Updates from the Arctic energy budget group

L. Haimberger, M. Mayer,
S. Winkelbauer, I. Winterer

University of Vienna

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universität wien
imgw Institut für Meteorologie und Geophysik
b·geos
FWF Der Wissenschaftsfonds.
MERCATOR OCEAN INTERNATIONAL
Copernicus Marine Service

Overview of recent activities

- Two projects with involvement in analyzing pan-Arctic budgets and oceanic transports are nearing completion:
  - FWF project “A consistent framework for quantifying global energy budgets”
  - CMEMS-funded “Validation and Intercomparison of Global Reanalyses for Ocean Currents and Transports”
- Contribution to upcoming Marine Environment Reanalyses Evaluation Project (MER-EP) planned
- New ESA-Projekt MOTECUSOMA (Monitoring the energy cycle for a better understanding of climate change) with Arctic component:
  - Get improved near-surface temperature estimates in the marginal ice zone
- Susanna part of Fresh Eyes on CMIP initiative

Arctic ocean transports

- Pivotal role in regulating the global climate and integral part of the Arctic's energy and mass budgets
- Effects on state of and changes within the Arctic system (e.g. sea ice)
- Accurate monitoring is critical → measuring lines (moorings) measure deep water velocities and other sea state variables
- Need of precise transport estimates from reanalyses and climate models

  → Challenging due to used modelling grids

https://worldoceanreview.com/en/wor-6/the-polar-regions-as-components-of-the-global-climate-system/ice-floes-ice-sheets-and-the-sea/

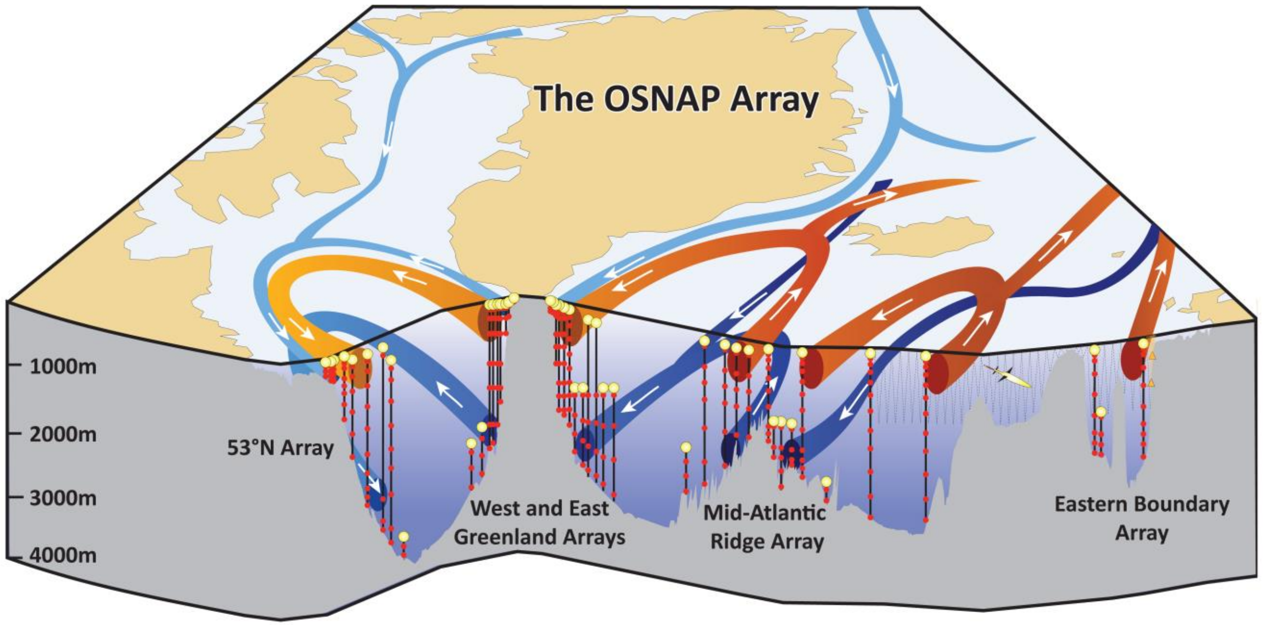
StraitFlux (Winkelbauer et al., 2024)

→ Tools for precise calculation of oceanic volume, heat, salinity and ice transports

- Calculations consistent with discretization schemes of models
- Direct comparisons to observations easily possible
- Analysis of mean states, variabilities, seasonal cycles etc. of net transports
- Analysis of the ocean’s vertical structure and flow patterns through cross-sections
- Available as python package via pypi
- Already used for multiple case studies in the Arctic:
  - Winkelbauer et al., 2024: Validation of key Arctic energy and water budget components in CMIP6
  - Mayer et al., 2023: Recent variations in oceanic transports across the Greenland–Scotland Ridge
  - Winkelbauer et al., 2022: Diagnostic evaluation of river discharge into the Arctic Ocean and its impact on oceanic volume transports

OSNAP (Winterer et al., in preparation)

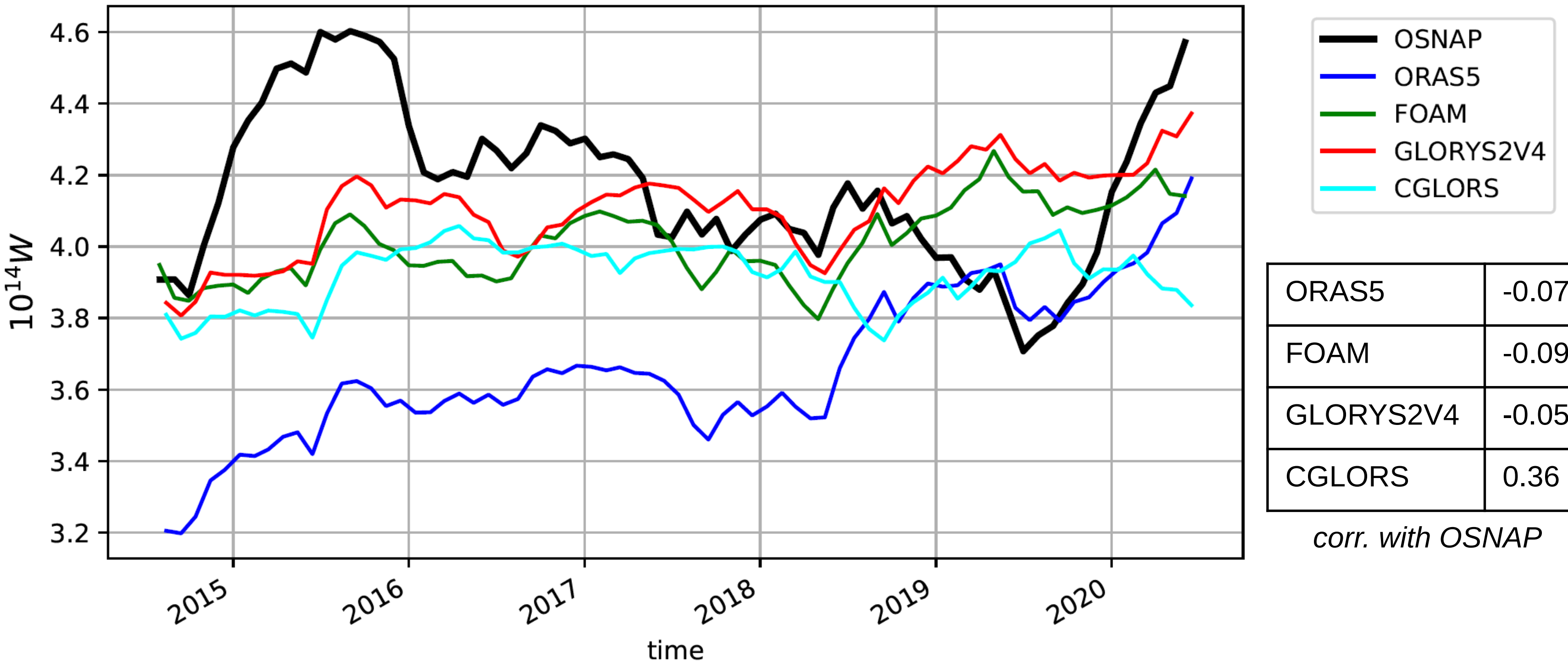
- Overturning in the Subpolar North Atlantic Program (OSNAP)
- Provides estimates of:
  - Strength and variability of the Atlantic Meridional Overturning Circulation
  - Net integrated transports
  - Cross-sections of currents, temperatures and salinity



