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High resolution aerosol-cloud modelling over the Southern Ocean and Antarctic

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Australian Antarctic Program Partnership

The Australian Antarctic Program Partnership is funded by the Australian Government Department of Industry, Science, Energy and Resources through the Antarctic Science Collaboration Initiative.

The Australian Antarctic Program Partnership is led by the University of Tasmania, and includes the following partner agencies

Climate models still have a large radiative bias over the Southern Ocean, including ACCESS

Too much radiation allowed to reach the surface

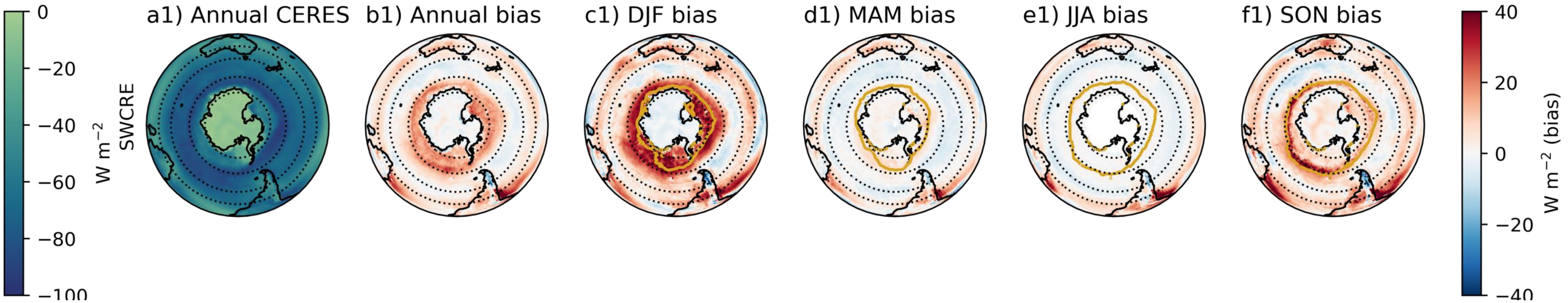
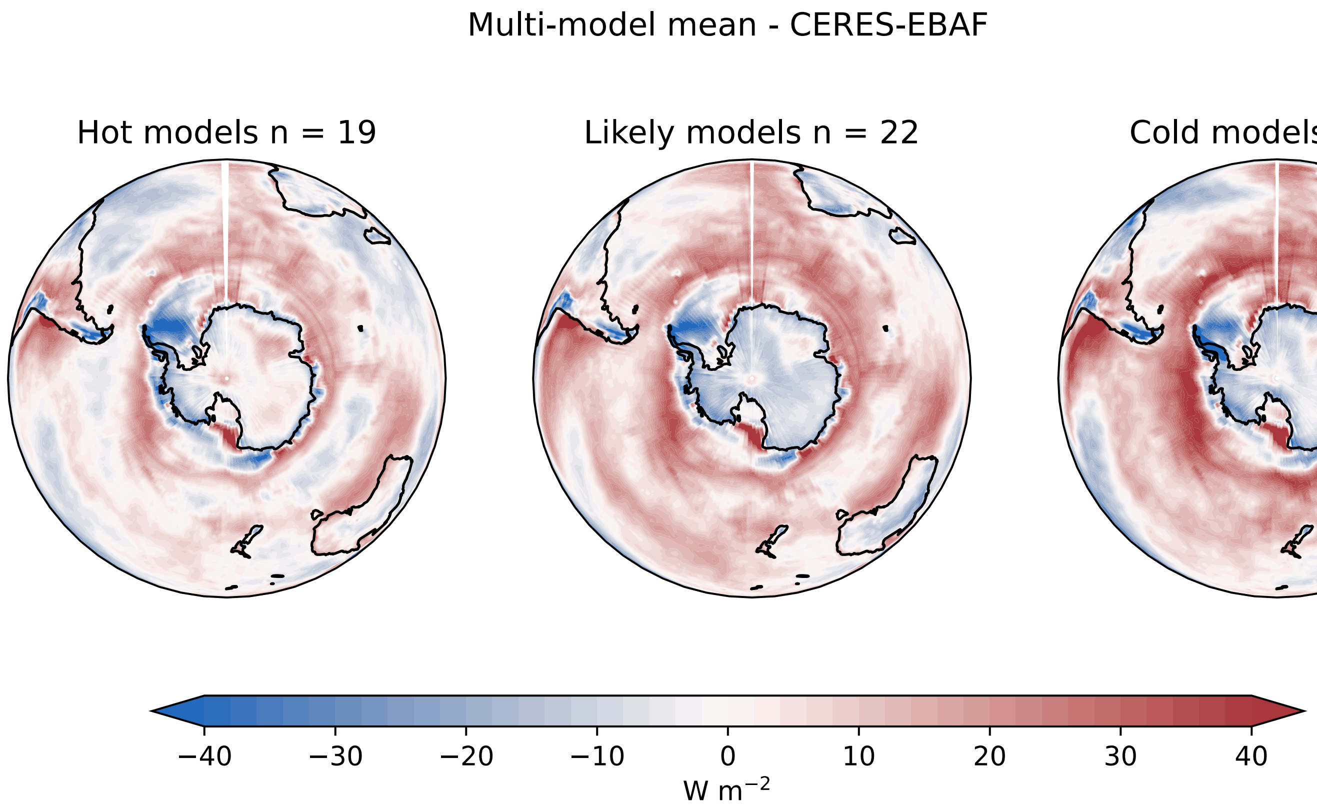


Fig: Top of atmosphere outgoing shortwave cloud radiative effect

Fig: Fiddes et al. 2022, *ACP*
https://doi.org/10.5194/acp-22-14603-2022

The same is found generally for the CMIP6 models

Fig: The DJF bias in surface incoming shortwave cloud radiative effect for the CMIP6 models based on their equilibrium climate sensitivity against CERES-EBAF



See Mallet et al. (2023) for details
https://doi.org/10.1525/elementa.2022.00130

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Also in reanalysis!

Fig: The surface shortwave radiation bias of ERA5 compared to observations from the Aurora Australis over 25 years a) by month, b) by latitude

We are exploring the long wave story with an honours student now

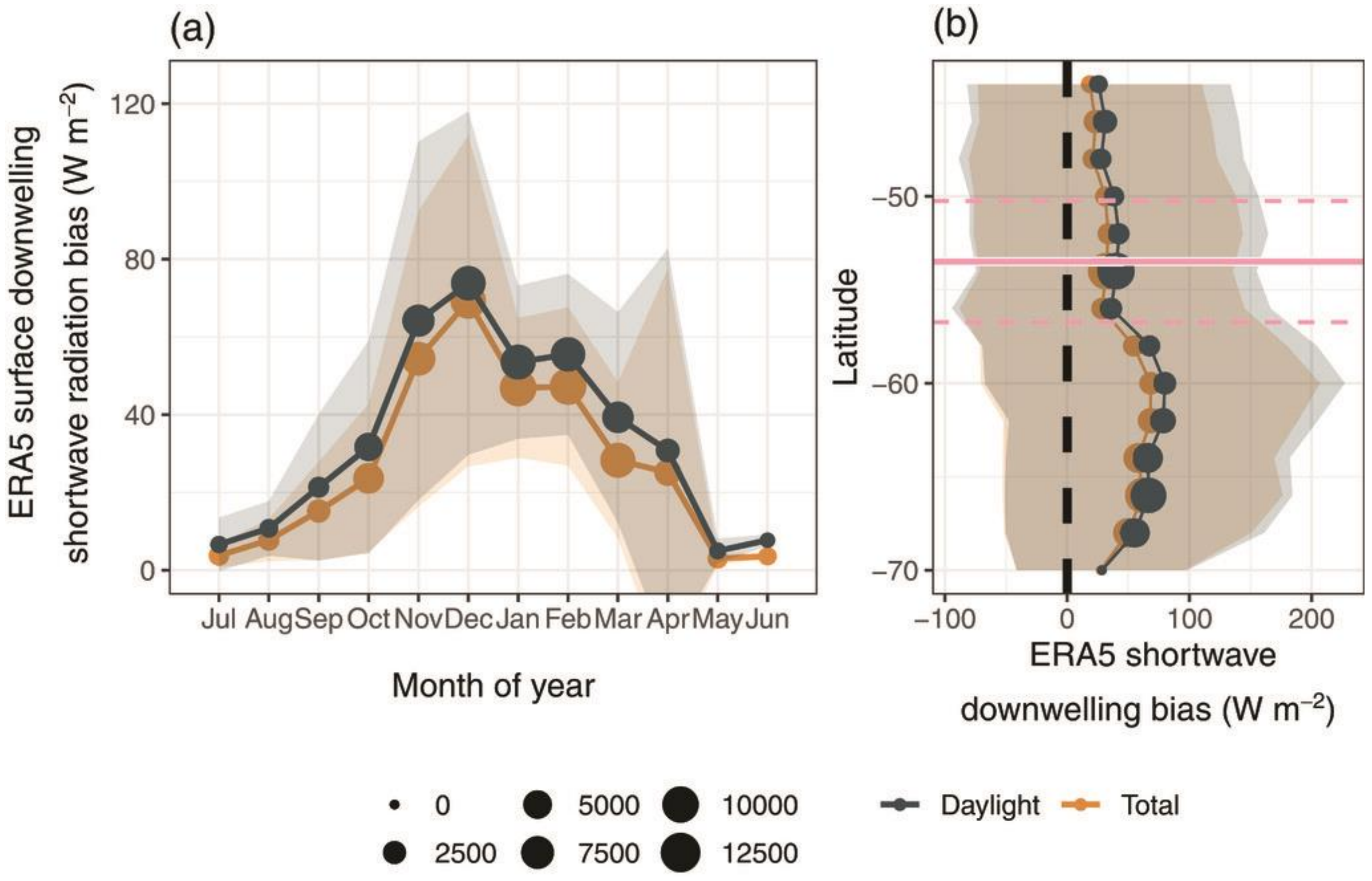


Fig: Mallet et al. 2023, *Artificial Intelligence for the Earth Systems*
https://doi.org/10.1175/AIES-D-22-0044.1

