

Thank you very much for your positive comments and constructive feedback, you addressed some important points. Your clarifications helped to make the manuscript clearer for the reader. Our responses are provided in green (changes made in the manuscript are written in **bold**) together with your original comments in black. We really appreciate your time and insight in reviewing our manuscript!

Kind regards,
Susanna (on behalf of all co-authors)

This paper presents the python package StraitFlux, and demonstrates how it can be used to calculate ocean strait transports for various ocean model grids. It seems like a valuable and easy to use tool, and I appreciate the effort put into making this a public tool that can save other users a lot of time. I recommend that this manuscript is published after some clarifications are made:

L4-5: A bit unclear what you mean by this sentence. Are you referring to the complications from the singularity at the true North Pole? Or errors in fields that are interpolated to standard lat/lon grid?

We refer to errors being generated through regridding of the velocity fields onto regular lat/lon grids. We clarified it to the following:

*Use of data **regridded to standard latitude/longitude grids is not an option since transports computed from those are not mass consistent and may feature substantial errors.***

L9: What exactly do you mean by the integrand for the second method? This word is not used for anything elsewhere in the manuscript.

We refer to the velocity/temperature/salinity cross-sections, which need to be integrated over depth and along the strait to yield the net volume/heat/salinity transports. We changed it in the manuscript:

*Apart from the input data on the original model grids the user only needs to specify the start and end points of the required section to get the integrated net transports **(for the first method) and cross-sections (for the second method). Integration of the cross-sections along their depth and horizontal extent also yields net transports.***

Eq. (4) ice is mentioned here, but not any further. Would be good to discuss further, e.g. by including an example of ice transport in the paper if mentioning it here.

We adapted Fig. 10 to also show heat and ice transports. And adapted the associated sentence in the manuscript (L301-302):

*While we have not compared the cross-section method with the analytical solution as we did for the LM, we show the credibility of the VPM by comparing **volume, heat and ice transports** obtained through the LM and the VPM (Fig. 10).*

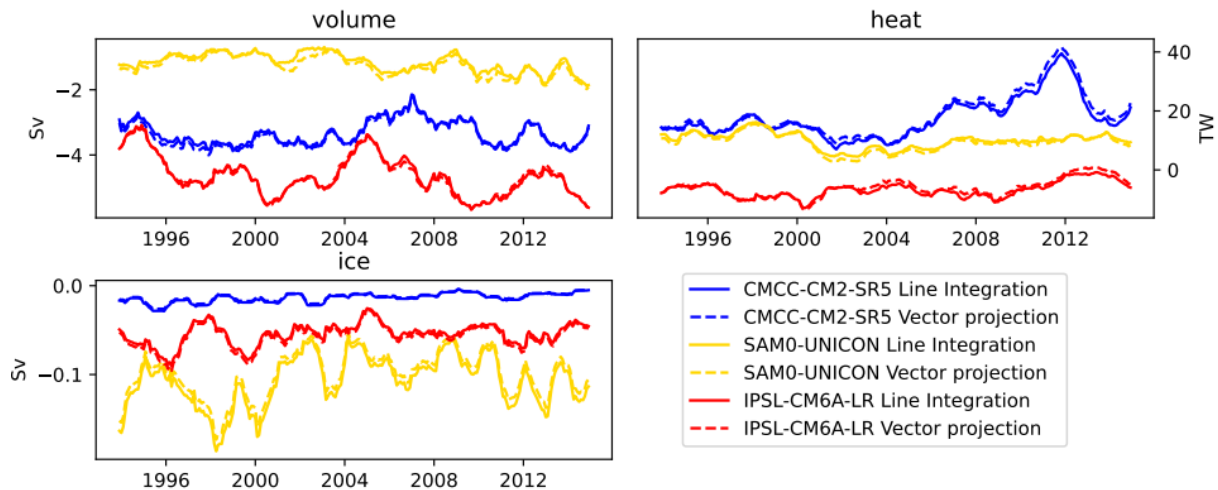


Figure 10. Comparison of volume, **heat and ice transports** obtained through the LM (solid) and through integration of cross-sections obtained through the VPM (dashed). The selected models use different grid types (see text) all with a horizontal resolution of about 1°

L86: Maybe briefly explain why closed volume transport is not generally the case? It is generally not the case for partial sections as transports are e.g. compensated by flows through other passages. Good examples are given by the four Arctic passages (Bering Strait, Fram Strait, the Canadian Archipelago and the Barents Sea Opening). Looking at the net flow into the Arctic, volume transports are balanced, however none of the individual straits feature balanced volume transports. This would generally introduce the dependence of the heat transports for the individual straits on the chosen temperature scale via T_{ref} .

