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PolarRES
Exploring future polar climates

Impacts of regional grid refinement on climate extremes over the Arctic in storyline-based VR-CESM simulations

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Research Motivation & Objectives

Research Motivation:

- Arctic environment is rapidly warming.
- Characteristics future climate extremes most likely change.
- To improve understanding of future changes in extremes over the Arctic, storylines could be helpful.

Research Objectives:

1. Understanding future changes in temperature and precipitation extremes over the Arctic by means of climate change storylines.
2. Impacts of regional grid refinement in Earth System Models.

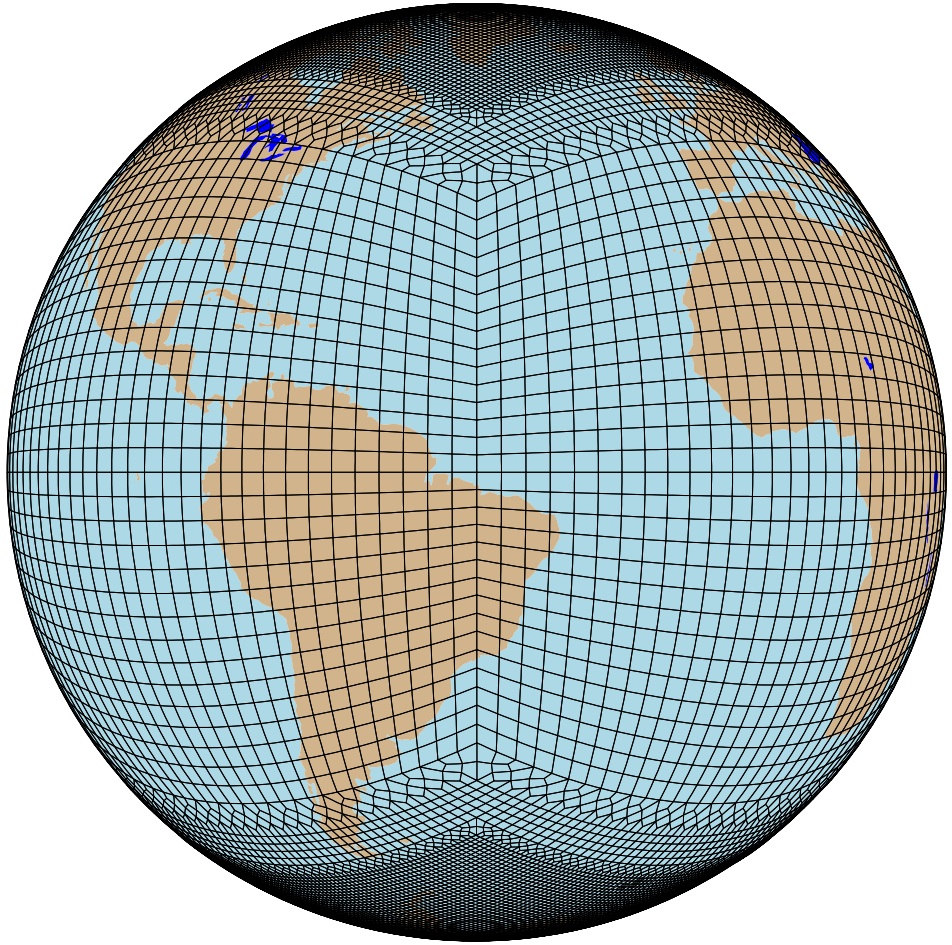
Variable-resolution Community Earth System Model (VR-CESM)

AMIP-style simulations with CESM version 2.3[1]

1. Interactive atmosphere (Community Atmosphere Model; CAM-SE[2]) and land surface models (Community Land Model; CLM-SP[3])
2. Prescribed daily sea surface temperature and sea ice from ERA5[4]/CMIP6 models