And in forecast models…

Fig: The mean shortwave and long wave cloud radiate effect biases based on cloud type in the ACCESS-C3 model compared to observations during CAPRICORN I (2016)

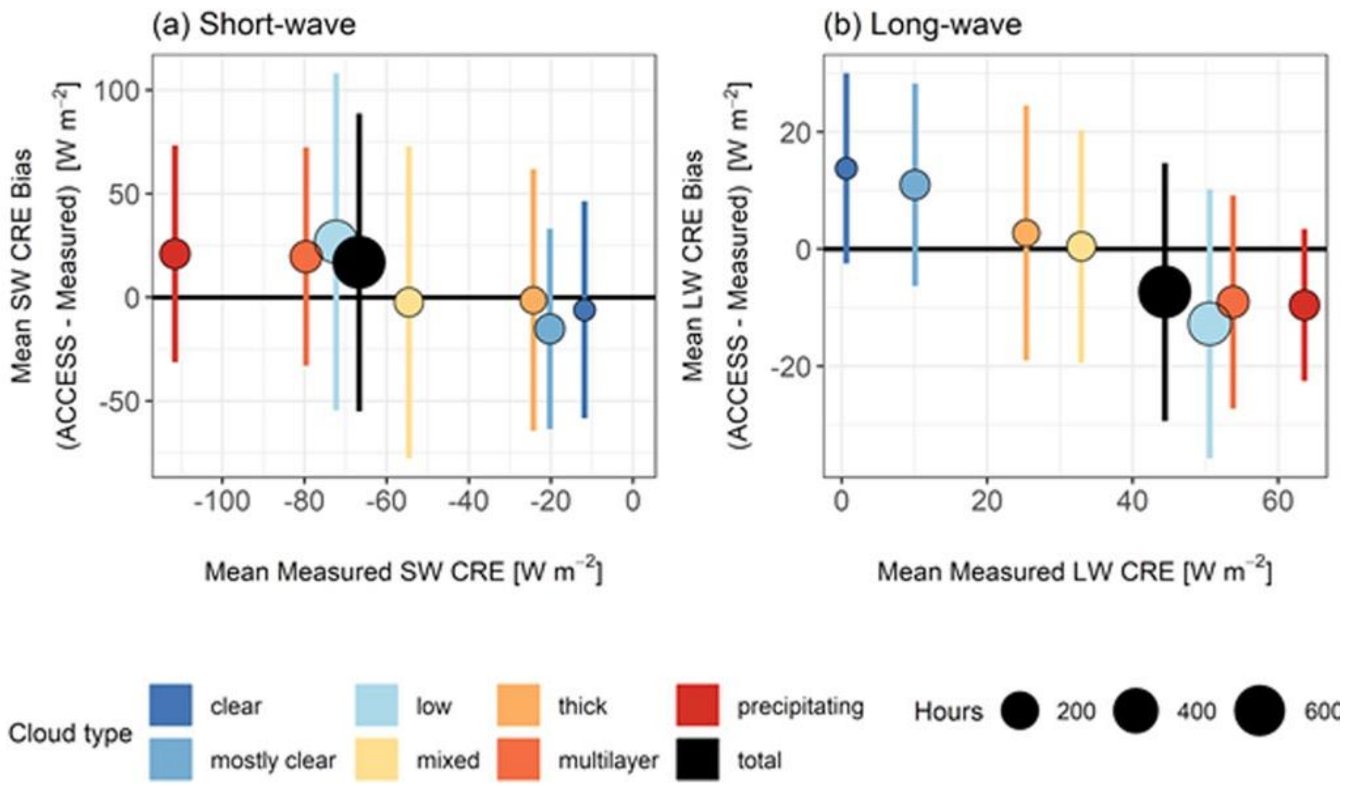


Fig: McFarquhar et al. 2021, *BAMS*

We are also concerned that the satellite products we use to evaluate our models are biased

This could make our model biases even worse.

This is being explored by PhD student Calum Knight currently.

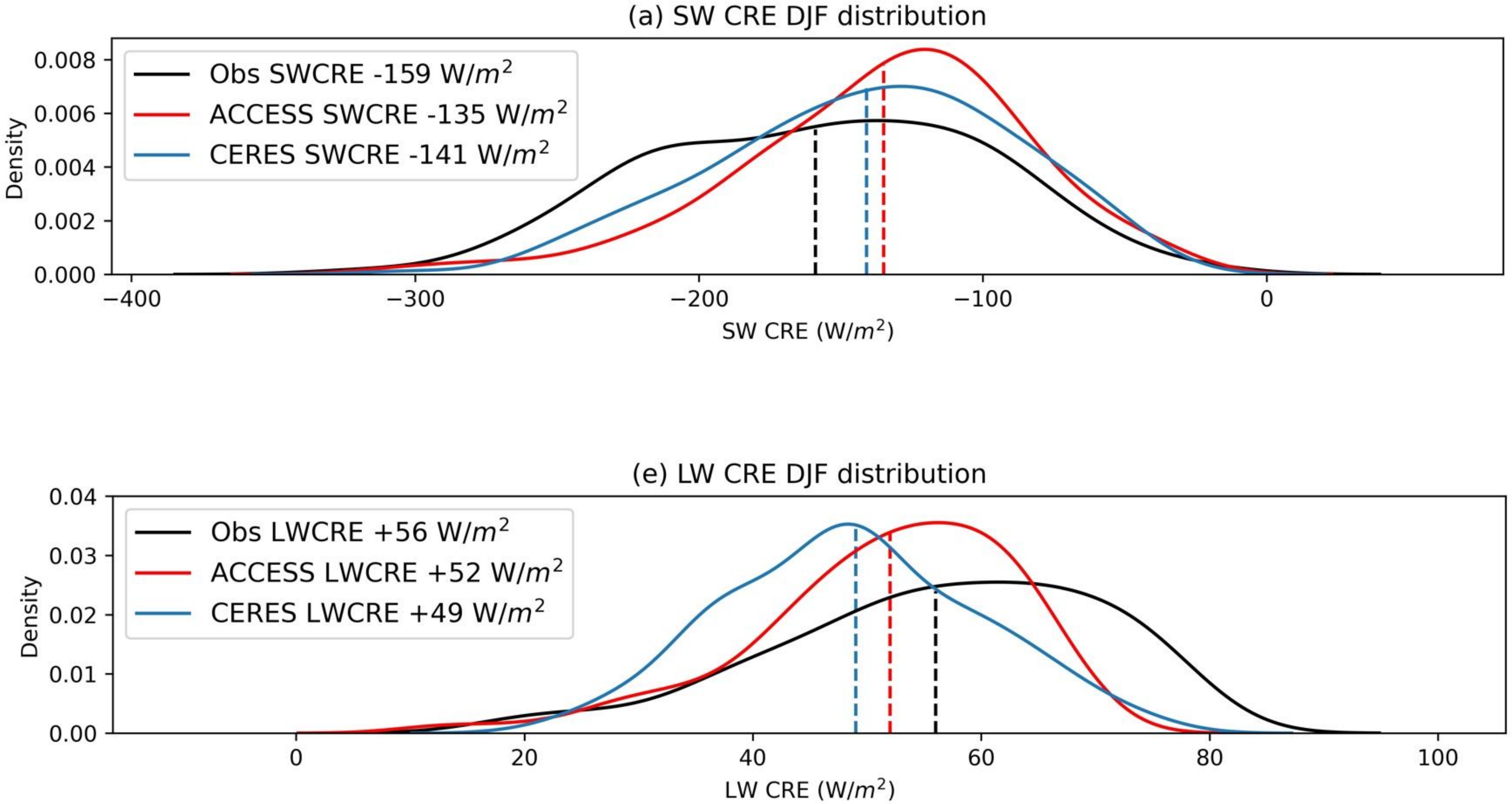


Fig: The surface shortwave and longwave cloud radiative effect at Macquarie Island for ACCESS, CERES and in situ observations.

Fig: Pei et al. 2023, *ACP*
https://doi.org/10.5194/acp-23-14691-2023

Too much ice in clouds instead of liquid water is the primary cause of the radiative bias

Ice clouds do not reflect as much sunlight back out to space.

