Left: Ocean [WMO]
Right: Arctic sea ice [NASA]

Interactions between ocean heat transport (OHT) and Arctic sea ice

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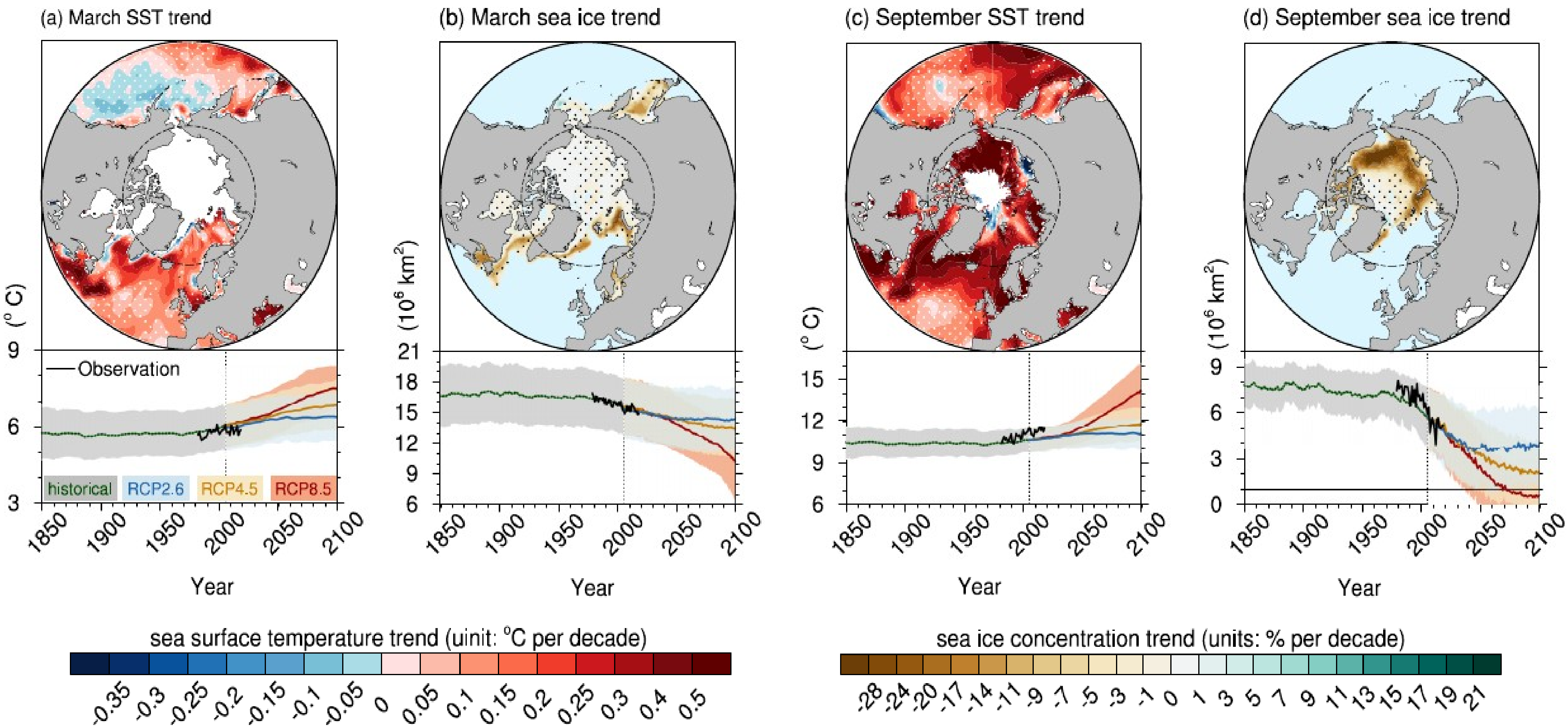
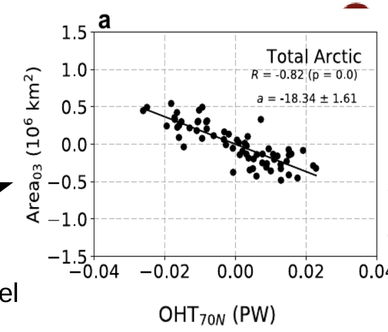
1. Intro: SST increase and Arctic sea-ice area decrease