We adapted the sentence as follows:

Previous studies (Schauer and Losch, 2019; Schauer and Beszczynska-Möller, 2009) correctly point out that true heat transports would actually demand closed volume transports through the examined straits. This is generally not the case for partial sections as transports may be compensated by flows through other passages and unbalanced volume transports would generally introduce the dependence of heat transports on the chosen temperature scale via T_{ref} .

Schauer, U. and Beszczynska-Möller, A.: Problems with estimation and interpretation of oceanic heat transport – conceptual remarks for the case of Fram Strait in the Arctic Ocean, *Ocean Sci.*, 5, 487–494, <https://doi.org/10.5194/os-5-487-2009>, 2009.

Vector Projection Method: Is it using the same method for Arakawa A, B and C grids? Yes, in general the Vector Projection Method is independent of the Arakawa partition. Only the cell thicknesses have to be transformed to the correct u/v positions on the grid cell.

Fig 2b. One of the cells is not in contact with the red line. From the text I understand that only cells in contact with the line is used.

We added a cell not touching the reference line, as for the Vector Projection Method

the cells in contact with the lines and also their neighboring cells are needed for the bilinear interpolation onto the reference line.

We clarified it in the text at L116-118:

*For every grid cell touching the strait **and their neighboring cells (needed later on for the interpolation onto the strait)** we calculate direction vectors of the u and v components (blue and green arrows), and normal vectors pointing from the tracer grid cell in the direction of the strait (yellow arrows).*

And at L123-125:

*The projection vectors' magnitudes are then used to compute orthogonal transports at all grid cells touching the strait **and their neighboring cells**. In the final step, these transports are interpolated bilinearly onto the closest points on the reference line (black crosses in Fig. 2b, called T_{proj} henceforth) and divided by the respective cell thicknesses on the reference line to obtain velocities.*

L124-126: Why do you convert velocities to transports and then after interpolation divide by the respective cell thicknesses to obtain velocities again, instead of just interpolating the velocities?

As pointed out at L47-49 and at L.292-295 and Fig. 9 interpolation of the velocities (=vector components) prior to the transport calculation may compromise the conservation properties of the model and therefore it may lead to quite substantial interpolation errors (see Figure 9) and unrealistic behavior in the simulated system, especially in regions with complex topography, sharp gradients or complex flow patterns. By calculating the orthogonal transports first (= scalar quantities) we ensure that the conservation properties of the models are maintained.

We changed the paragraph as follows:

*In the final step, these transports are interpolated bilinearly onto the closest points on the reference line (black crosses in Fig. 2b, called T_{proj} henceforth) and divided by the respective cell thicknesses on the reference line to obtain velocities. This results in velocity cross-sections of the vertical plane which are spaced irregularly along the along-strait distance (x) in accordance with the distribution of T_{proj} points. The interpolation onto evenly distributed points on the section, to e.g. enable the calculation of differences with other models/reanalyses, is initially left to the user and eventually will be included in a future version of StraitFlux. **By calculating transports (scalar quantities) prior to the interpolation onto the strait we ensure that the conservation properties of the models are maintained. This ensures that integration of the cross-sections along the along-strait distance (x) and depth (z) provides net transports, which agree very well with the values obtained by the LM (see Sect. 3).***

L155: How is a straight reference line drawn between the endpoints? Is it following the shortest/great-circle distance along a sphere? Or can it be defined to e.g. follow a specific latitude?

When two endpoints are given the reference line is drawn following the shortest distance along the sphere. Therefore, if the 2 endpoints have the same latitude, the

strait will automatically follow this specific latitude. There is also the option to provide a list of individual coordinates by setting the functions 'set_latlon' to True and providing latitude and longitude points via the 'lat_p' and 'lon_p' parameters. We clarified it in the manuscript:

*The determination of section positions for transport calculations is accomplished in the def_indices function. **Users can specify the start and end points of a section using the 'coords' parameter in the 'transports' function, the section will then follow the shortest distance along the sphere. Alternatively, users may pass specific coordinates by setting the 'set_latlon=True' parameter and providing a list of latitude ('lat_p') and longitude ('lon_p') points. The latter option also allows the calculation of "kinked" sections.***

Write also somewhere how the example straits used in the paper are defined, e.g. specify the start and endpoints used. Or a latitude for the Fram Strait.

