EPS 231, Climate dynamics

Eli Tziperman; Museum bldg 456, 24 Oxford. eli@eps.harvard.edu

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Dijkstra, nonlinear physical oceanography,

Hartman, global physical climatology

Strogatz, nonlinear dynamics and chaos,

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Odyssey jupyter server account: TBA, For GCM analysis experience

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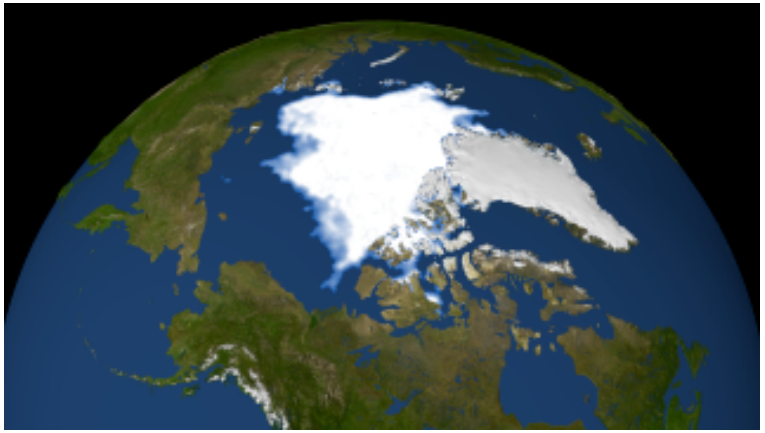
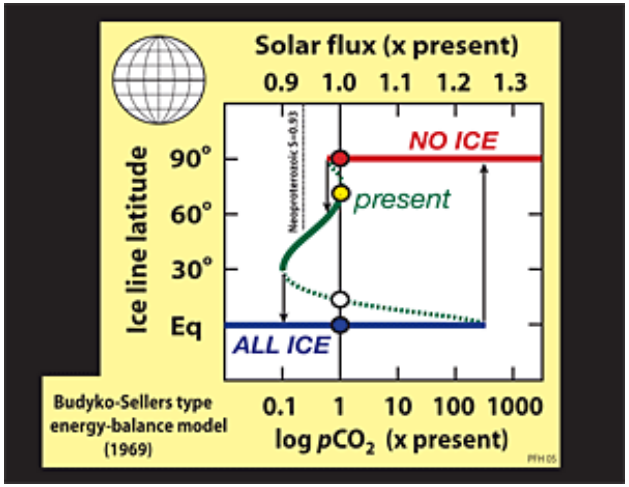
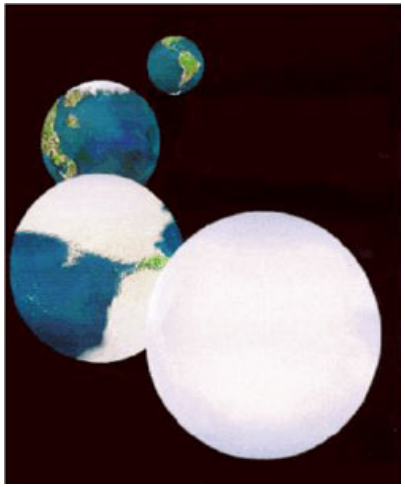
Requirements: HW every 9–10 days (50%); final project (50%)

Energy balance, greenhouse effect



NASA





snowballearth.org

Run away ice albedo, snowball events:

- Ocean frozen to a depth of ~1km, land ice-covered for Myrs
- Initiation? Termination: CO_2 emissions from volcanoes
- Predicted by Budyko-Sellers (1969) energy-balance toy model

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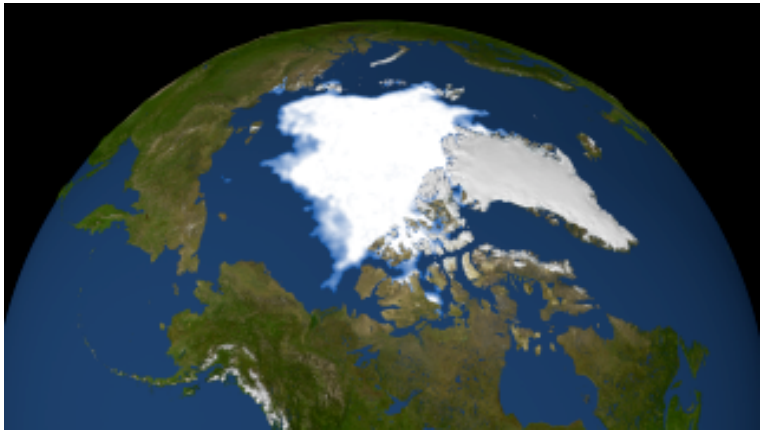

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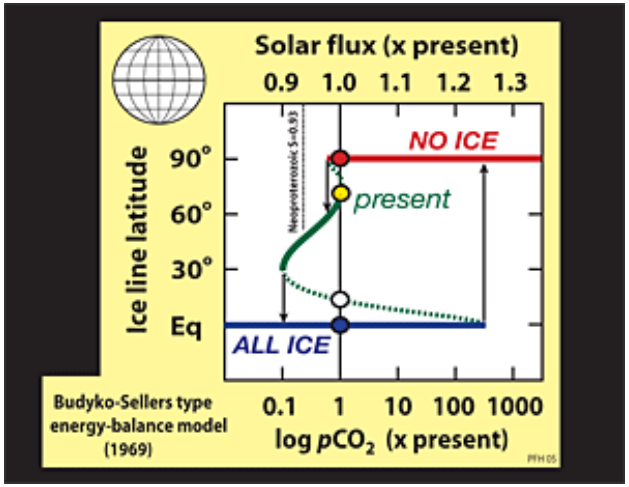

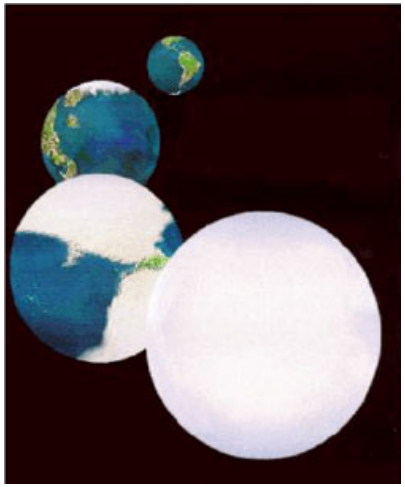

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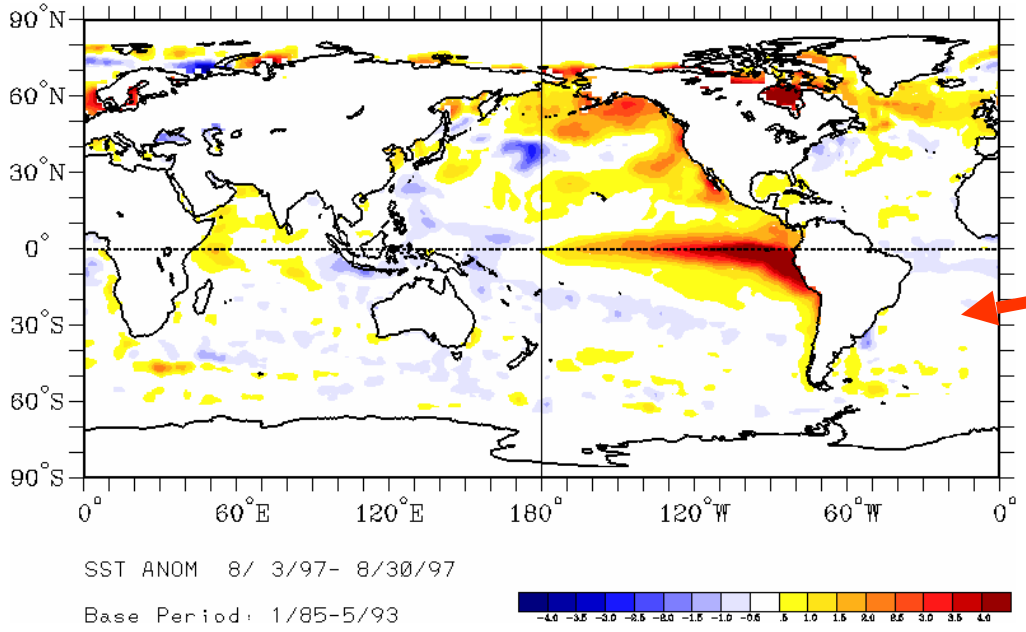
Greenhouse effect:

- 2-layer model,
- Lapse rate and changes to emission height

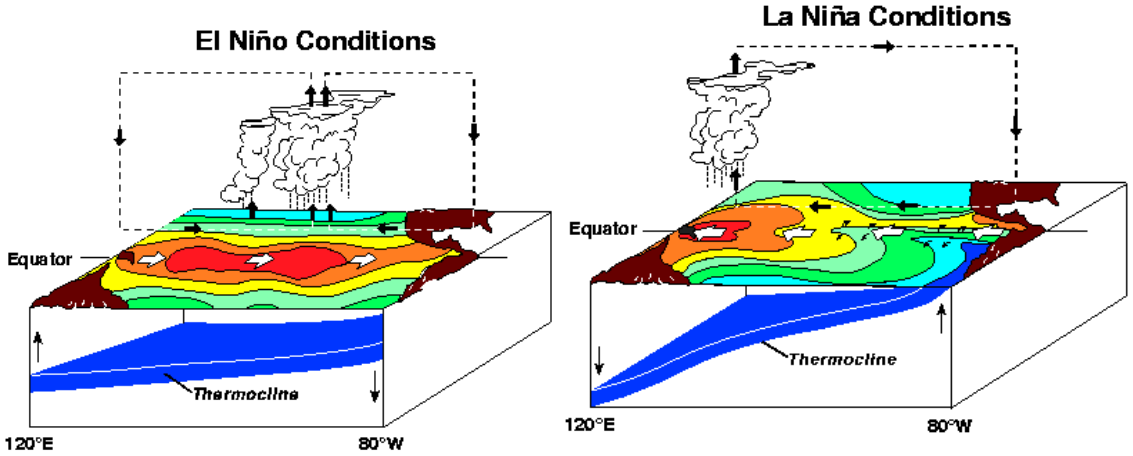
El Niño – Southern Oscillation (ENSO)

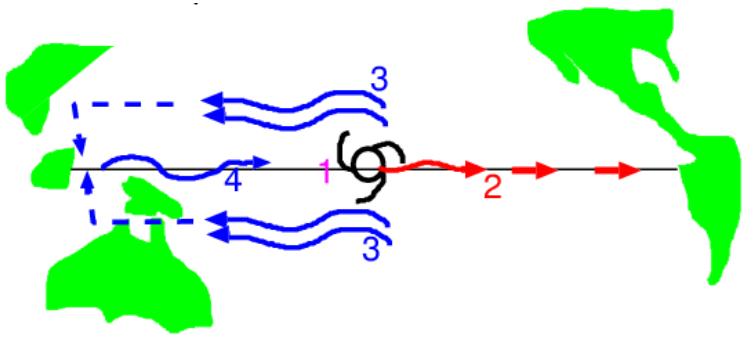


Sea surface temperature, 1997: strongest El Niño in 100 years

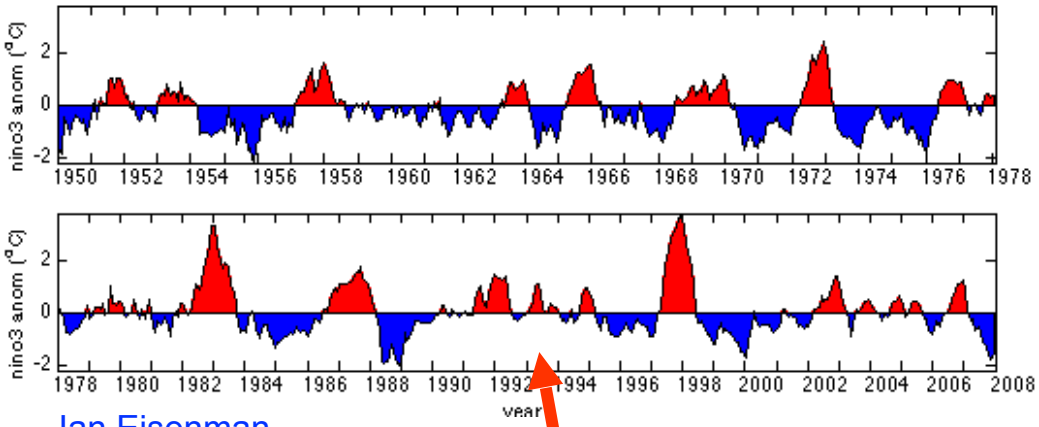
Mechanism: ocean waves, thermocline, SST; atmospheric heating, winds; & ocean-atmosphere coupling

www.pmel.noaa.gov/elnino

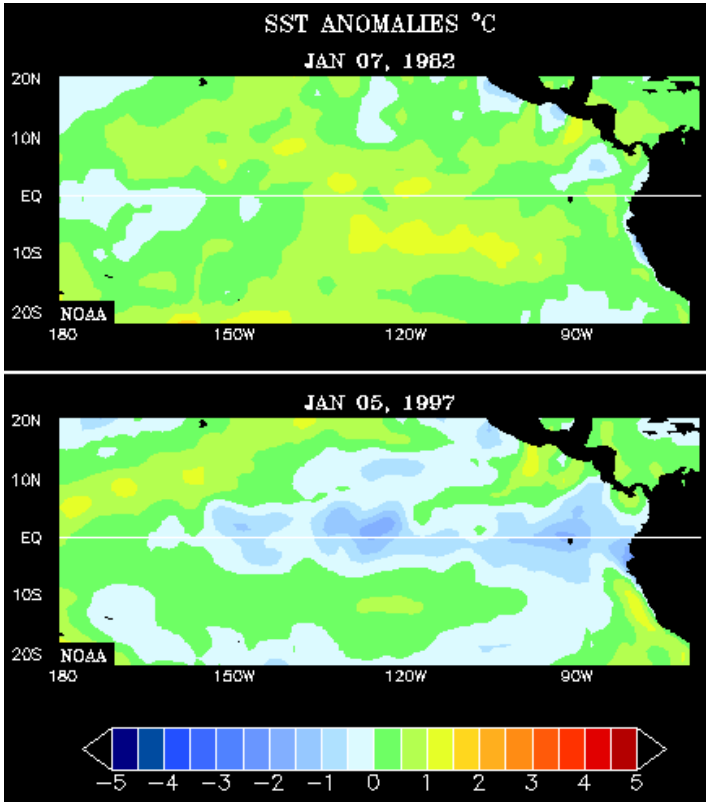




ENSO

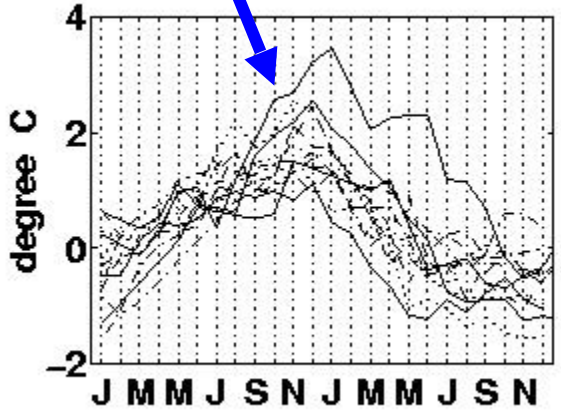


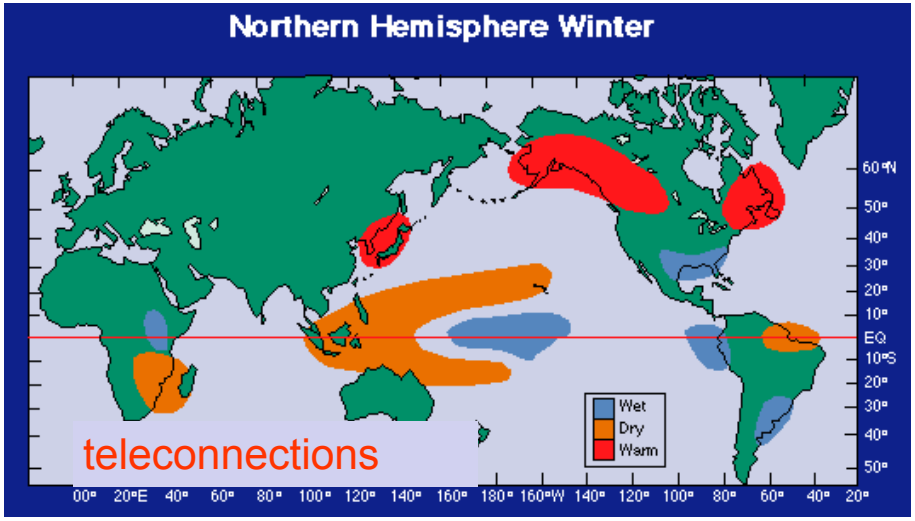
Ian Eisenman



https://psl.noaa.gov/map/clim/sst_olr/old_sst/sst_anim_2panel.shtml

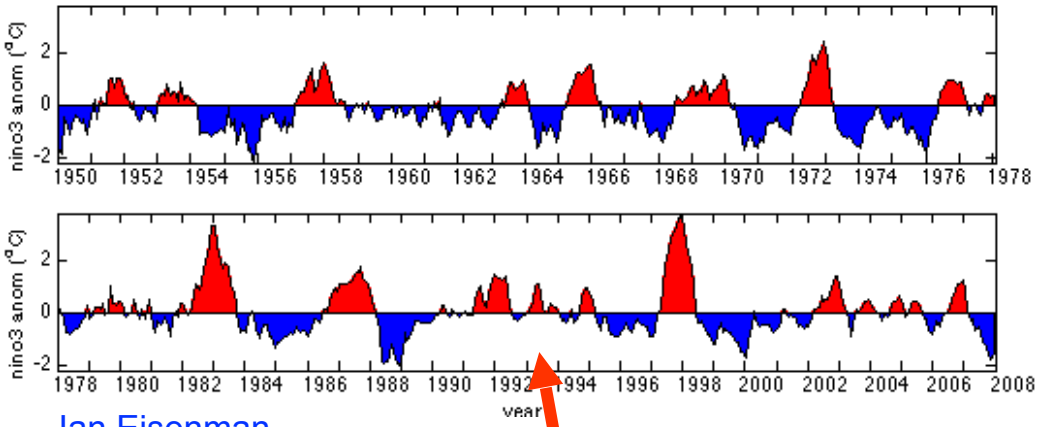
ENSO is irregular (nino3 SST), yet locked to seasonal cycle