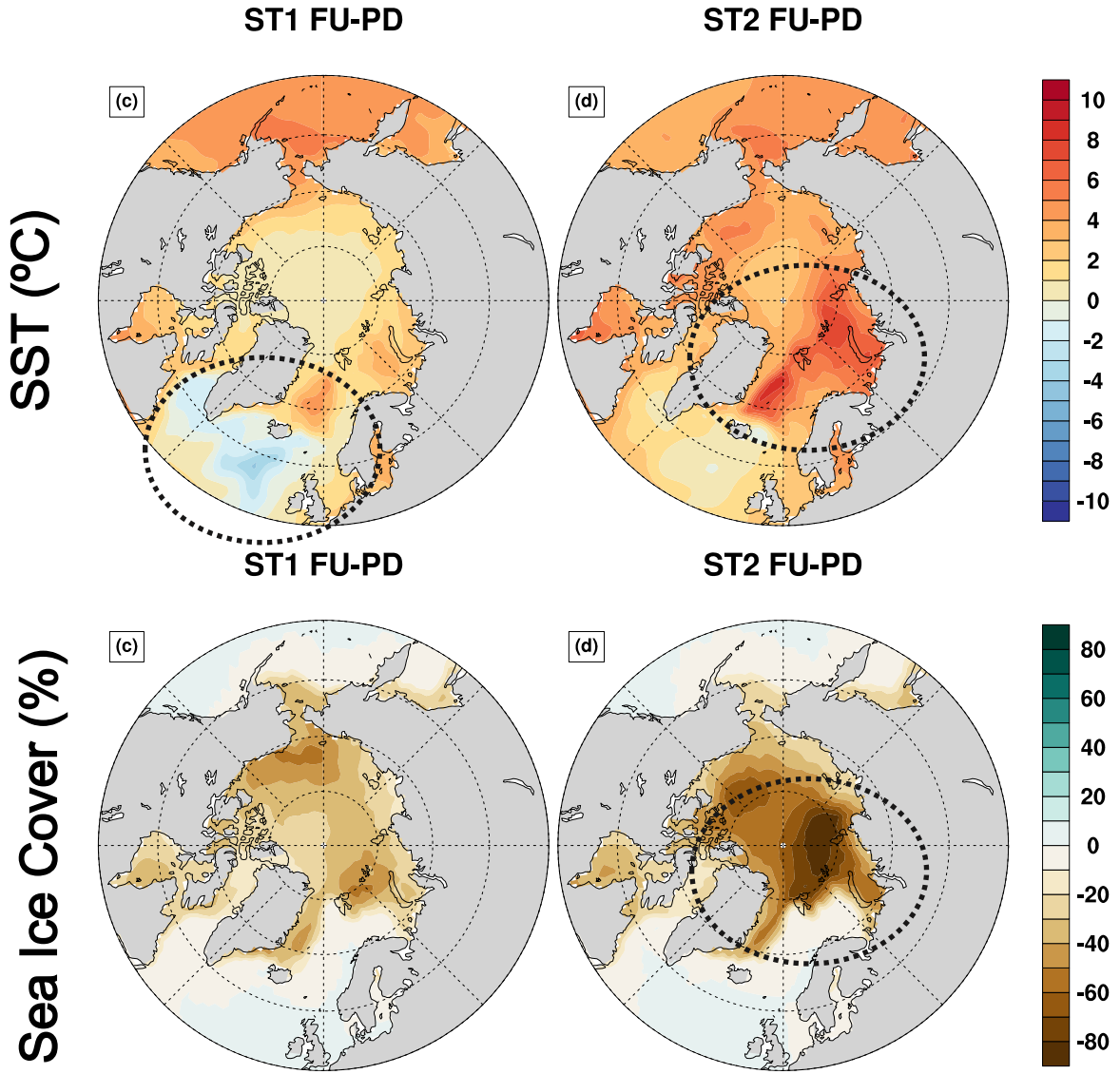
Model runs with uniform grid (**U**)(1°; ~111 km) and bipolar variable resolution grid (**R**):