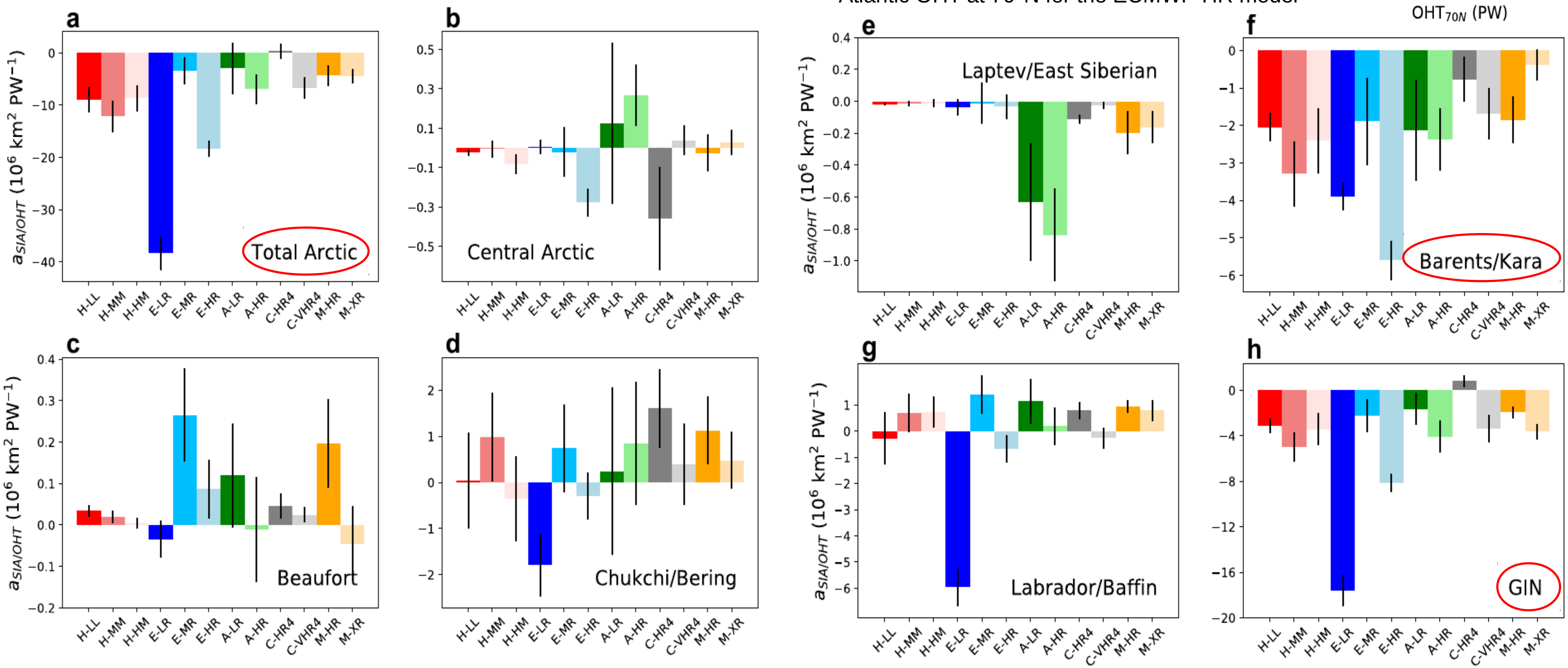


Trends computed over 1982-2017 [IPCC (2019), SROCC, Chap. 3, Fig. 3.3, CMIP5 projections]

1. Intro: Sea-ice area in the Total Arctic / Barents-Kara / GIN Seas decreases with increasing Atlantic OHT in 12 HighResMIP model configurations