We added the coordinates (start and endpoints) as table in the appendix:

Strait	start point (lat[°N],lon[°E])	intermediate points (lat[°N],lon[°E])	end point (lat[°N],lon[°E])
Fram	(78.82,-20.7)	-	(78.83,12.00)
Davis	(66.65,-61.80)	-	(67.31,-52.50)
Barents Sea Opening	(78.00,18.00)	-	(69.20,19.80)
Bering	(65.99,-170.50)	-	(66.75,-166.00)
Greenland Scotland Ridge	(68.53,-30.82)	(66.01,-23.24), (64.41,-15.07)	(59.47,6.11)
RAPID	(26.00,-80.50)	(62.07,-6.87), (60.28,-1.17)	(26.00,-13.50)
Drake	(-55.70,-66.92)	-	(-64.10,-59.20)

Table A1. Start- and endpoints for the straits used. The net Arctic transports are calculated using the sum of Fram, Davis, Bering and Barents Sea Opening. The Greenland Scotland Ridge is defined as kinked line with 4 intermediate points.

And added the following sentence in the Validation section:

The exact definitions (start and end points) of all straits used throughout this paper are given in the Appendix (Tab. A1).

L167: How are the points i on the refile defined?

i is the index that we use to select the points along the equally spaced reference line. In the newest version of StraitFlux spacing of the reference line is dependent of the resolution of the used modelling grid (see Reviewer 2 minor comment 7). E.g. 0.1° spacing for a model with 0.25° horizontal resolution, would mean that i moves along the reference line with 0.1° steps.

Following a comment from Reviewer 2 we changed Fig.3 to be easier to comprehend and changed the caption to the following:

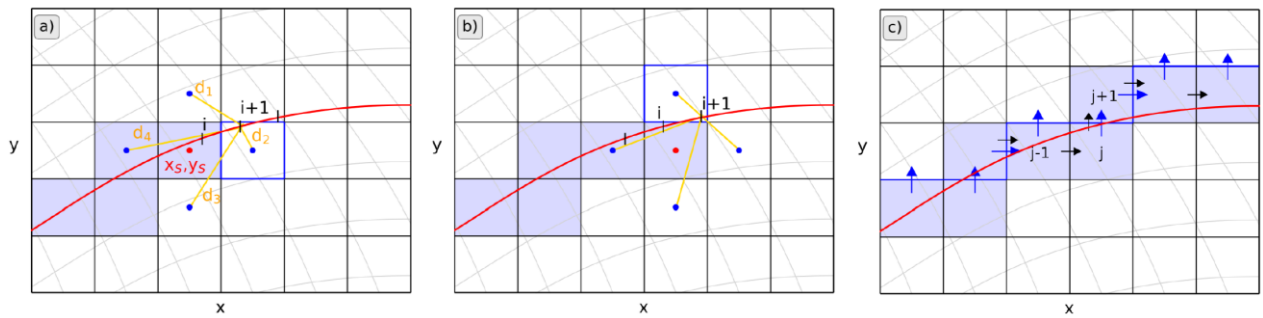


Figure 3. Illustration of the indices selection process using `select_points`. **Lines of constant latitude/longitude are shown in grey.** a) and b) Determination of consecutive grid-cells **on the native grid** by comparing distances d (orange lines) of 4 surrounding grid-cells **for all equally spaced points i along the reference line**. c) Specification whether a u or v component should be taken.

We adapted the indexing for Fig3c) in the text (L176-178):

For instance, to get to cell j in Fig. 3c, we came from left, hence the v component of cell j is taken. In order to get to cell $j + 1$ we come from below, therefore the u component of cell $j + 1$ is taken.

And we added the following footnote:

Note that we follow the native grid points (x,y) and the local direction of x is not necessarily west-east and the local direction of y not south-north. For instance, coming from left means coming from point $[x_{i-1}, y_i]$ to point $[x_i, y_i]$.

L230-231: I don't understand why the difference between velocity components is taken? Has it something to do with correcting the positions on the Arakawa grid?

To calculate the projections for the vector projection method we need vectors pointing in the direction of the velocity components, we call them "direct vectors" (= u_{dir} and v_{dir} in Eq.7; blue and green arrows in Fig. 2b) pointing from one u/v -point to the next u/v -point. To obtain the direct vectors we simply take the difference between the u/v points (in cartesian coordinates) of two neighboring cells which gives us the desired vector between those points.