- Polar regions: 0.25° (~28 km)
- 1° (~111 km) global

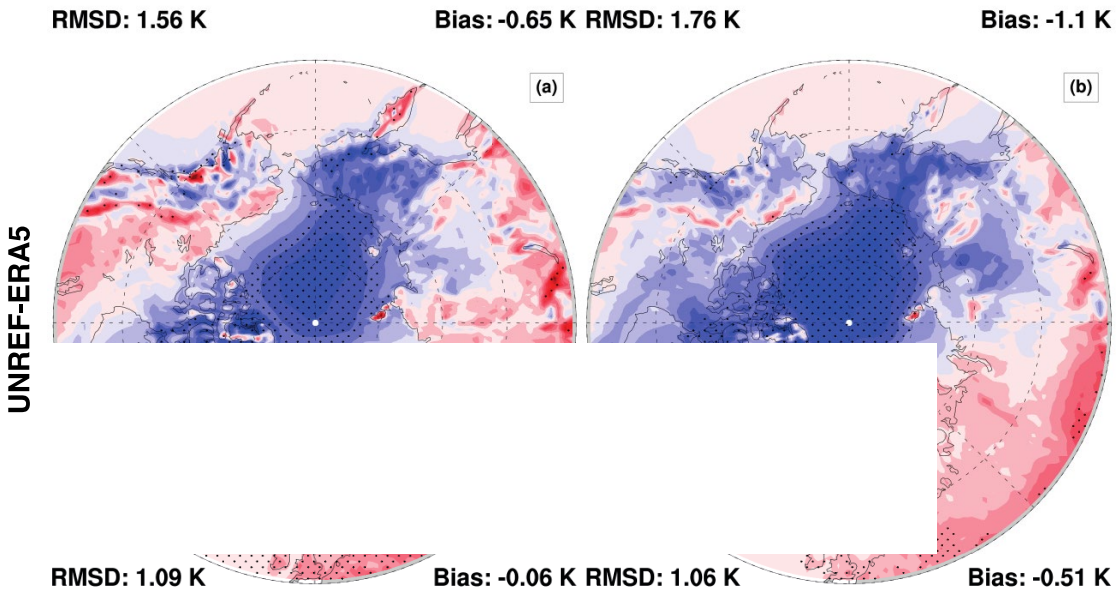


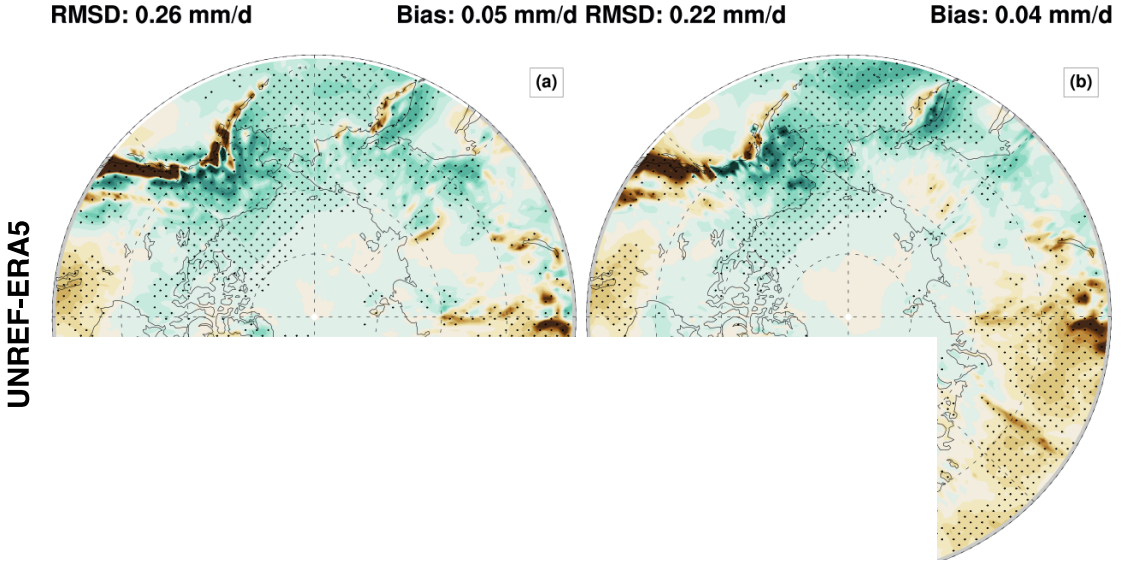
Experimental Design

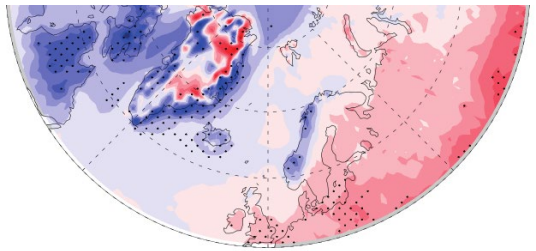
- ERA5-based present-day simulations (observational control)
  - 1985-2014
- CMIP6-based present-day simulations (**PD**)
  - 2005-2014
- CMIP6-based future simulations (**FU**)
  - 2090-2099
- 2 storylines (following SSP5-8.5) for Arctic[5]:
  - **ST1**: Strong Polar Amplification / weak SST warming in Barents-Kara Seas (NorESM2-MM)
  - **ST2**: Weak Polar Amplification / strong SST warming in Barents-Kara Seas (CNRM-ESM2-1)

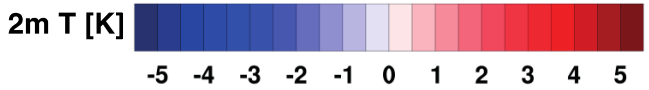


Evaluation annual T/P wrt. ERA5 and JRA-3Q



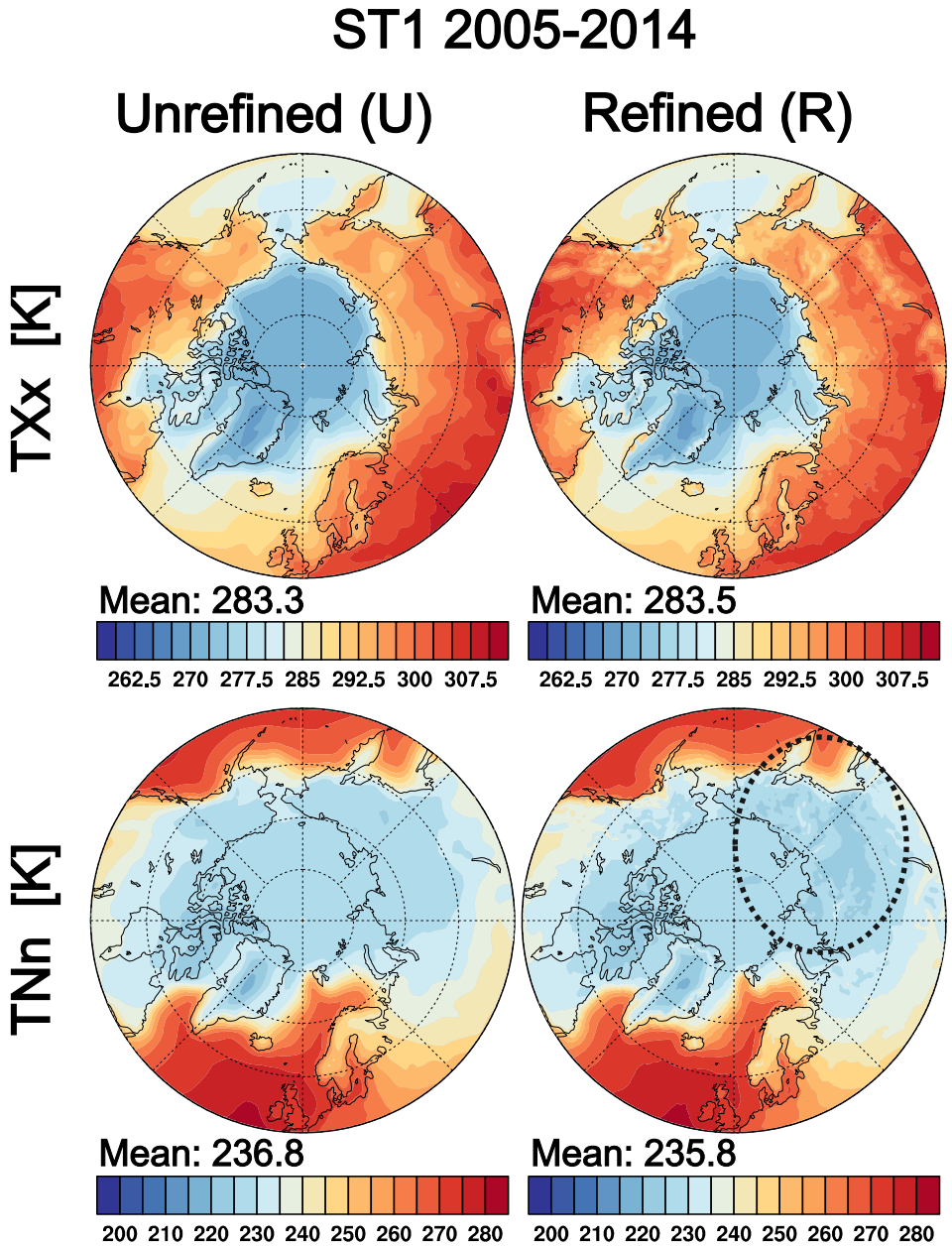






P [mm/d

Temperature Extremes: annual max. T (TXx) and annual min. T (TNn)

