Improving short-term forecasts of the Arctic ocean-sea ice-atmosphere coupled system using wintertime statistics from the MOSAiC campaign

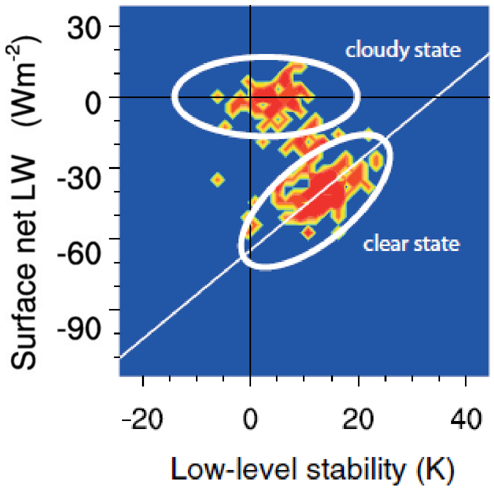
Amy Solomon (CIRES/NOAA), Matt Shupe (CIRES/NOAA), Gunilla Svensson (SU), Yurii Batrak (MetNO), Neil P. Barton (NOAA), Eric Bazile (Meteo-France/CNRS), **Jonny Day (ECMWF)**, James Doyle (NRL), Helmut Frank (DWD), Sarah Keeley (ECMWF), Teresa Remes (MetNO), Mikhail Tolstykh (MINM/HR)

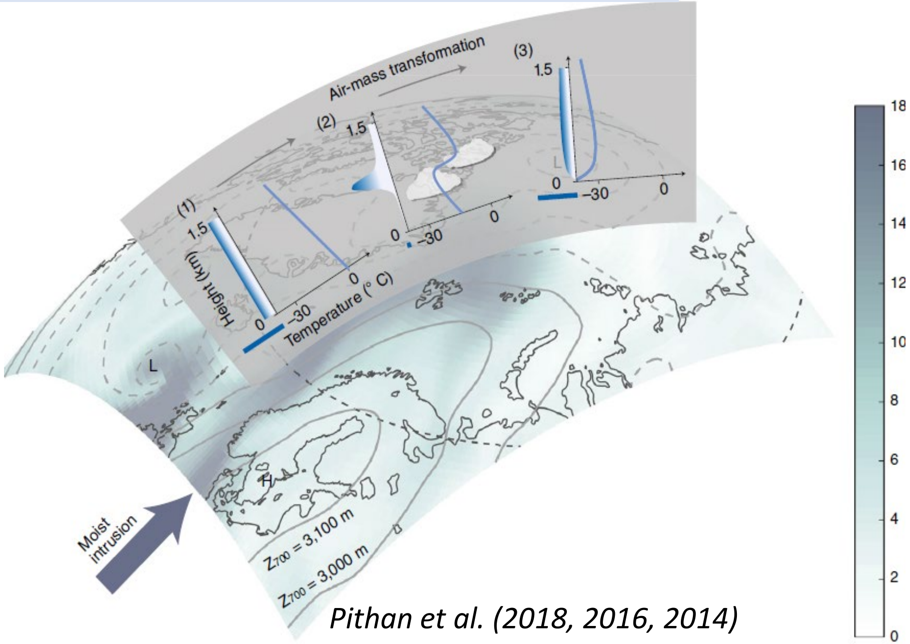
Winter boundary layer states and BL processes

Arctic boundary Layer:

- Predominantly in a cloudy and clear-sky states
- Mixed phase clouds are key radiative drivers for transition between states
  - Challenging to represent!

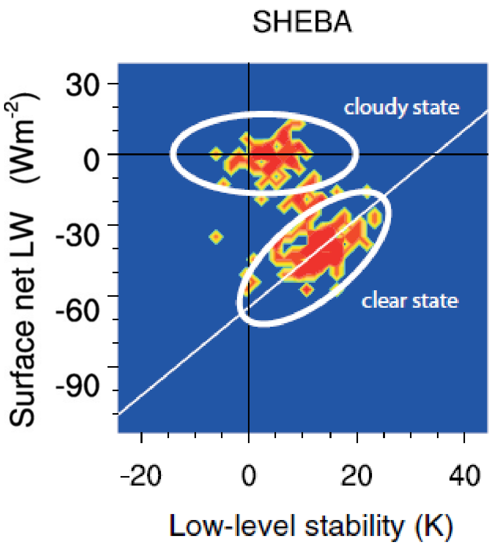
SHEBA observations





Pithan et al. (2018, 2016, 2014)
See also Wexler (1936) and Stramler (2011)

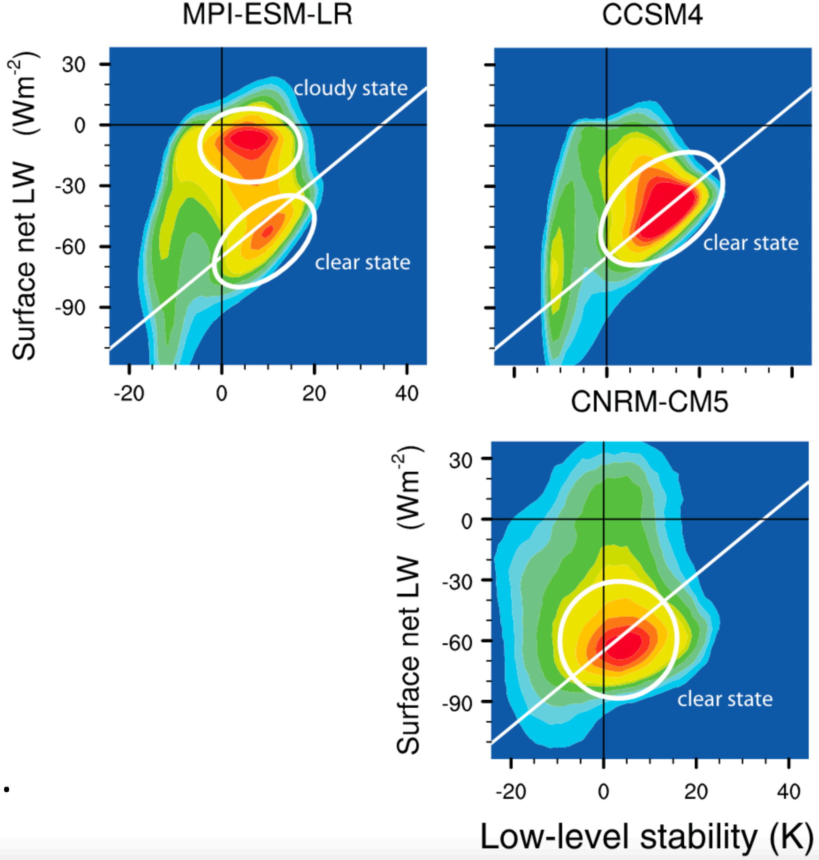
A mixture of states emerge in climate models



