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Evidence for atmosphere - ocean meridional energy transport compensation in the past decades

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Background

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More details about this work can be found in the paper:

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Atmosphere–Ocean Interactions and Their Footprint on Heat Transport Variability in the Northern Hemisphere

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ABSTRACT

Interactions between the atmosphere and ocean play a crucial role in redistributing energy, thereby maintaining the energy balance of the climate system. Here, we examine the compensation between the atmosphere and ocean's heat transport variations. Motivated by previous studies with mostly numerical climate models, this so-called Bjerknes compensation is studied using reanalysis datasets. We find that atmospheric energy transport (AMET) and oceanic energy transport (OMET) variability generally agree well among the reanalysis datasets. With multiple reanalysis products, we show that Bjerknes compensation is present at almost all latitudes from 40° to 70°N in the Northern Hemisphere from interannual to decadal time scales. The compensation rates peak at different latitudes across different time scales, but they are always located in the subtropical and subpolar regions. Unlike some experiments with numerical climate models, which attribute the compensation to the variation of transient eddy transports in response to the changes of OMET at multidecadal time scales, we find that the response of mean flow to the OMET variability leads to the Bjerknes compensation, and thus the shift of the Ferrel cell at midlatitudes at decadal time scales in winter. This cell itself is driven by the eddy momentum flux. The oceanic response to AMET variations is primarily wind driven. In summer, there is hardly any compensation and the proposed mechanism is not applicable. Given the short historical records, we cannot determine whether the ocean drives the atmospheric variations or the reverse.

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BLUE ACTION

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Atlantic Air-Sea Interaction

J. Bjerknes

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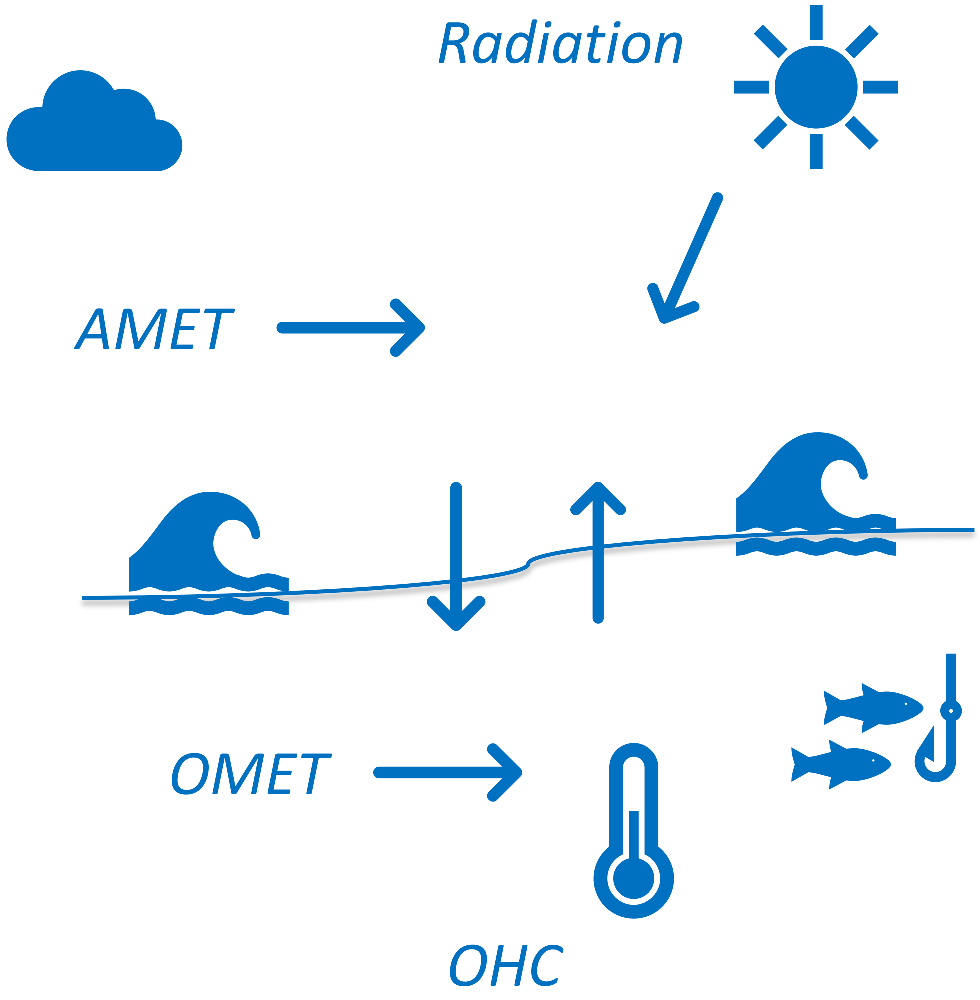
Publisher Summary

This article is concerned with the causes of the variations in the surface temperature of the Atlantic Ocean from year to year and over longer periods. The processes, which influence the ocean temperature, are partly radiative transfers, partly heat exchange at the interface of ocean and atmosphere, and partly advective heat transfers by the ocean currents. The net radiative heat balance of the ocean is influenced by possible variations of the solar radiative output, and by the transmissivity of the atmosphere for short- and long-wave radiation. Variations in cloudiness would be the factor, most likely to influence measurably the annual radiative heat budget of the ocean. The ocean currents provide important contributions to the local heat budget, positive in the warm currents and negative in the cold currents. The changes in intensity of the oceanic circulation are mainly dictated by changes in the atmospheric circulation, and the resulting changes in the temperature field of the ocean surface must in turn, influence the thermodynamics of the atmospheric circulation. A clarification of these relationships is a prerequisite for the understanding of the mechanism of climatic change. This article will present some empirical findings, which have a bearing on those problems. Before proceeding to display the empirical findings on

Motivation



$$\frac{\partial OHC}{\partial t} \approx -\nabla(OMET + AMET) + F_{TOA}$$

At long time scales close to equilibrium (MET=Meridional Energy Transport)

$$OMET \approx -AMET$$

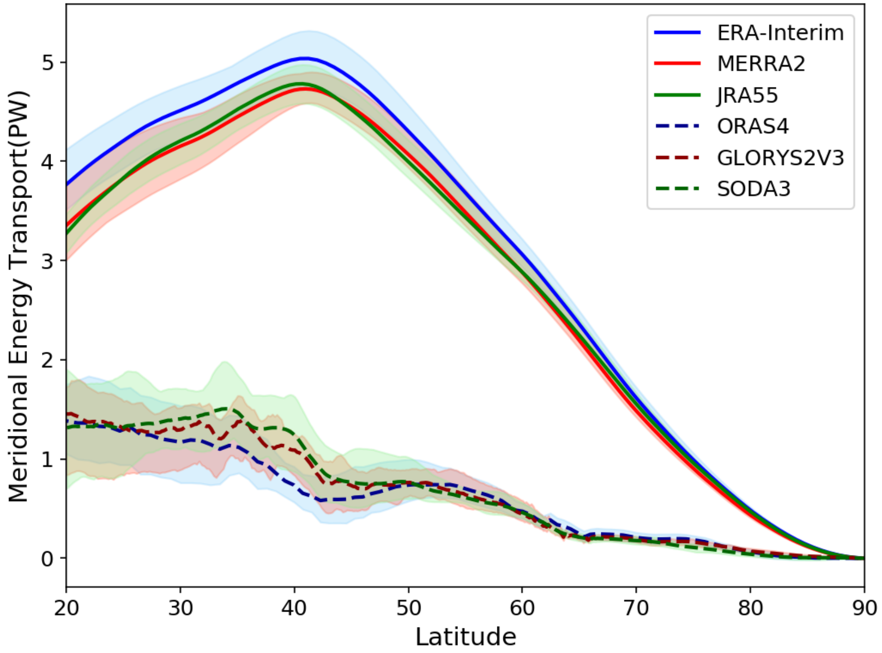
1) Evidence in numerical climate models. Does it occur in the observationally constrained reanalysis products?
2) If so, what processes are involved to achieve compensation?