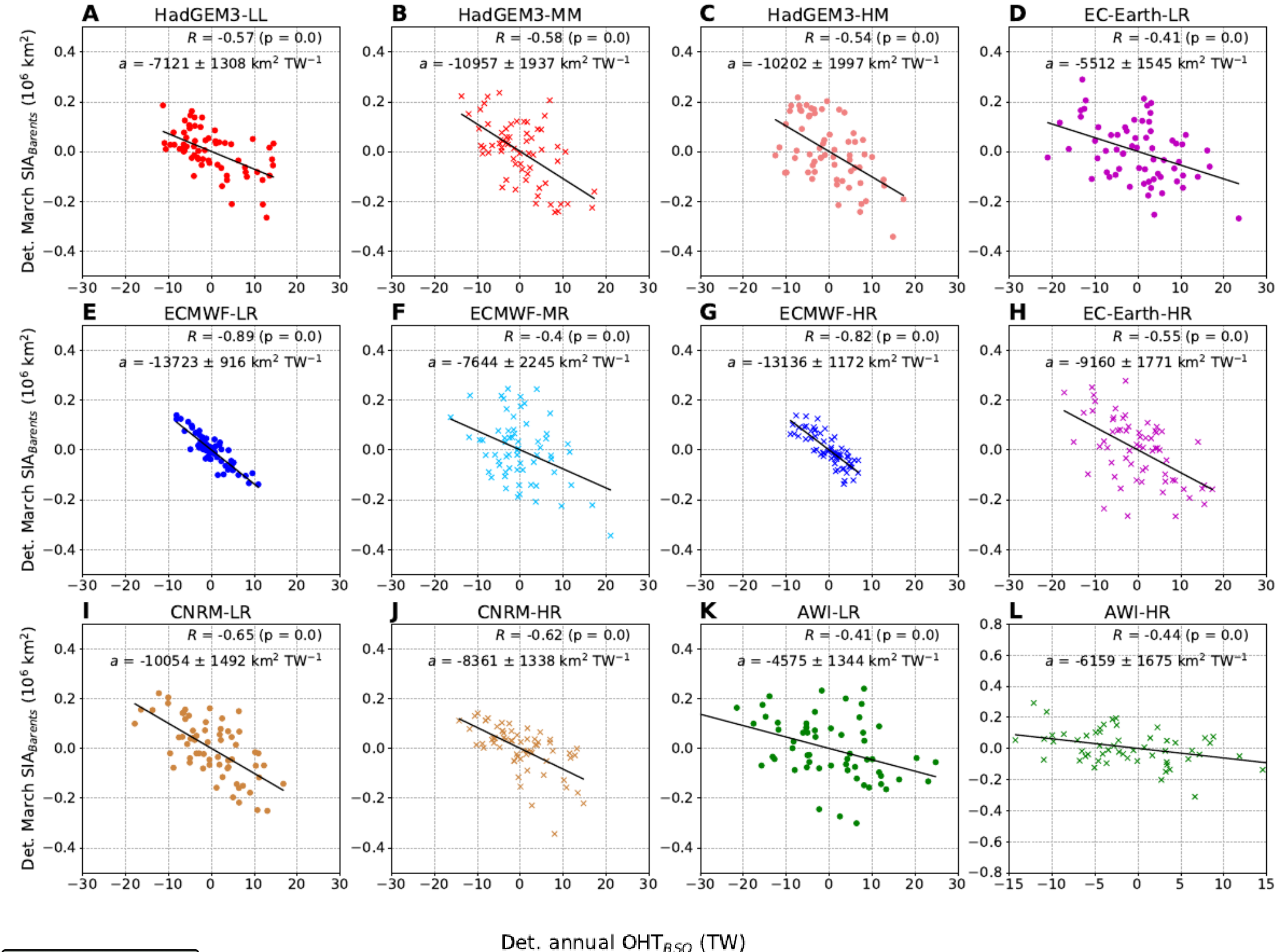


March Arctic sea-ice area vs. annual mean Atlantic OHT at 70°N for the ECMWF-HR model



Regression slopes *a* between March sea-ice area (SIA) in the (a) Total Arctic / (b-h) specific Arctic seas and annual mean Atlantic OHT at 70°N for the period 1950-2014. 1 bar for 1 model configuration.

Docquier et al. (2019), Fig. 14



1. Intro:

Barents sea-ice area decreases with increasing OHT at the Barents Sea Opening in 16 HighResMIP model configurations (only 12 shown here)

Fig.: March Barents sea-ice area (SIA) vs. annual mean OHT at the Barents Sea Opening with OHT leading SIA by 1 year over 1950-2014. 1 point corresponds to 1 year.

Docquier et al. (accepted)

2. Methodology

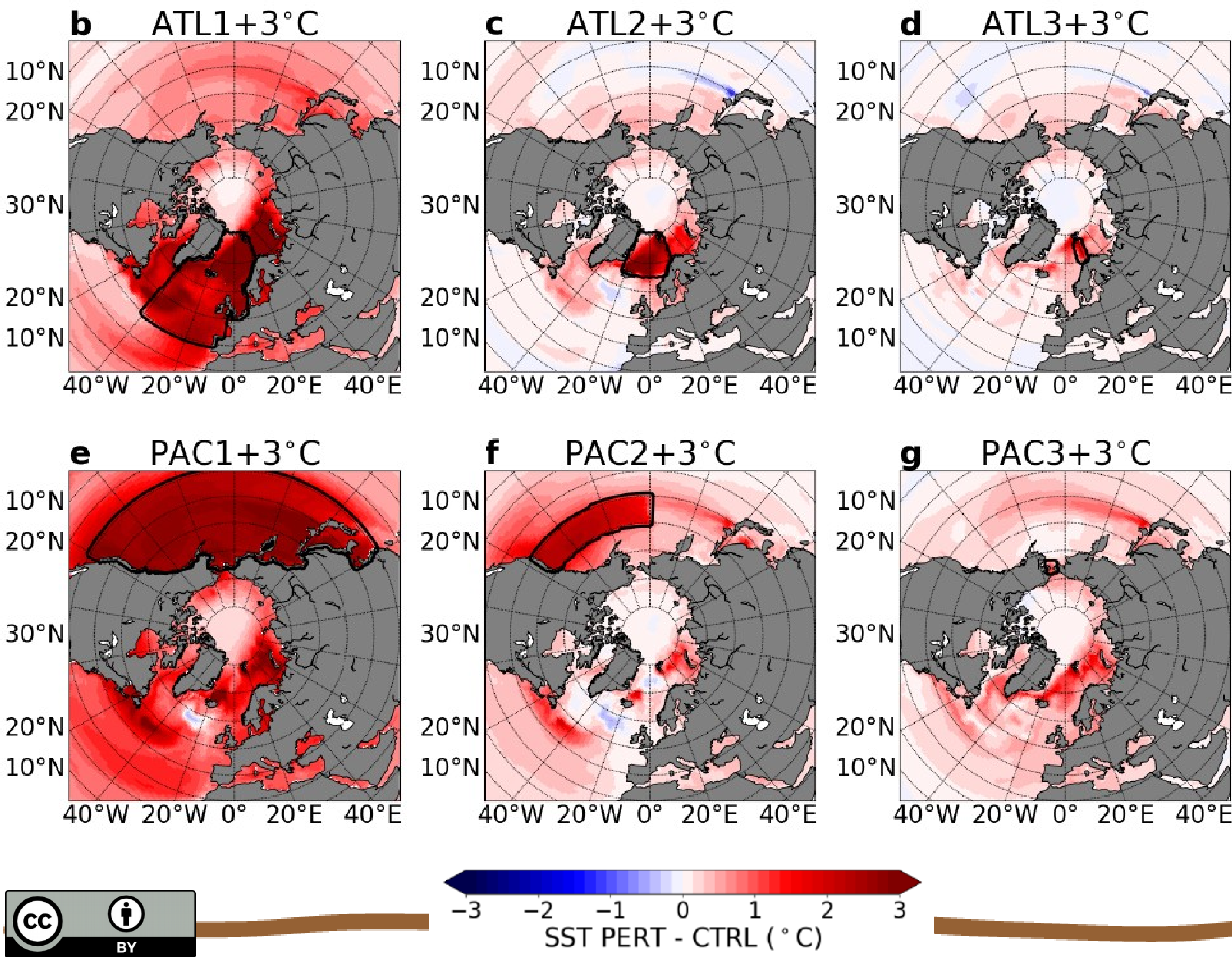
- The 2 previous studies show that there is a clear link between Arctic sea ice and ocean heat transport (OHT), but does not explore the causal links in details
- Aim of our study: explore the impact of OHT on Arctic sea ice
- EC-Earth model (coupled AOGCM)
  - Run with T255-ORCA1 configuration (nominal resolution of 100 km in atmosphere and ocean)
  - 200-year long control run (CTRL) starting in year 2014 of a historical CMIP6 simulation, with 2000-year constant forcing
  - 50-year long sensitivity experiments starting in the middle of CTRL with SST restoring (+1K, +3K, +5K)

