The relative importance of ocean and atmosphere response to forcing in determining SST change patterns

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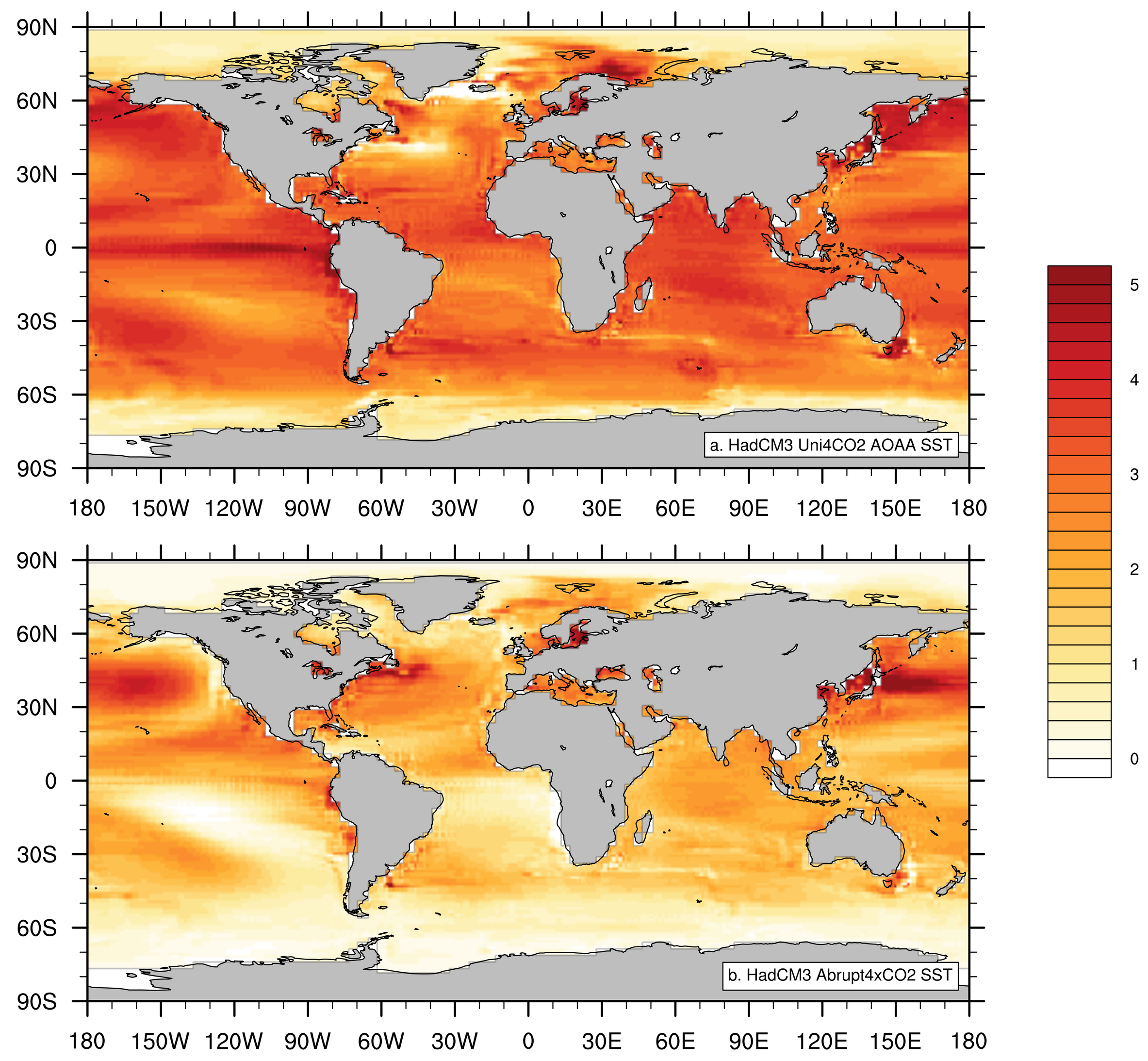
Motivation

The global-mean surface temperature change T(K), computed with respect to the pre-industrial value, is commonly used to monitor the response in climate model simulations. Despite the importance of the global-mean temperature change, response patterns matter more because local climate change is what causes the biggest impacts on people and ecosystems. Furthermore, surface temperature change patterns determine the effective climate sensitivity through the pattern effect [2]. Considering a specific forcing agent F, a simple global-mean energy balance can be written as $N = \bar{F} - \alpha\, T$, where N is the net downward radiation into the climate system, and α (W m^{-2} K^{-1}) is the climate feedback parameter. This energy balance deals with variables as global quantities, and it is not satisfactory for two main reasons.