Data

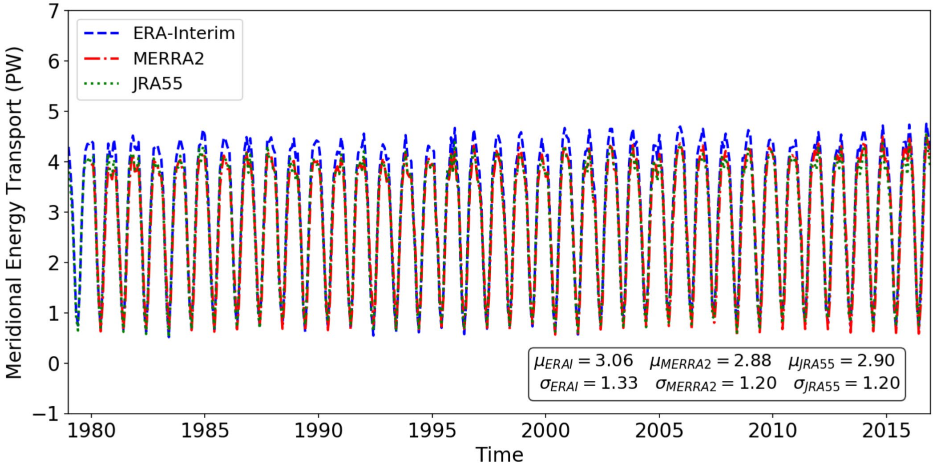
ERA-Interim	1979 - 2016	6 hourly	0.75° x 0.75° x 60 lev
MERRA2	1980 - 2016	3 hourly	0.5° x 0.667° x 70 lev
JRA55	1979 - 2015	6 hourly	0.56° x 0.56° x 60 lev
ORAS4	1979 - 2014	monthly	ORCA1
GLORYS2V3	1993 - 2014	monthly	ORCA025
SODA3	1980 - 2015	5 daily	MOM5

Six reanalysis products are used to compute the AMET and OMET

Mean and variability in AMET and OMET



(a)



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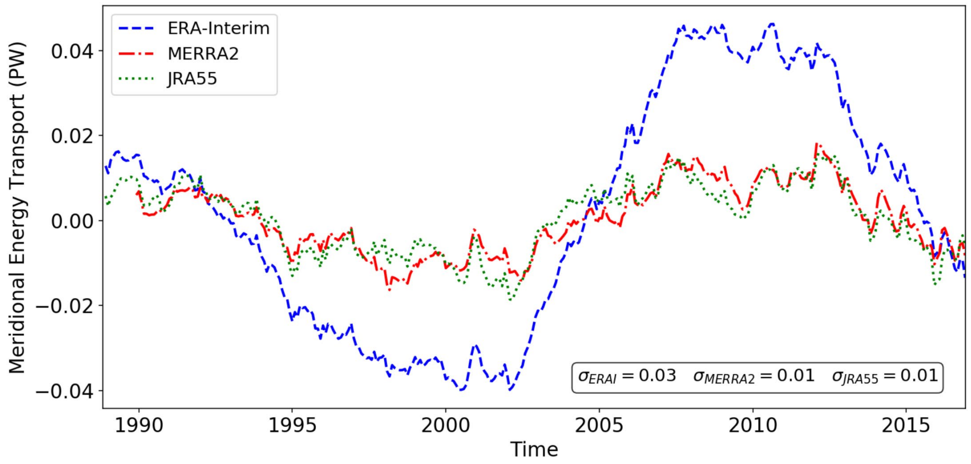


Time series of the zonal integral of AMET at 60N. (a) The original time series (i.e., no filter) and (b) the anomalies with a low - pass filter after detrending.

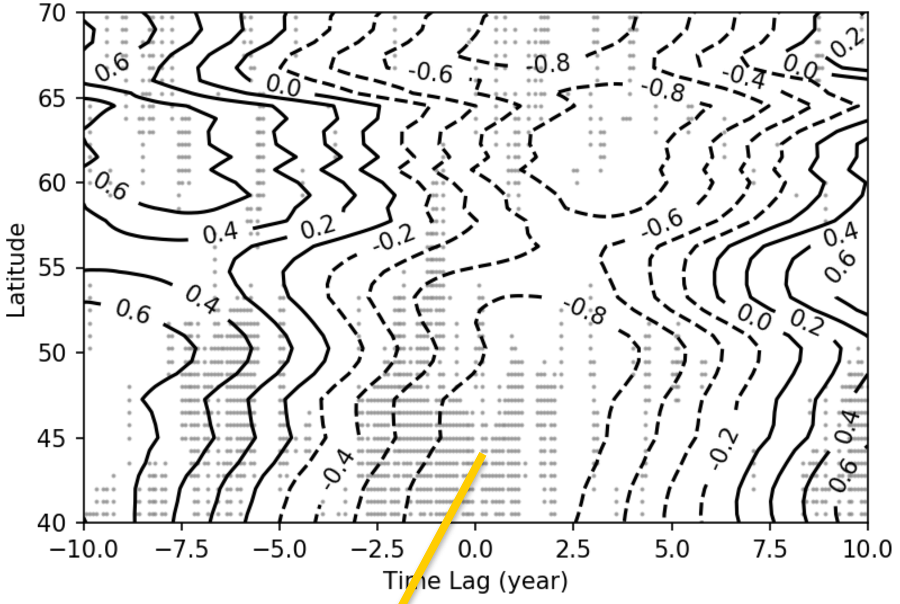
Heat transport compensation between the atmosphere and ocean

Lag regression of OMET anomalies on AMET in the Northern Hemisphere.

Similar results are found in the reanalysis products and numerical models, <u>but at different time scales and not in subtropics.</u>

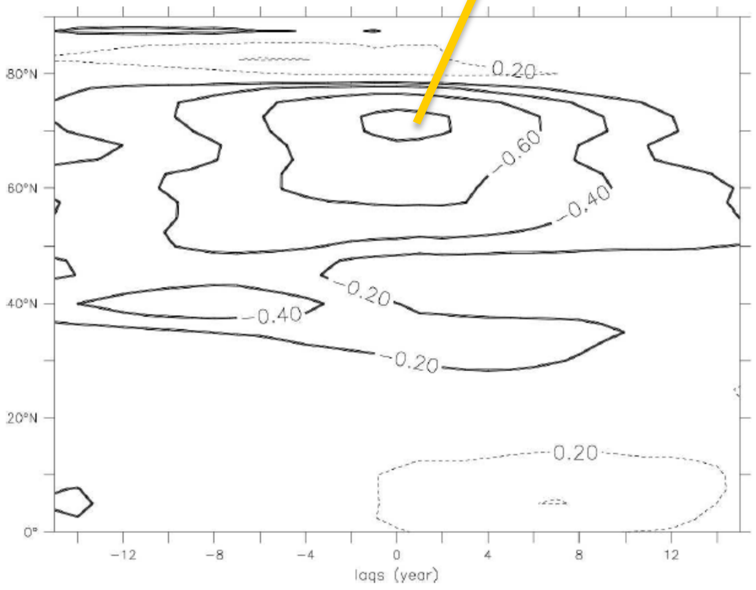
Compensation at lag 0

ERAInterim and ORAS4 (decadal)