https://www.o-snap.org/

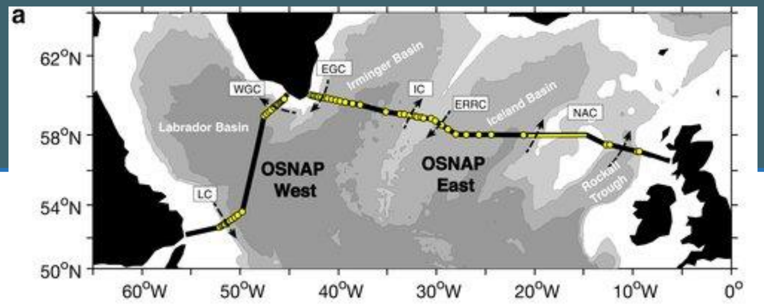
- **OSNAP (Winterer et al., in preparation)**

OSNAP East OHT

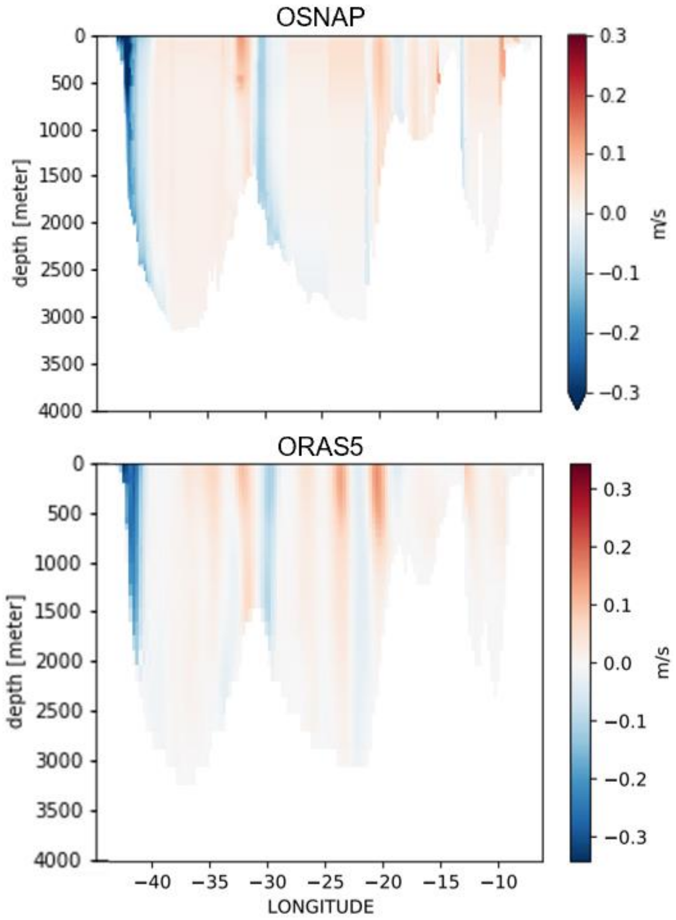


ORAS5	-0.07
FOAM	-0.09
GLORYS2V4	-0.05
CGLORS	0.36

corr. with OSNAP



Li et al., 2021



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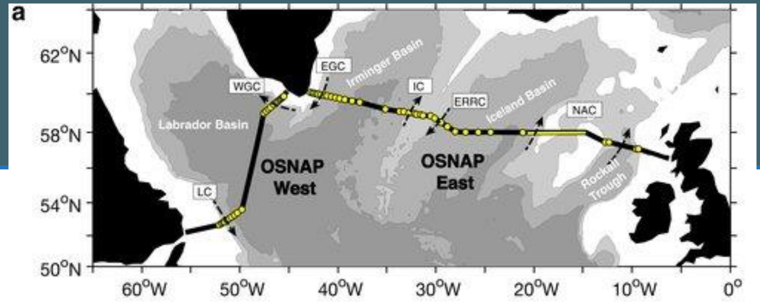

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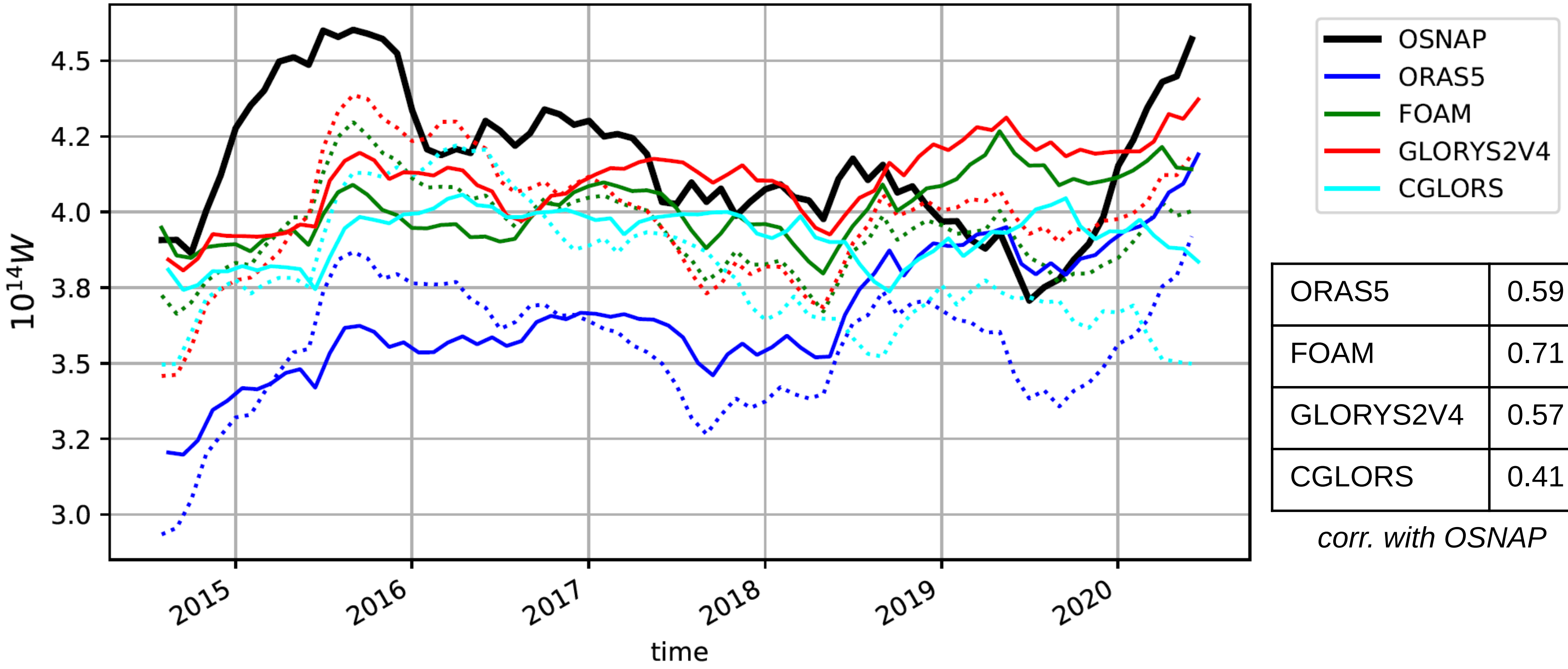
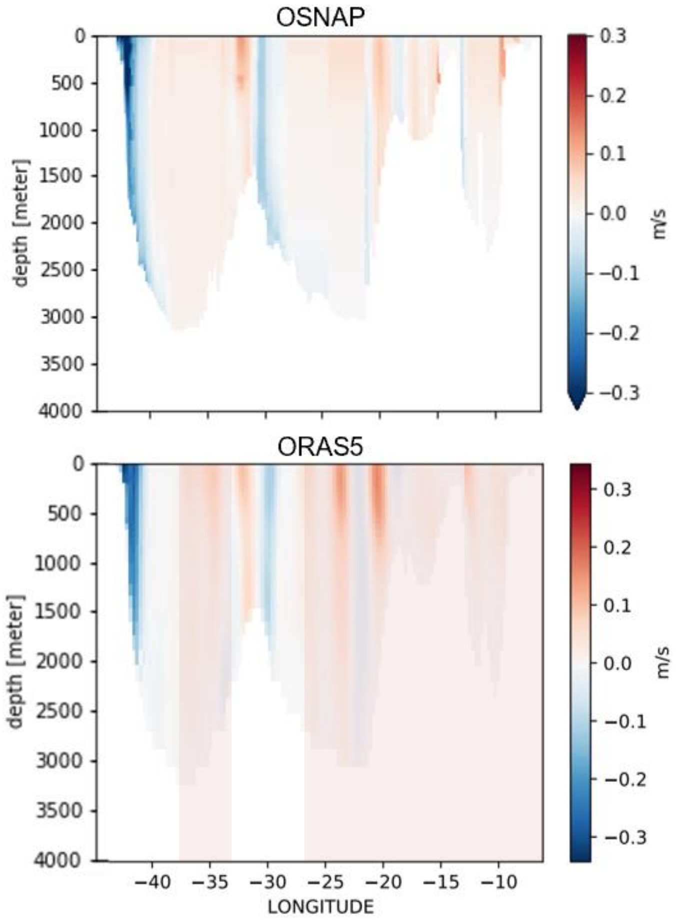


