CLASSIC meeting 2024

Snow cover heterogeneity and its impact on the Climate and Carbon cycle of Arctic regions

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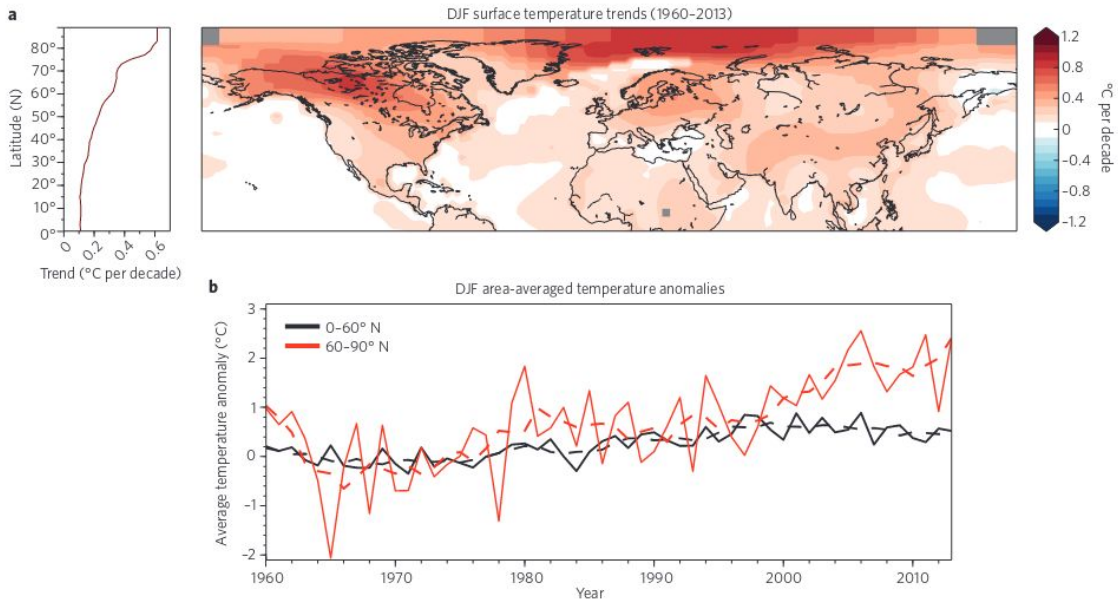
ESA CCI Fellowship — 01/10/2023 to 30/09/2025 (2 years)

supervised by Christophe Kinnard and Alexandre Roy

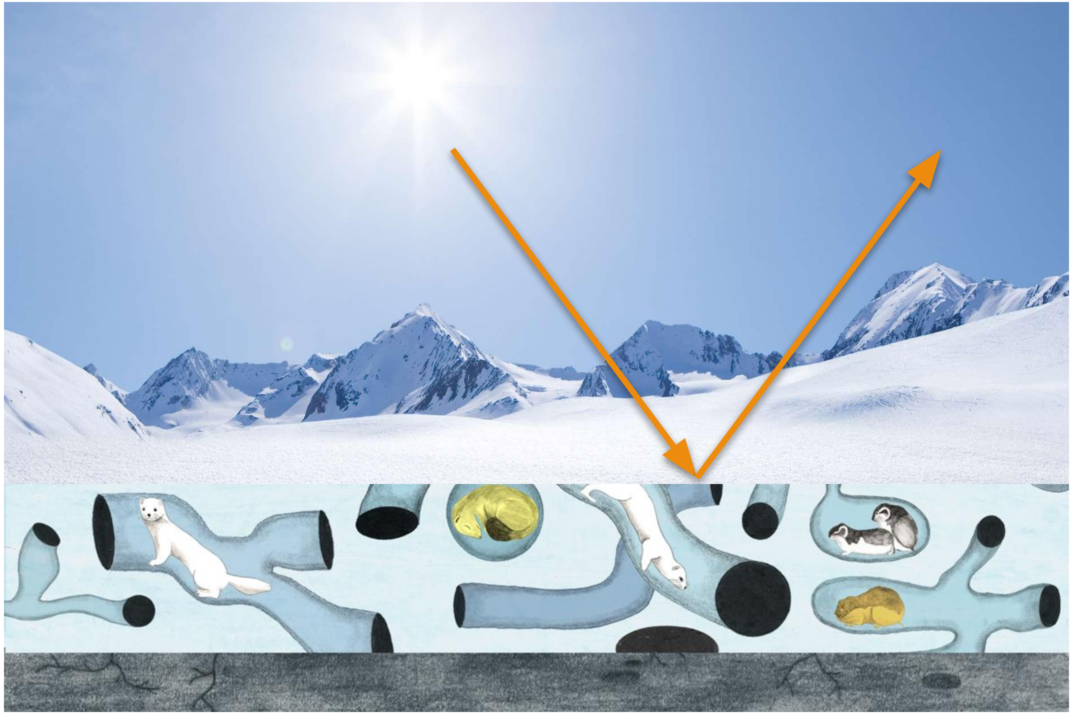
Context: Arctic Amplification



Cohen et al., (2014)

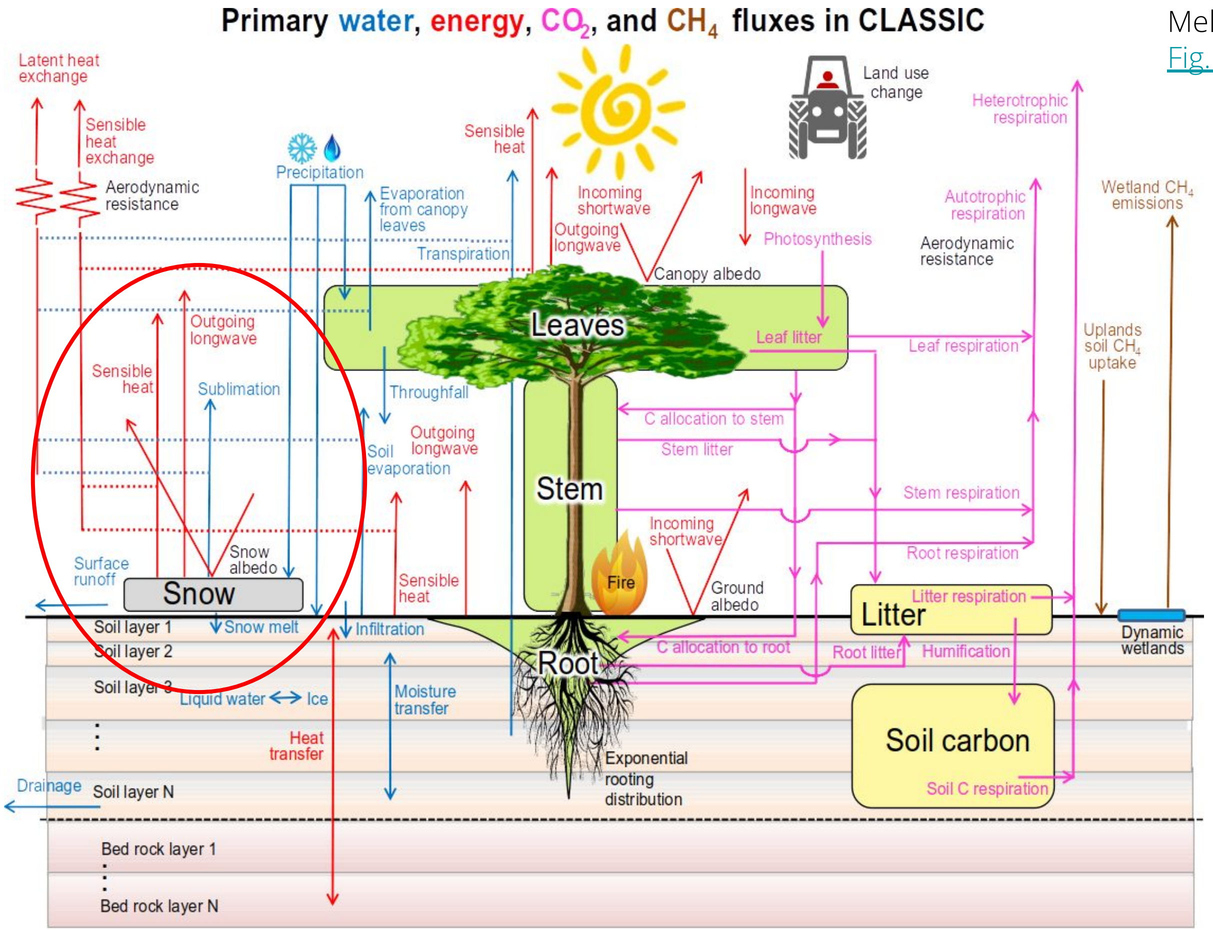
- The Arctic has warmed 2 to 3 times faster than the global average (e.g., Cohen et al., 2014) ; nearly four times faster than the globe since 1979 (Rantanen et al., 2022)
- ⇒ melting of Arctic sea ice and spring snow cover
- Impacts on ecosystems and human activities such as transportation, resource extraction, water supply, use of land and infrastructure among others.
- 1.035 Pg-C (>66° N, 3m soil) - By 2100, 55 to 232 Pg C-CO2-e could be emitted via permafrost degradation (Schuur et al., 2022)

Snow: essential component of the climate system

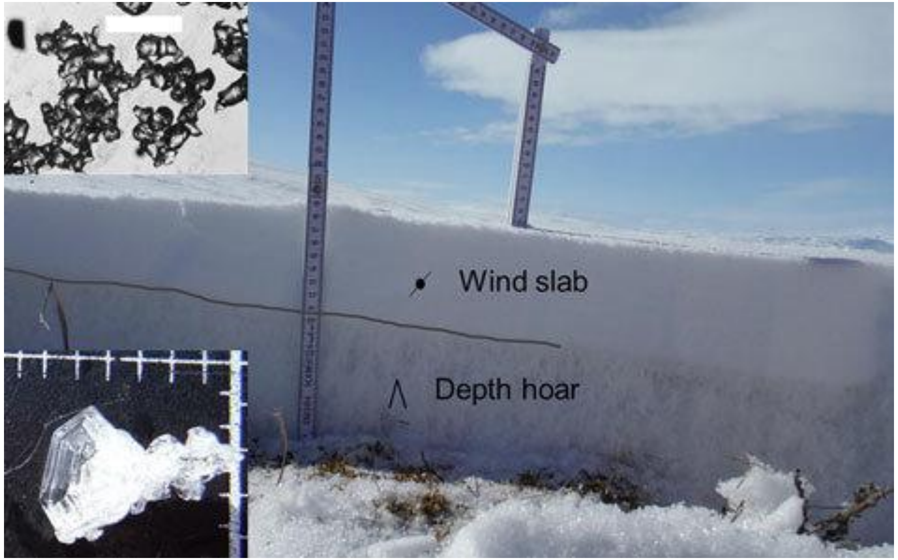


Snow model in CLASSIC: description

Melton et al. (2020), Fig. 1



Arctic snowpack



Domine et al., (2019)

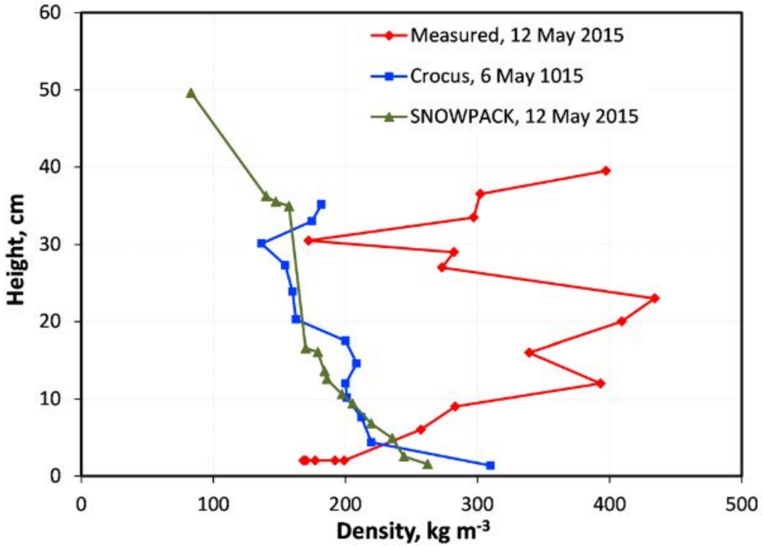


Figure 3. Comparison of measured snow density profiles at Bylot Island in May 2015 with those simulated using the detailed snow models Crocus and SNOWPACK. Crocus runs of 6 May are shown because Crocus simulates melting on 7 May, and this extra process makes comparisons irrelevant on 12 May.

Domine et al., (2018)

Arctic snowpack: solution?

Physical solution

Implement the water vapor fluxes explicitly in the snowpack (→ snow mass redistribution):

- IVORI project (Marie Dumont, ERC ~2M €)
- Jafari et al., (2020): The Impact of Diffusive Water Vapor Transport on Snow Profiles in Deep and Shallow Snow Covers and on Sea Ice
- Simson et al. (2021): Elements of future snowpack modeling – Part 2: A modular and extendable Eulerian–Lagrangian numerical scheme for coupled transport, phase changes and settling processes

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Practical solution

Increase the compaction due to the wind + reduce the density of the lower layers, e.g.:

- Royer et al. (2021): Improved Simulation of Arctic Circumpolar Land Area Snow Properties and Soil Temperatures
- Lackner et al., (2022): Snow properties at the forest–tundra ecotone: predominance of water vapor fluxes even in deep, moderately cold snowpacks

Challenge: never applied worldwide and often site specific...

Objectives of the project

1. Implement a multilayer snowpack in CLASSIC (1D simulations)
    - technical challenges: model not so modular and snow is included in many files/routines
    - physical challenges: include Arctic snowpack characteristics (if possible) + blowing snow, etc.
    - → assess these changes at site level simulations (SnowMIP + 3 Arctic sites)

Model development and assessments

#1 Implement multilayer snow model in CLASSIC (site simulations)

Credit: Sawtooth Avalanche Center

New Arctic simulations

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1. Implement a multilayer snowpack in CLASSIC (1D simulations)
2. Test new snow cover fraction parameterizations + multilayer snowpack in spatial simulations (Arctic) → use of ESA CCI data (snow, land type, etc.) to calibrate and asses these new developments

Model development and assessments

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#2 Snow cover param + multilayer snowpack (spatial simulations)

New Arctic simulations

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3. New simulations over the whole Arctic with new snowpack (assessment on the surfaces fluxes)

Model development and assessments

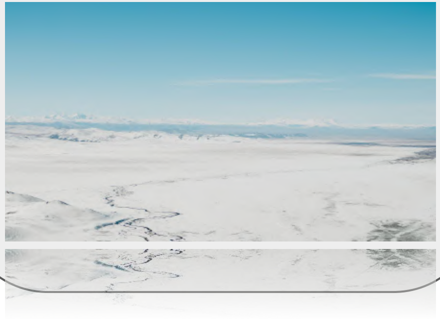
New Arctic simulations

#1 Implement multilayer snow model in CLASSIC (site simulations)

Credit: Sawtooth Avalanche Center

#2 Snow cover param + multilayer snowpack (spatial simulations)

#3 Improved Arctic simus (snow, energy/carbon fluxes, etc.)



