Quantifying uncertainty in decadal ocean heat uptake due to intrinsic ocean variability

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(1) Global surface warming since 1850 consisted of a series of decadal timescale slowdowns (hiatus periods) followed by surges. These are likely due to a combination of external forcing and intrinsic variability (either in the ocean alone or in the coupled system).

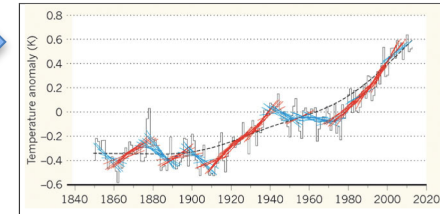
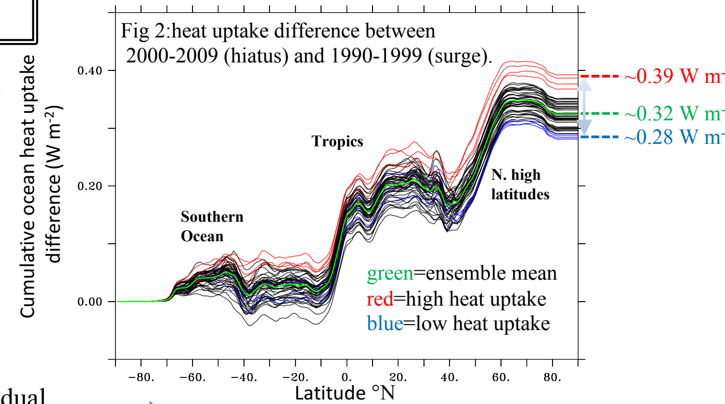


Figure 1: Surges & hiatuses (Risbey, 2015)

Here we evaluate the influence of ocean intrinsic variability on global ocean heat uptake and hence the rate of global surface warming, using a 50-member ensemble of eddy-permitting ocean general circulation model simulations (OCCIPUT ensemble), forced with identical surface atmospheric conditions during 1960-2015 (Bessières et al., 2016) .

(2) Air-sea heat flux, integrated zonally and accumulated with latitude provides a useful measure of ocean heat uptake (Drijfhout et al., 2014). **Main diagnostic is the difference between the 2000s and the 1990s**.



OCCIPUT suggests the 2000s saw ocean heat uptake of +0.32 W m^{-2} compared to the 1990s shared between the tropics and the high latitudes. Intrinsic ocean variability modifies the mean ocean heat uptake change by up to 0.05 W m^{-2} or ±15%.

(3) Composite analysis of the ensemble members with the most extreme individual decadal heat uptake changes pinpoints the southern and northern high latitudes as the regions where intrinsic variability plays a large role: tropical heat uptake change is largely fixed by the surface forcing. Note the asymmetry between high and low extremes.

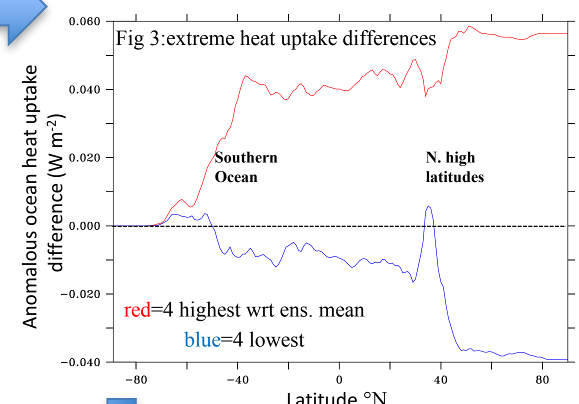
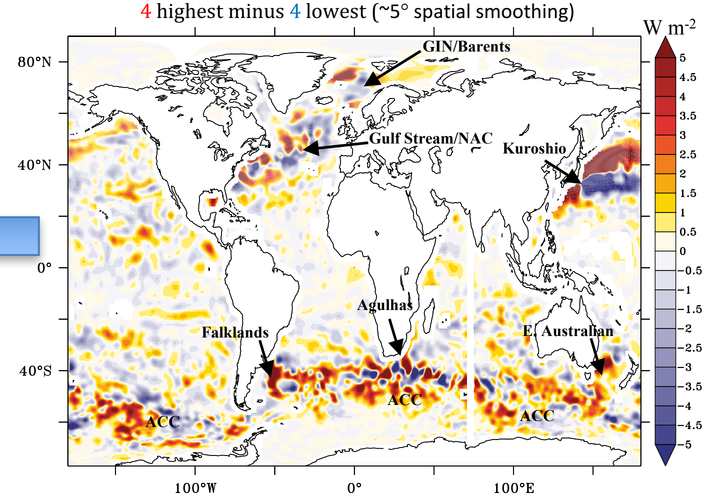


Fig 4:Change in air-sea heat flux difference (2000s minus 1990s)
4 highest minus 4 lowest (~5° spatial smoothing)



(4) The western boundary currents and the Antarctic Circumpolar Current (eddy rich regions) are responsible for the range of simulated ocean heat uptake, with the North Pacific exhibiting a particularly strong signal.