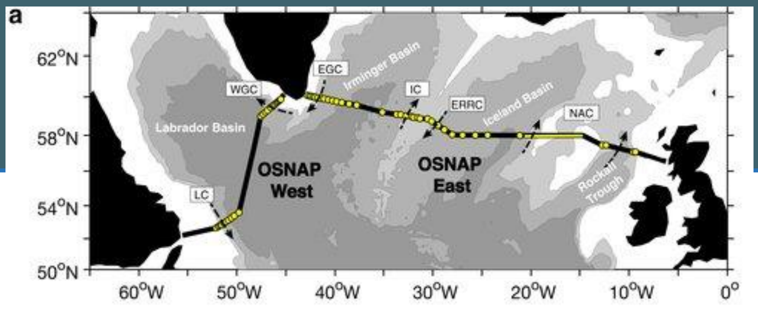
ORAS5	0.59
FOAM	0.71
GLORYS2V4	0.57
CGLORS	0.41

corr. with OSNAP



Adjust reanalysis data to climatology in regions with no observations → significantly improved correlations

OSNAP (Winterer et al., in preparation)

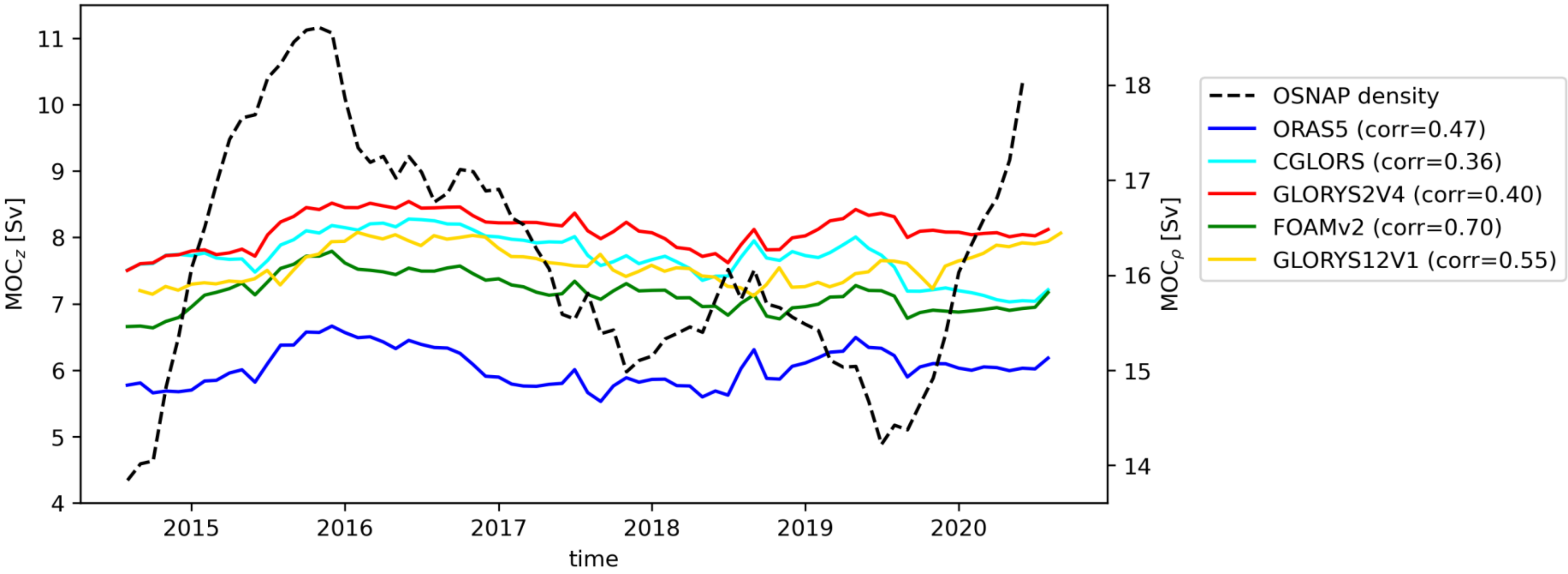


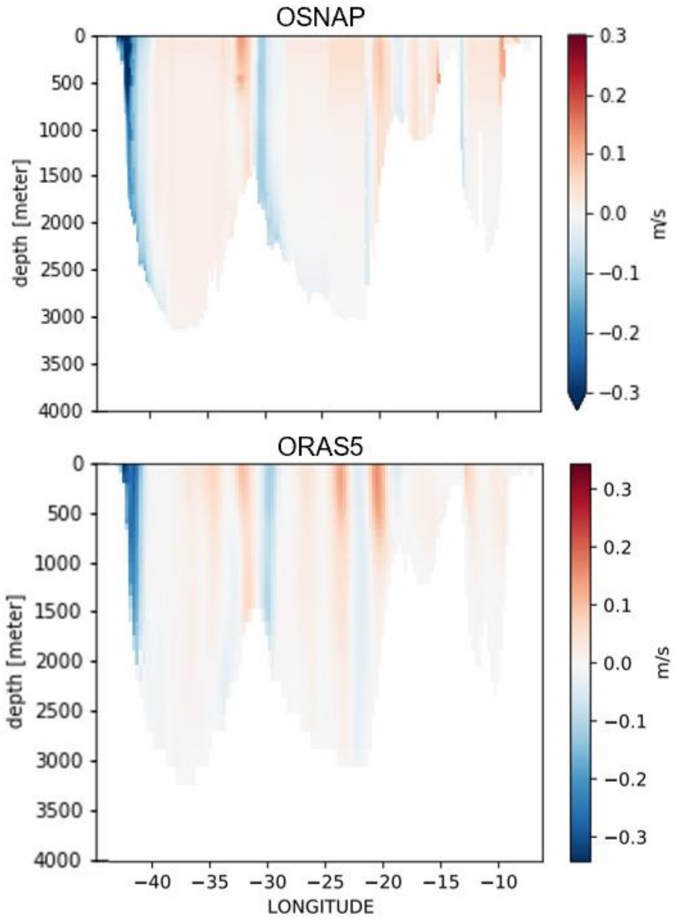
Li et al., 2021

- **OSNAP (Winterer et al., in preparation)**

Meridional Overturning Circulation (MOC)
→ vertical maximum of the stream function

