APPLICATE.eu
Advanced prediction in polar regions and beyond

Measuring model improvement using surface energy budget process relationships: the impact of a new snow model

Jonathan Day, Gabriele Arduini, Linus Magnusson, Irina Sandu, Anton Beljaars, Gianpaolo Balsamo, Mark Rodwell and David Richardson

This study has been submitted to Journal of Advances in Earth System Modeling, and a preprint is available here:
https://www.essoar.org/doi/10.1002/essoar.10502951.1

j.day@ecmwf.int

ECMWF

Key points

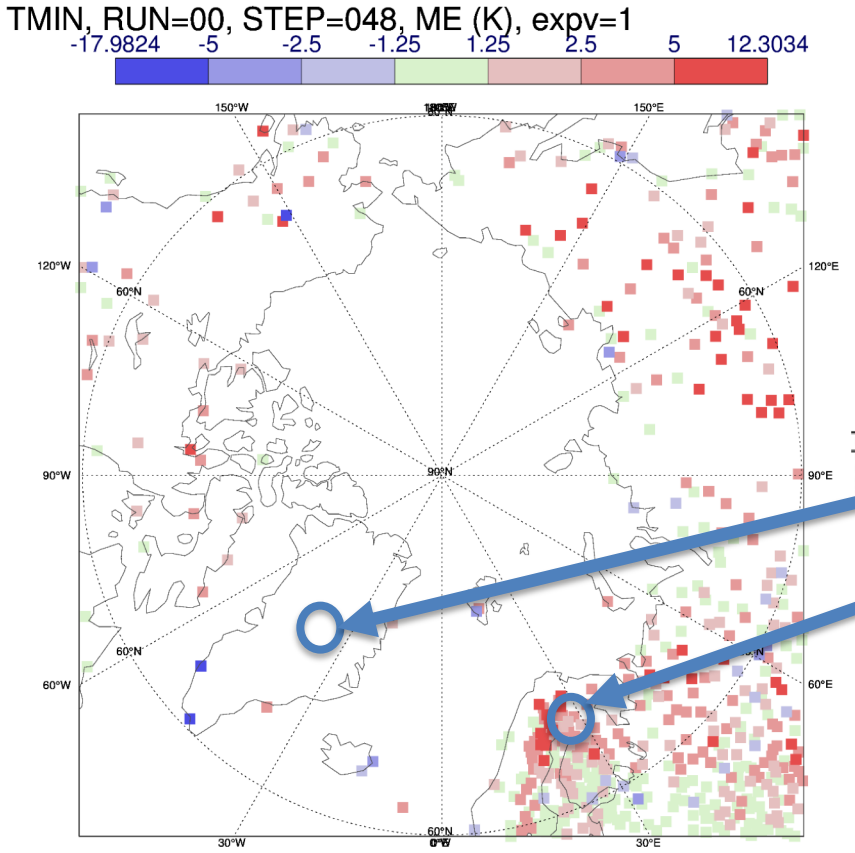
APPLICATE.eu
Advanced prediction in polar regions and beyond

- A set of "coupling-strength" diagnostics is presented for use in the evaluation and development of Earth System Models.
- These diagnostics are used to link an Arctic-wide warm bias in the ECMWF operational model to the use of a single-layer snow model.
- They are used to demonstrate that a multi-layer snow model improves this by reducing the coupling-strength to the land-surface.

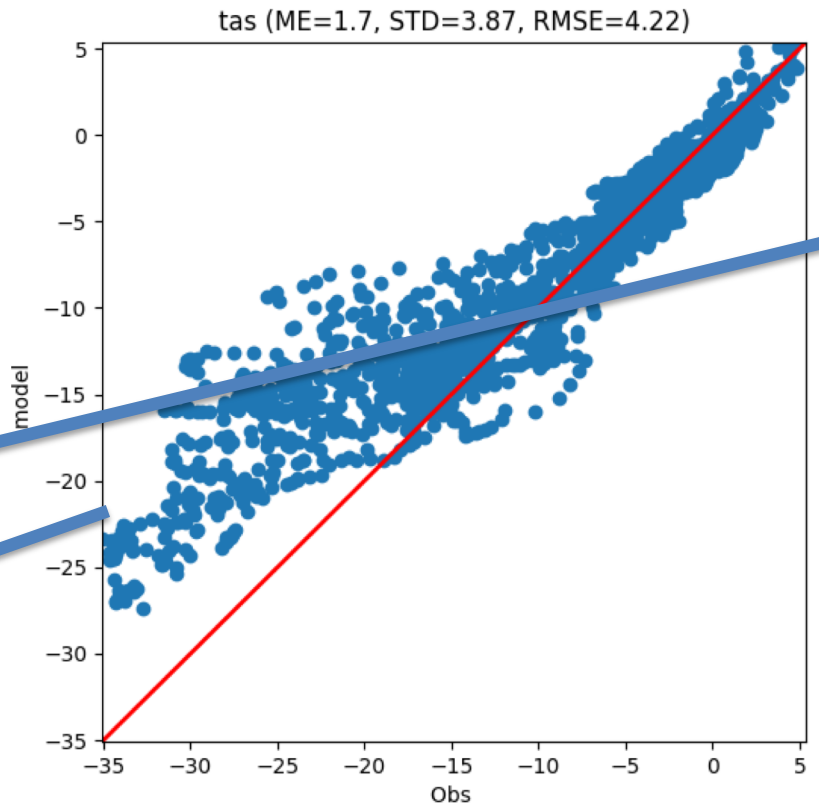
Warm bias in forecasts of cold conditions are a common issue