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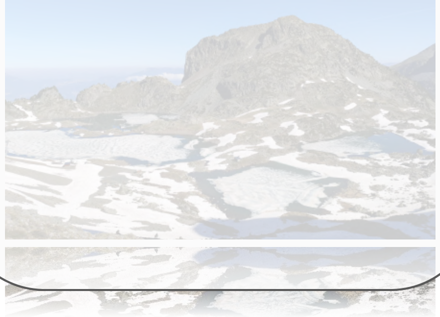

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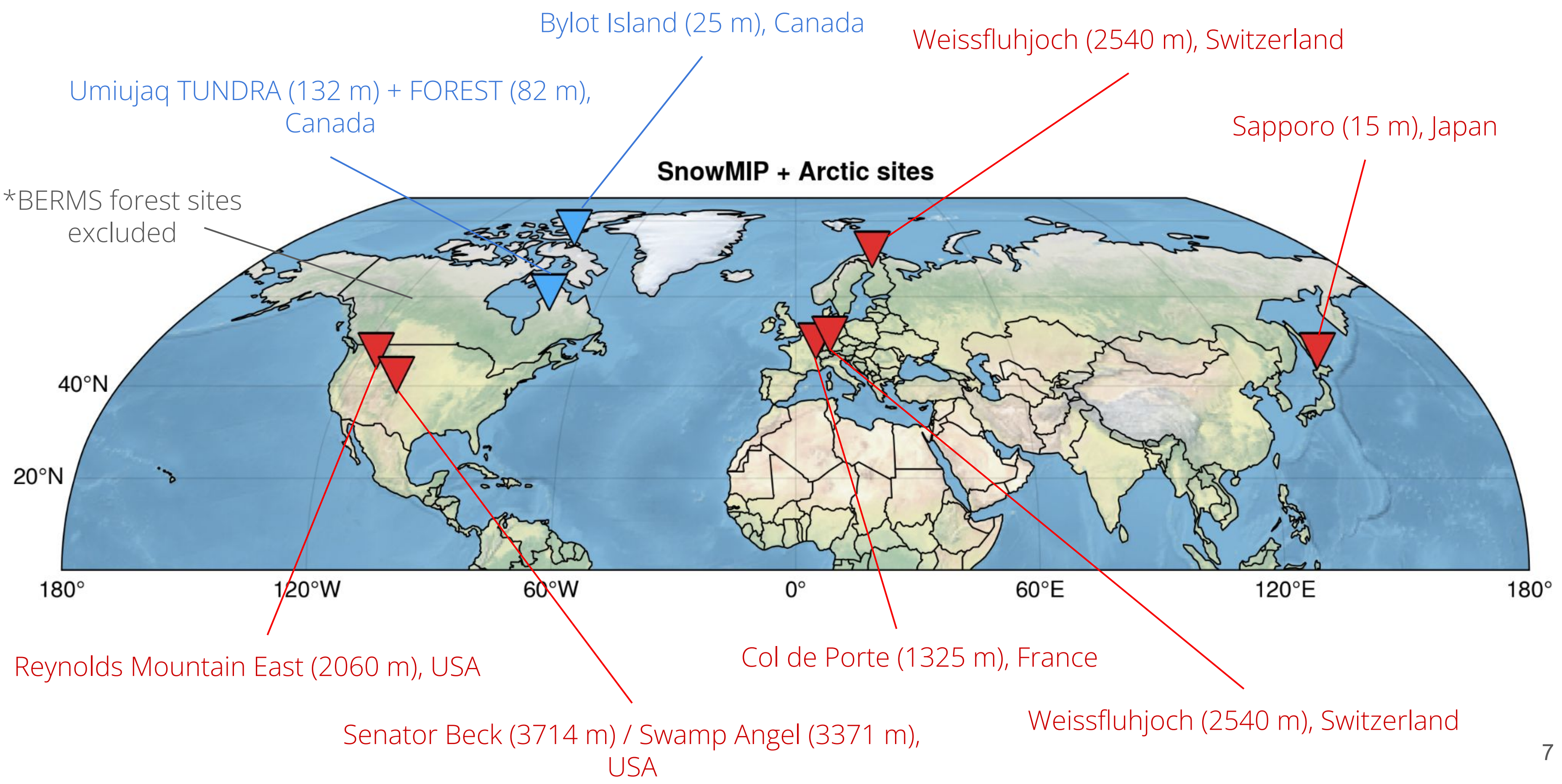
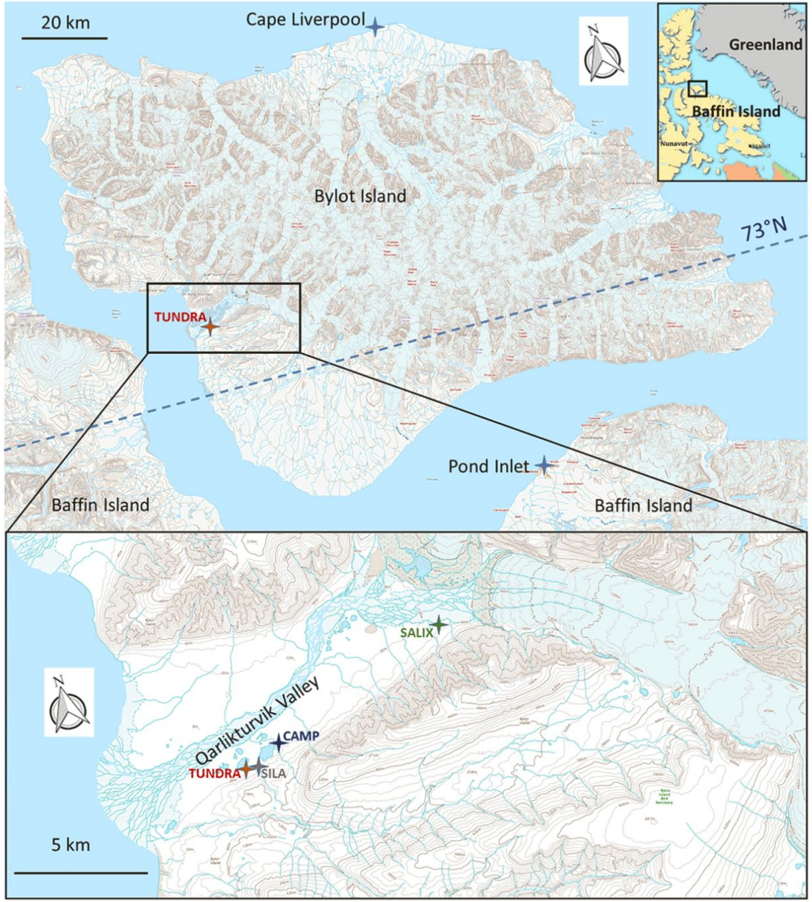
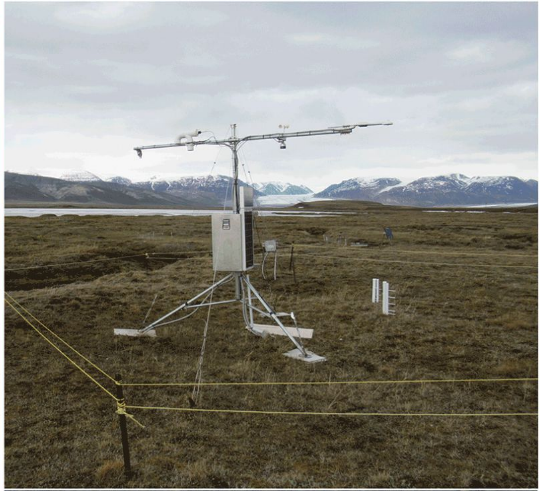
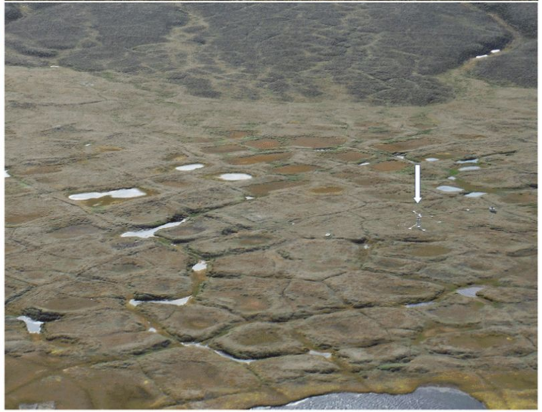
SnowMIP sites* + Arctic sites



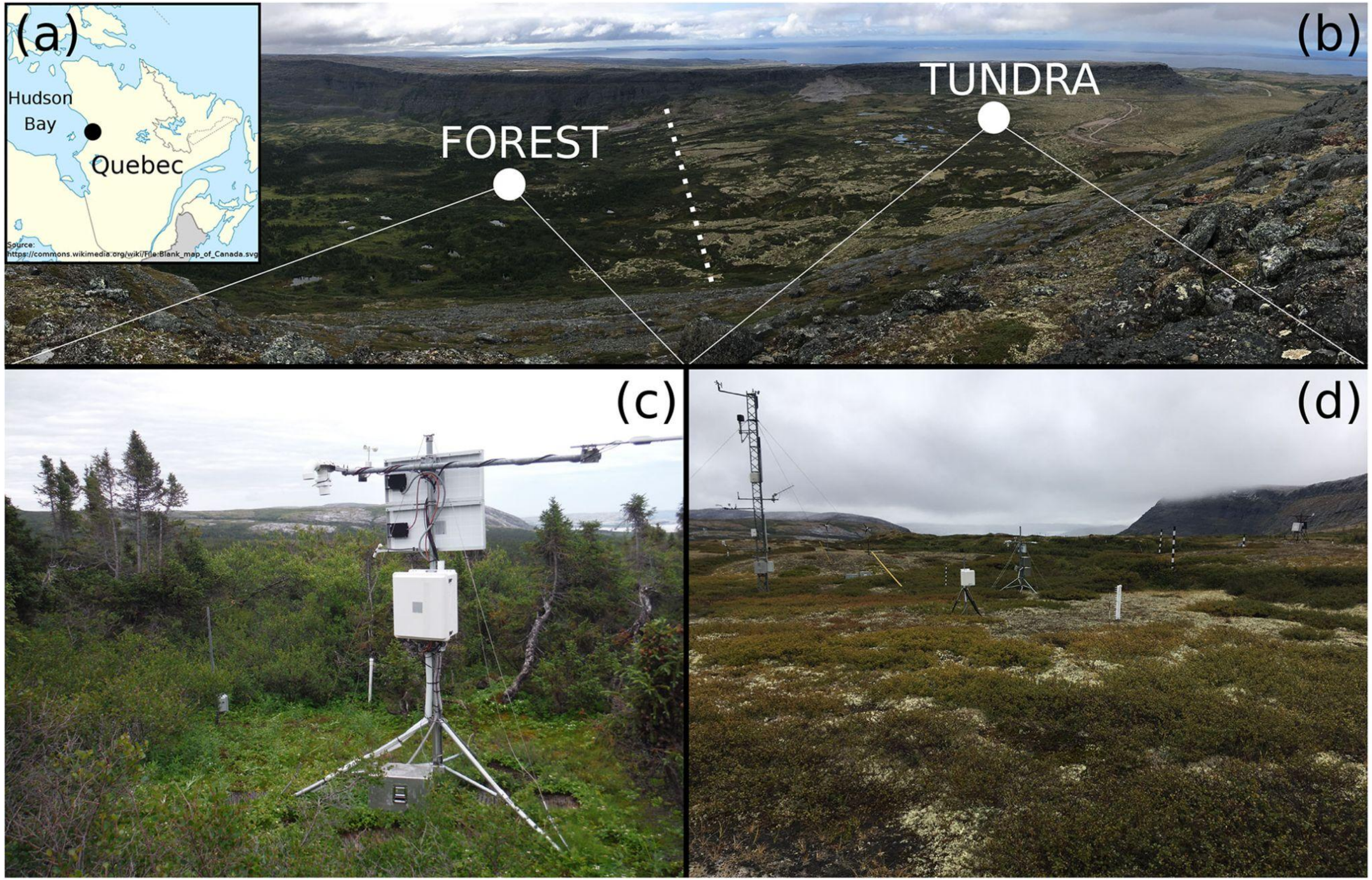
Bylot Island, Canada







Umiujaq TUNDRA + FOREST, Canada

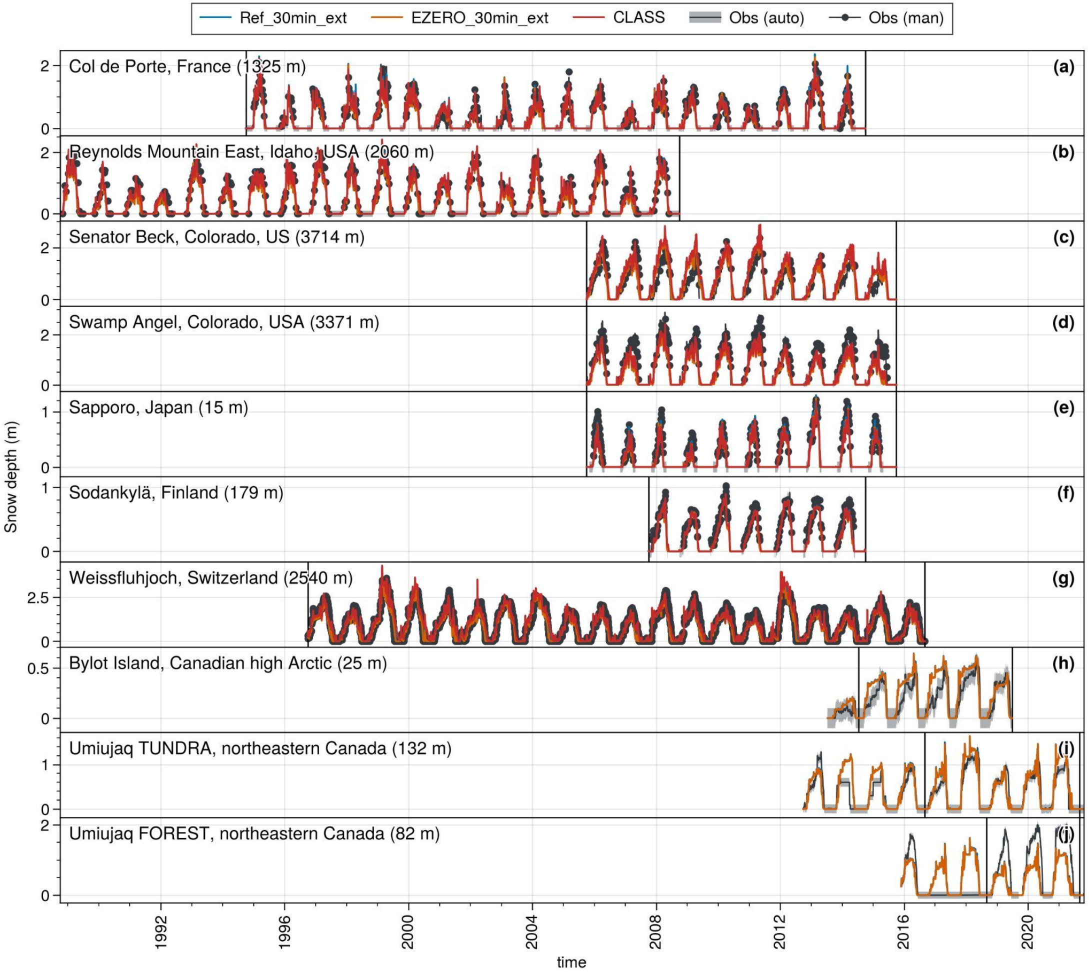


Model and simulation set up

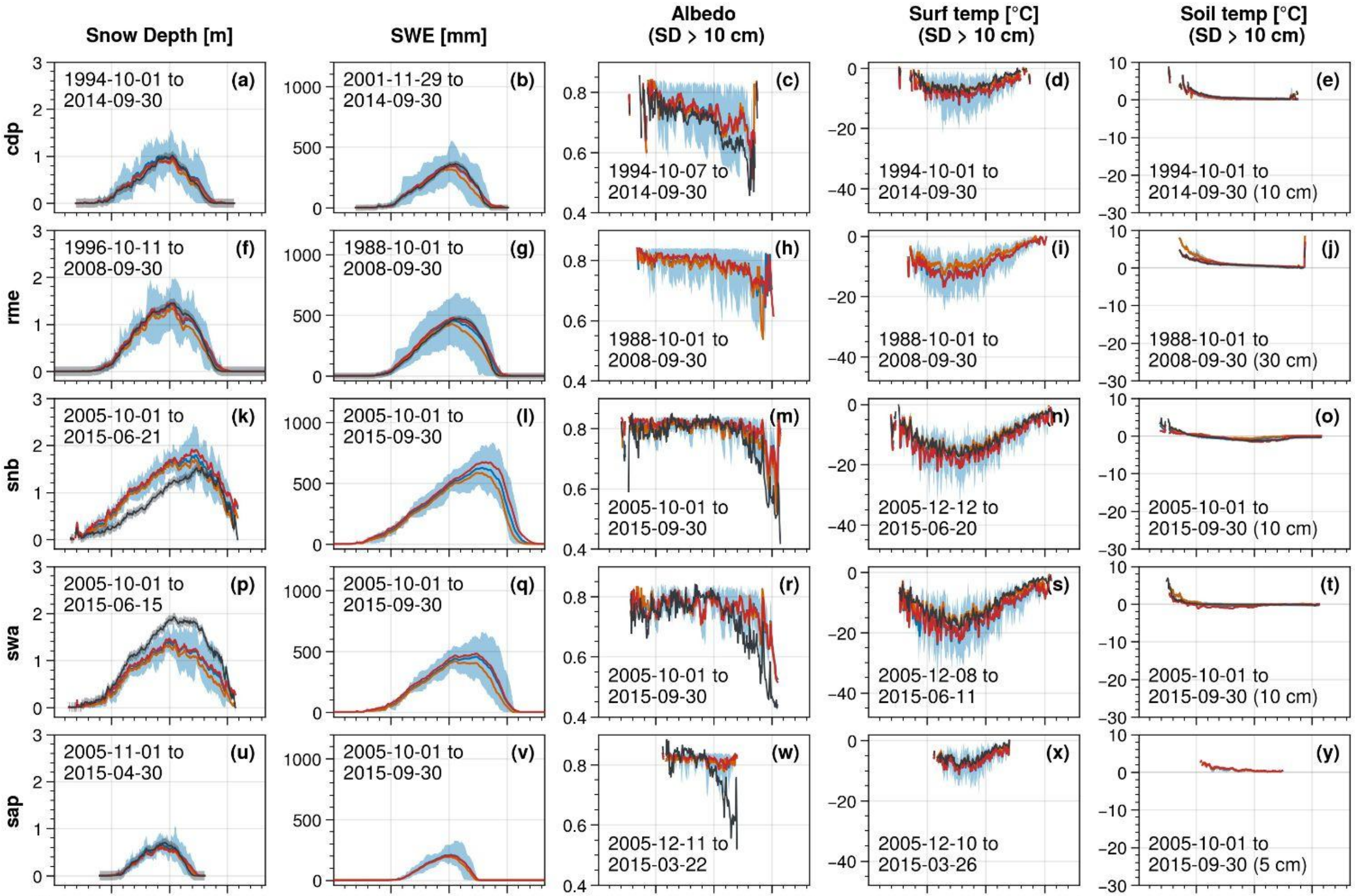
- CLASSIC v1.0 (Melton et al., 2020) including CLASS 3.6.2 (Verseghy et al., 2017) and CTEM 2.0 (Melton & Arora, 2016) + shrubs (Meyer et al., 2021)
- SnowMIP forcing and evaluation data (Menard et al., 2021) + Arctic (Domine et al., 2021, 2024) (linearly interpolated from hourly to 30 minute time step → see issue on GitLab)
- Soil properties: mix of site information + satellite data / PFTs site information (+ peat sometimes)
- Spin up: ~100 to 300 years with spinfast = 10 (cycle over the forcing with CO_2 fixed) + last cycle with spinfast = 1 (10-years averaged NEP/NPP and NBP close to 0; cSoil stable)