CMIP5

strong stability in clear state

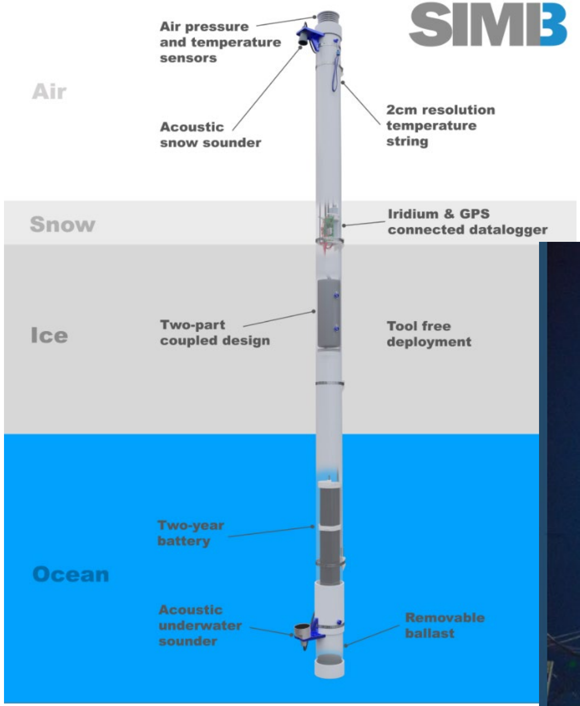
weak stability in clear state



Pithan et al. (2016)

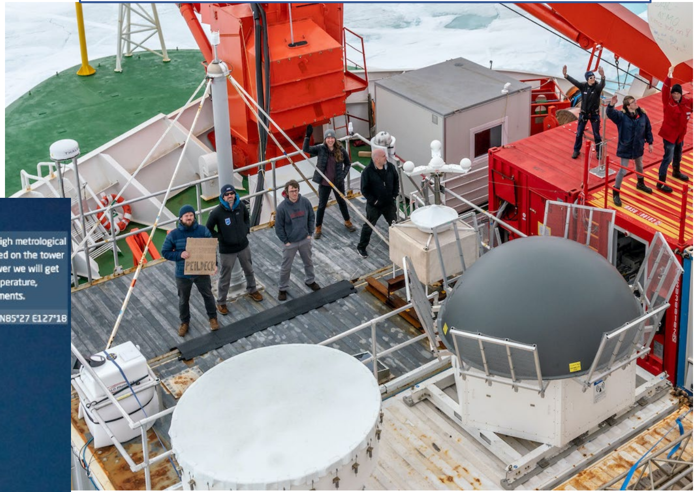
Wintertime Measurements at L-Sites and Polarstern

Sea ice and snow measurements at L-sites
(Don Perovich and colleagues)



30-meter Tower and 3-meter Flux stations at L-sites and Met City
(Matt Shupe and colleagues)

Radar, Lidar, Aerosol particle counters, etc on Polarstern
(DOE ARM scientists)



Goals of MOSAiC Forecast Verification Studies

(Coordinated with YOPP Processes and Sea Ice Task Teams)

Use observations taken during MOSAiC to improve the simulation of wintertime coupled processes unique to the Arctic, such as;

- The persistence and maintenance of mixed-phase clouds
- The representation of the stable boundary layer
- Atmosphere-snow interaction
- Ocean-sea ice-atmosphere coupling

Short-term forecasts and wintertime statistics are used in this project to identify potential errors in the representation of "fast" processes that cause biases in climate model projections of Arctic climate change

Forecast systems used in the intercomparison:

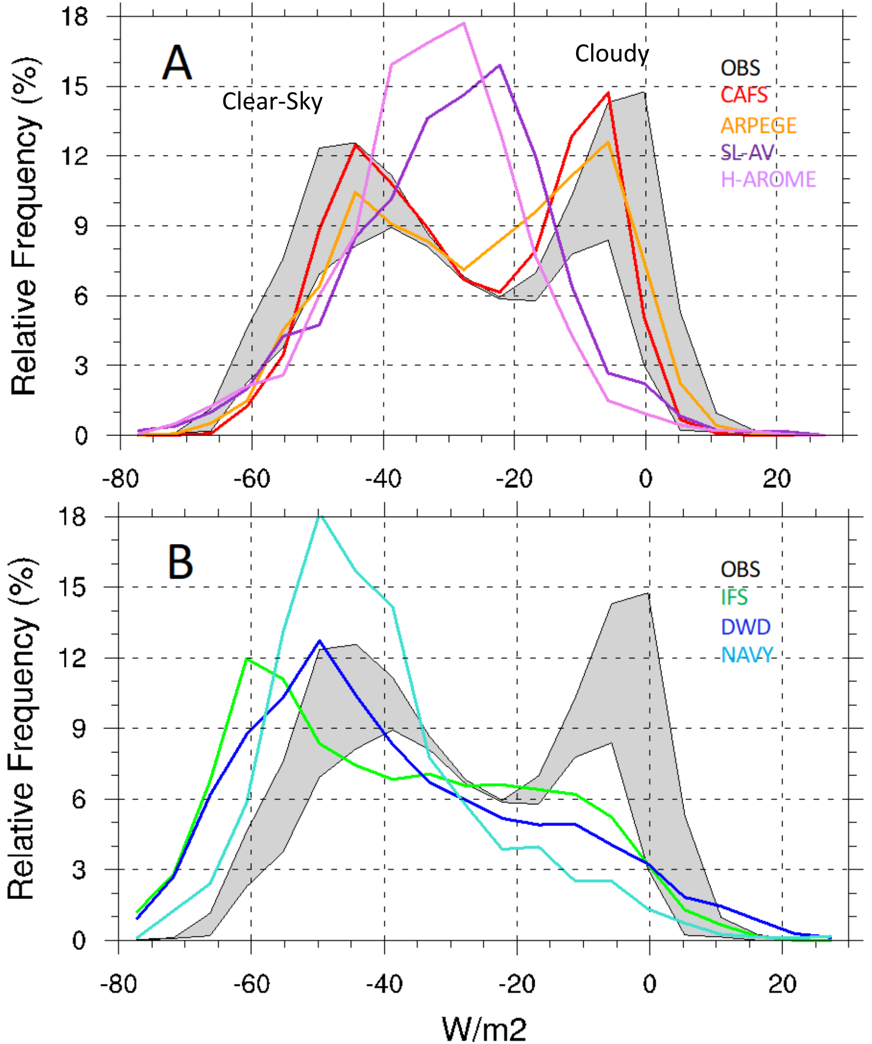
- NOAA-PSL Coupled Arctic Forecast System (CAFS)
- ECMWF Integrated Forecasting System (IFS)
- MétéoFrance Action de Recherche Petite Echelle Grande Echelle (ARPEGE-GELATO)
- MetNo Applications of Research to Operations at Mesoscale (HARMONIE-AROME)
- US Navy Earth System Prediction Capability Model (NAVY)
- DWD Icosahedral Nonhydrostatic Model (DWD)
- Russian Hydromet Forecast System (SL-AV)