- α can depend on the geographical pattern of the response, which in turn depends on the forcing agent [6].
- α changes over time with changing forcing [4], but it can also change over time with constant forcing [1].

We seek here to explain the SST response patterns to forcing. In the plot, panel a shows the time-mean SST change in the fifth decade of an AOGCM run in which a constant *spatially uniform* heat flux forcing, equal to the global-mean abrupt4xCO_2 forcing, is applied at the sea surface. Panel b shows instead the fifth-decade mean SST response for abrupt4xCO_2 forcing. The two panels are quite similar, indicating that the pattern of response is mainly not determined by the pattern of the forcing.

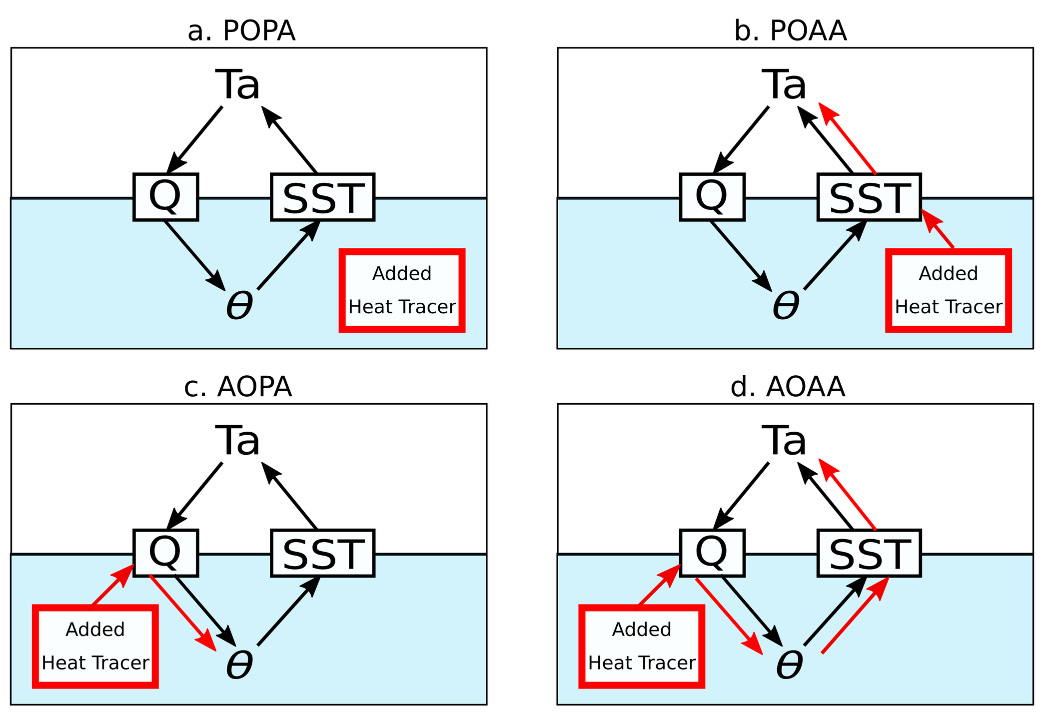


Modelling Setup

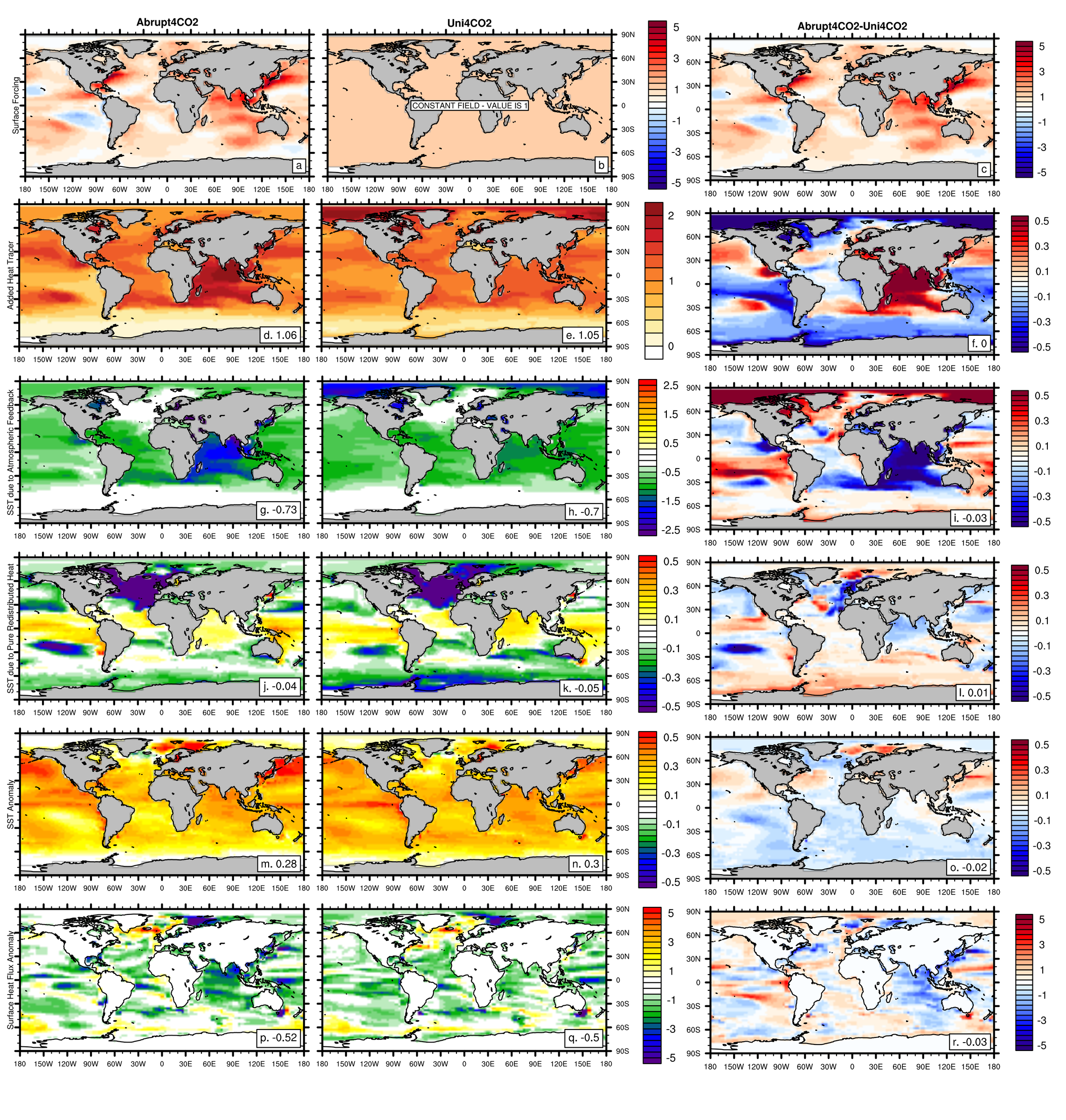
We employed the coupled atmosphere-ocean model HadCM3 [3]. We show here two types of forcing: Abrupt (realistic) and Uni (uniform), taken from the surface response pattern of an abrupt4xCO_2 simulation. Four types of experiments are performed, according to the way each component reacts to the "added heat" tracer [5], which is injected in the top ocean layer.

The added heat may be either a passive tracer in the ocean (PO), or treated as "active" heat which changes the ocean temperature and causes dynamical ocean response (AO). The added heat may either be invisible to the atmosphere (PA), or it may be included in the SST to which the atmosphere responds (AA). See the plot for details. All experiments are compared with the control climate, and are all 50 years long.

To analyse the SST response to a specific forcing, we are mainly looking at: SST change due to the added tracer, SST change due to pure redistribution of heat by the ocean (arising from changes in transport processes stimulated by the added heat), SST change due to atmospheric feedback (whose surface flux is the difference between the actual net surface heat flux and its unperturbed climatological mean), and net SST change.

