The effects of *rotation* and *salinity* on exoplanet oceans

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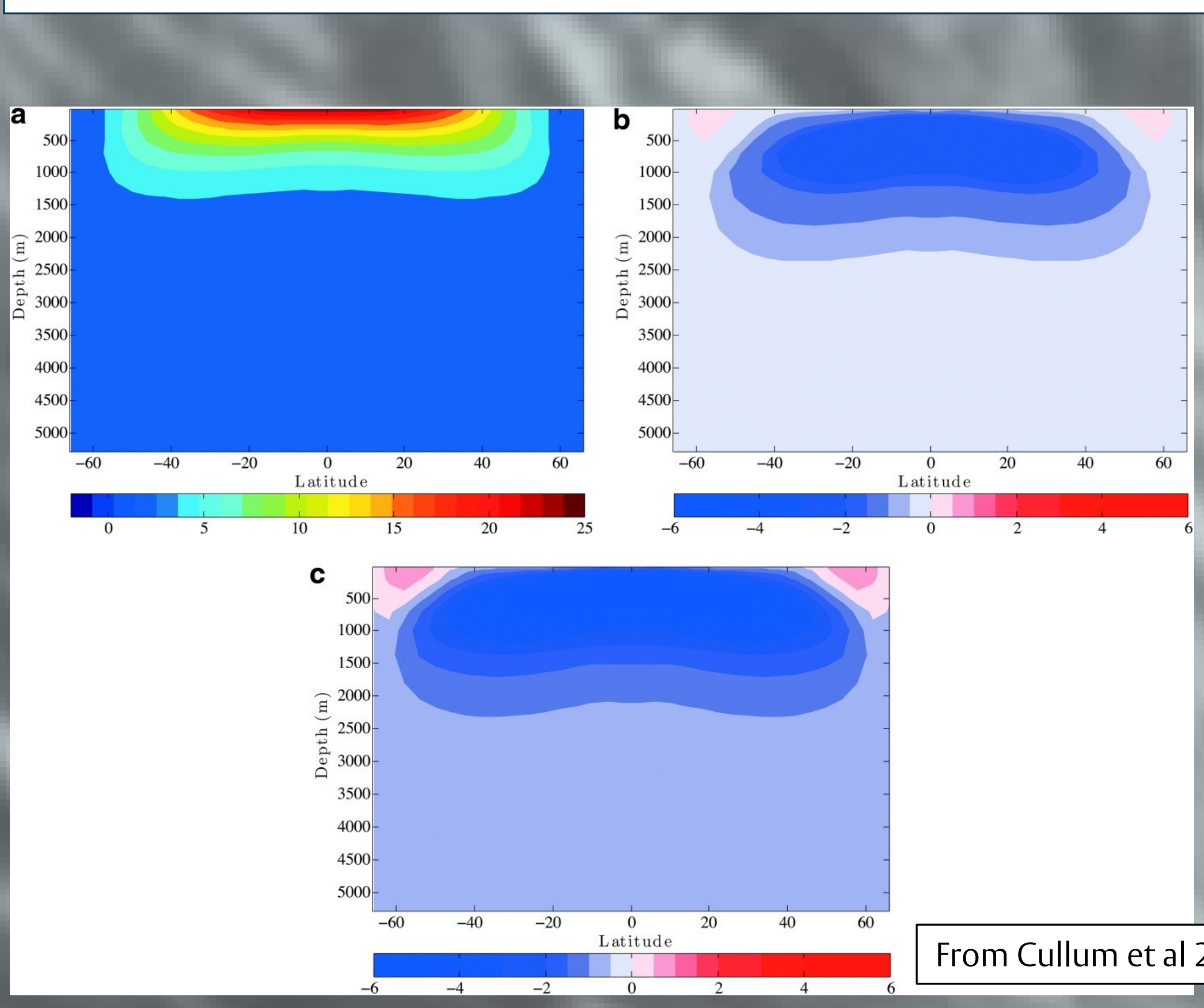
Introduction

- The world's oceans play a huge role in governing climate through transporting heat globally- and through playing an important role in the carbon cycle over timescales of thousands of years
- Most previous studies of exoplanetary climate have varied parameters in the atmosphere, and/or assumed that exoplanet oceans have similar properties to those of Earth (e.g. Del Genio and Suozzo 2009, Hu and Yang 2013)
- Here we demonstrate the effects of changing two basic parameters, planetary rotation rate and ocean salinity, in two models: a simple two-box model of the ocean, and a more complex three-dimensional ocean circulation model having a horizontal resolution of 4º