Total liquid cloud fraction bias in ACCESS compared to MODIS via COSP

Total ice cloud fraction bias ACCESS compared to MODIS via COSP

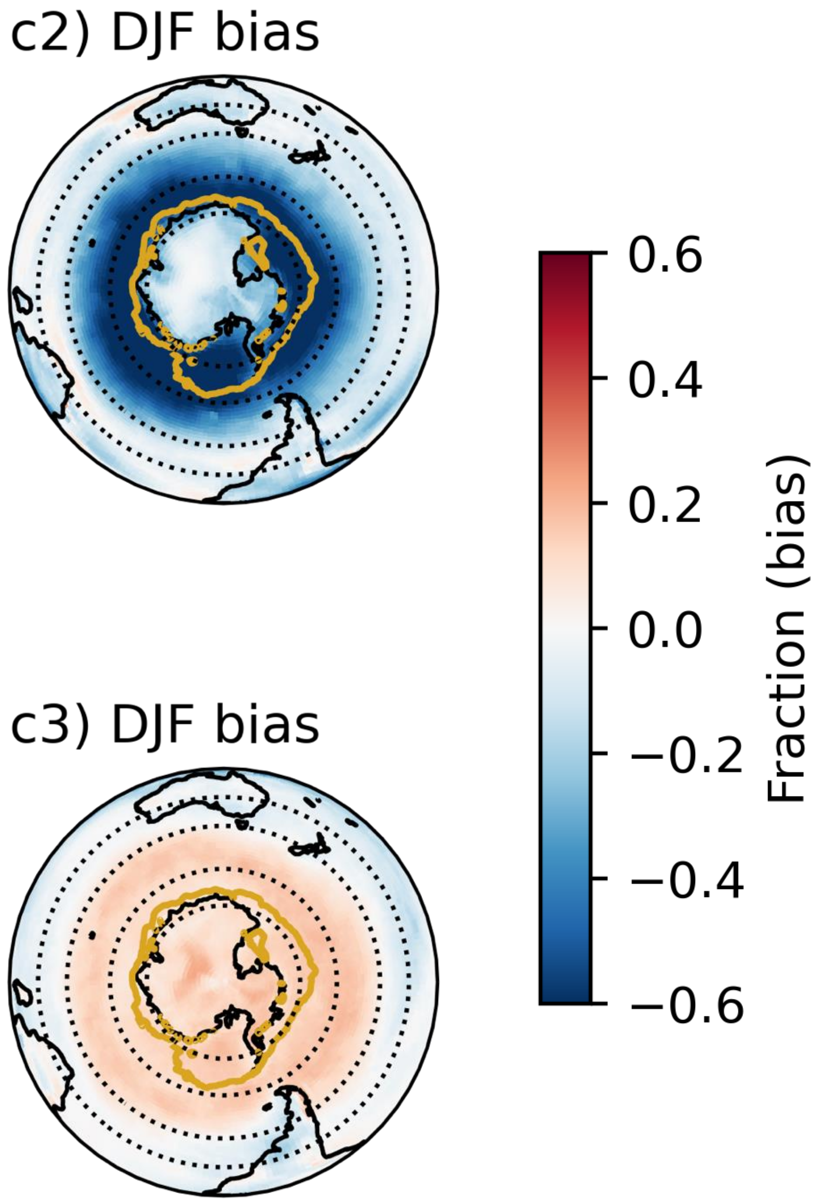


Fig: Fiddes et al. 2022, *ACP*
https://doi.org/10.5194/acp-22-14603-2022

The presence of ice nucleating particles (specific types of aerosol) can influence the phase and optical properties of a cloud

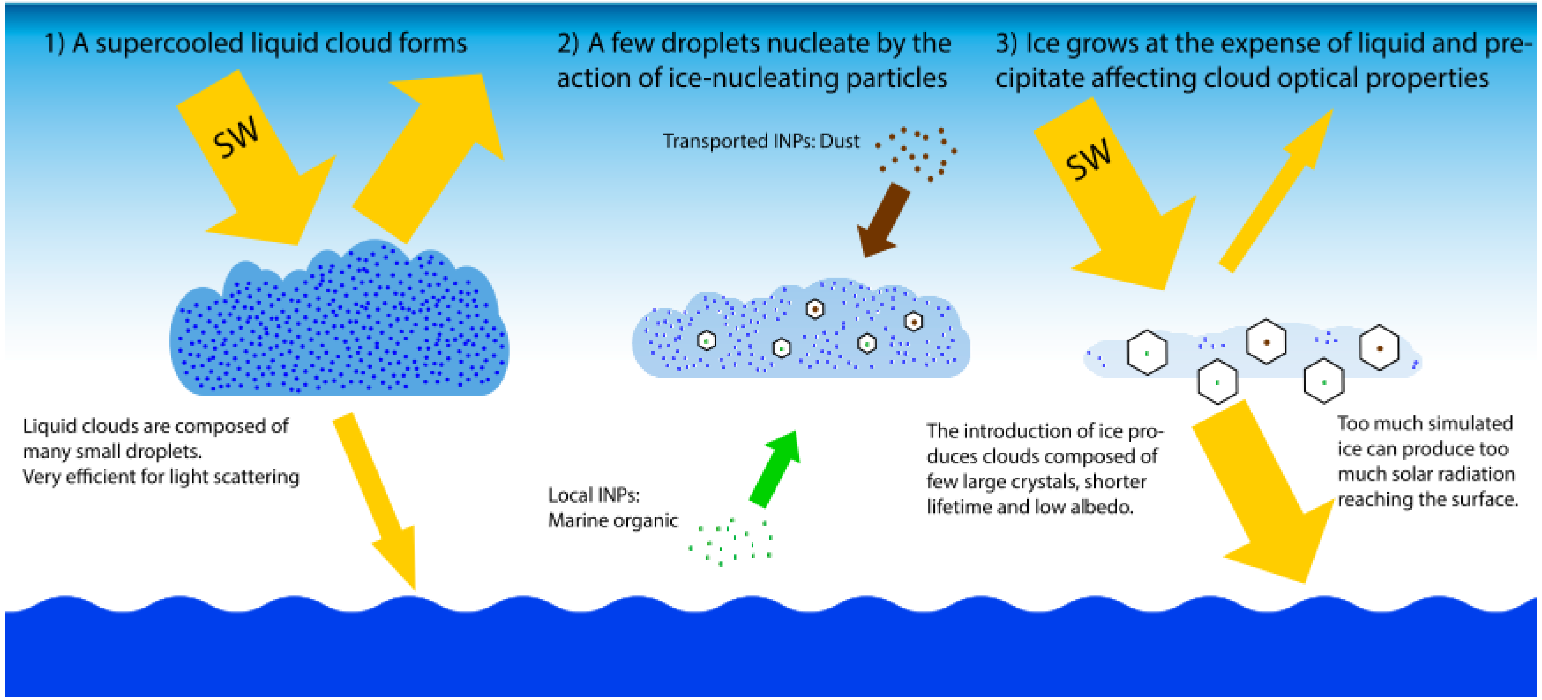


Fig. 1. Schematic representation of the effect of INPs on marine mixed-phase clouds. Variations on the concentrations of INP both transported and emitted locally can strongly modify the evolution of low-level clouds by affecting the number of ice nucleation events. Each cloud represents a different time in the evolution of the cloud system. The yellow arrows represent radiative fluxes, the green arrow represents INP sources from below cloud, and the brown arrow represents INP sources from the free troposphere.

Figure from: Vergara-Temprado et al (2018) *PNAS*

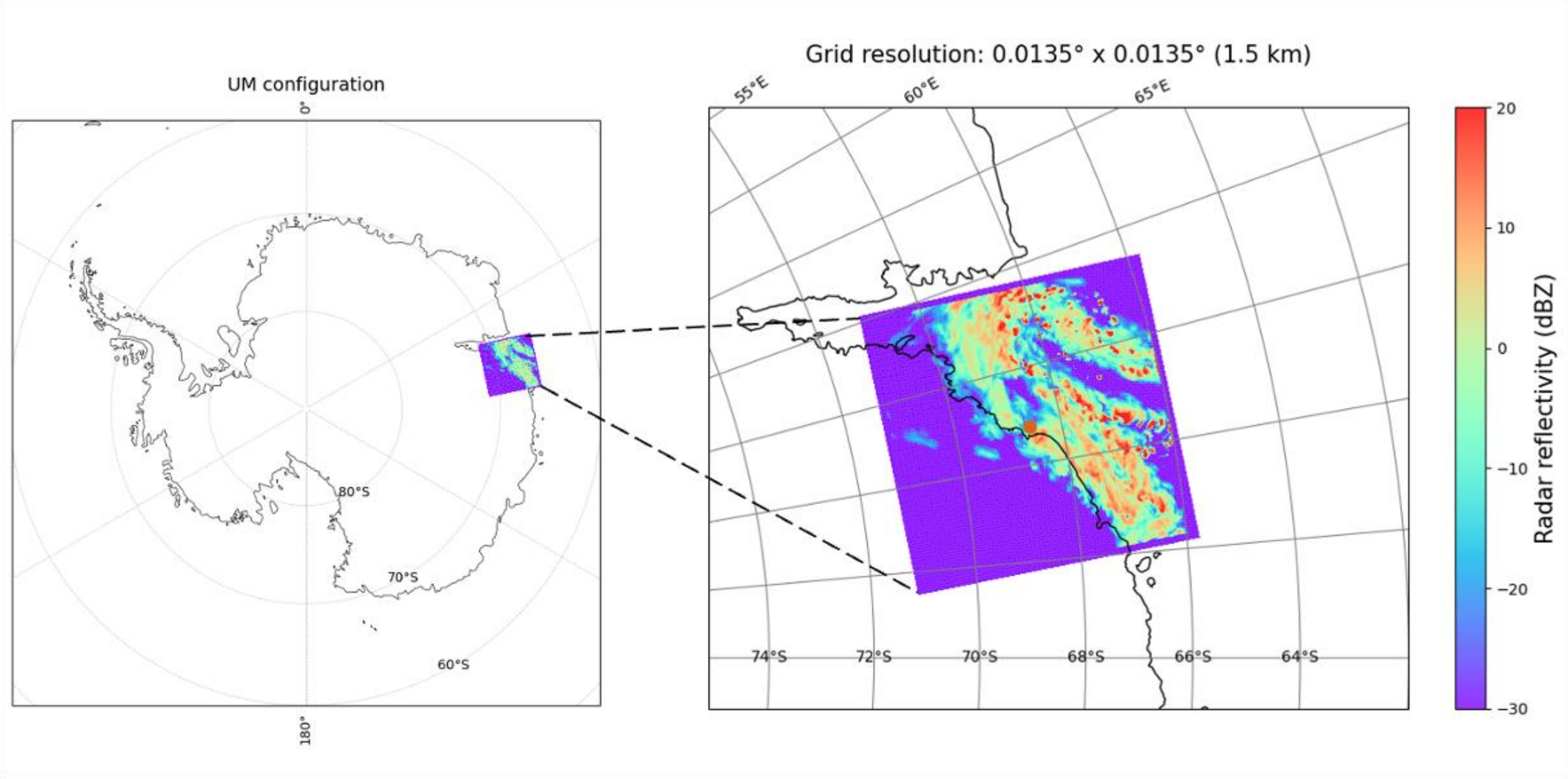
We want to evaluate the radiative bias with the new CASIM microphysics, which has more opportunity to connect the clouds to aerosol.