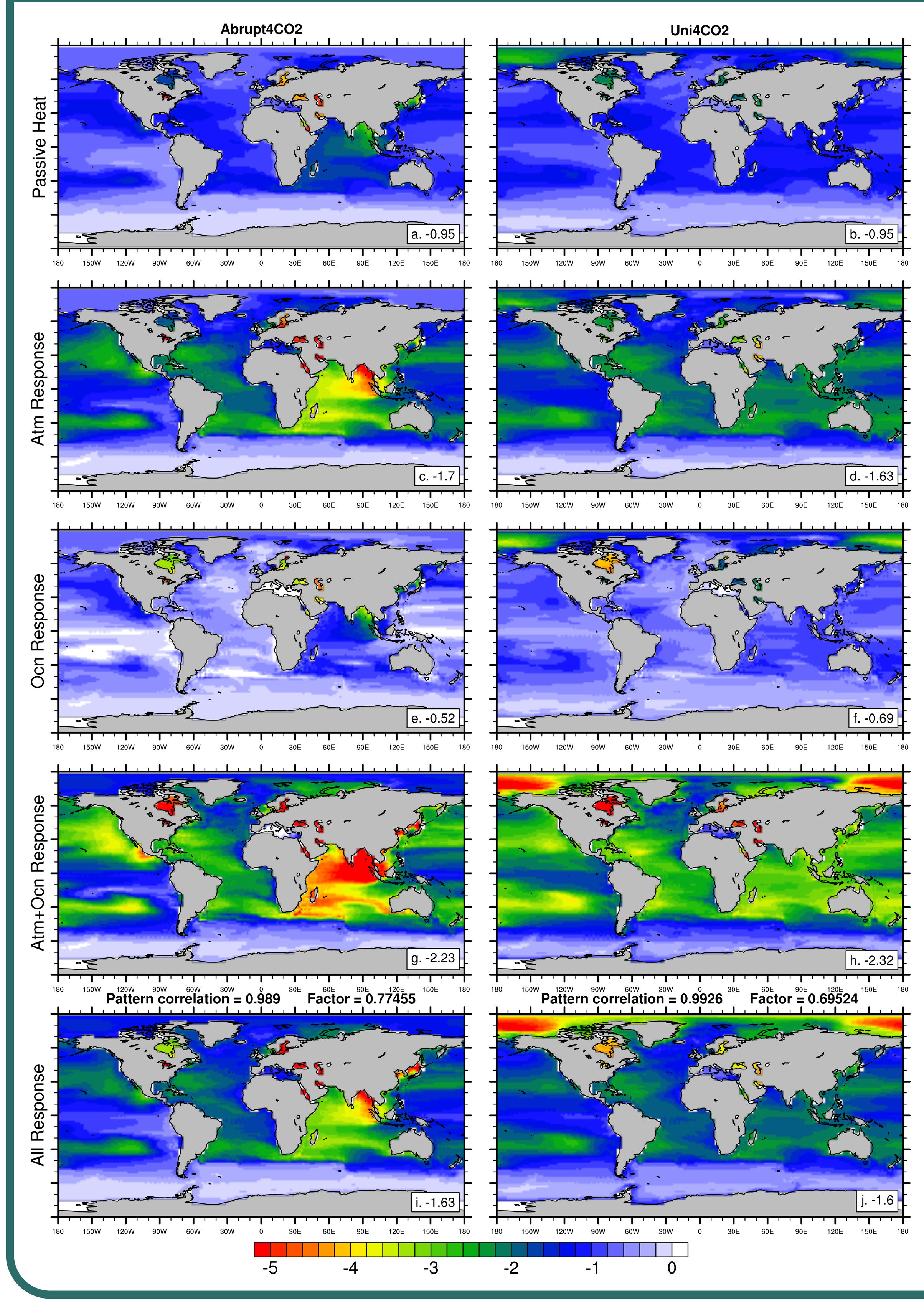


Surface Response Patterns



Response patterns for fully-coupled Abrupt and Uni experiments (AOAA), with their respective difference. All fields are divided by the global-mean surface forcing. The plot shows surface forcing, added tracer, pure redistributed heat, atmospheric feedback, SST change and surface heat flux change with respect to the control run.

Linear Combination of SST Response Patterns



We can understand the role of atmosphere and ocean on setting the SST response by combining quantities from the different model configurations we introduced.

- The change in SST due to the addition of heat as a passive tracer (in the POPA run, shown in the top row with its sign reversed).
- The atmosphere response (second row) can be defined as the SST change in the atmospheric-only run (POAA) minus the passive SST change (POPA).
- The ocean response (third row) can be defined as the SST change in the ocean-only run (AOPA) minus the passive SST change (POPA).
- The coupled response (bottom row) can be defined as the SST change in the atmosphere-ocean fully-coupled run (AOAA) minus the passive SST change (POPA), or as the sum (fourth row) of atmosphere and ocean responses.

Atmosphere and ocean responses combine linearly regarding their patterns, but not regarding their global means.

References

[1] Andrews, T., et al. (2012). doi: 10.1029/2012GL051607.
[2] Andrews, T. et al. (2015). doi: 10.1175/JCLI-D-14-00545.1.
[3] Gordon, C., et al. (2000). doi: 10.1007/s003820050010.
[4] Gregory, J.M., et al. (2015). doi: 10.1098/rsta.2014.0417.
[5] Gregory, J.M., et al. (2016). doi: 10.5194/gmd-9-3993-2016.
[6] Marvel, K., et al. (2015). doi: 10.1038/nclimate2888.

Conclusions

- The forcing pattern has little effect on the SST change pattern, which does not resemble the surface heat flux change pattern either.
- The added heat tracer tends to get concentrated by ocean transport processes in the mid-latitude ocean gyres.
- That is resisted by atmospheric feedback and ocean heat redistribution, which give SST patterns that combine linearly.