NOAA

ENSO



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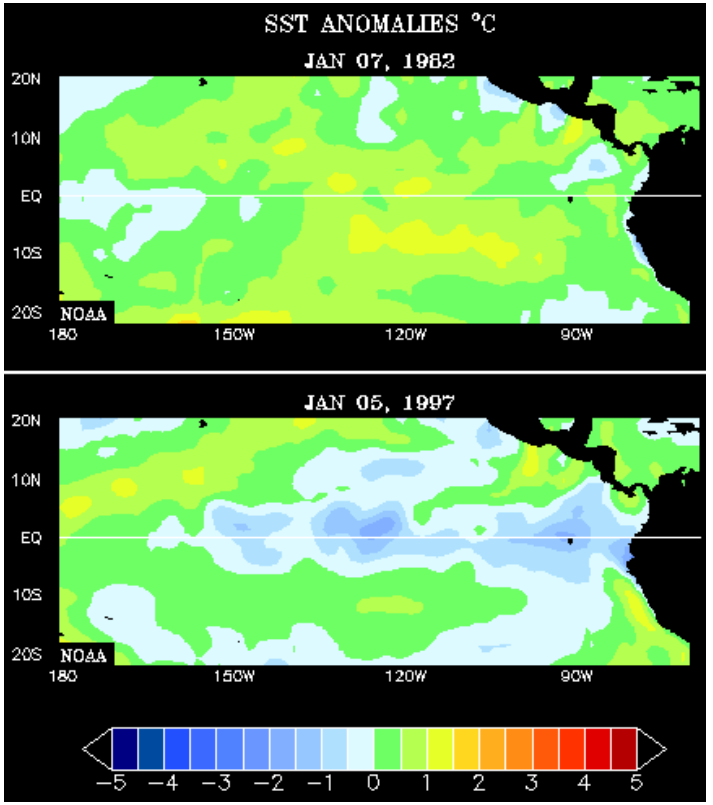

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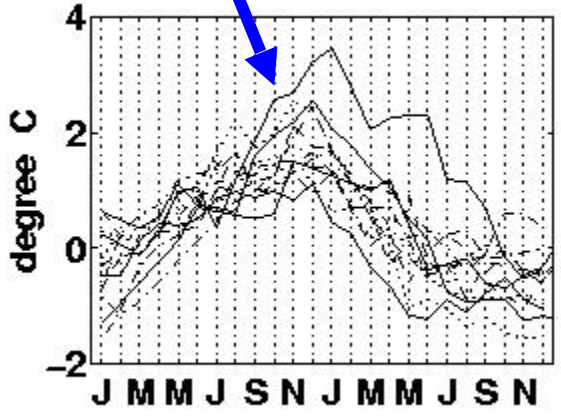
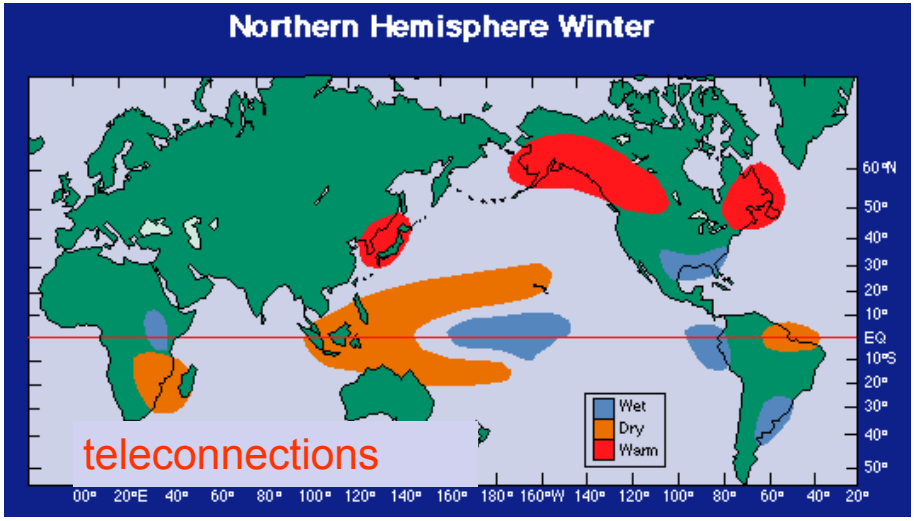
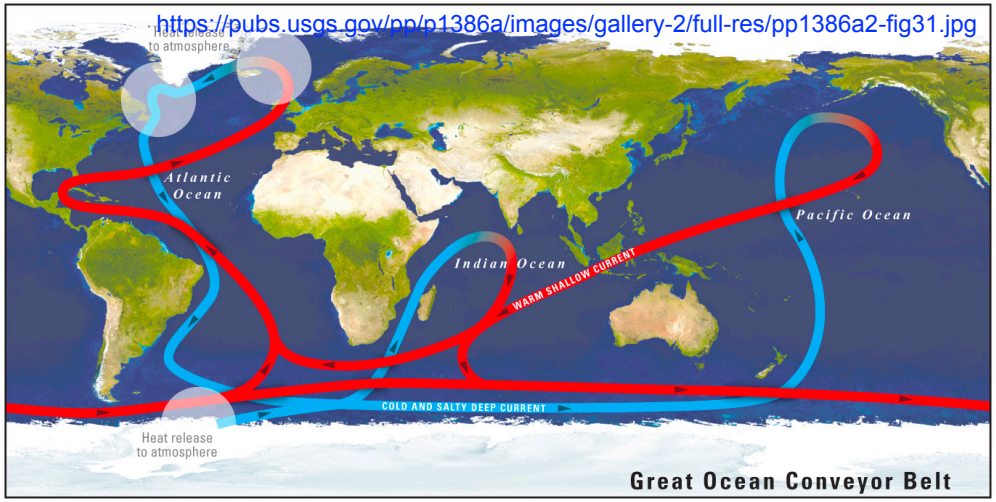




NOAA

Meridional overturning circulation (THC/MOC)

- Transport: 20 x world rivers combined. Warms Europe…?
- Driven by temperature & salinity gradients + wind + mixing + more
- Can become unstable, multiple equilibria, hysteresis, … affects climate on a hundred-year time scale



A winter scene in Europe's Little Ice Age, 14th Century Pieter Breugel the Elder.

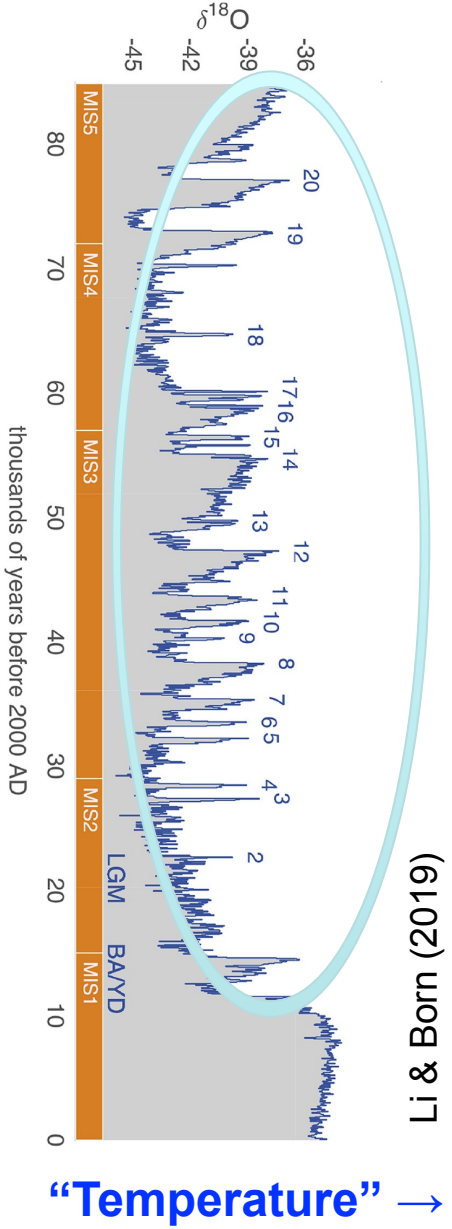
Dansgaard-Oeschger Events

DO events in Greenland ice cores:

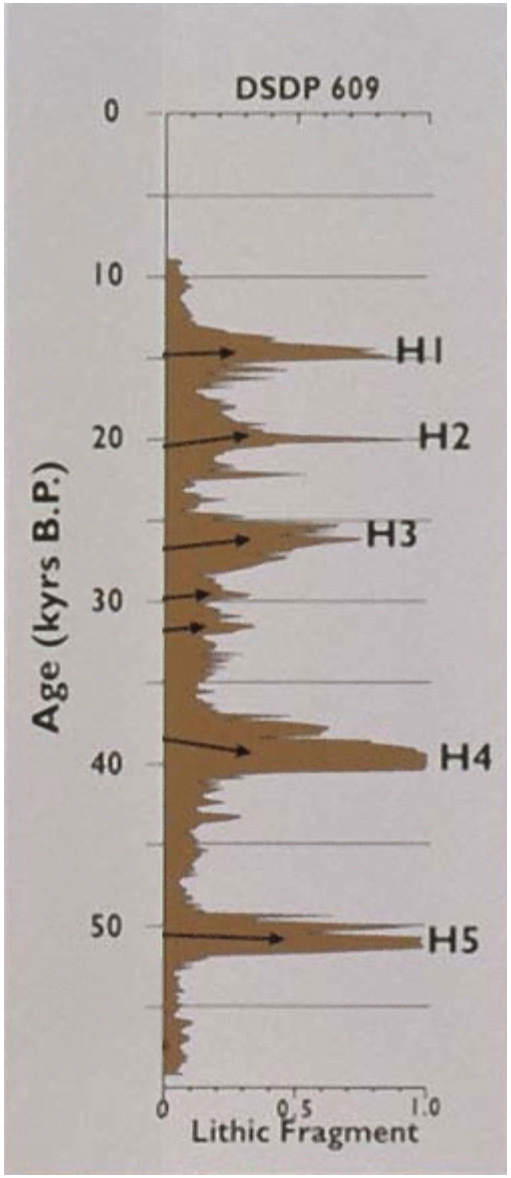
- Warmings every ~1500yr
- ~10 deg C warming
- Start & end within 20 yrs!
- Warmings last 500-1000 yrs

Mechanism:

- THC + sea ice?



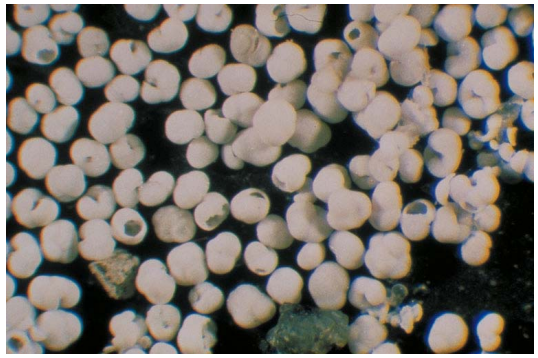
Heinrich events



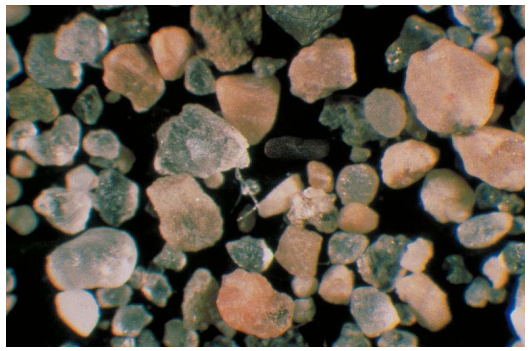
https://slideplayer.com/slide/12822818/
After Grimm et al (1993)

- Ice Rafted Debris (IRD) sediment layers due to massive glacier discharges from Laurentide & other ice sheets, every 7–10,000 yr.
- Occurred 20–60,000 ago
- Possibly synchronous collapses/ discharges of several ice sheets
- Mechanism: Bing/purge + THC + sea ice?

Micrograph of sand-size fraction in core HU87033-009
Sand-size fraction from the same core at 670-672 cm depth, within H-2.
from https://slideplayer.com/slide/12822818/
or https://slidetodoc.com/environmental-geosciences-natural-global-change-some-special-events/ Andrea Koschinsky



Typical sediments

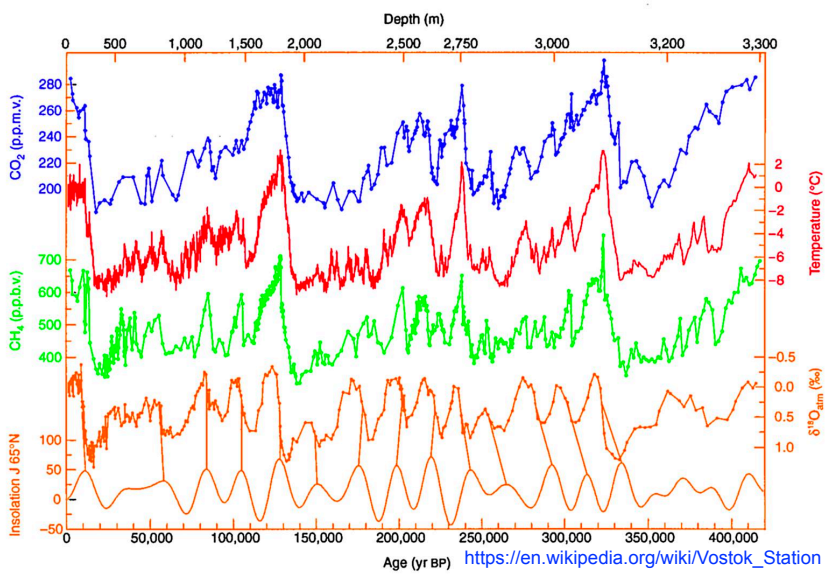


Ice rafted debris

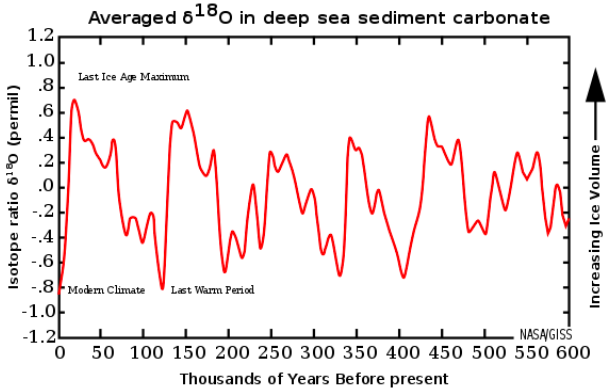
Glacial cycles

Largest climate signal in past 3 Myrs. Still not understood:

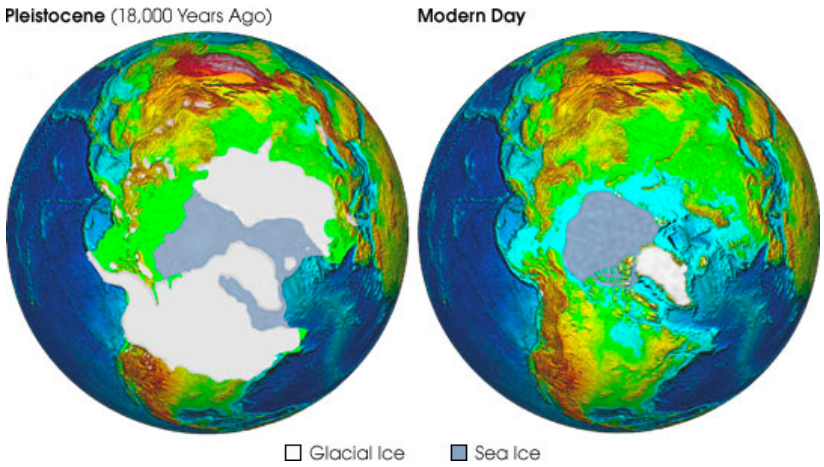
- Mechanism/ forcing?
- What caused CO_2 to change?
- Role of Milankovitch forcing?
- Change from 41 kyr to 100 kyr?