Image taken on V2 of the Aurora Aus., 2017/18, MARCUS field campaign, S. Fiddes

We are running the UM RNS (RAL3.1+) over Davis, Antarctica, targeting a Year or Polar Prediction deployment of instruments

UM version 13.0

RAL3.1+ vs RA2M
CASIM vs WB
Bimodal cloud scheme
1.5 km & 100m resolution
Driven by ERA5



Pei et al. 2024 (submitted JGR Atmos)

We have chosen a complex precipitation event to test the model

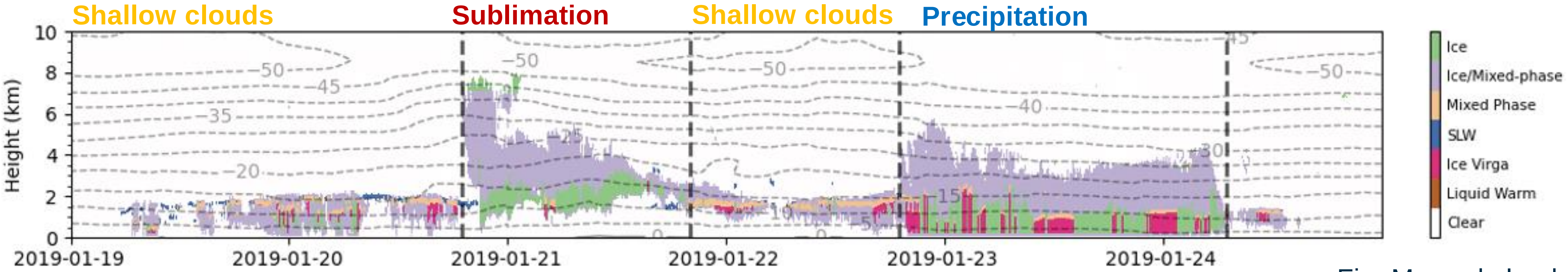
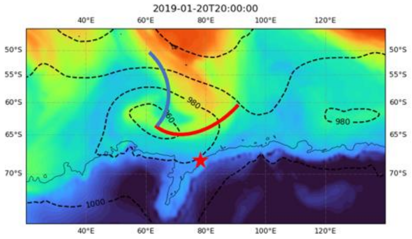


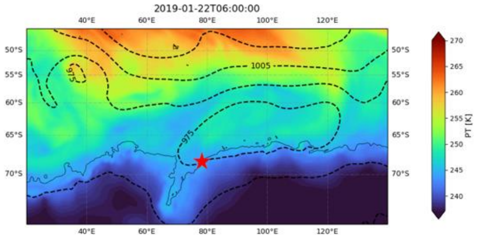
Fig: Merged cloud radar/lidar cloud phase product

Super-cooled liquid water layers, pre-frontal, shallow clouds

Synoptics interacting with Foen winds causing sublimation of snowfall. Deep ice cloud.

Low pressure system moves away from coast, katabatics weaken, precipitation observed at ground level. Mixed phase cloud





Pei et al. 2024 (submitted JGR Atmos)

UM shows cold biases and weaker horizontal winds.

RA2M slightly outperforms RAL3 in simulating the surface temperature and wind speed.

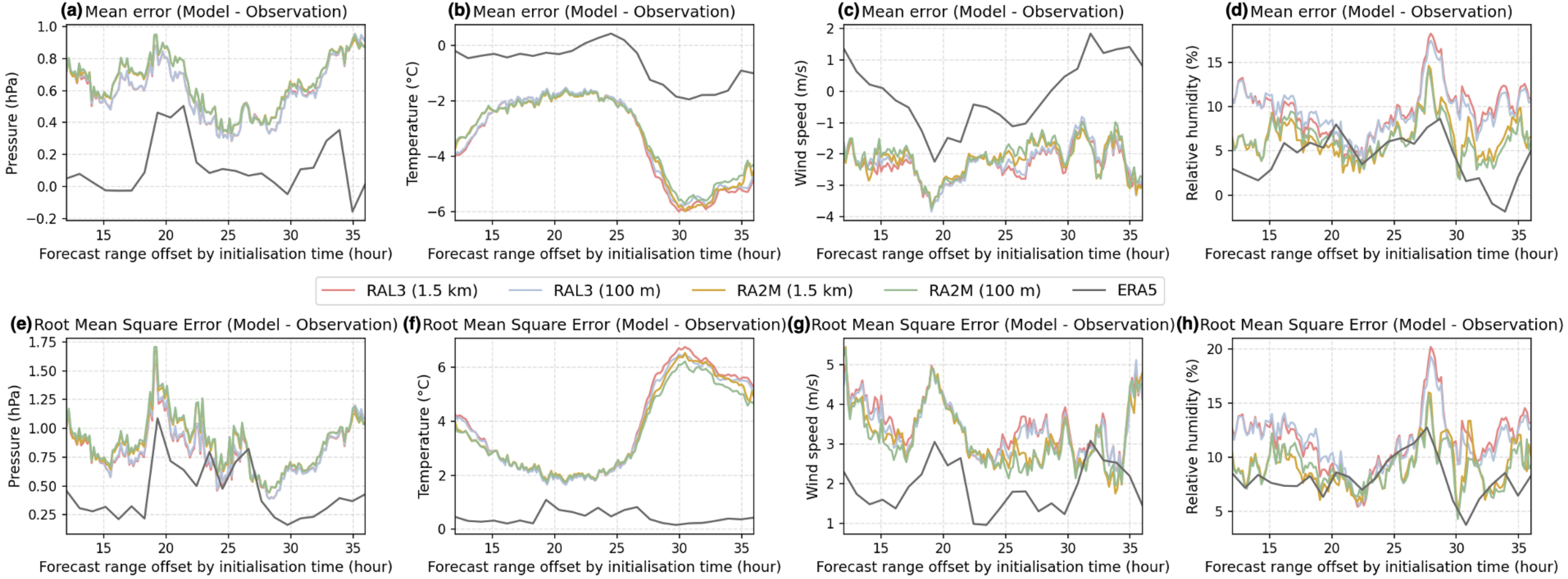


Fig: Top – mean error; bottom – RMSE for MSLP (left), temperature (middle left), wind speed (middle right), humidity (right)

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Pei et al. 2024 (submitted JGR Atmos)

UM models can generally simulate the timing and vertical structure of the larger-scale clouds, but problems with phase exist.

