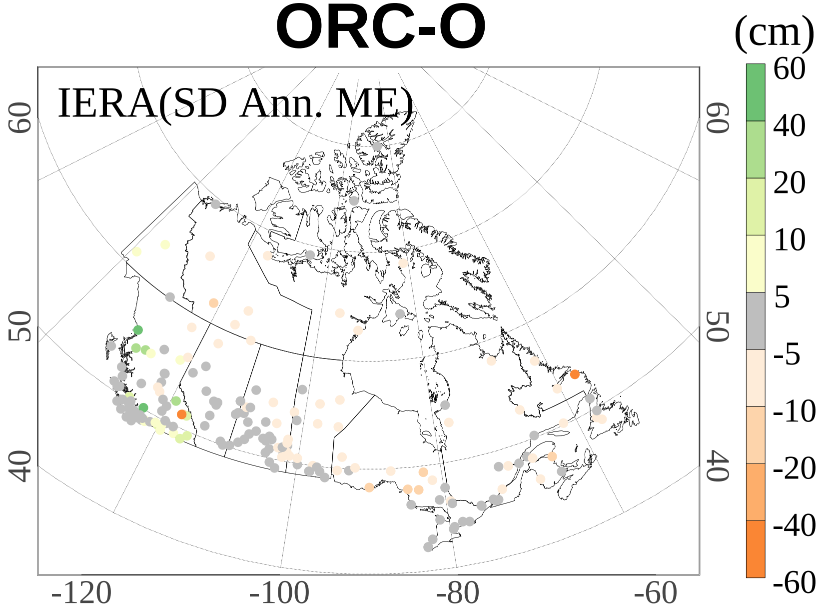
A rough look at the quality of IERA temperature and snowfall based on snow depth data from Canada meteorological station sites

ORC-N



SD RMSE = 2.5 cm

ORC-O



SD RMSE = 3.7 cm

Large scale snow products (1999-2009)

GlobSnow Product (Version 1.0)