2. Methodology

- SST is restored to the mean climatology +1K/+3K/+5K in a specific domain throughout the full duration of sensitivity experiments
- 3 domains in the North Atlantic: wide, medium, small
- 3 domains in the North Pacific: wide, medium, small

	Wide	**Medium**	**Small**
North Atlantic	40-80°N, 40°W-20°E **ATL1**	66-80°N, 22°W-20°E **ATL2**	70-77°N, 15-22°E **ATL3**
North Pacific	30-66°N, 120°E-120°W **PAC1**	40-50°N, 180-120°W **PAC2**	64-67°N, 172-166°W **PAC3**

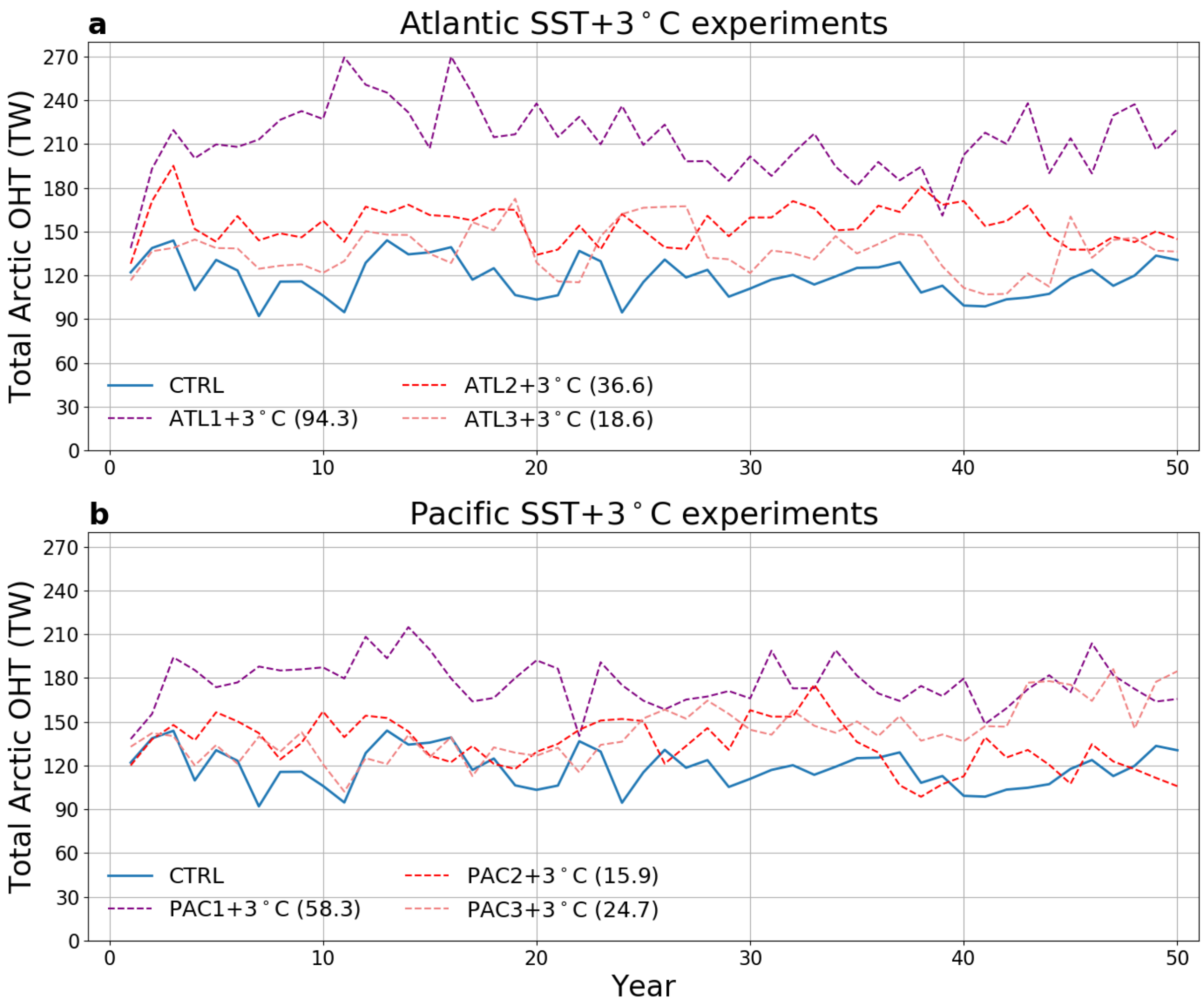
3. Results: SST increase



- The larger the domain for SST restoring, the more widespread the SST increase
- SST increase not solely restricted to the SST restoring region

Fig.: Difference in mean SST, averaged over 50 years, between the Atlantic (top panels) / Pacific (bottom panels) SST+3K experiments and CTRL. The domain in which the SST restoring is applied is shown for each experiment.