$$\Psi(z) = \int_{x_w}^{x_e} \int_{-H}^{z} \mathbf{v}(x,z)\,dz\,dx$$





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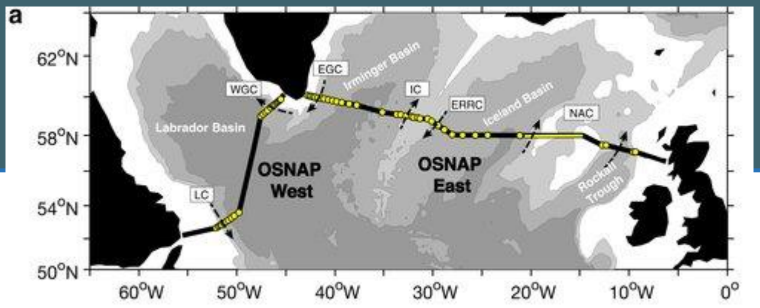

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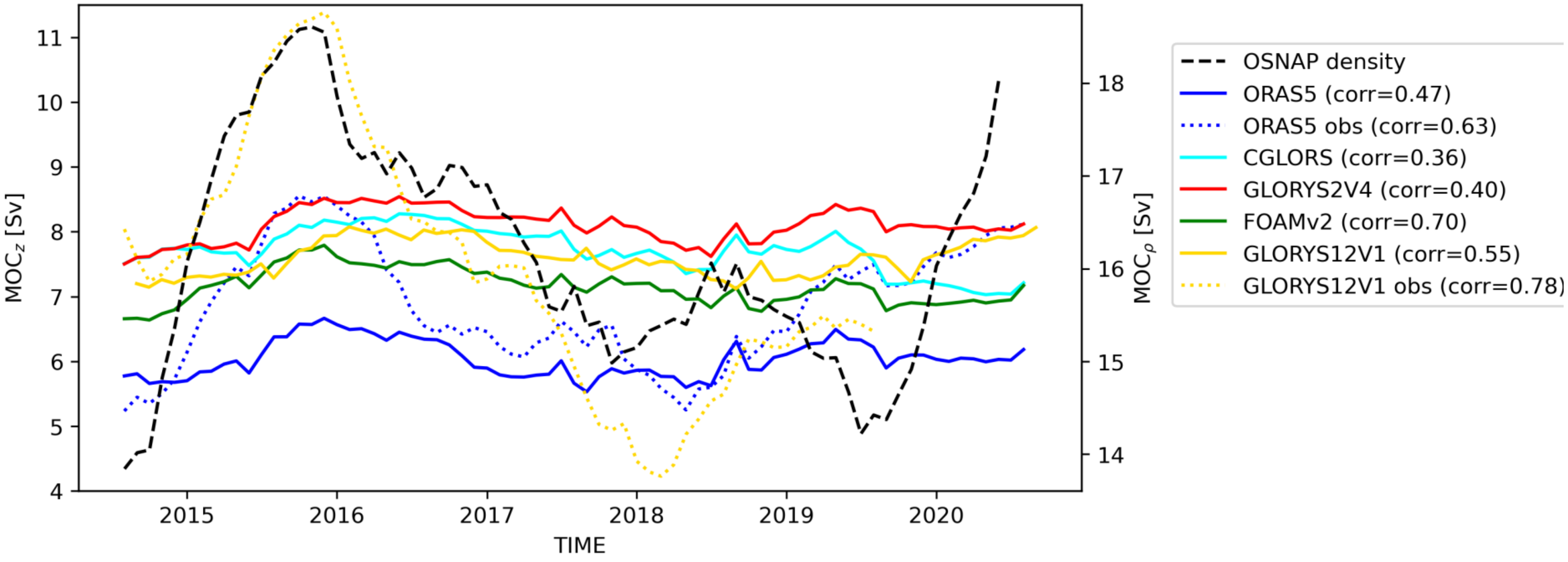