Possibly we created some confusion using the term direct vectors instead of direction vectors, so we changed it to the following:

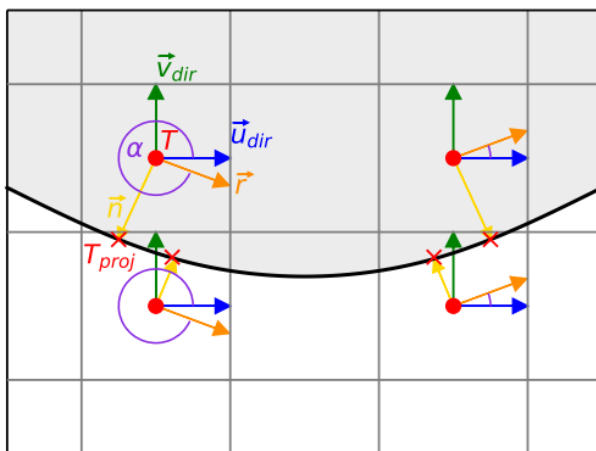
*For the projection of the u and v velocities onto the strait, **direction** vectors and normal vectors for every grid-cell are determined using the functions `calc_dir_vec` and `calc_normvec`. **Direction** vectors are assumed to point from one grid-cell to the neighboring ones and are simply calculated by taking the difference between the **Cartesian coordinates of $u_{x,y}$ and $u_{x+1,y}$ for u_{dir} and the difference between the Cartesian coordinates of $v_{x,y}$ and $v_{x,y+1}$ for v_{dir} .***

Fig 7: I cannot fully understand this figure, and how the angle α is defined. Intuitively, I would think u was defined negative if the absolute value of the angle between r and u_{dir} was more than 90 degrees.

Alpha is the angle between u_{dir} and the strait (=vector r). If the angle is smaller than 180 degrees u is defined negative, and if it's $>180^\circ$ u is defined positive.

It's not about u pointing to the east or west, we always consider the positioning of u to the strait. In Fig. 7 transports into the grey area are defined positive and out of it negative. Due to the curvature of the strait the 2 points on the left pass the strait (black bold line) from the other side than the points on the right side. The angle between u_{dir} at the upper left and lower left points and r at those points is $>180^\circ$ and therefore u_{dir} is counted positive. However, for the two points on the right, the angle is $<180^\circ$ and u_{dir} is counted negative.

We adapted the figure and included the r -vectors and the alpha-angles to make it easier to comprehend:



L241-243: I don't understand this sentence, and why the u and v components are scaled.

The formulation was a bit misleading. By "scale" we actually meant the projection of u/v onto the orthogonal. With "scale" we just meant to express that u/v have to be multiplied by the norm of the projection vector as not 100% of u/v actually pass through the strait. [for flows parallel to the strait actually 0% pass through ("scaling" factor of 0) and for flows orthogonally onto the strait 100% pass through ("scaling" factor of 1)]

We changed the formulation to omit the phrase "scale":

*Using the norm of the projection vectors, the u and v components of every vertical layer **are projected orthogonally onto the strait. To obtain cross-sections of velocities we additionally multiply by the actual cell thicknesses of the cells.***

L293: What is ESMFgrid? Do you mean xesmf's Regridder?

Yes, we changed it to:

*We compare both, bilinear and conservative interpolation as defined **in xESMF, a python package for regriding**, and calculate volume and heat transports through the sum of*

Arctic main gateways (Fram Strait, Barents Sea Opening, Davis Strait and Bering Strait) for the CanESM5 model.

Fig 12. Maybe add in figure title or text that this is the Transports for the Fram Strait. We added it to the figure caption:

*Figure 12. Volume and heat transport time series **at Fram strait** for ten selected CMIP6 models from Heuzé et al. (2023) (solid) and our LM estimates (dashed).*

L339: ITF: please define abbreviation

We defined it as Indonesian Throughflow.

If possible, can you sketch an example showing why interpolation methods make such large errors? Or cite eventual other papers who discuss why? I find it a little hard to imagine how interpolation errors can give such large errors in the net Arctic volume transport.

The net Arctic volume transport is quite sensitive to small inaccuracies in the calculation, as large transports through the individual straits (e.g. >2Sv for the Barents Sea Opening) add up to a very small net transport (about 0.2Sv).

