Arctic Climate Simulations with the ICON Model

Comparison with Reanalyses and Observations, with a Focus on Intrusion Events

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Outline

Arctic climate simulations with the ICON model:

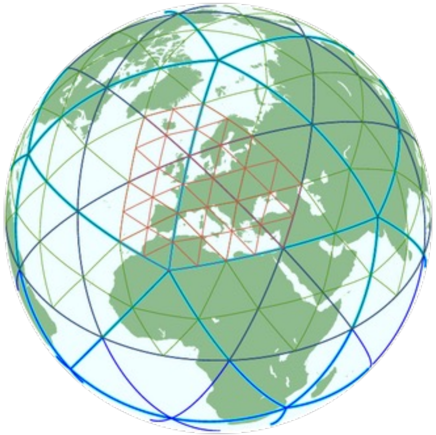
1) Climatologic evaluation & storyline projections (PolarRES WP3)

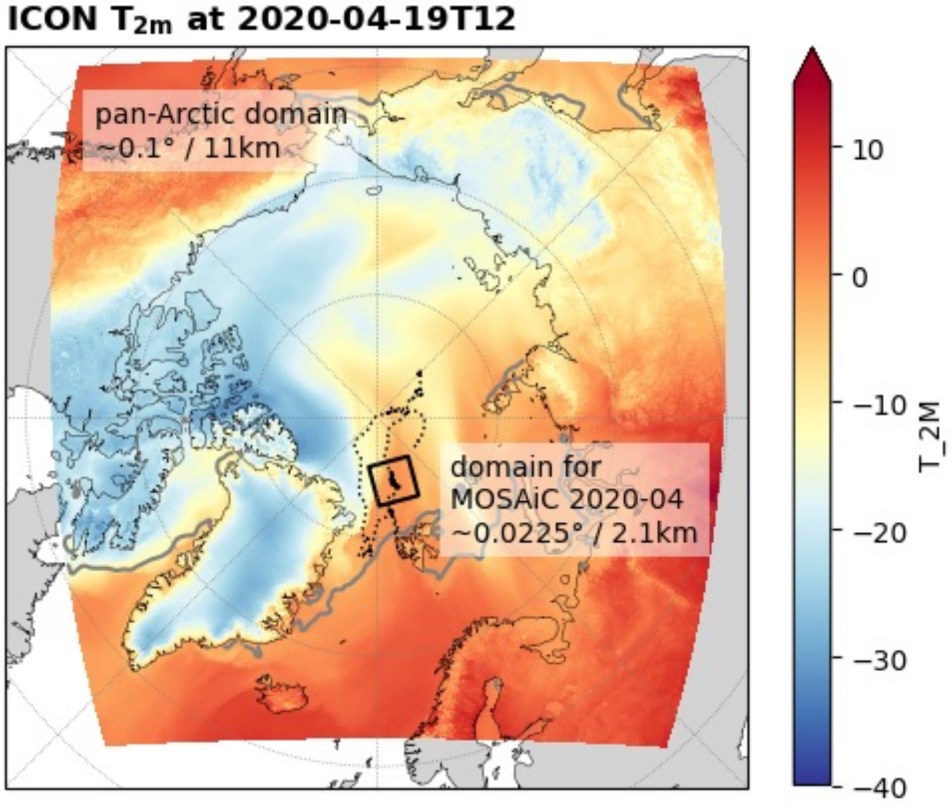
2) Warm Air Intrusions during April 2020 and comparison with MOSAiC observations (PolarRES WP4)

3) Tracking Moist Air Intrusions

ICON - ICOsahedral Nonhydrostatic model

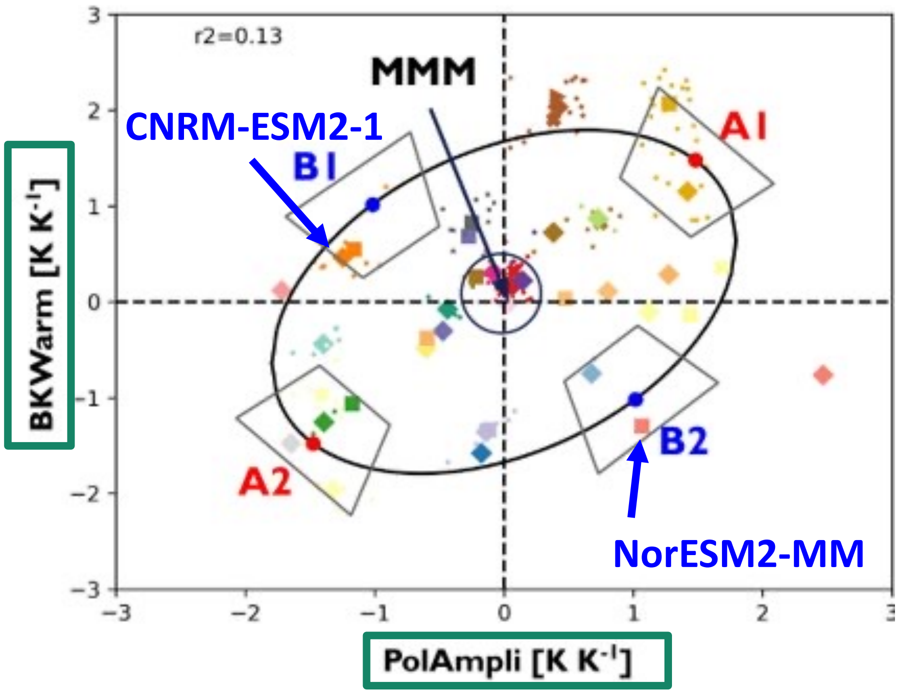
- from DWD, MPI-M Hamburg
- v2.6.6, on DKRZ Levante
- limited-area mode → forcing:
  - ERA5 / CMIP6 GCM (incl. SST, SIC)
  - grid point nudging





WP3 – Arctic storyline simulations

- ensemble, ~11km resolution
- evaluation for 2000-2021:
  ERA5 boundary forcing (3 hourly)
- storyline projections until 2100:
  downscaling
  ≥2 CMIP6 GCMs (SSP3-70 scenario)
- Arctic storyline predictors:
  - **Polar Amplification**
  - **Barents-Kara-Sea Warming**
- up to hourly output at ESGF for users!



(from Xavier Levine)

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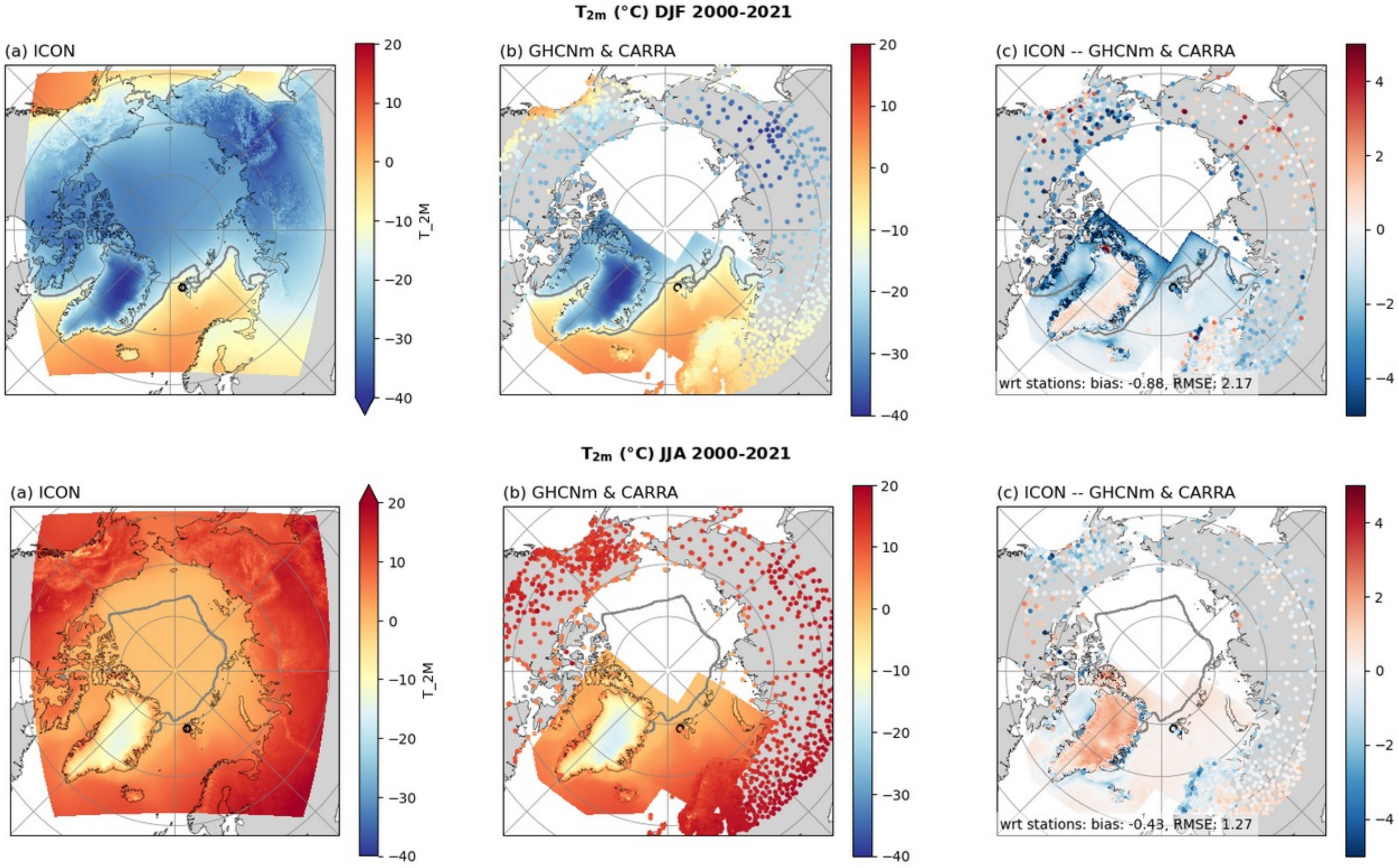
Evaluation: T_{2m}

ICON vs. GHCNm station data and CARRA reanalysis

- winter:
  - cool over sea ice and land
  - warm Siberia

pan-Arctic CARRA2 will arrive 2025-2026



*Note: CARRA West data only 2000-2001

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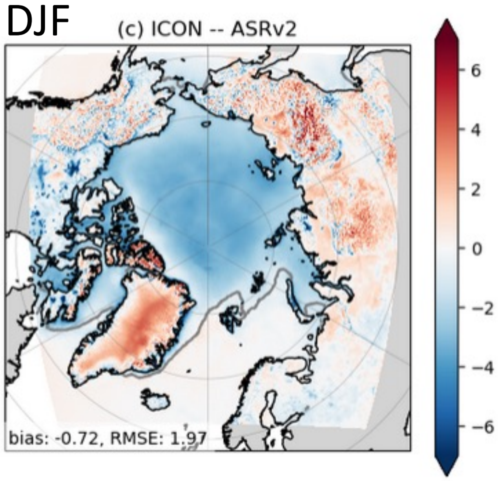
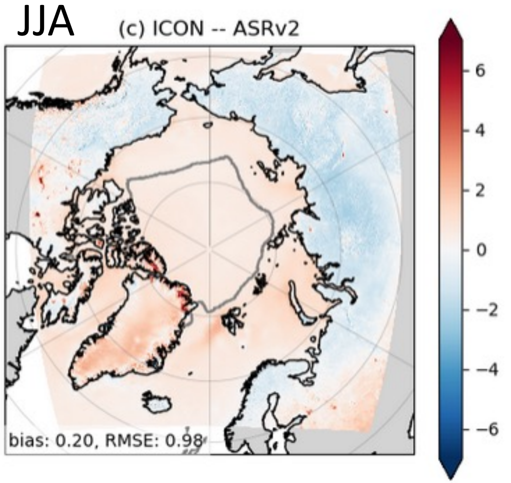
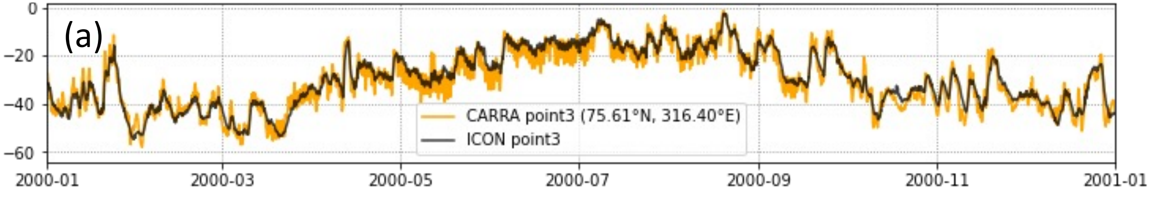
Evaluation: T_{2m}