→ Five fully coupled atmosphere – ocean – sea ice forecast systems

PDFs of Net Surface Longwave Fluxes

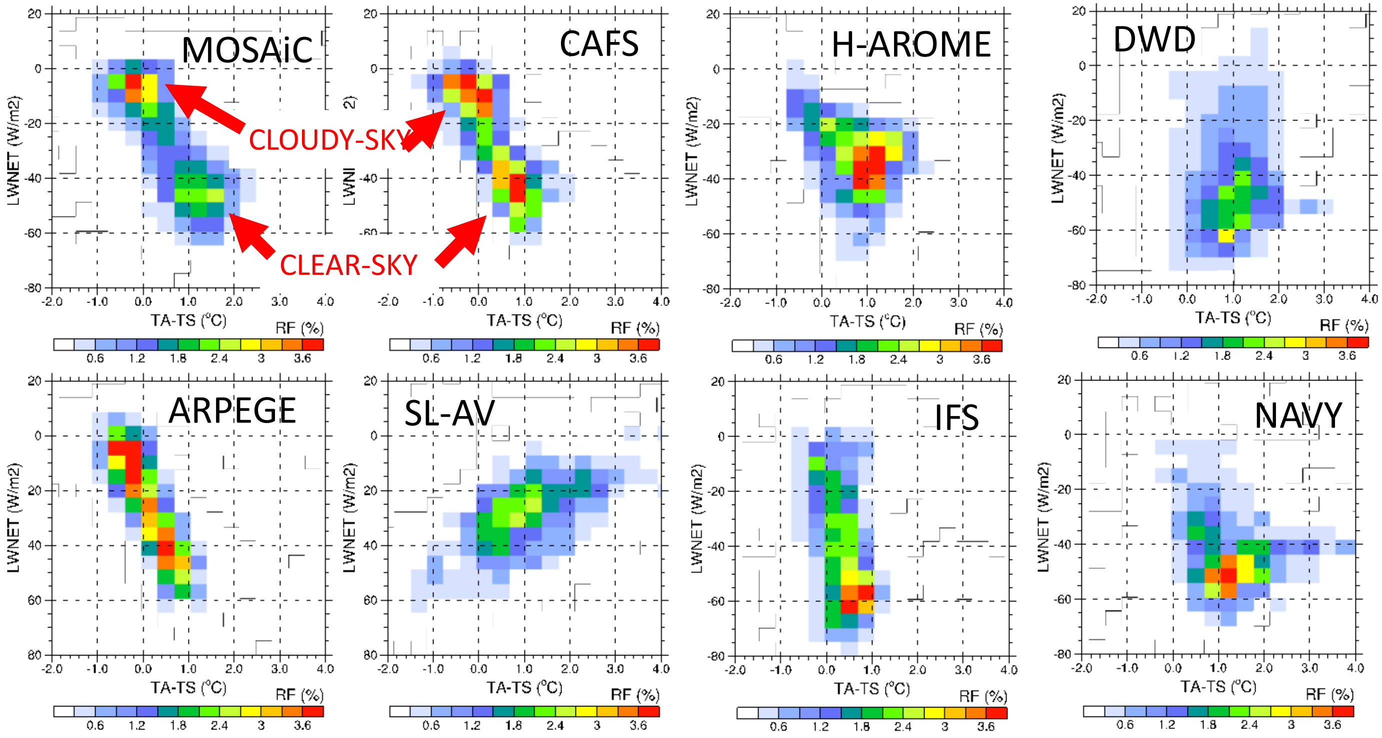
Only 2 models simulate observed distinct bi-modal clear-sky & cloudy modes

3 models have distinct clear-sky modes but underestimate the cloudy mode



Joint PDFs of Near-Surface Stratification and Net Surface Longwave Flux

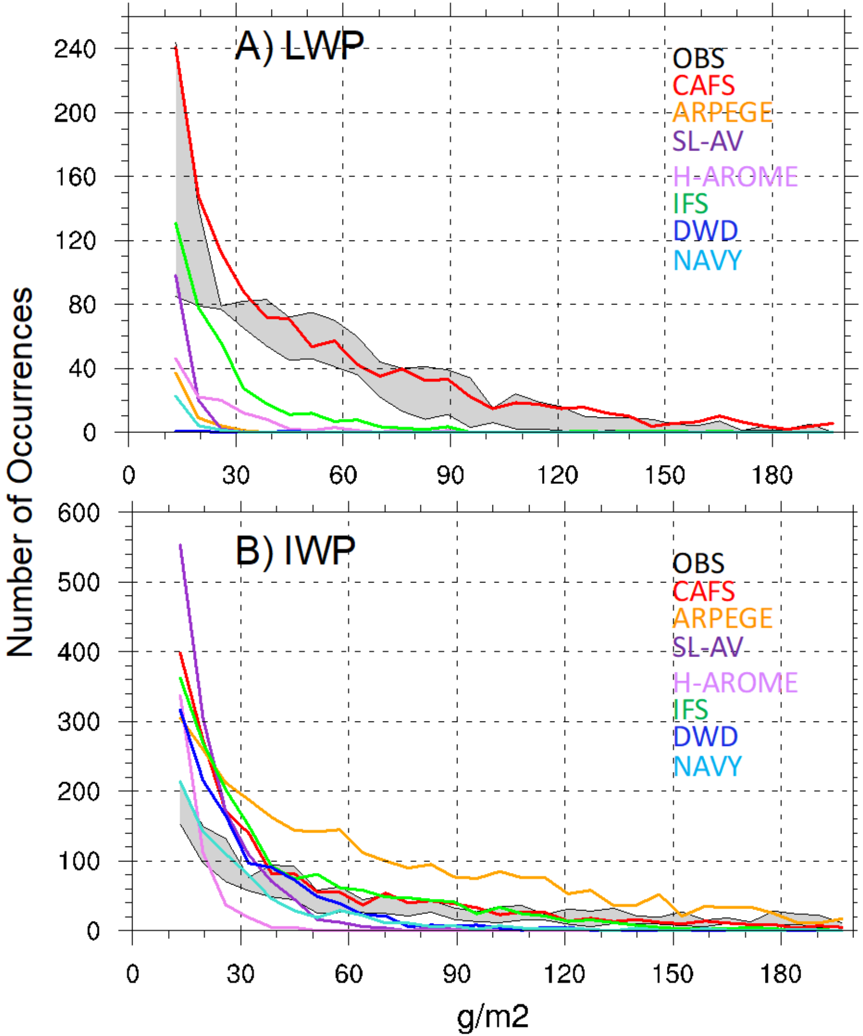
Current state-of-the-art forecast systems are still challenged to simulate the bi-modal distributions observed in the Arctic