3. Results: OHT increase



- Total OHT through all Arctic straits increases in all experiments compared to CTRL (left Fig.), with more pronounced increase in the wide domain experiments (dashed purple lines)
- The increase in OHT at the BSO (Bering Strait resp.) is largest in the North Atlantic (North Pacific resp.) experiment (not shown)

Fig.: Time series of total OHT through all Arctic straits for the CTRL (solid blue), the 3 Atlantic (top panel) and the 3 Pacific (bottom panel) SST+3K experiments; the number in brackets in the legend is the difference in mean OHT between the experiments and the CTRL

3. Results: Arctic sea-ice area decrease

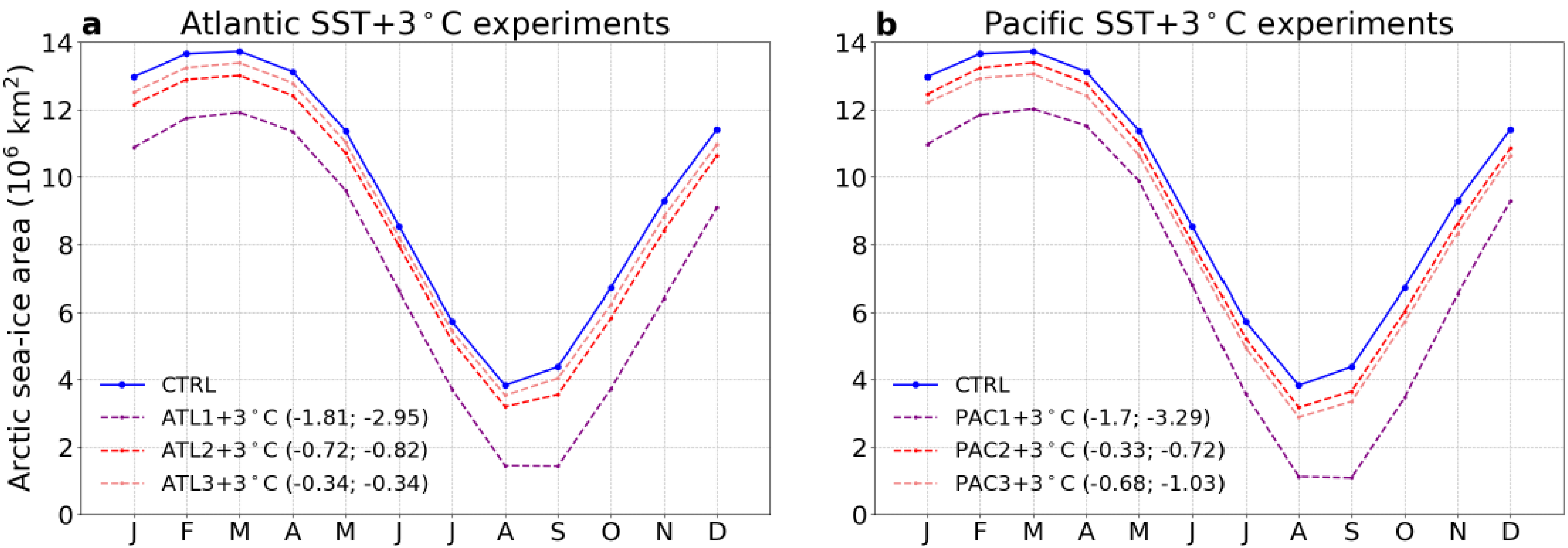
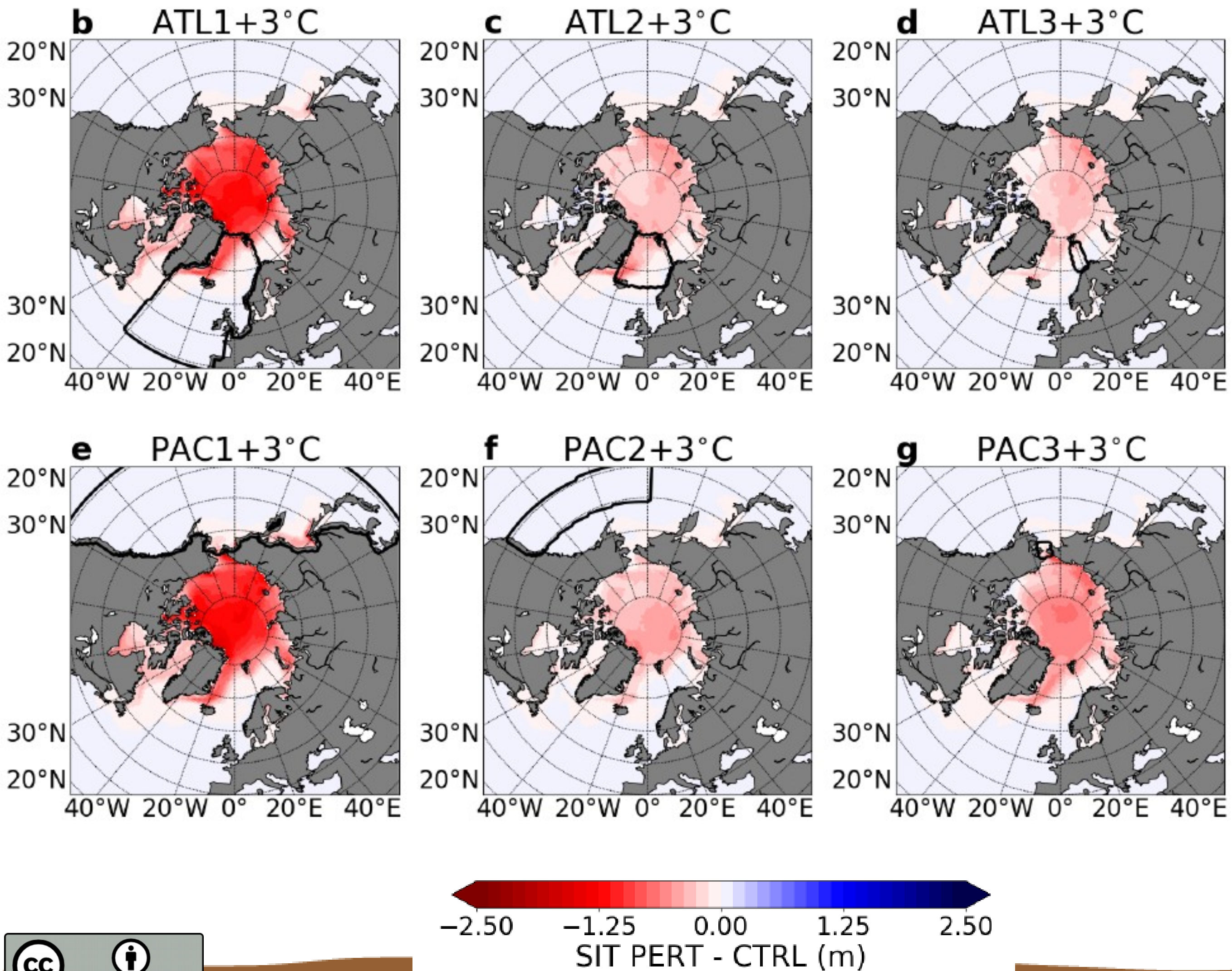