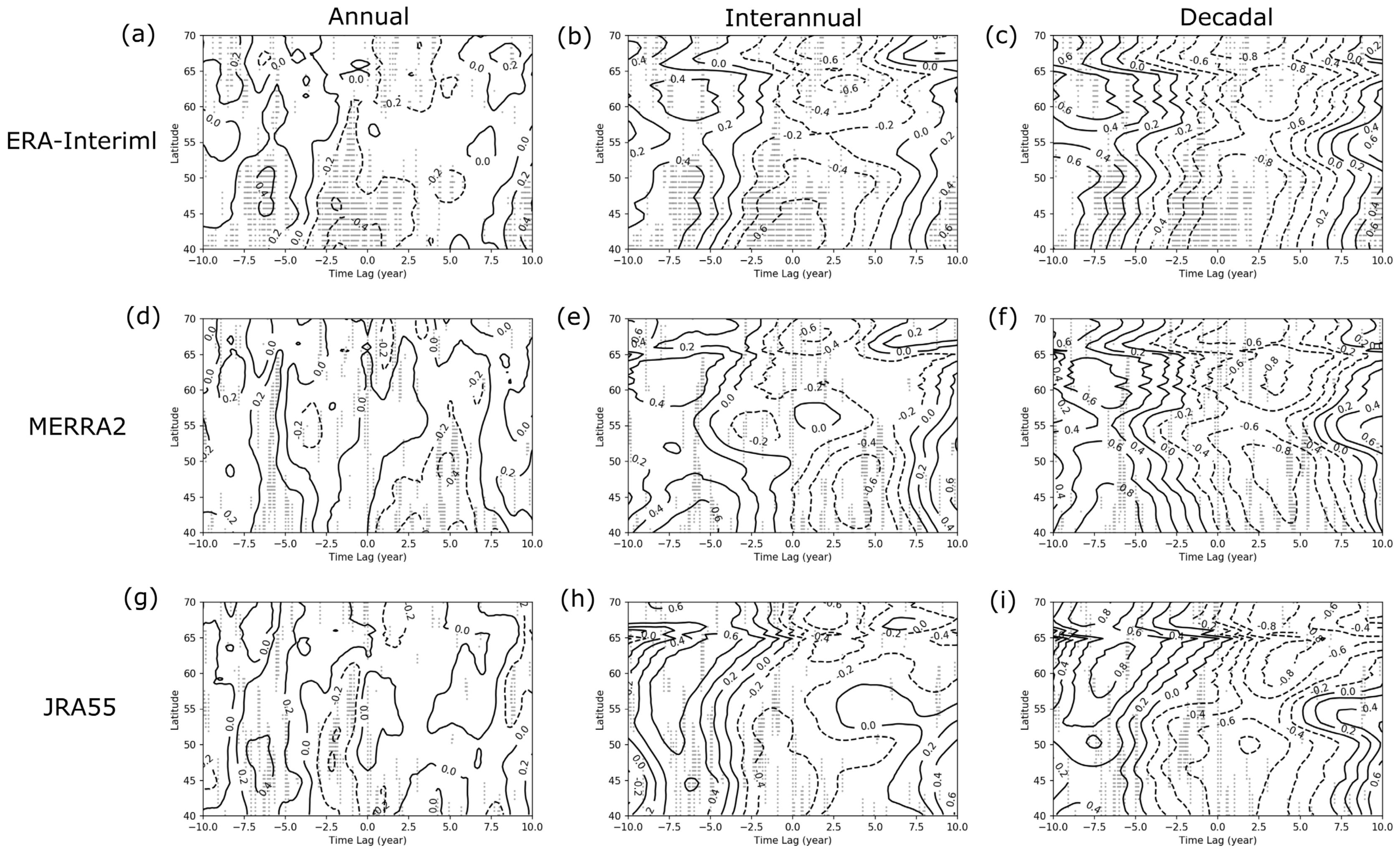
Compensation at lag 0

HadCM3 (interdecadal)



van der Swaluw, E., Drijfhout, S. S., & Hazeleger, W., 2007; (note contouring convection different)

Heat compensation between the atmosphere and ocean

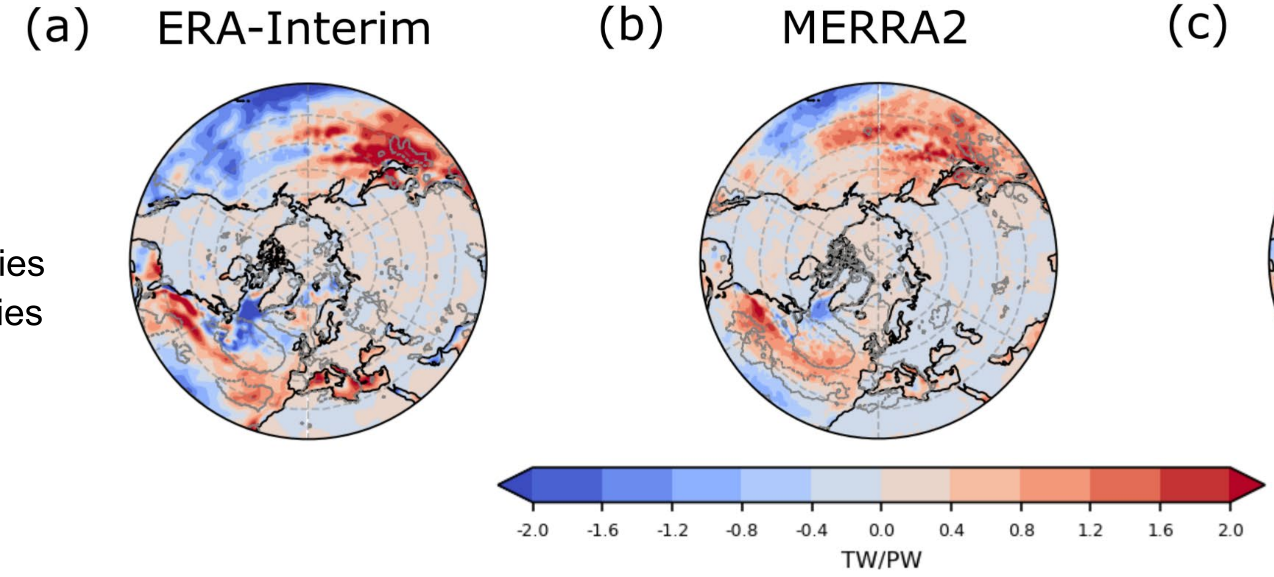


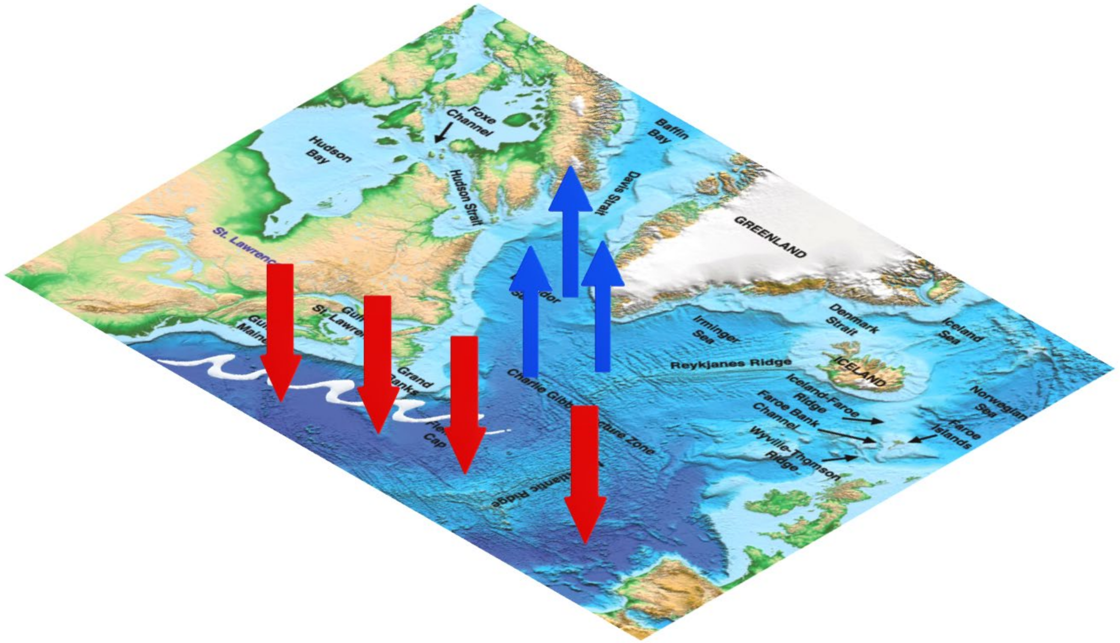
Lag regression of OMET anomalies on AMET anomalies in the Northern Hemisphere at (left) annual, (center) interannual, and (right) decadal time scales.