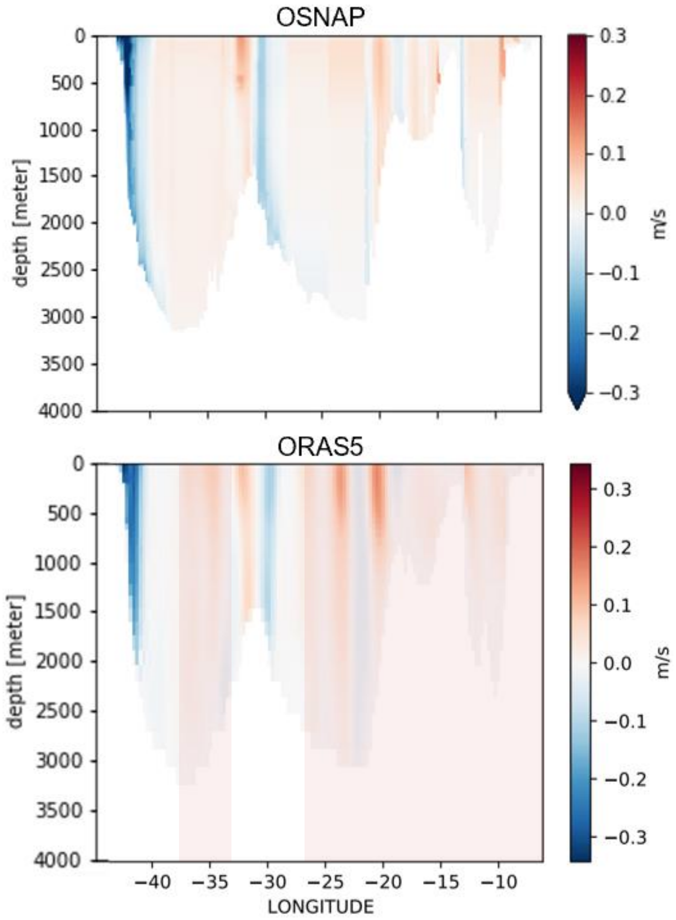

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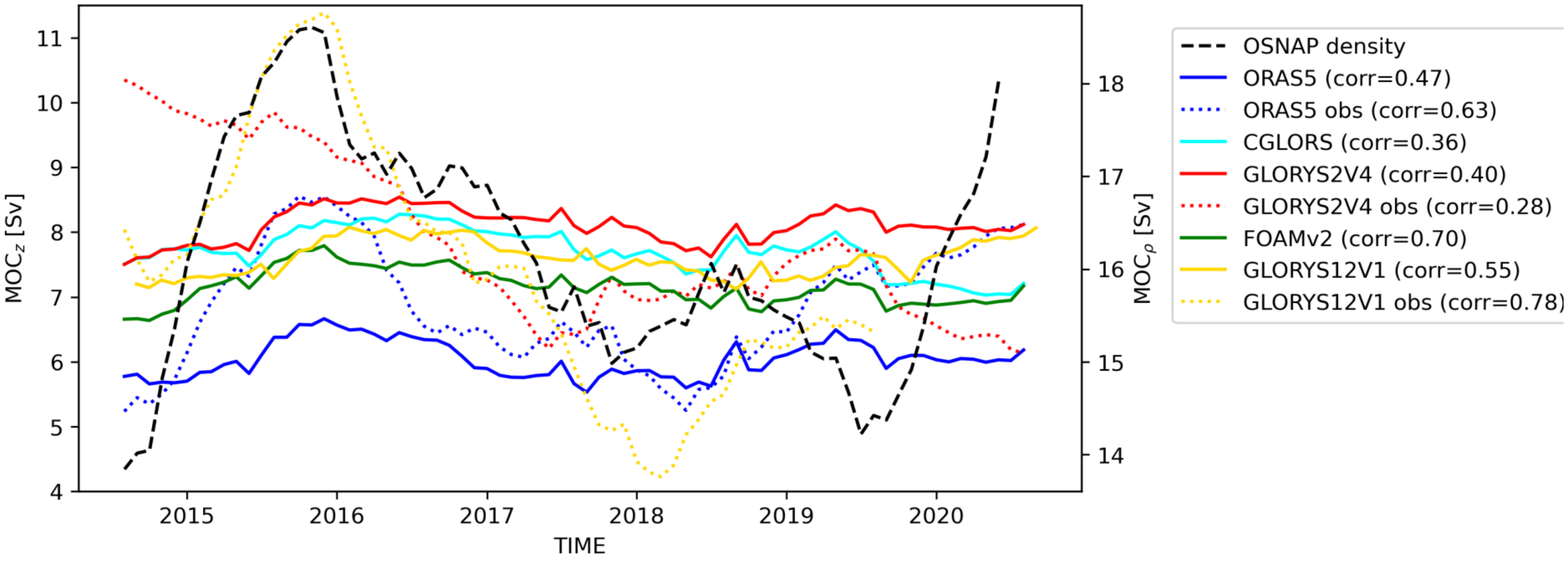

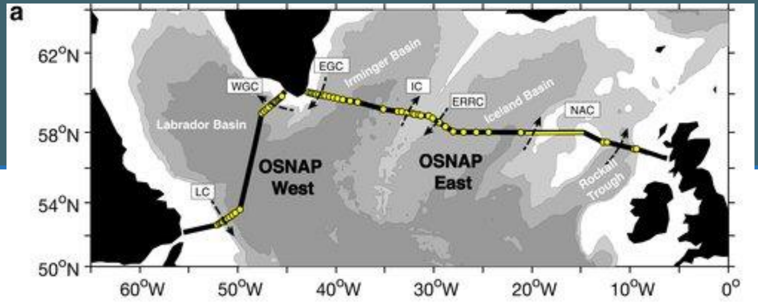

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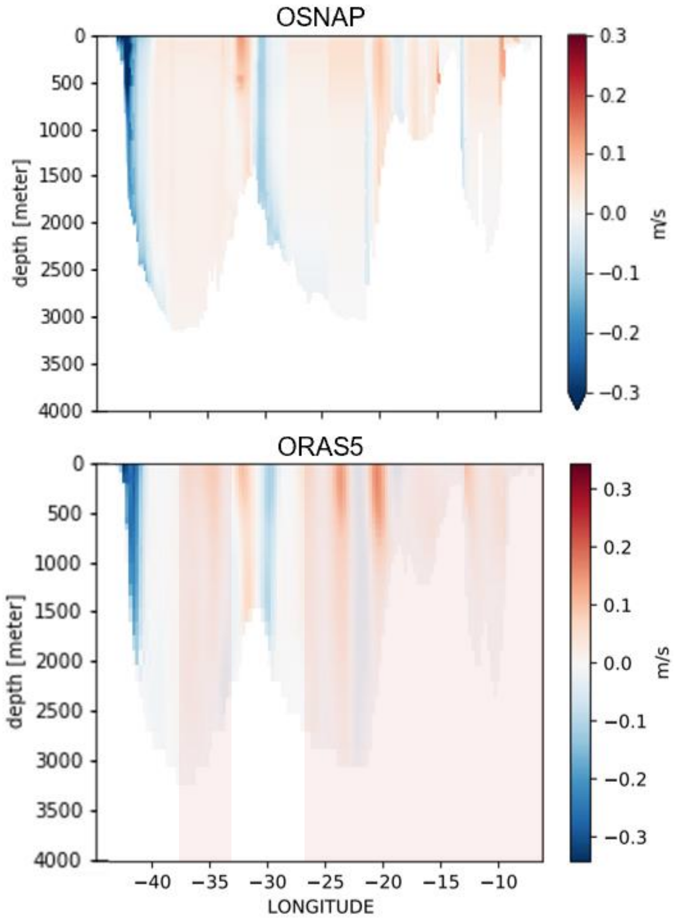


Model uncertainties

Large uncertainties in projections of various ocean and sea ice variables

1. Scenario uncertainties
2. Internal variability
3. Model uncertainty

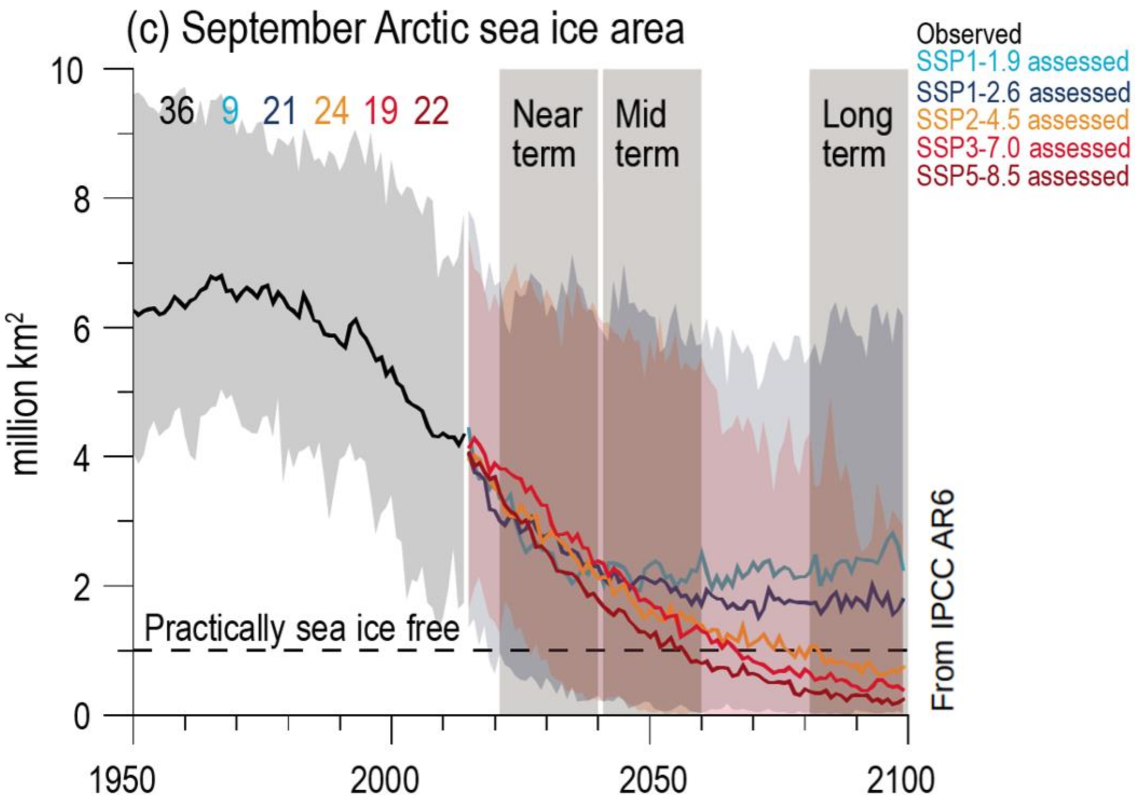
→ Multimodel ensembles essential for assessing range of uncertainty