APPLICATE.eu
Advanced prediction in polar regions and beyond

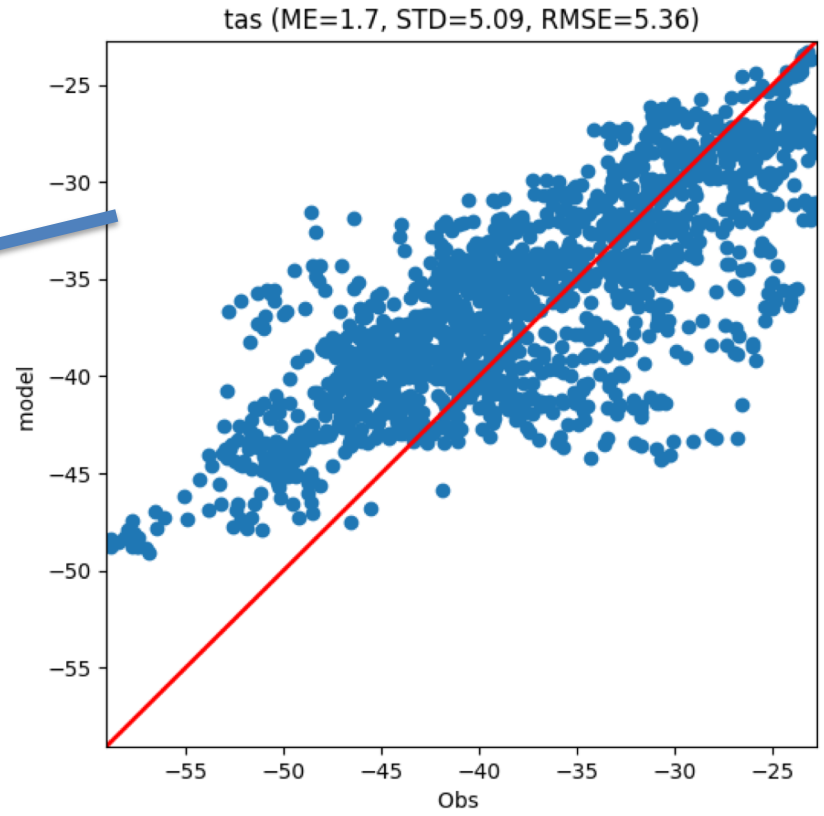
ECMWF Mean error in TMIN



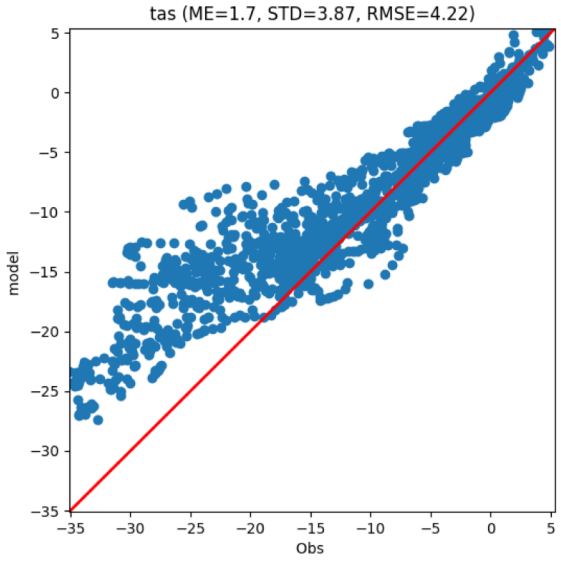
T2m: Sodankyla, Finland

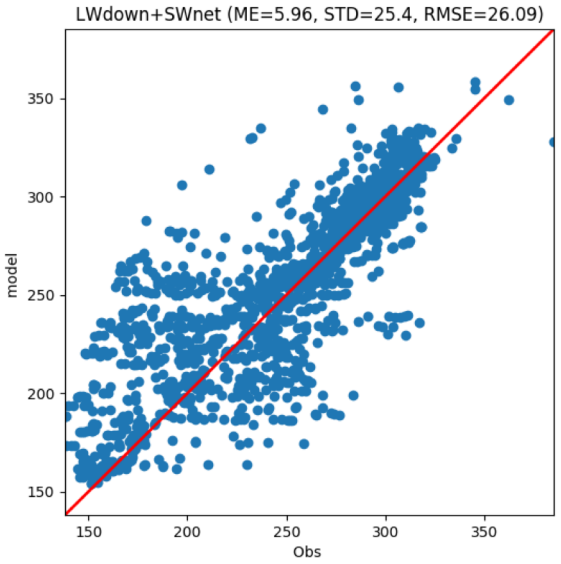


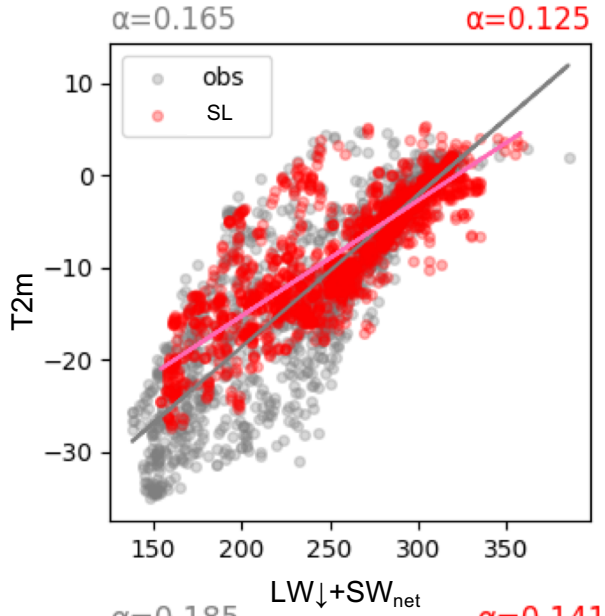
T2m Summit, Greenland



Partitioning temperature errors into 1) radiative forcing errors and 2) response to forcing