Liquid and Ice Water Paths

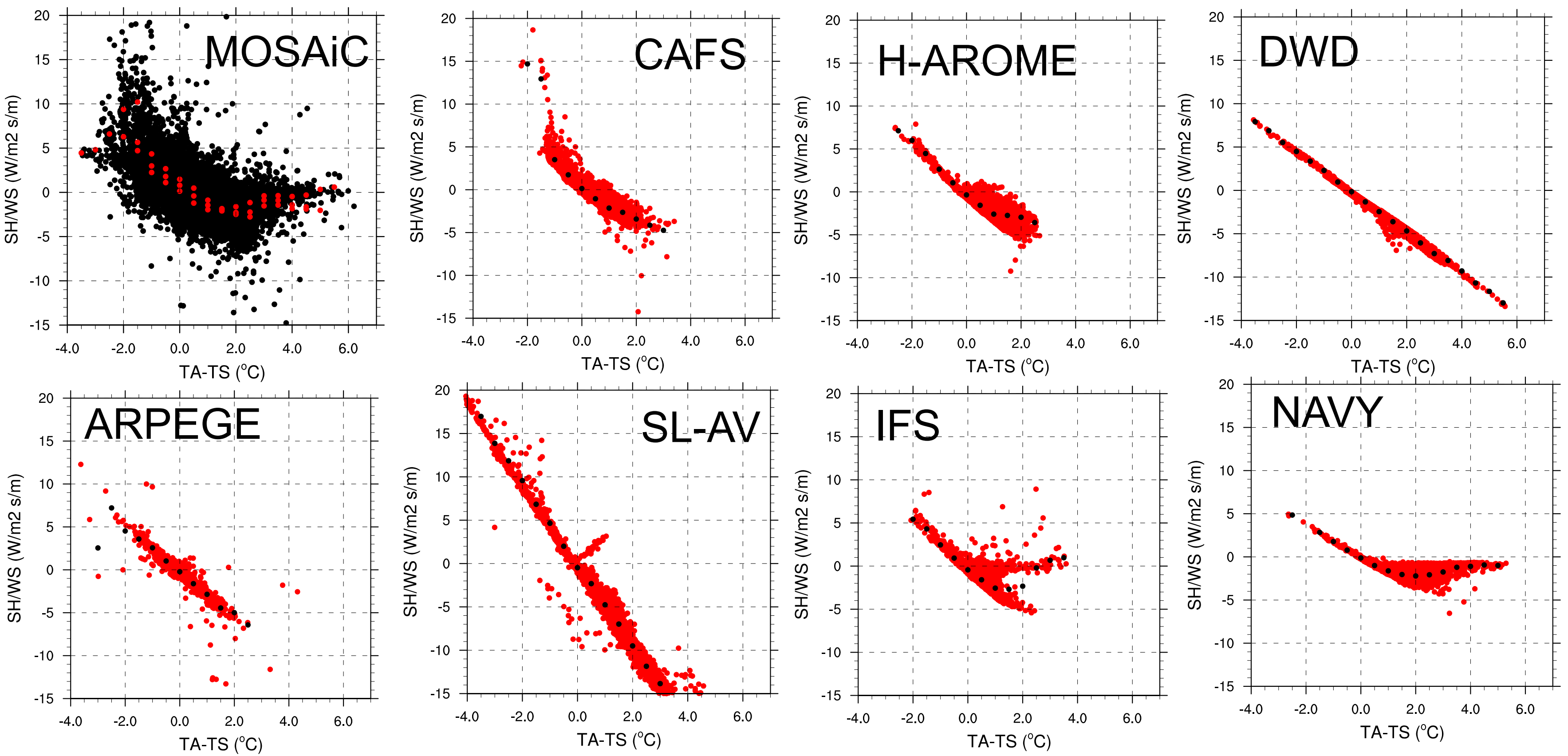
Current state-of-the art forecast systems can not maintain liquid in clouds at cold temperatures

Only one of the seven forecast systems used in this study has liquid water paths close to observations taken during MOSAiC