→ “Model democracy” not always ideal:

  → different performance

  → shared code

→ **Pre-selection, constraining or weighting might mitigate uncertainties and biases**



Model weighting

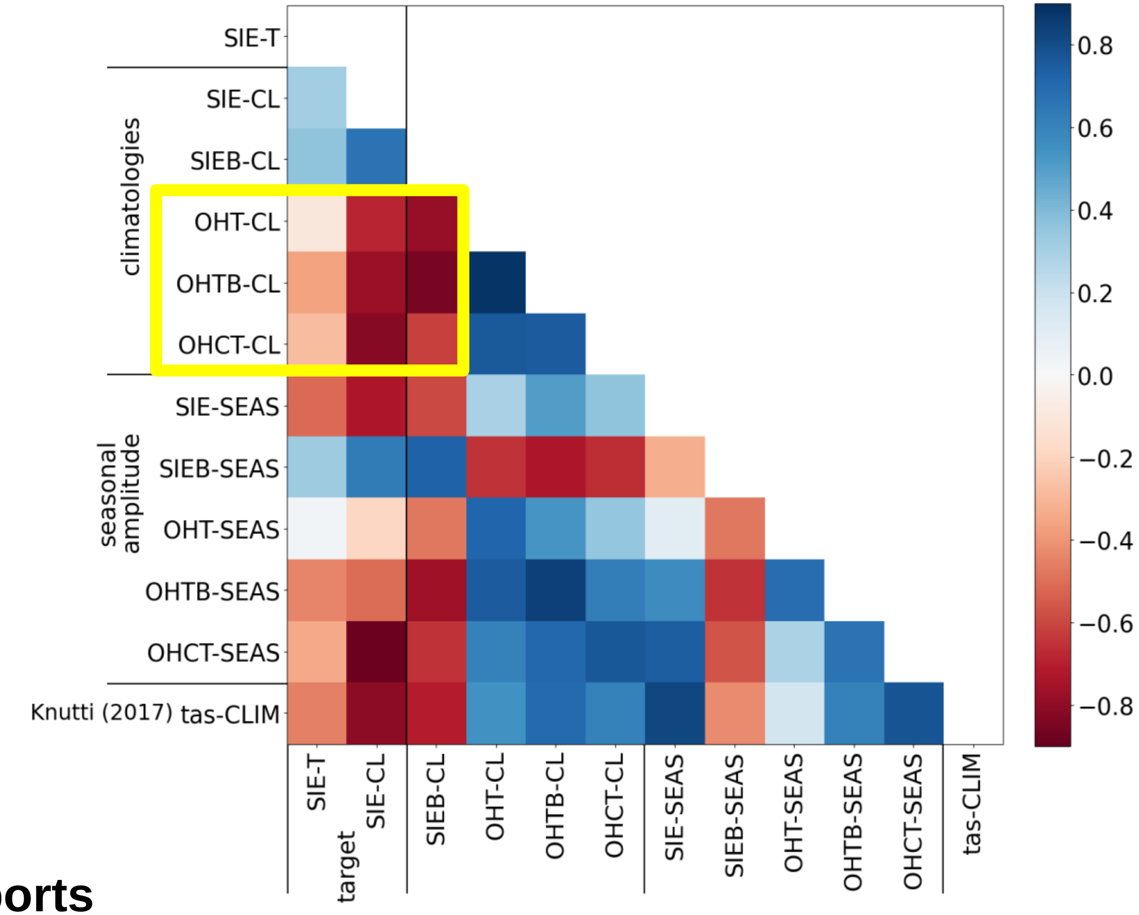
Model weighting approach by Knutti et al. (2017):

$$w_i = \frac{e^{-\frac{D_i^2}{\sigma_d^2}}}{1 + \sum_{j \neq i}^{M} e^{-\frac{S_{ij}^2}{\sigma_s^2}}}$$

performance (numerator)

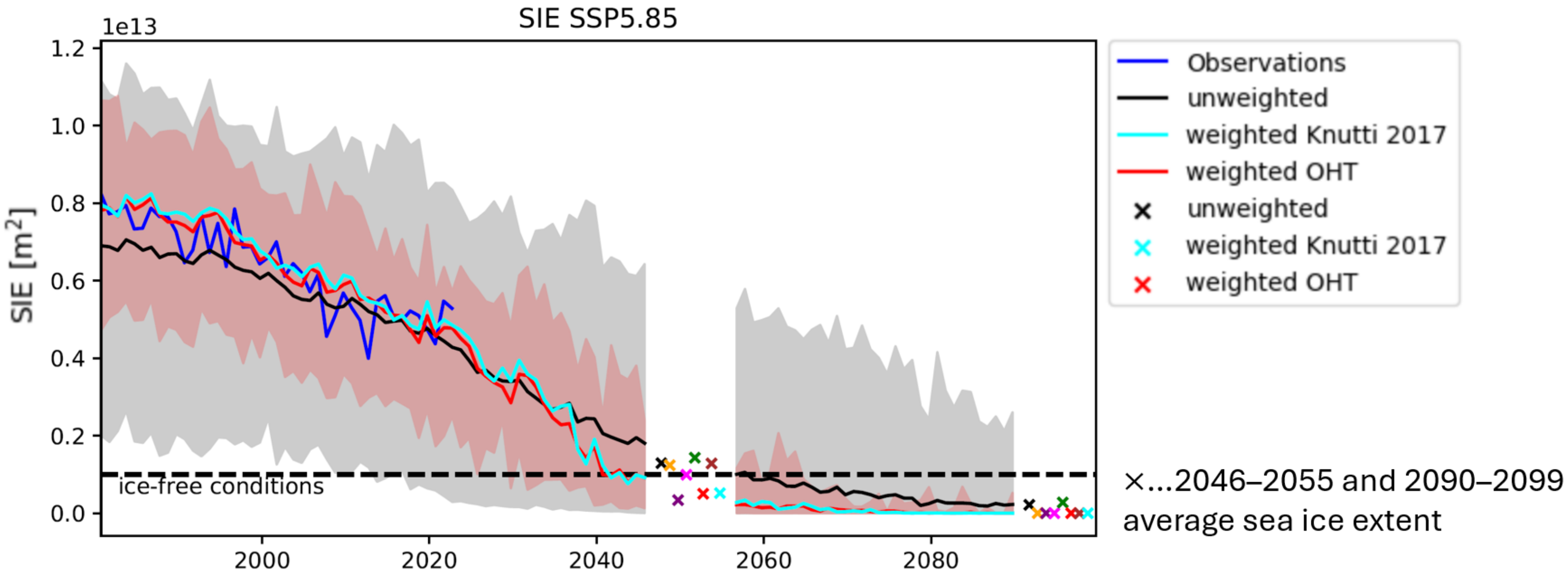
independence (denominator)

correlation matrix for different diagnostics in the Arctic



→ use more process-based diagnostics like **<u>oceanic transports</u>**

Model weighting



*ice-free: first September were SIE drops below 1e6 km^2

→ Indicates an earlier ice-free Arctic and

→ Reduces spread in the first year of ice-free Arctic

→ Agrees well with earlier studies (Knutti et. al 2017; Zhao et al 2022)