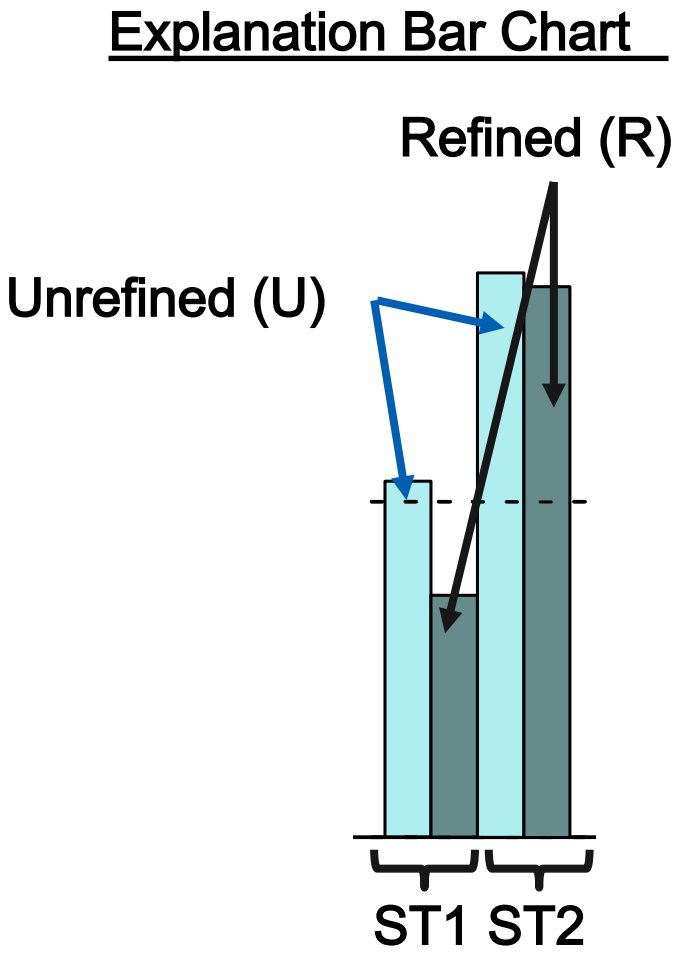


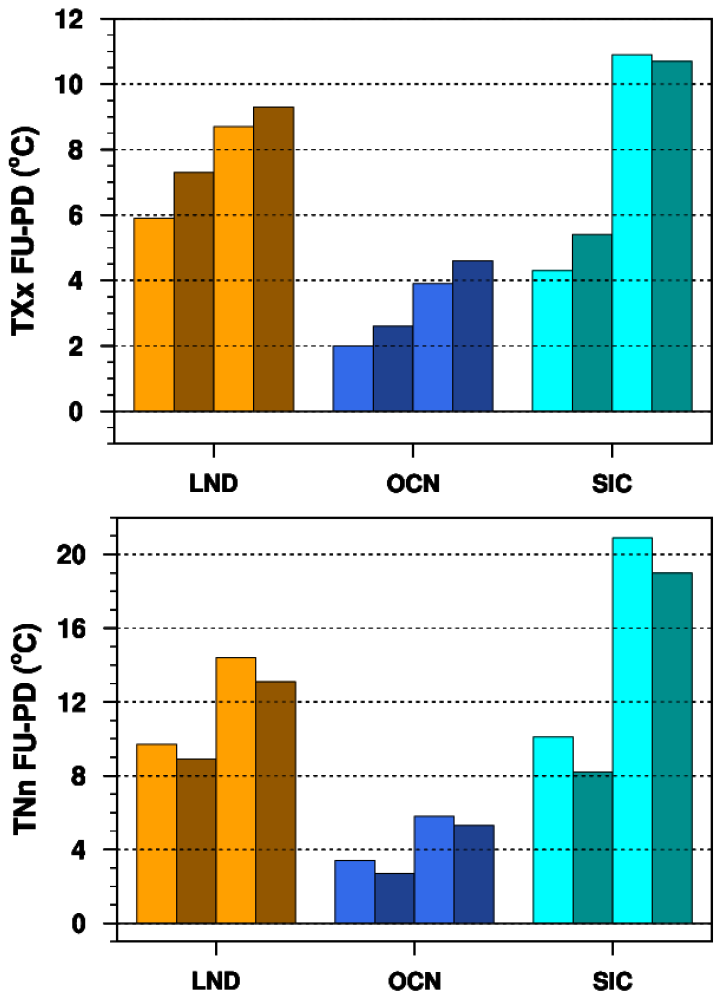
TXx patterns are similar between unrefined and refined simulations

TNn patterns are also similar, but simulations get slightly colder with refinement (e.g. over Siberia)

*The mean is computed as an area -average over the domain poleward of 50N

Temperature Extremes: annual max. T (TXx) and annual min. T (TNn)





TXx and TNx increase in both storylines.

Increase stronger in ST2, most likely related to larger loss in sea ice.