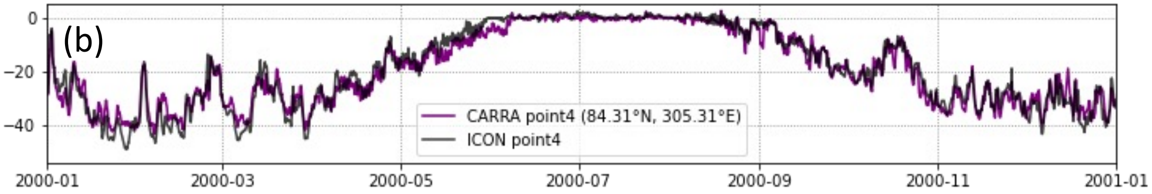
- ICON vs. ASRv2 reanalysis

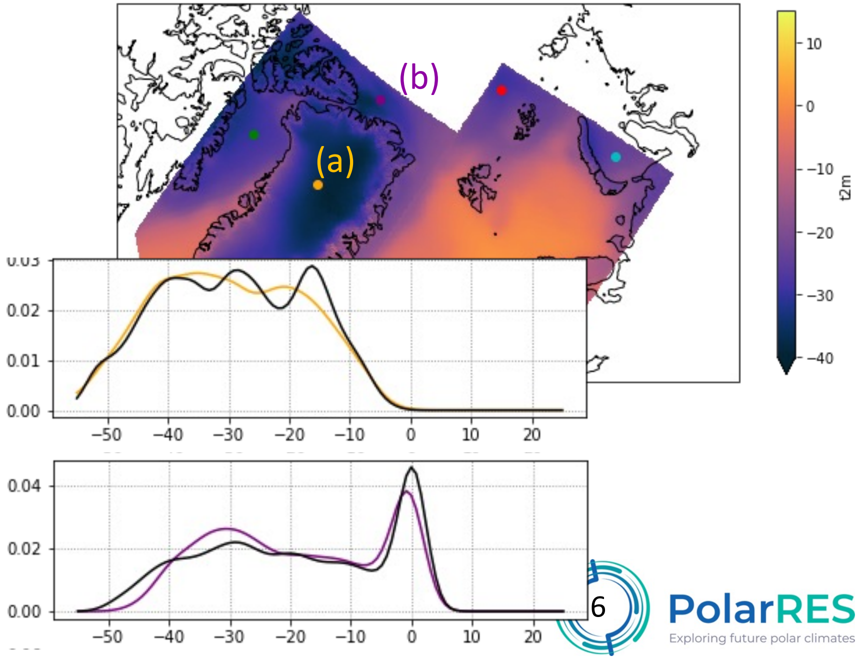




- ICON vs. CARRA reanalysis, locally







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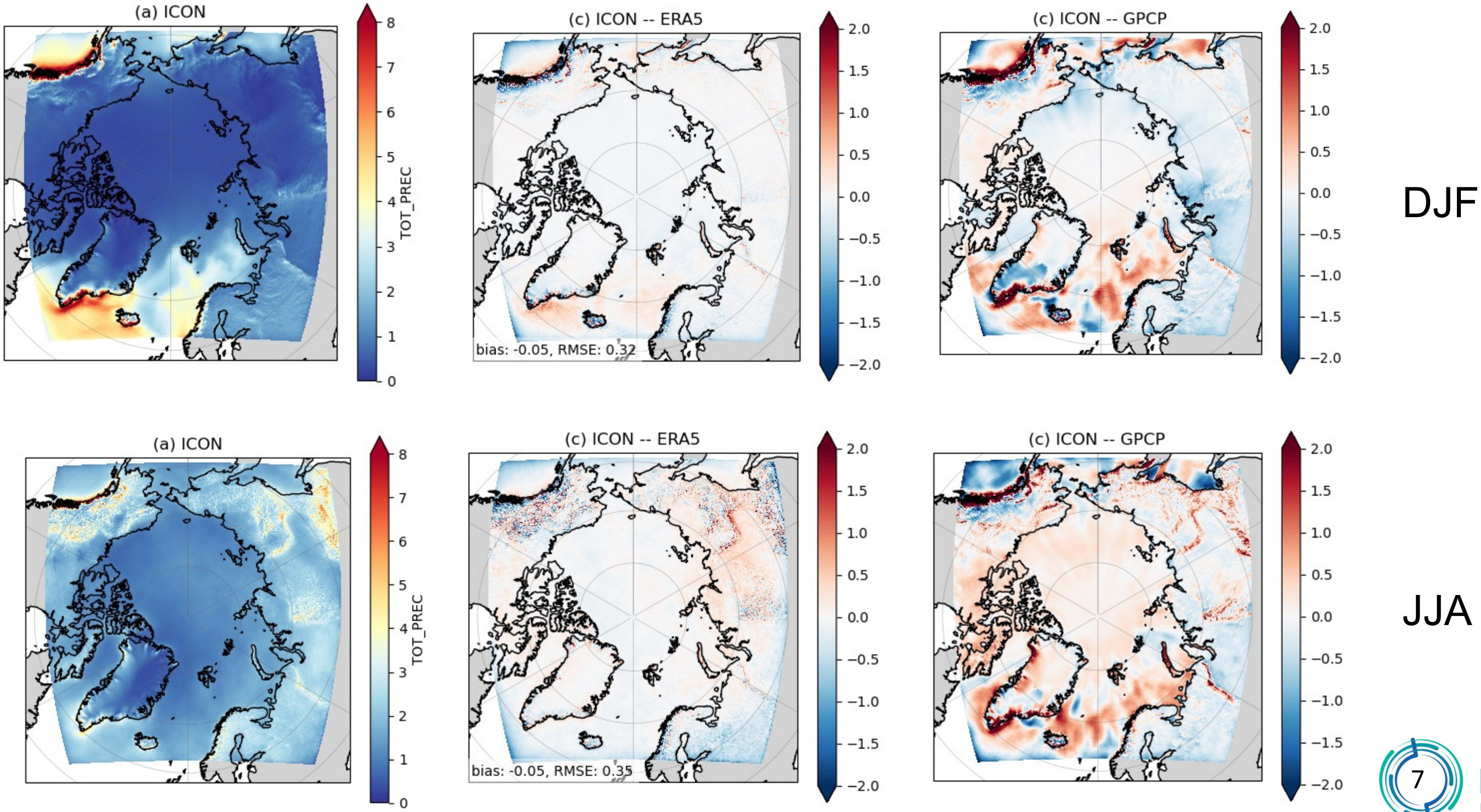
Evaluation: Precipitation

ICON: close to ERA5, domain boundary effects



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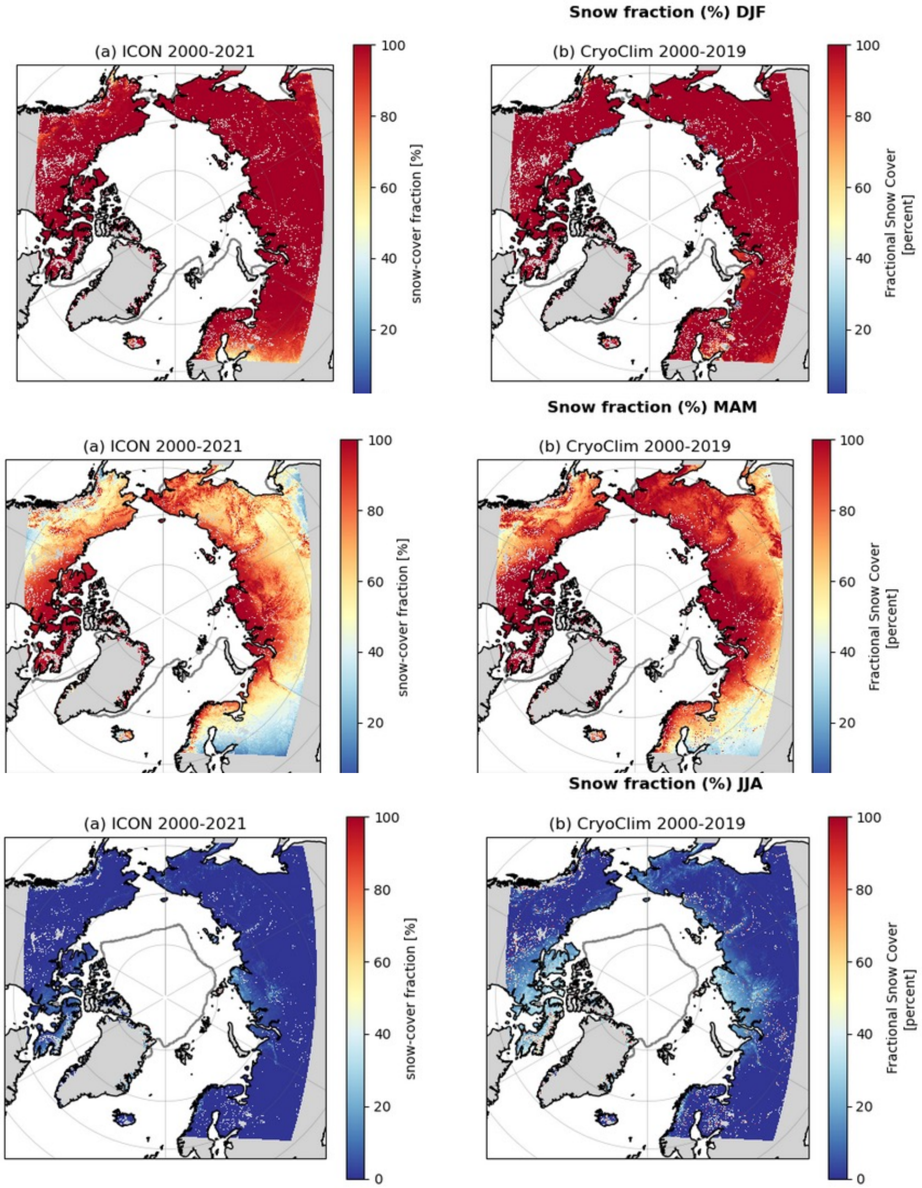
Evaluation: snow cover

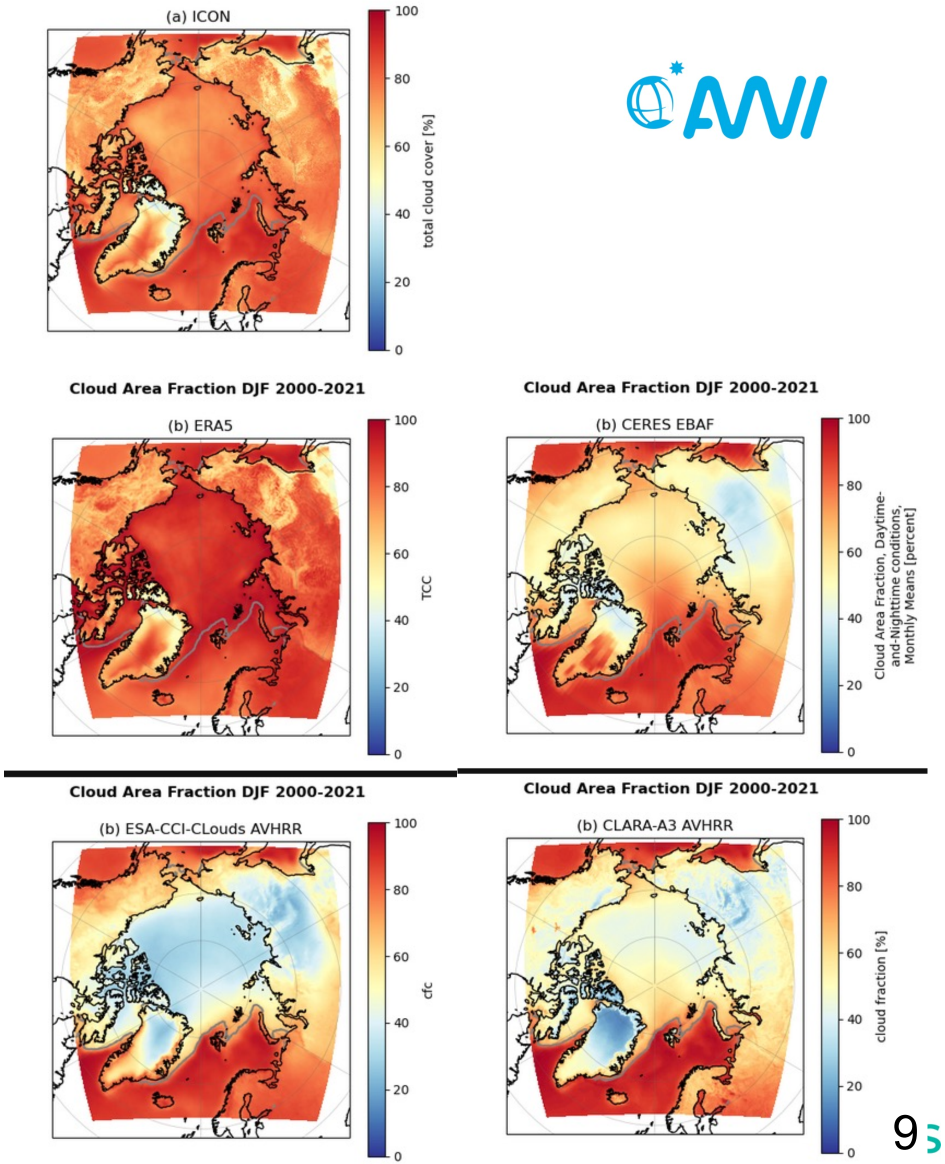
ICON vs. CryoClim satellite product (from ESA-CCI Snow)

- snow cover less dense, except in winter



Evaluation: various

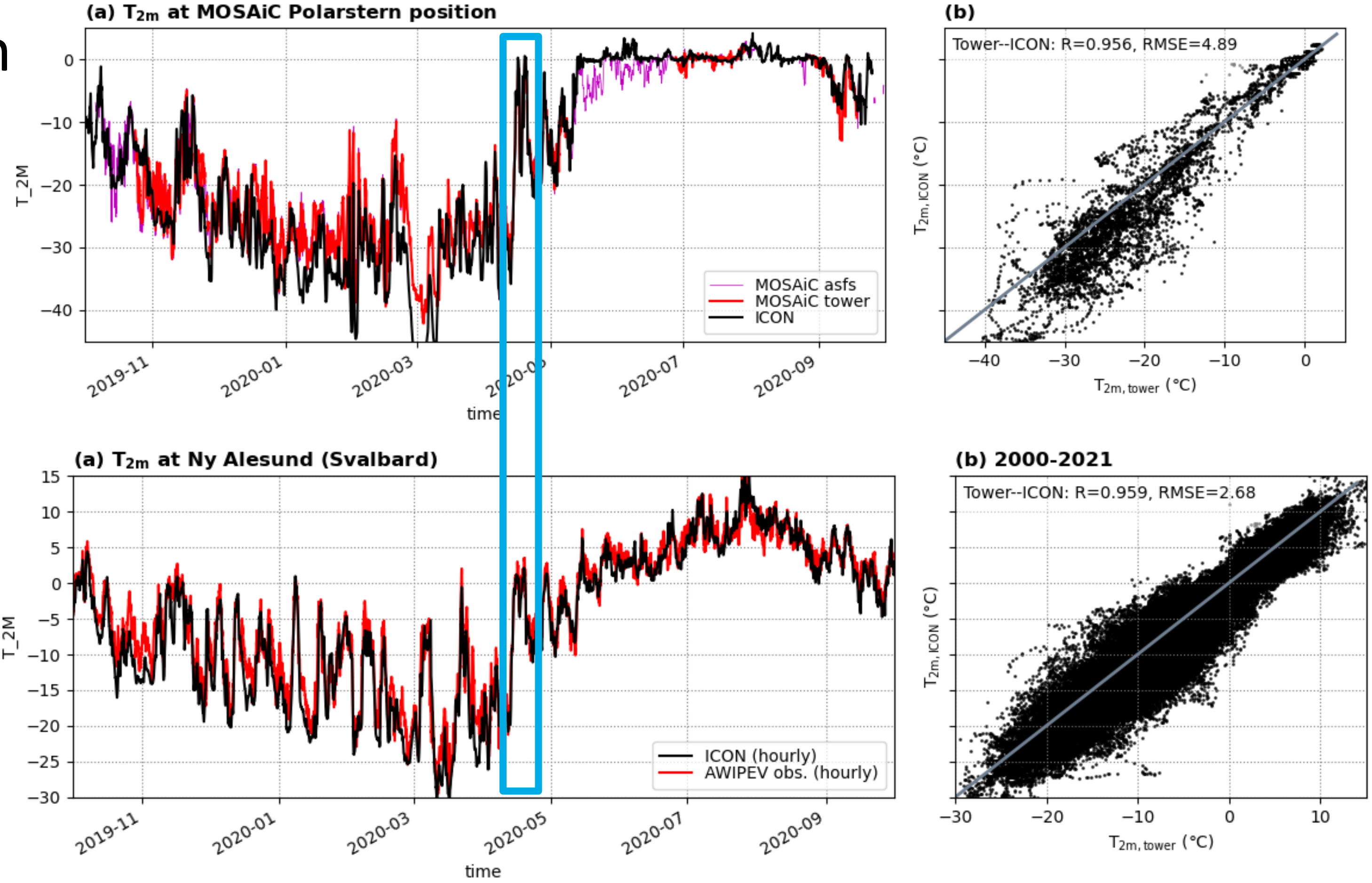
- we tried:
  - satellite products:
    CLARA-A3, ESA-CCI Clouds / Vapor, CERES EBAF, CMEMS Arctic Ocean Surface Temperature
  - in-situ observations:
    MOSAiC, IABP, ICOADS
  - reanalyses:
    ERA5, CARRA, ASRv2, MERRA2
- What's useful / reliable for the Arctic (winter)?

