Climate Regimes: a minimal complexity model

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Goals of the Model

Model created by Kerry Emanuel and published in “A simple model of multiple climate regimes” with Journal of geophysical research, vol. 107. 2002.

Incorporate several forcings to explain:

1. Abrupt climate transitions
2. Sensitivity to orbital variations
3. Arctic cycles
4. High bottom water temperature in Eocene and late Cretaceous
5. Possible deep ocean anoxia, or extreme low oxygen content

Create a model which is sensitive to small variations but insensitive to large variations.

Climate model which possesses a limited number of possibly overlapping states is appealing.

Predominant Feedback Mechanism: Oceanic Thermohaline Circulation

Thermohaline Circulation: Ocean circulation driven by surface heat and freshwater fluxes.

No internal heat sources or sinks in the ocean. Only top surface exchange.

We need a turbulence mechanism which must:

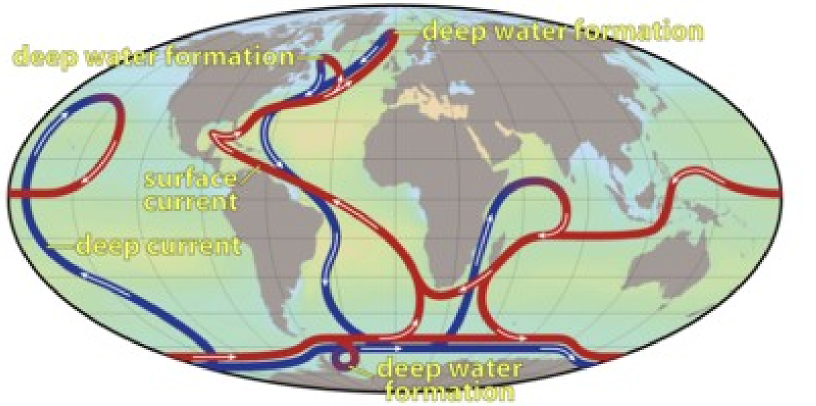
1. Occur on warm side of system
2. Interact with the surface
3. Highly localized
4. Satisfy the following accepted equation:

$$F \approx P^{2/3} B^{2/3}$$

F = lateral heat flux

P = power expended in vertical mixing

B = total buoyancy gradient at sea surface



Predominant Feedback Mechanism: Oceanic Thermohaline Circulation

Why can global tropical cyclone activity be the mechanism we are looking for?

Occurs locally on the surface of warm waters and causes vertical mixing which is vital to global ocean currents.

Liu and Fearn examined sediment cores from nearshore lakes in the Gulf of Mexico to determine when heavy storms were present.

Pro: Gives reliable data that hurricanes were present. And allows for analysis between current/recent climate and cyclones.

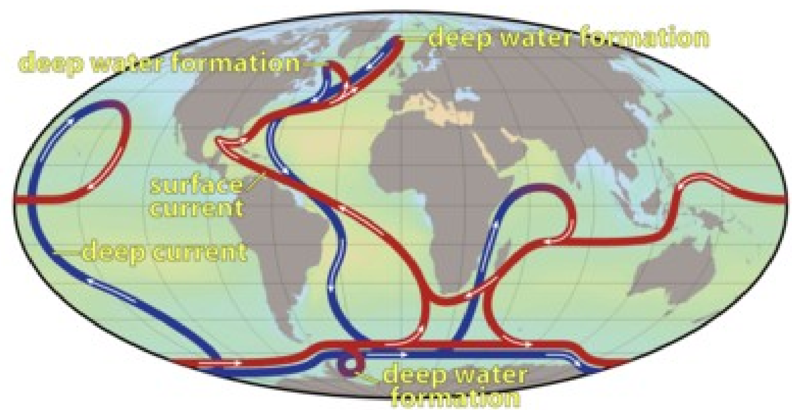
Con: data doesn’t reach back to last ice age.

Brandt and Elias show correlation between tempestite deposits and atmospheric CO_2.

Pro: shows severe storms were more frequent during warm periods of global history.

Con: weak correlation.