- **Land (LND):** All land poleward of 60N
- **Sea Ice (SIC):** Maximum present-day sea ice extent, where sea ice fraction > 15%
- **Ocean (OCN):** All ocean poleward of 60N, excluding SI domain

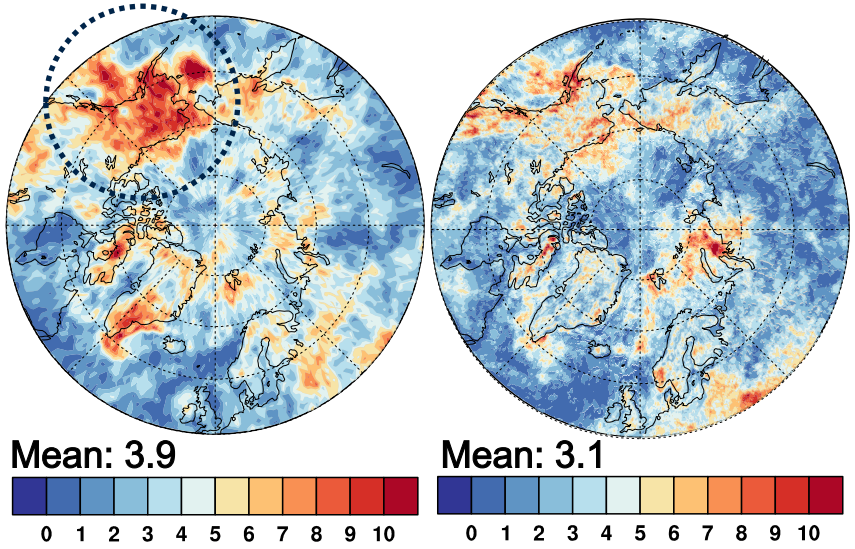
Temperature Extremes: warm spells (WSDI) and cold spells (CSDI)*

*annual number of extreme warm/ cold days in intervals of at least 6 consecutive days

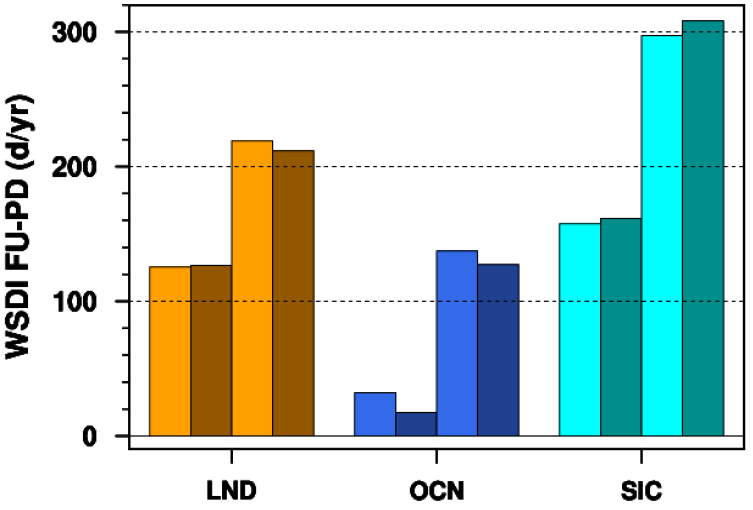
ST1 2005-2014

Unrefined (U) Refined (R)

WSDI [d/ yr]



Bar1: ST1 U, Bar2: ST1 R
Bar3: ST2 U, Bar4: ST2 R

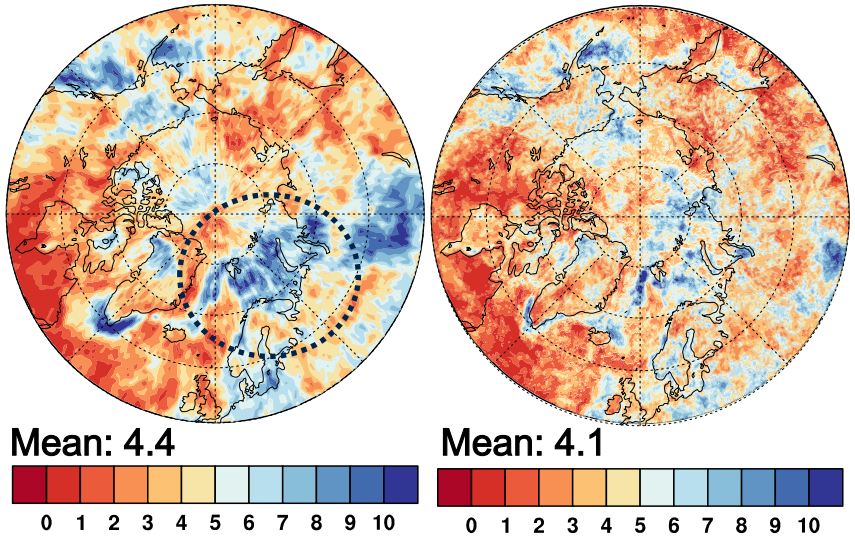


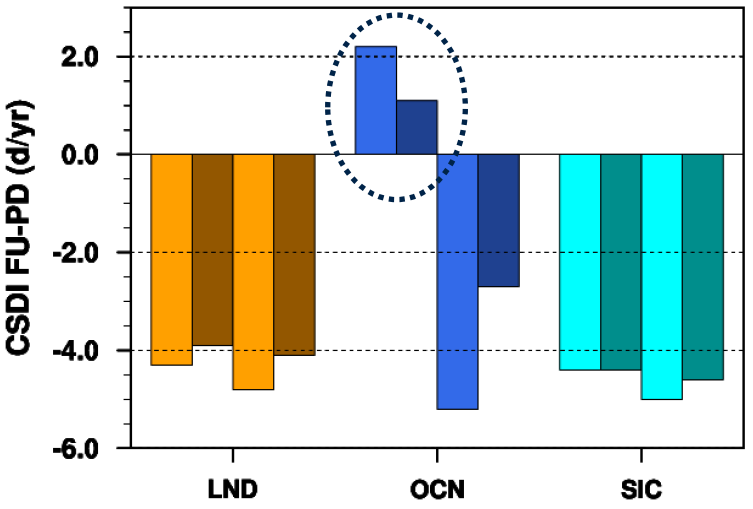
PD: Warm spells more frequent in unrefined simulations.