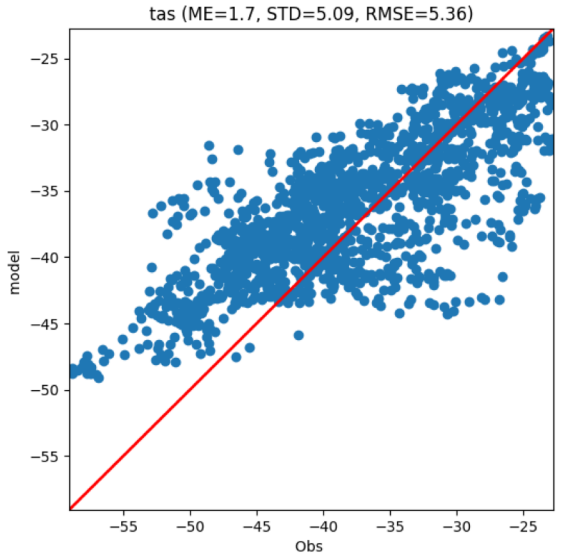


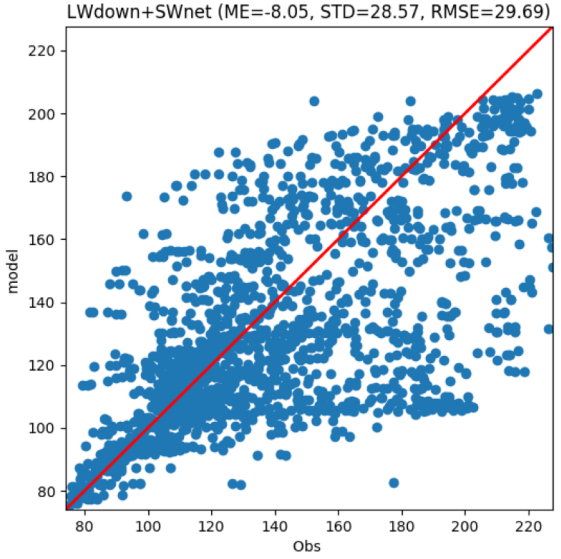


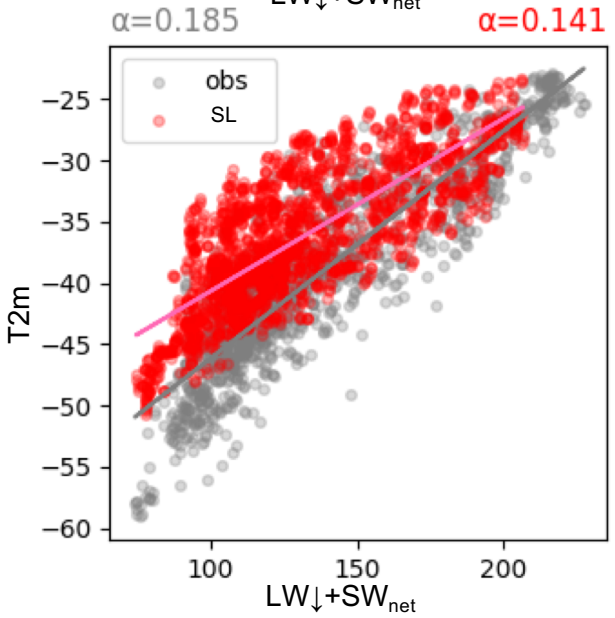


Sodankyla

Obs: 0.165 ºC/Wm^{-2}
Model: 0.125 ºC/Wm^{-2}





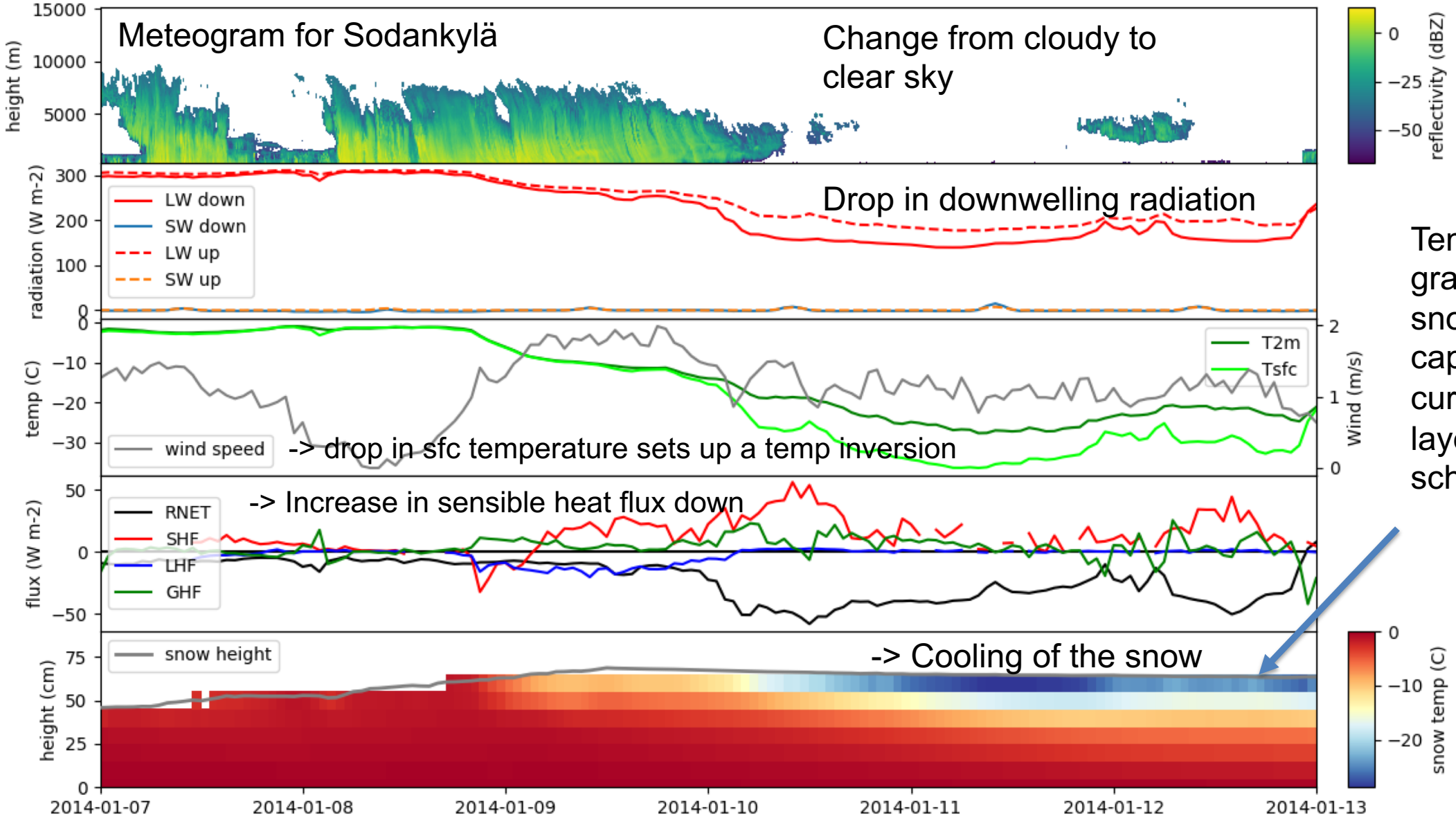


Summit Greenland

Obs: 0.185 ºC/Wm^{-2}
Model: 0.141 ºC/Wm^{-2}