→ try on other target variables (e.g. SST, OHC)
→ try with larger ensemble (now: 30 models, only 1 run per model)

Summary and Outlook

- StraitFlux (Winkelbauer et al., 2024) allows for:
    - Precise calculations consistent with discretization schemes of models
    - Analysis of transports and the ocean’s vertical structure through cross-sections
    - Analysis of Meridional Overturning Circulation at desired sections
    - Direct comparisons to observations easily possible
    - Precise analysis of oceanic budgets
- Continuous advancement of StraitFlux (atm: integration of vvl/non-linear free surface)
- First tests using transports from StraitFlux to constrain future projections of Arctic change look promising
- Planned continuation of oceanic transport assessments via contribution to upcoming MER-EP (planned to start in 2025) → strong link to ORA-community

References

- Knutti, R., J. Sedláček, B. M. Sanderson, R. Lorenz, E. M. Fischer, and V. Eyring (2017), A climate model projection weighting scheme accounting for performance and interdependence, Geophys. Res. Lett., 44, 1909–1918, doi:10.1002/2016GL072012.
- Mayer, M., Tsubouchi, T., Winkelbauer, S., Larsen, K. M. H., Berx, B., Macrander, A., Iovino, D., Jónsson, S., and Renshaw, R.: Recent variations in oceanic transports across the Greenland–Scotland Ridge, in: 7th edition of the Copernicus Ocean State Report (OSR7), edited by: von Schuckmann, K., Moreira, L., Le Traon, P.-Y., Grégoire, M., Marcos, M., Staneva, J., Brasseur, P., Garric, G., Lionello, P., Karstensen, J., and Neukermans, G., Copernicus Publications, State Planet, 1-osr7, 14, https://doi.org/10.5194/sp-1-osr7-14-2023, 2023.
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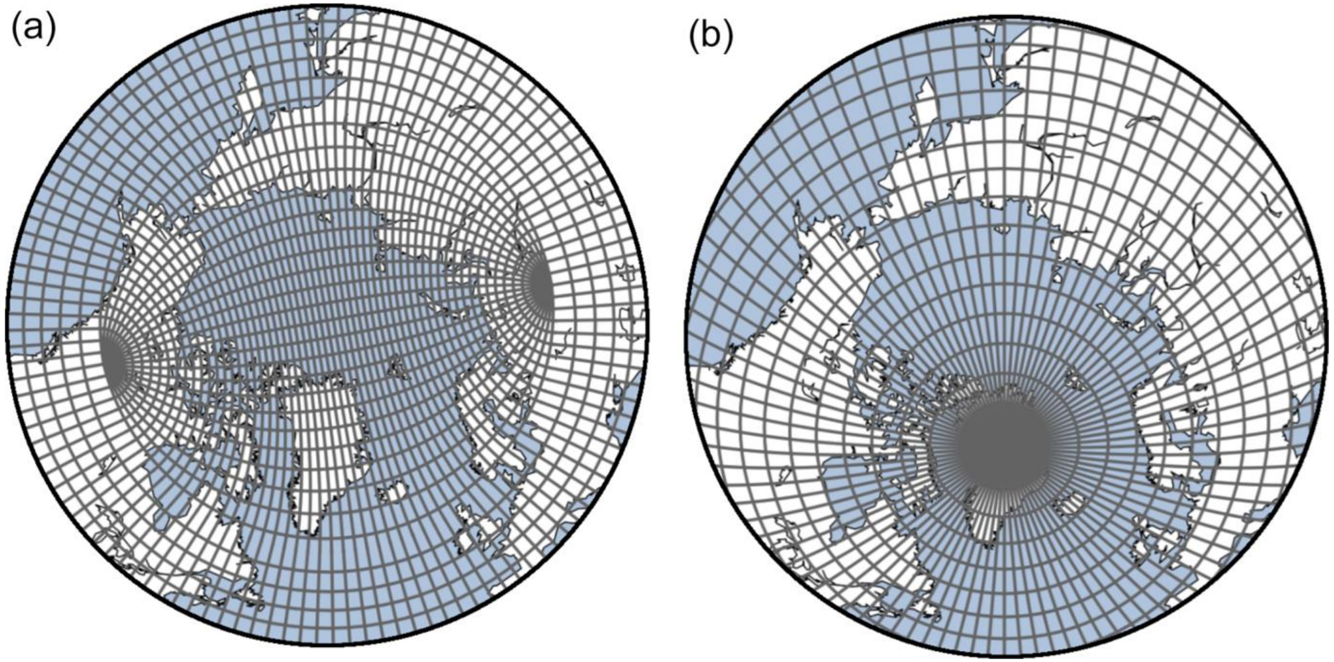
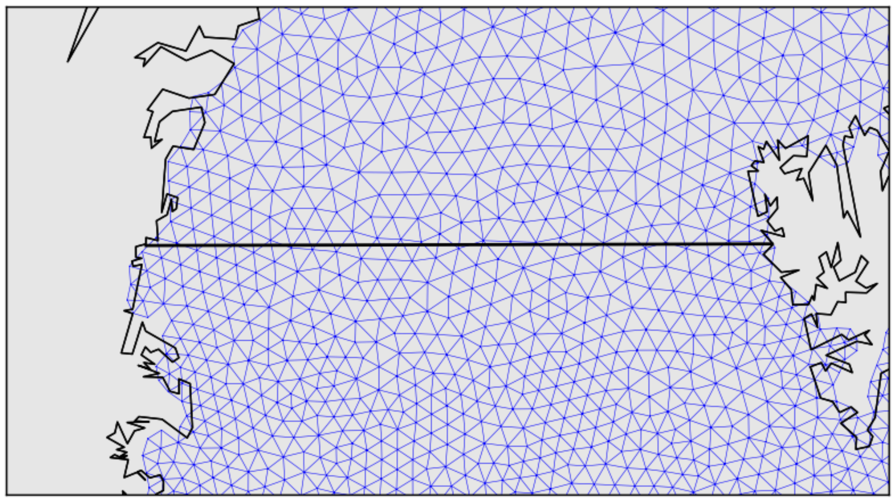
- Winkelbauer, S., Mayer, M. & Haimberger, L. Validation of key Arctic energy and water budget components in CMIP6. Clim Dyn 62, 3891–3926 (2024). https://doi.org/10.1007/s00382-024-07105-5
- Winkelbauer, S., Mayer, M., and Haimberger, L.: StraitFlux – precise computations of water strait fluxes on various modeling grids, Geosci. Model Dev., 17, 4603–4620, https://doi.org/10.5194/gmd-17-4603-2024, 2024.