Positive time lag indicates that ocean leads the atmosphere and vice versa.

Surface heat flux

Regression of net surface flux anomalies on vertically integrated OMET anomalies at 60N at decadal time scales.





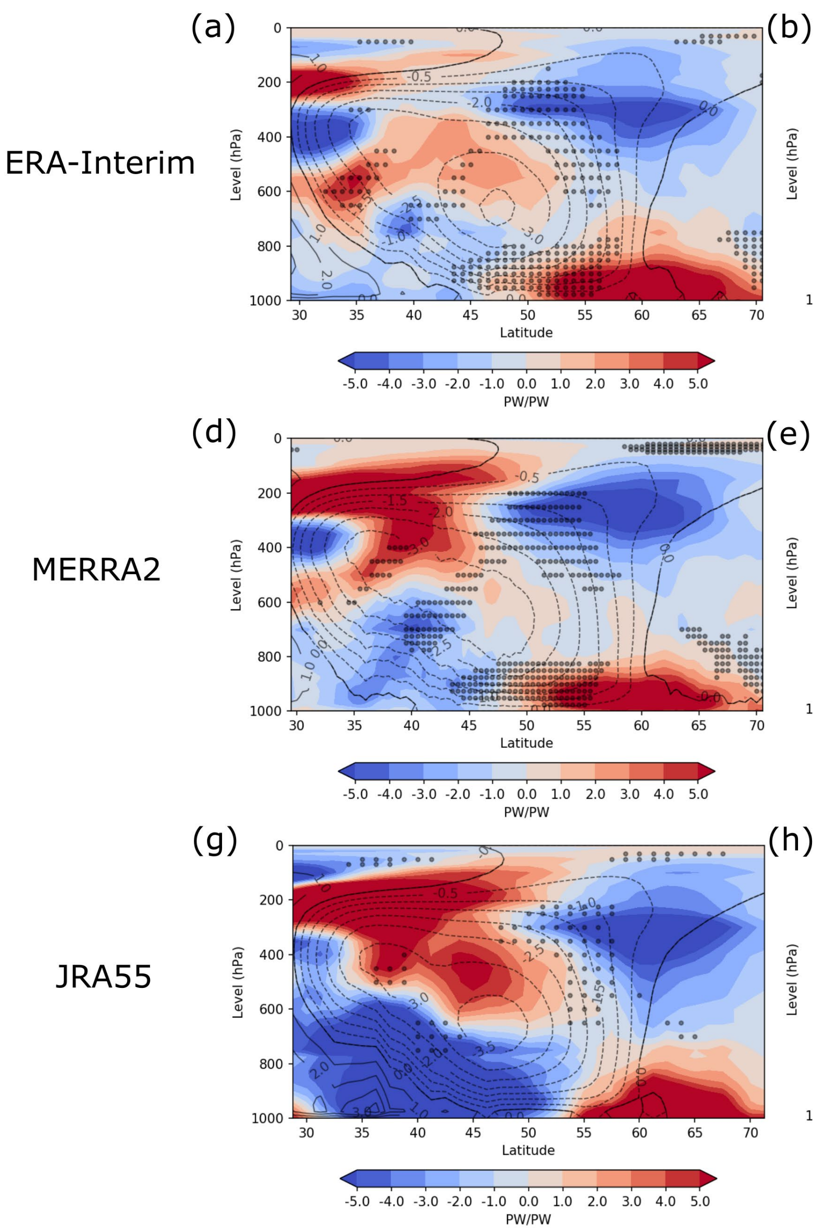
Heat is released from atmosphere to the ocean at subtropical regions and is passed from ocean to the atmosphere at subpolar regions over the Atlantic.

Atmospheric response to OMET variations

Regressions are shown in colors. Mean meridional stream function in contours.

High level atmospheric heat transport accounts for compensation of ocean heat transport → <u>dynamical processes at play</u>