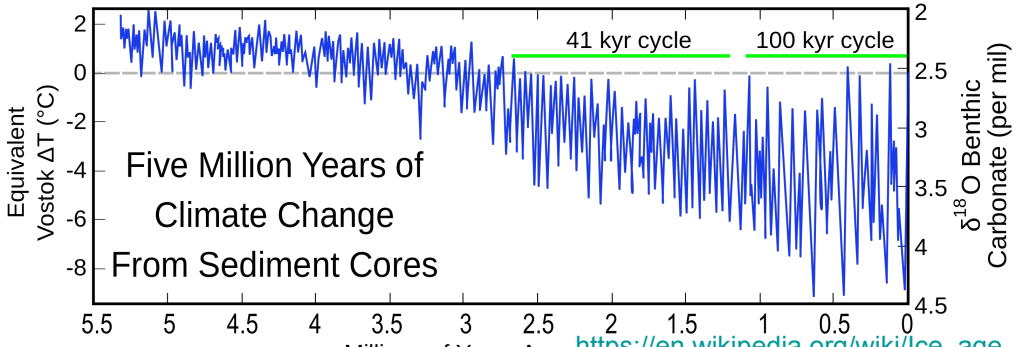
https://en.wikipedia.org/wiki/Vostok_Station



https://en.wikipedia.org/wiki/100,000-year_problem



https://earthobservatory.nasa.gov/features/BorealMigration/boreal_migration2.php



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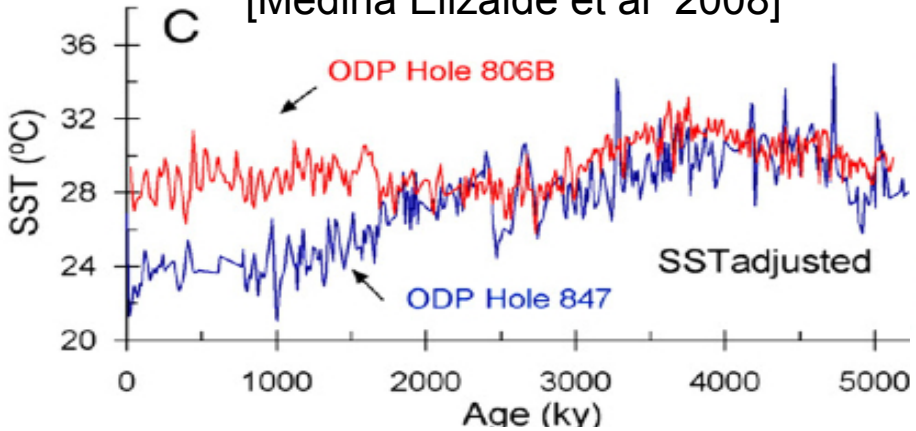
The Pliocene, 2–5Myr: "Permanent El Niño"

[Medina Elizalde et al 2008]



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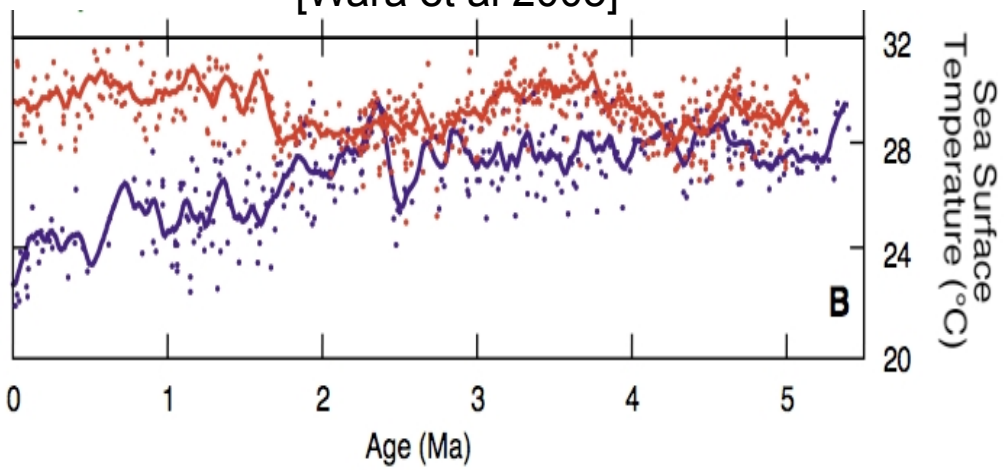

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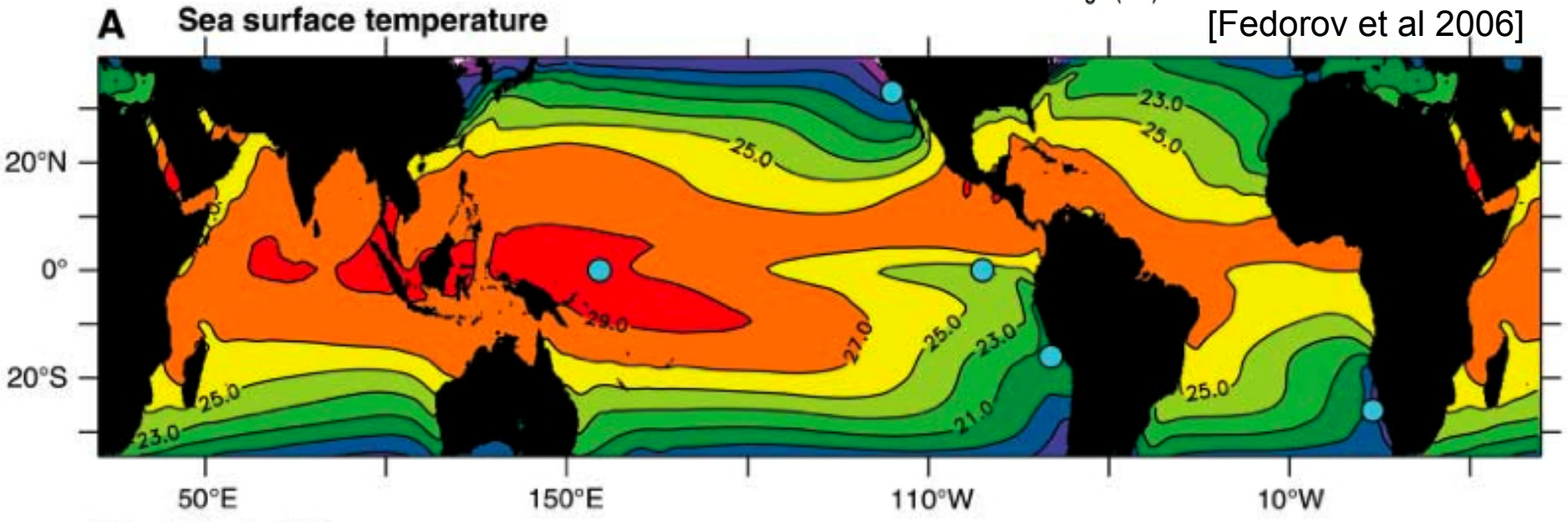

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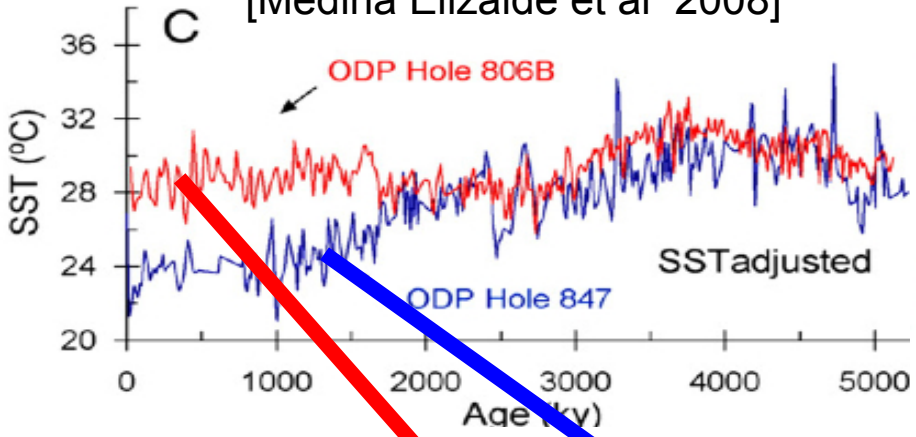

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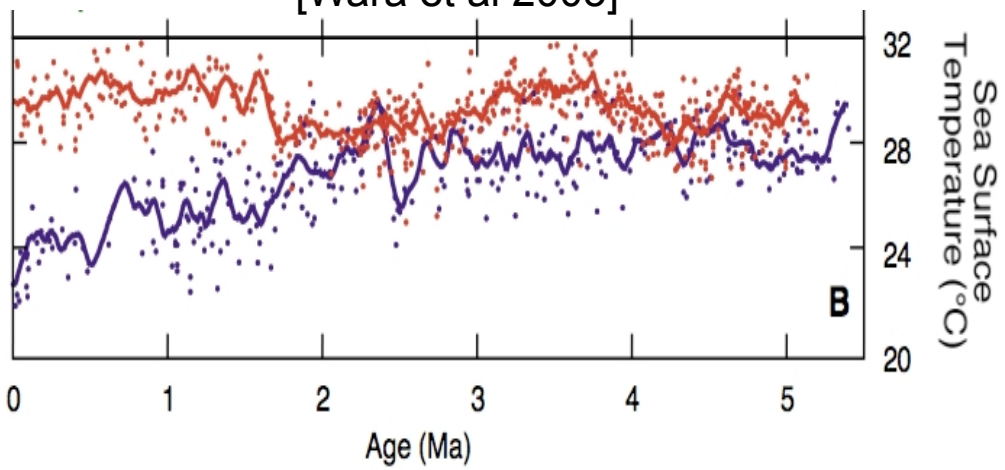

