SPECIAL PROJECT PROGRESS REPORT

Reporting year	2024/25
Project Title:	Applying hydrodynamic constraints to coupled energy budget analysis and to physics-informed machine learning based forecasting
Computer Project Account:	spatlh00
Principal Investigator(s):	Leopold Haimberger, Alexander Bihlo
Affiliation:	University of Vienna
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Michael Mayer
Start date of the project:	1.1.2024
Expected end date:	31.12.2026

Computer resources allocated/used for the current year and the previous one

		Previous year		Current year	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	10000	0	10000	23391
Data storage capacity	(Gbytes)	500	32	1000	32

Summary of project objectives

The special project focuses on optimally extracting energy budget terms from the IFS in the version to be adopted for the forthcoming Copernicus reanalysis ERA6. Its second focus is to investigate the use of machine learning for meteorological applications, in particular for replacing the ensemble prediction system and for physics-informed machine learning based weather forecasting.

Summary of problems encountered (if any)

Use of European Weather Cloud not yet extensive. Setting up a VM and login worked, but no time yet to explore more.
The allocated units were exceeded when we tried to aggregate full-resolution ocean reanalysis data for calculating horizontal energy transports on the HPC system. We contacted the Austrian Met Service representative (Mathias Langer) and he agreed to transfer 500.000 SBU to the special project account so that we have enough resources now for doing similar calculations.

Summary of results of the current year (from July of previous year to June of current year)

The energy budget group at Univ. Vienna worked on using the newly developed Straitflux (Winkelbauer et al. 2024) tool for an in-depth comparison of the variability of horizontal oceanic energy transports through the OSNAP array (Lozier et al. 2017). This proved challenging, particularly for the year 2015 where OSNAP transports in the OSNAP-East section appear significantly different from the majority of reanalysis based transports (Fig. 1b). A publication of the comparison is about to be submitted.