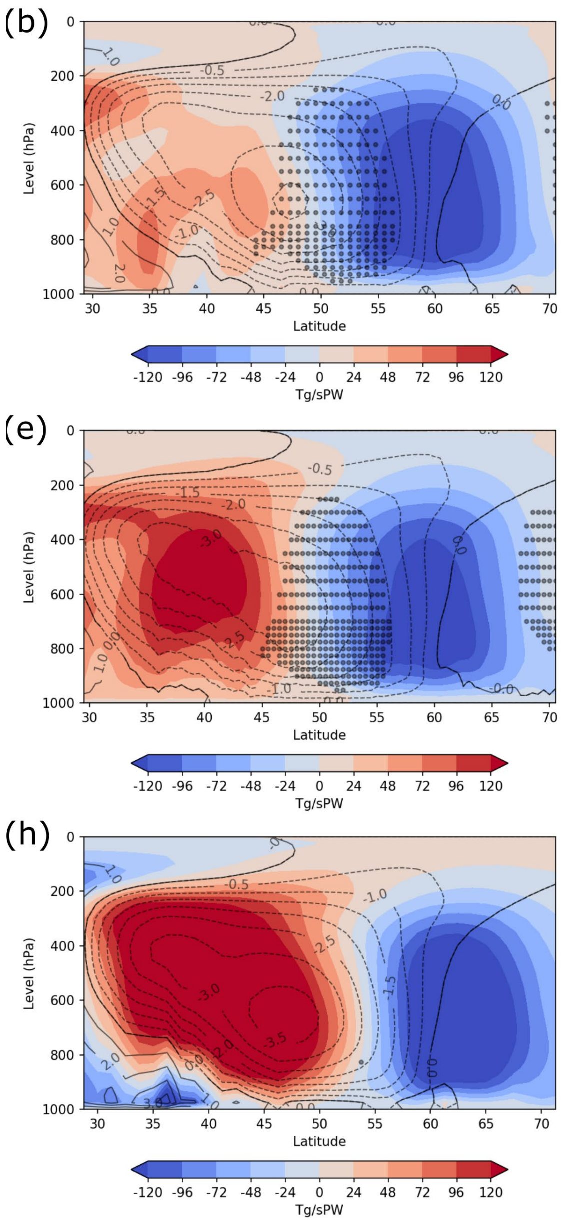
Regression of AMET on OMET at 60N



Atmospheric response to OMET variations

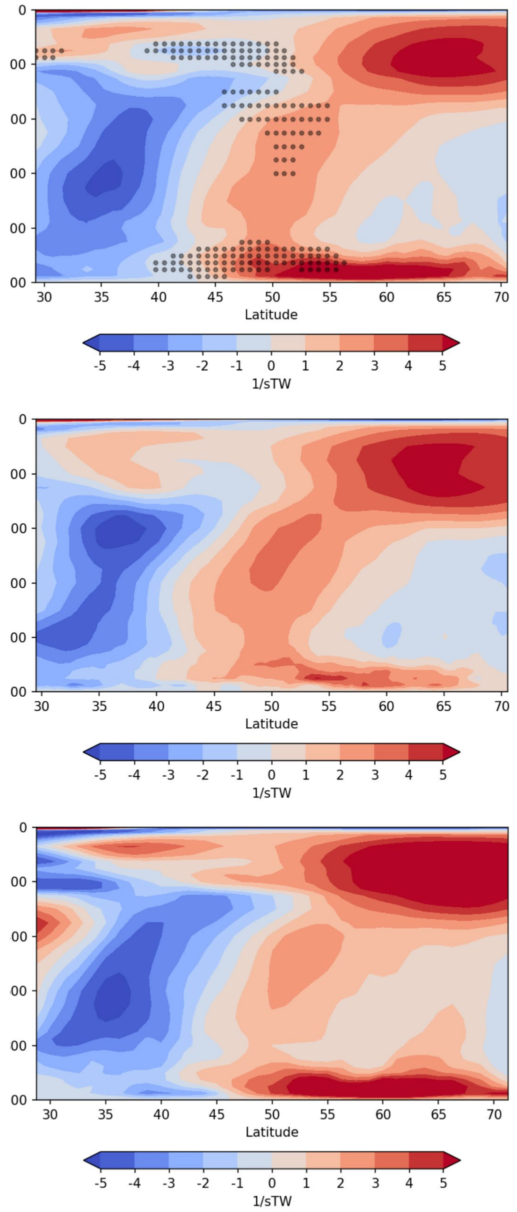
Indeed, Ferrell cell responds.