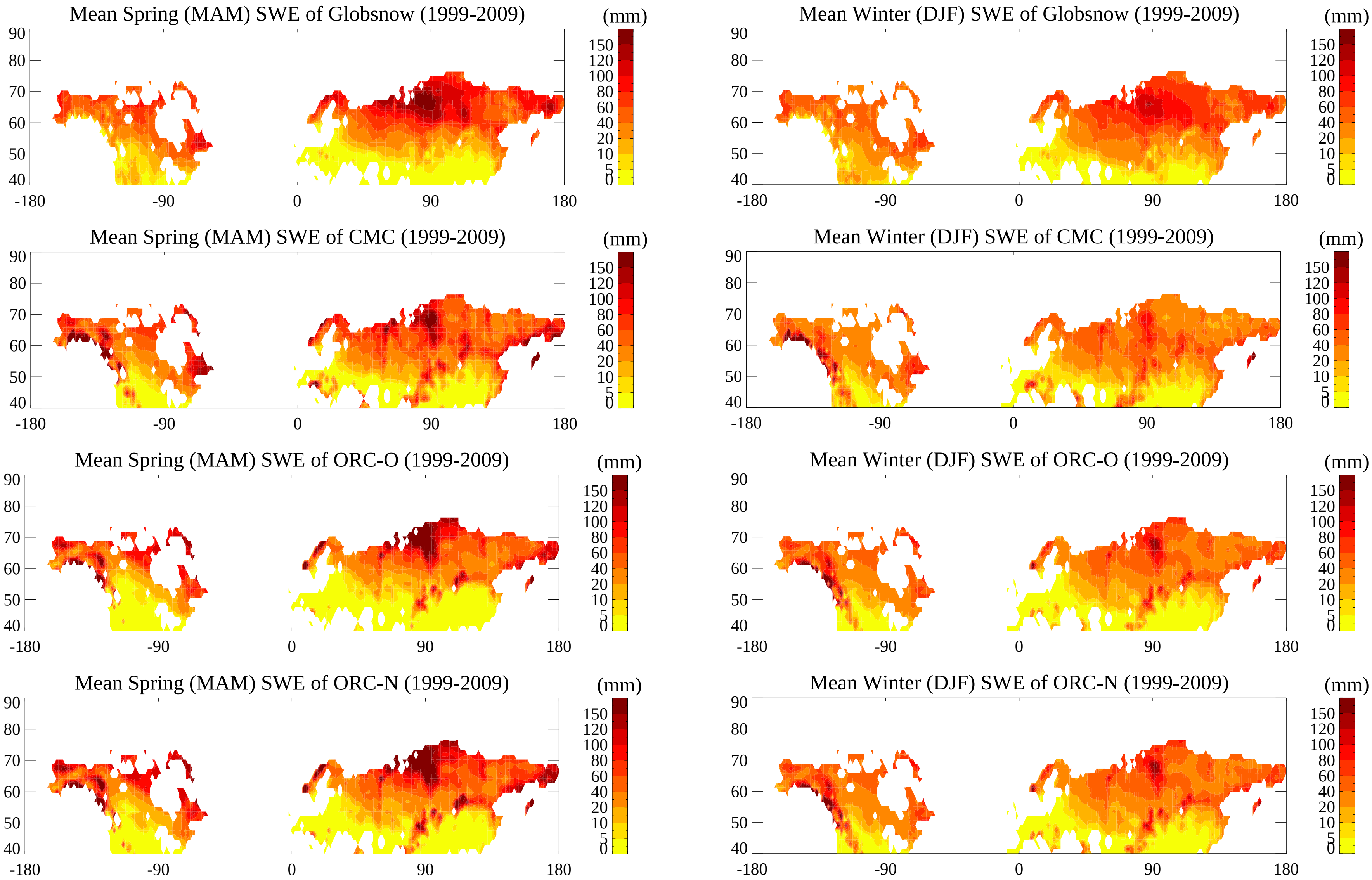
Masking out the **mountainous** regions

CMC gridded Snow product (1999-2009)

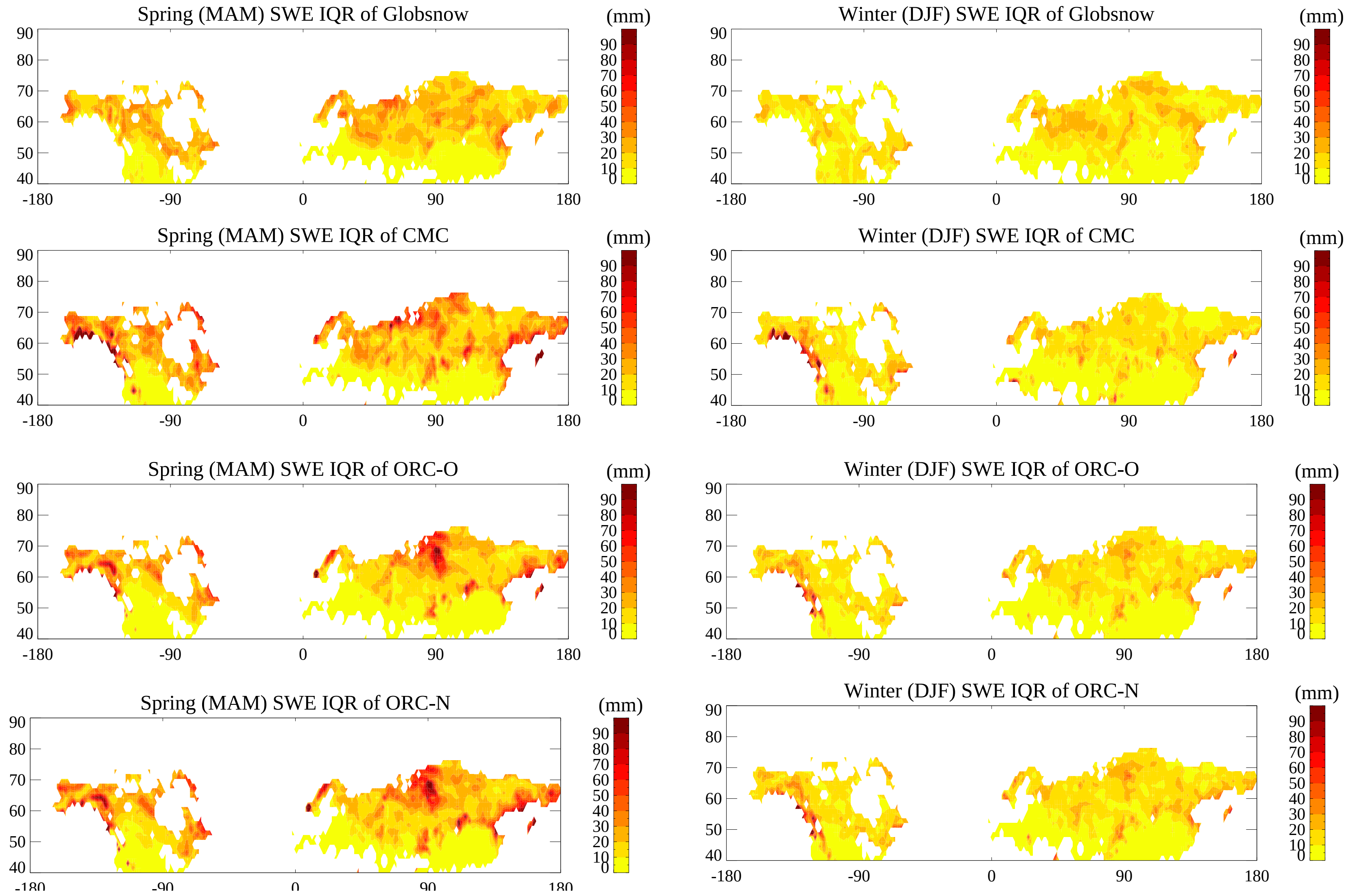
The CMC (Canadian Meteorological Centre) snow cover analysis differs substantially from the NOAA product in that it is based solely on in-situ daily snow depth observations, with spatial and temporal continuity provided through the temperature and precipitation fields generated by the CMC global NWP (*NCEP*'s mesoscale numerical weather prediction) model.
The authors (Brown et al., 2010) have the confidence on the data rich region like the south of 55 °N in NA.