- 1D simulations:
    - *Ref*: latest developing model version
    - *EZERO*: same as *Ref* but with a windless exchange coefficient activated in the calculation of the sensible heat fluxes for stable atmospheric conditions over snow (Brown et al., 2006)
    - *CLASS*: older model version that was used in the latest SnowMIP experiments (Krinner et al., 2018) using CLASS v3.6 not coupled to CTEM (produced by Paul Bartlett)

Snow depth time series



Annual cycles



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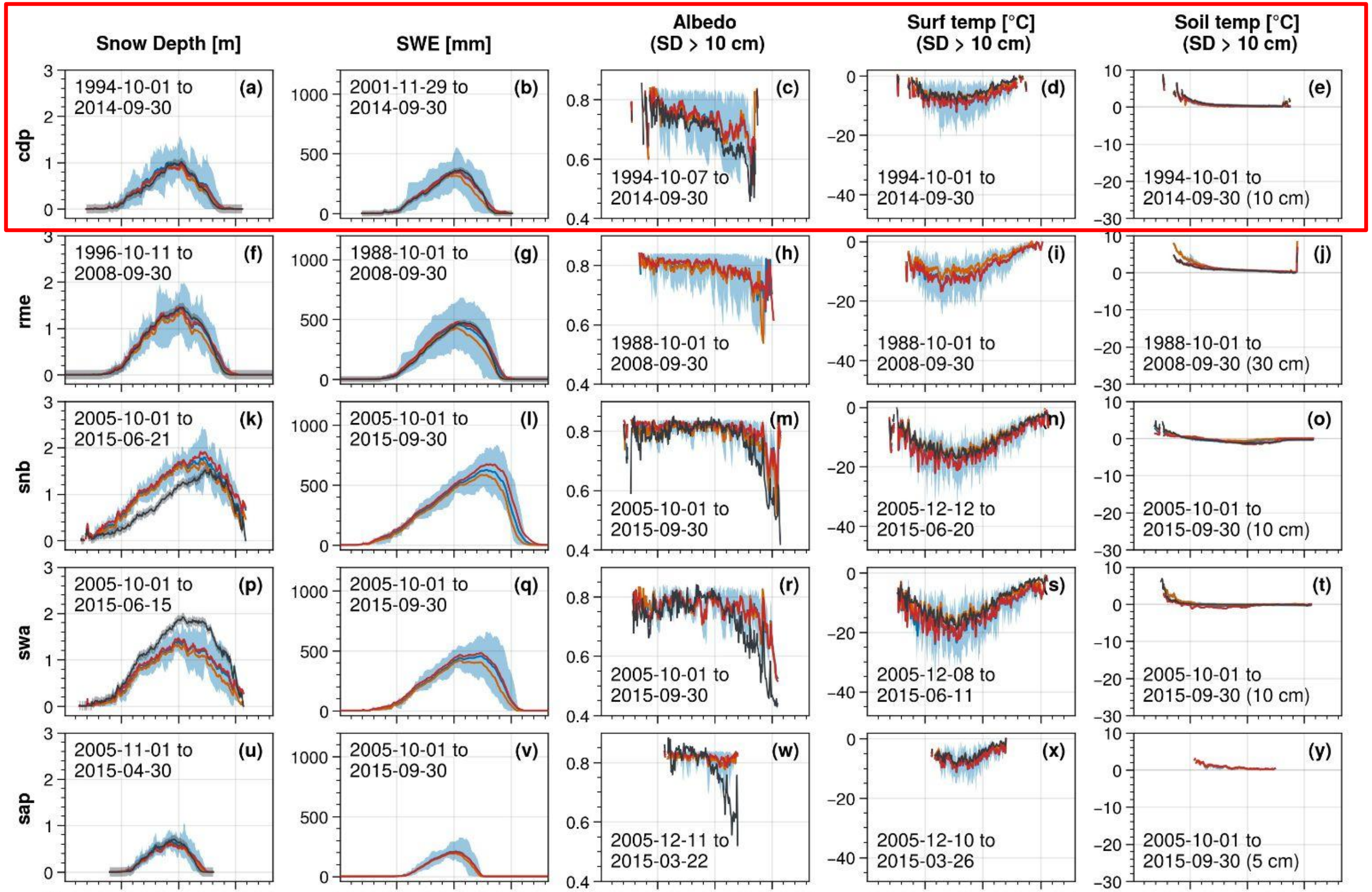

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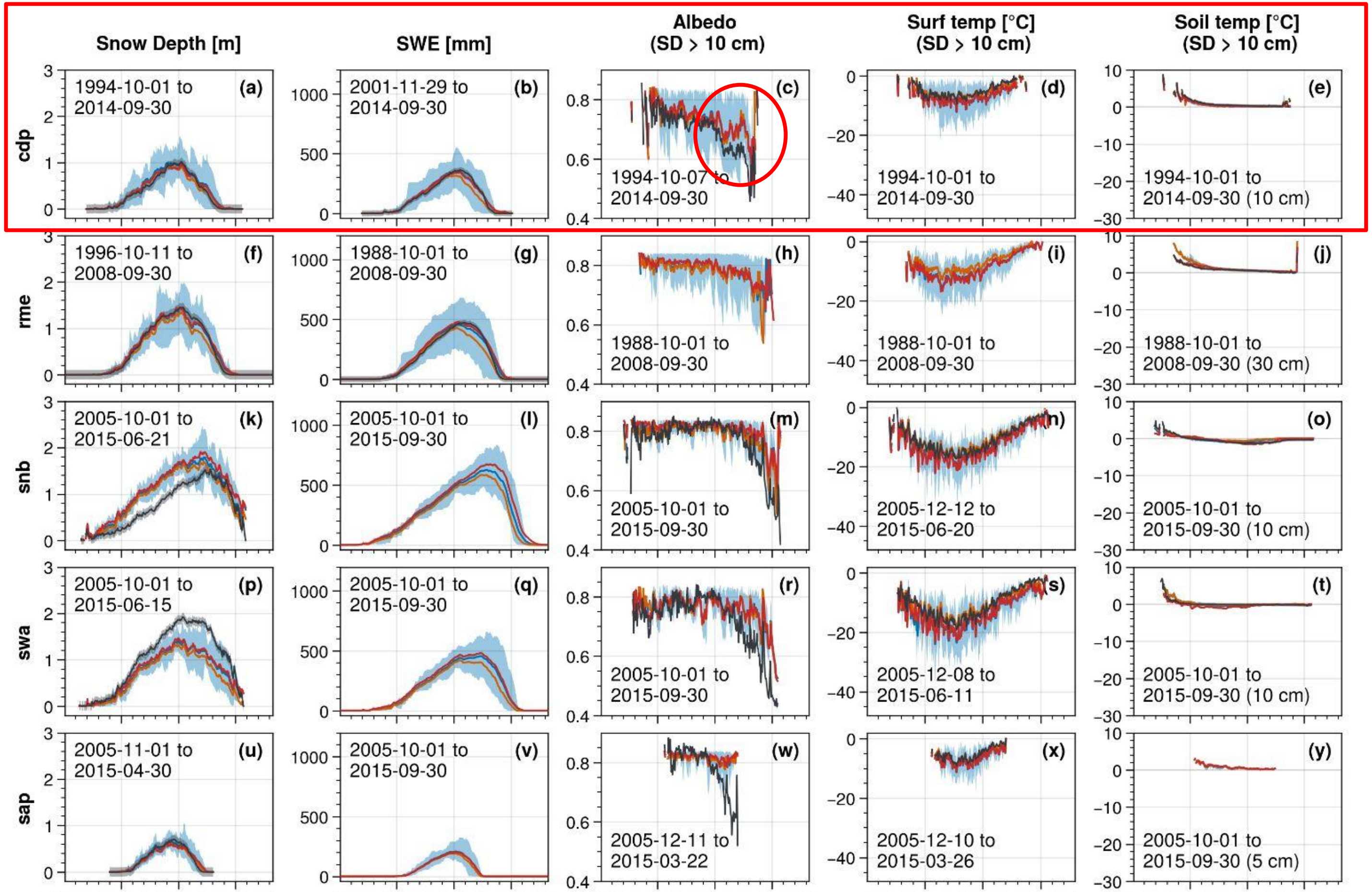

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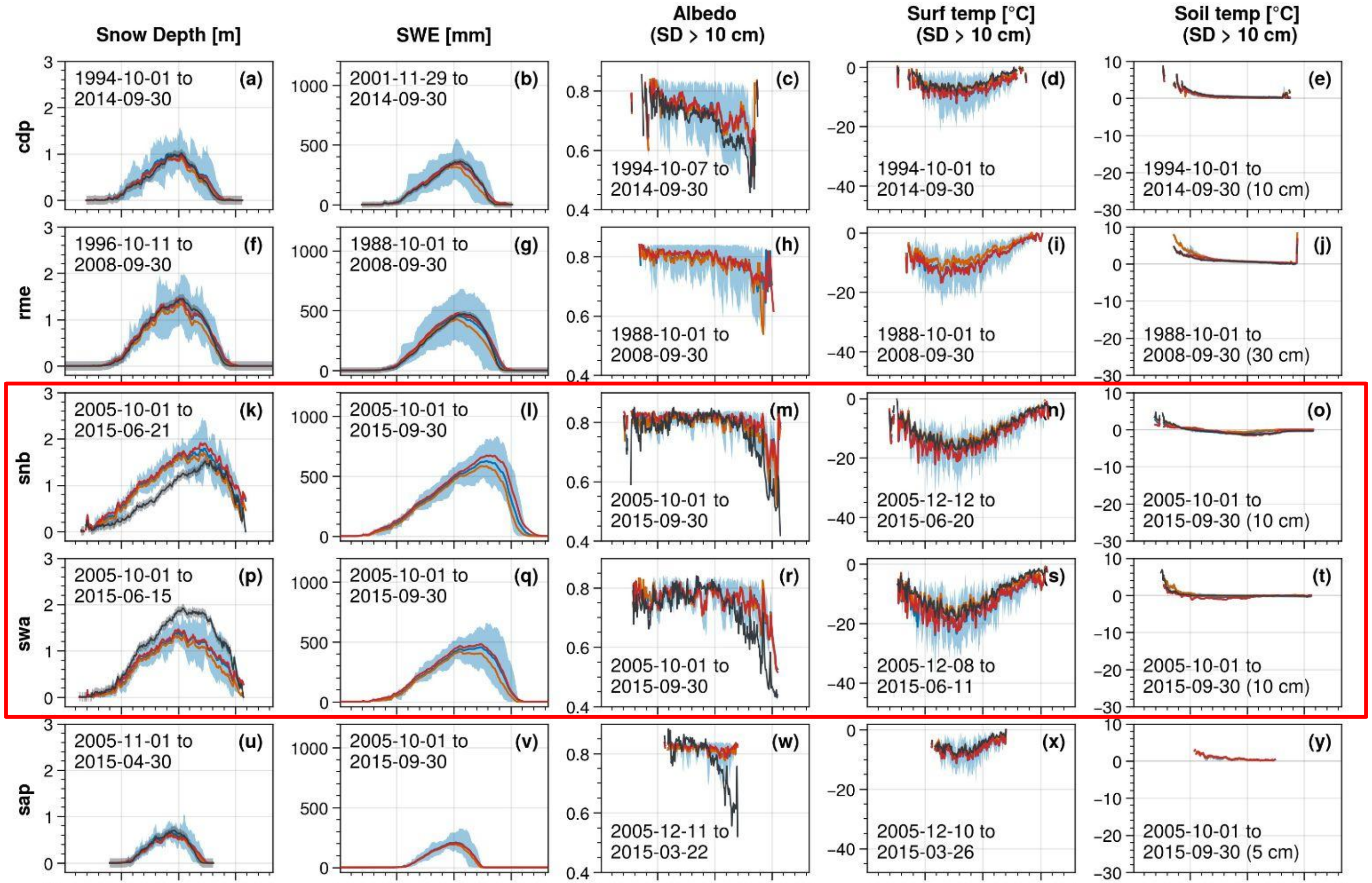

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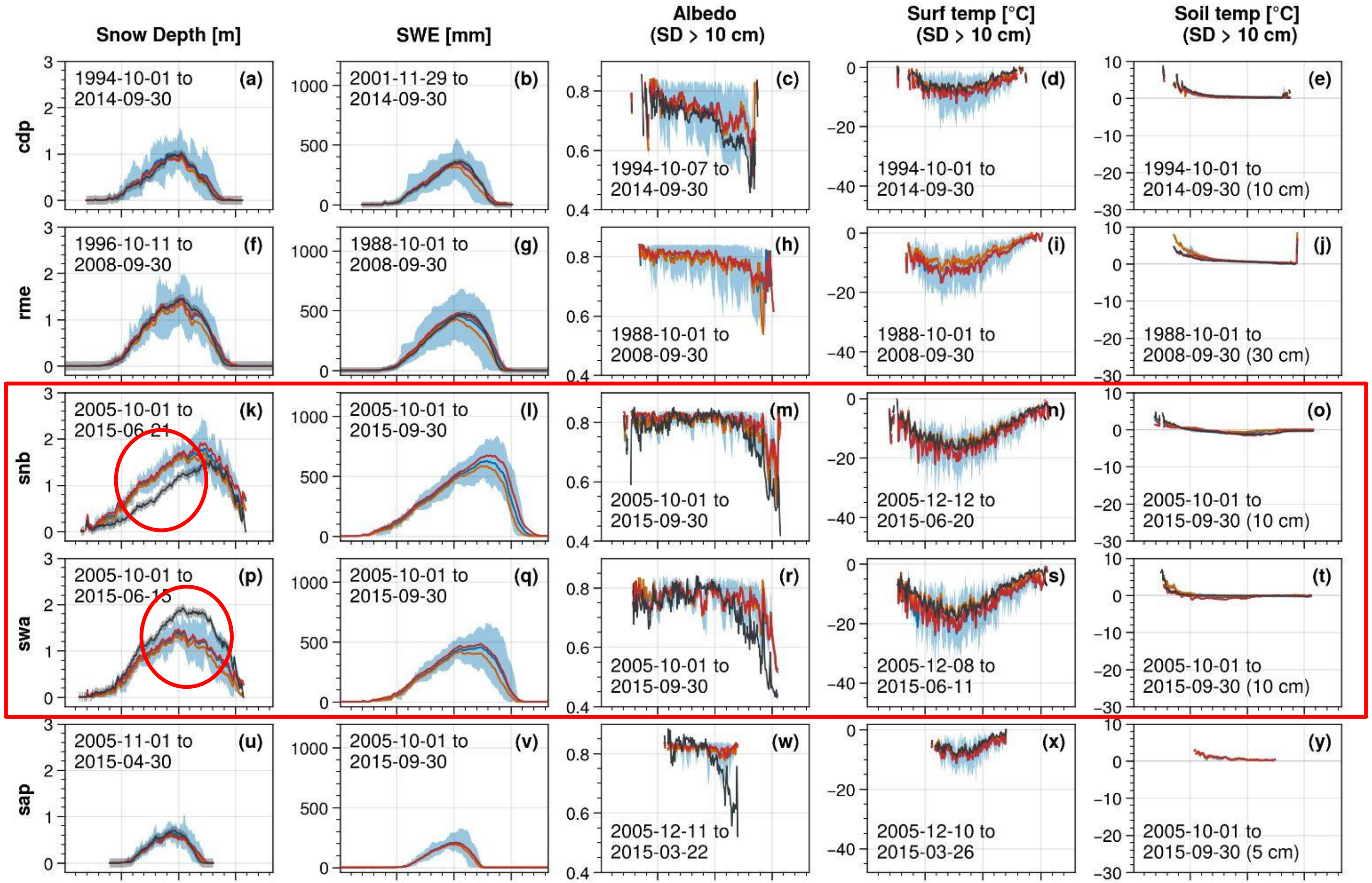