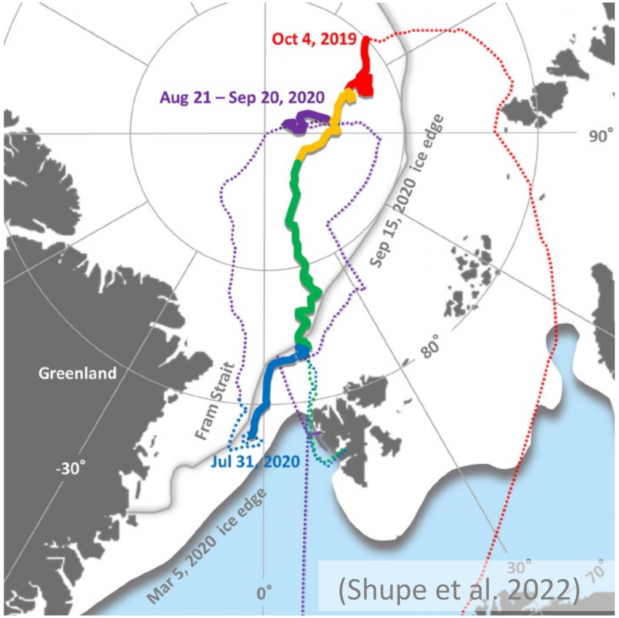


Evaluation: T_{2m} local timeseries

MOSAiC expedition

- cold bias in winter





(Shupe et al. 2022)

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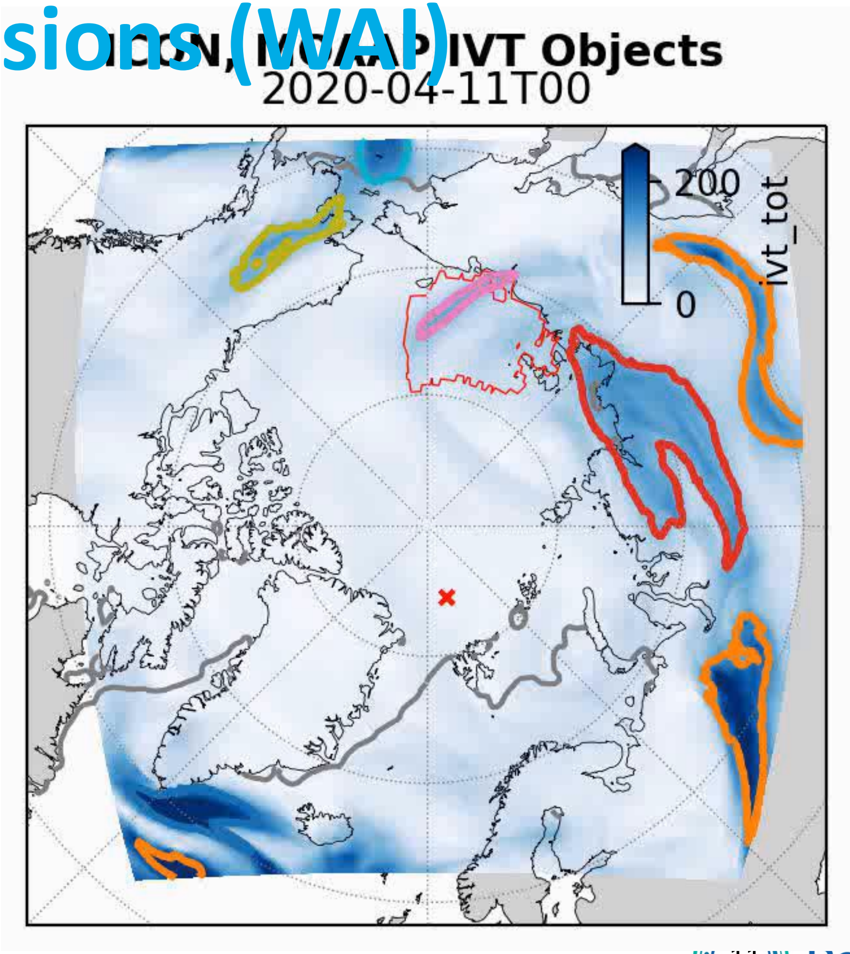
MOSAiC 2020-04
Warm and Moist Air Intrusions (WAI)

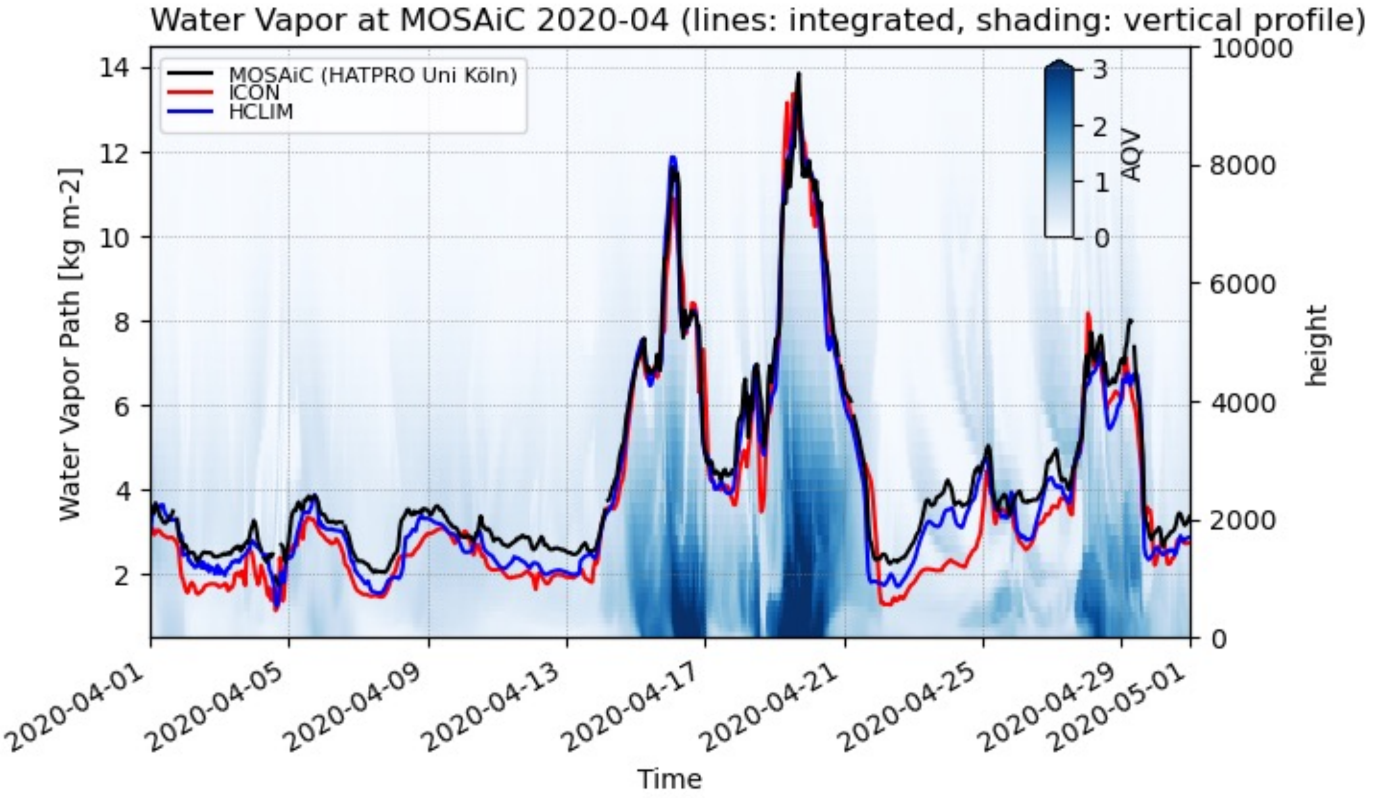
2 extreme warm events, different circulation patterns:

- WAI#1: April 16, from Eurasian continent, aerosol-rich
- WAI#2: April 19, from Atlantic



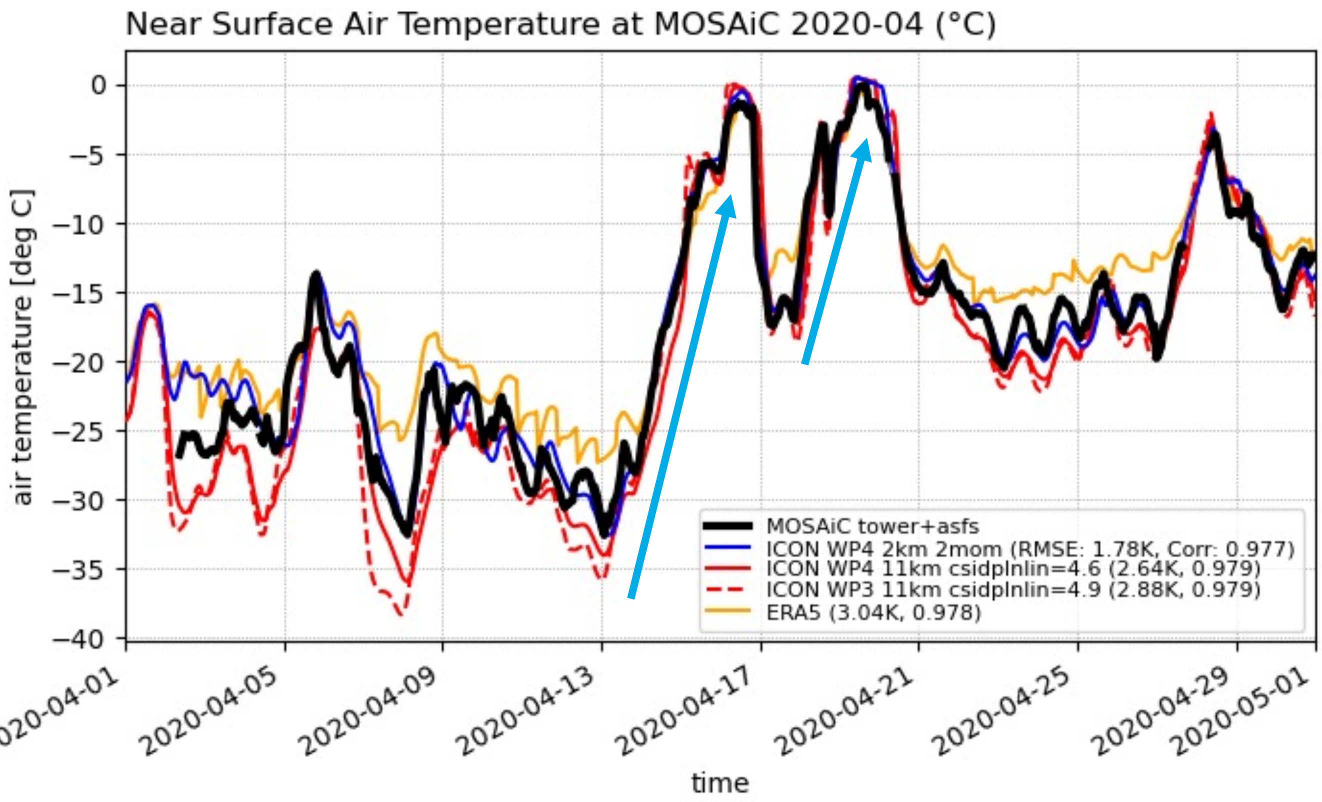
MOSAiC 2020-04 WAIs

- massive increases in moisture
- ICON:
  - IWV good during intrusions
  - but otherwise low



MOSAiC 2020-04 WAIs

- rapid surface warming by ca. +30K
- captured also in ICON



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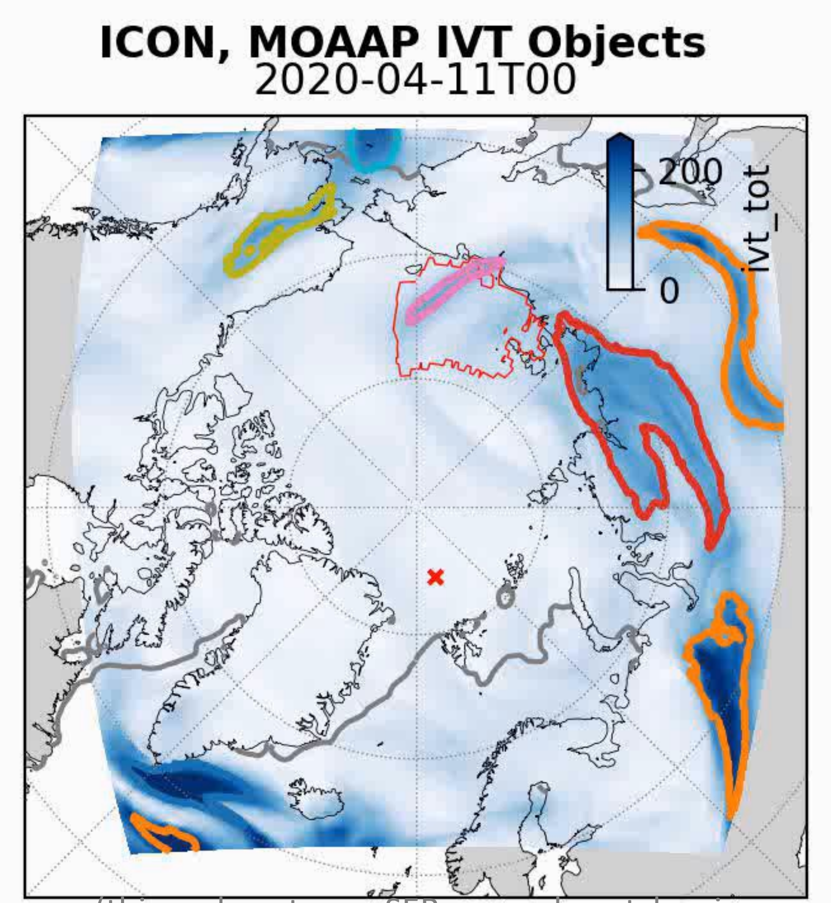
Tracking Moisture Intrusion Events

- identify IVT anomaly patches
- Track their movement and evolution
  → Life Cycle Events
- Arctic extreme events (surface energy balance and temperature …)



(thin red contours: SEB anomaly patches in ERA5. Provided by Sonja Murto)

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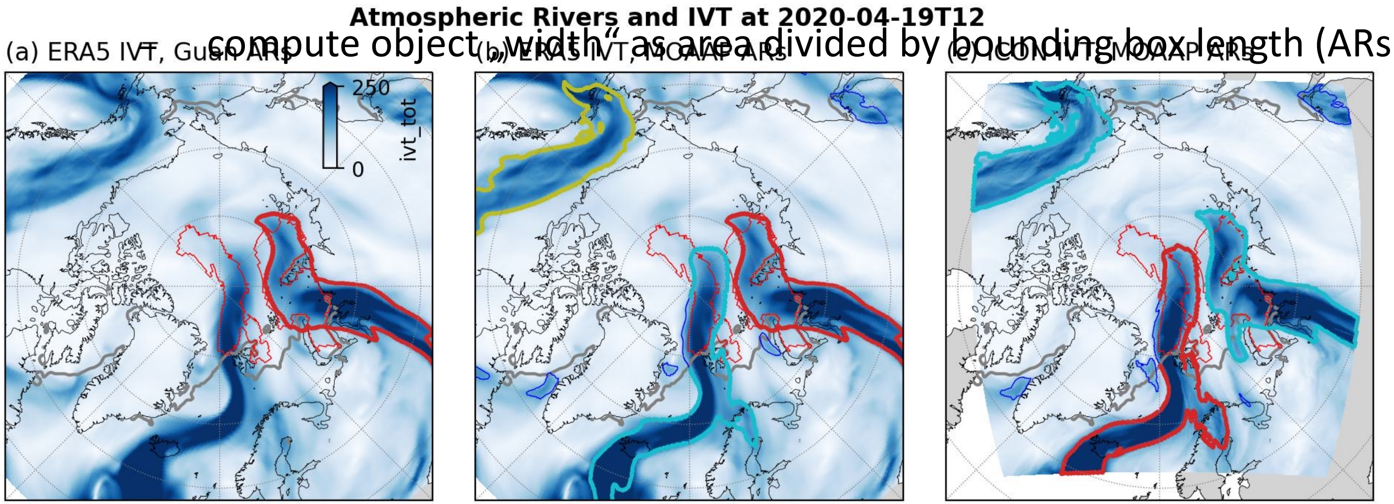
Feature Tracking Tools

tARget (Guan, Waliser, Ralph 2023)

- sophisticated Atmospheric River tracking (e.g. Lauer et al. 2023)

MOOAP (Prein, Mooney and Done 2023, in review)

- versatile tracking suite (fronts, ARs, cyclones, MCS …)
- modifications:
  - IVT threshold >100 kg/(m*s) & >85th percentile → varying in space and by month
  - compute object „width“ as area divided by bounding box length (ARs should be elongated objects)



Sidenote:
MOAAP tracking works more nicely on PolarRES rotated grid (without periodicity across 0° lon.)