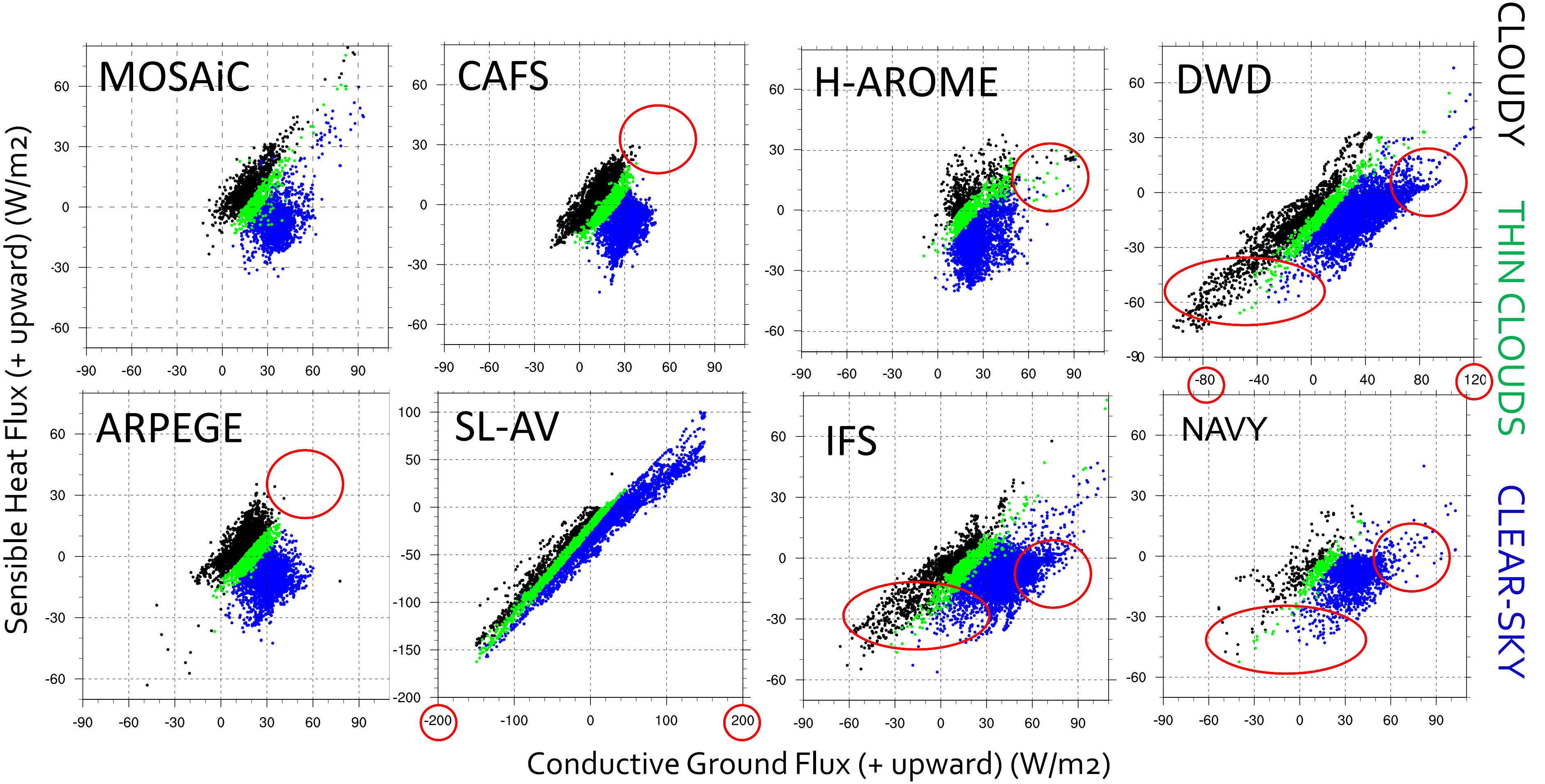


Scaled Sensible Heat Fluxes vs Near-Surface Stratification

$SH \propto C_t WindSpeed\, \Delta T$; $C_t \propto SH*WindSpeed/\Delta T$



Cloud-Turbulence-Ground Flux Interactions



Findings:

- Models struggle to maintain liquid water in clouds at cold temperatures, with only one of seven models producing cloud liquid water similar to observations.

- Only 2 models simulate observed distinct bi-modal clear-sky & cloudy modes.
  - One model has cloud liquid similar to observations and the other produces enough cloud ice without cloud liquid to produce two distinct modes.
  - 3 models have distinct clear-sky modes but underestimate the cloudy mode.
  - Only 2 models produce the observed near shutdown of turbulence for strongly stably stratified near-surface conditions.
  - 4 models do not simulate strongly stratified near-surface environments

- Diagnosis of the three surface energy budget terms, 3 models have variability in regimes with few observed occurrences; clear-skies with large upward conductive surface flux and small sensible heat flux, and large downward sensible heat flux and small conductive surface flux.

- Focused model studies are required to improve these parameterizations in order to produce reliable forecasts of the Arctic system and projections of the role of the Arctic in the climate system

Thank you to all the MOSAiC participants that made these studies possible

This research was funded by
the National Science Foundation, DOE, NOAA/ARP, and NOAA/PSL

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 105, NO. D10, PAGES 12,337–12,349, MAY 27, 2000

A comparison of cloud and boundary layer variables in the ECMWF forecast model with observations at Surface Heat Budget of the Arctic Ocean (SHEBA) ice camp

J. A. Beesley,[1,2] C. S. Bretherton,[3] C. Jakob,[4] E. L Andreas,[5] J. M. Intrieri,[6] and T. A. Uttal[6]

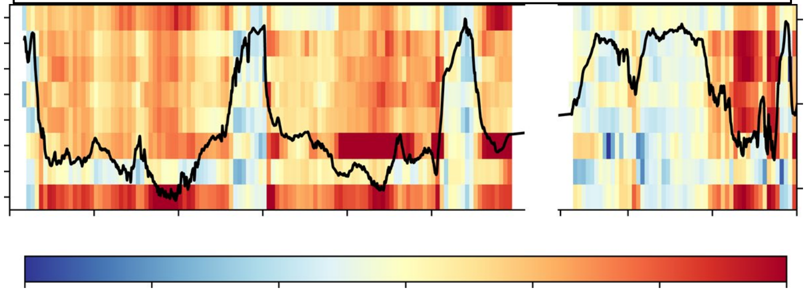
dependent partitioning of cloud condensate between water and ice. Lidar depolarization measurements at SHEBA indicate that both liquid and ice phase clouds occurred over a wide range of temperatures throughout the winter season, with liquid occurring at temperatures as low as 239 K. A much larger fraction of liquid water clouds was observed than the ECMWF model predicted. The largest discrepancies between the ECMWF model and the observations were in surface temperature (up to 15 K) and turbulent sensible heat fluxes (up to 60 W m^{-2}). These appear to be due at least partially to the ECMWF sea ice model, which did not allow surface temperatures to respond nearly as rapidly to changing atmospheric conditions as was observed.

Modelling of snow over sea ice (Gabriele Arduini)

Substantial temperature biases over sea-ice surfaces

- Implications for ice growth

Biases of different reanalysis surface temperature



Bias in wintertime clear-sky surface temperature between ERA5 and satellite product

Warm biases of several K in reanalyses and operational IFS

Biases focussed on high snow cover over the Arctic

No thermodynamic effect due to snow (insulation)