Fig.: Mean seasonal cycle of Arctic sea-ice area (SIA), averaged over 50 years, for the CTRL (solid blue), the 3 Atlantic (left panel) and the 3 Pacific (right panel) SST+3K experiments; the 2 numbers in brackets in the legend are the differences in March/September SIA between the experiments and the CTRL

- Arctic sea-ice area decreases in all experiments, with a much more pronounced decrease in the 2 wide domain experiments (dashed purple lines)
- Similar response for Arctic sea-ice volume (not shown)

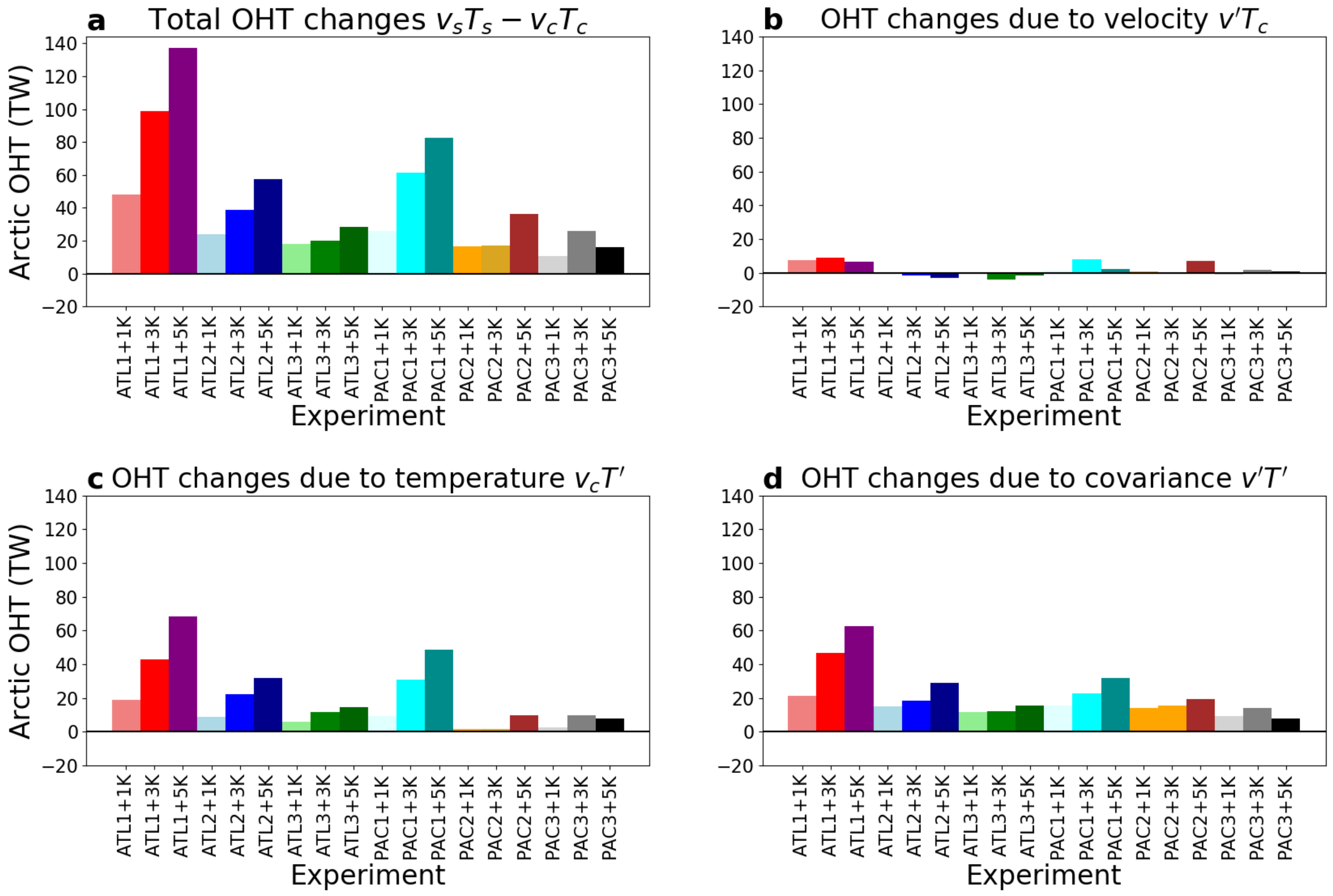
3. Results: Arctic sea-ice thickness decrease