The response to radiative forcing is underestimated at both sites

Near-surface temperature and SEB are driven by incoming radiation



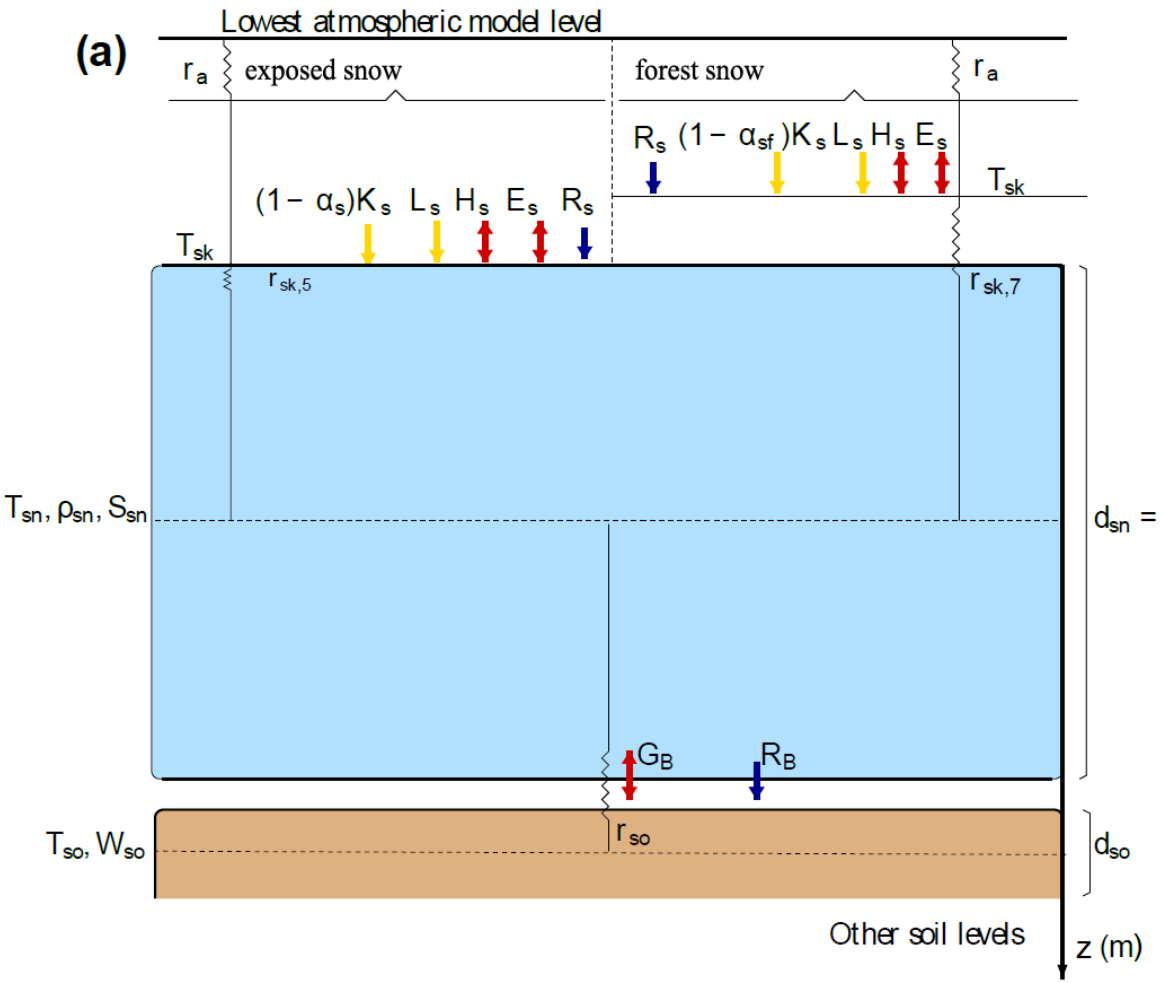
Temperature gradients in the snow can't be captured with current single layer snow scheme

See also :Miller et al. (2017; Pithan et al. (2014) & Stramler et al. (2011).