In short: this claim needs more evidence.

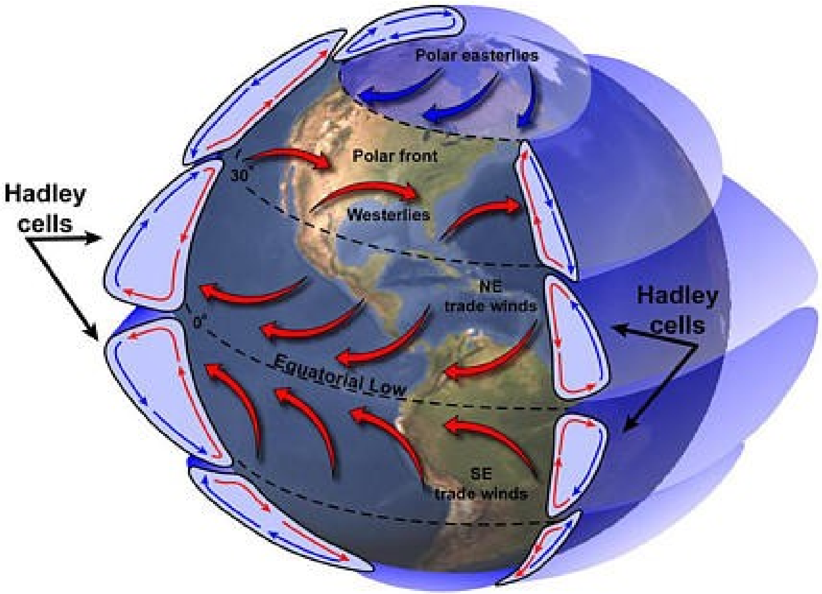


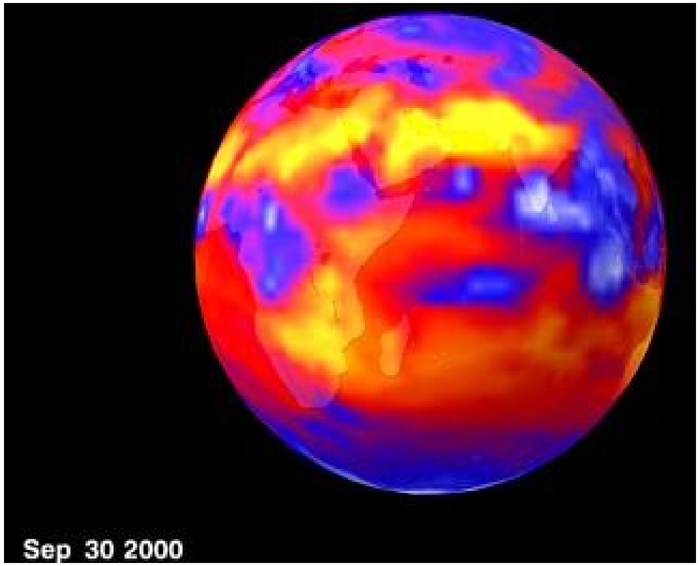
Predominant Feedback Mechanism: Greenhouse trapping and global atmosphere circulation

Greenhouse Trapping: The difference between the infrared emissions on the planet surface versus what makes it to space.

Longwave radiation leaves the planet through large-scale patches of cloud free skies primarily in the subtropics.

Interestingly- these are areas where the air is descending in Hadley and Walker Cells.