Inaccuracies may lie in the regions with a sparse climate station observing network

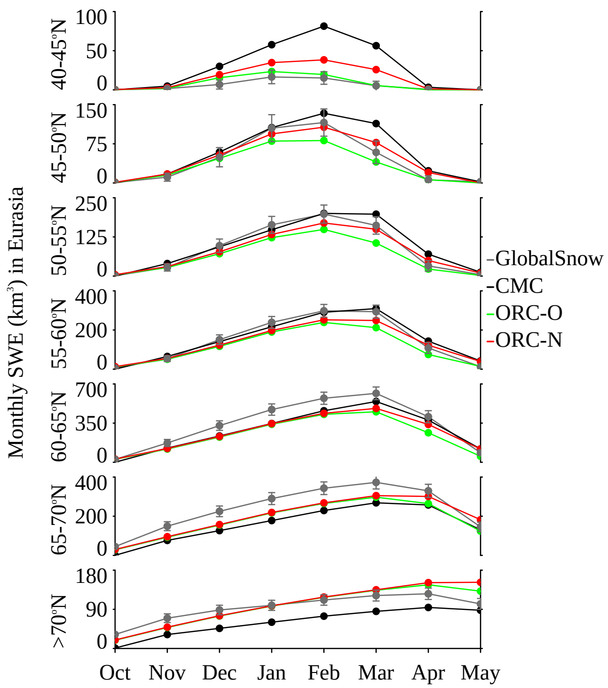
Mean spatial pattern of seasonal SWE (1999-2009)

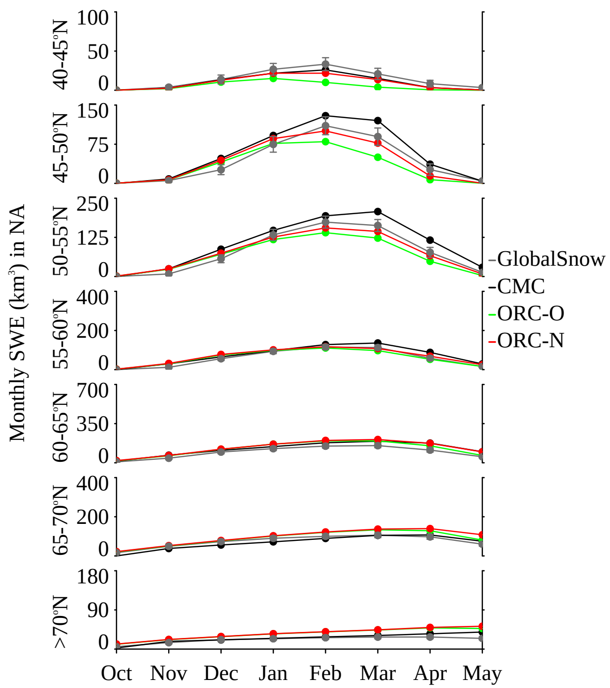


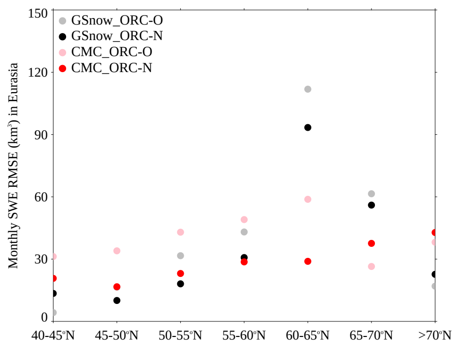
Spatial pattern of seasonal SWE IQR (interquantile range) (1999-2009)

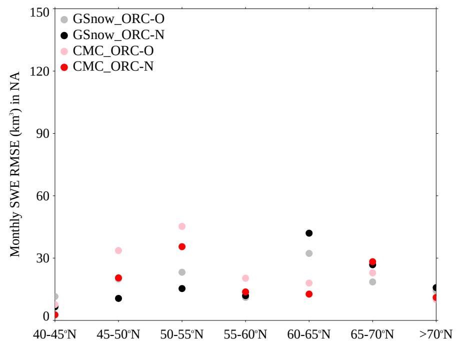


Mean (1999-2009) monthly SWE (in km^3)