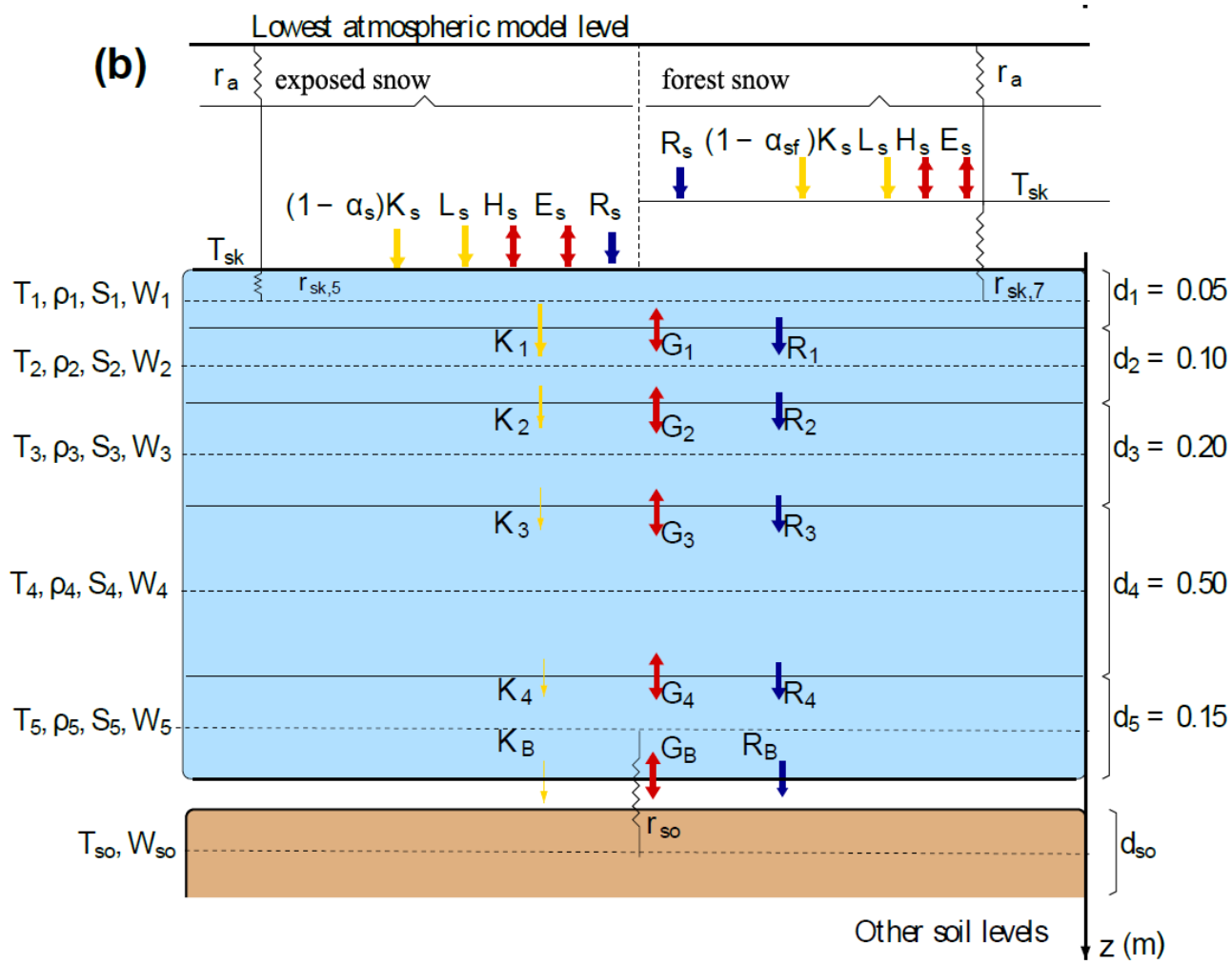
Implementation of multi-layer snow at ECMWF

APPLICATE.eu
Advanced prediction in polar regions and beyond

Single layer



Multi layer

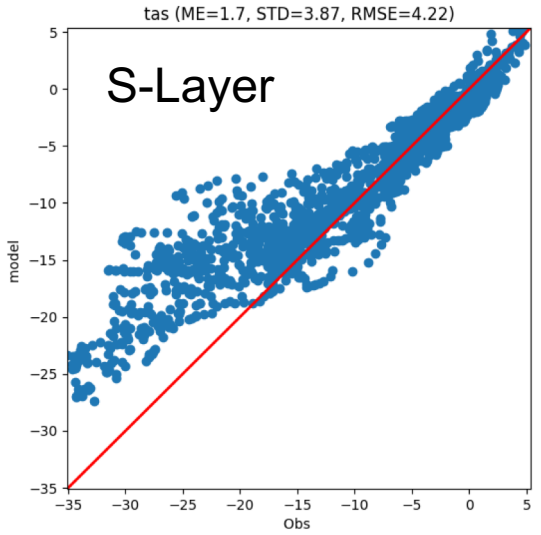


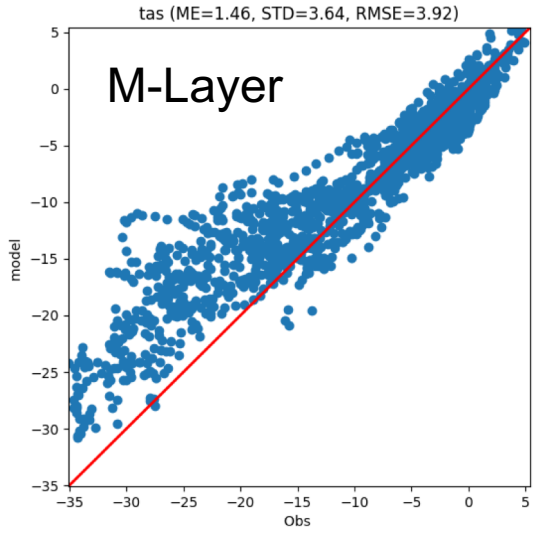
Arduini et al. (2019)

Improvement in T2m scores and T2m response to radiative forcing

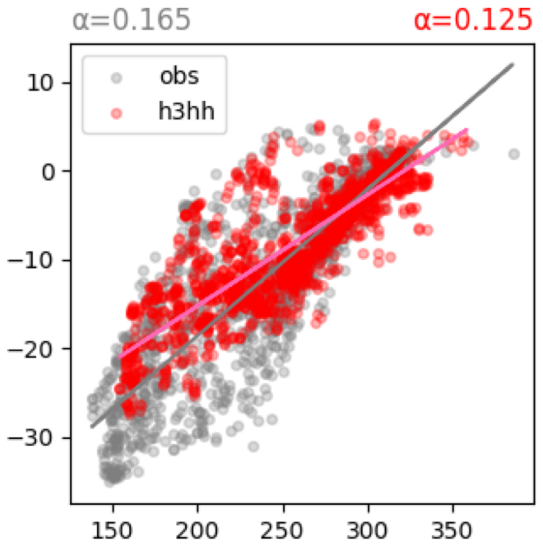
APPLICATE.eu
Advanced prediction in polar regions and beyond