FU: Warm spells more frequent in both storylines.

ST2 increases are stronger.

CSDI [d/ yr]





PD: Cold spells more frequent in unrefined simulations.

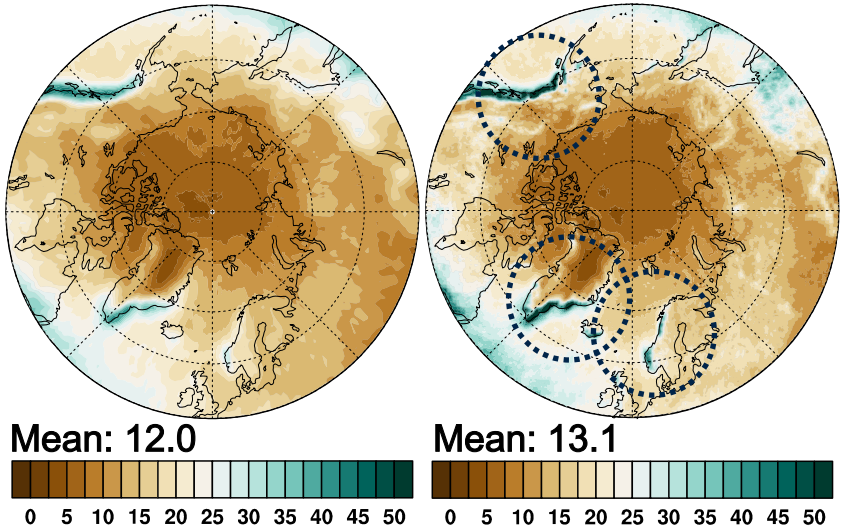
FU: Cold spells less frequent, except over the ocean in ST1 -> SST cooling N. Atlantic

Precipitation Extremes: extreme P (P99) and highest 5-day P (Rx5day)

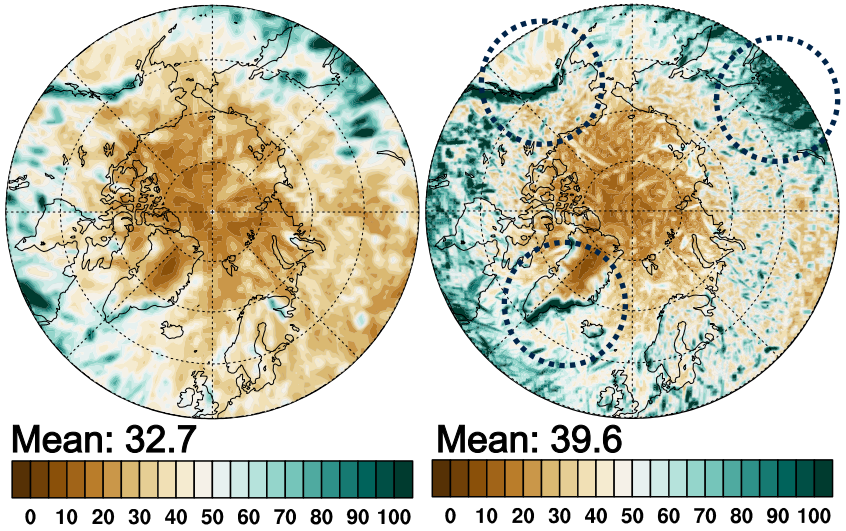
ST1 2005-2014

Unrefined (U) Refined (R)

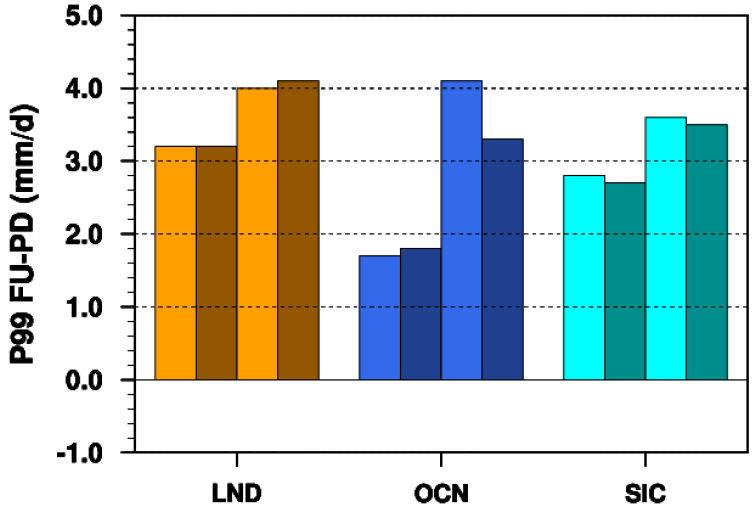
P99 [mm/d]