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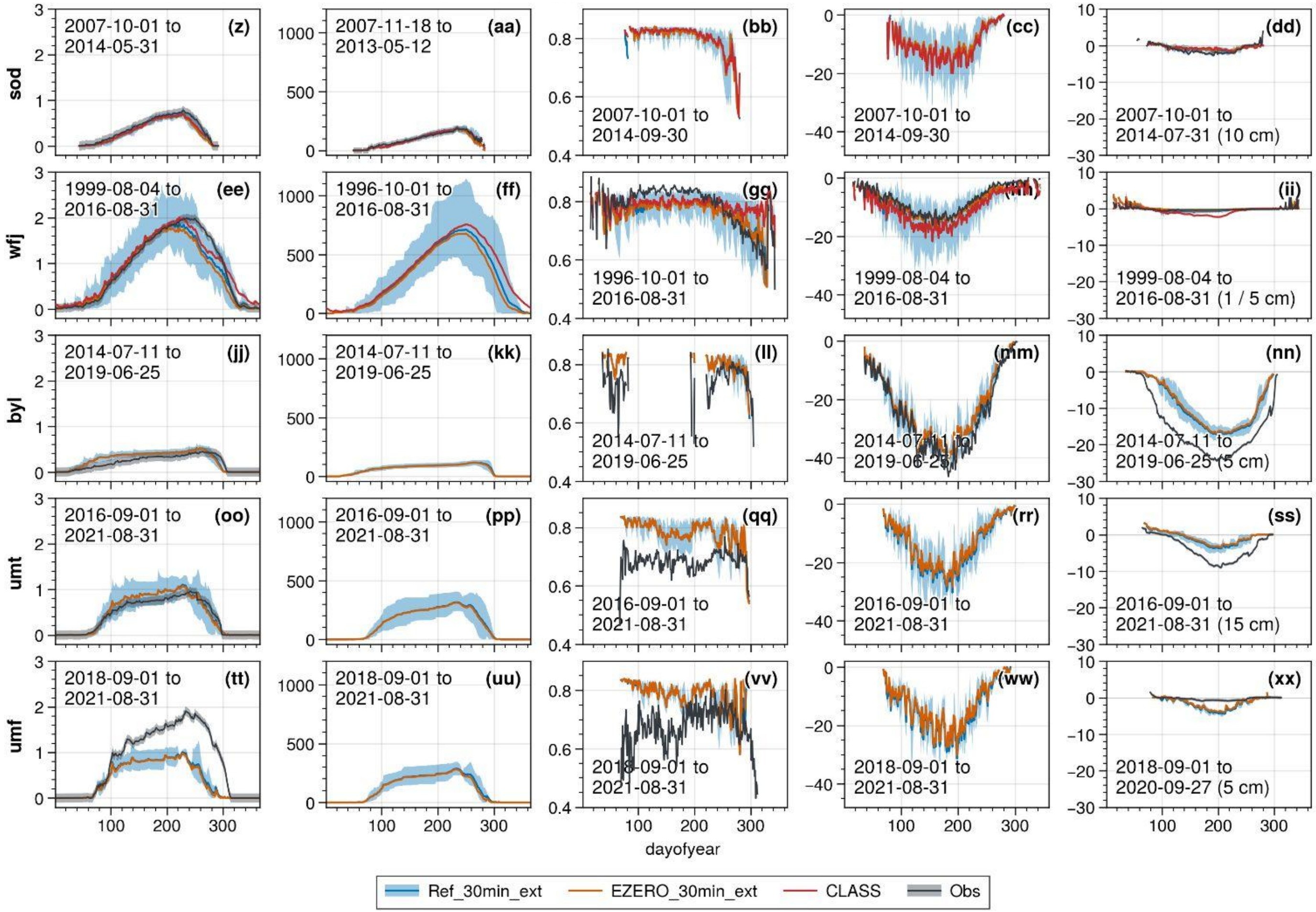

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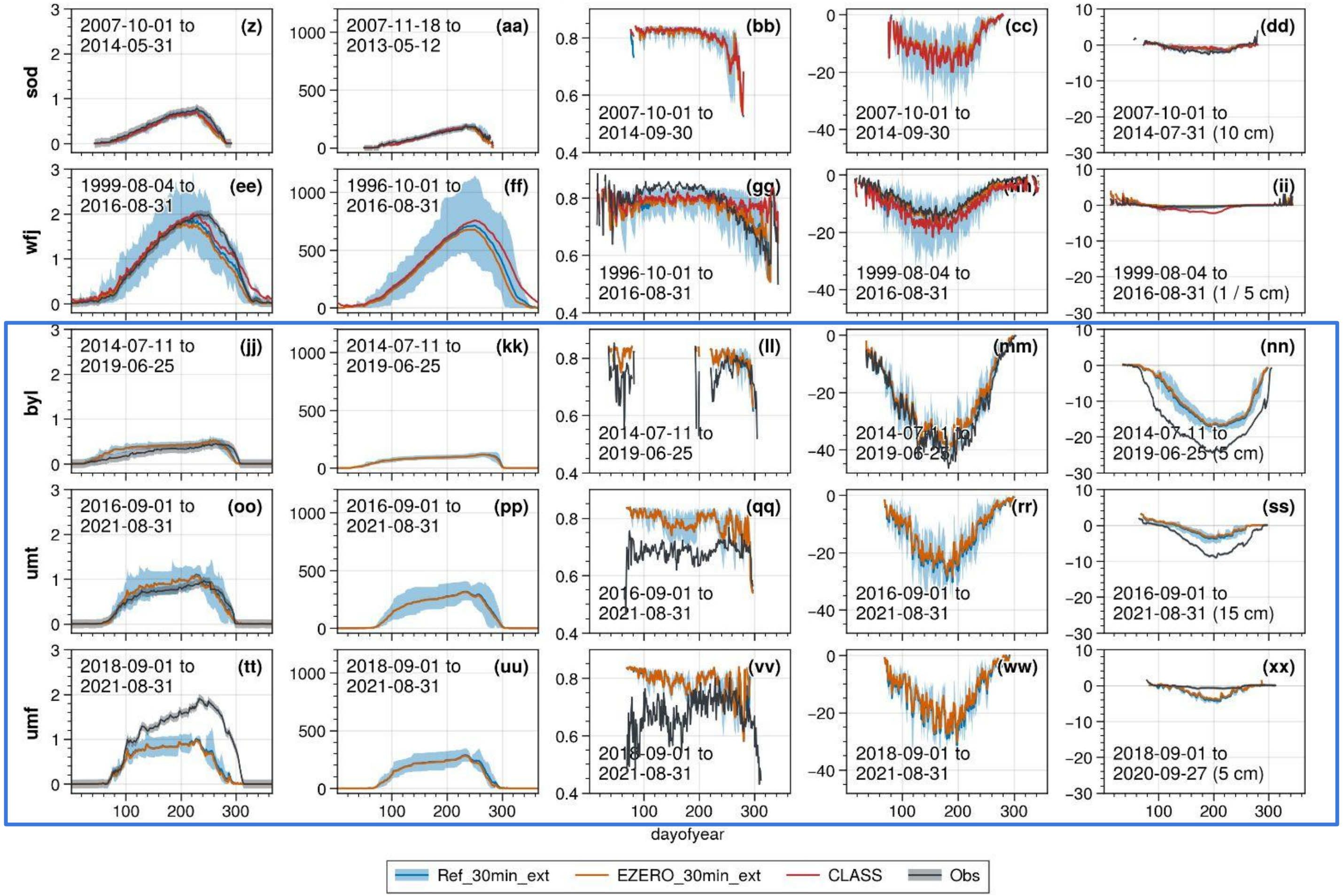

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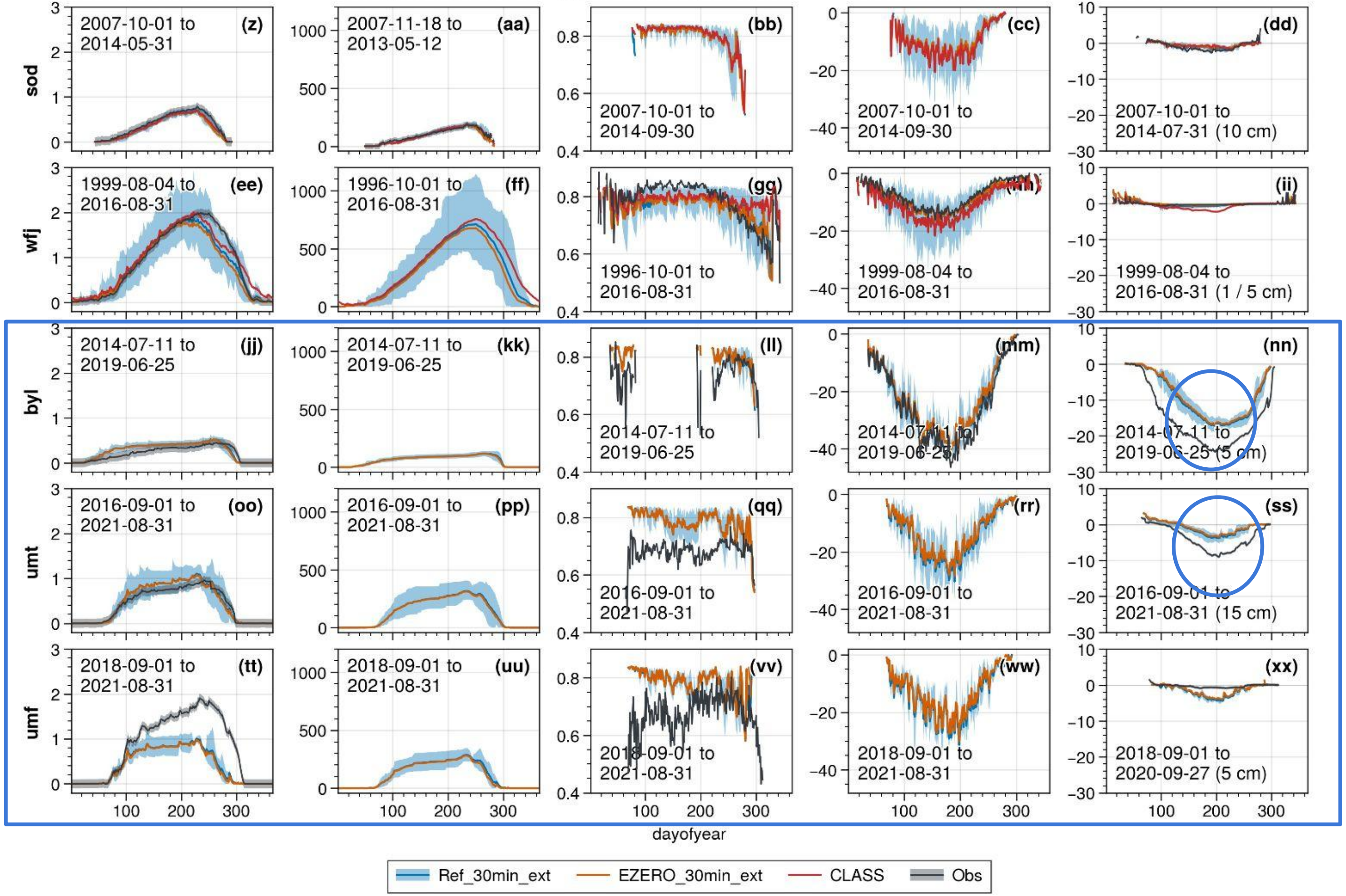
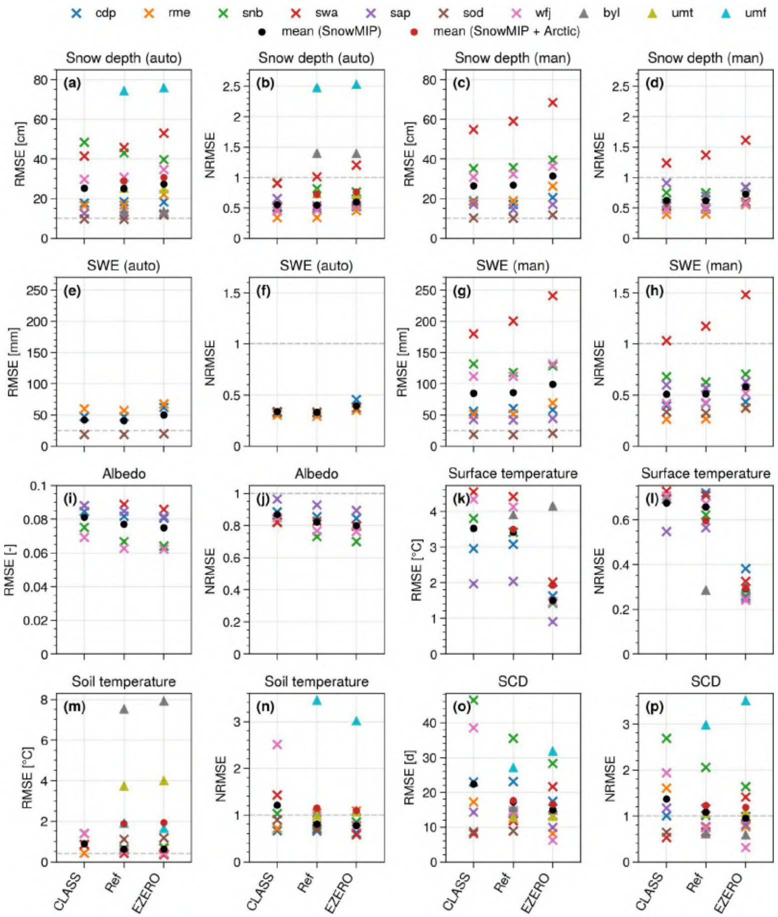
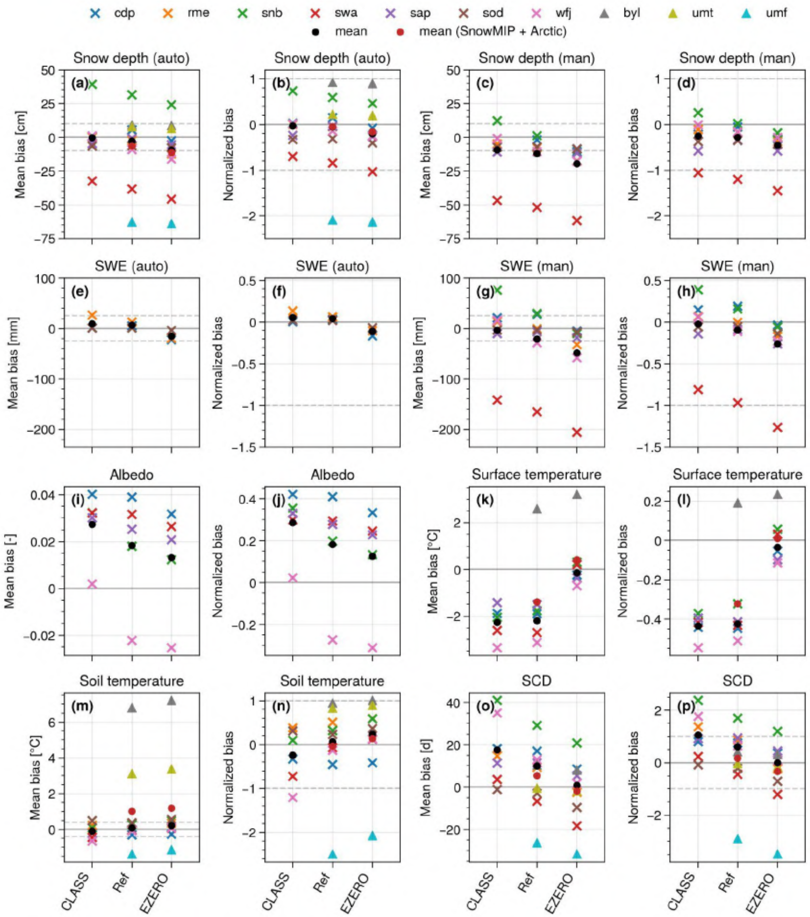


Metrics (SD > 10 cm)





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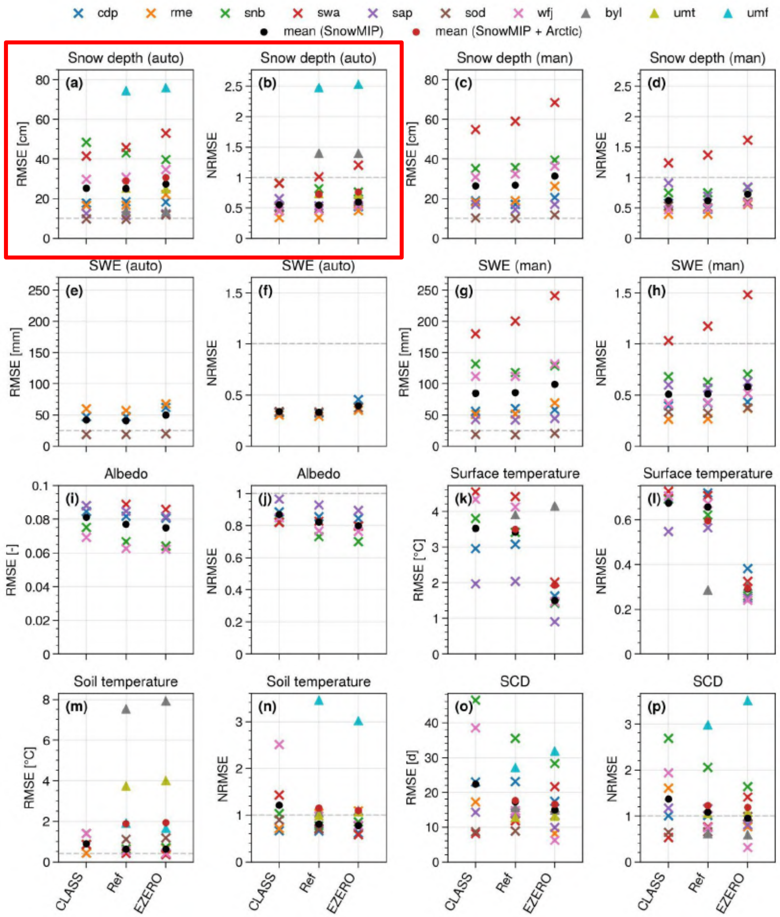