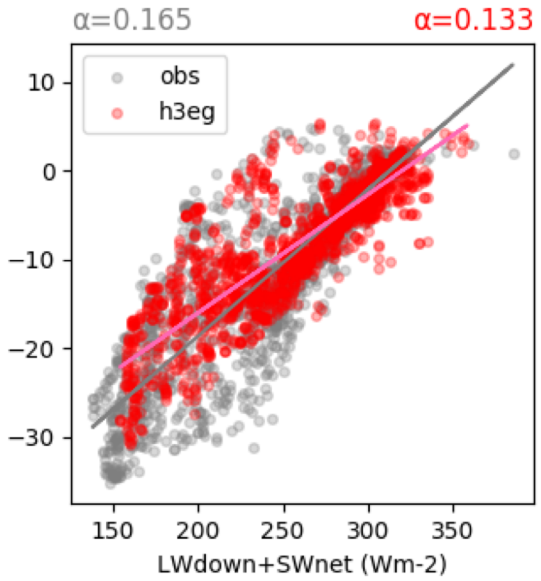
Sodankyla



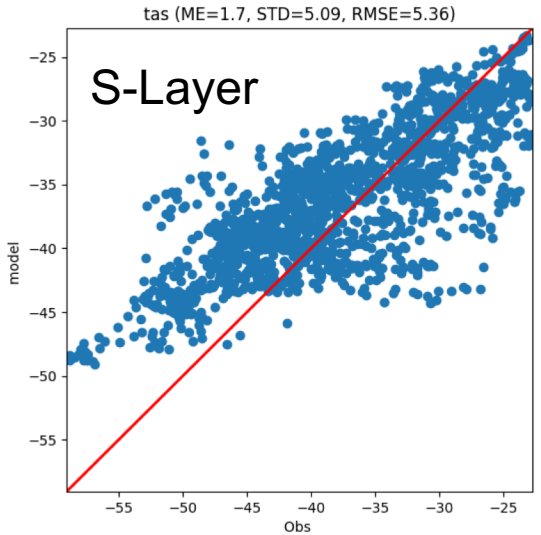


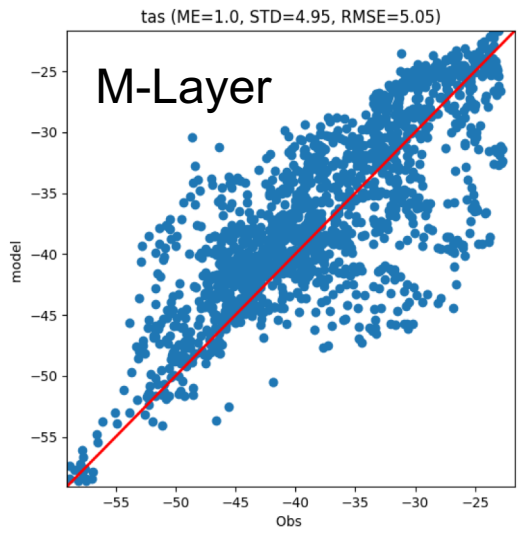
T2m

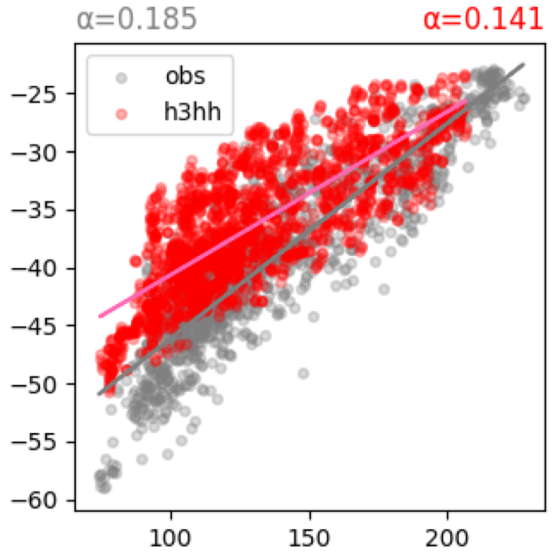


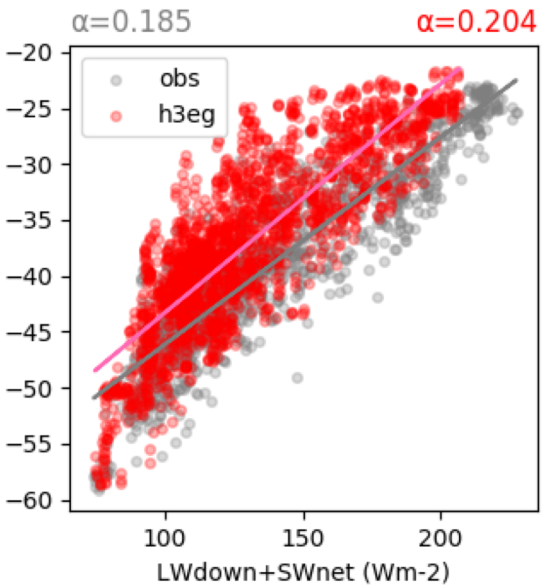


Summit









Driving and response terms in the Surface energy budget

APPLICATE.eu
Advanced prediction in polar regions and beyond

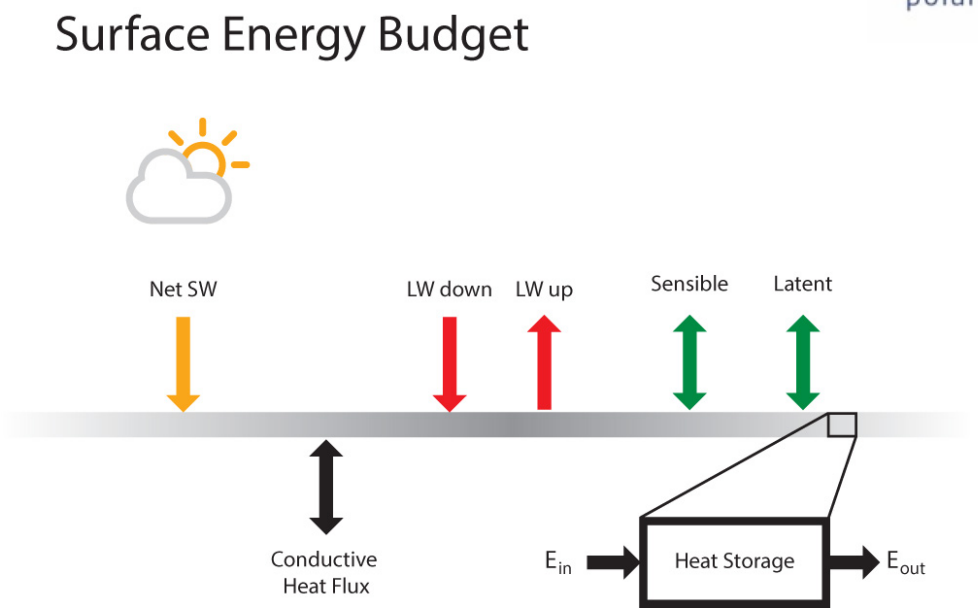
$$SW_{net} + LW\downarrow = -(SHF + LHF + GHF - LW\uparrow)$$