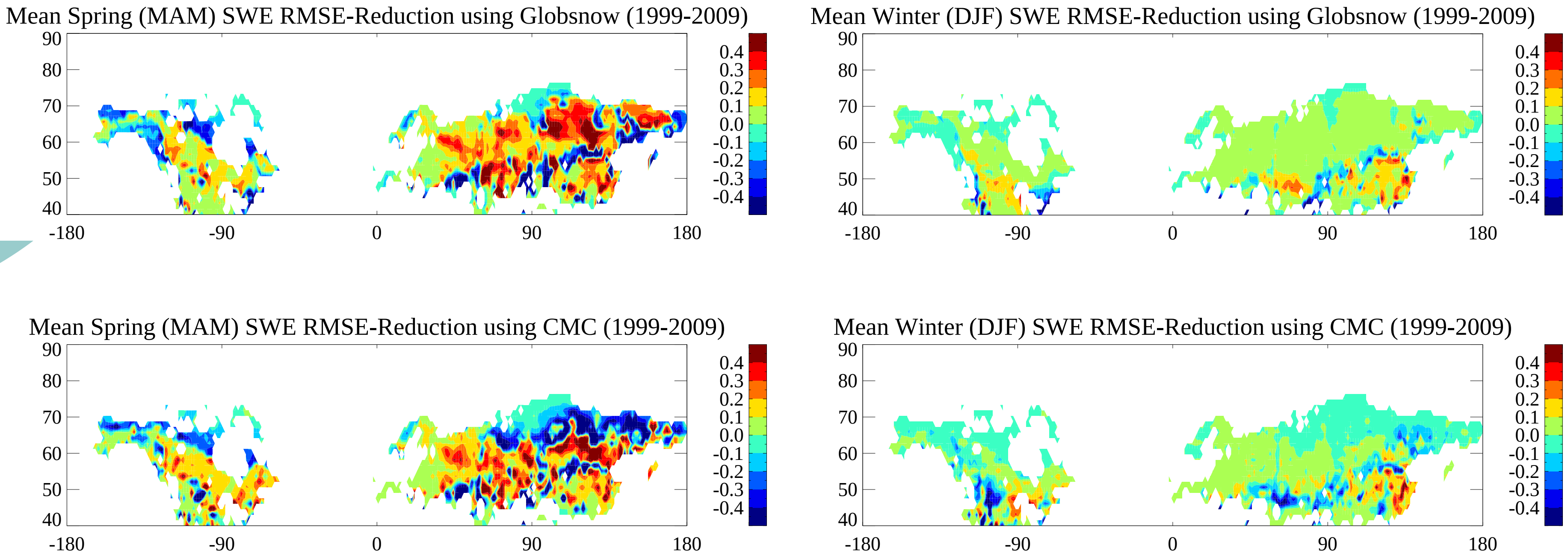








Seasonal SWE RMSE reduction between ORC-N and ORC-O (1999-2009)



The RMSE reduction is calculated by dividing two RMSE values difference (ORC-O_RMSE – ORC-N_RMSE) by their mean RMSE values.

Conclusions

1. At open sites, ORC-N is superior to ORC-O in snow simulations. The sensitivity analysis showed that the inclusion of modified snow albedo scheme could significant improve the model behaviror.
2. ORC-N is significantly improved in capturing the spatial and temporal (intra-annual and inter-annual) variation of spring SWE at relatively lower latitudes (< 60°N) when the modeled SWE is ev aluated against both SWE products.
3. Our study suggest that the ORC-N is problematic in the snow simulations of dense needleleaf forests (larger than 70% of canopy coverage), but we still expect that the benefits might be gained if albedo effect significantly contributes to the snow simulations in the deciduous forests and the needleleaf forests with sparse canopy coverage (inferred from continental snow comparison). To well capture the snow under canopy, at least two-layer energy budget is badly needed!

```
snow_age(ji) =(snow_age(ji) + (un - snow_age(ji)/max_snow_age) * dtradia/one_da
     & * EXP(-precip_snow(ji) / snow_trans)
```

```
snowa_ini+snowa_dec(jv)*agefunc_veg(ji)
```

```
agefunc_veg(ji) = EXP(-snow_age(ji)/tcst_snowa)
```

```
! Time constant of the albedo decay of snow
  REAL(r_std),PARAMETER :: tcst_snowa = 5._r_std
! Maximum period of snow aging
  REAL(r_std),PARAMETER :: max_snow_age = 50._r_std
! Transformation time constant for snow (m)
  REAL(r_std),PARAMETER :: snow_trans = 0.3_r_std
```