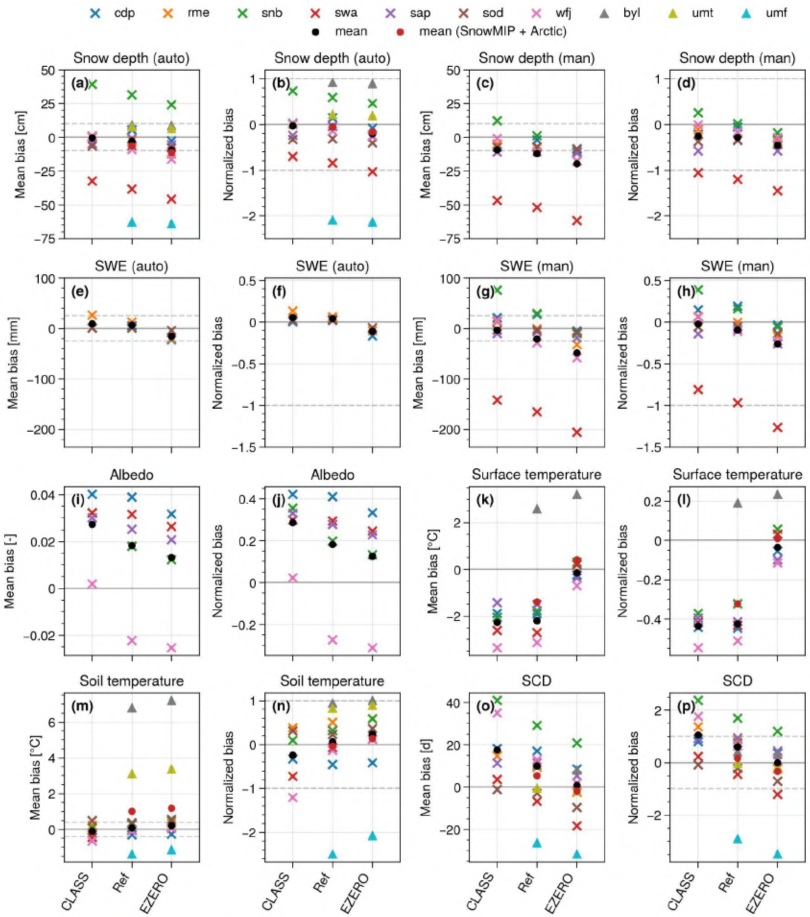

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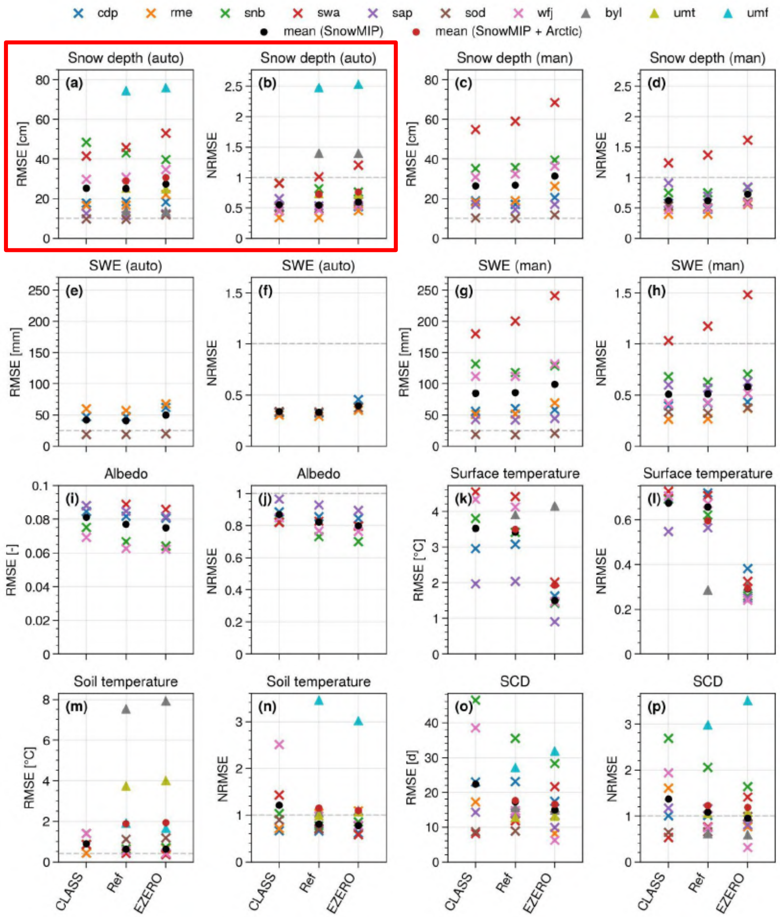

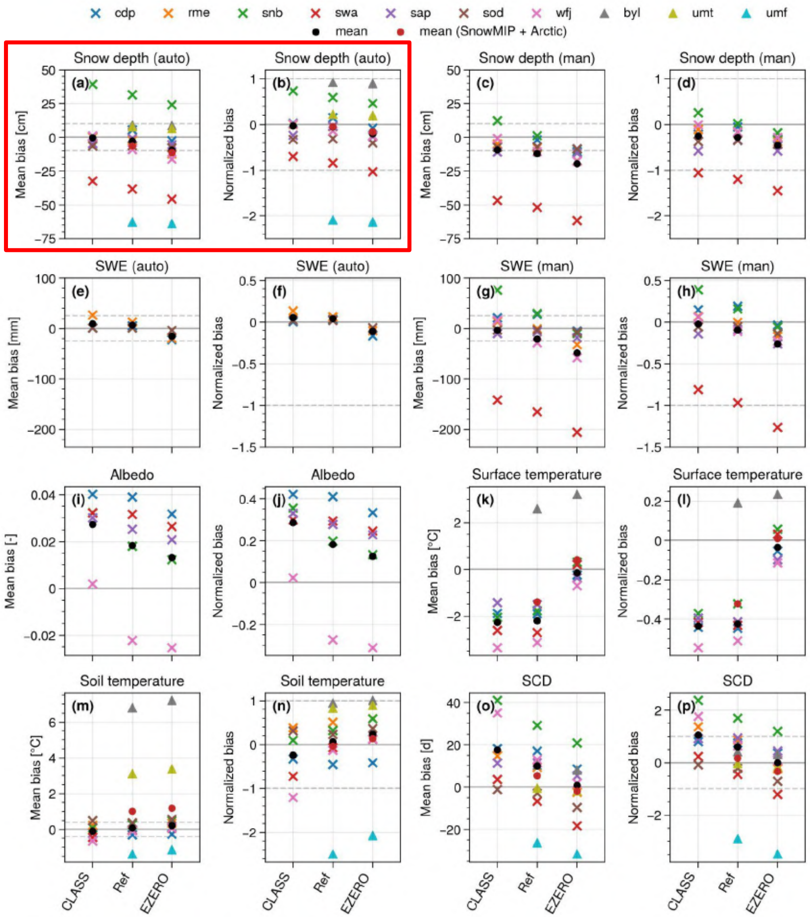

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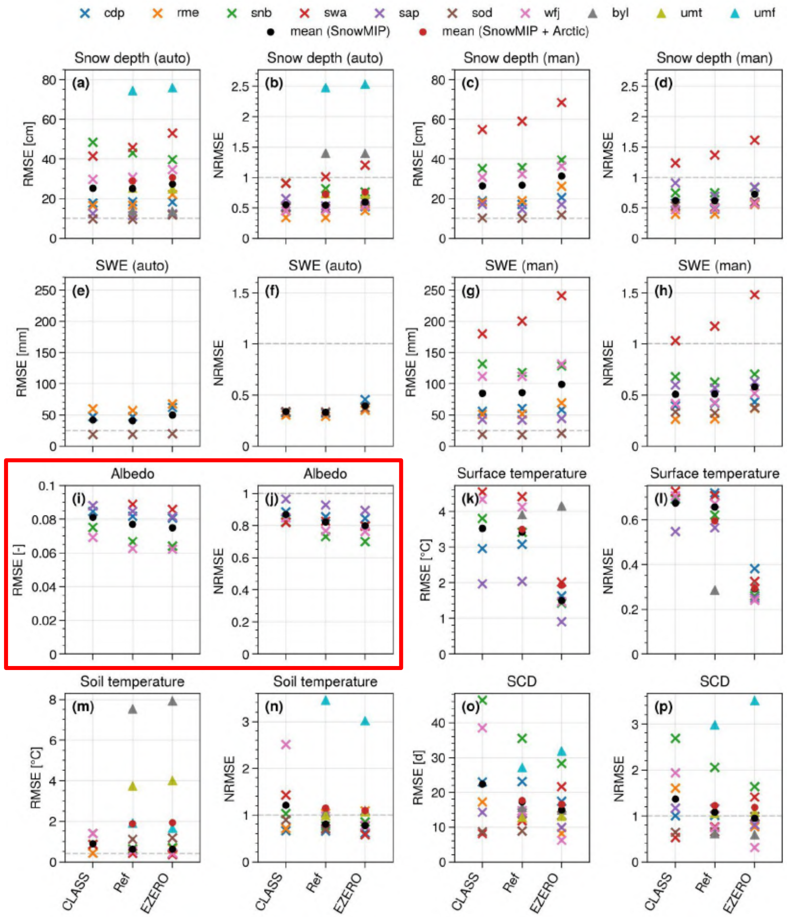

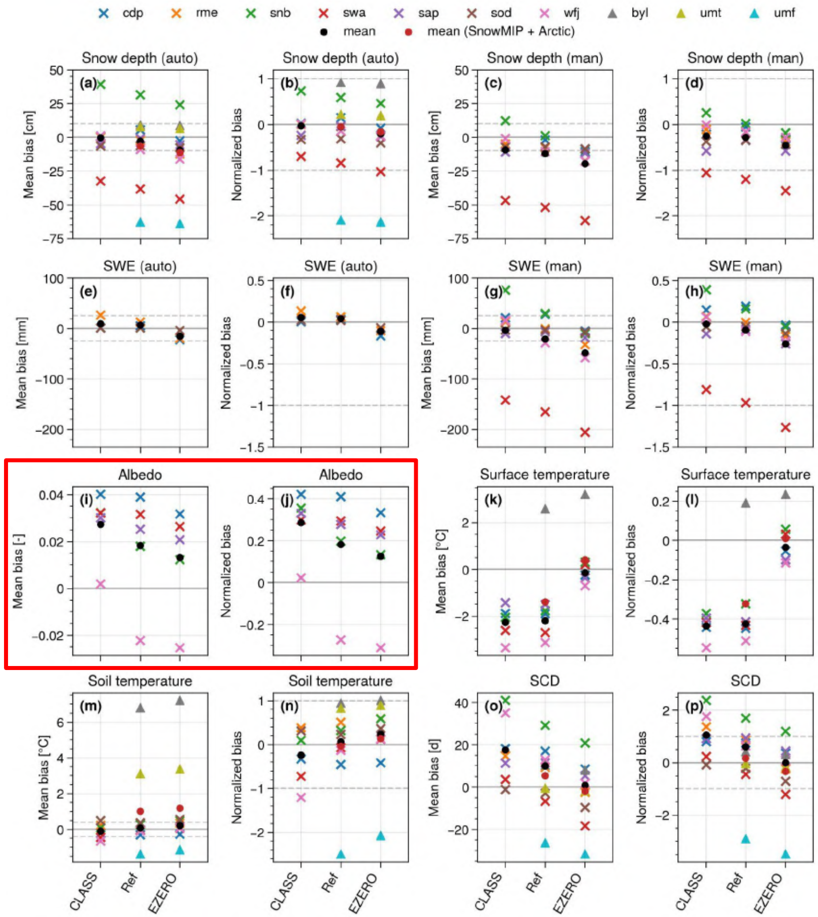

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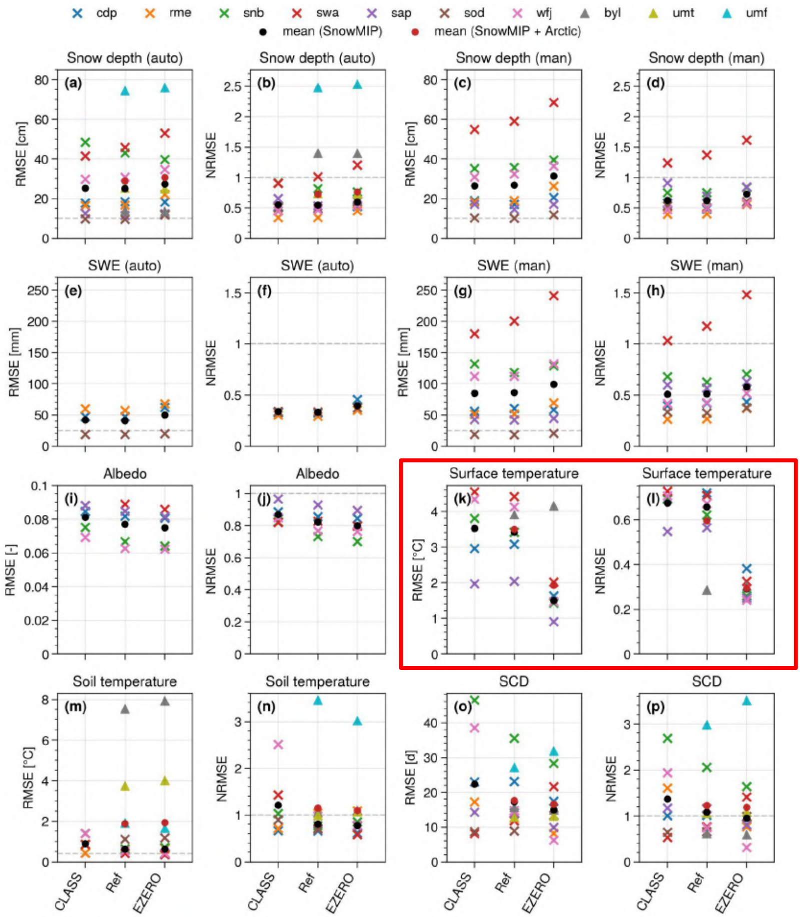

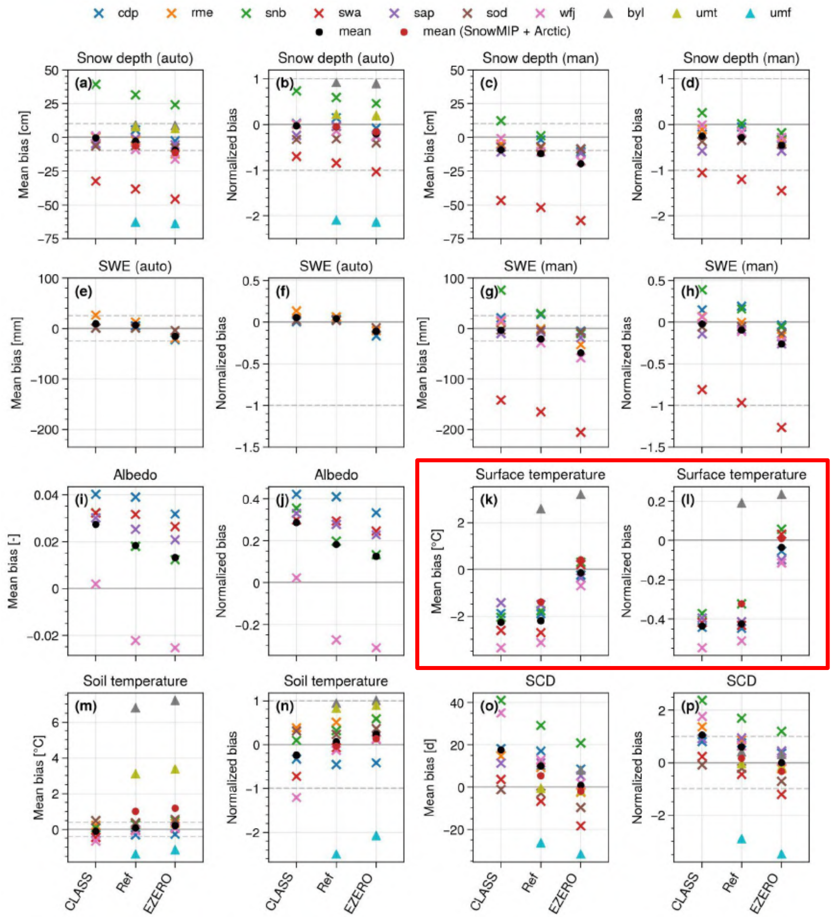

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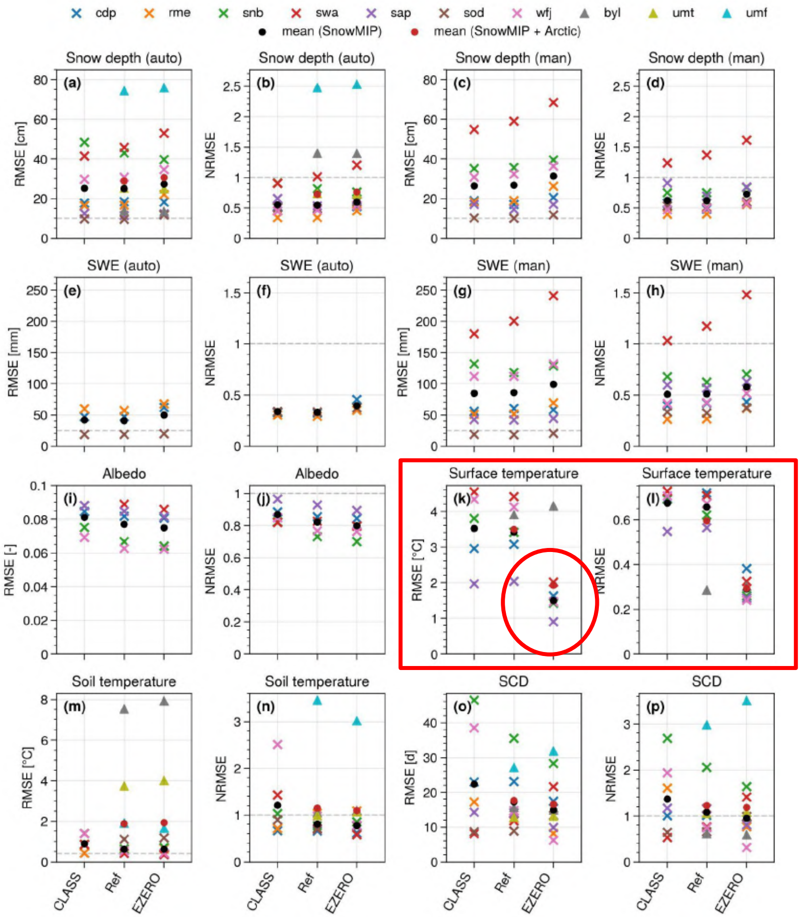