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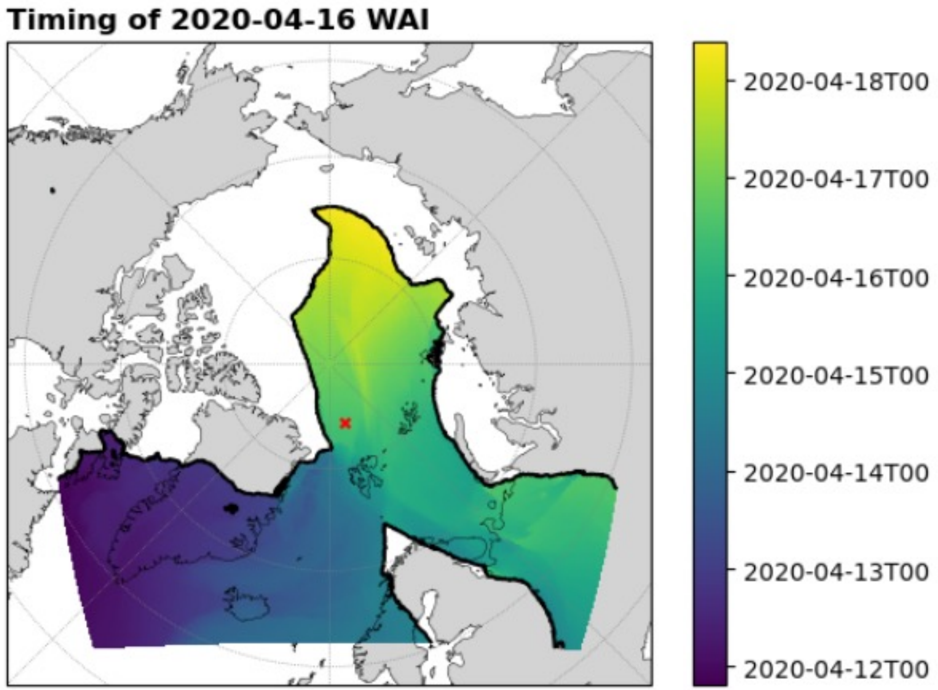
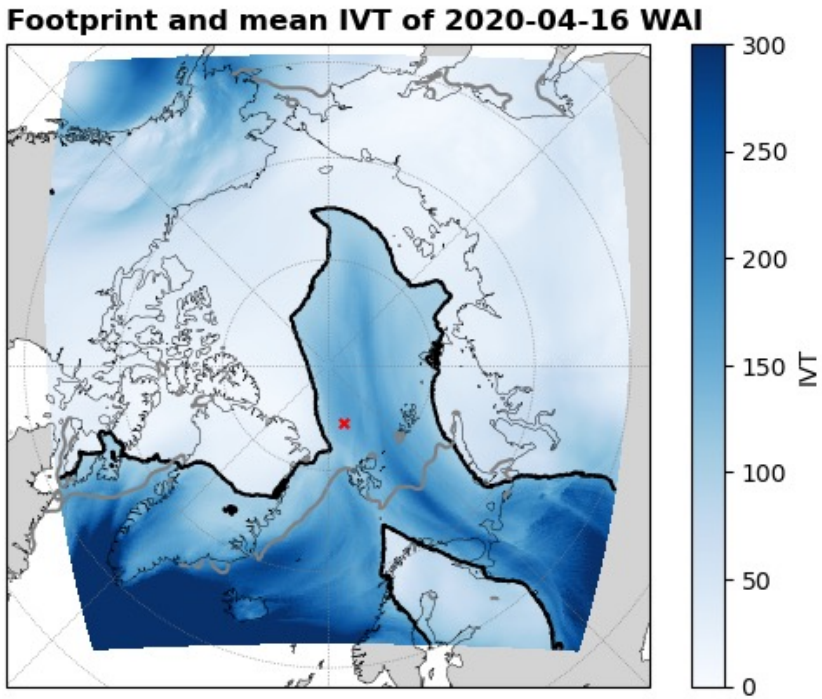
Tracking Moisture Intrusion Events

spatial footprint of ΔIVT LCEs





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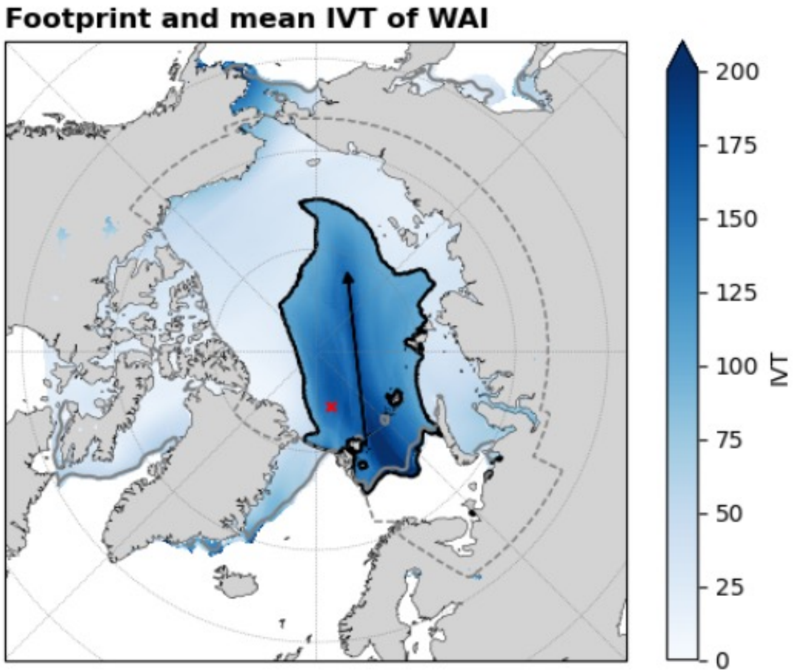
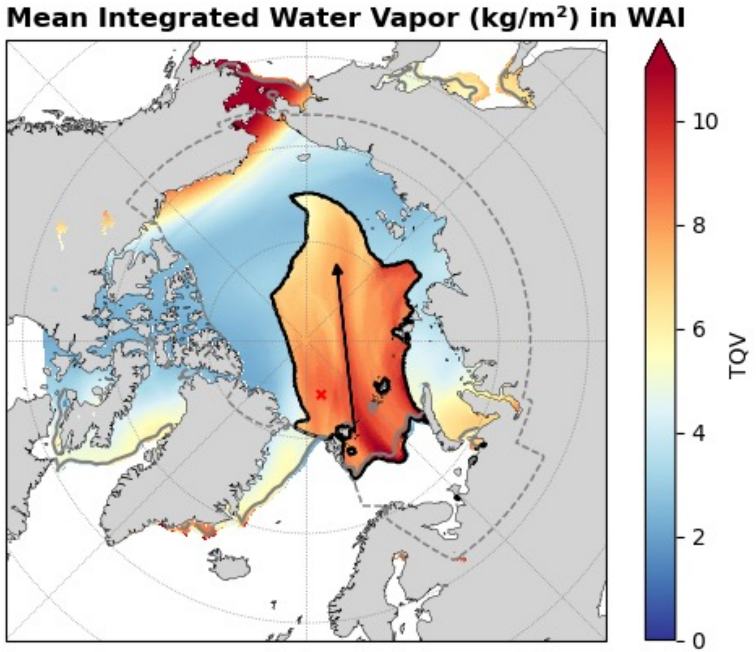
Tracking Moisture Intrusion Events

- ΔIVT LCE over central Arctic sea ice
- arrow indicates movement (between centers during first/last 24 hours)
- high IWV, decays along event





(outside of footprint: average over duration of the event)

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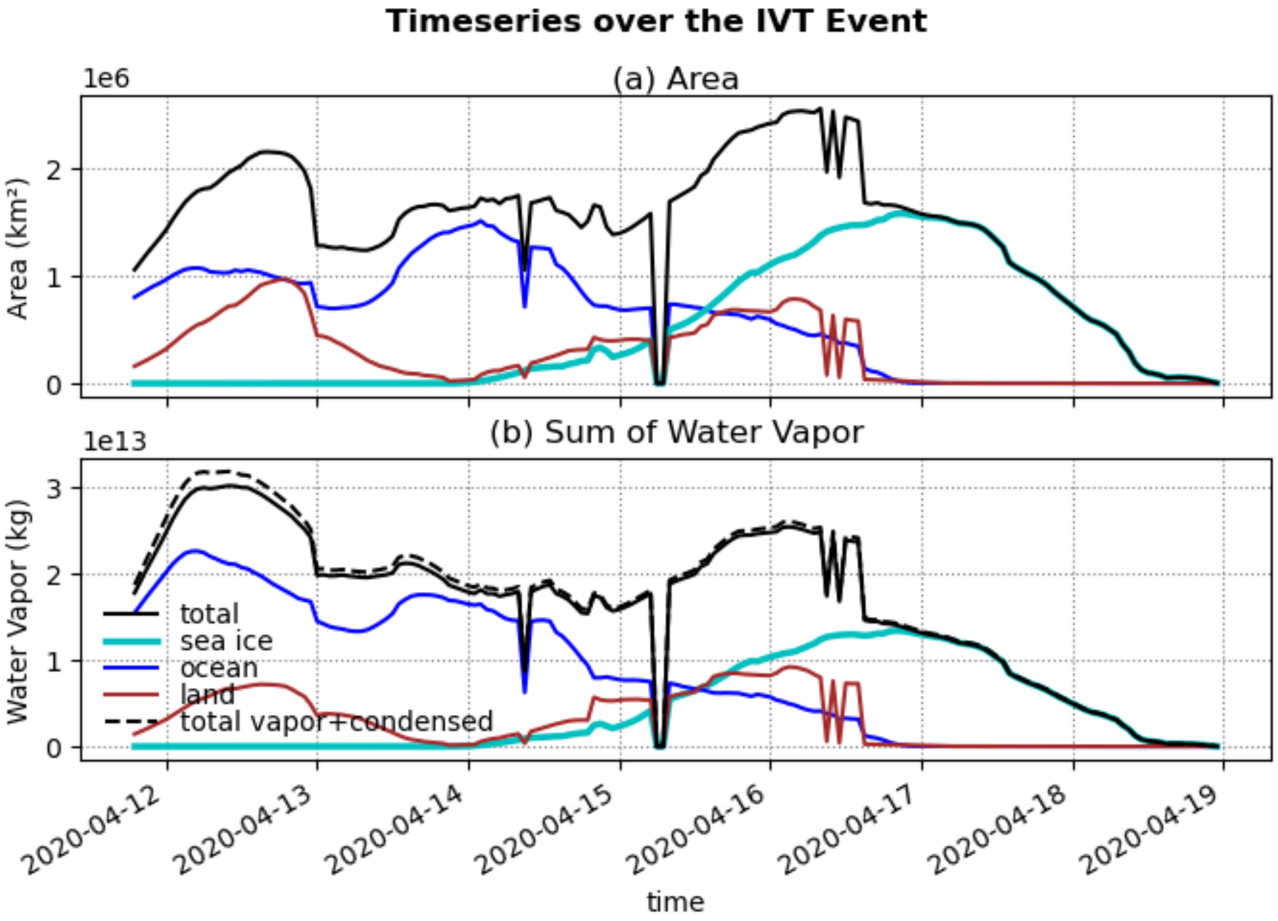
Tracking Moisture Intrusion Events

Temporal evolution of MOSAiC WAI#1

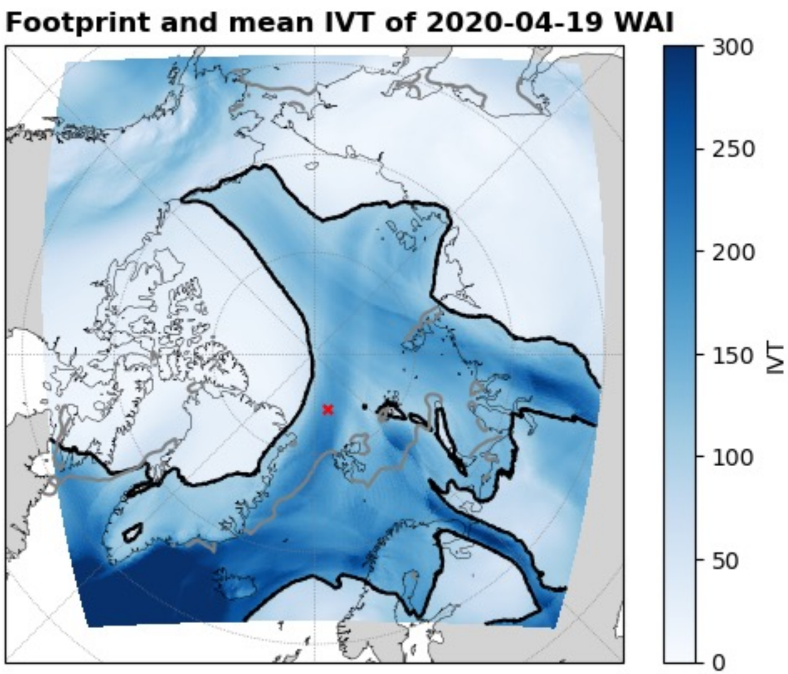
over sea ice:

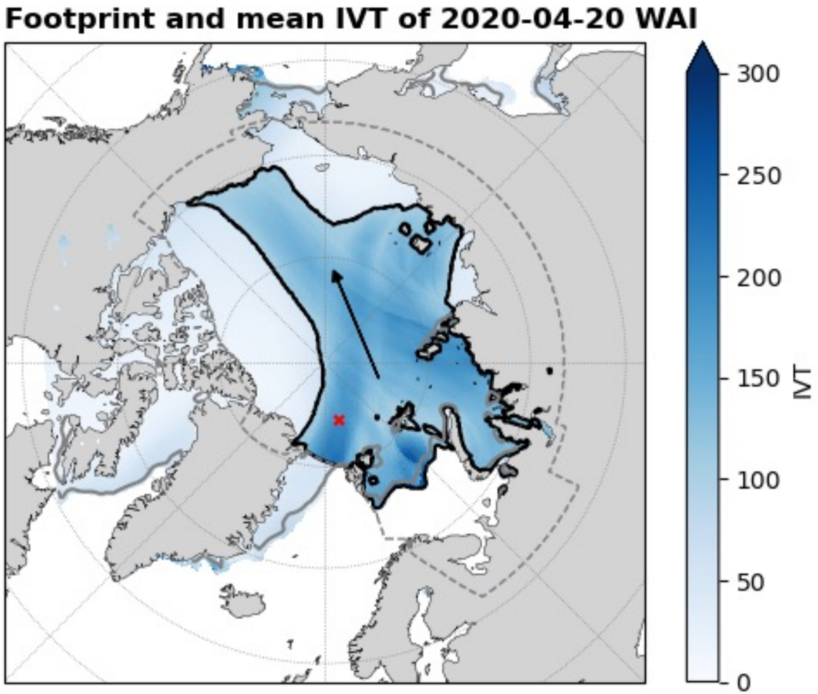
- ~5 days duration
- largest area on April 16-17



Tracking Moisture Intrusion Events

… do the same for WAI#2





→ crossing the entire Arctic!

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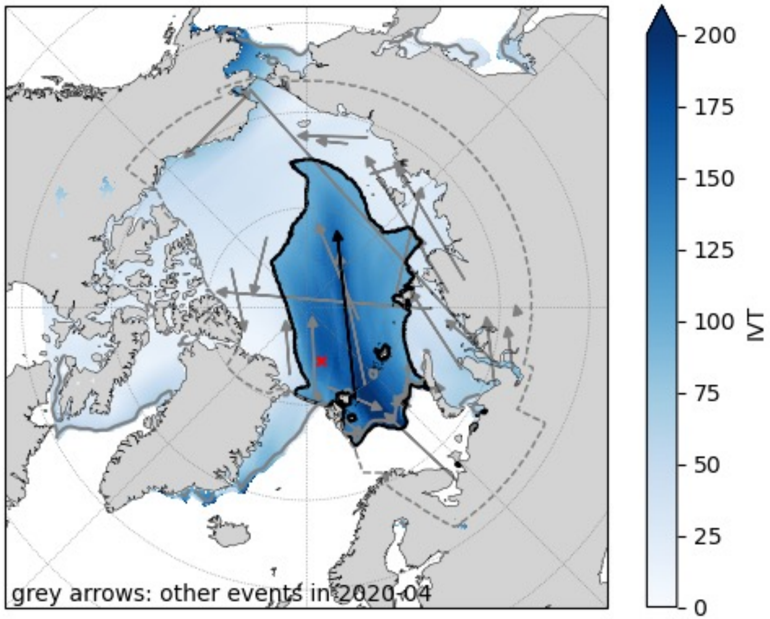
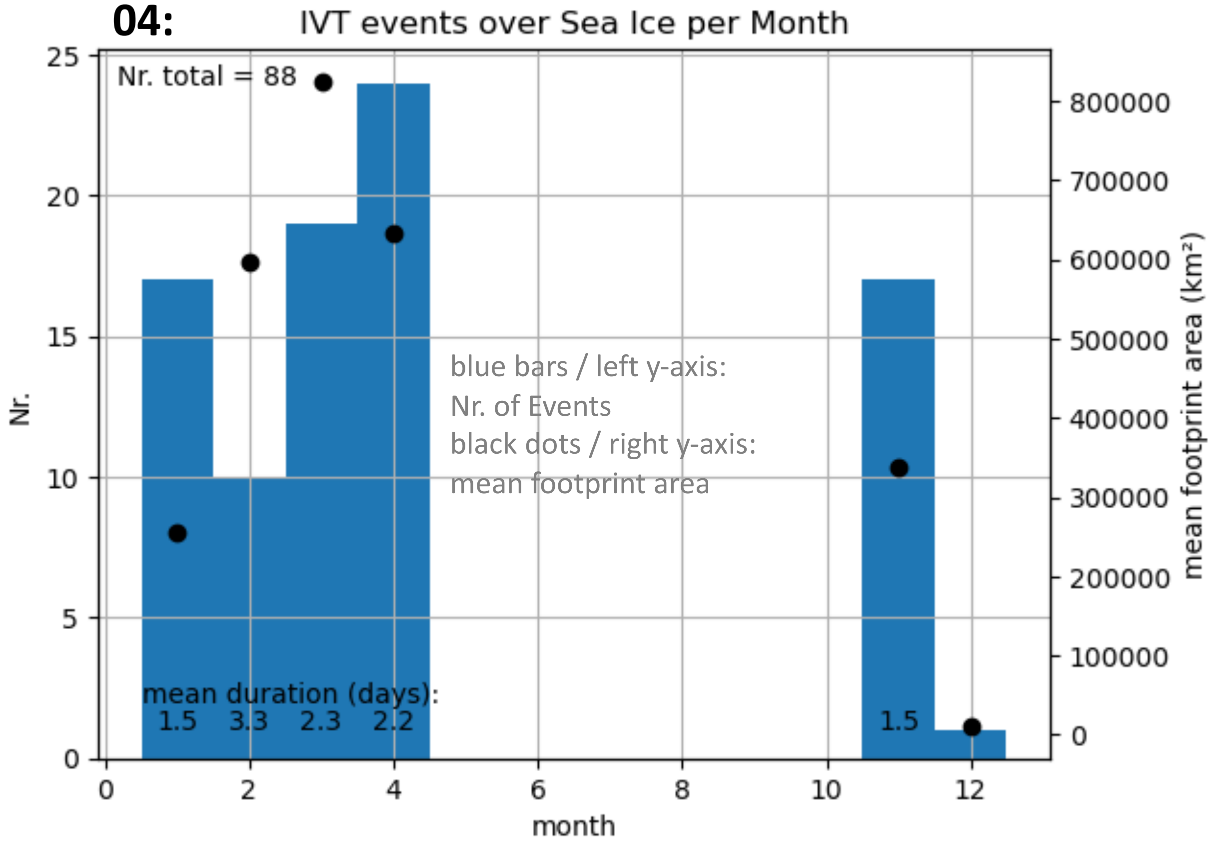
Tracking Moisture Intrusion Events