Oceanic Transports

→ Direct comparison to model-based transports challenging due to nature of used modelling grids



tripolar *and* ***displaced dipolar***
grid (Winkelbauer et al., 2024)



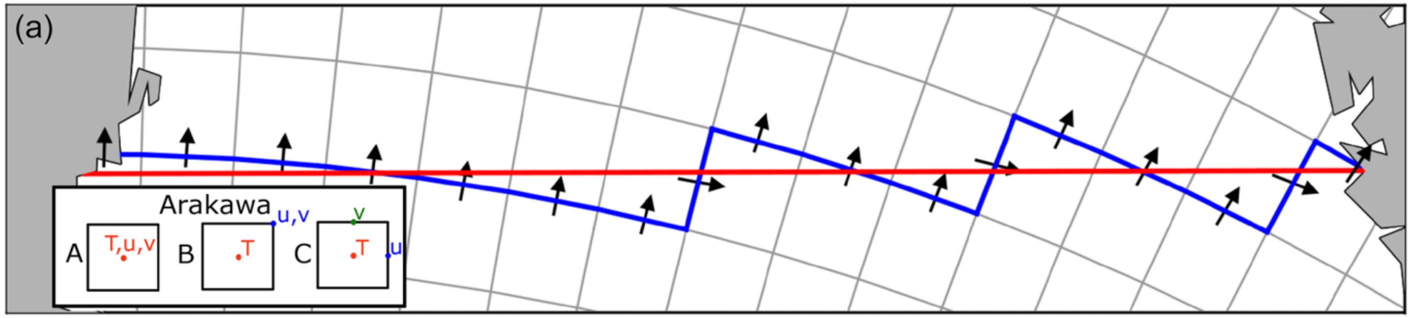
unstructured FESOM grid

StraitFlux

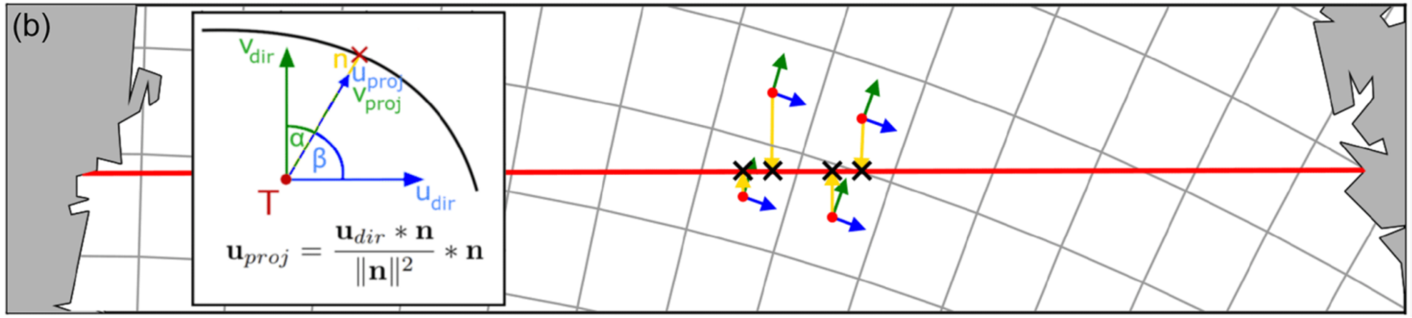
→Tools for precise calculations of oceanic volume, heat, salinity and ice transports for various CMIP6 models and reanalyses

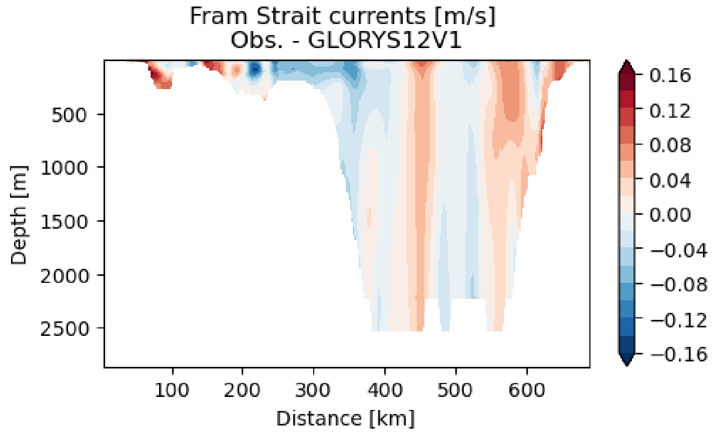
- Available as python package via pypi

Method1



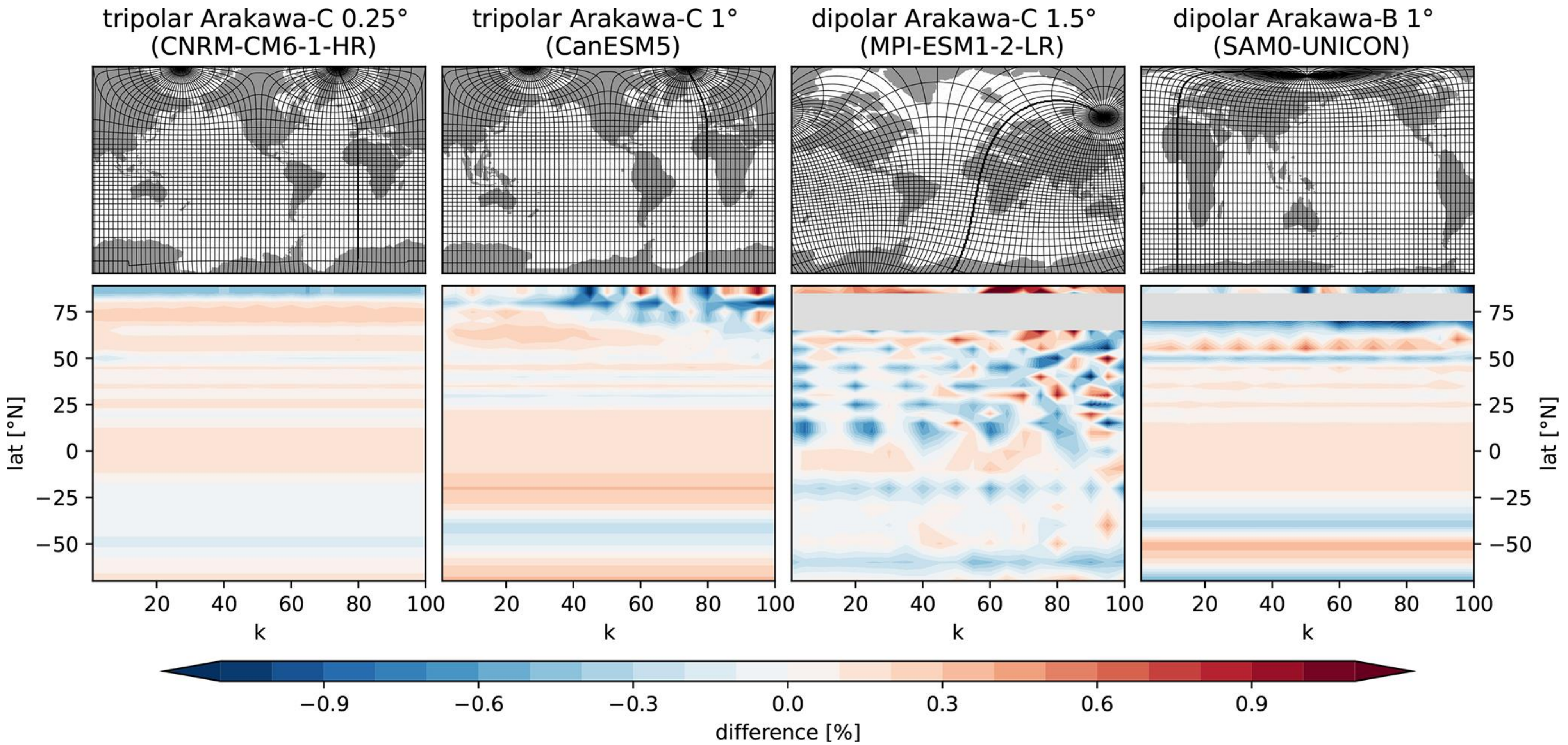
Method2





StraitFlux - Validation

$$u(\lambda,\varphi)=0; \qquad v(\lambda,\varphi)=v_r(\varphi)+v_0\cos\varphi\sin k\lambda; \qquad T=T_r+T_0\cos\varphi\sin(k(\lambda+\psi))$$



StraitFlux - Validation

Large interpolation errors → calculations on native grid needed