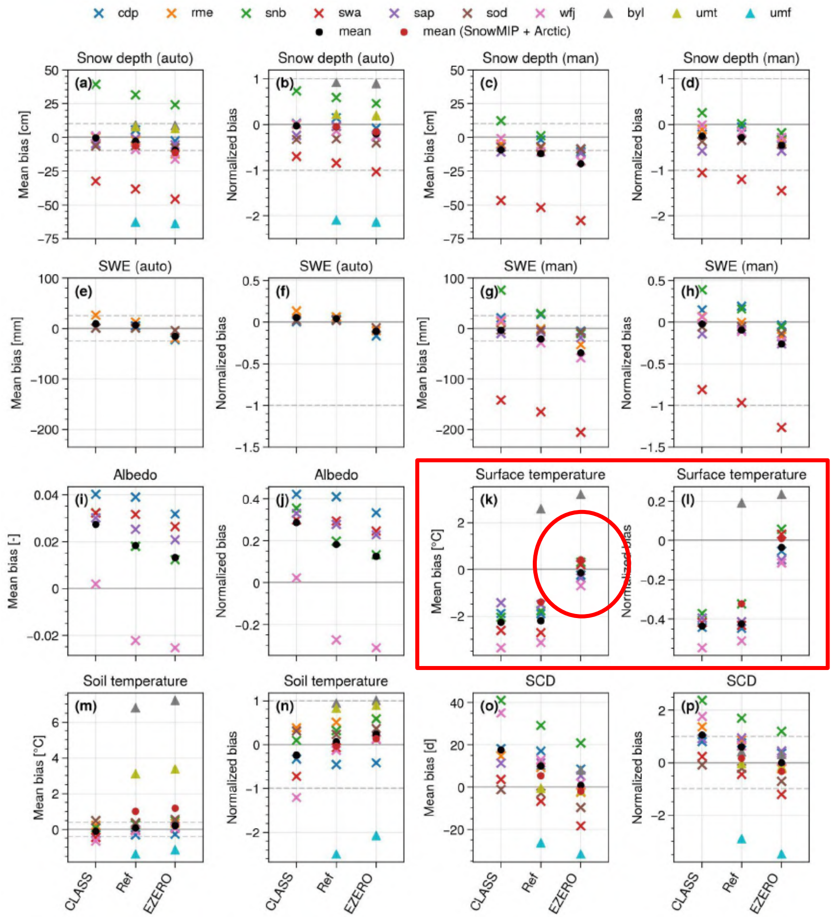

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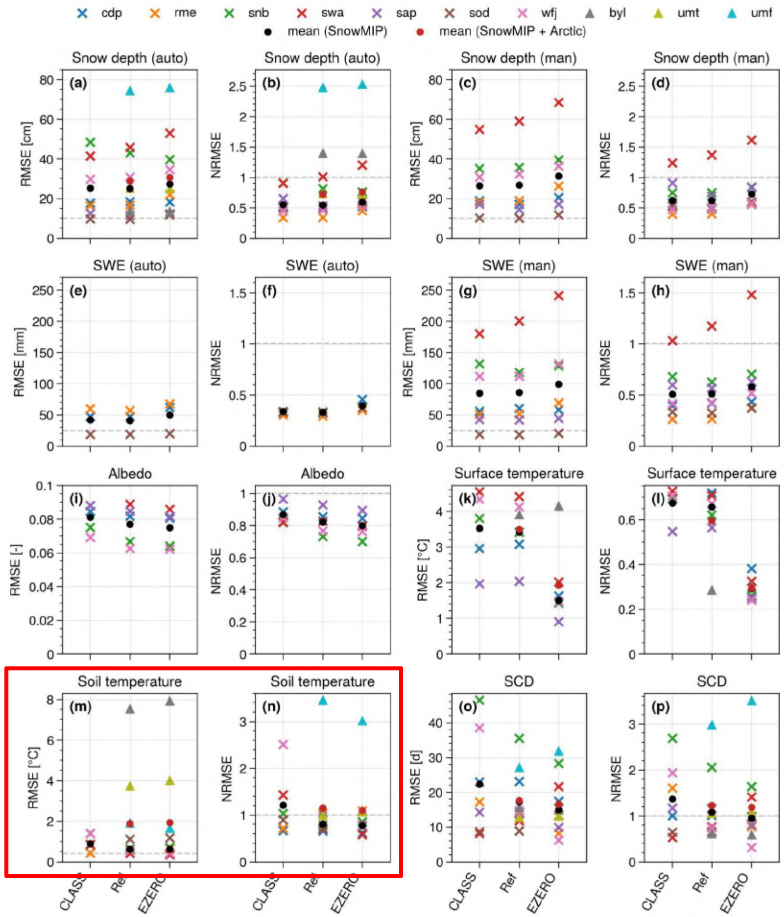

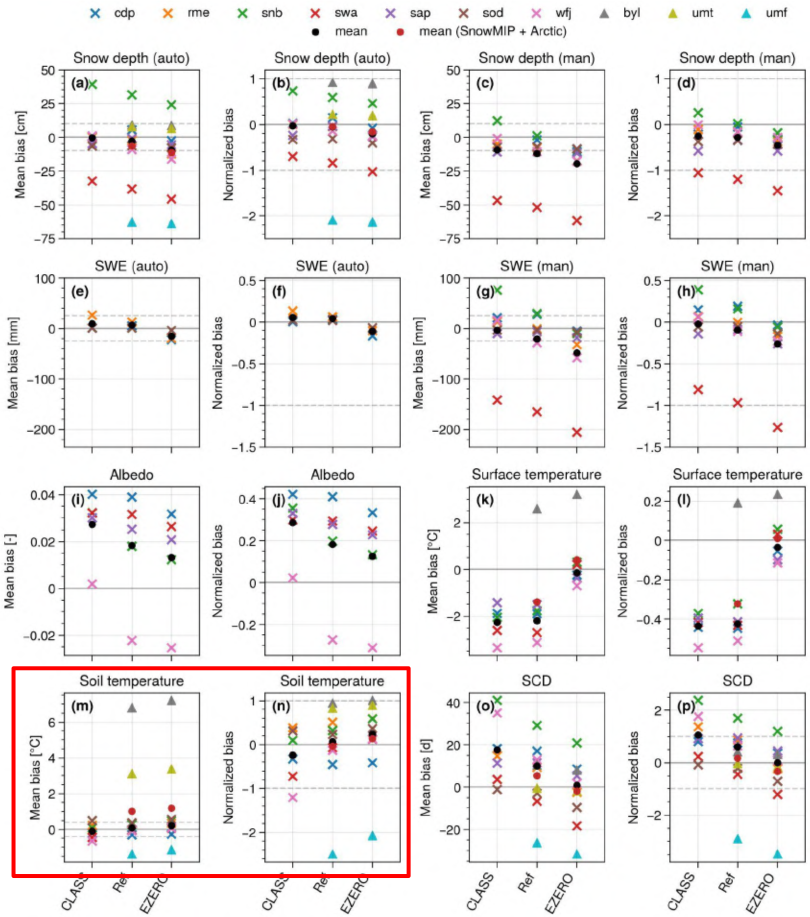

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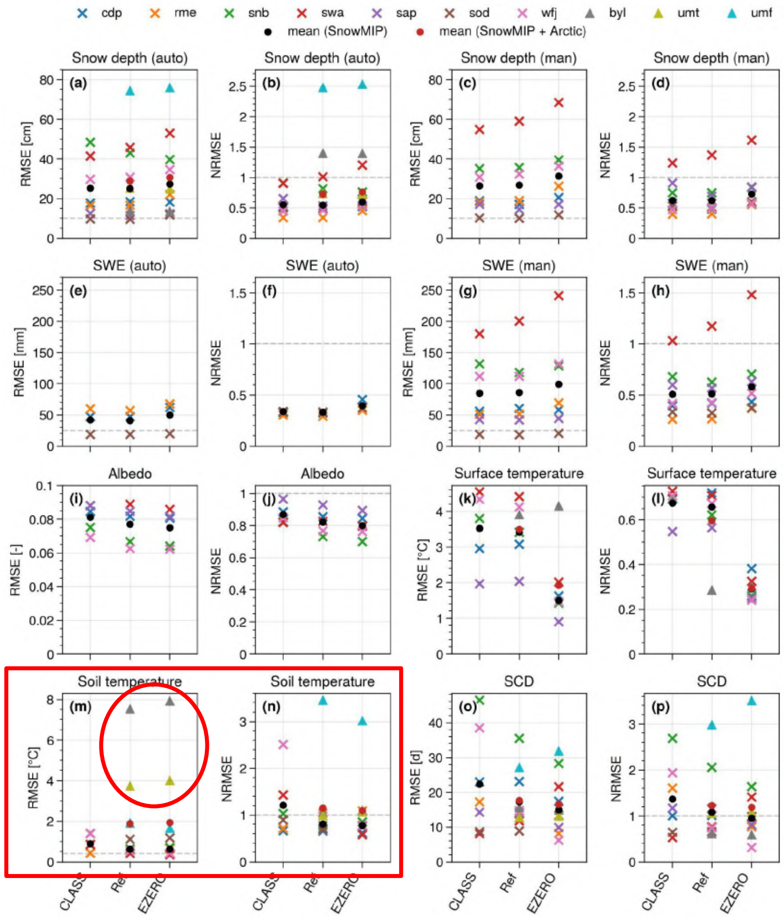

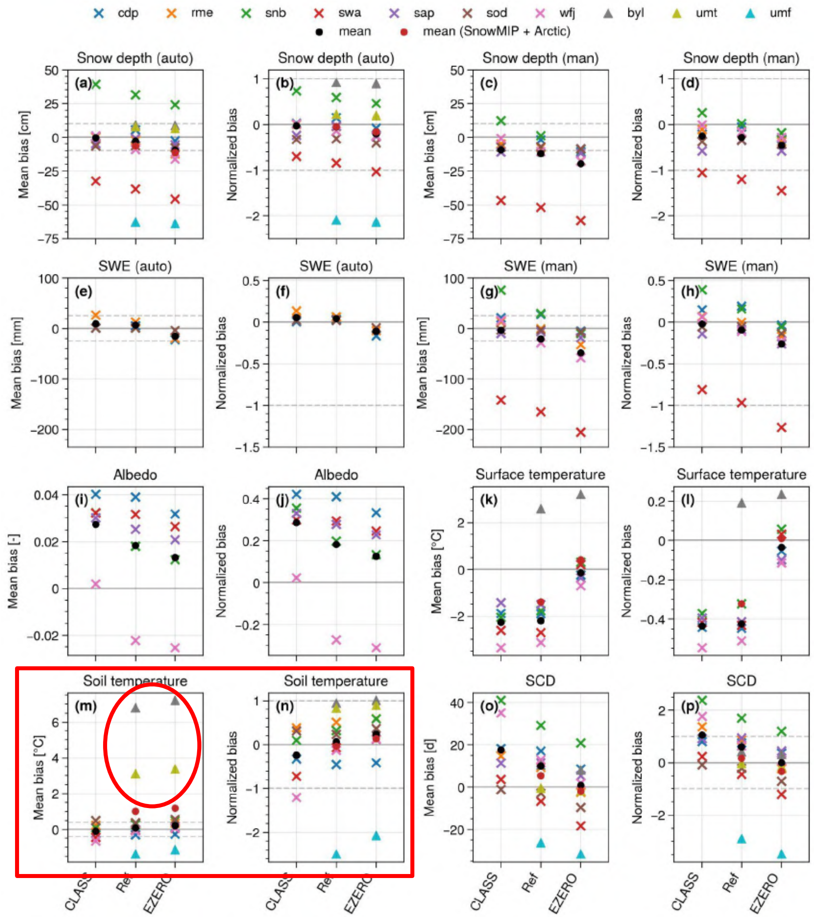

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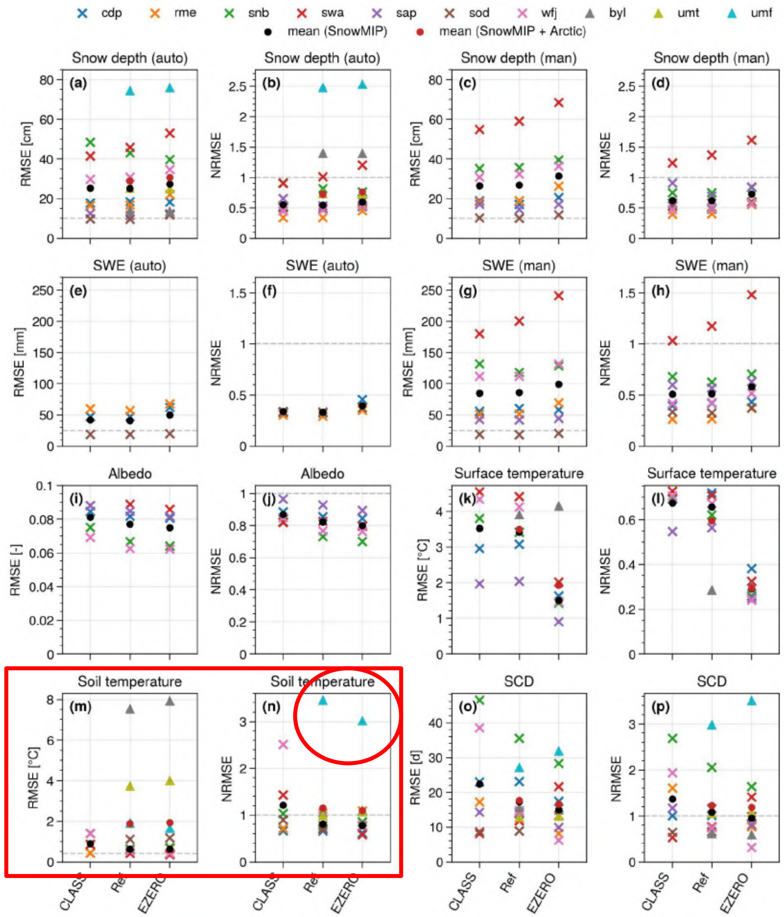