… do the same for many events



monthly statistics of ΔIVT LCEs during 2019-11 to 2020-04:



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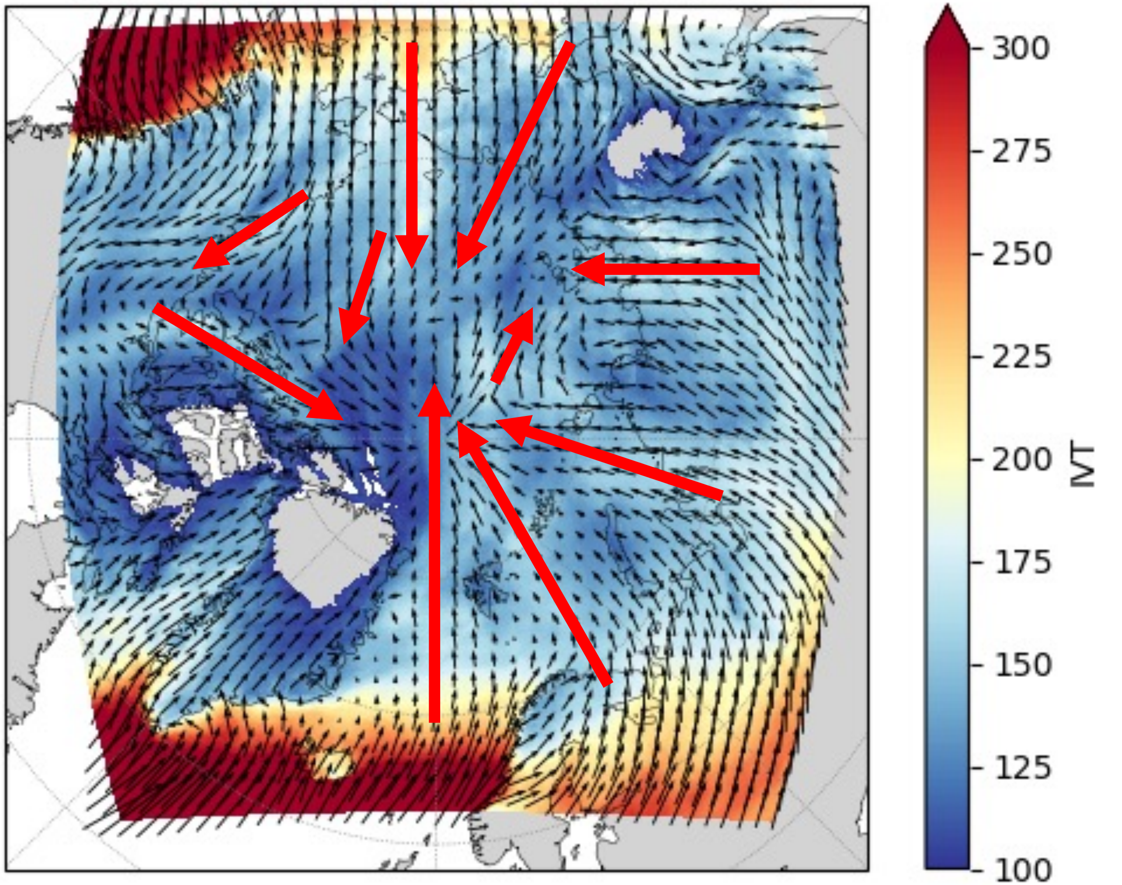
Tracking WAIs

- moisture transport pathways in ΔIVT LCEs
- with tracking: in different Arctic regions: How much from Atlantic / Pacific / Eurasia / North America?



or one map each, average how much of events reaching each point in central Arctic has been over Atlantic/Pacific/Eurasia/NorthAmerica?

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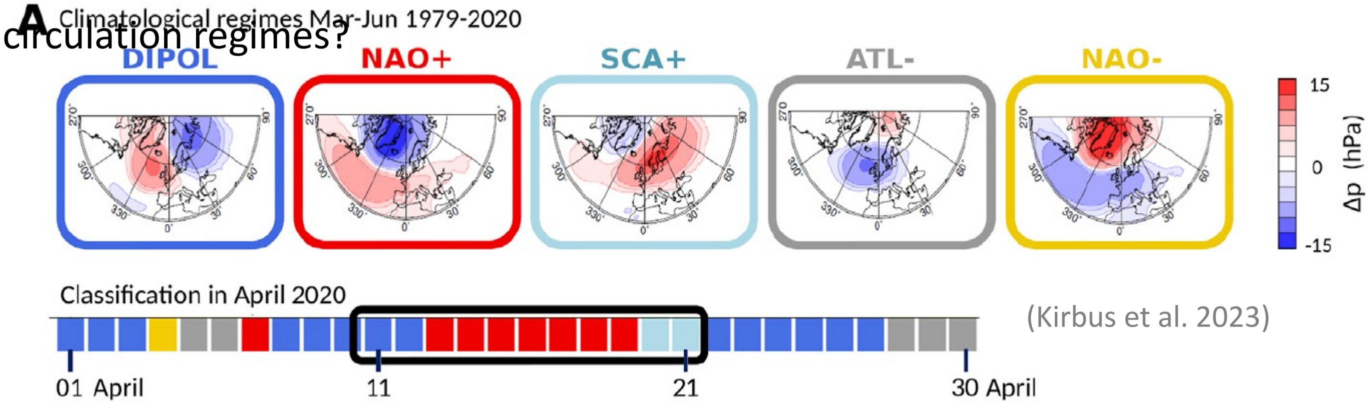
Tracking – Ideas?

characteristics of the ΔIVT LCEs

- size, lifetime, splitting/merging, speed
- Common corridors (of moisture transport)? Atlantic vs. Pacific?
- Relation to circulation regimes?



(Kirbus et al. 2023)

processes within these (extreme) events

- energy balance, temperature, moisture flux / precipitation, clouds
- general vertical / horizontal structure
- What happens with the moisture?

Restrict to sea ice and winter?

Future changes?

Summary

- **PolarRES is producing an ensemble of ~11km resolution polar climate simulations for the 21st century**
  - for users / applications!
  - ICON works decently, but challenges (winter, sea ice, clouds, snow, sparse observations)
- April 2020 warm air intrusion case studies
  - evaluation of model ensemble against MOSAiC observations
  - ICON (nudged to ERA5) can do better than ERA5 itself, but cloud and snow/ice processes remain challenging
- **we can track moisture intrusions, based on hourly IVT**
  - assess characteristics of Life-Cycle Events, and their impacts

Thank you for your attention!

Acknowledgments:

All the colleagues from PolarRES, AWI and DWD / ICON / CLM-Community!

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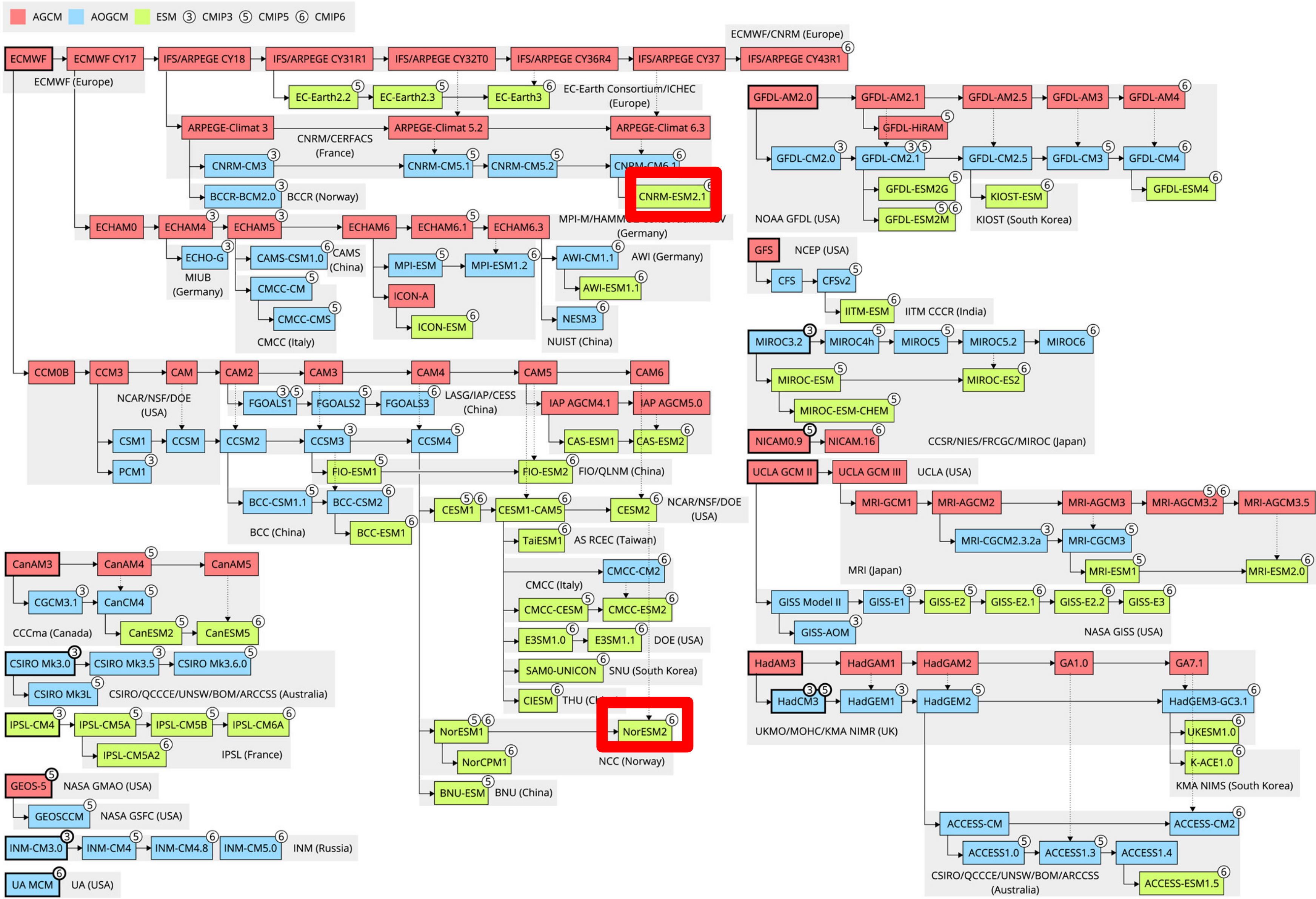
Genealogy of CMIP models

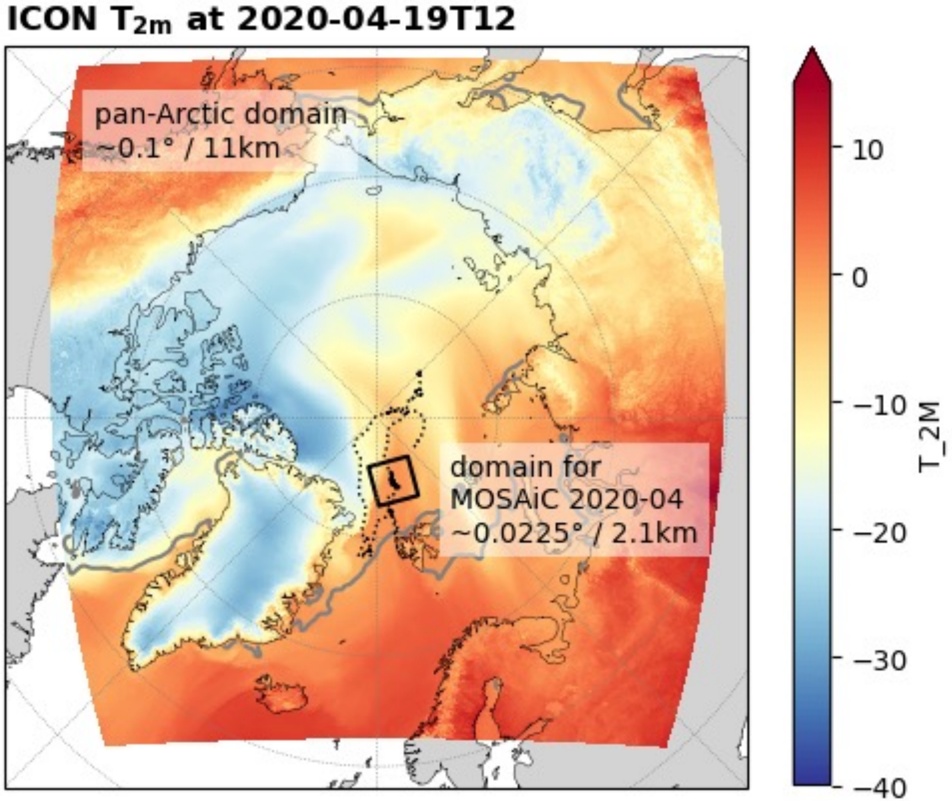


Kuma et al. 2023 Climate Model Code Genealogy and Its Relation to Climate Feedbacks and Sensitivity

MOSAiC 2020-04 WAIs

ICON set-ups:

- **pan-Arctic domain, ~11km**
- **MOSAiC domain, ~2.1km**
  - options:
    - deep convection parameterization off (but shallow convection)
    - 2 moment cloud microphysics scheme
    - CCN scenarios (maritime / continental / polluted / intermediate)