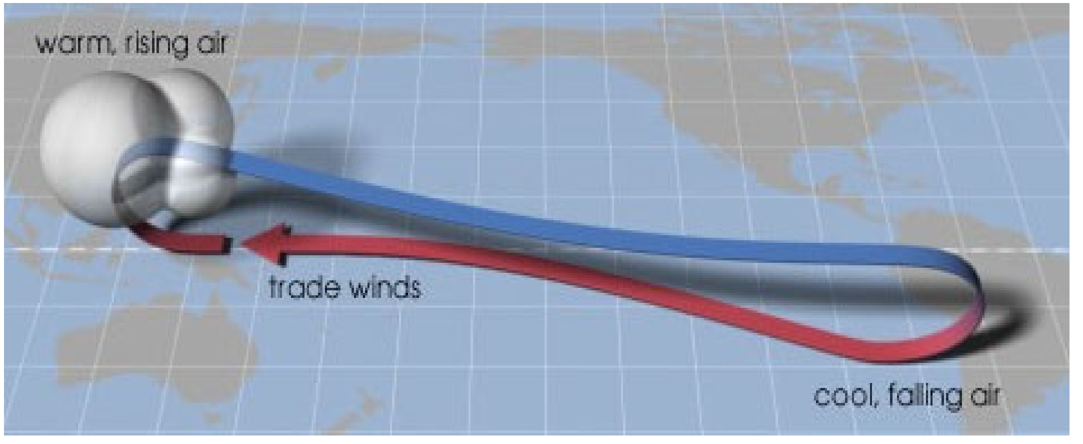




http://asd-www.larc.nasa.gov/ceres/press_releases/release_0201.html

Predominant Feedback Mechanism: Greenhouse trapping and global atmosphere circulation

Under normal conditions this descending areas are very dry because the downward flow of air inhibits deep moist convection.



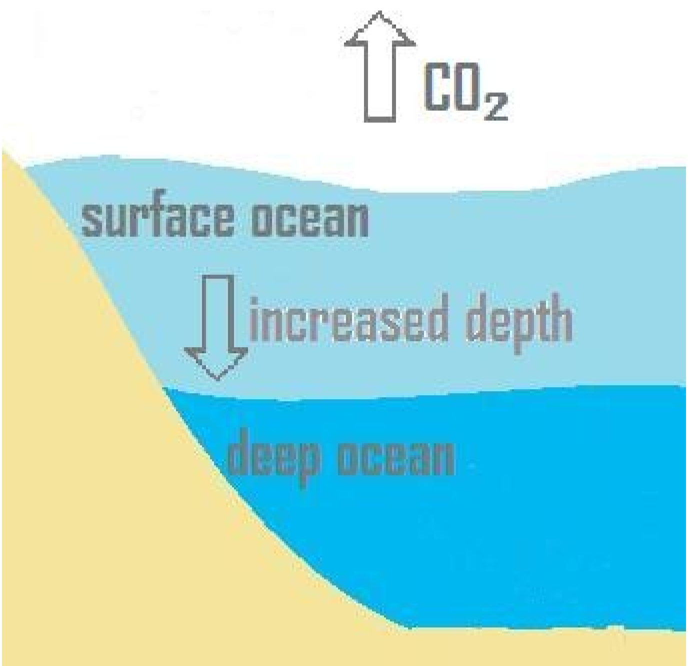
If and when the circulation slows, the areas of downward flow become more humid which decreases the amount of radiation sent into space, thereby increasing greenhouse trapping.

http://earthobservatory.nasa.gov/Features/DelicateBalance/balance3.php

Predominant Feedback Mechanism: Atmosphere CO2 and Thermohaline Circulation

Fact: CO_2 is more soluble in cold, fresh water

Changes in temperature distribution affect the balance between ocean and atmosphere.



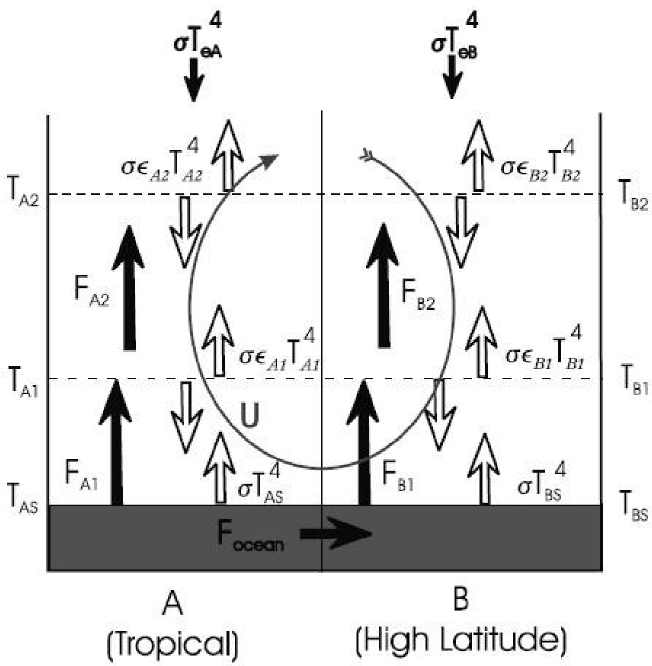
Thermocline: line between the warm top waters and the cold deep waters.