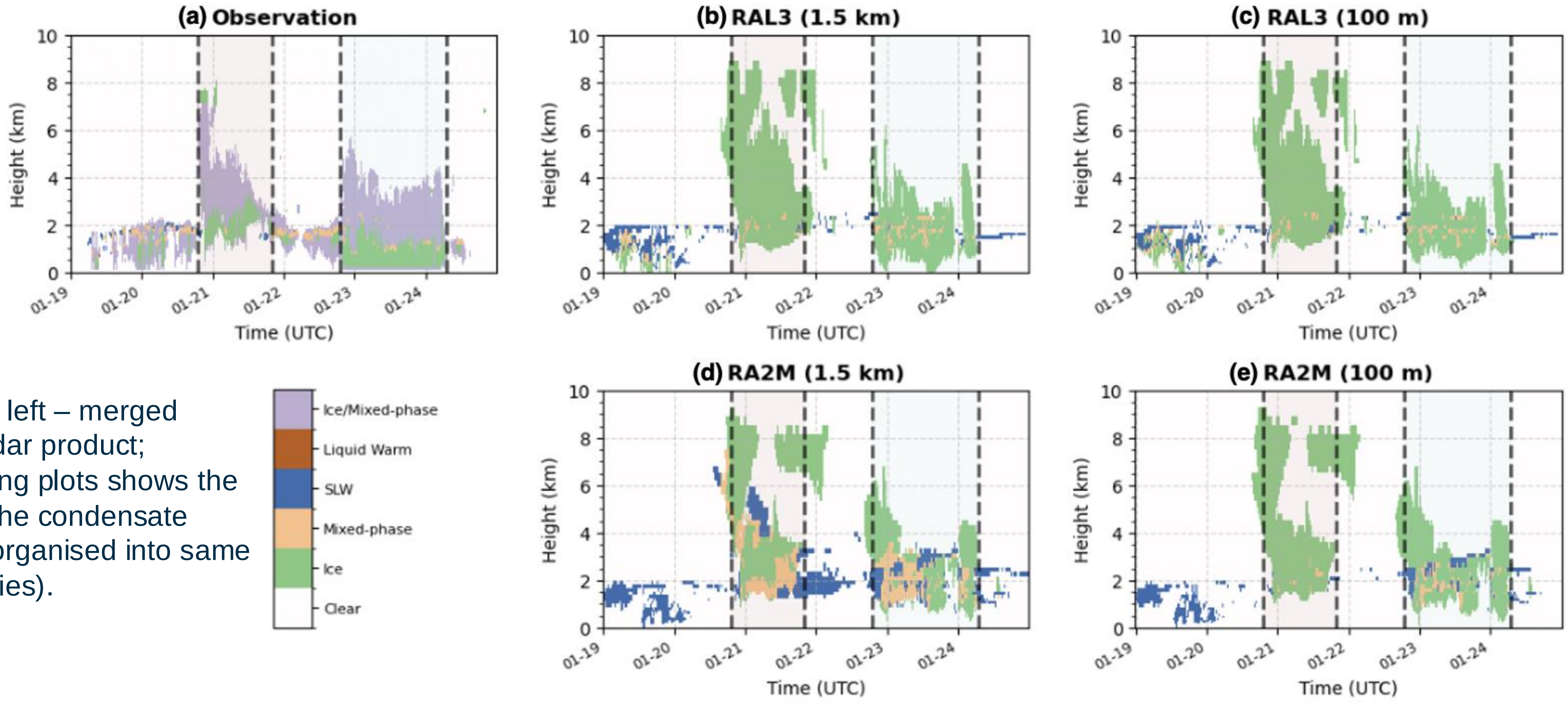


Fig: top left – merged radar/lidar product; remaining plots shows the model the condensate mass (organised into same categories).

Pei et al. 2024 (submitted JGR Atmos)

All model configs are not producing enough cloud at low levels and the SCLW is not distributed correctly with height or temperature. RAL3 produces more frequent clouds at right level

This comparison is done with the Ceilometer data combined with the Automatic Lidar Ceilometer Framework (ALCF) – a simulator to compare model output to observations (Kuma et al. 2021 https://doi.org/10.5194/gmd-14-43-2021)

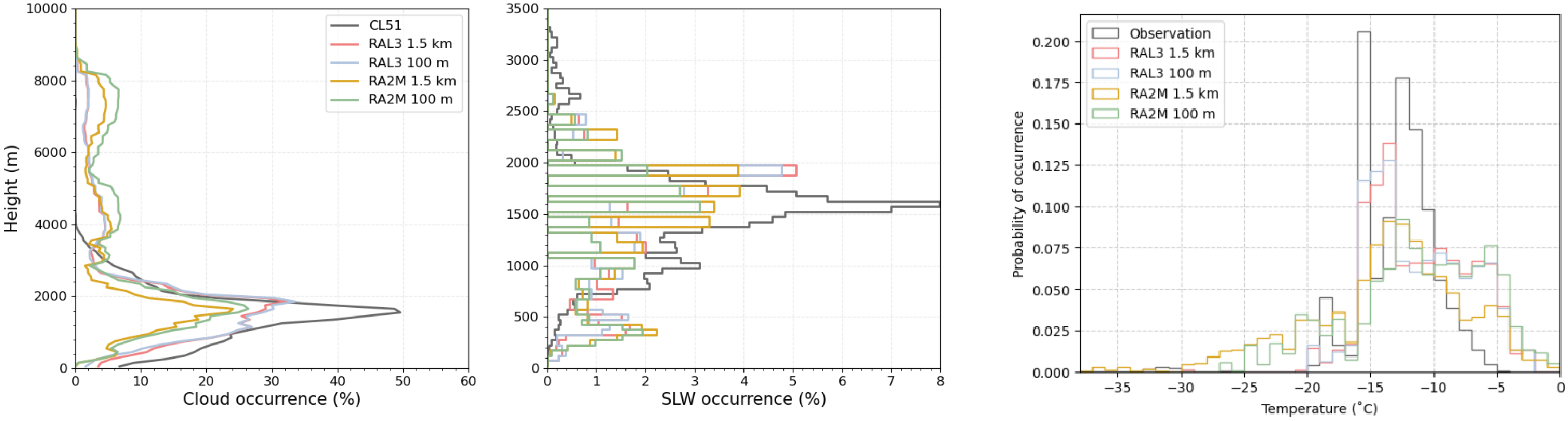
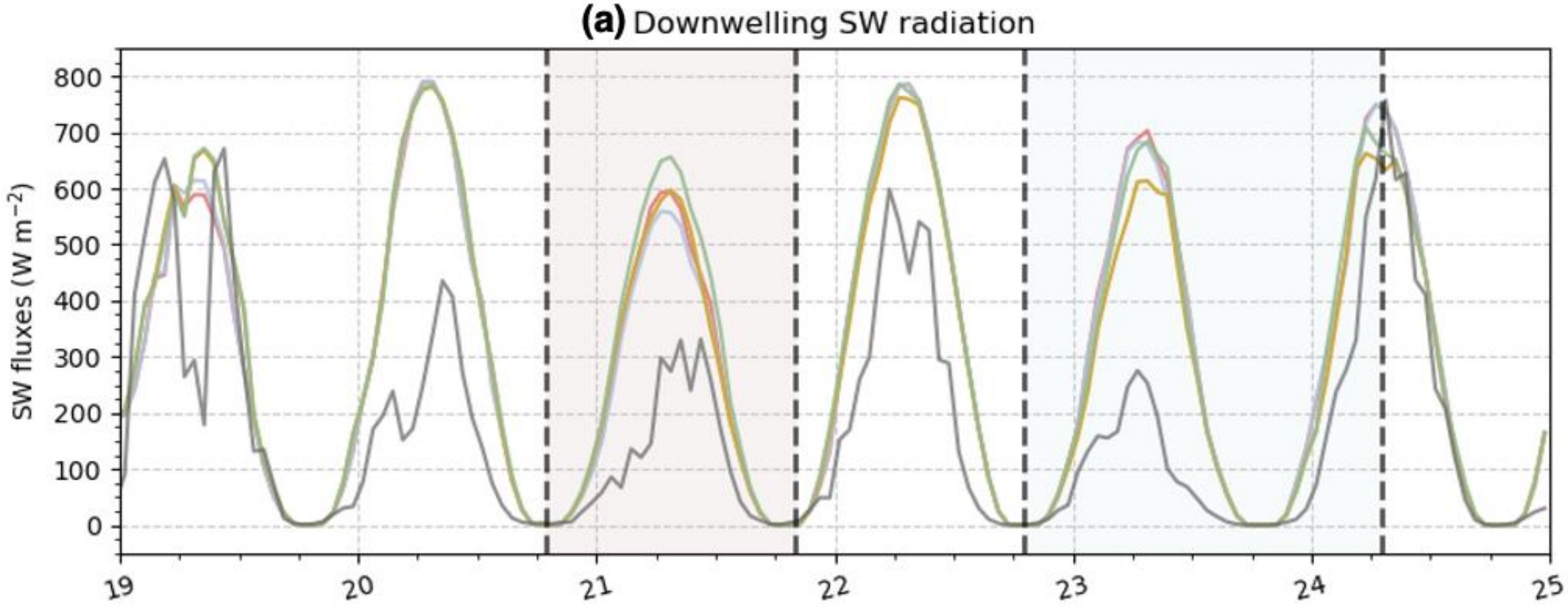


Fig: left – cloud occurrence with height; middle – SCLW occurrence with height; right – SCLW occurrence with temperature.

Pei et al. 2024 (submitted JGR Atmos)

Significant radiation biases are apparent in both long wave and short wave



Model not getting timing of shallow cumulus clouds, also not producing enough SCLW

Model allowing too much sunlight through despite overestimating IWP & little evidence of SCLW present. ???