Regression of stream function on OMET at 60N



Atmospheric response to OMET variations

Regression of du/ dz on OMET at 60N

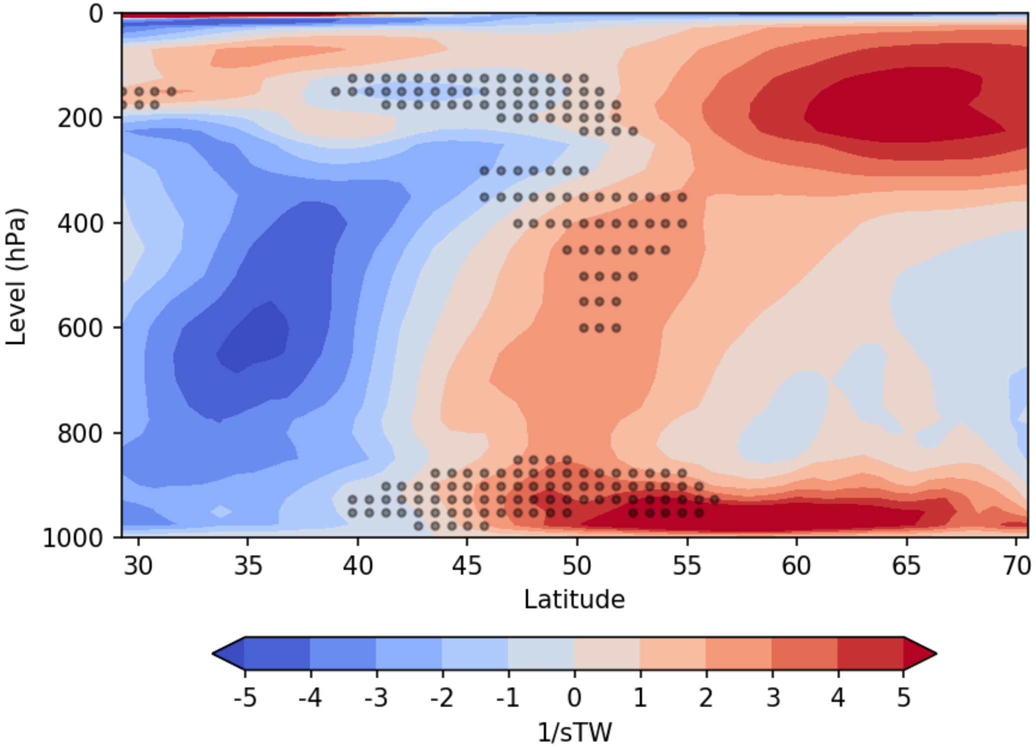


Consistent changes of baroclinicity of the atmosphere

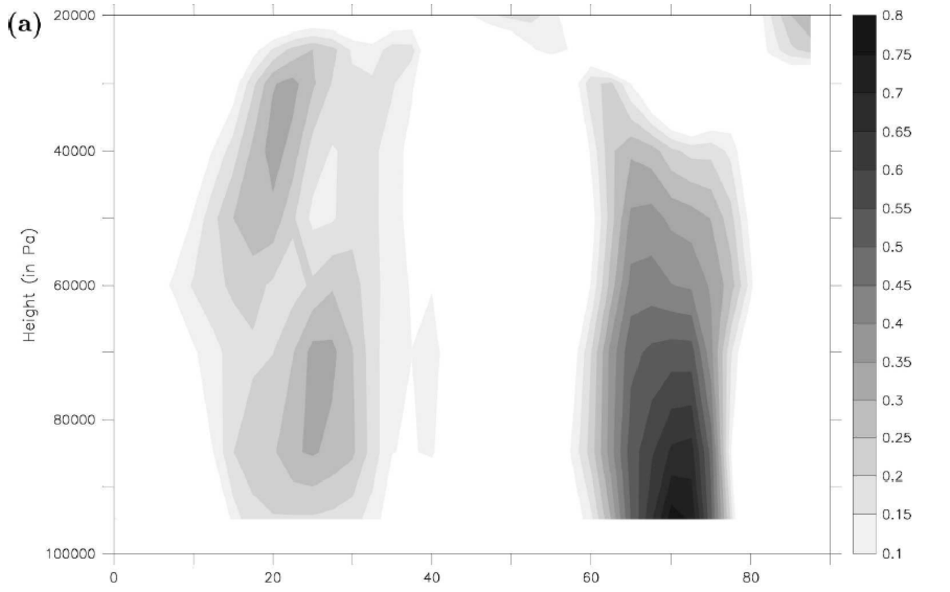
Consistent result across data sets

Atmospheric response to OMET variations

Regression of du/dz (ERAInterim) on OMET (ORAS4) at 60N



Regression of du/dp on OMET (HadCM3) at 70N

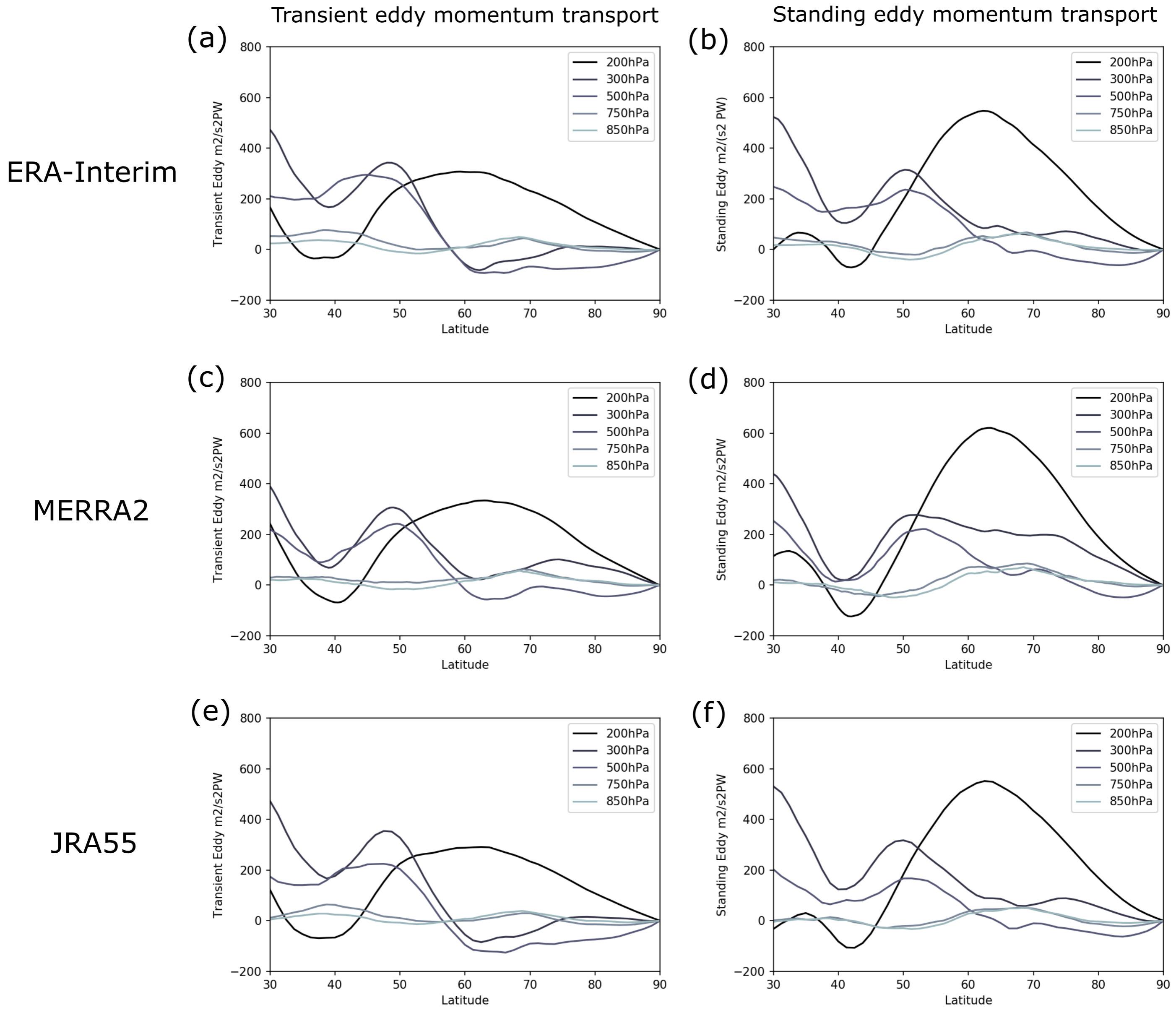


Changes of baroclinicity of the atmosphere

<u>Results between reanalysis and numerical climate models are different!</u>

van der Swaluw, E., Drijfhout, S. S., & Hazeleger, W., 2007;

Eddy momentum transport

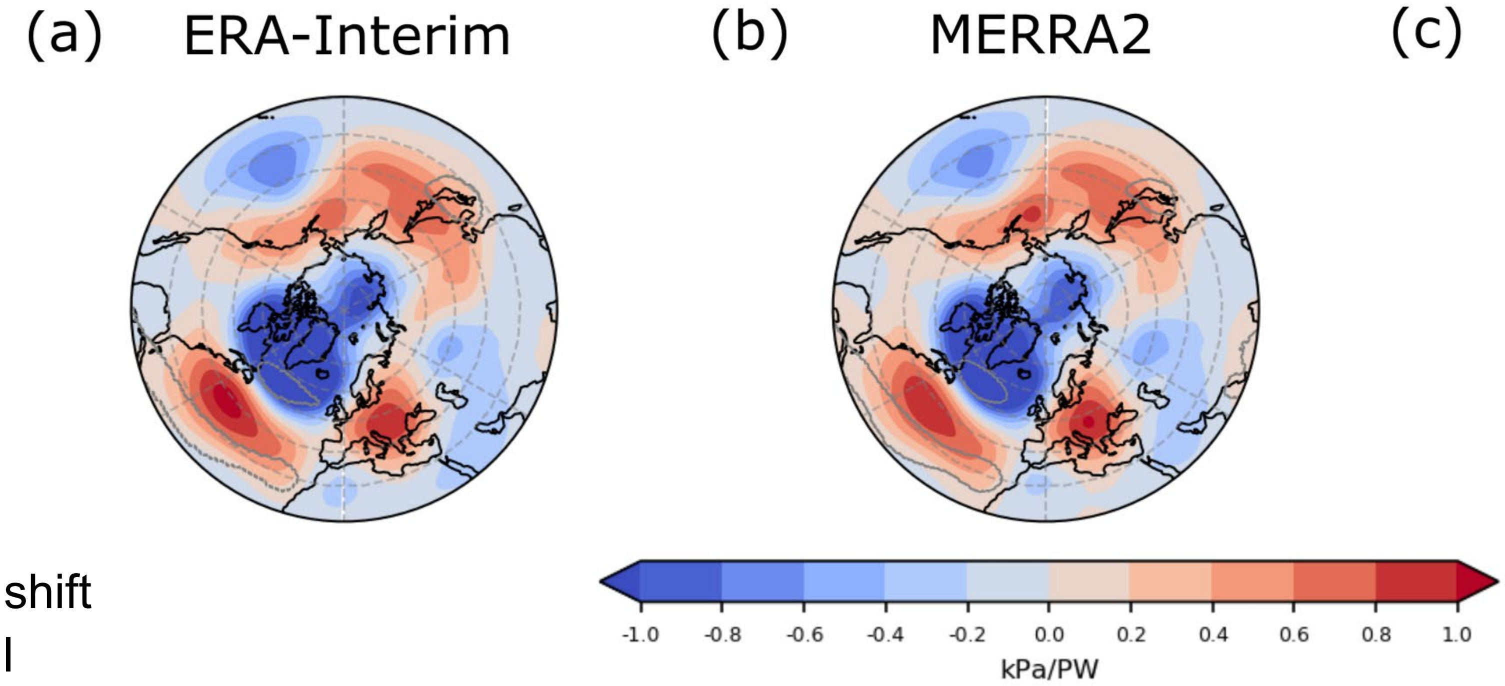


- Momentum transported by standing / transient eddies

- Mean flow variations are quite likely to be driven by eddies

Atmospheric response to OMET variations

Regression of geopotential height anomalies at 500 hPa on vertically integrated OMET anomalies at 60N



Horizontally the shift in the Ferrel Cell shows as an AO/NAO pattern.

Conclusion

1. We find Bjerknes compensation in reanalysis data. This is similar to studies with numerical climate models, <u>but different time scales and also in subtropics</u>.

2. The atmosphere responds to OMET variations with a <u>shift in the Ferrel Cell</u>. This shift may be driven by eddy momentum fluxes due to change in baroclinicity. Horizontally this shift shows an AO like response.

3. The related AMET variations are primarily found in the zonal mean part, driven by eddy momentum fluxes, and less in the eddy heat transport part. <u>This is significantly different from models, but it is consistent among reanalysis products.</u>

4. The oceanic response to AMET variations is primarily wind-driven (Ekman and Sverdrup), but we cannot discard AMOC variations due to thermohaline processes (not shown).