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(5) Focusing on the North Pacific we modify our diagnostic, accumulating air-sea heat flux from 18°N within the boundaries of the North Pacific only (normalized by global ocean surface area). OCCIPUT suggests the 2000s saw North Pacific ocean heat uptake of +0.04 W m^{-2} compared to the 1990s. Intrinsic ocean variability modifies the mean ocean heat uptake change by -0.08 to +0.04 W m^{-2} – one to two times the ensemble mean value.

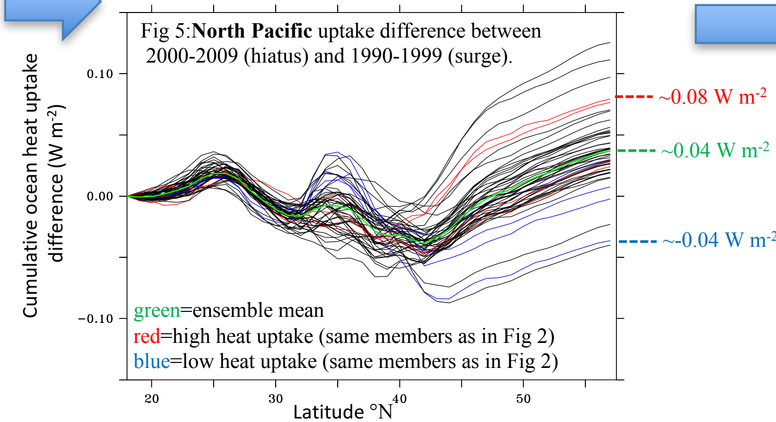


Fig 5:**North Pacific** uptake difference between 2000-2009 (hiatus) and 1990-1999 (surge).

(6) Associated spatial patterns in heat uptake show a North-South dipole like pattern. Similar patterns in SST and SSH indicate a link to the strength of the Kuroshio current and its extension.

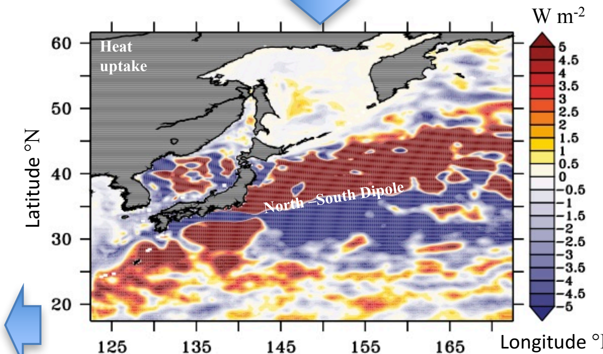
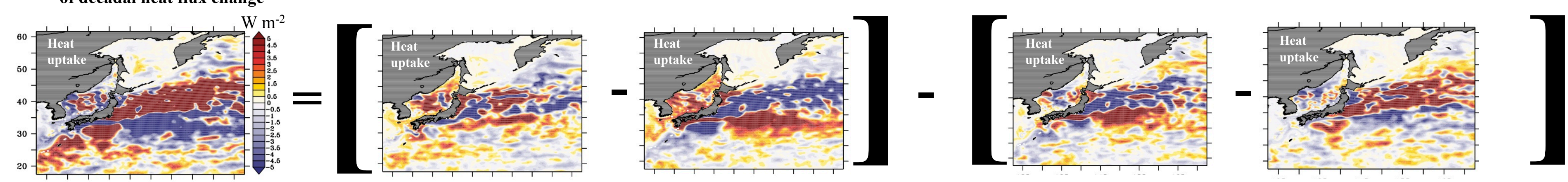


Fig 6: Decadal difference in air sea heat flux: average HIGH minus average LOW

(7) We are looking at the influence of intrinsic variability (difference between ensemble members) on decadal variability (difference between decades). Accordingly we split Fig 6 into four contributions: the HIGH/LOW heat uptake in each decade. Apart from HIGH in the 2000s (more on this later), the other three contributions are all dipole-like with different amplitudes, so the dipole like behaviour in Fig 6 originates from a dipole-like mode present in each decade. **It looks like the model has an intrinsic dipole-like mode of decadal variability in the Pacific similar to that observed (e. g. Schmeits and Dijkstra (2002).**

Fig 7: **Range within ensemble of decadal heat flux change** = [**HIGH (2000s)** - **HIGH (1990s)**] - [**LOW (2000s)** - **LOW (1990s)**]