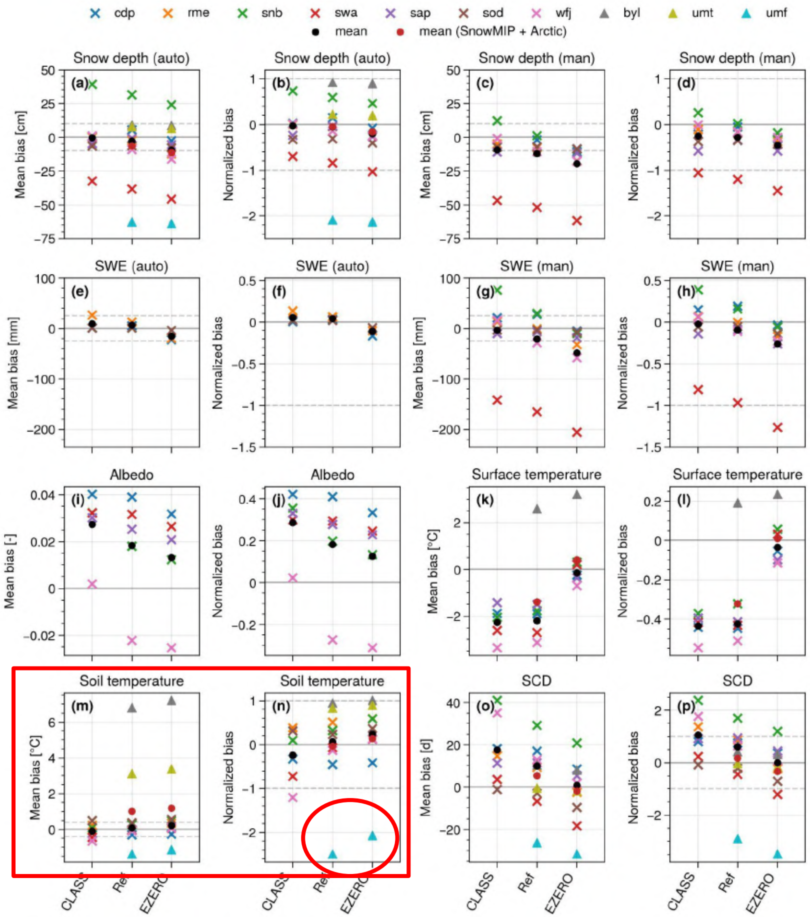

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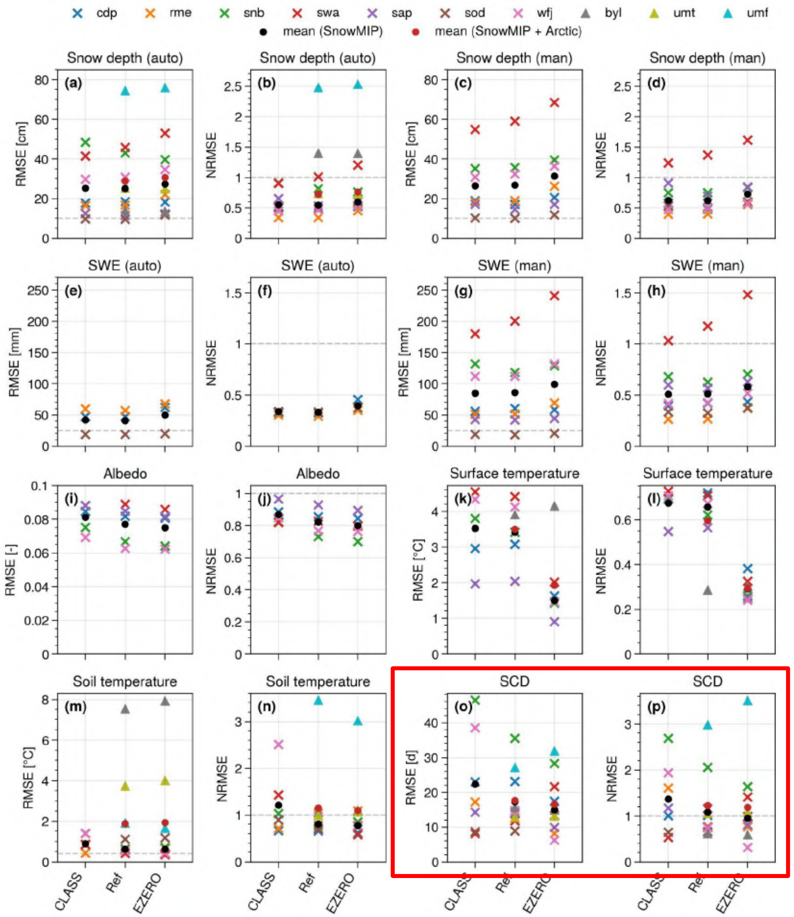
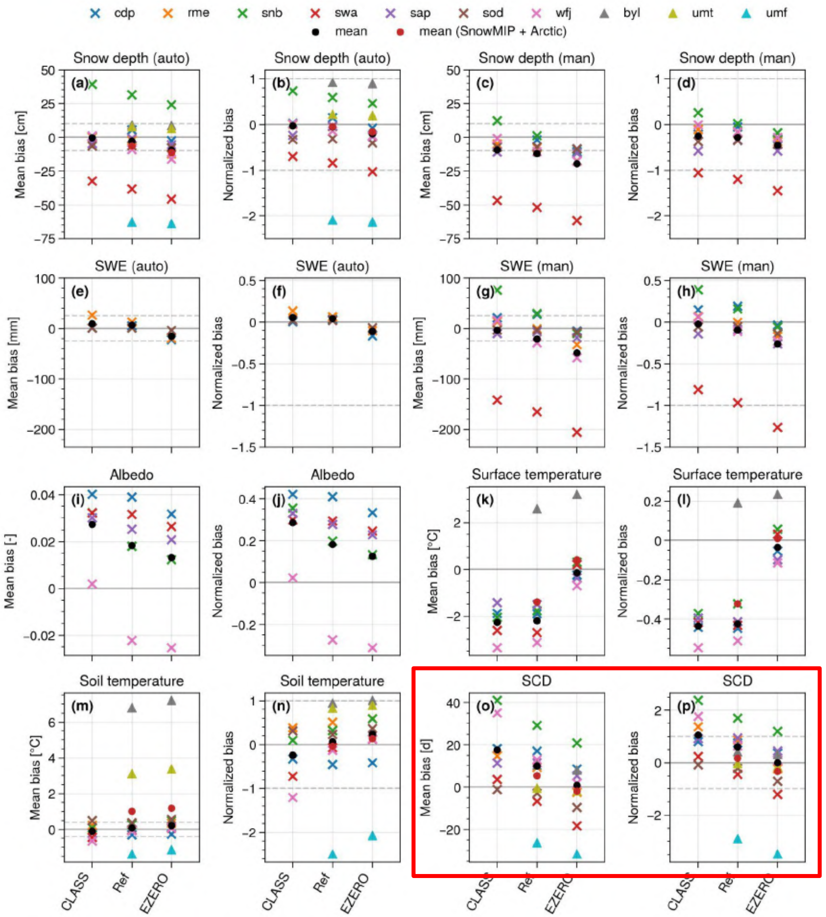




Main results

- CLASS v3.6 → CLASSIC v1.0 overall slight improvement (albedo, surface/soil temperatures, SCD)
- *EZERO* improves significantly the simulated surface temperature (but slight deterioration for SD/SWE)
- Large snow depth biases at Senator Beck, Swamp Angel, and Umiujac FOREST
    - issues with wind-driven snow redistribution (possible solution, e.g., Lackner et al., 2022 → correct precipitation rates during high wind-speed events)
    - e.g. Lackner et al. (2022) made 172 measurements of the snow height within a 100 m radius of Umiujaq TUNDRA on 12 April 2018 and observed heights varying between 50 and 210 cm
    - blowing snow sublimation losses? (Gordon et al., 2006)
- Large soil temperature biases at Arctic sites
    - non-consideration of Arctic snowpack characteristics? (e.g., Gouttevin et al., 2018; Royer et al., 2021)
    - other issues?
- Further investigation needed → snow profiles (density, thermal conduction, temperature, etc.) at several sites (e.g., Col de Porte and Arctic sites) + CO_2 at Umiujac (+ add TVC?)

Model development work

- Planned improvements (1D):
  - multilayer snowpack 3 to 12 layers? (e.g., Boone & Etchevers, 2001; Wang et al., 2013; Decharme et al., 2016)
  - Arctic snowpack adaptations → increasing wind-induced surface snow compaction to simulate the wind slab and reducing the density of lower layers through the vegetation height to approximate the depth hoar formation (e.g., Barrere et al., 2017; Gouttevin et al., 2018; Royer et al., 2021; Lackner et al., 2022)
  - blowing snow sublimation losses (Gordon et al., 2006)

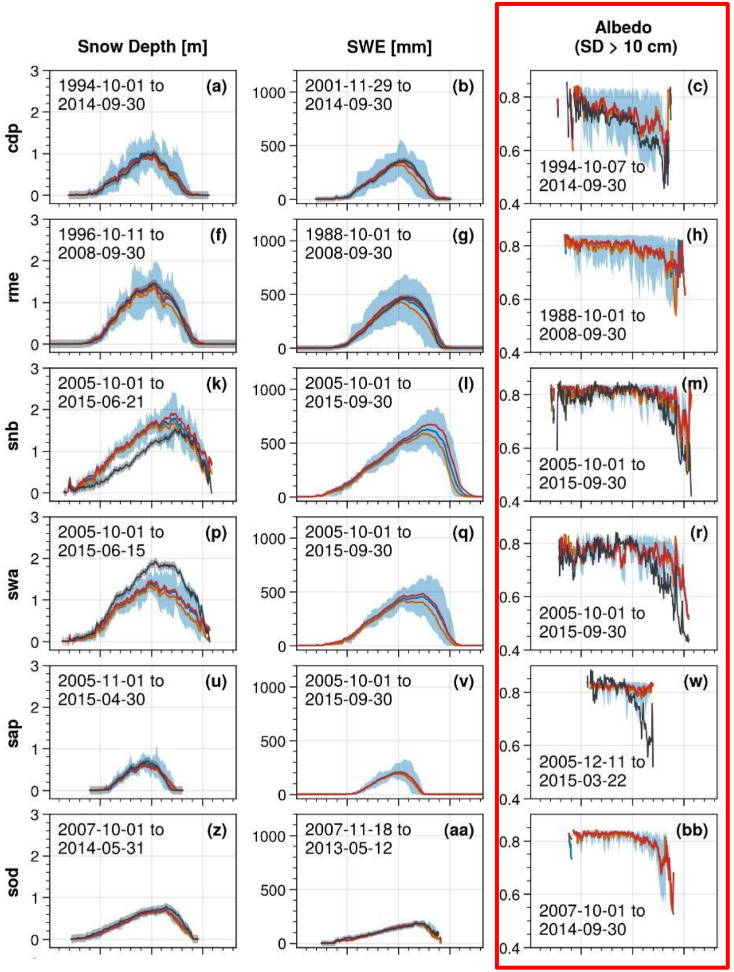
- After this first study (spatial):
  - + new snow cover fraction parameterizations (e.g., Roesch et al., 2001; Liston, 2004; Niu & Yang, 2007; Swenson & Lawrence, 2012; Lalande et al., 2023)

/!\ vertical energy and water fluxes are modeled separately in CLASSIC for four subareas in each grid cell: vegetated, bare soil, vegetated with snow cover, and bare soil with snow cover /!\

Model development work

- Current CLASSIC v1.0 snow model (Verseghy et al., 2017):
  - single layer with fitted quadratic temperature curve (first-order way of accounting for the characteristic sharp near-surface temperature gradient in snow packs)
  - snow albedo / snow density → exponential empirical functions (Tabler et al., 1990; Brown et al., 2006)
  - fresh snow density → function of the air temperature (Pomeroy & Gray, 1995)
  - snow thermal conductivity (Sturm et al., 1997)
  - takes into account melting, infiltration, and refreezing (Bruce & Clark, 1966)
  - interception of snowfall by vegetation is explicitly modeled (depending on the LAI) (Hedstrom & Pomeroy, 1998; Bartlett et al., 2006; Bartlett & Verseghy, 2015).
  - snow cover is assumed to be complete if the diagnosed snow depth is equal to or greater than a threshold value of 0.10 m; if it is less, the snow depth is set to this threshold value, and the fractional snow cover is determined based on the conservation of snow mass.

Discussion: albedo



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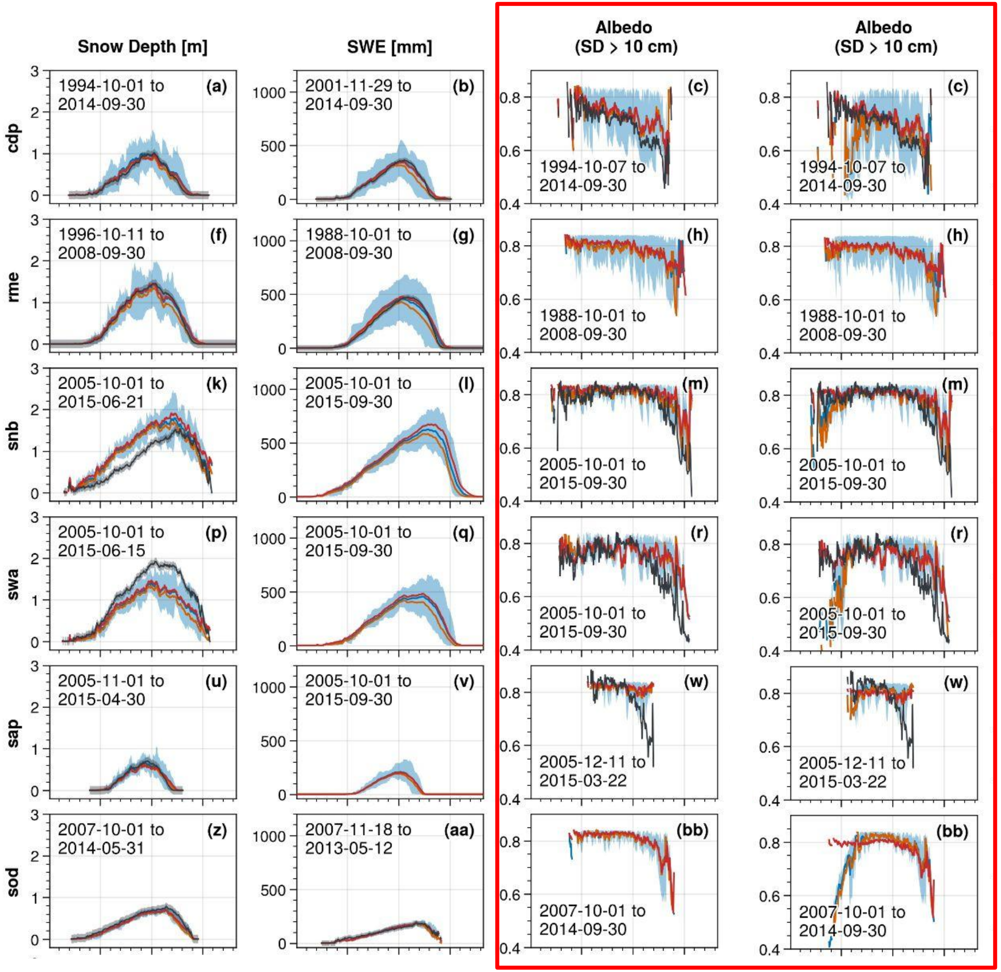

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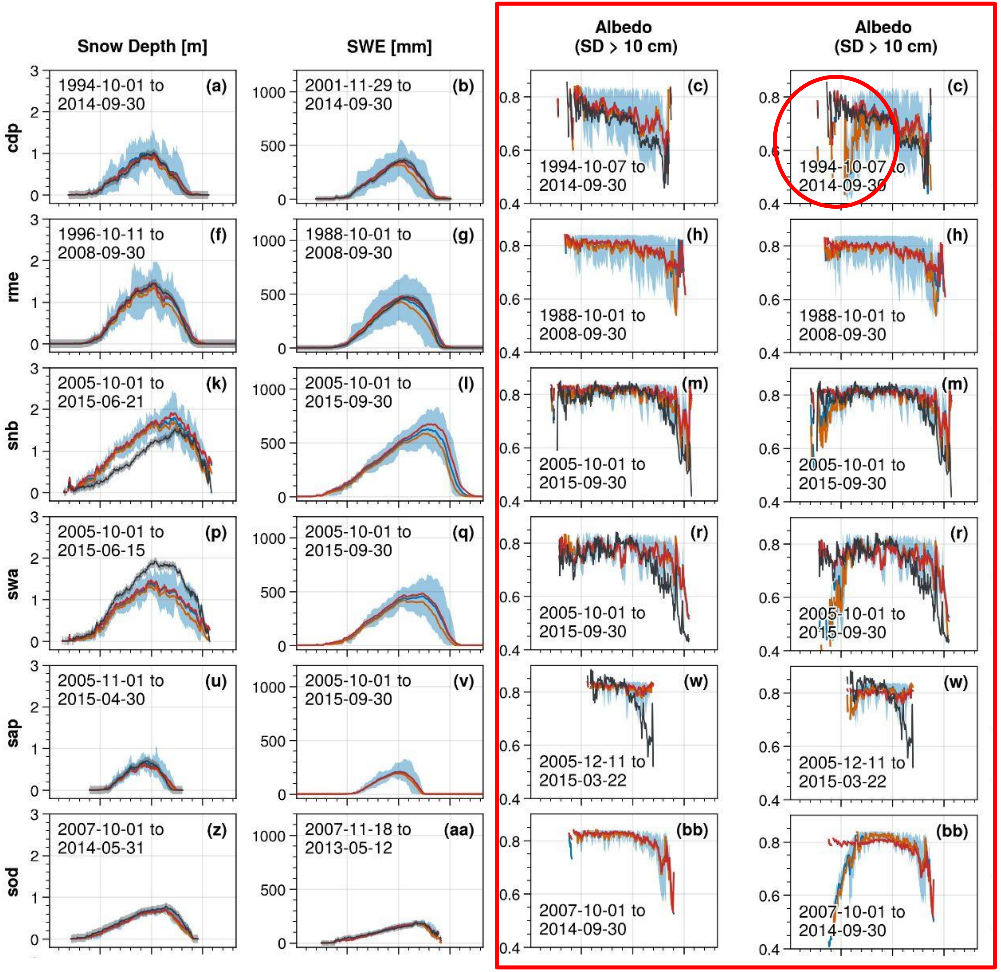

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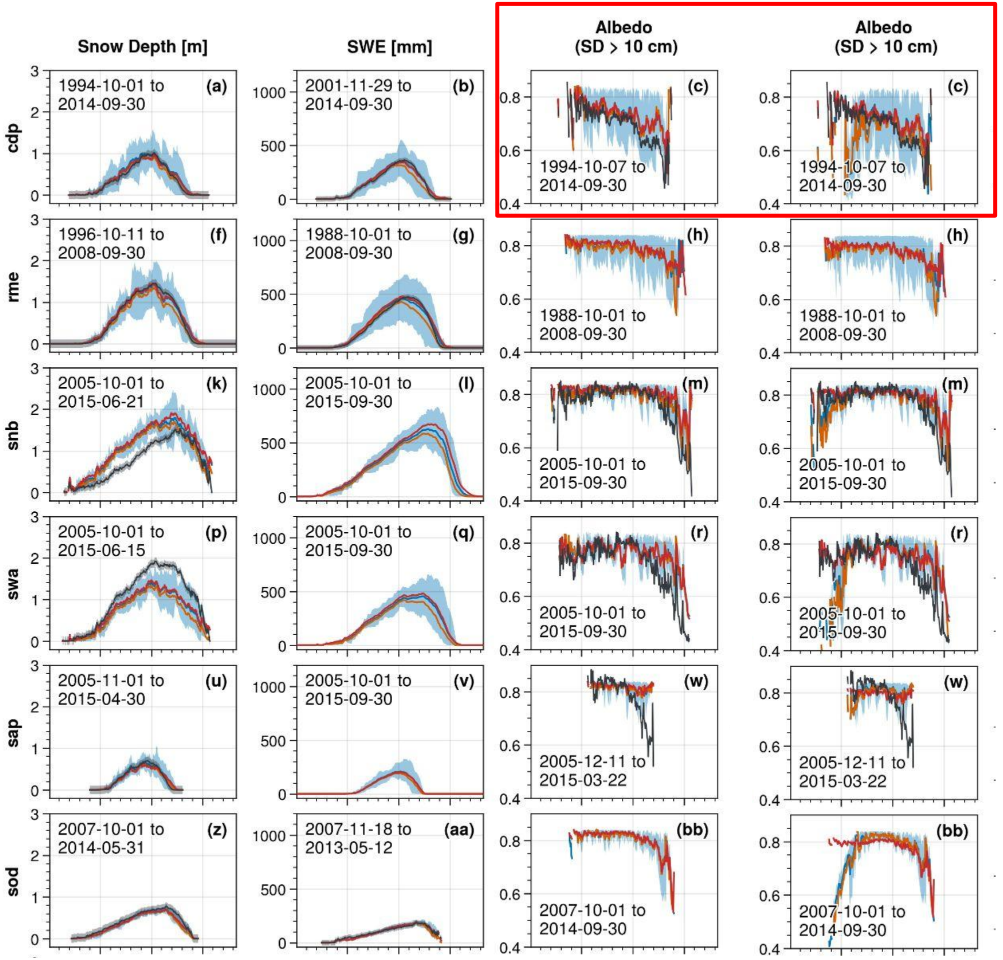