Nevertheless, we discovered an error in our interpolation from curvilinear to native grid concerning the rotation of the vector components. Therefore, we repeated the calculation for Drake Passage and the RAPID array (see Figure below), two sections where the grid of the considered CanESM5 model is regular and therefore the rotation of the vector components may be omitted. Interpolation errors are smaller than what we showed in Fig. 9, however especially for the RAPID array, a very long strait with a relatively small net volume transport, they are still quite significant. Complications due to the rotation of u/v will possibly introduce even larger errors further north (although probably smaller than what we've assumed before). We changed the figure and revised the whole paragraph:

Interpolation of the vector components u and v onto regular grids is quite complex and may lead to significant errors in the calculated transports. The complexity arises from the rotation of the u and v components in comparison to the directions on a geographic latitude-longitude grid. Regridding would involve rotating the wind components to the new wind direction (eastward/northward) prior to the interpolation as done e.g. by He et al., 2019 (<https://doi.org/10.1038/s41558-018-0387-3>). However, for the rotation the exact grid angle at each grid cell is needed, which is not standard output for most CMIP6 models and reanalyses. Outten 2018 (<https://doi.org/10.1175/JreCLI-D-18-0058.1>) found that small inaccuracies in the used angles, e.g. the exact position of the angles in the grid cell (center vs. cell edges or corners) may lead to differences in the calculated transports. Even if the model configurations and grid angles were archived correctly, it is still hard to guarantee the conservation properties of the interpolated fluxes. Fig. 9 compares transports calculated from interpolated u and v values on a regular grid with those derived from u and v on the native grid for the CanESM5 model. Transports are calculated through Drake passage and the RAPID array, two straits where the native grid of the CanESM5 model is not distorted, and therefore any errors

connected to the rotation of the velocity components are avoided. Even here interpolation (both bilinear and conservative as defined in xESMF) leads to significant deviations from the actual transports obtained through both StraitFlux methods. Especially so at the RAPID array, a very long strait with a relatively small net volume transport.

An alternative approach would be to write each vector in terms of scalar vorticity and streamfunction using helmholtz decomposition, remap those scalar quantities to a regular grid and then recover eastward and northward velocity components using gradients.

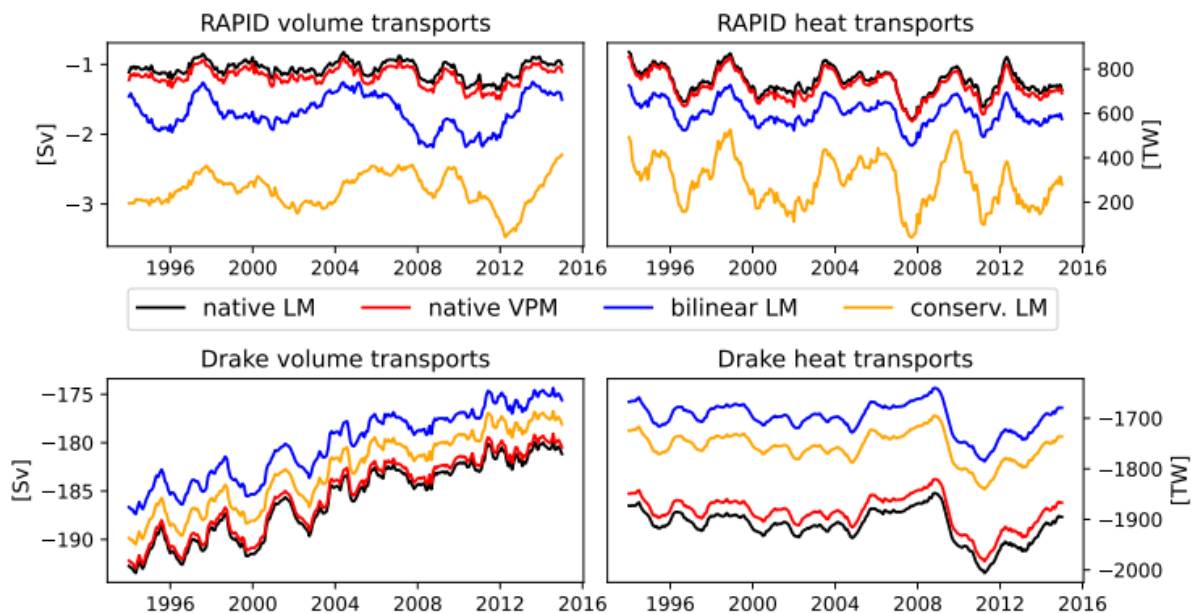


Figure 9. Display of the interpolation error for volume (left) and heat (right) transports at the RAPID array and at Drake passage from the CanESM5 model (1° resolution).

Typos:

L268: radiant - should be radians

We corrected it.

L313: VPN - should be VPM

We corrected it.

L360: Gitlab - maybe you mean github instead, since the urls provided go to github?

Yes, we changed it to github.

L373 i.a. - should be i.e. (?)

We changes it to "for instance".

L383: northern most – cut space between words
We corrected it.

L397: downlaoded – should be downloaded
We corrected it.