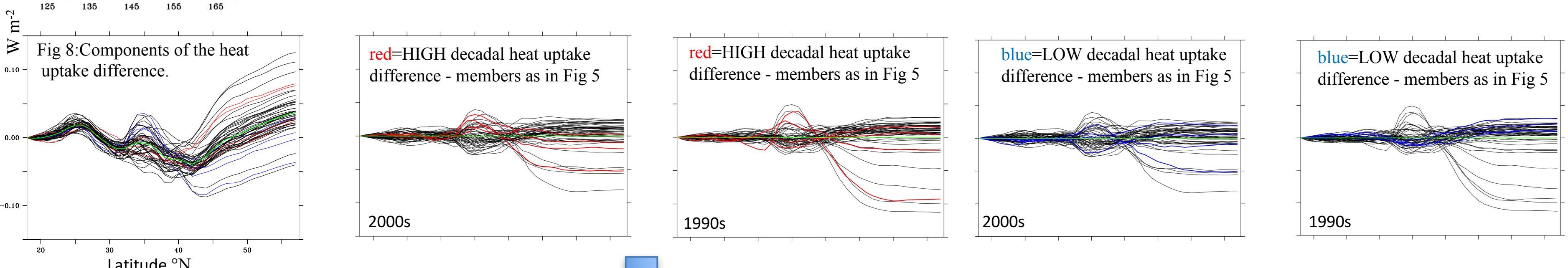
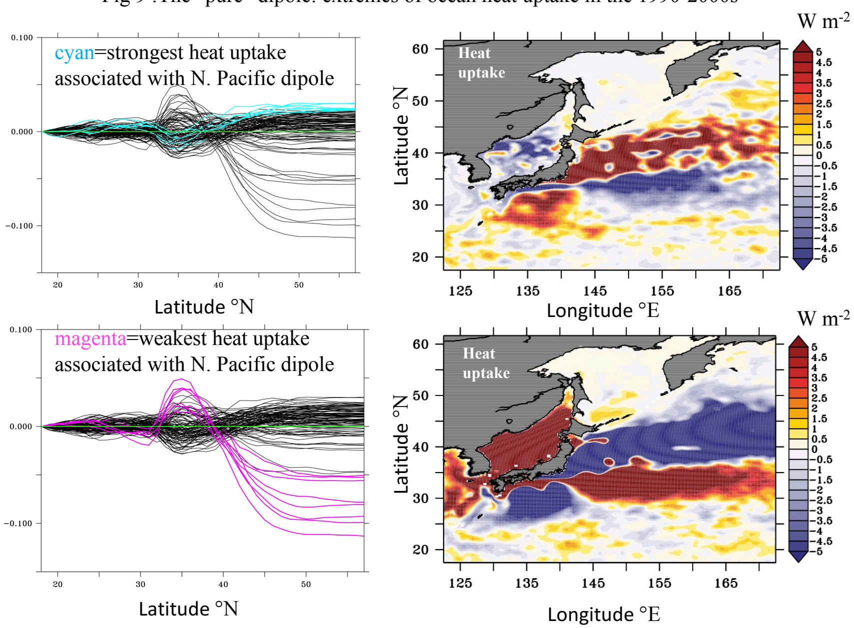


Fig 8:Components of the heat uptake difference.

(8) if we separate the heat uptake curves for each decade (heat uptake minus the ensemble mean for each decade) we see that the heat uptake distribution in each decade is skewed with most values small and positive. By contrast there are a few values which are large and negative. This is the cause of the asymmetry in Fig 5 with respect to extremes of heat uptake. Members with values close to the ensemble mean can only make large excursions to negative values, not positive ones. Paradoxically, the members labelled HIGH have negative values because HIGH refers to the decadal difference (2000s minus 1990s) which is positive, a similar argument holds for LOW.

(9) The dipole pattern becomes particularly clear if we select members to maximize and minimize the heat uptake (with respect to the ensemble mean of each decade) in both decades. This is the "pure" dipole mode and the examples in Fig 7 are combinations of these. The magnitude of the dipole is strongly asymmetrical – extreme negative heat uptake is much larger than extreme positive.

Fig 9 :The "pure" dipole: extremes of ocean heat uptake in the 1990-2000s



Conclusions

- OCCIPUT suggests the 2000s saw ocean heat uptake of +0.32 W m^{-2} compared to the 1990s shared between the tropics and the high latitudes. Intrinsic ocean variability modifies the mean ocean heat uptake change by up to 0.05 W m^{-2} or ±15%.
- The western boundary currents and the Antarctic Circumpolar Current (eddy rich regions) are responsible for the range of simulated ocean heat uptake, with the North Pacific exhibiting a particularly strong signal.
- In the North Pacific, the spatial patterns associated with extreme heat uptake differences show a dipole like pattern. Similar patterns in SST and SSH indicate a link to the strength of the Kuroshio current and its extension, similar to those previously observed.
- There is an asymmetry in the distribution of the pattern strength, with most states having weak positive amplitude, and a smaller number having large negative amplitude. The distribution, including the asymmetry remains similar from decade to decade.
- The impact of intrinsic variability on ocean heat uptake thus reflects "allowed" or "physically consistent" transitions between states in decadal timescales. These transitions are likely driven by mesoscale eddy-mean flow interaction and the mechanism requires further study.
- Since it is unlikely that intrinsic variability is coordinated across the world ocean it is possible that on rare occasions ocean heat uptake changes due to intrinsic ocean variability could exceed the values seen in the 50-member OCCIPUT ensemble.
- The large ensemble approach is a key element in this study.

References

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