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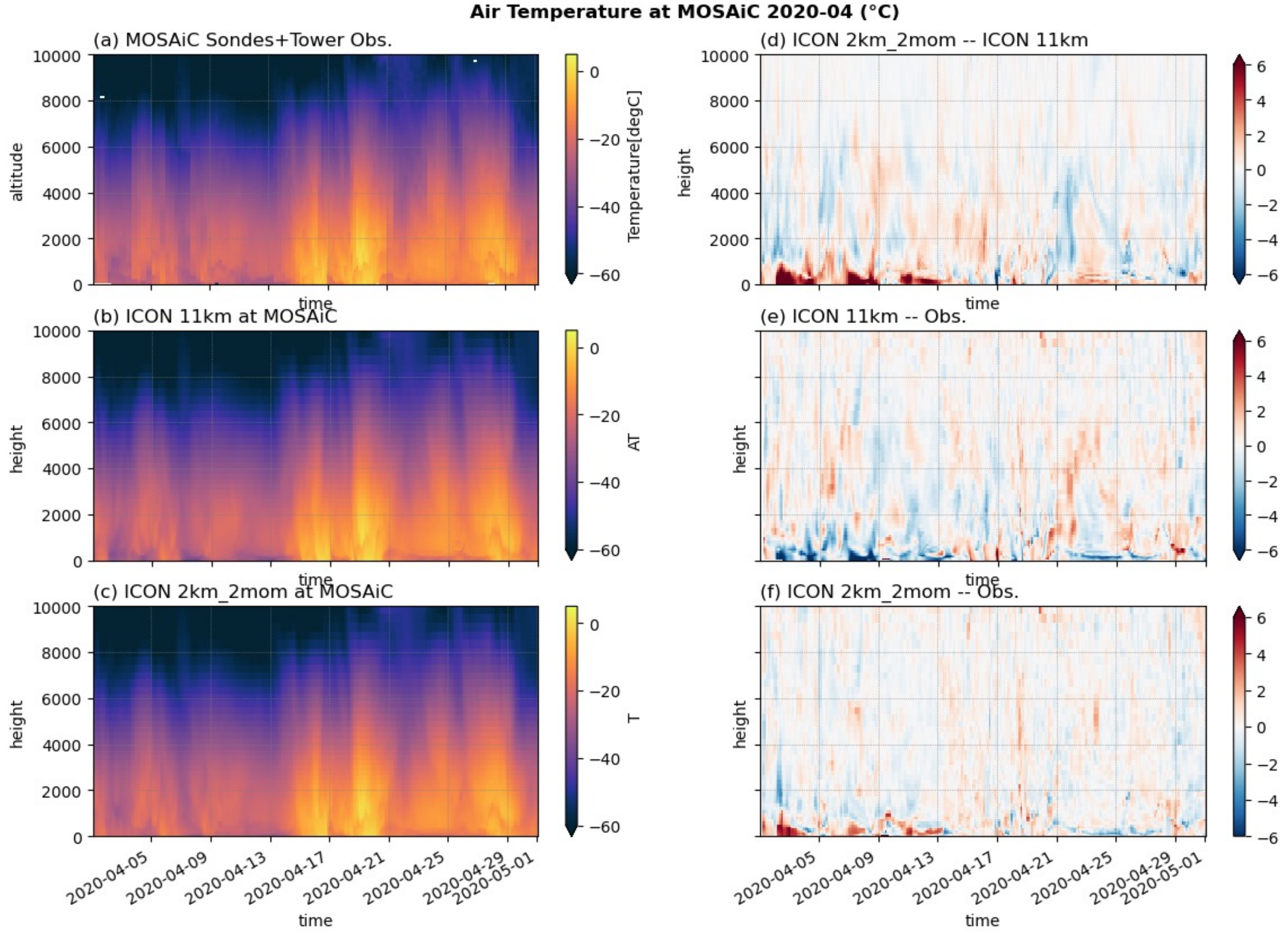
MOSAiC 2020-04 WAIs

- vertical T structure
- ICON set-ups work
- hi-res set-up:
  - better T, but surface warm bias



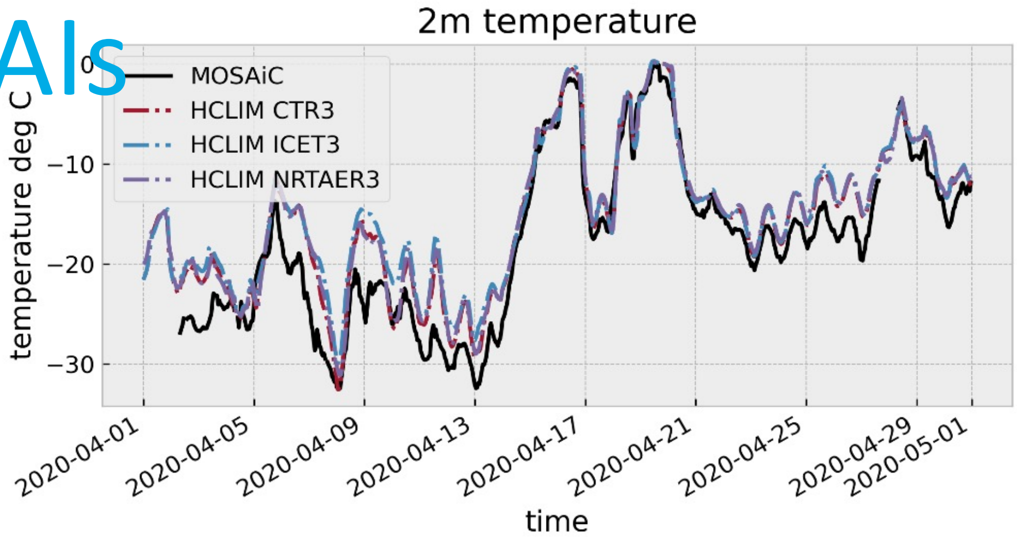
MOSAiC 2020-04 WAIs

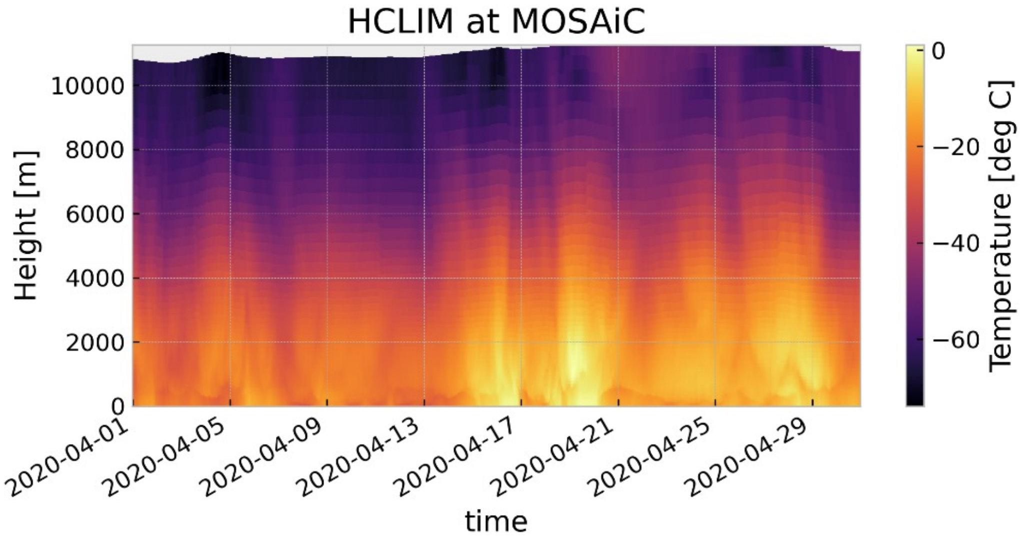
WP4 model intercomparison:

- HCLIM model

  Oskar Landgren, Filip Severin von der Lippe …

  - 2.5km resolution
  - CAMS near-realtime aerosol input
  - UM-UKCA aerosol input





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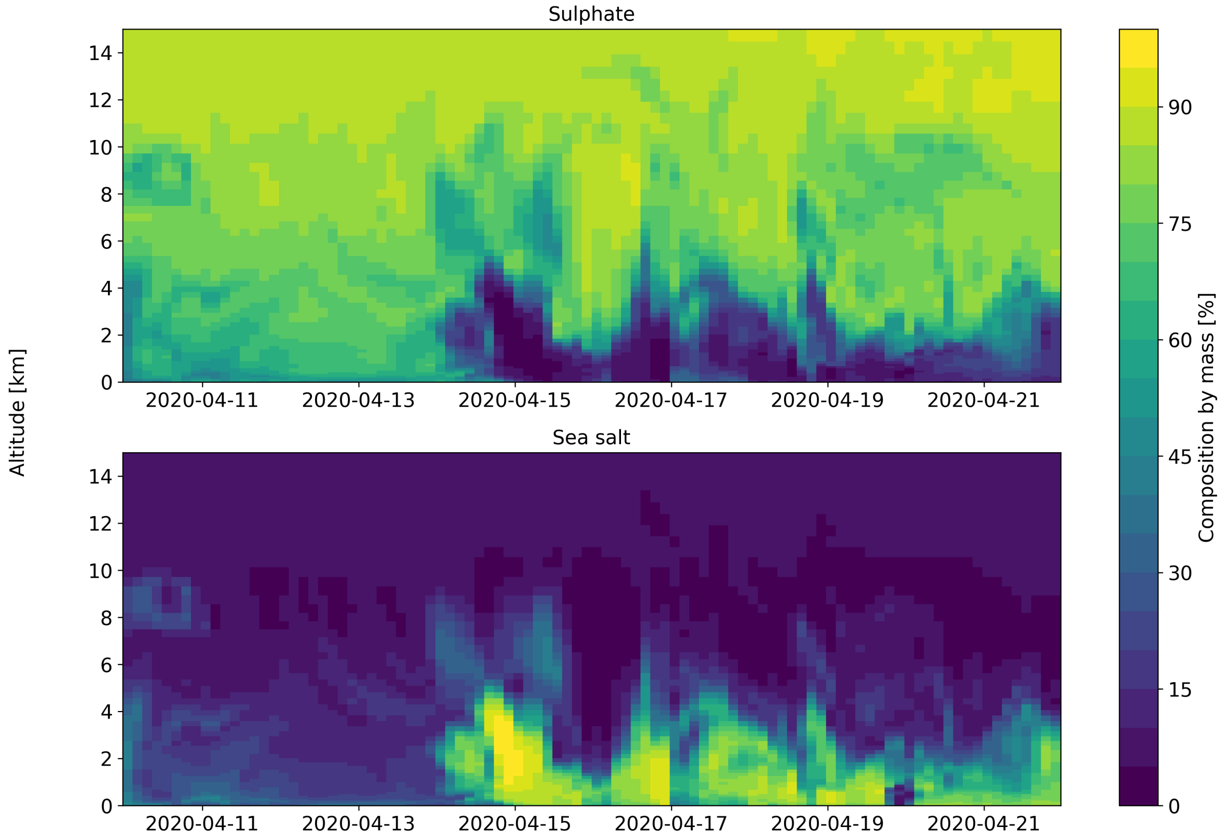
WP4 model intercomparison:

- UM-UKCA
  Ruth Price, Ella Gilbert, Andrew Orr…
  - 2.5km resolution
  - 2-moment cloud microphysics with cloud droplet nucleation and wet scavenging coupled to UKCA aerosol microphysics



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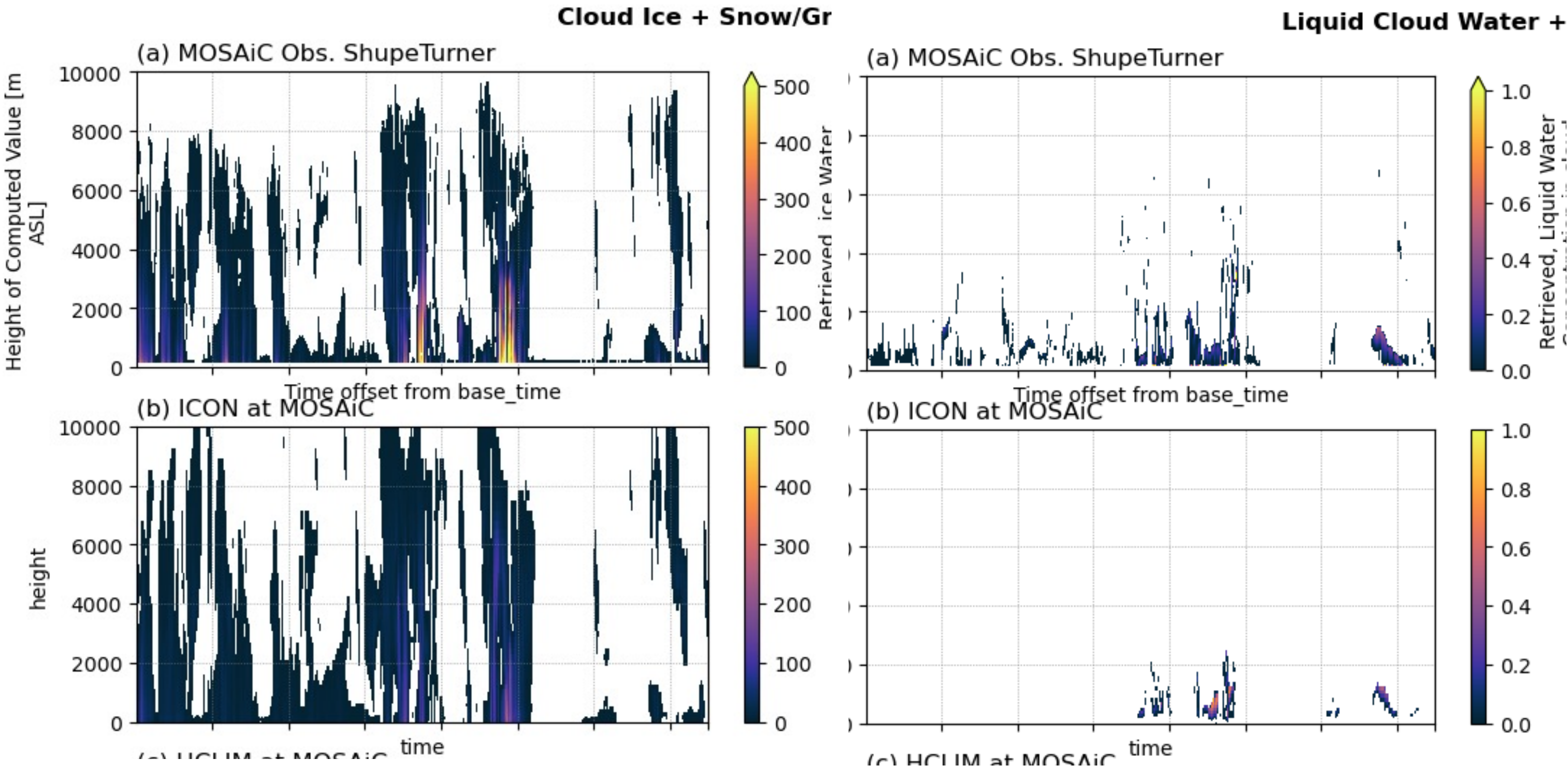
MOSAiC 2020-04 WAIs

Cloud ice & water

- spatiotemporal structure well captured
- cloud formation in intrusions
  - high ice concentrations not in models
  - not all liquid