$$-LW\uparrow = \alpha_{LW\uparrow}(LW\downarrow + SW_{net}) + \beta_{LW\uparrow},$$

$$SHF = \alpha_{SHF}(LW\downarrow + SW_{net}) + \beta_{SHF},$$

$$LHF = \alpha_{LHF} \ldots,$$

$$-1 = \alpha_{SHF} + \alpha_{LHF} + \alpha_{GHF} + \alpha_{-LW\uparrow} + \epsilon$$



Provides a way to categorise coupling at different sites (along the lines of the Bowen ratio), in different regimes, and modelling diagnostic:

i.e. coupling to atmosphere is greater than coupling to sub-surface:

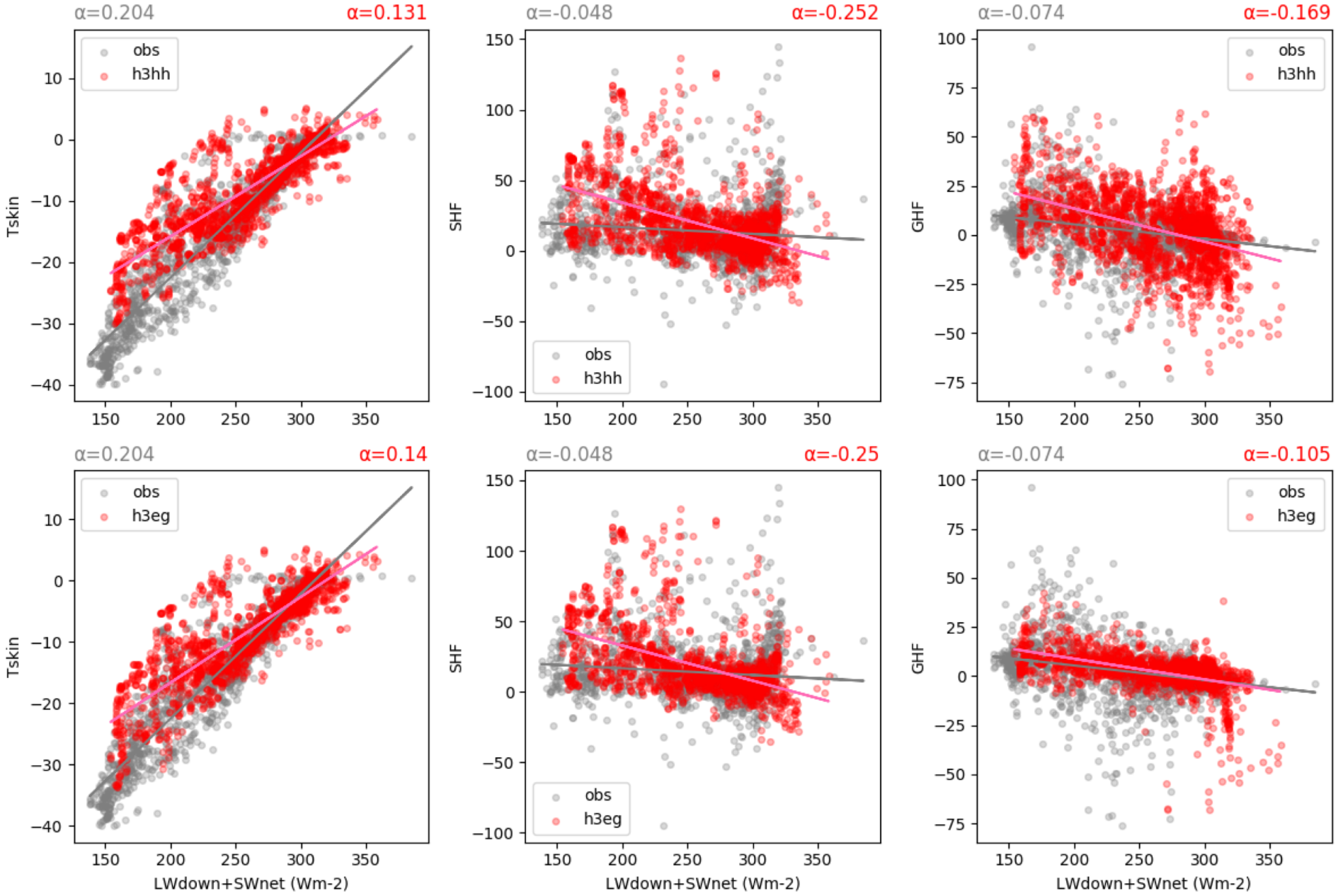
$$|\alpha_{SHF} + \alpha_{LHF}| > |\alpha_{GHF}|$$

See also Miller et al. (2017 and 2018)