Deepening the tropical thermocline (with cyclones I presume) increases atmospheric CO_2 because more warm water will absorb less CO_2 into the ocean.

$$h \approx P^{1/3} B^{-2/3}$$

h= thermocline depth
P = power expended in vertical mixing
B = total buoyancy gradient at sea surface

Basic Model Explanation



Two-layer atmosphere and single ocean layer.

Black arrows show convective (fluid) fluxes and ocean fluxes.

White arrows show infrared fluxes.

Infrared fluxes (T with scalars ∊ and σ) carry enthalpy "up" the model.

Downward white arrows are from a forced condition which restricts the maximum enthalpy carried upwards such that temperature lapse rates are not too large.

Enthalpy: quotient of the thermodynamic energy (internal heat) of a system;

Temperature lapse: negative rate of change of the temp with respect to height in the atmosphere.

Some of the Model’s Equations

$$\frac{\partial T_{A2}}{\partial t} = -2\varepsilon_{A2}T_{A2}^4 + \varepsilon_{A2}\varepsilon_{A1}T_{A1}^4 + \varepsilon_{A2}(1-\varepsilon_{A1})T_{AS}^4 + F_{A2} \quad \text{(A1)}$$

$$\frac{\partial T_{A1}}{\partial t} = -2\varepsilon_{A1}T_{A1}^4 + \varepsilon_{A2}\varepsilon_{A1}T_{A2}^4 + \varepsilon_{A1}T_{AS}^4 + F_{A1} - F_{A2} - U(T_{A2} - T_{B1} + \Gamma) \quad \text{(A2)}$$

$$\chi\frac{\partial T_{AS}}{\partial t} = 1 + \varepsilon_{A1}T_{A1}^4 + \varepsilon_{A2}(1-\varepsilon_{A1})T_{A2}^4 - T_{AS}^4 - F_{A1} - F_O \quad \text{(A3)}$$

$$\frac{\partial T_{B2}}{\partial t} = -2\varepsilon_{B2}T_{B2}^4 + \varepsilon_{B2}\varepsilon_{B1}T_{B1}^4 + \varepsilon_{B2}(1-\varepsilon_{B1})T_{BS}^4 + F_{B2} + U(T_{A2} - T_{B2}) \quad \text{(A4)}$$

$$\frac{\partial T_{B1}}{\partial t} = -2\varepsilon_{B1}T_{B1}^4 + \varepsilon_{B2}\varepsilon_{B1}T_{B2}^4 + \varepsilon_{B1}T_{BS}^4 + F_{B1} - F_{B2} + U(T_{B2} - T_{B1} + \Gamma) \quad \text{(A5)}$$

$$\chi\frac{\partial T_{BS}}{\partial t} = T_{eB}^4 + \varepsilon_{B1}T_{B1}^4 + \varepsilon_{B2}(1-\varepsilon_{B1})T_{B2}^4 - T_{BS}^4 - F_{B1} - F_O. \quad \text{(A6)}$$

$$U = \beta(T_{A2} - T_{B2} - \Delta T_c), \quad \text{(A7)}$$

$$\varepsilon_{i,j} = 1 - e^{-CO_2 - \gamma q_{i,j}}. \quad \text{(A8)}$$

$$q_{B2} = \mathrm{H} q_{B2}^{*}(1 - aU). \quad \text{(A9)}$$

$$CO_2 = C + \lambda(T_{BS} + h(T_{AS} - T_{BS})), \quad \text{(A10)}$$

$$F_{i,j} = \beta\left(T_{i,j} - T_{i,j+1} - \Delta T_{i,j}\right), \quad \text{(A11)}$$