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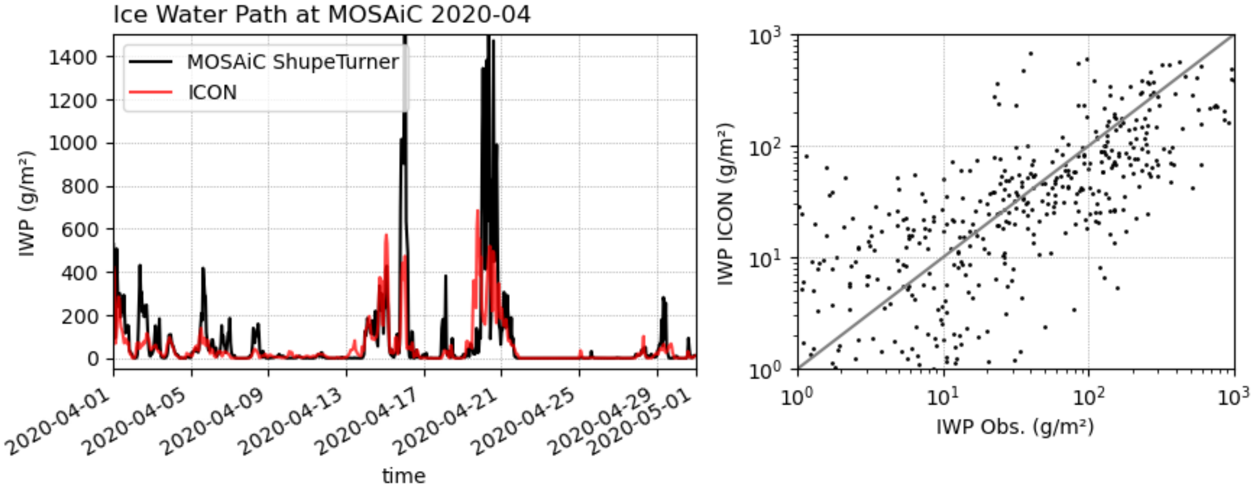
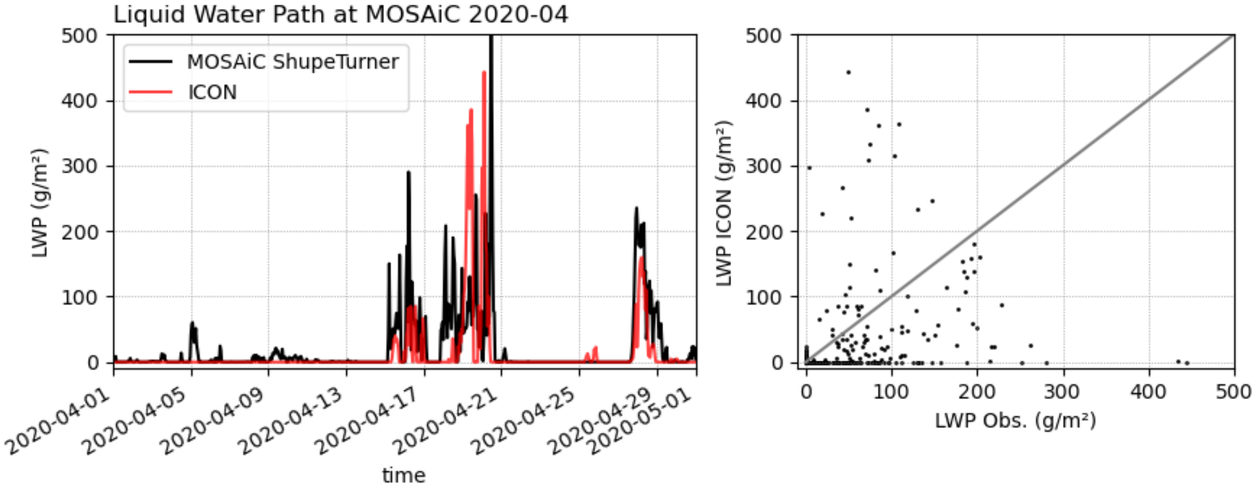
MOSAiC 2020-04 WAIs

Cloud ice & water

- spatiotemporal structure well captured
- cloud formation in intrusions
  - high ice concentrations not in models
  - not all liquid water in ICON

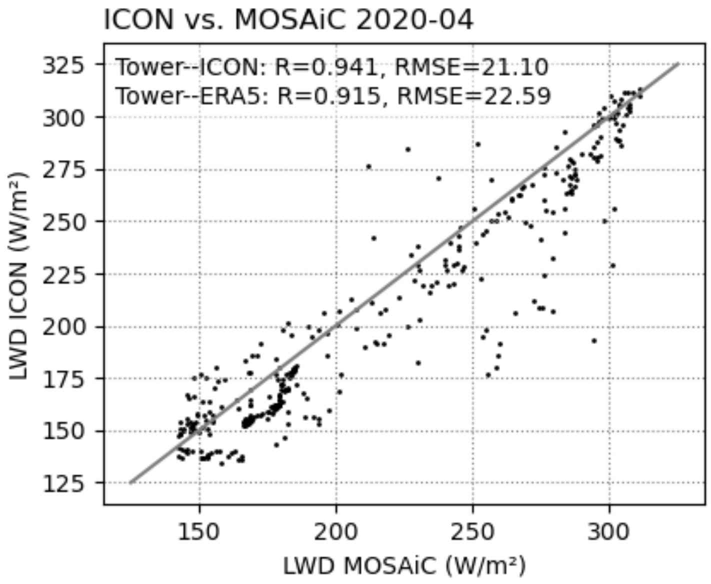


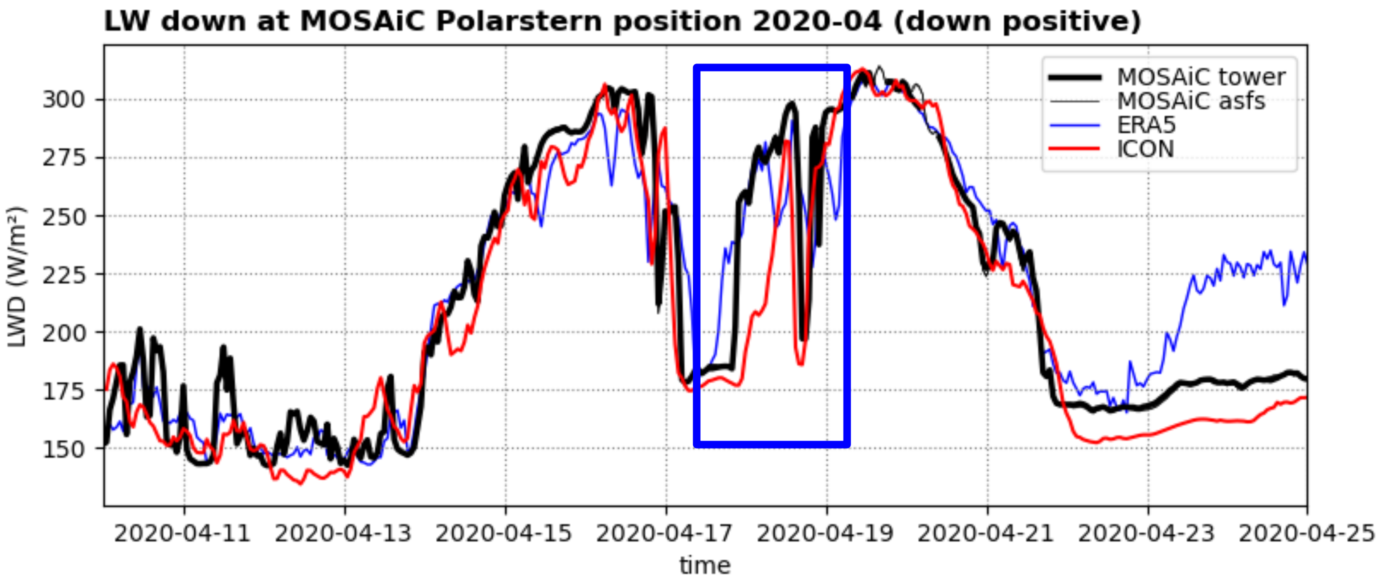


MOSAiC 2020-04 WAIs

Effect of intrusions on surface energy balance?

- increased LWD, due





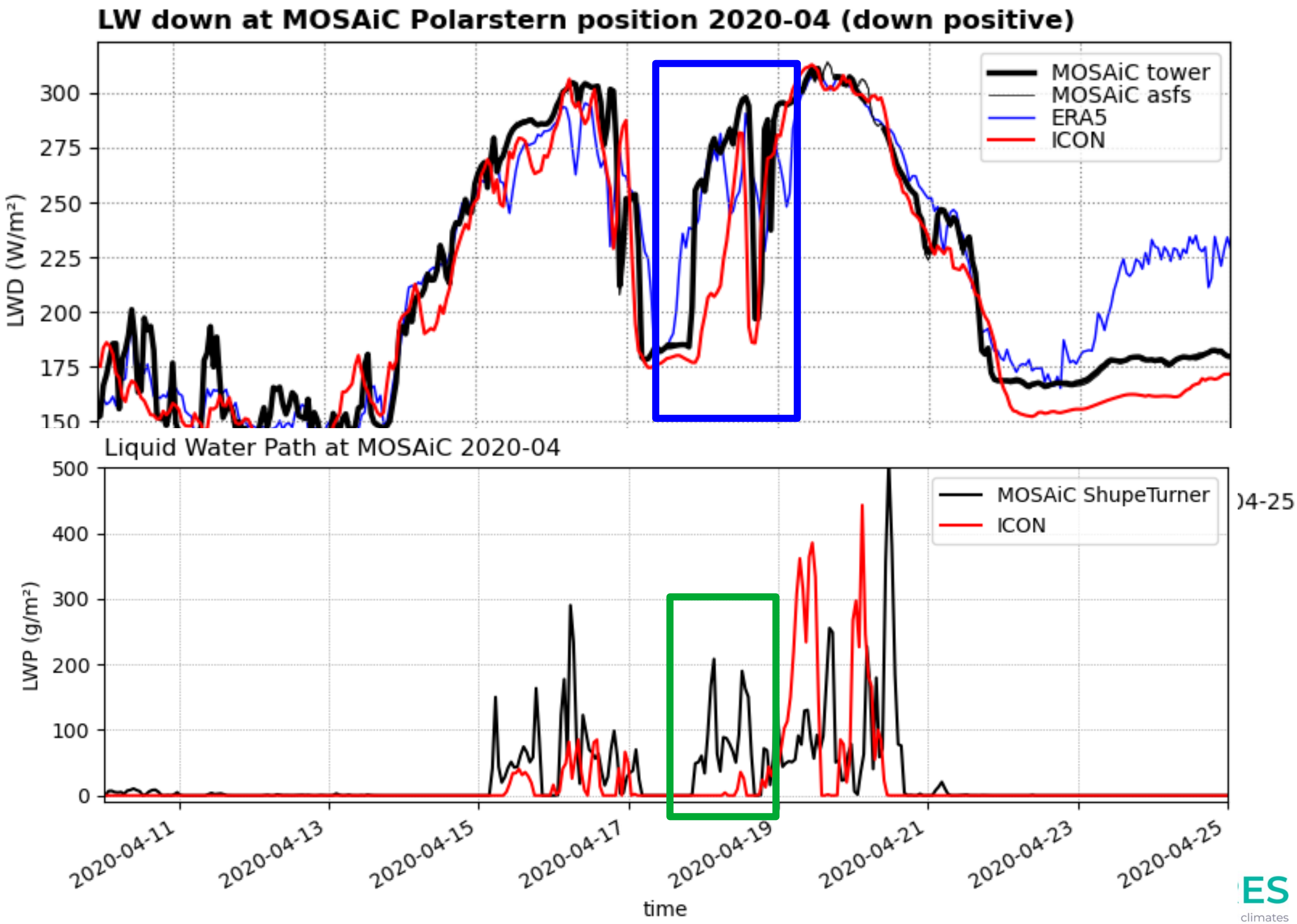
ICON:

- LWD generally good, slightly low
- misses LWD increase at onset of WAI#2

MOSAiC 2020-04 WAIs

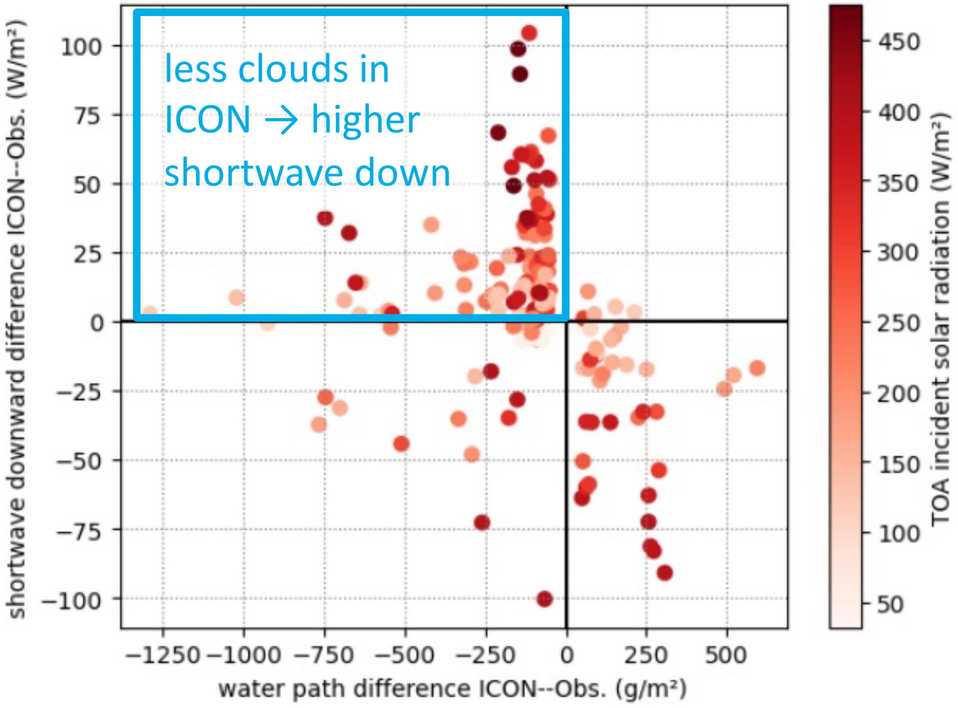
ICON:

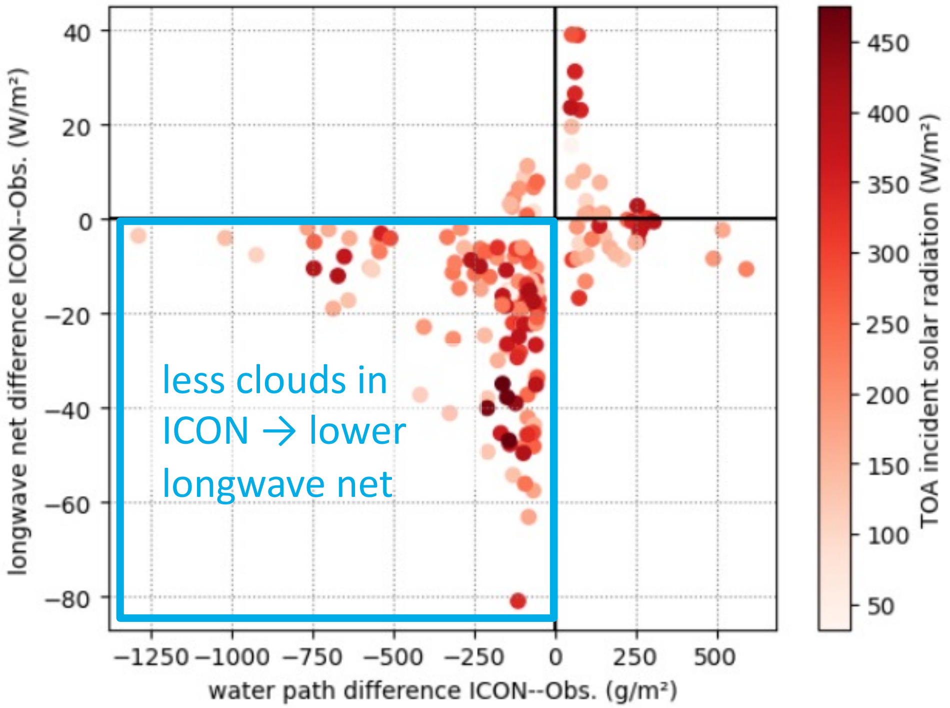
- misses LWD increase at onset of WAI#2
- due to missing low-level liquid clouds (?)



MOSAiC 2020-04 WAIs

Do cloud differences explain (some) SEB differences?





particularly at high insolation (dark red)
→ shortwave down is slightly too high and
surface warms more strongly → high LWU

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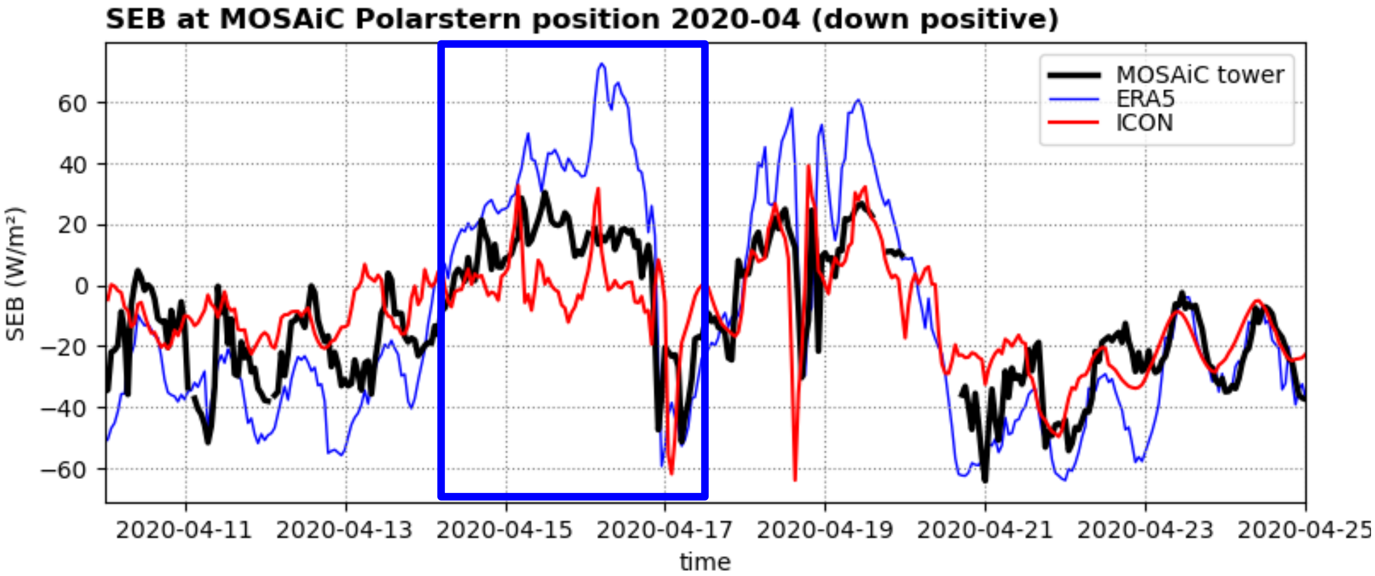
MOSAiC 2020-04 WAIs

Effect of intrusions on surface energy balance?

