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

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

This study has been accepted to Journal of Advances in Earth System Modeling

j.day@ecmwf.int
A warm bias in cold conditions is a common issue

T+1-T+24 temperature errors at Sodankyla, Finland

From forecasts uploaded to the YOPPsiteMIP database

Aim: to address the need for diagnostics to assess the causes for surface and near-surface temperature errors.

Day et al. (ECMWF newsletter 2020)
Warm bias in ECMWF forecasts during Arctic winter

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 °C/Wm⁻²
- **Model:** 0.125 °C/Wm⁻²

The response to radiative forcing is underestimated at both sites.

**Summit Greenland**
- **Obs:** 0.185 °C/Wm⁻²
- **Model:** 0.141 °C/Wm⁻²

The response to radiative forcing is underestimated at both sites.
Near-surface temperature and SEB are driven by incoming radiation

Meteogram for Sodankylä

Change from cloudy to clear sky

Drop in downwelling radiation

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

-> drop in sfc temperature sets up a temp inversion

-> Increase in sensible heat flux down

-> Cooling of the snow

See also: Miller et al. (2017; Pithan et al. (2014) & Stramler et al. (2011).
Implementation of multi-layer snow at ECMWF

Arduini et al. (2019)
Improvement in T2m scores and T2m response to radiative forcing

Figure 3. Hourly observed vs forecast (during day 2) 2m temperature (a & d), LW↓ + SW↑ net (b & e), and the relationship between them (c & f) in observations (black) and each model formulation (red) for Sodankylä with single layer snow (top row) and multi-layer snow (bottom row) for DJF 2013/14. The regression coefficient is shown for the observations (black text) and the models (red text).

Figure 4. Hourly observed vs forecast (during day 2) 2m temperature (a & d), LW↓ + SW↑ net (b & e), and the relationship between them (c & f) in observations (black) and each model formulation (red) for Summit with single layer snow (top row) and multi-layer snow (bottom row) for DJF 2013/14. The regression coefficient is shown for the observations (black text) and the models (red text).
Driving and response terms in the Surface Energy Budget

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

\[-LW \uparrow = \alpha_{LW\uparrow} (LW \downarrow + SW_{net}) + \beta_{LW\uparrow}, \]
\[ SHF = \alpha_{SHF} (LW \downarrow + SW_{net}) + \beta_{SHF}, \]
\[ LHF = \alpha_{LHF} \ldots, \]
\[-1 = \alpha_{SHF} + \alpha_{LHF} + \alpha_{GHF} + \alpha_{-LW\uparrow} + \epsilon \]

If \( \alpha_{SHF_{mod}} + \alpha_{LHF_{mod}} + \alpha_{GHF_{mod}} > \alpha_{SHF_{obs}} + \alpha_{LHF_{obs}} + \alpha_{GHF_{mod}} \) then \( \alpha_{-LW\uparrow_{mod}} < \alpha_{-LW\uparrow_{obs}} \)

i.e. \( T_{sfc} \) will be insensitive changes in \( LW \downarrow + SW_{net} \)

See also Miller et al. (2017 and 2018)
### SEB coupling strength: Sodankyla

**Single-layer**

- Figure 4a: Hourly observed vs forecast (during day-2) 2m temperature (a & d), LW↓ + SW net (b), and the relationship between them (c & f) in observations (black) and each model formulation (red) for Summit with single layer snow (top row) and multi-layer snow (bottom row) for DJF 2013/14. The regression coefficient is shown for the observations (black text) and the models (red text).
SEB coupling strength: Summit

Single-layer

Multi-layer
SHF diagnostic

Figure 7. Sensible heat, scaled by wind speed, as a function of inversion strength at Summit from forecasts with the single-lager model (SL, a) and multi-layer model (ML, c). Inversion strength as a function of radiative forcing ($LW_{\downarrow} + SW_{net}$) for SL (b) and ML (d). Observations are shown in black and forecasts are shown in red.
Conclusions

• 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.

Day, J. J., Arduini, G., Sandu, I., Magnusson, L., Beljaars, A., Balsamo, G., et al. (2020). Measuring the impact of a new snow model using surface energy budget process relationships. Journal of Advances in Modeling Earth Systems, 12, e2020MS002144. https://doi.org/10.1029/2020MS002144
YOPPsiteMIP: Year of Polar Prediction supersite Model Inter-comparison Project

- **Supersites**: Suites of instruments measuring variables that lead to process understanding
- **Models**: High frequency column output on model levels at supersites

- **MIP**: Developed Format and Semantics used for both models and observations promoting multi-model and multi-site verification and process evaluation

- **Data**: Available through the YOPP Data Portal (yopp.met.no)

- **Targeted processes**: Low level clouds (including phase), Stable boundary layers, Atmosphere-snow interactions over land and sea-ice (@MOSAIC), Coupling procedures (variables and frequencies), Ocean mixing, ...

- **To participate**: Talk to me (Jonny Day), Barbara Casati or Amy Solomon for more information.
Funding

APPLICATE (https://applicate.eu/)
(Advanced Prediction in Polar regions and beyond: modelling, observing system design and Linkages associated with a Changing Arctic climate)
has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 727862.
Motivation

WGNE survey of modelling centres to rank systematic error type by importance:
1. Convective precipitation
2. Surface fluxes/diurnal cycle of T
3. Surface T error inc. diurnal cycle

Aim: to address the need for diagnostics to assess the causes for surface and near-surface temperature errors.