Planetary Rotation

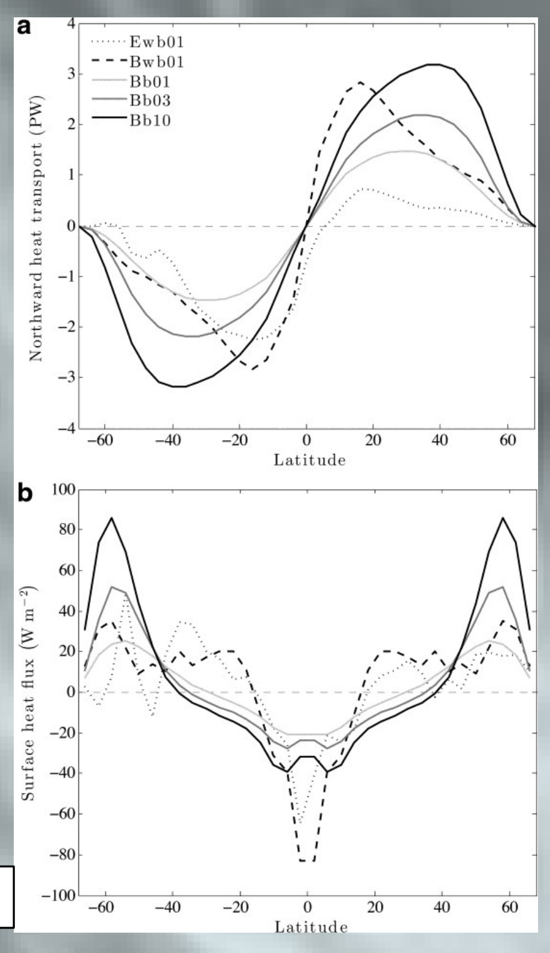
- Experiments conducted with OGCM (see below)
- Increasing rotation period from 1 day to 3 or 10 days cools so-called thermocline in the upper tropical and subtropical ocean and shallows it
- Impact on ocean structure could also play a role on carbon cycle on some timescales
- Ocean with simple barrier has strong poleward heat fluxes (see below right)
- Increasing rotation period increases poleward heat fluxes: this implies smaller tropical-polar temperature gradients
- Potential effects include a wider habitable zone due to slightly cooler tropics (water escape from atmosphere may be triggered at higher stellar flux) and warmer polar regions (glaciation from feedbacks triggered at lower stellar flux)
- Wind forcing neglected here: but effects could amplify the effects shown here
- See Cullum et al (2014) for more details



From Cullum et al 2014

(a) Zonally averaged temperature (°C) with 1-day rotation period and no wind forcing in the OGCM

(b, c), The difference in the zonally averaged temperature (°C) for a planet with no wind forcing, from a 1- to 3-day rotation period and a 10-day rotation period, respectively



(a) Northward ocean heat transport (PW) for Earth configuration (Ewb01) of OGCM, 'barrier' at a 1-day rotation period with wind forcing (Bwb01) and with no wind forcing (Bb01), solely buoyancy-forced 'barrier' with 3-day rotation period (Bb03) and 10-day rotation period (Bb10).

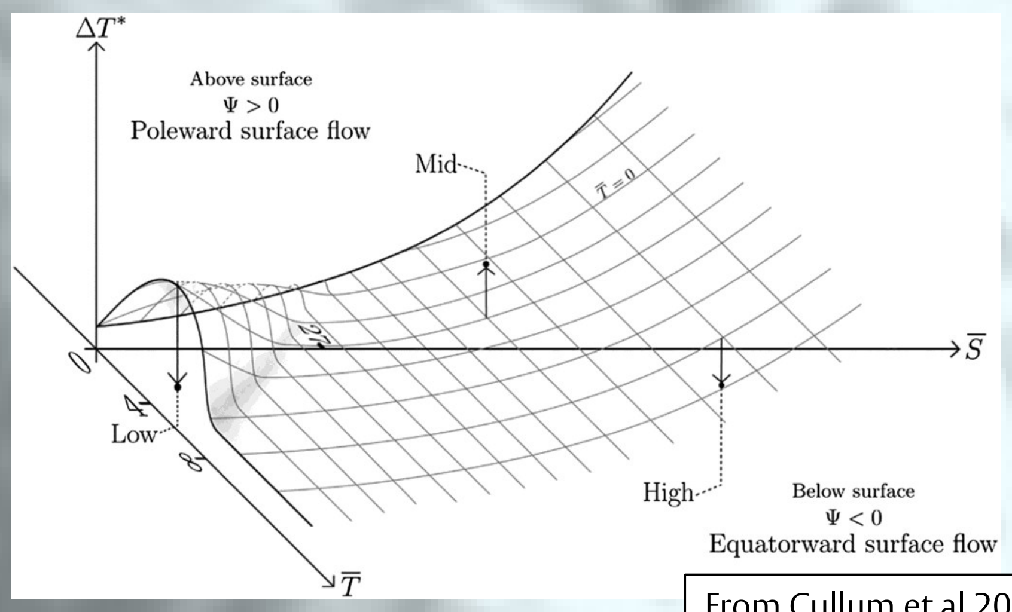
(b) Zonally averaged surface heat flux (W m−2) for each of the configurations, using the same run notations as in (a). Positive heat flux is from the ocean to the atmosphere.