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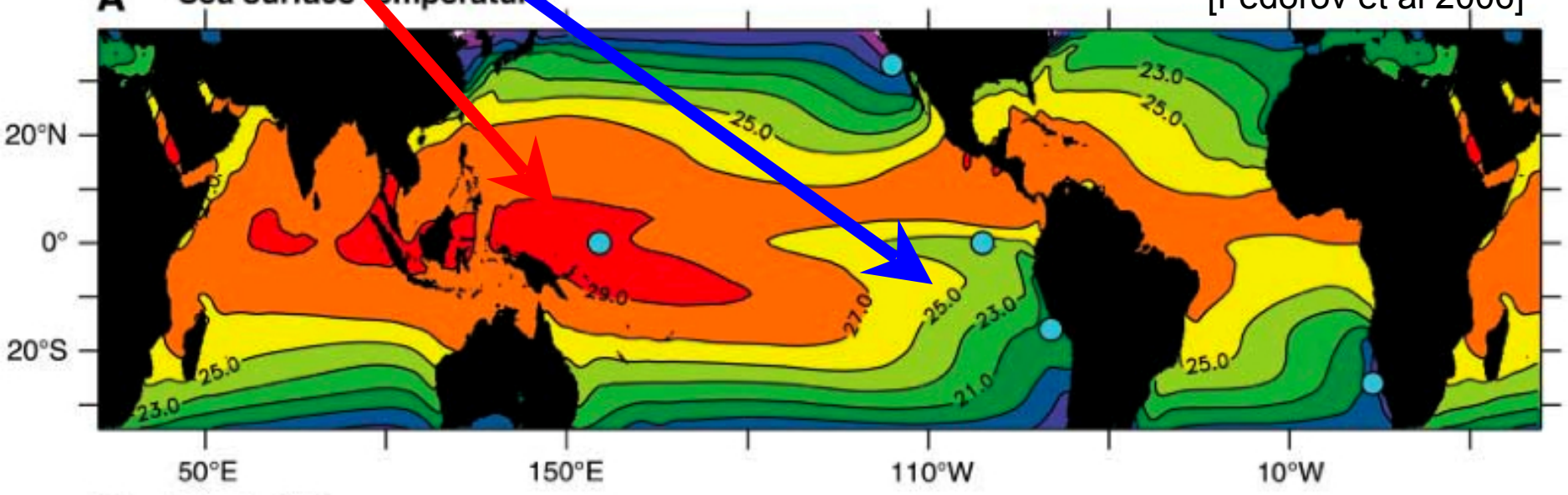

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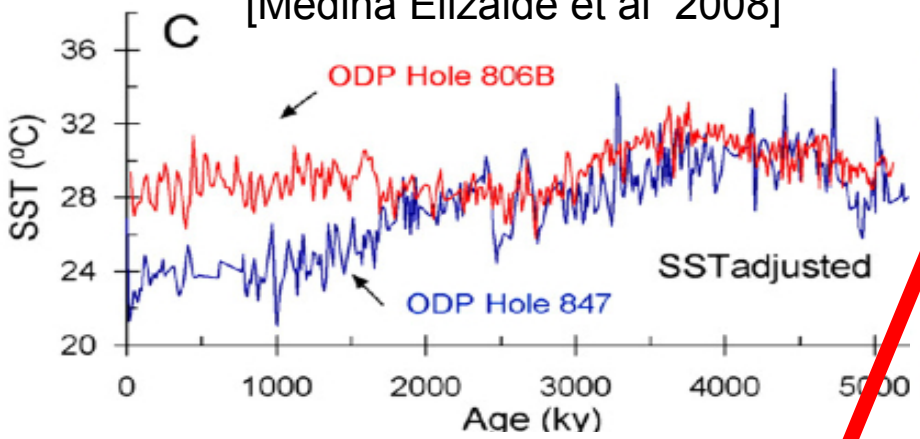

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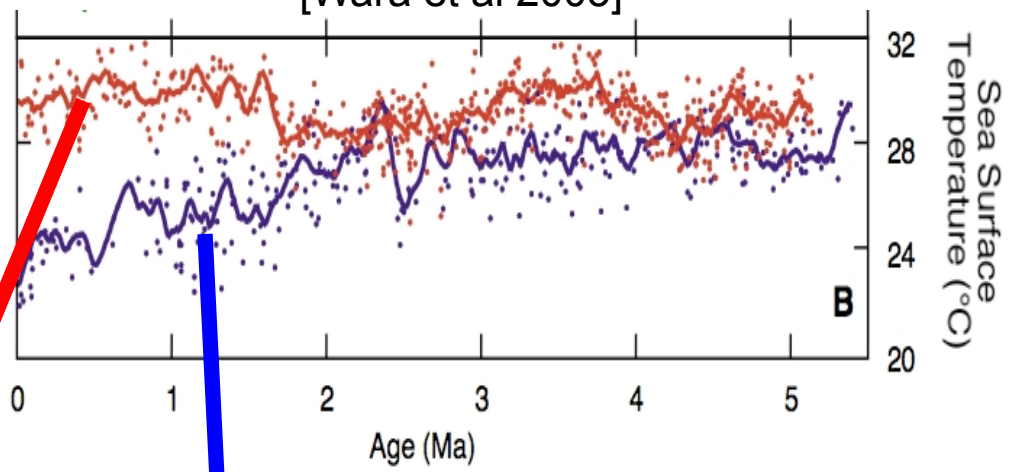

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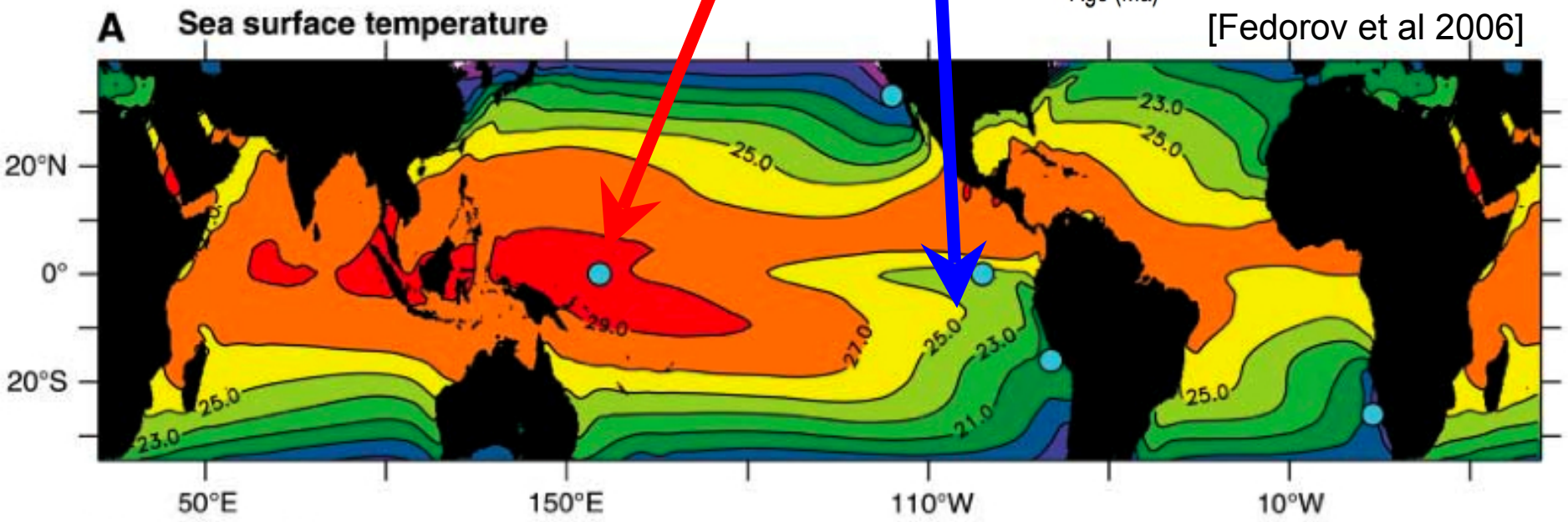

➡ east-west temperature gradient in equatorial Pacific was weaker 2-5 Myr; coastal mid-lat upwelling sites = today+10C

The Pliocene, 2–5Myr: “Permanent El Niño” mechanisms

Move Papua/ New Guinea;

