The exact heat distribution depends critically on the nature of the ocean mixing and dissipative heat transfer. A new Energy-balance model is presented, to describe the 2D heat transfer and dissipation of tidally generated energy within a hypothesized ocean. On such planets, the climate will be dominated by the nature of the ocean, which is currently poorly understood.

The vast heat distribution depends critically on the nature of the ocean mixing and dissipative mechanisms. For an air-liquid phase transition to exist, a high albedo and hence cloud cover is required. The cloud cover and albedo are hence modelled for two cases: that of a Neptune-like H2/He (H2/He = 2) atmosphere, and that of a CO2-dominated super-Earth. We show that it would be possible to infer ocean state such as composition, e.g. from heat transport and cloud cover.

Ocean Planets

Ocean planets are earth-like planets with high water content (eg 50 %) such that no continents are present. The oceans may be 100 km deep, on circulation and life if present. We can make terminator in a high-pressure ice mantle. Their first estimate of the composition by referring geophysical cycles are as yet unknown. With different sea waters in soda brines (eg Keppe no land present there will be no weathering, no et al, 2030) paleo-Earth, paleo-Mars (eg Iaffen carbonate-silicate cycle to control atmospheric et al (2008) and Escucelis’ plumes (Porco et al) the water can be treated as Earth-like with different salinities. These will have a formidable effect. For life to be present, minerals would be required effects on the circulation: the mixing of water near the surface in the photic zone. So is there bodies of different salinity leads to thermohaline a deep circulation to bring minerals up from the effects, cabelling, diffusion, etc. which deep, or will precipitate out to leave a sterile can have detectable effects on the changes in surface? oceans dominate the climate. Here we start it may be possible to infer the water composition modelling exoplanet oceans, on concentrating on from observable climate consequences.

their observable effects on the atmosphere: heat distribution and clouds.

Tidally-driven Circulation

Unlike the atmosphere, Earth’s ocean circulation is not a heat engine. It is driven instead by:

- Solar heating
- Tidal forcing
- Inertial (Coriolis) forces
- Buoyancy differences due to heat and salinity differentials, at the poles, cold, salty water

Tidal forces drive the circulation by mixing water masses: without mixing the water becomes stratified and sinking stops when it meets an intermediate layer of the same density. This happens in the North Pacific, for example, while well-mixed layers in the Atlantic allow water to sink to the bottom. But this is tidal mixing sufficient on oceans planets to create a deep circulation?

Secondly, the direction of circulation on Earth is driven by topography as westerly-driven currents hit continental block boundaries; mixing is dominated by internal waves on the bottom topography. Since ocean planets lack these features, tidally-driven mixing and buoyancy will drive the circulation pattern and hence heat transport. So determining the mixing mechanism is interesting.

Rosby-waves are planetary-scale inertial waves. Tyler (2008) showed that these can be driven by obliquity tidal interactions; while ocean tides on Earth were believed to be damped by interannual with faster gravity-waves, Tyler showed that Rosby-Haurwitz waves with no vertical extent (and hence no gravitational interaction) would not be damped but could be forced by obliquity tides. To date, nobody has yet modelled the actual circulation expected. Such modelling is the next generation goal.

Maximum Entropy Production Principle

In 1975, Paradee hypothesized that climate are a state of Maximum Entropy production. The principle has been shown to be true of many different climate systems (See Ozawa (2003) for a review. By requiring MEP to hold we can test if a heat distribution is physical.

Cloud cover

The presence of cloud cover is critical to the existence of an ocean. Bond Albedo can vary from 0.05 to 0.75. A high albedo can reduce stellar heating of the point where an ocean can condense. Alternatively the lack of clouds on the dark-side of the planet can help cooling. However the presence and location of clouds will depend sensitively on convection and upwelling of water vapour from the ocean, which can depend on the location of ocean heating by tidal mixing.

The Model

CEO is modelled on a 2-D energy balance model for tidally locked planets. It’s main components are:

- Atmospheric & ocean thermodynamics are based on Kitzmann (2007). This follows the moist adiabat down from a known (or guessed) photospheric (p,T) until the mixing ratio intersects the ocean floor, if present. This is re-formulated based on enthalpy to avoid singularities in heat flow at critical points.
- Energy input is both from stellar radiation and tidal heating
- Heat flow (zonal and radiative-correction)

Dissipation of tidal energy is then calculated for different ocean mixing parameterisations, resulting in a planetary heat and cloud cover map.

The calculated T-P profiles show a nearly isothermal stratosphere: unlike Earth, where temperatures rise. Similar isothermal stratospheres have been seen in exoplanet models around M dwarfs before (e.g Segura 2005). The stratospheric H2O profiles then allow for the injection of considerable water high into the stratosphere.

Tidal Heating

Total tidal heating was calculated according for eccentricities < 0.27 as Parnes. In practice tidal drag is assumed to circulate the orbit to e < 0.10 in a few kyr.

Clouds:

- Clouds can be determined by (a) Albedo. Bond Albedo can vary from 0.05 (cloud free) to 0.75 (Vein-like). This is potently detectable, depending no instrument. Additionally clouds can present a flat, featureless emission spectrum.
- Two types of cloud may be expected: water clouds and methane-based stratospheric hazes. The latter may be seen in transit spectra (as per Titan). To distinguish between water clouds and methane or other clouds, detection of water features in 1-3 µm may be possible. Further distinction of H2O and CO2 atmosphere components would require spectral resolution of 10^4, though (Miller-Ricci, 2009).
- Given that water is heavier than H2, a H2O-dominated cloud deck in a H2 atmosphere requires significant convective energy, and hence heating from below.
- Detection of a cloud base in itself does not require a liquid-water ocean (See Wotkowycz, 2007) but with albedo constraints and water vs. Tidal dissipation parameter it should be possible to infer the presence / lack of ocean.

Future Work

The model is being tested to find the likelihood of an ocean from the observed or hypothesized heat distribution of a planet for different ocean mixing parameterisations.

A fully tidally-driven ocean general circulation model based on the MITgcm is being developed to determine the circulation on ocean planets, using GCPGU acceleration for tidal heat distribution of a planet for different ocean mixing parameterisations.