Experimental Set-up

- The "box model" simulates exchange of heat and salt between two boxes forced by different values of temperature and salinity (e.g. Stommel 1961)
- The circulation model is based on MOMA (Webb, 1996) and solves the so-called primitive equations on a sphere. Such a set-up is commonly used for process studies of the Earth's ocean circulation
- The model has one meridional (North-South) barrier, allowing the circulation to form gyres: this is the simplest representation of the effect of ocean bathymetry
- The model is run with and without the effect of atmospheric wind stress, which can have a significant effect on the ocean circulation
- Other parameters such as ocean depth are as Earth

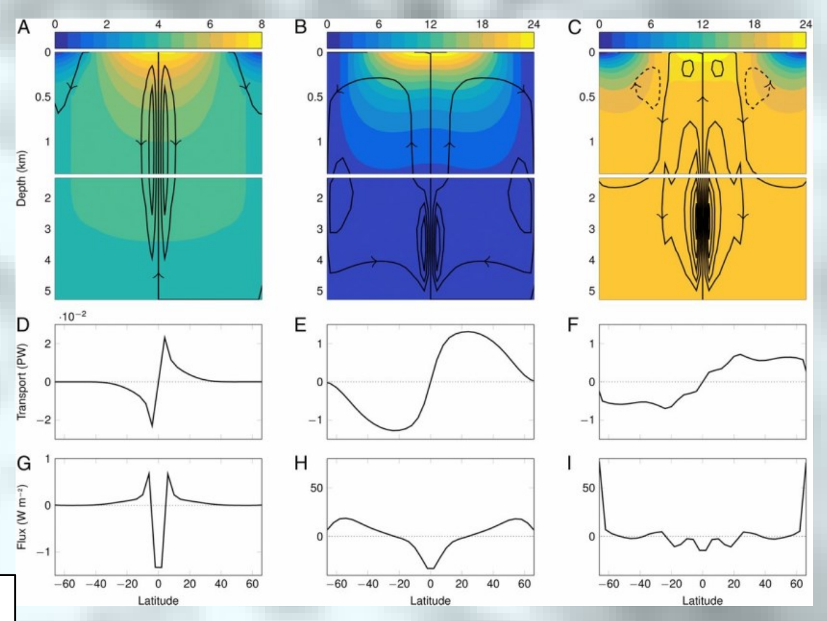
Ocean Salinity

- Present-day Earth has a meridional ocean circulation which consists of poleward motion at surface with return flow at depth
- Density gradients crucial in maintaining this, but ocean density depends on both temperature and salinity
- Experiments with box model (see below left) and 3D OGCM (below right)
- When salinity high (7x present-day Earth's oceans, or similar to Dead Sea), circulation reverses- deep ocean fills up with warm subtropical water
- Polar oceans warm up: again potentially wider habitable zone
- Similar reversal can happen when temperature gradients small and ocean is completely fresh (fresh water has maximum density at ≈4ºC)
- See Cullum et al (2016) for more details



From Cullum et al 2016

Schematic illustrating the direction and magnitude of the overturning circulation, Ψ, from the box model. The behaviour depends on the values of temperature gradient forcing ΔT*, the mean temperature T, and mean salinity S. The proportionality between the salinity gradient forcing ΔS* and S means the two values do not need separate consideration, whereas ΔT* and T can be varied independently. Note the lower limit of T decreases as S increases and lowers the freezing point. Values lying on the surface have zero circulation Ψ=0; those above and below have positive and negative circulation, respectively, with increasing magnitude with increasing distance from the surface. The values defining the low-salinity, low-temperature range are indicated; 0–8 °C and 0–27 g·kg−1, with the local maximum at T = 4 °C, S = 0 g·kg−1. The locations of the low, mid-, and high salinity ranges considered in this study are indicated in reference to the surface. The curvature of the surface results from the nonlinear dependence of density on temperature and salinity.



Plots showing the results from the OGCM for the freshwater (A, D, and G), mid- (B, E, and H), and high (C, F, and I) range salinity scenarios with the inclusion of wind forcing. (A–C) Black contours of the overturning streamfunction Ψ show the structure of the meridional overturning circulation through the depth of the ocean; the contour interval is 20 Sv (=106 m3·s−1). Note the different depth scales. The colour shading in A–C shows the zonally averaged temperature (°C); note the different scale in A. (D–F) Northward ocean heat transport (PW = 1015 W). (G–I) Surface heat flux (W·m−2); positive values are from ocean to atmosphere

Conclusions and Future work

- Rotation rate and salinity play an important role in ocean circulation, ocean structure and heat transport
- Future work can include investigating other parameters such as coupled ocean-atmospheric processes and ocean eddies

Acknowledgements

- JC is funded by a UK EPSRC PhD studentship

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