nature COMMUNICATIONS

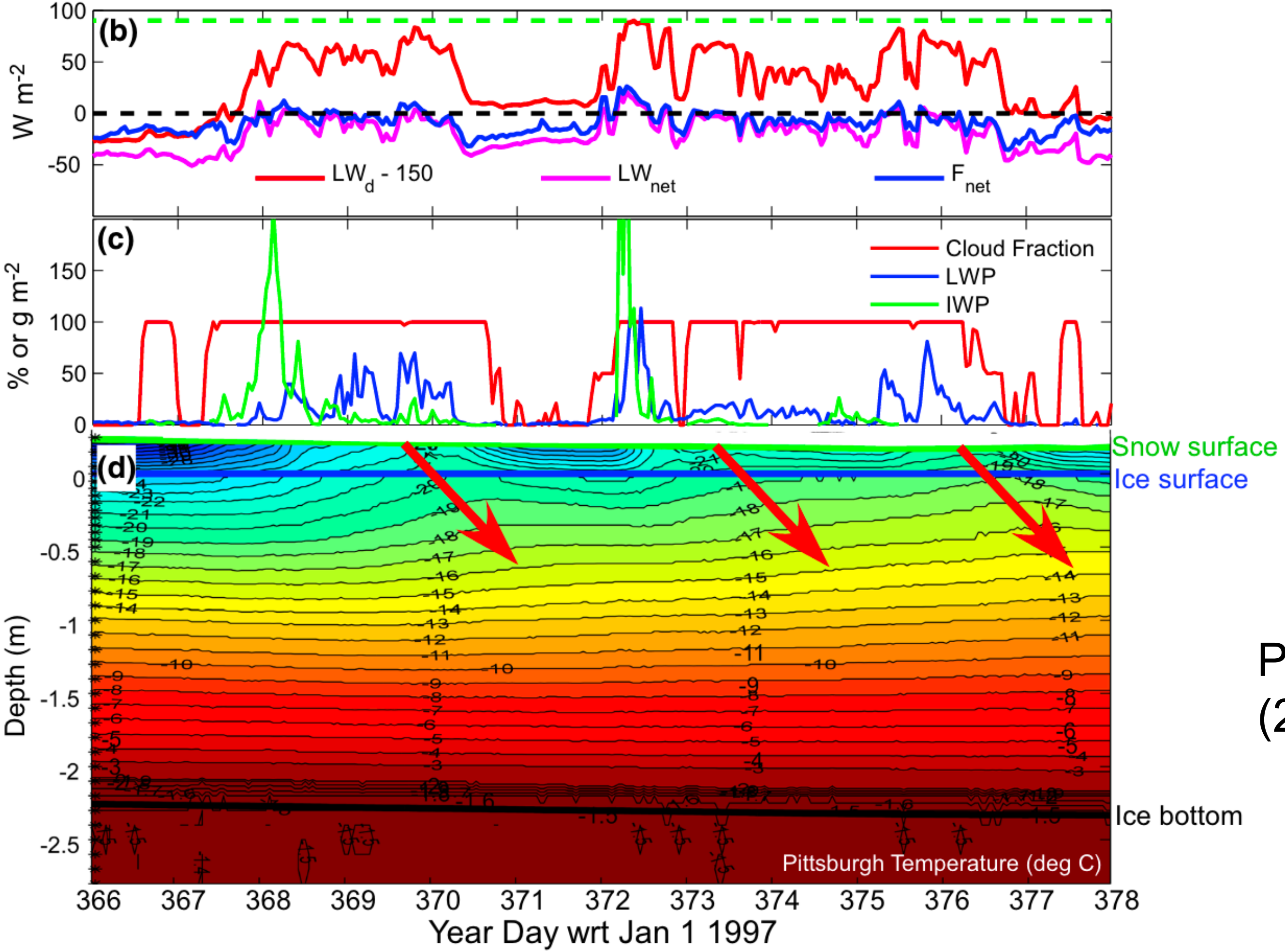
ARTICLE

https://doi.org/10.1038/s41467-019-11975-3 OPEN

On the warm bias in atmospheric reanalyses induced by the missing snow over Arctic sea-ice

Yurii Batrak[1] & Malte Müller[1]

Thermal structure within the snow and sea ice

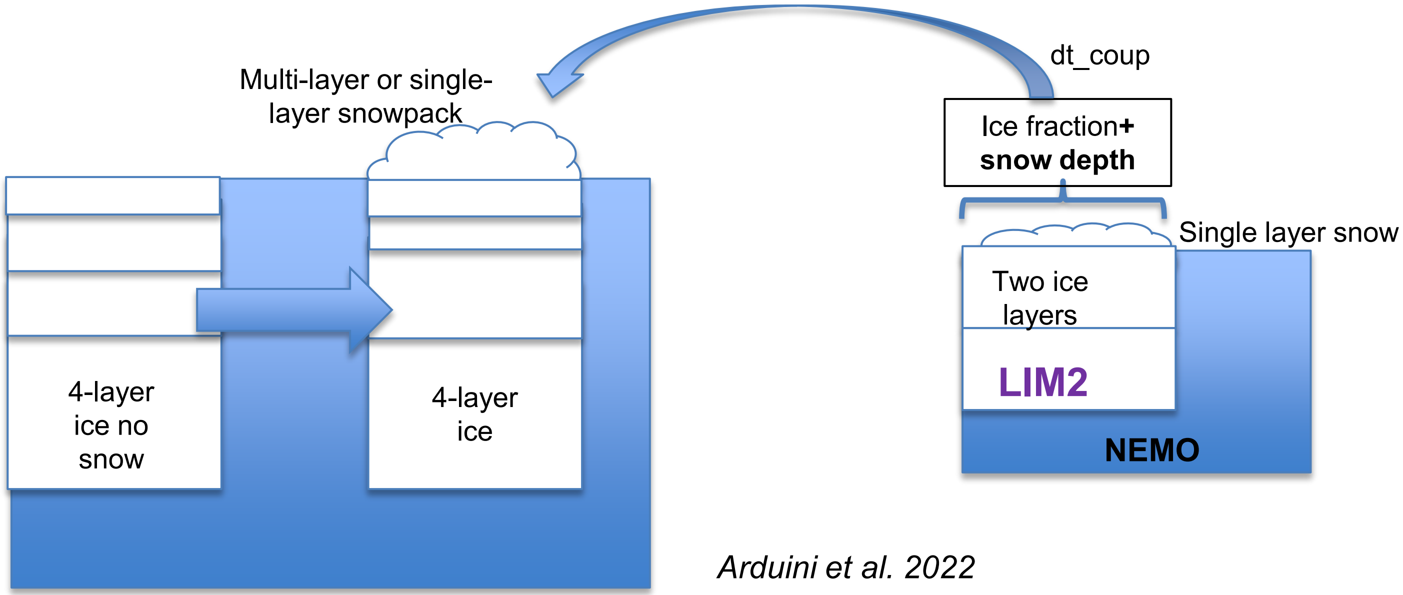


Persson et al. (2018)