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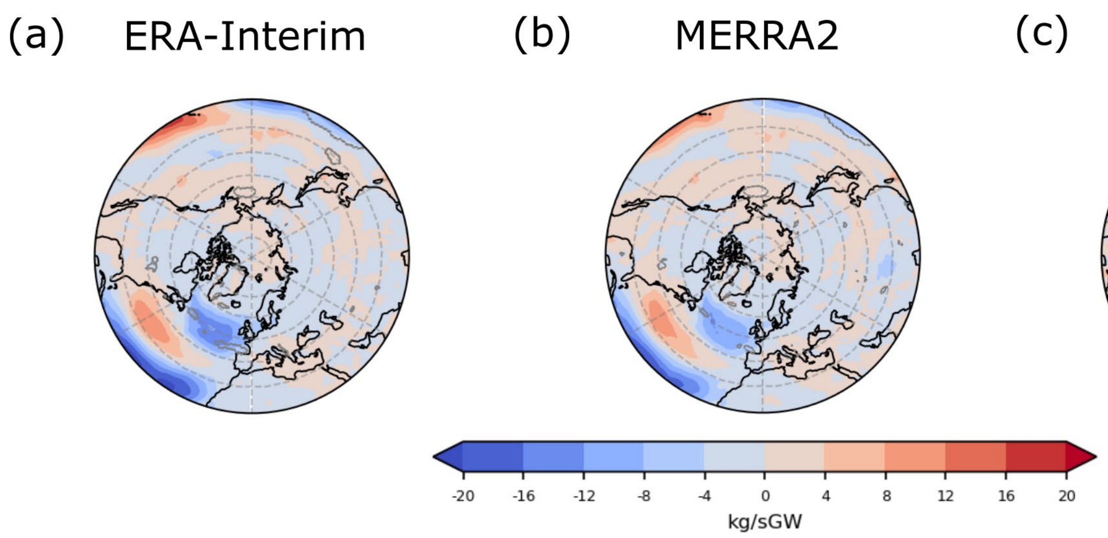
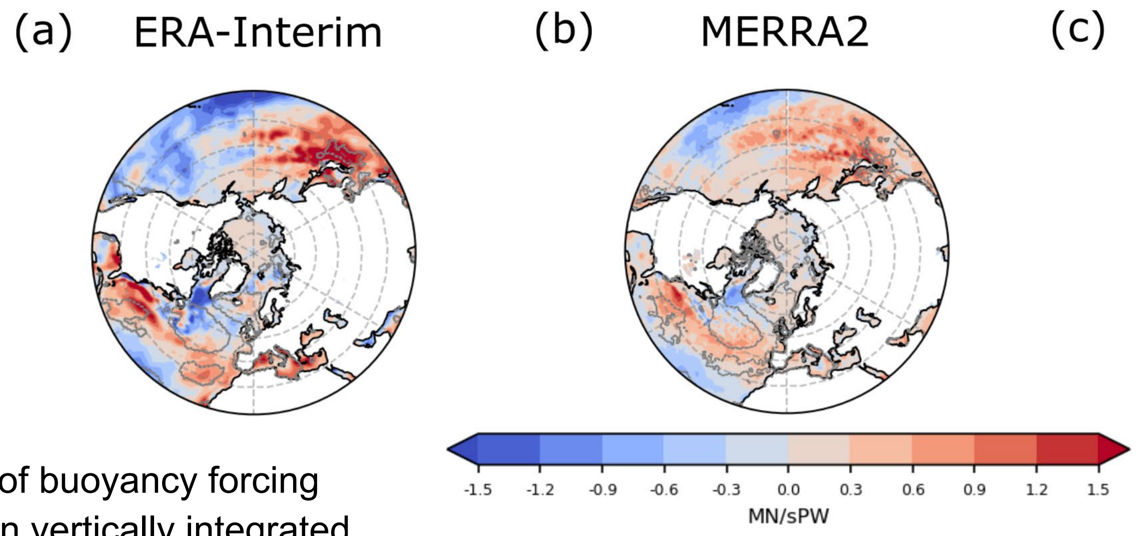
Backup slides

Oceanic response to AMET variations



Regression of meridional Ekman transport anomalies on vertically integrated OMET anomalies at 60N



Regression of buoyancy forcing anomalies on vertically integrated OMET anomalies at 60N at decadal time scales without time lags.

- Surface wind driven (Ekman/Sverdrup transport)

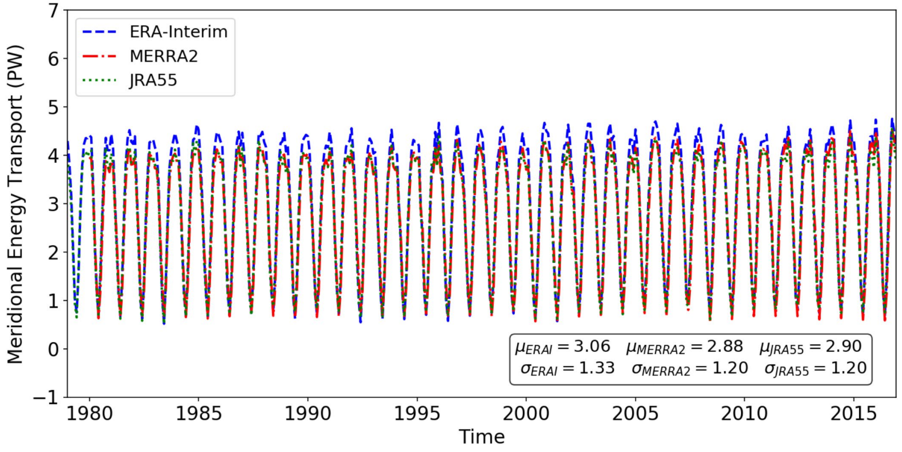
- Buoyancy forcing driven (Thermal/Saline force)

Computation of AMET and OMET

Compute AMET and OMET and their anomalies as a function of latitude in the Northern Hemisphere.

Time series of the zonal integral of AMET at 60N. (a) The original time series (i.e., no filter) and (b) the anomalies with a low - pass filter after detrending.

(a)



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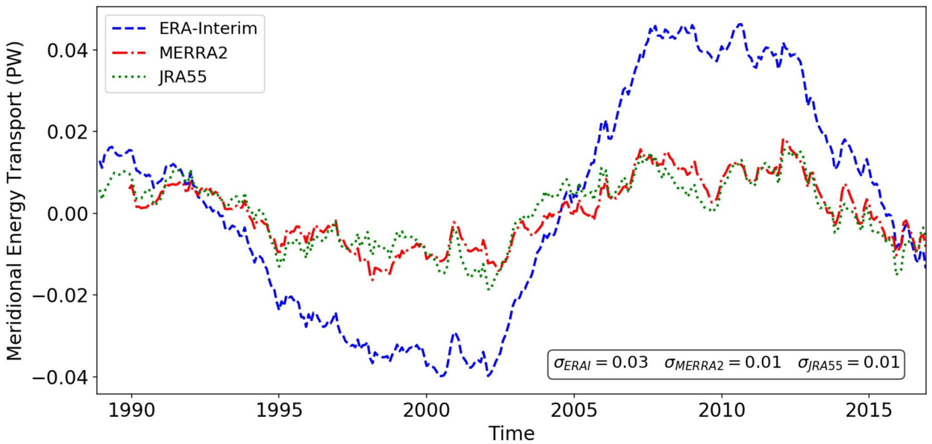
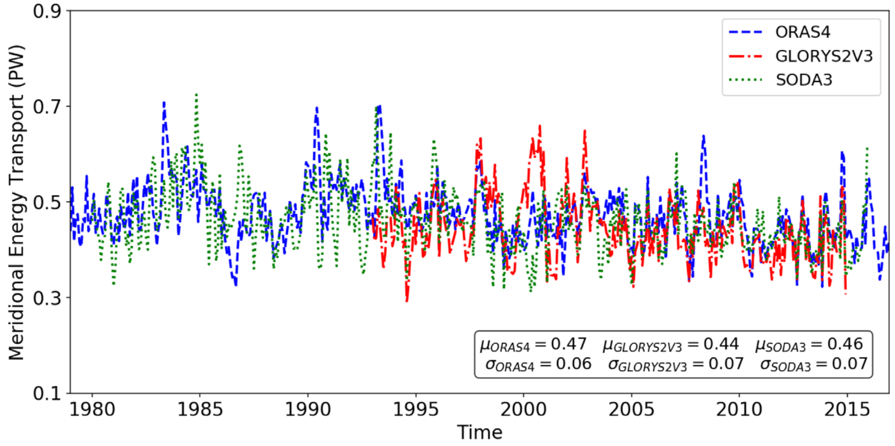


Time series of the zonal integral of OMET at 60N. (a) The original time series (i.e., no filter) and (b) the anomalies with a low - pass filter after detrending.