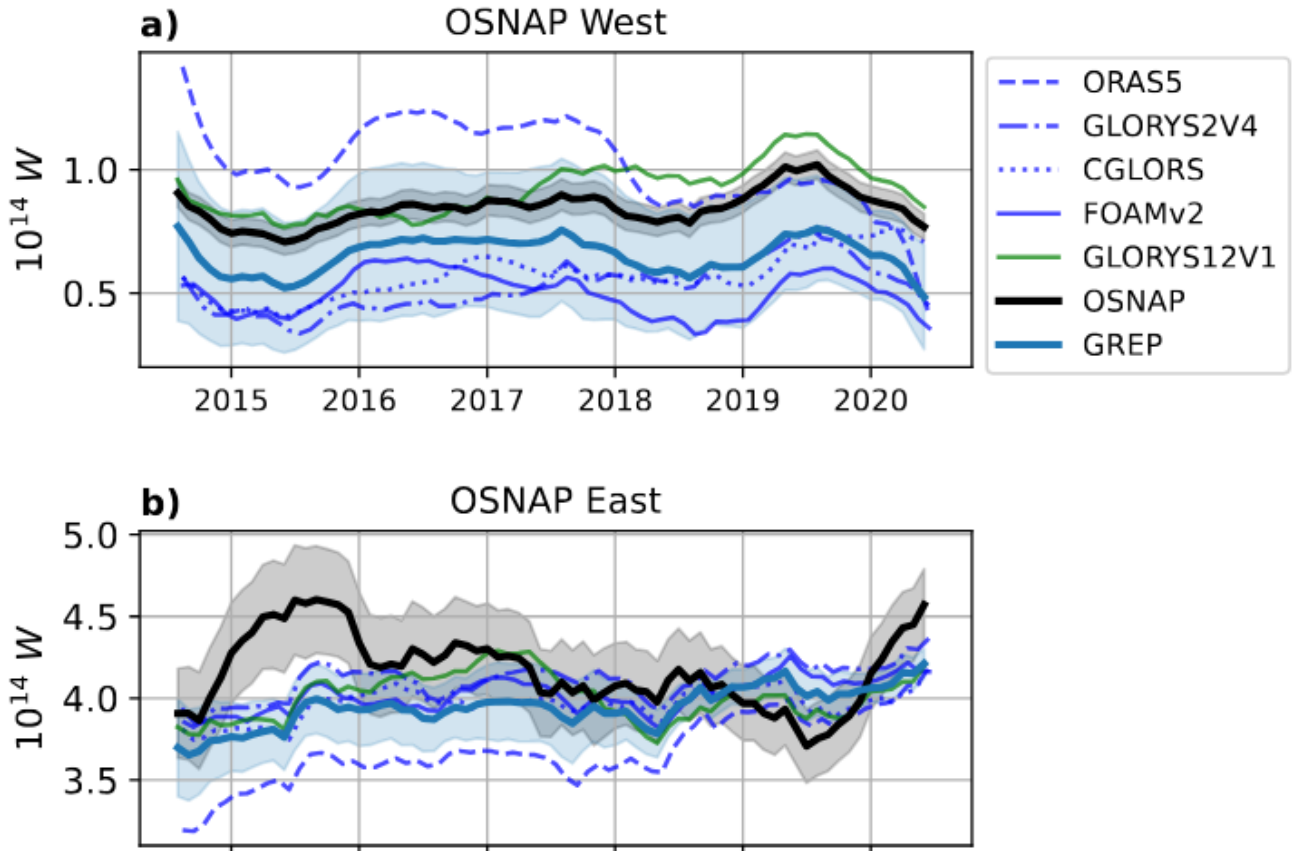

Figure 1: Time series of Meridional Heat Transport estimates through a) the OSNAP-West (between Newfoundland and the Southern tip of Greenland) and b) the OSNAP-East sections (Southern tip of Greenland to Scotland), respectively. OSNAP is MHT derived from subsurface observations, the other estimates are from oceanic reanalyses with ¼ degree resolution (except GLORYS12V1, which has 1/12 degree resolution).

Preliminary results show that the transports from the new ORAS6 reanalysis do not significantly change this picture.

We also calculated atmospheric energy budgets and transports to update the fields on the CDS (https://cds.climate.copernicus.eu/datasets/derived-reanalysis-energy-moisture-budget?tab=overview) which are currently available up to 2022. Further we started to extend the energy budget time series back to 1950. For that we use both ERA5 and JRA3Q model level fields. We note that budget calculations performed in the previous and current special project supported the review publication of Mayer et al. (2024).

We ported the energy budget calculation code from FORTRAN to python, using SHTns (https://nschaeff.bitbucket.io/shtns/) for the spectral transform and gradient calculations. While not as fast as the FORTRAN version, we envisage that the python version will facilitate experiments with

different noise filtering methods. The python/SHTns version of budget calculation already worked for preliminary assimilations with ERA6 (at TCO399 resolution), with encouraging results.

List of publications/reports from the project with complete references

Lozier, M. S., Bacon, S., Bower, A. S., Cunningham, S. A., de Jong, M. F., de Steur, L., deYoung, B., Fischer, J., Gary, S. F., Greenan, B., J. W., Heimbach, P., Holliday, N. P., Houpert, L., Inall, M. E., Johns, W. E., Johnson, H. L., Karstensen, J., Li, F., Lin, X., Mackay, N.,Marshall, D. P., Mercier, H., Myers, P. G., Pickart, R. S., Pillar, H. R., Straneo, F., Thierry, V., Weller, R. A., Williams, R. G., Wilson, C.,Yang, J., Zhao, J., and Zika, J. D.: Overturning in the Subpolar North Atlantic Program: A New International Ocean Observing System, Bulletin of the American Meteorological Society, 98, 737 – 752, https://doi.org/10.1175/BAMS-D-16-0057.1, 2017.380

Mayer, M., Kato, S., Bosilovich, M. *et al.* Assessment of Atmospheric and Surface Energy Budgets Using Observation-Based Data Products. *Surv Geophys* **45**, 1827–1854 (2024). https://doi.org/10.1007/s10712-024-09827-x

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.

Winkelbauer, S., Winterer, I., Mayer, M., Fu, Y. and Haimberger, L., 2025: Subpolar Atlantic meridional heat transports from OSNAP and ocean reanalyses - a comparison. To be submitted.

Summary of plans for the continuation of the project

To improve noise filtering for atmospheric energy budgets, we plan to follow two routes. One is to use OpenIFS v48.1 or at least some of the filtering routines of it to be able to do these calculations offline. The other is to experiment with a python version of the budget calculations (as noted above).

We plan to improve the temporal resolution of the energy budget calculations, since essential input fields for this purpose, e.g. CERES Top of Atmosphere fluxes, are now available at higher than monthly resolution.

We still plan to use the EWC for doing the budget calculations so that we can avoid copying all the input data to university premises. One idea would be to establish Straitflux as a calculation tool for horizontal oceanic transports within a VM of the EWC.

The port of the recently developed multi-parameter ensemble machine learning systems to the HPC or EWC has not yet been materialized. This system can forecast not only single meteorological parameters as in our previous work, but the entire catalogue of meteorological parameters of interest.