Model not producing enough SCLW/too much ice

Model not getting timing of shallow cumulus clouds/not enough SCLW

Pei et al. 2024 (submitted JGR Atmos)

Updating the ice nucleating particle parameterization to the Vignon et al. (2021), derived from observations at Mawson, improves LWP

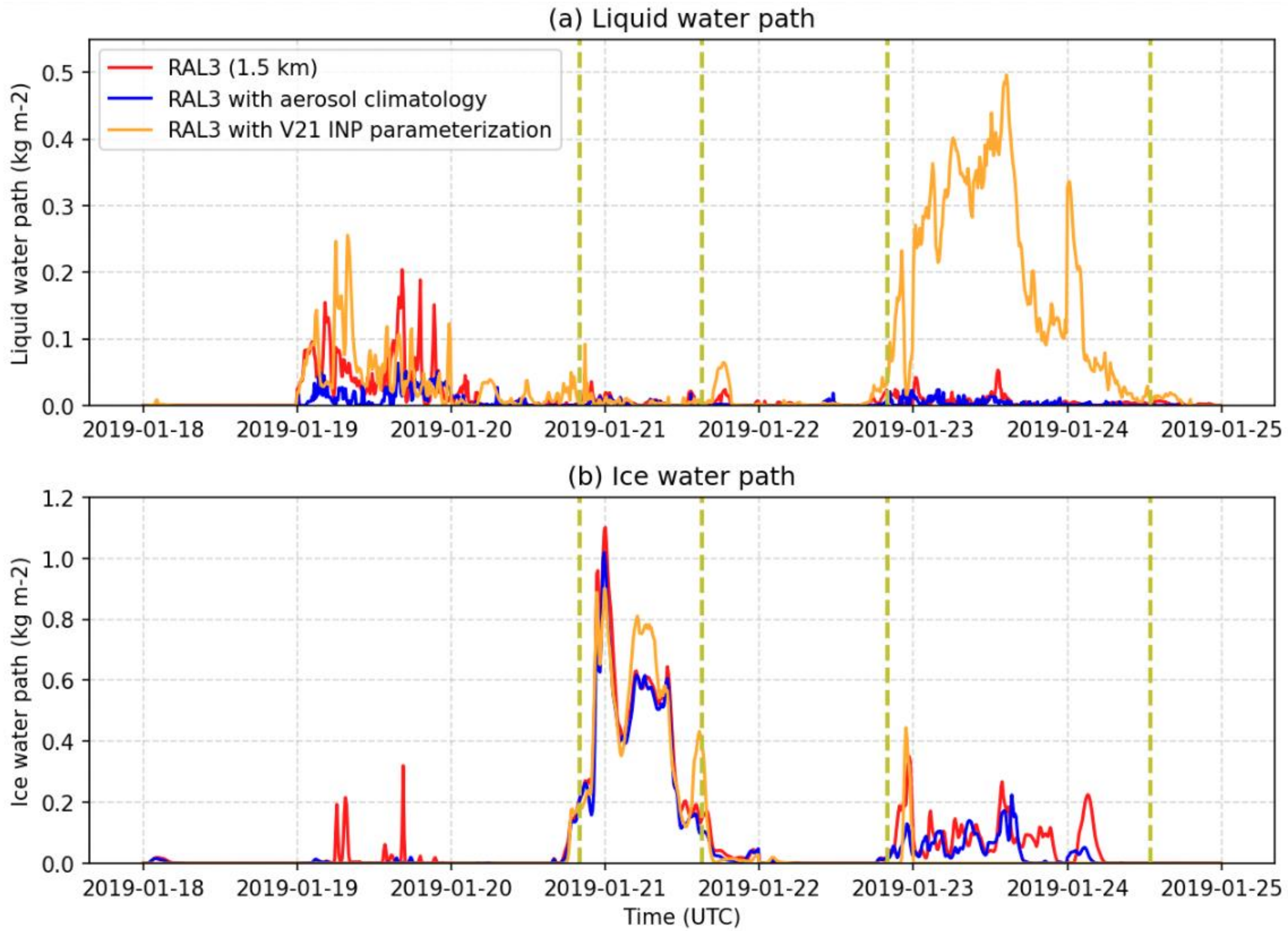


Figure from Z. Pei

And improves radiation in times where LWP is present.

No improvement during our large ice cloud (red shading).

Overestimated IWP still allowing too much sunlight through???

Different microphysical process needs to be addressed here!

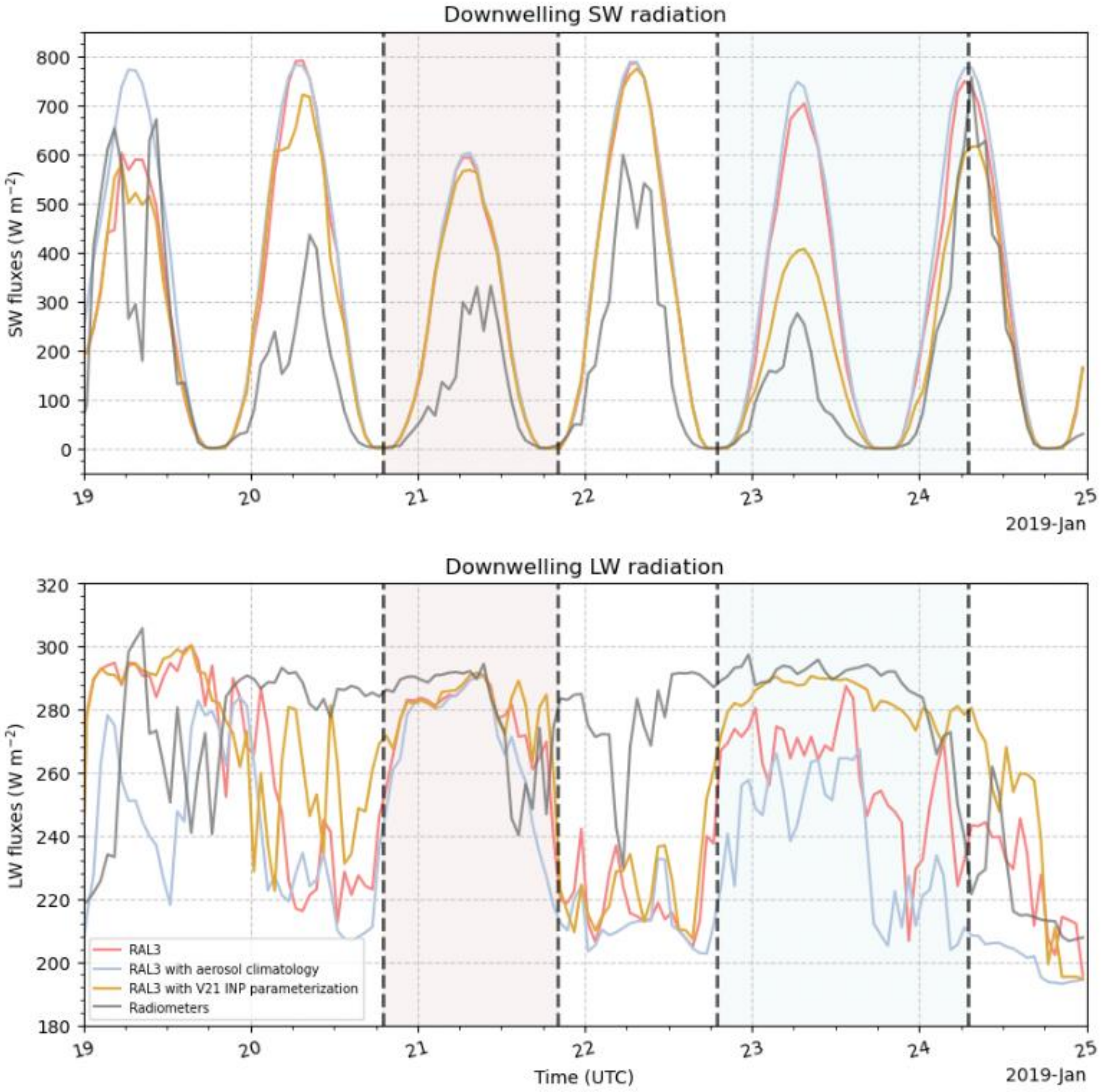
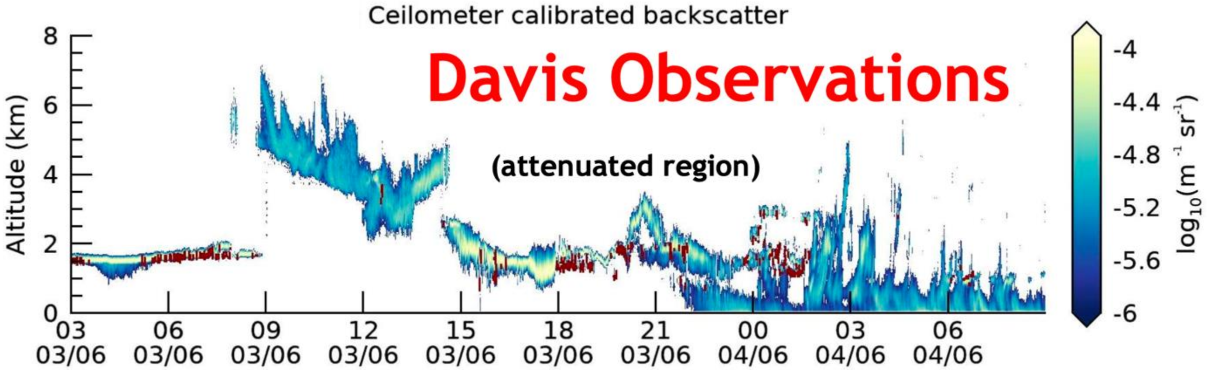


Figure from Z. Pei

Similar results when we compare to a comparative atmospheric river event at Davis in the winter of June 2022.