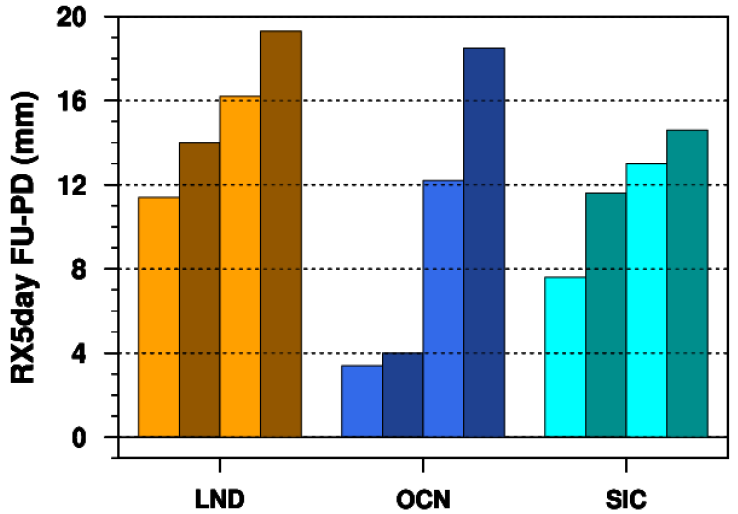


RX5day [mm]