Testing the impact of snow over sea-ice in the ECMWF IFS

Accounting for the thermal effect of snow on top of sea-ice in the IFS

Coupling of ice fraction **and snow depth** from sea-ice model

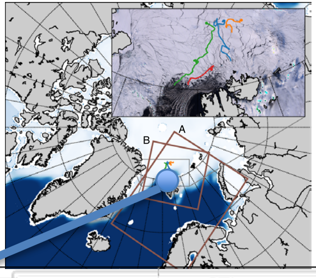


Arduini et al. 2022

APPLICATE.eu
Advanced prediction in polar regions and beyond

Evaluating the impact of snow over sea-ice in the ECMWF IFS – **in situ**

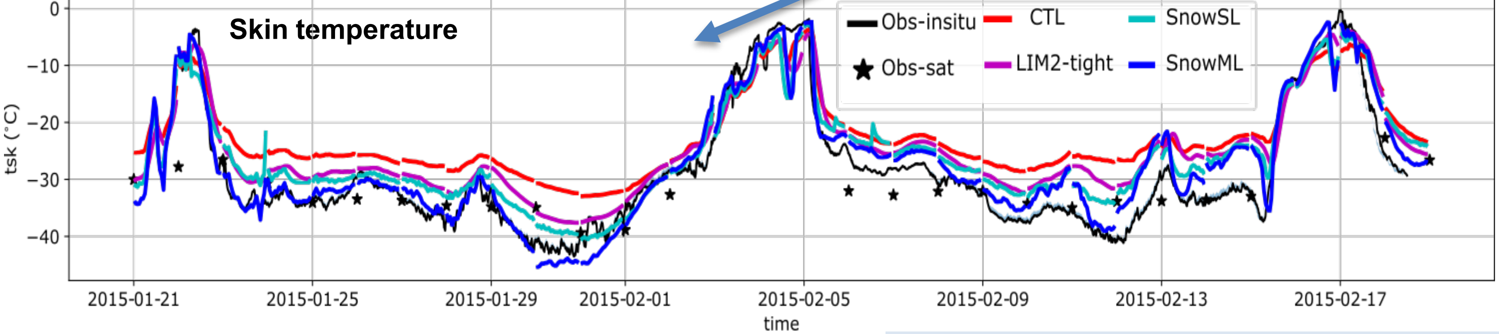
Evaluation using *in situ* observations from **N-ICE2015** campaigns and co-located CMEMS satellite observations, Jan/Feb 2015



Obs *in-situ*

Obs *satellite*

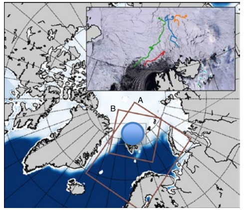
Ctl (no snow) Multi layer snow

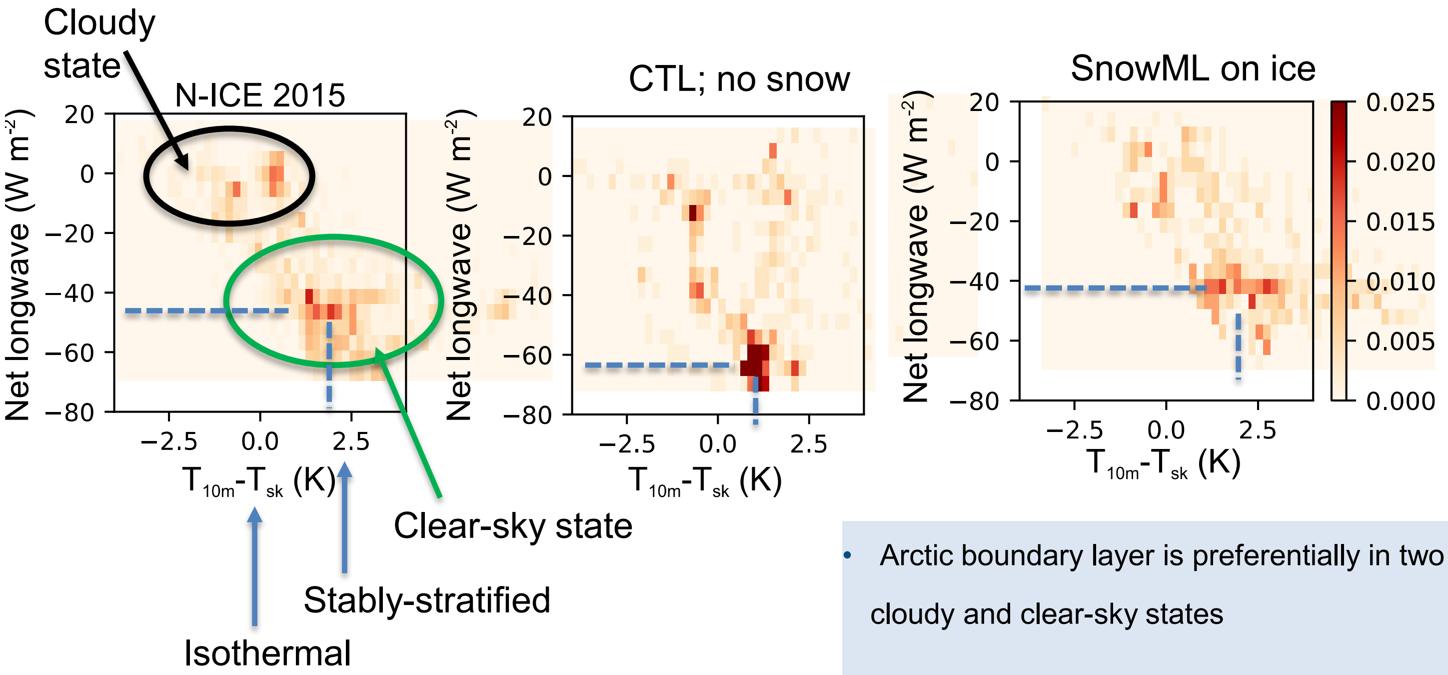


Arduini et al. 2022

- Accounting for snow over sea-ice improves the match of the short-range FC to in-situ observations
- Variability of surface temperature more consistent with observations