$$F_O = DP^{4/3}(T_{AS} - T_{BS})^{4/3}, \quad \text{(A12)}$$

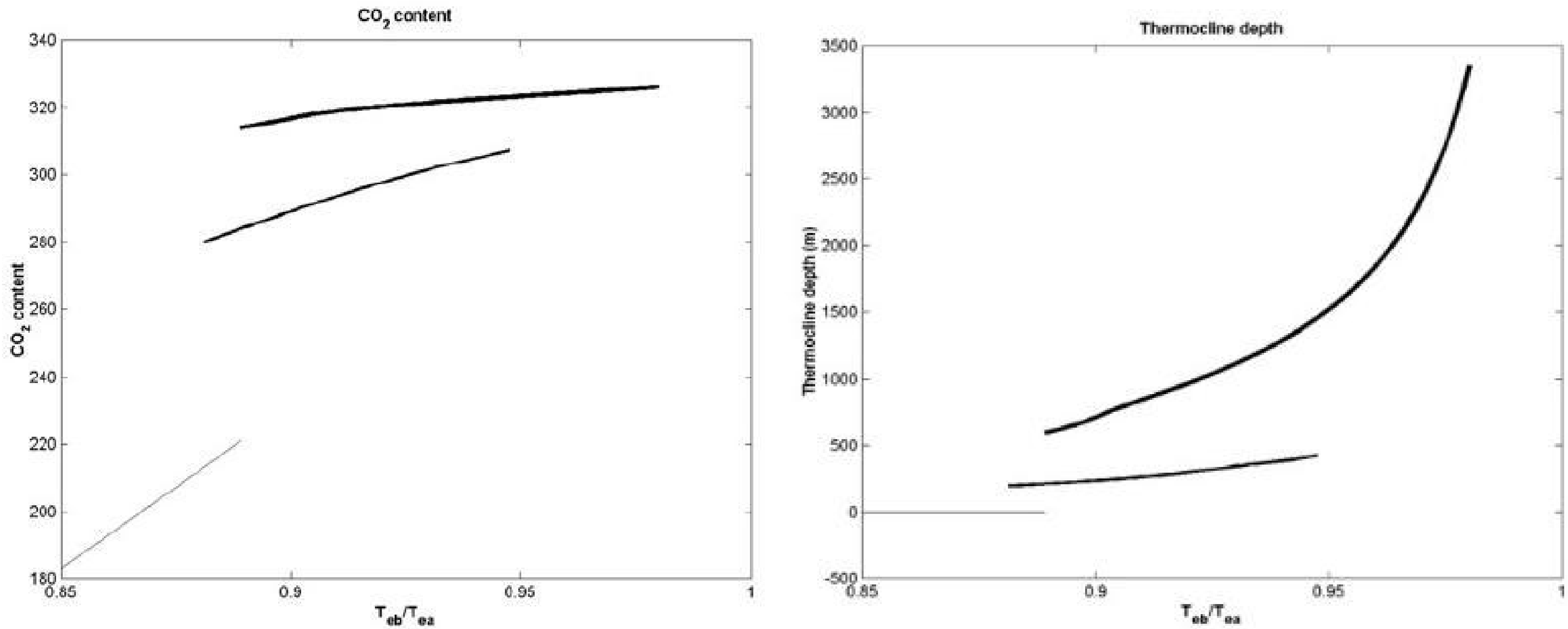
$$P^{2/3} \sim \varepsilon_T \frac{F_{A1}}{\sqrt{u_*^2 + U^2}}, \quad \text{(A13)}$$

$$h = \Lambda P^{1/3}(T_{AS} - T_{BS})^{-2/3}, \quad \text{(A14)}$$

What does it all mean?

Model's Achievements

- Multiple Overlapping Stable States as desired.