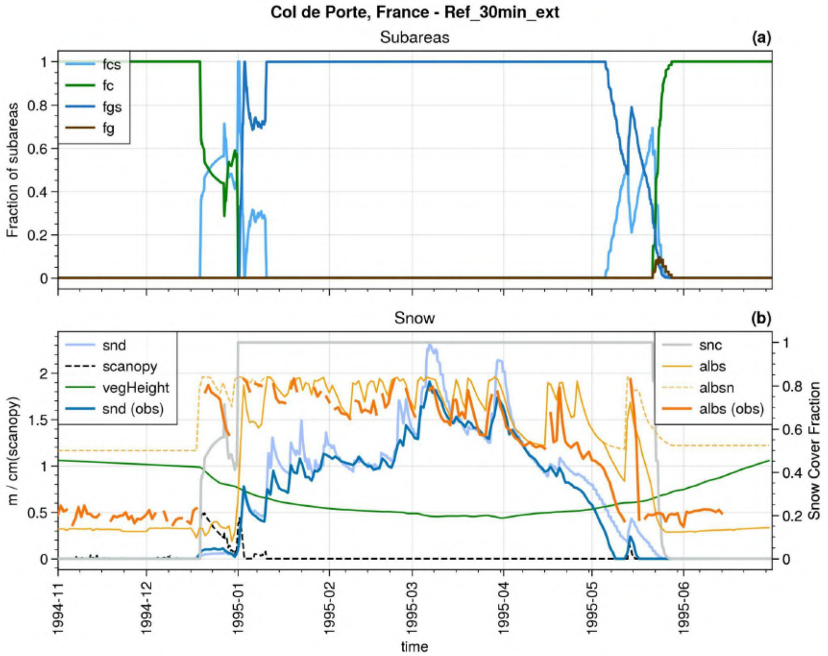

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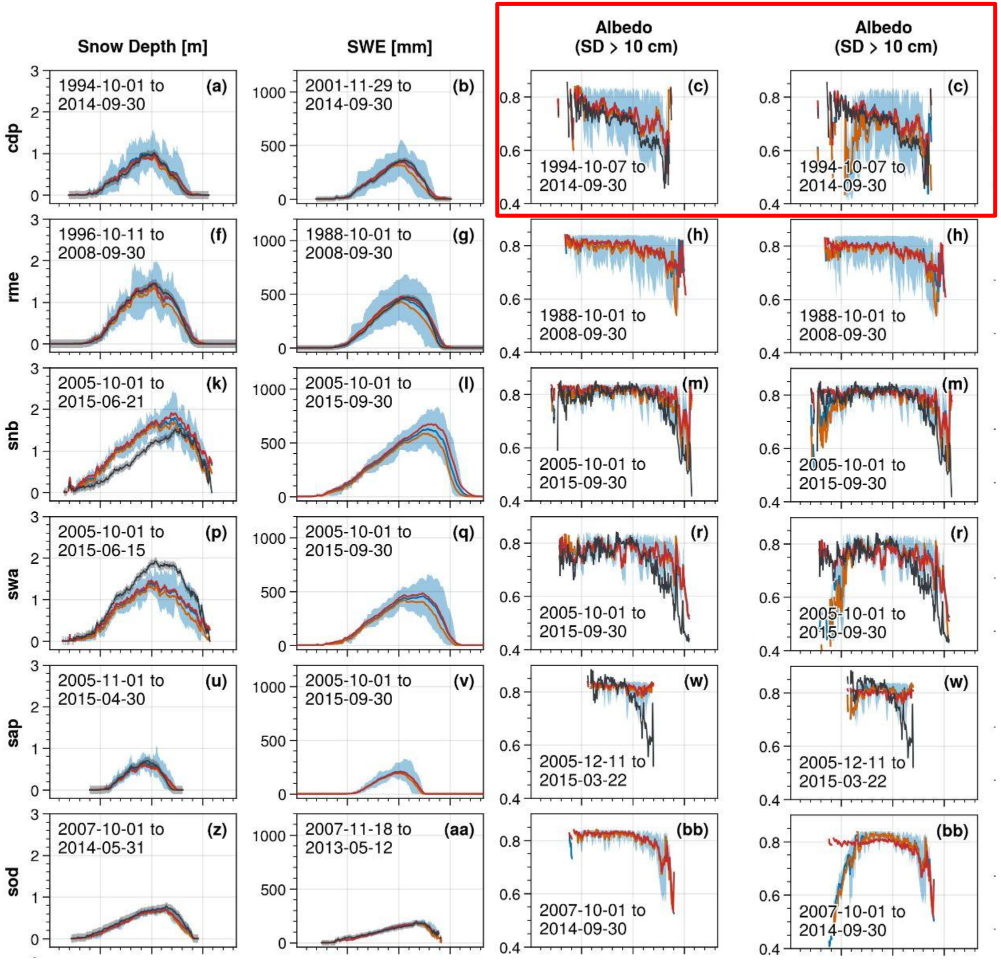

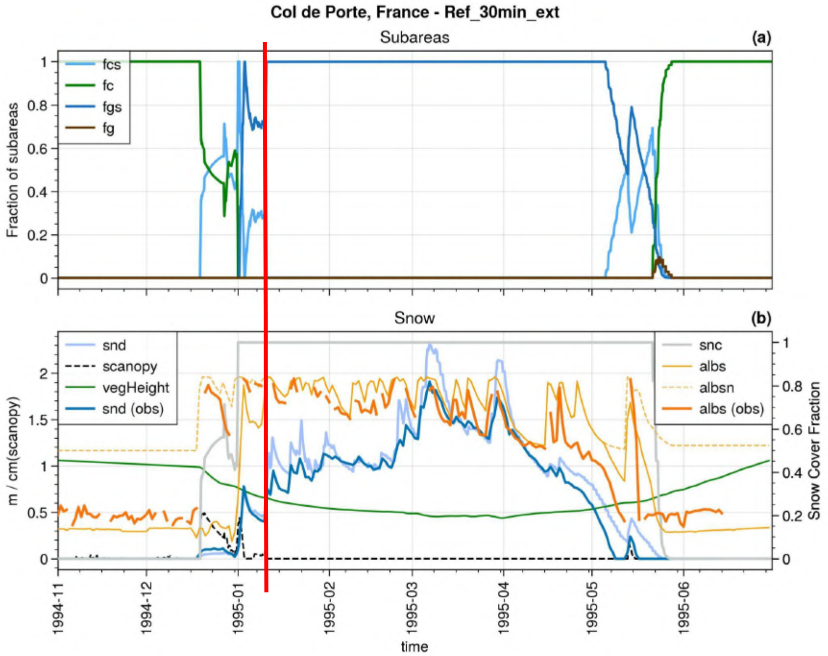

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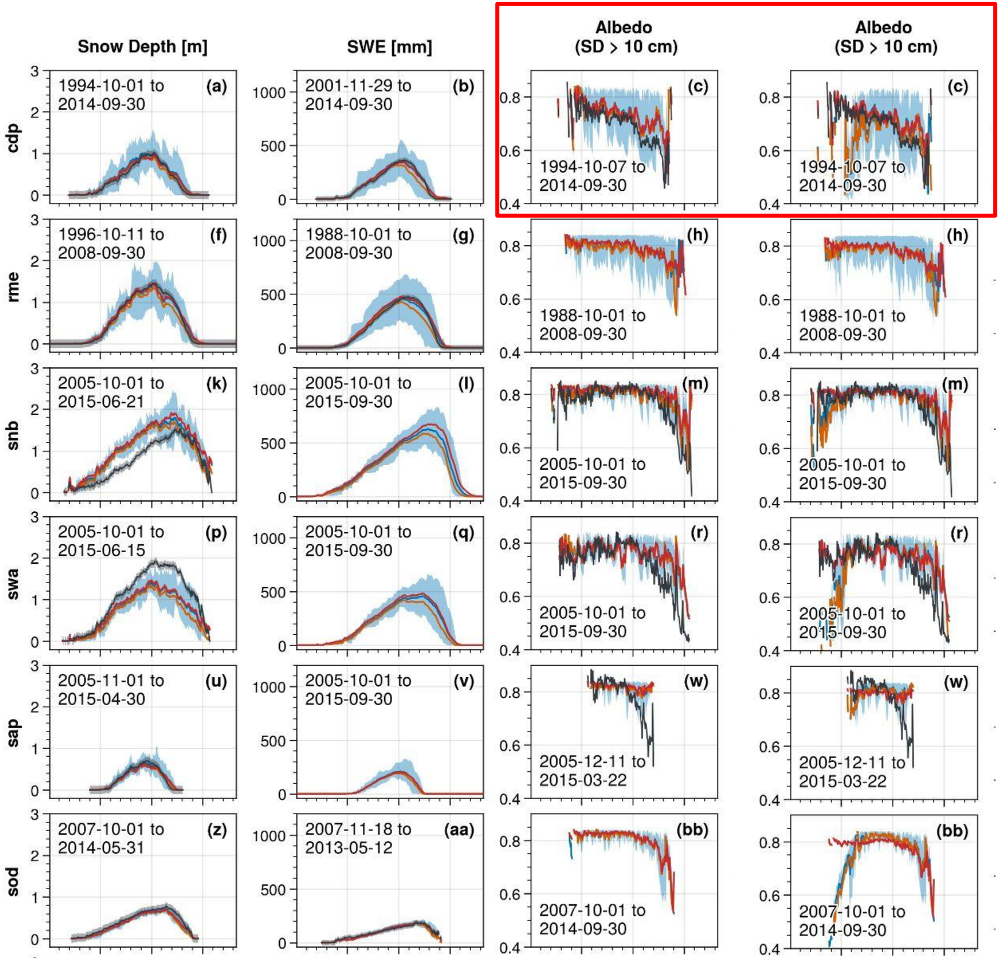

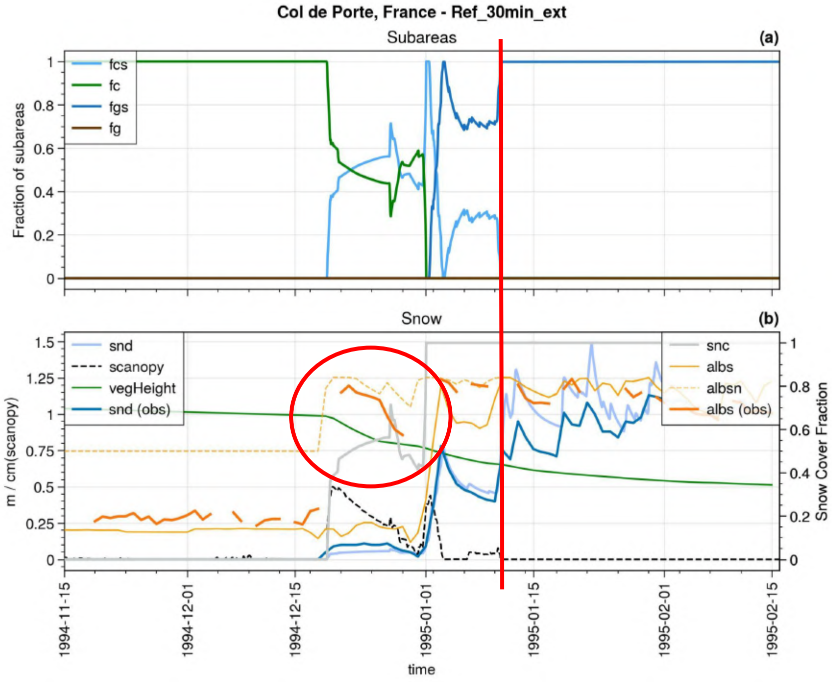

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SOCIAL NETWORKS

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Bibliography

References

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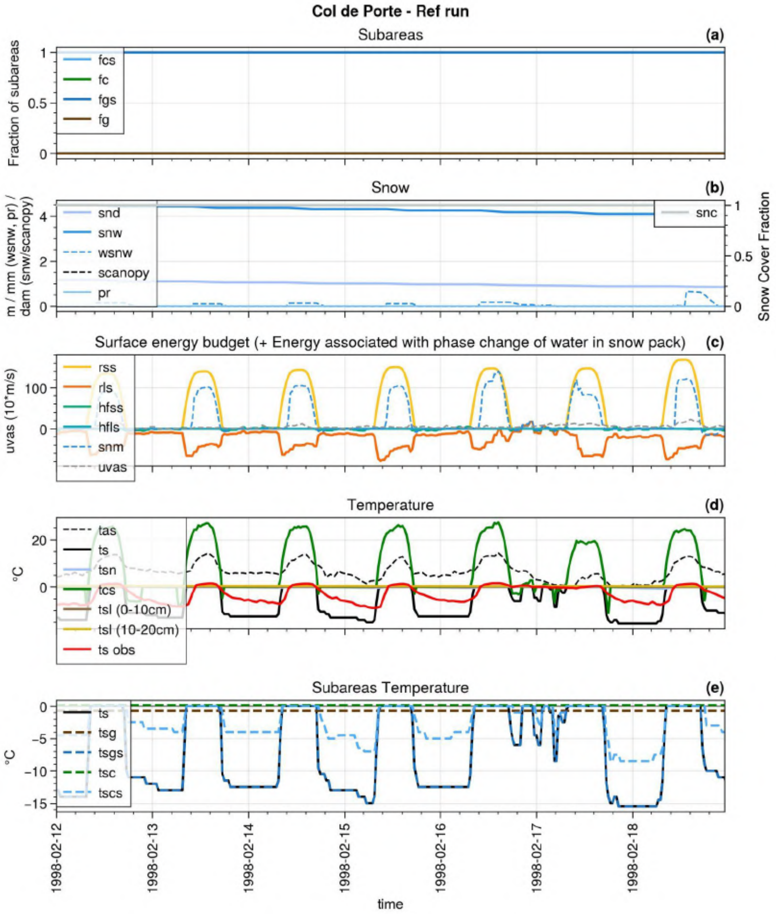
Supplementary slide

EZERO


Col de Porte - Ref run
Subareas
(a)
Fraction of subareas
fcs
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Snow
(b)
m / mm (wsnw, pr) / dam (snw/scanopy)
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snw
wsnw
scanopy
pr
snc
Snow Cover Fraction
Surface energy budget (+ Energy associated with phase change of water in snow pack)
(c)
W m⁻² / uvas (10*m/s)
rss
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hfls
snm
uvas
Temperature
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tcs
tsl (0-10cm)
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Subareas Temperature
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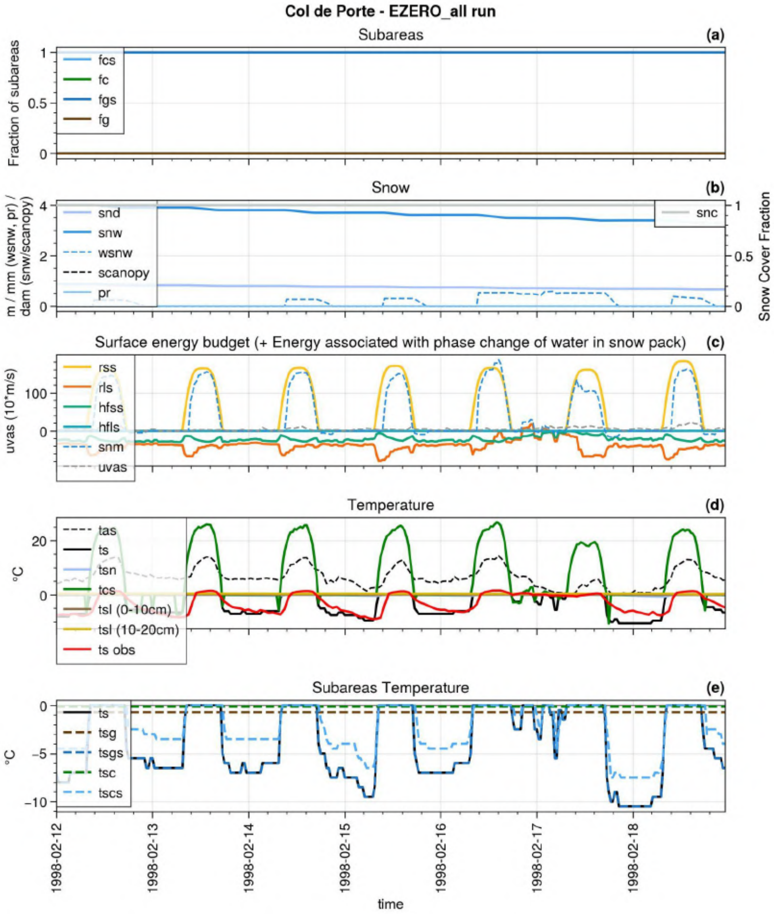
Col de Porte - EZERO_all run
Subareas
(a)
Fraction of subareas
fcs
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Snow
(b)
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Snow Cover Fraction
Surface energy budget (+ Energy associated with phase change of water in snow pack)
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Temperature
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