Impact on Arctic winter states – NICE2015 case

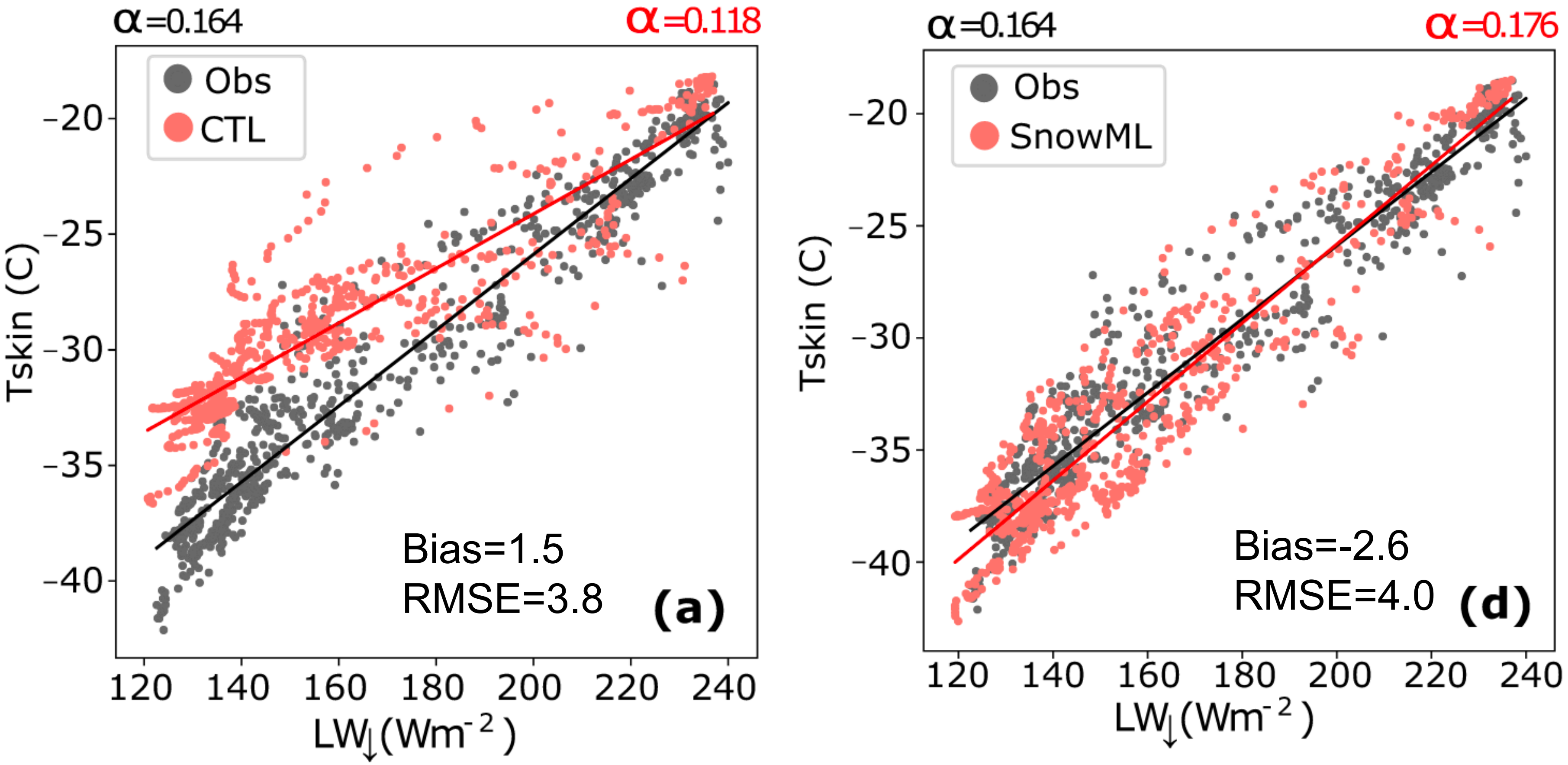




Arduini et al. 2022

- Arctic boundary layer is preferentially in two states – cloudy and clear-sky states
- No-snow experiment shows little sensitivity in temperature inversion to net longwave variations
- Accounting for snow over sea-ice enables a better description of the clear-sky state and atmospheric inversions

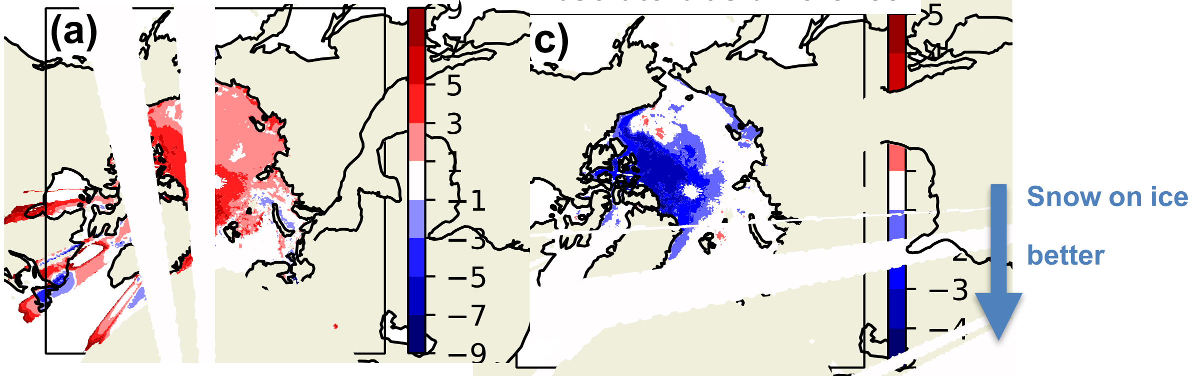
ML snow improves the sensitivity of Tsk to LW↓



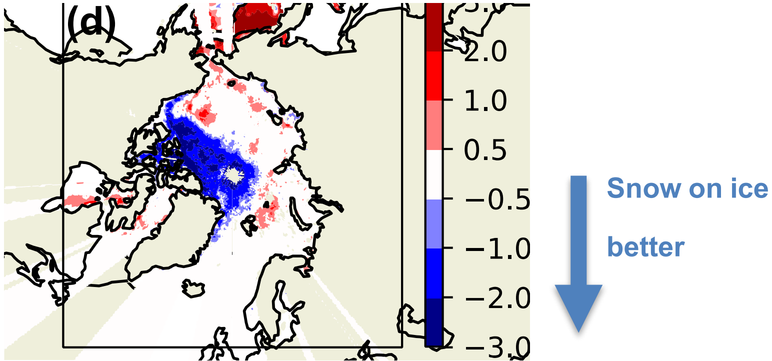
Evaluating the impact of snow over sea-ice in the ECMWF IFS – Arctic

Skin temperature of **analysis** against CMEMS satellite surface temperature observations, DJF 2020/2021

Bias in control experiment | **Absolute bias difference**



RMSE diff against satellite Surface temperature



ECMWF

Conclusions and additional thoughts

- Beesley's main issues: 1) insensitive sea ice surface, 1) too many liquid clouds, 3) errors in sensible heat flux.

1) Experiments with a multi-layer snow model increase the sensitivity in the near-surface temperature over sea ice, improving the physical realism of the winter boundary-layer states in the IFS (particularly for the "clear-state")

2) A –ve bias in LW↓ , resulting from under-representing the frequency of "cloudy-state" (potentially related to a –ve bias in LWP) in the IFS remains a challenge.

3) Parameterization of SHF looks OK in the IFS, but some models incorrectly represent the link to thermal stratification.

4) 1) and 2) need to be addressed in parallel due to compensating errors.