Steady equilibrium temperature as a function of CO2 content and thermocline depth

Thin line = cold regime   Medium line = moderate regime   Thick line = hot regime

"A sufficient variation of any parameter that affects the pole-to-equator temperature gradient will produce two or three regimes." pg7

Model’s Achievements

Atmospheric poleward enthalpy transport can explain early Eocene era climates.

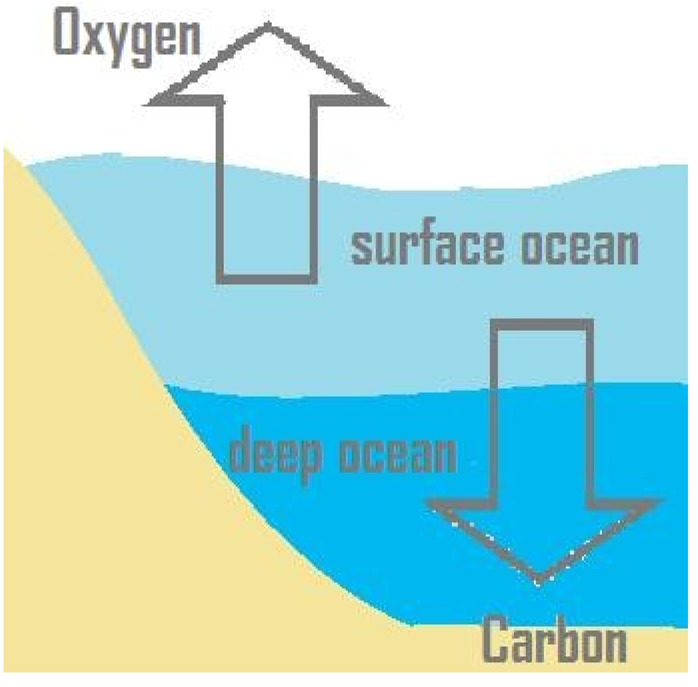
Eocene is noted for having tropical species at high latitudes and warm bottom water temps.

In a hot regime, greater hurricane activity drives a stronger poleward enthalpy flux by the oceans. This oceanic enthalpy flux is so strong it shuts down atmospheric circulation.

Shutting down atmospheric circulation would allow bottom water to warm because the enthalpy is not mixing with the atmosphere.

Model’s Achievements

The model allows for creation of anoxic , or low-oxygen, conditions in deep oceans.



In model the transition from moderate to hot stable states, the deep ocean may be isolated from the surface for at least 1 kyr.

Scientific evidence for anoxic oceans in Cretaceous period as well as the rapid climate warming and abrupt decrease in deep-sea sediment in the following Eocene period.

Also evidence in Mediterranean during the Pleistocene era.

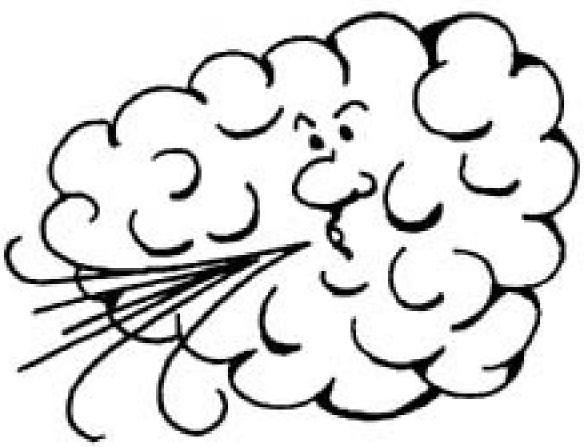
Model's Achievements

Wind speed research matches the results of this model.

Paleoclimatological evidence that average wind speeds are inversely correlated with global temperature.

Sea salt-derived chloride in ice cores suggest 50-80% greater wind speeds over North Atlantic and Southern oceans.

Evidence in model: strong changes in oceanic enthalpy transport are at least partially compensated by changes in atmospheric transport. Which is likely correlated with increased wind speeds.



What’s next for Emanuel?

1. Expanding model to have more degrees of freedom.
2. Extending the scenarios run through the model.
3. Making model more time-dependent.

Thanks!