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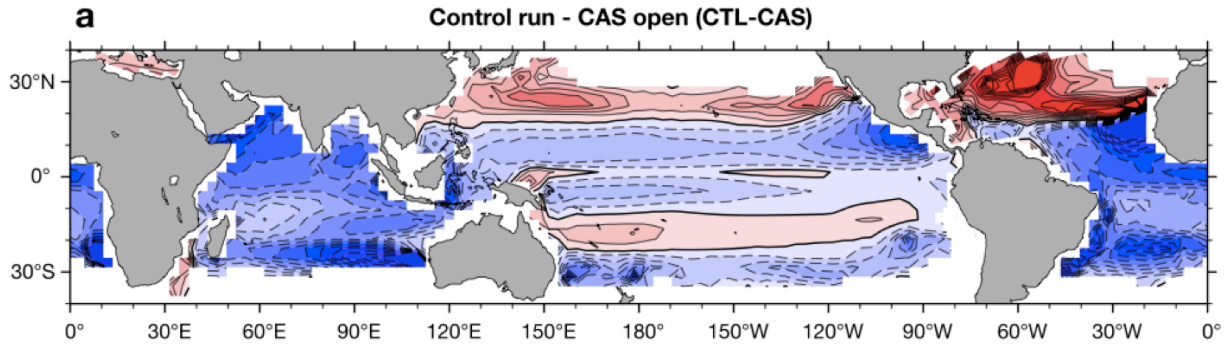

Open central American seaway [Steph et al 2010]

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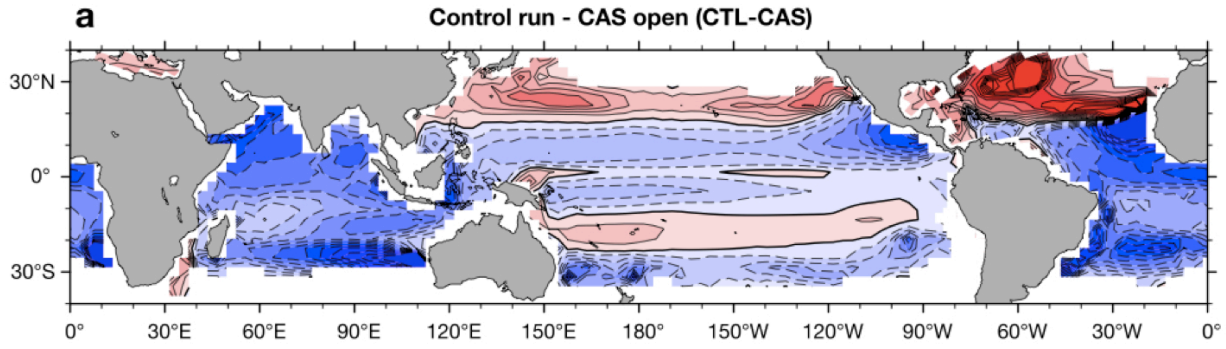

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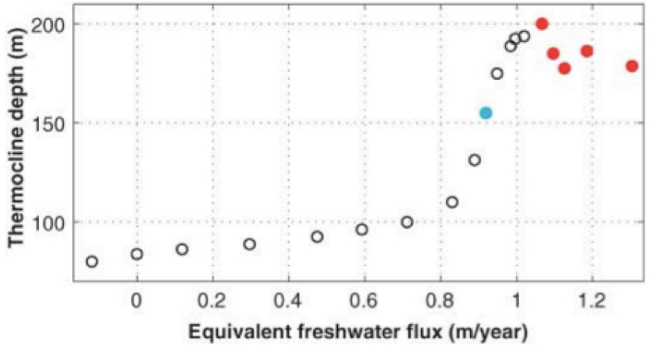

collapse equatorial thermocline w/ N. Pacific fresh water flux [Fedorov et al 2004/2006]

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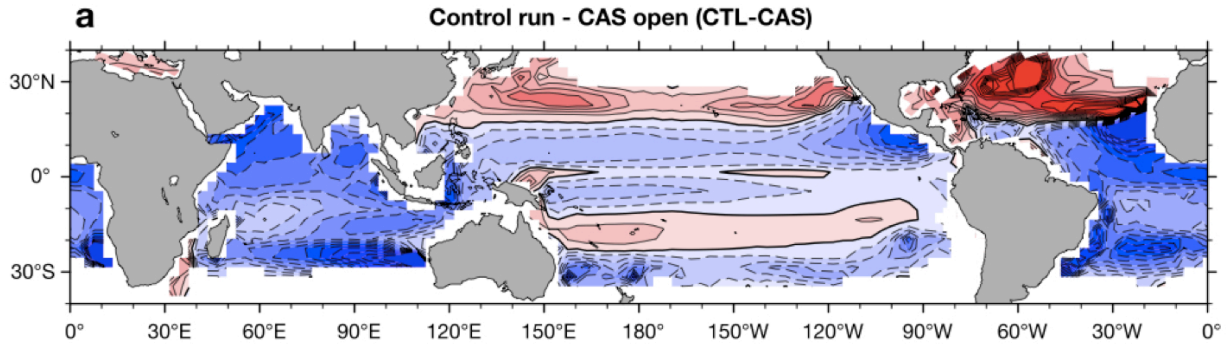

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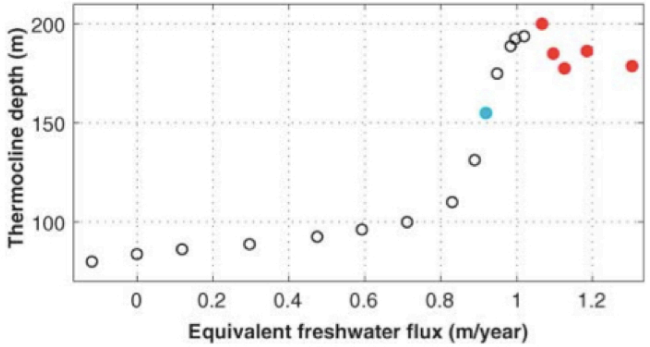

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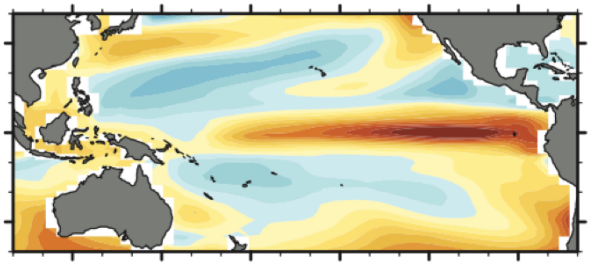

Hurricanes/ ocean mixing [Emanuel 2002… Fedorov et al 2010/2013]

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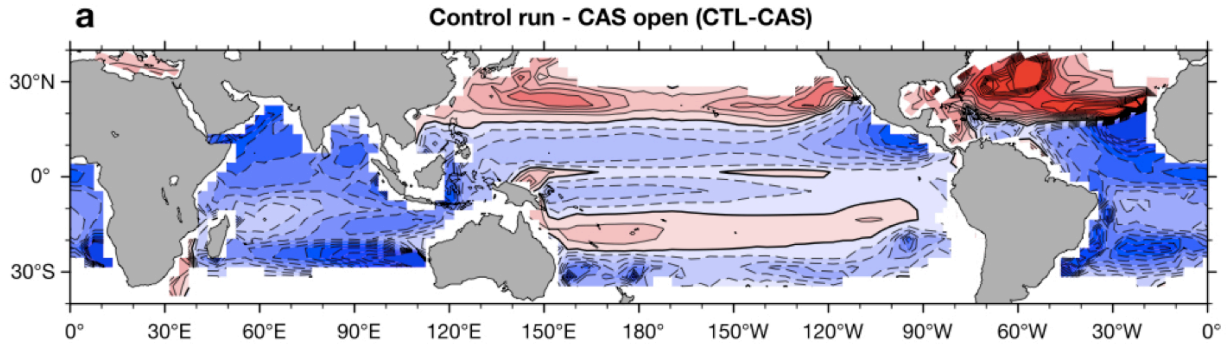

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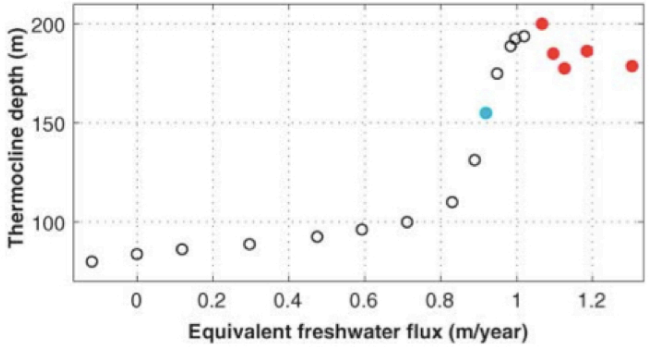

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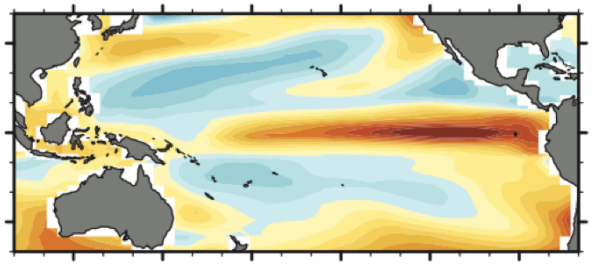