- Arctic sea-ice thickness decreases in all experiments
- Spatial pattern relatively similar between experiments

Fig.: Difference in mean March sea-ice thickness (SIT), averaged over 50 years, between the Atlantic (top panels) / Pacific (bottom panels) SST+3K experiments and CTRL

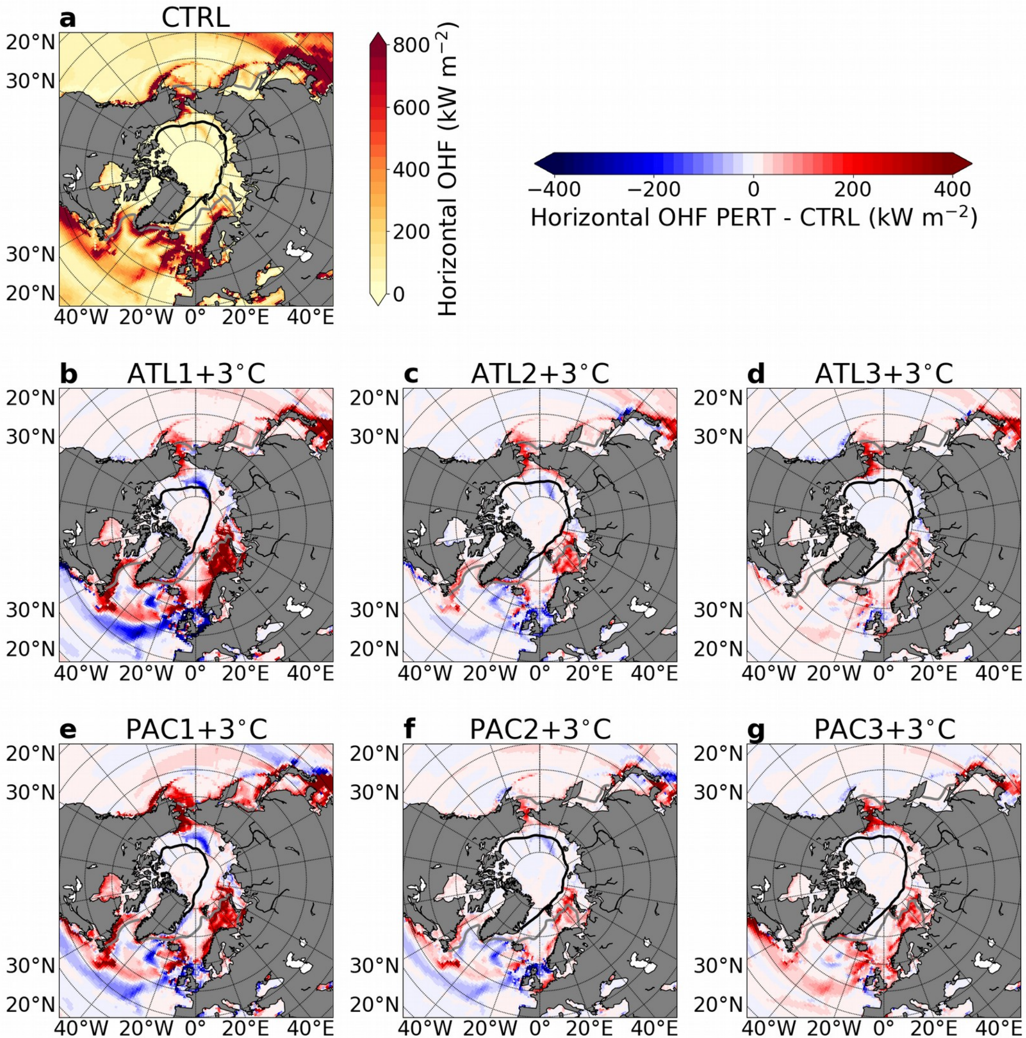
3. Results: Changes in OHT driven by temperature



- Temperature and covariance are the main contributors to OHT changes
- OHT changes are enhanced with higher level of warming

Fig.: Mean changes in OHT through all Arctic straits between the sensitivity experiments and CTRL: (a) total changes, (b) changes due to velocity, (c) changes due to temperature, (d) covariance.