Bar1: ST1 U, Bar2: ST1 R
Bar3: ST2 U, Bar4: ST2 R



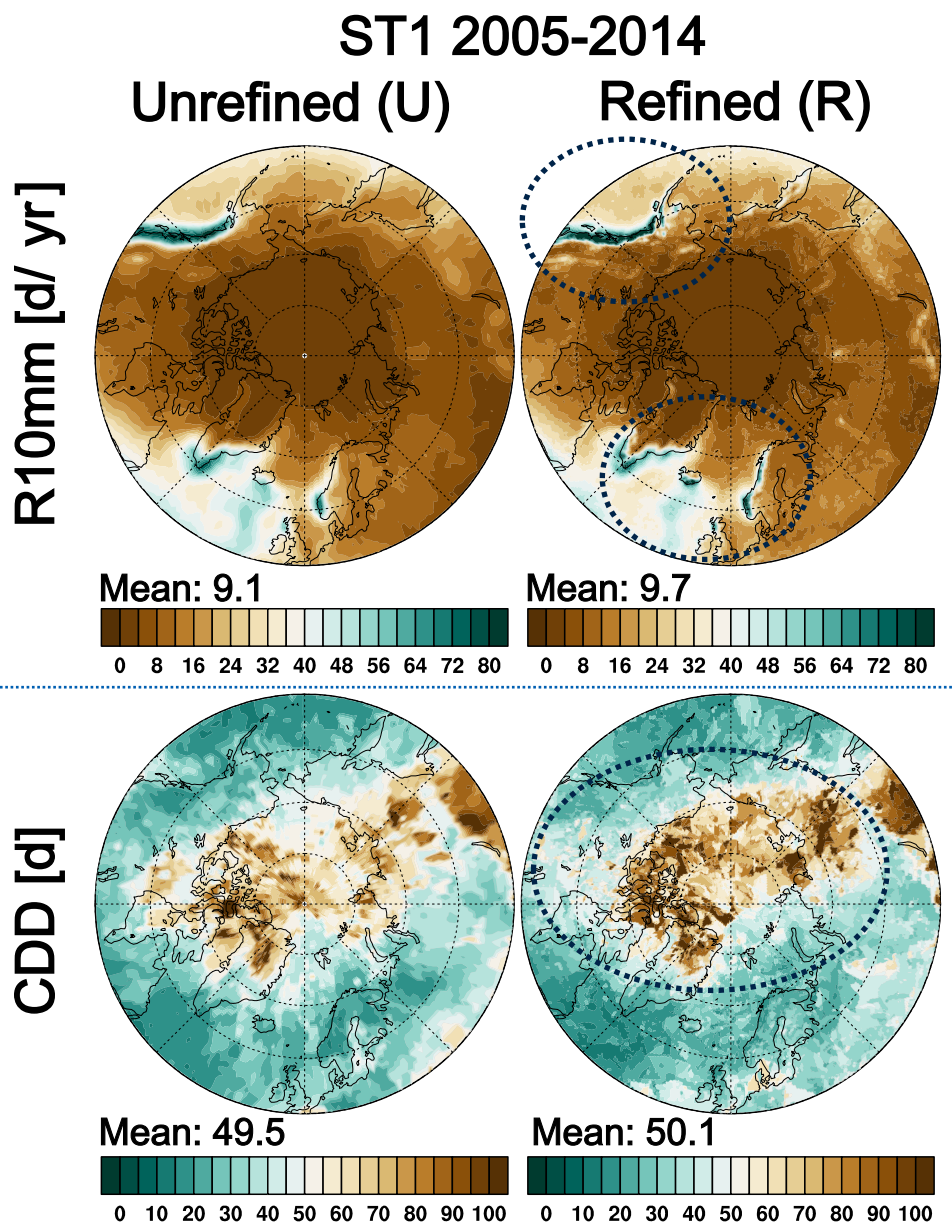


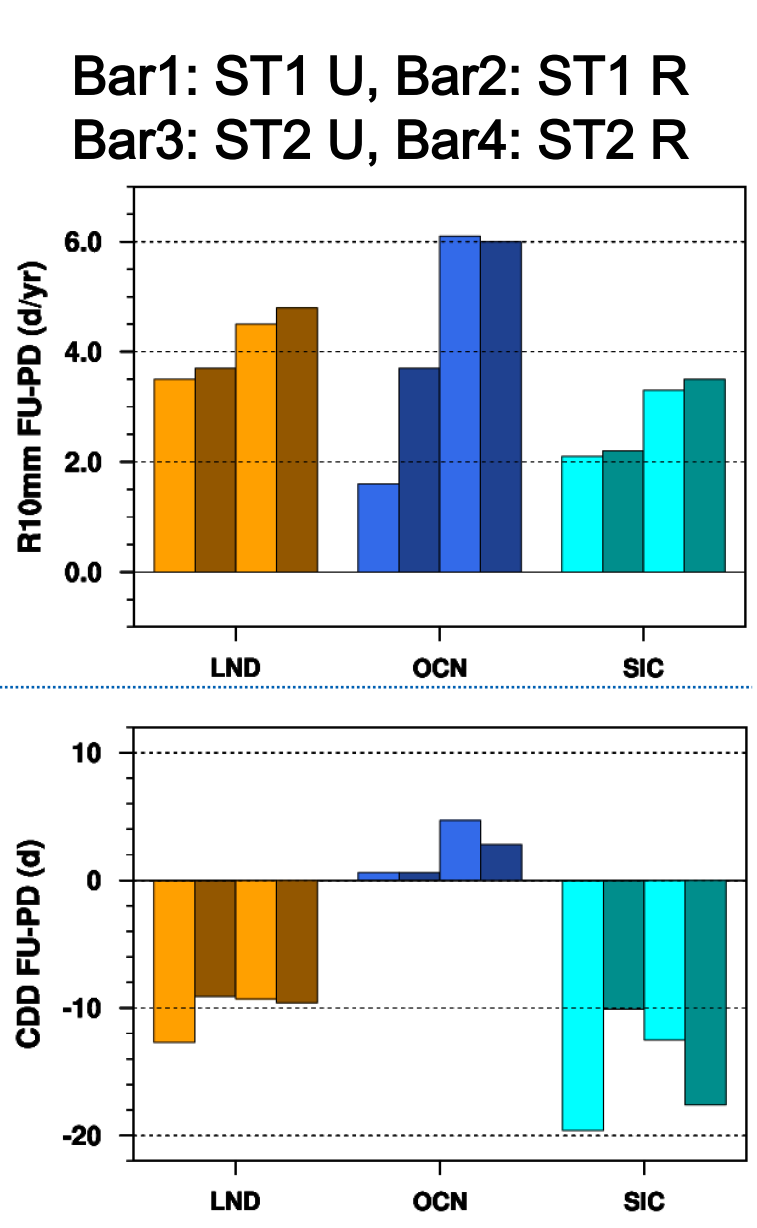
PD: P99 and Rx5day are higher in refined simulations:
- Better resolved topography.
- Increased convective precipitation.

FU: P99 and Rx5day increase in both storylines.

ST2 increases tend to be bit larger:
- SST warming -> more moist -> more precipitation.

Precipitation Extremes: heavy P days (R10mm) and consecutive dry days (CDD)





PD: Heavy precipitation days more frequent in refined simulations

FU: Heavy precipitation days increase in both storylines,

PD: CDD a bit higher in refined simulations, but patterns resemble largely.

FU: CDD decreases over land and sea ice and increases over ocean.

Conclusions

Temperature Extremes

Present-day:

- Annual max. and min. T mostly similar between refined and unrefined simulations. Annual min. T is a bit lower in the refined simulations.
- Cold/warm spells occur less frequently in refined simulations.

Future:

- Annual max. and min. T increase in both storylines.
- Warm spells occur more frequently. Cold spells occur less frequently.

Precipitation Extremes

Present-day:

- All precipitation indices (P99, Rx5day, CDD, R10mm) are higher in the refined simulations.

Future:

- Heavy precipitation increases in intensity and frequency.
- CDD decreases over land and sea ice and increases over ocean.

References

[1] Danabasoglu et al., The Community Earth System Model Version 2 (CESM2), J. Adv. Model Earth. Sy., 12, e2019MS001916, https://doi.org/10.1029/2019MS001916, 2020.

[2] Gettelman et al., High Climate Sensitivity in the Community Earth System Model Version 2 (CESM2), Geophys. Res. Lett., 46, https://doi.org/10.1029/2019GL083978, 2019.

[3] Lawrence et al., The Community Land Model Version 5: Description of New Features, Benchmarking, and Impact of Forcing Uncertainty, J. Adv. Model Earth Sy., 11, 4245–4287, https://doi.org/10.1029/2018MS001583, 2019.

[4] Hersbach et al., The ERA5 global reanalysis, Q. J. Roy. Meteor. Soc., 146, 1999–2049, https://doi.org/10.1002/qj.3803, 2020.

[5] Levine et al., Storylines of Summer Arctic climate change constrained by Barents-Kara Sea and Arctic tropospheric warming for climate risks assessment, EGUsphere [preprint], https://doi.org/10.5194/egusphere-2023-2741, 2023.

Thank you for your attention!

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Climate Extreme Indices

- **TXx (K)**: Annual maximum of daily maximum temperature.
- **TNn (K)**: Annual minima of daily minimum temperature.
- **WSDI (d/ yr)**: Warm spell duration index, defined as the annual number of days in intervals of at least 6 consecutive days on which TX > TX90, where TX90 is the 90th percentile of daily maximum temperature, calculated for each calendar day using a running window of 15 days.
- **CSDI (d/ yr)**: Cold spell duration index, defined as the annual number of days in intervals of at least 6 consecutive days on which TN < TN10, where TN10 is the 10th percentile of daily minimum temperature, calculated for each calendar day using a running window of 15 days.

- **P99 (mm/d)** : 99th percentile of daily precipitation.
- **RX5day (mm)** : highest amount of precipitation over an interval of 5 days.
- **R10mm (d/ yr)**: Number of days with heavy precipitation, defined as daily precipitation that is equal to or higher than 10 mm/d.
- **CDD (d)** : Greatest number of consecutive days with daily precipitation less than 1 mm/d.