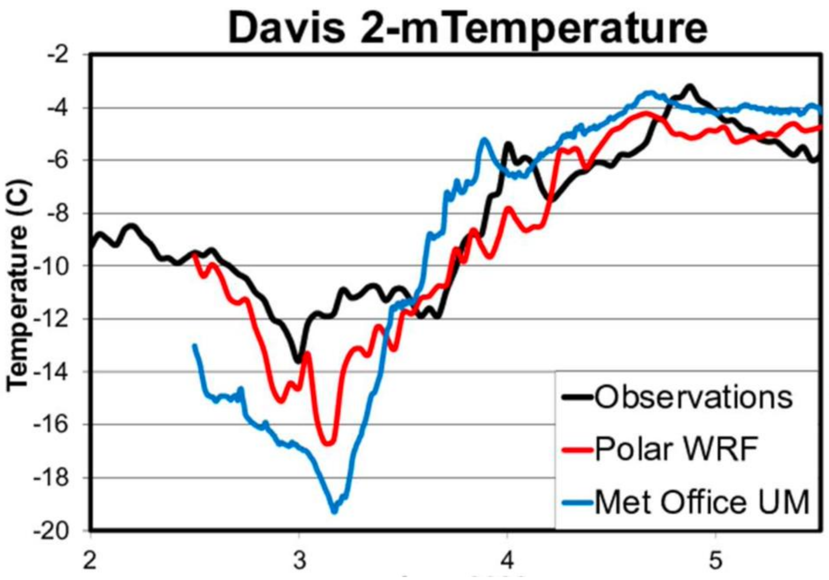
With thanks to Keith Hines and David Bromwich.
Byrd Polar and Climate Research Center, The Ohio State University, Columbus, OH, USA



Polar WRF (4.5.1) includes V21. Uses Morrison microphysics.

These runs both at 2km res, 500x500km rotated grid. 36hr runs, 12hr spin-up. Both driven by ERA5.

PWRF assimilates radiosondes + applies nudging



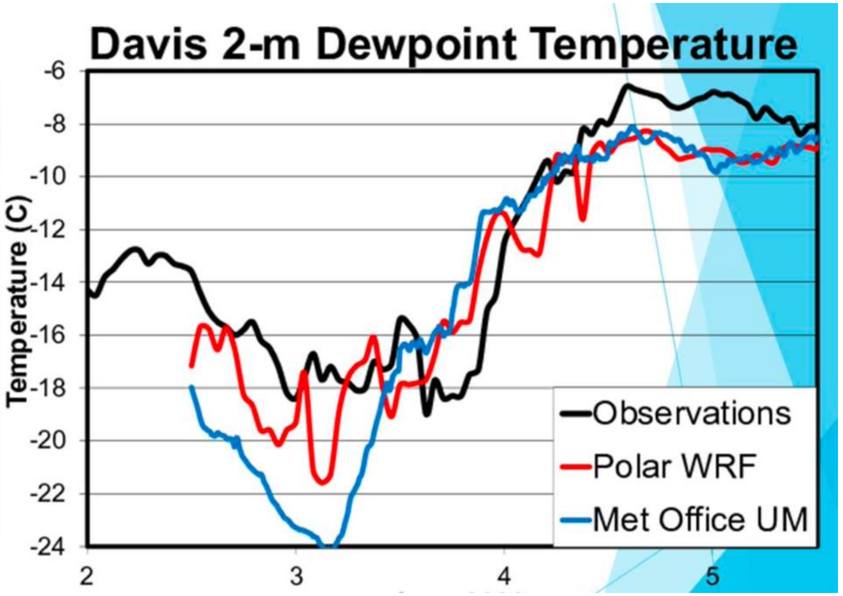
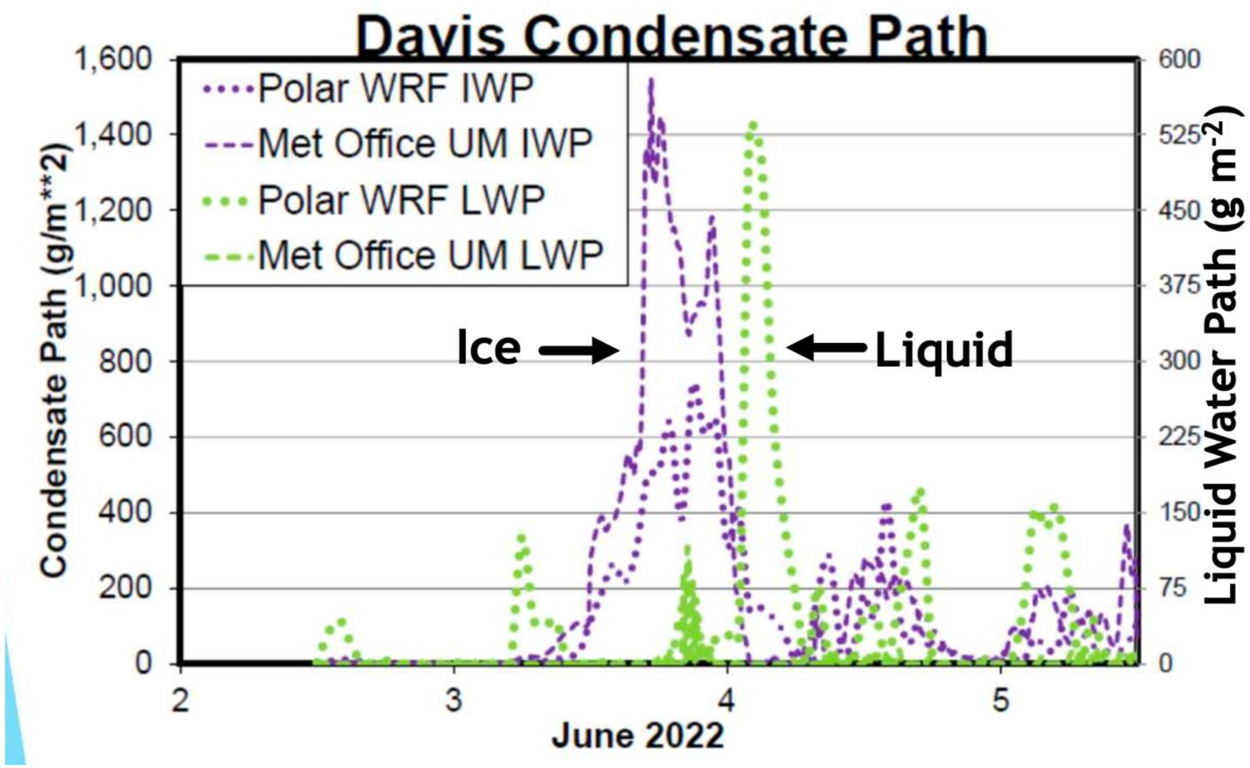
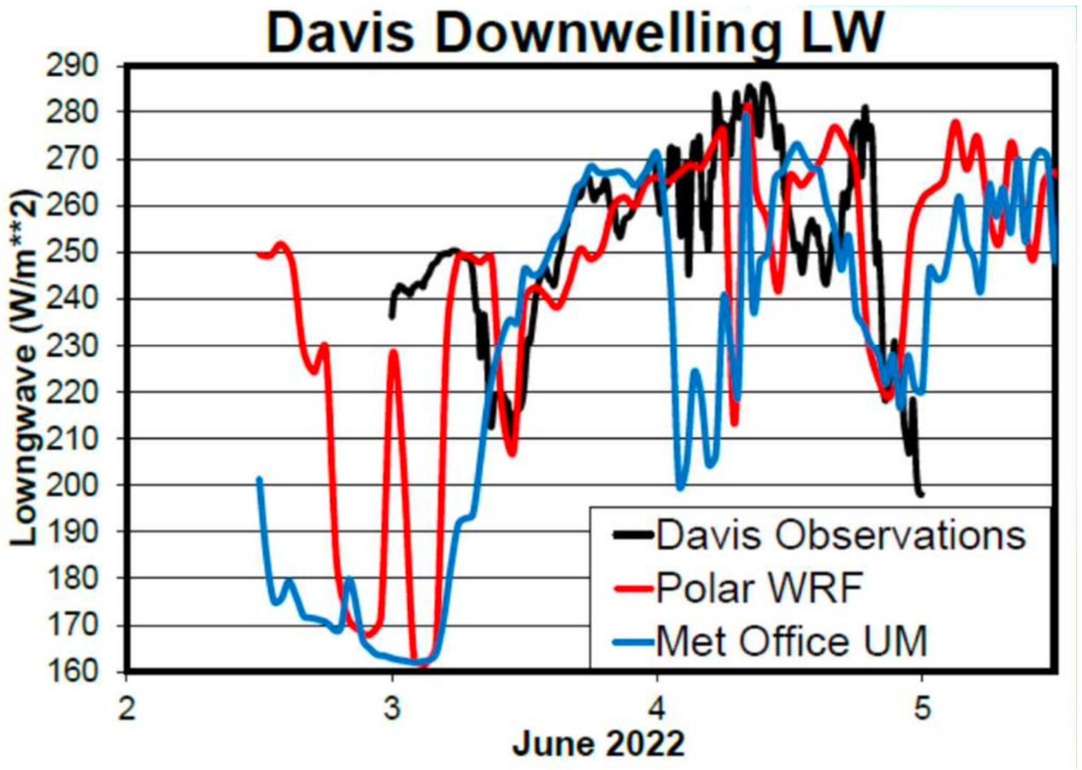


Figure from K. Hines

Without the INP parameterization the UM performs worse compared to Polar WRF for the same case study.