SEB coupling strength: Sodankyla

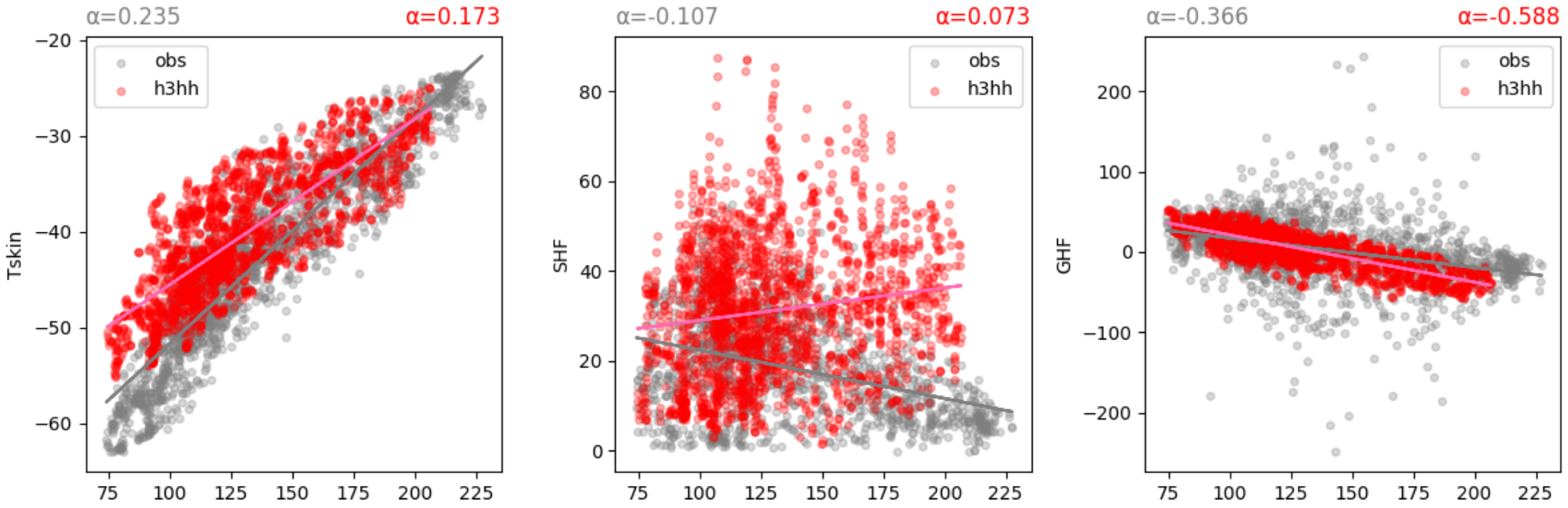
Single-layer

Multi-layer

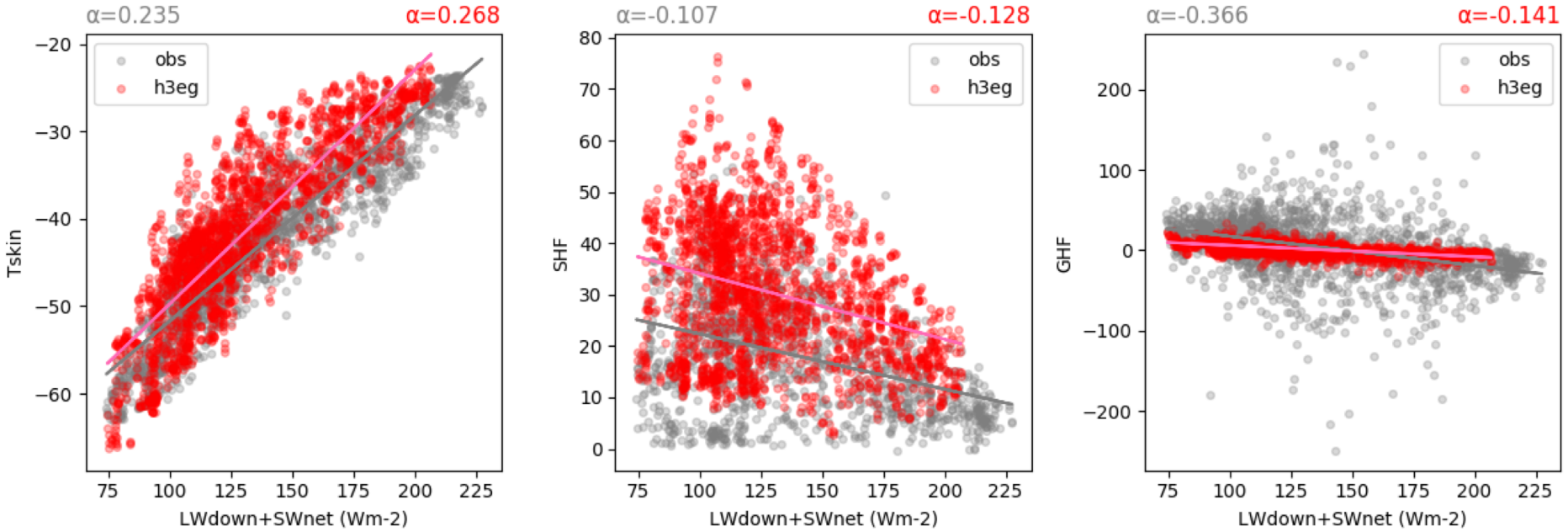


SEB coupling strength: Summit

Single-layer



Multi-layer



Conclusions

APPLICATE.eu
Advanced prediction in polar regions and beyond

- Systematic near-surface temperature errors can be understood by splitting and analysing separately errors in radiative forcing and errors in the near-surface and surface temperature response to radiative forcing.
- Systematic errors in the response of surface temperature to radiative forcing can be understood by analysing the coupling strength between radiation and energy balance terms:
  - Coupling strength to sub-surface is too high: $|\alpha_{GHF_{mod}}| > |\alpha_{GHF_{obs}}|$
  - Coupling strength to atmosphere is too high: $|\alpha_{SHF_{mod}} + \alpha_{LHF_{mod}}| > |\alpha_{SHF_{obs}} + \alpha_{LHF_{obs}}|$
- Adding the multi-layer snow reduces $|\alpha_{GHF_{mod}}|$ i.e. the coupling strength between the radiation and the GHF, which increases the surface temperature sensitivity.

This study has been submitted to Journal of Advances in Earth System Modeling, and a preprint is available here: https://www.essoar.org/doi/10.1002/essoar.10502951.1

Funding

APPLICATE.eu
Advanced prediction in polar regions and beyond

APPLICATE (https://applicate.eu/)
(**A**dvanced **P**rediction in **P**olar regions and beyond: modelling, observing system design and
LInkages associated with a **C**hanging **A**rctic clima**TE**)
has received funding from the European Union's Horizon 2020
research and innovation programme under grant agreement No 727862.