- positive SEB anomaly of WAI#1 underestimated (why?)
- ERA5 overestimates SEB in both events



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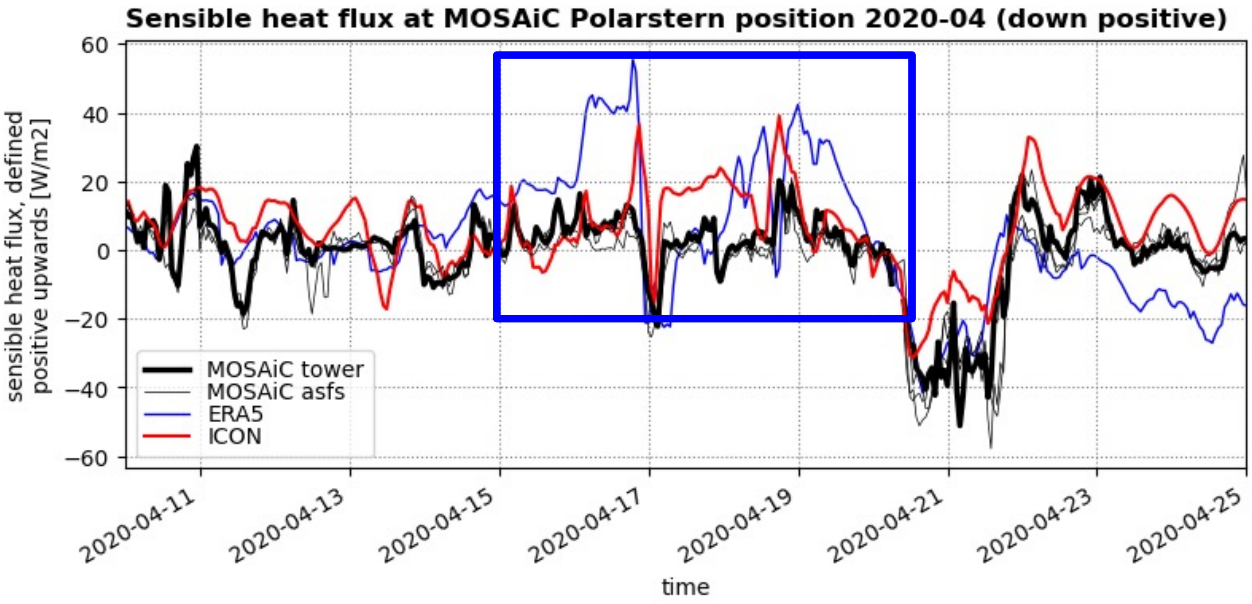
MOSAiC 2020-04 WAIs

Effect of intrusions on surface energy balance?

→ ERA5 overestimates SEB in both events

- strongly positive Sensible Heat Flux anomalies
  - no insulating snow layer on sea ice
  - ice surface responds slowly and remains cold
- ICON: also no snow-on-ice
  - sensitive to sea ice tuning parameters



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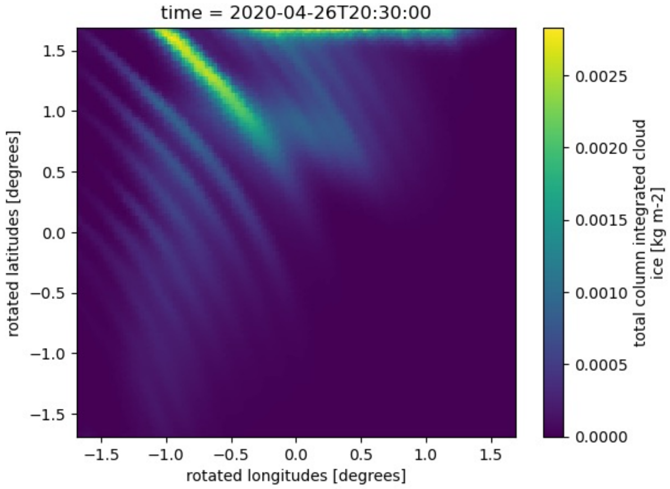
MOSAiC 2020-04 WAIs

further work within PolarRES:

- comparing model ensemble with extensive MOSAiC data
- analyses with ICON
  - domain and resolution
    - artifacts in 2km domain; need nesting?
  - cloud microphysics settings
    - 2 moment scheme → thicker clouds?
  - surface energy balance and temperature extremes in WAIs



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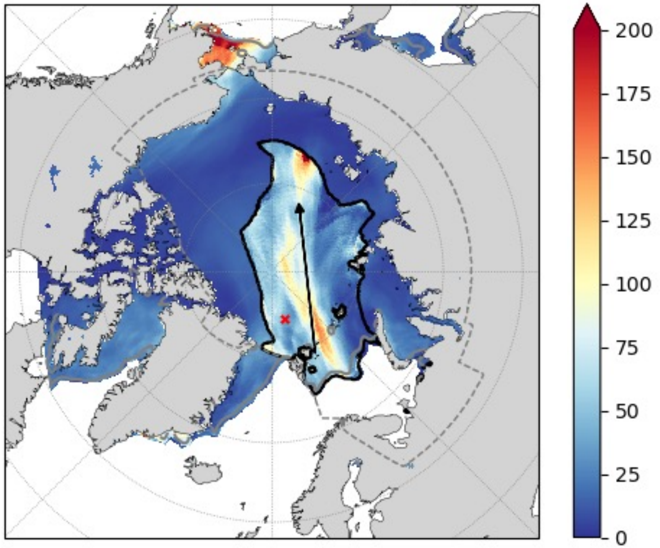
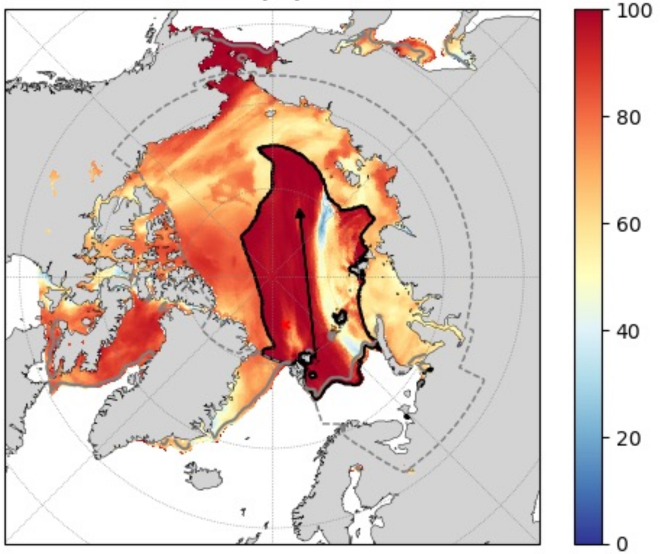
Tracking Moisture Intrusion Events

- cloud water+ice reflects IVT / IWV
- cloud cover high, but not homogeneously
- precipitation: different pattern than IVT / IWV / Cloud water+ice

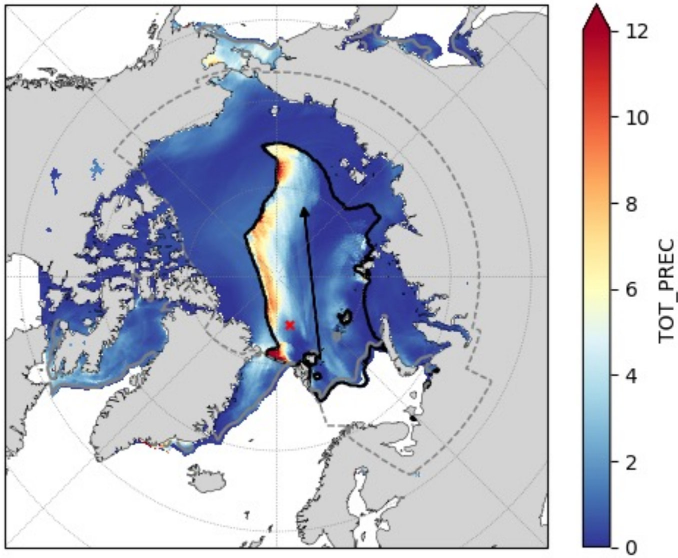
Mean Cloud Water+Ice Path (g/m²) in WAI



Mean Cloud Cover (%) in WAI

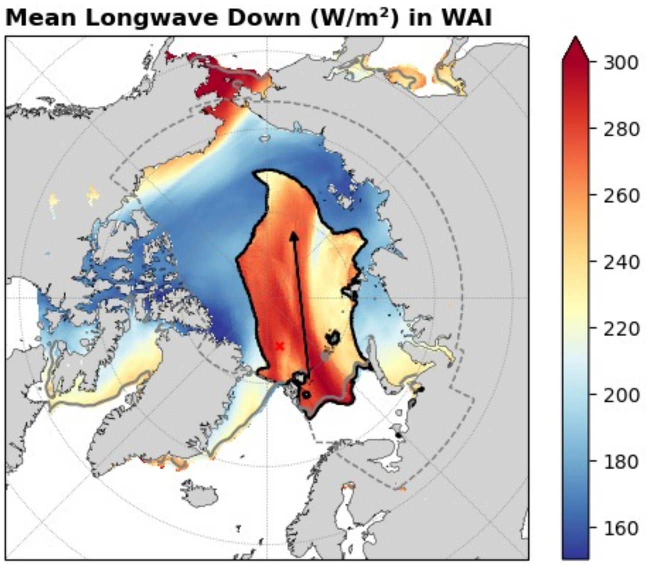


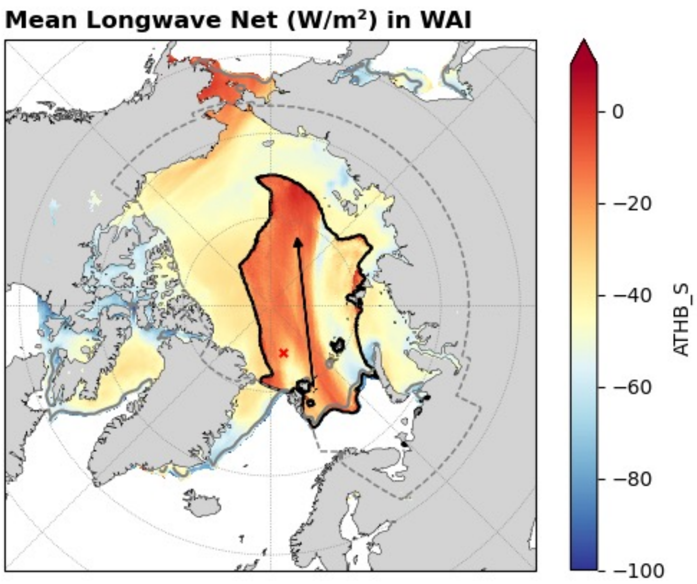
Mean Precipitation (mm/d) in WAI

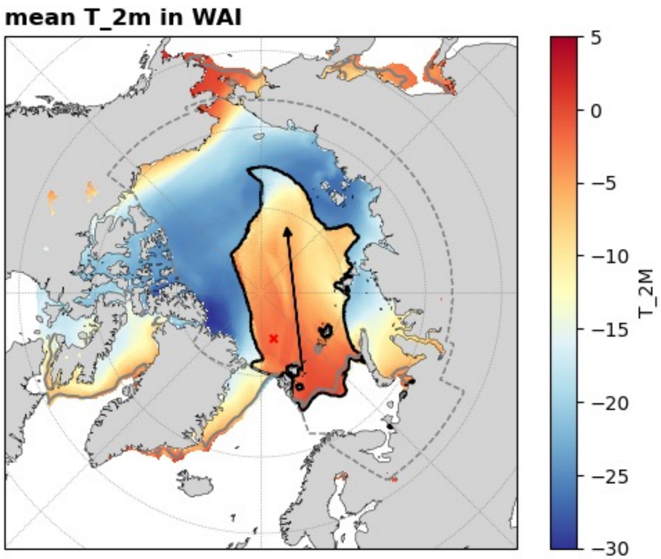


Tracking Moisture Intrusion Events

- Mean / net surface longwave: elevated where clouds
- T_{2m}: advected warm air + cloud effects (?)







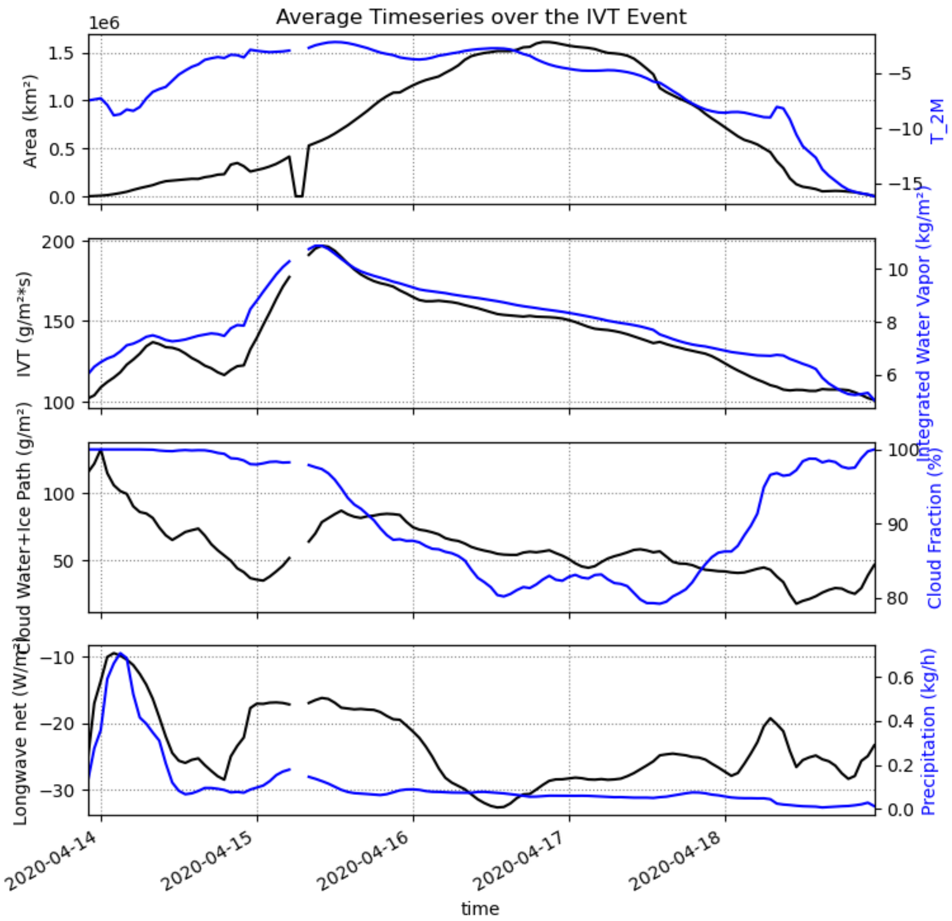
PolarRES
Exploring future polar climates

Tracking Moisture Intrusion Events

Temporal evolution of MOSAiC WAI#1

over sea ice:

- mean IVT, IWV (TQV), Cloud Water+Ice path peak on April 15



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