(a)



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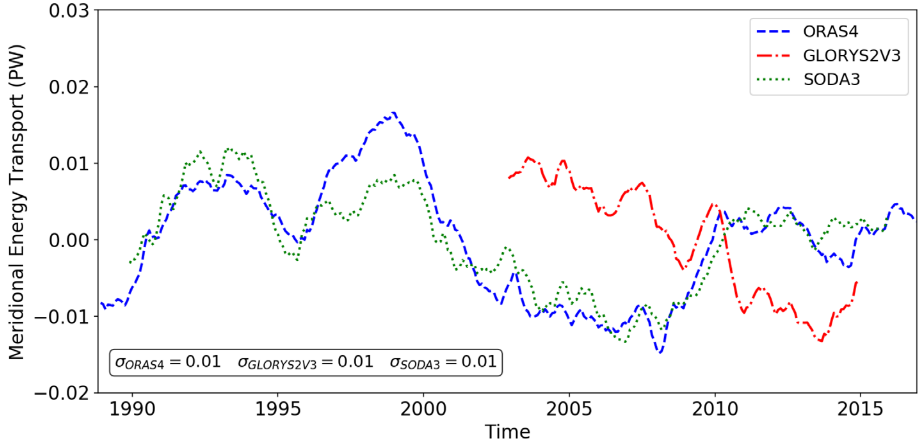
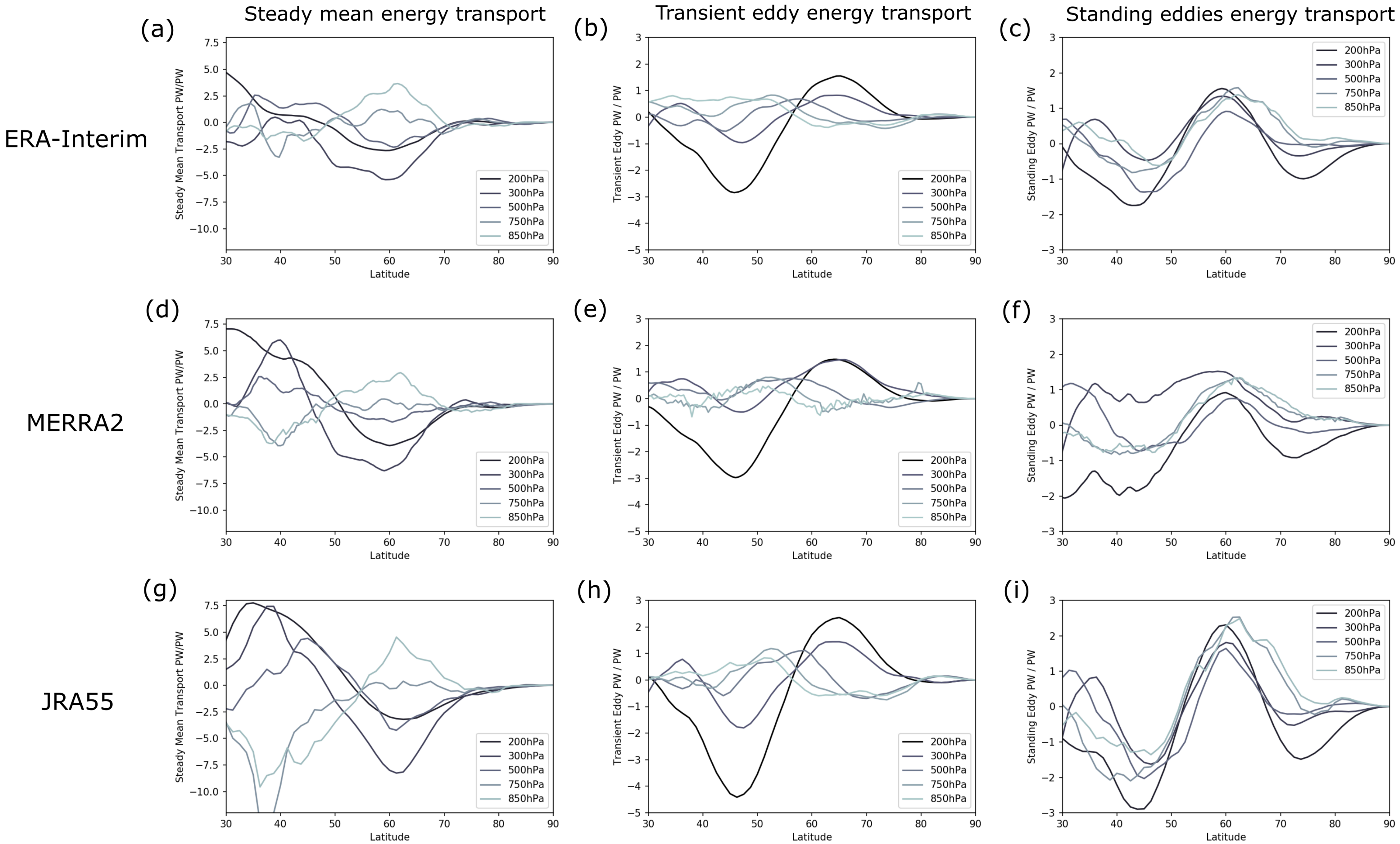
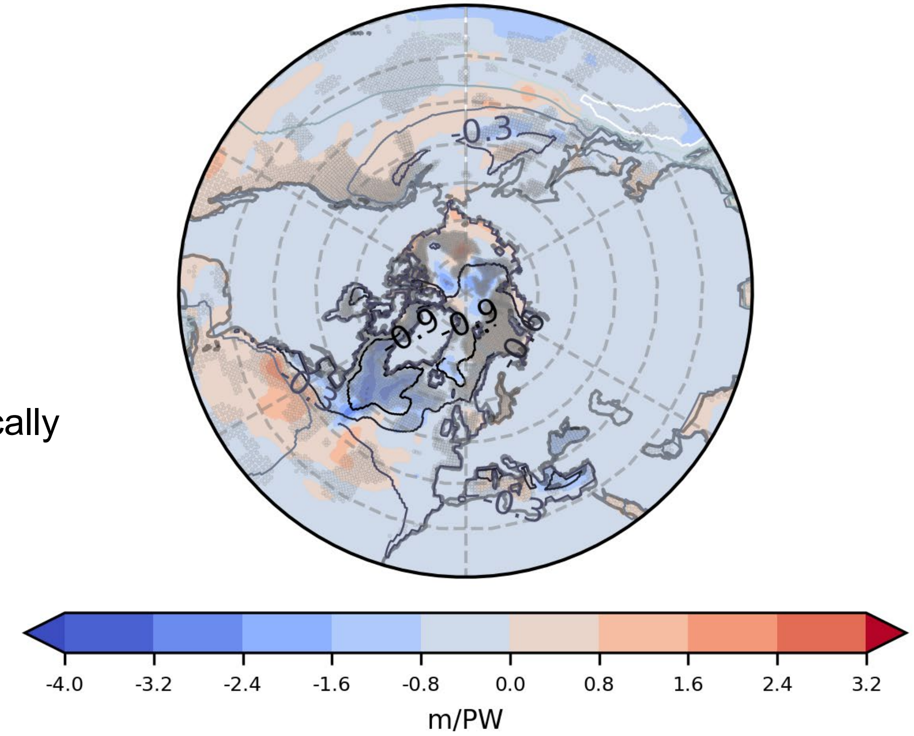


Eddy Energy Transport



Impact of wind stress curl on gyres



Regression of SSH anomalies on vertically integrated OMET anomalies at 60N at decadal time scales.