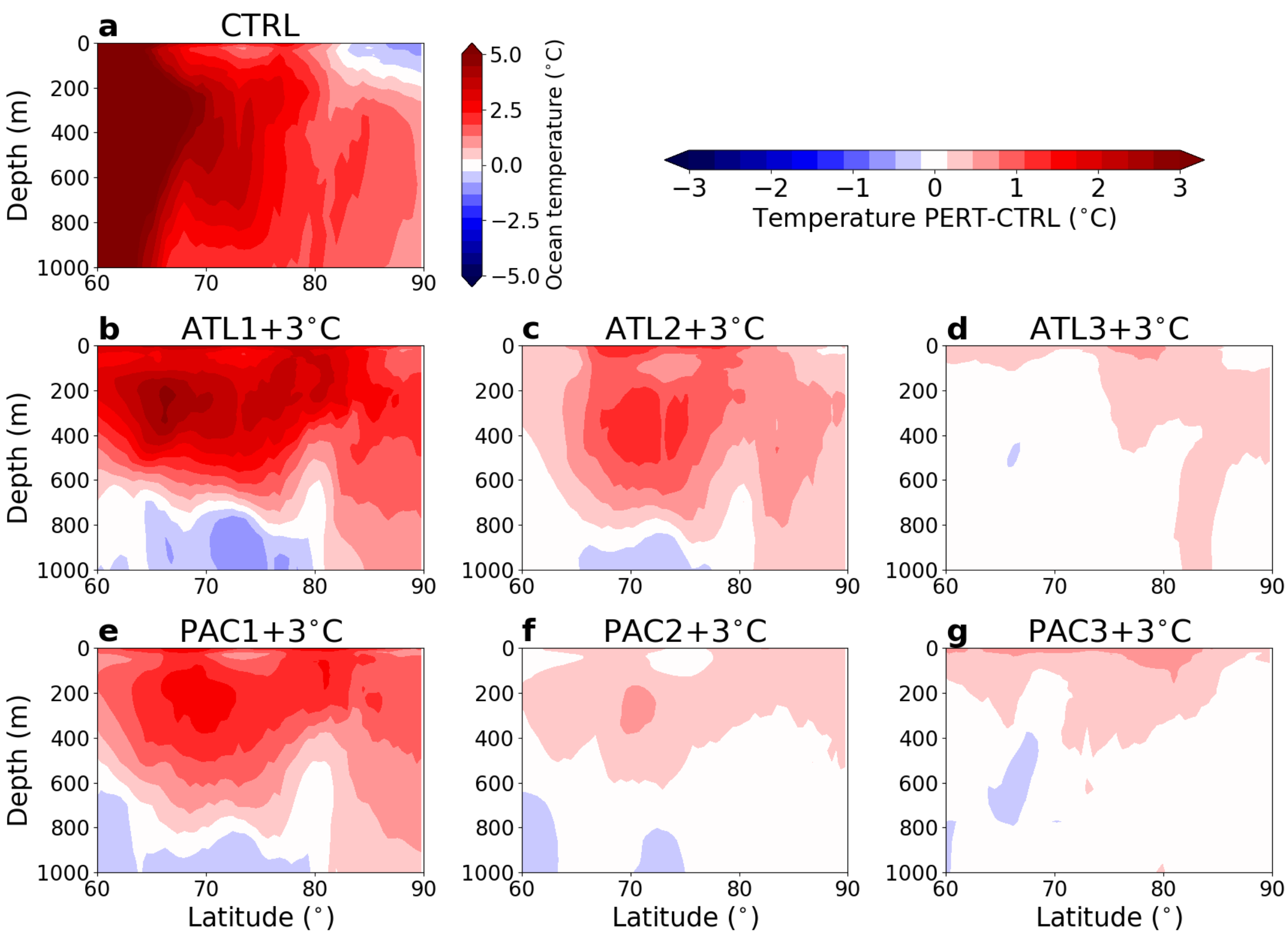
3. Results: Horizontal ocean heat flux (OHF)



- The 2 main regions of OHF increase in all experiments are the Barents Sea and the Bering/Chukchi Seas
- OHF decreases at around 40°N in the North Atlantic and between Chukchi and East Siberian Seas in wide and medium domain experiments
- The sea-ice edge considerably retreats in the wide domain experiments, in conjunction with a larger OHF increase

Fig.: (a) Horizontal ocean heat flux (OHF) of CTRL averaged over 50 years; (b-g) difference in mean OHF, averaged over 50 years, between the Atlantic (middle panels) / Pacific (bottom panels) SST+3K experiments and CTRL; black and gray contours show September and March sea-ice edges (15% concentration)

3. Results: Vertical profiles of ocean temperature



- Ocean temperature clearly increases in the upper 800m (max at 200m) in the wide domain experiments (left column)
- Temperature also increases in other experiments
- Ocean heat propagates through the whole Arctic, leading to sea-ice volume decrease (Slide 10)

Fig.: Vertical profiles of the Arctic Ocean temperature (Atlantic side) for CTRL (top left) and of the difference in temperature between Atlantic (middle panels) / Pacific (bottom panels) SST+3K experiments and CTRL, averaged over 50 years

4. Conclusions

- Clear link between ocean heat transport and Arctic sea ice
- Sensitivity experiments performed with EC-Earth, in which SST is increased, allow to quantify the impact of OHT on Arctic sea ice
- The larger the domain for the SST increase and the higher the level of warming, the larger the increase in OHT and the loss in Arctic sea ice
- Main changes in OHF and sea-ice concentration happen in the Barents and Bering/Chukchi Seas, while changes in sea-ice thickness occur everywhere
- Ocean heat propagates down to 800m and through the whole Arctic
- Further details: https://sites.google.com/view/daviddocquier/my-current-research and https://git.smhi.se/david.docquier/oseaice/-/wikis/home