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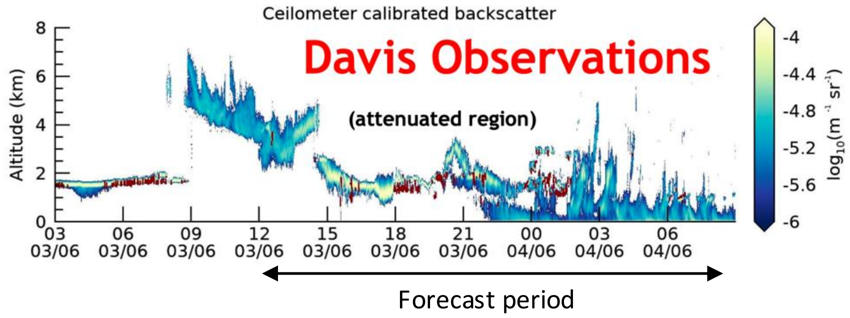
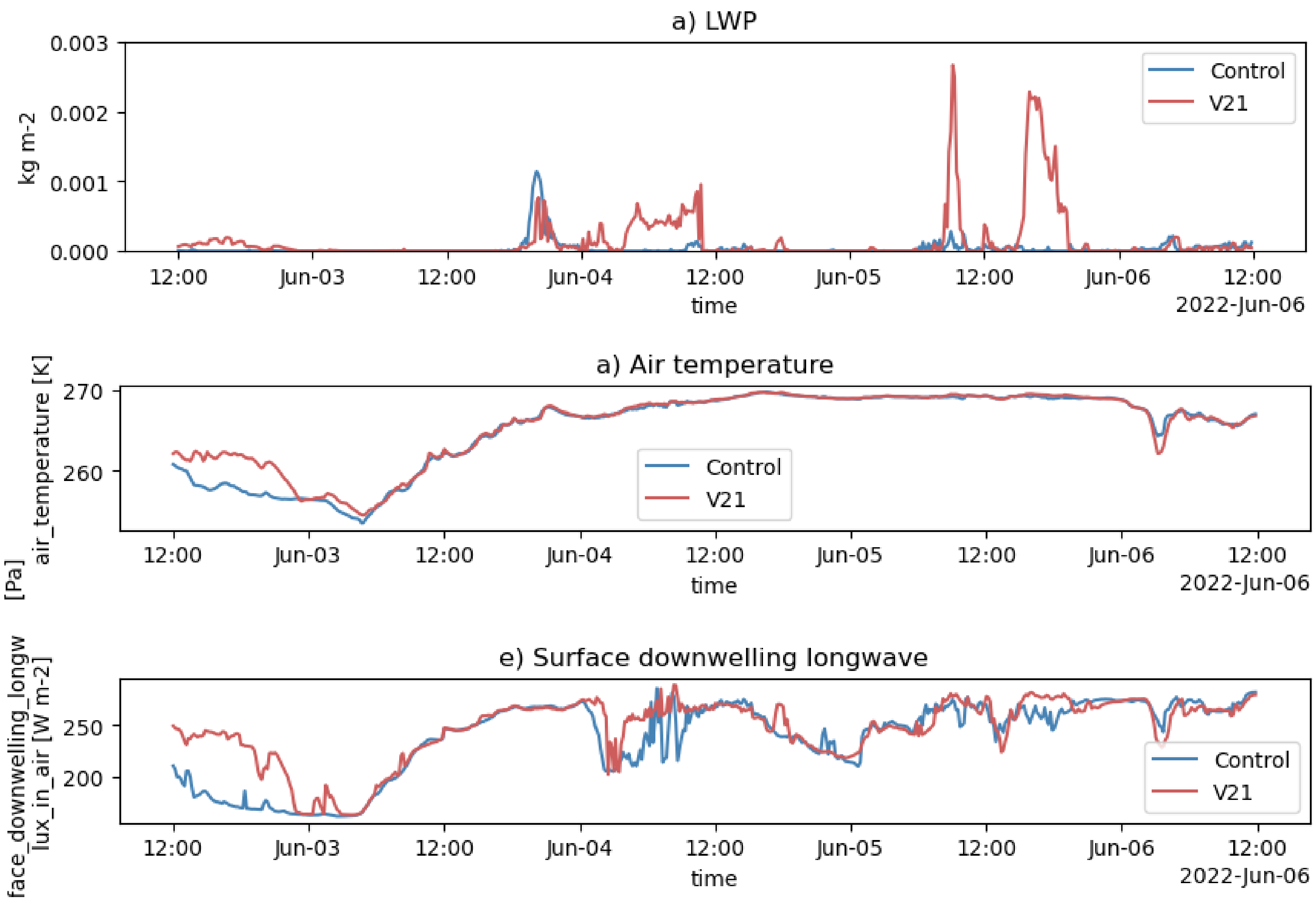
Including V21 improves radiation, again when SCLW is present, also improves surface temp at start of period.

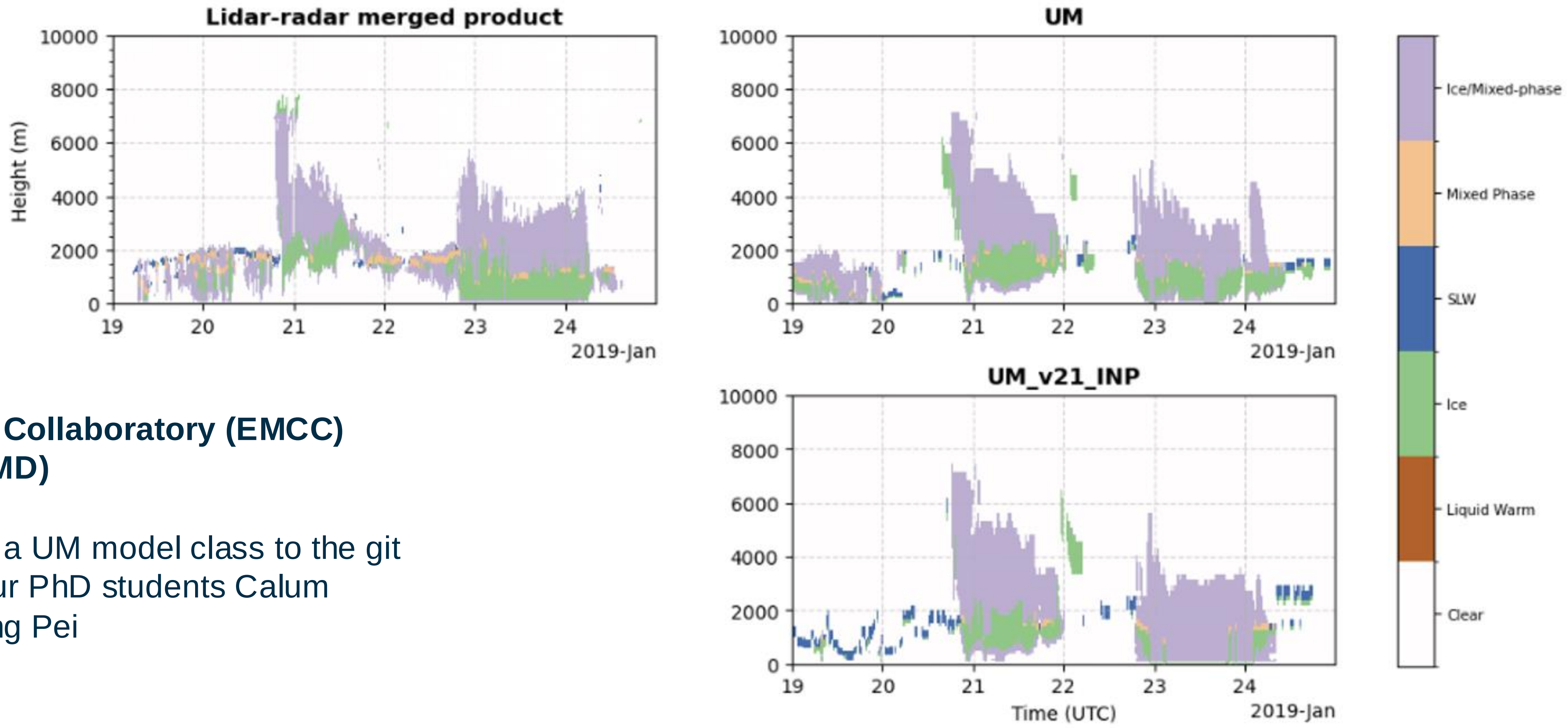




- Work in progress – watch this space!

We can do more with these observations and simulations with the EMCC radar/lidar simulator.

Eg. dig deeper into the microphysics, compare one-to-one with the merged lidar/radar cloud phase product (shown below)



Earth Model Column Collaboratory (EMCC)
Silber et al. (2021, GMD)

We hope to be adding a UM model class to the git repo soon thanks to our PhD students Calum Knight and Zhangcheng Pei

Figure from Z. Pei

THANK YOU

Any questions?

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Image taken on V2 of the Aurora Aus., 2017/18, MARCUS field campaign, S. Fiddes