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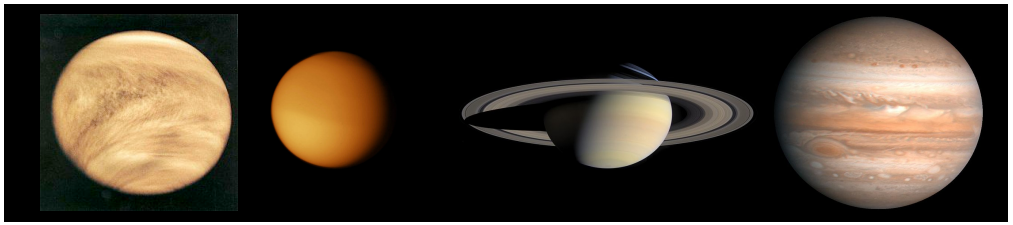


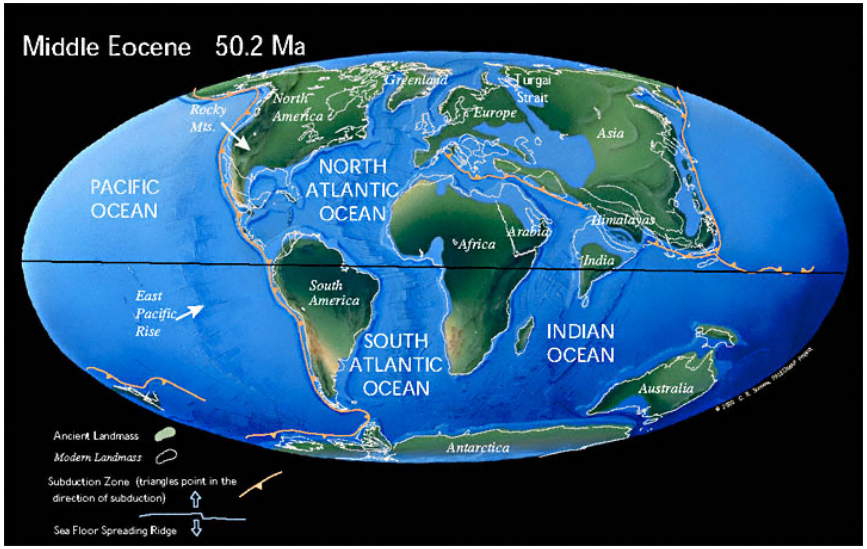
Change easterlies via R.W. induced Superrotation
[Tziperman & Farell 2009, Arnold, Tziperman & Farell 2012]

Equable climates: Eocene (55.8–33.9 Myr) and beyond

Observations: very warm climate ~146–34 Myr ago: deep ocean ~15C; above freezing **winter** temperatures at 60N, Greenland & middle of Canada (now –30C); equator to pole Temp gradient ~25C (now >40C).

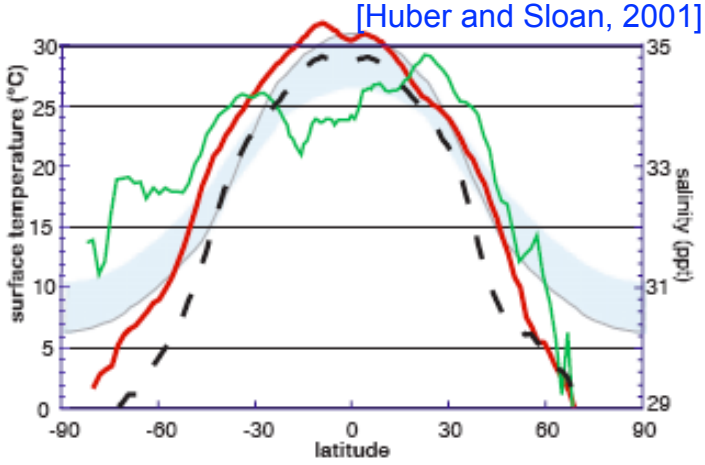
The mystery: Warm continental winter climate cannot be reproduced by GCMs even at very high CO_2 levels.

http://www.scotese.com/newpage9.htm



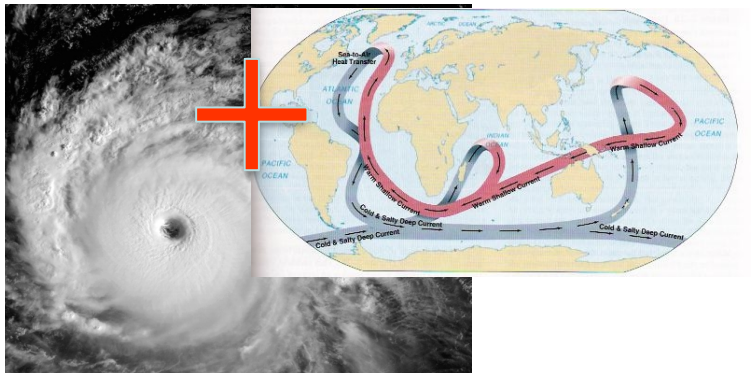
Present-day like geometry

[Huber and Sloan, 2001]



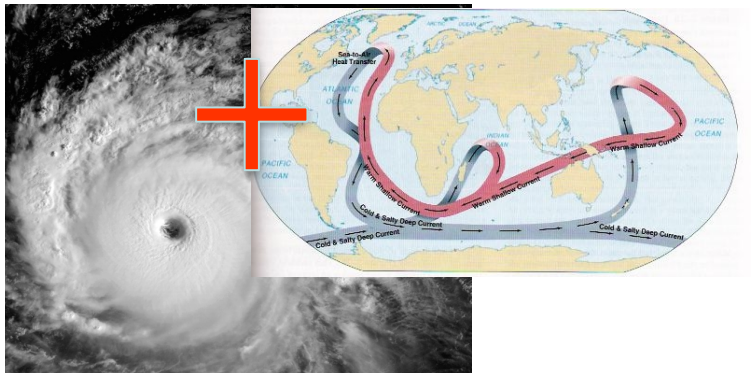
- Modern Model SST
- Eocene Model SST
- Eocene Proxy SST
- Eocene Model SSS

Equable climate ideas



Hurricanes & ocean mixing/
MOC (Emanuel 2002)

Equable climate ideas



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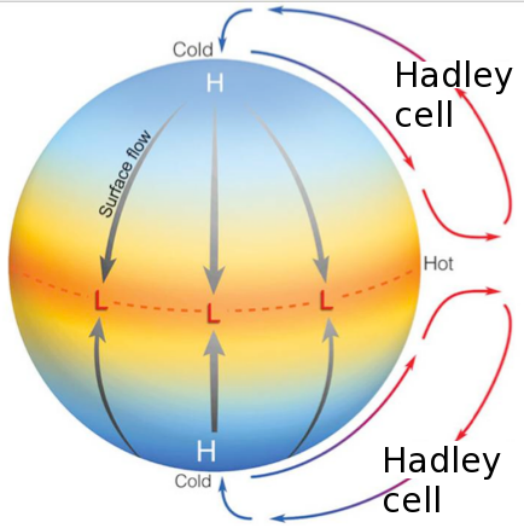
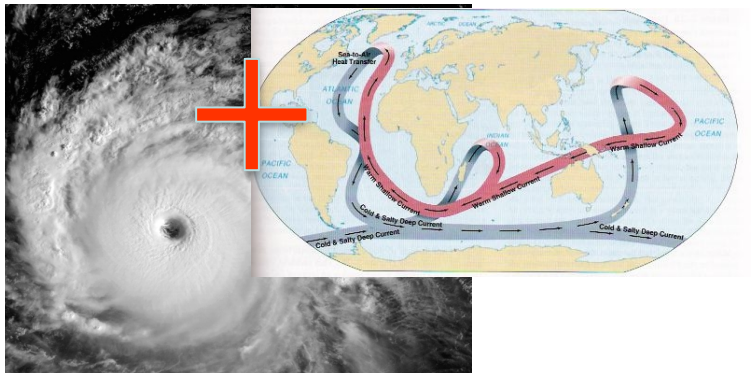


Equator-to-Pole Hadley cell (Farrell 1990)

Equable climate ideas



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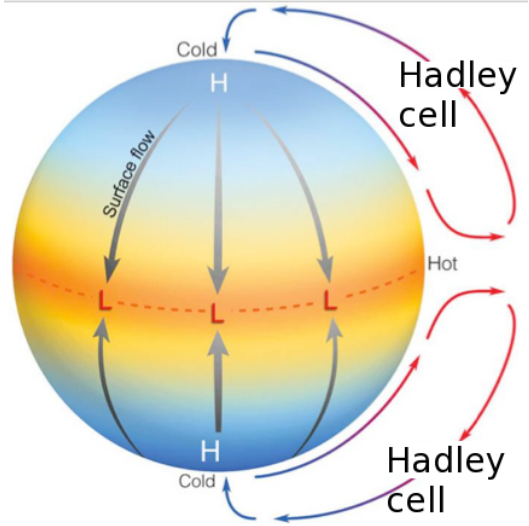

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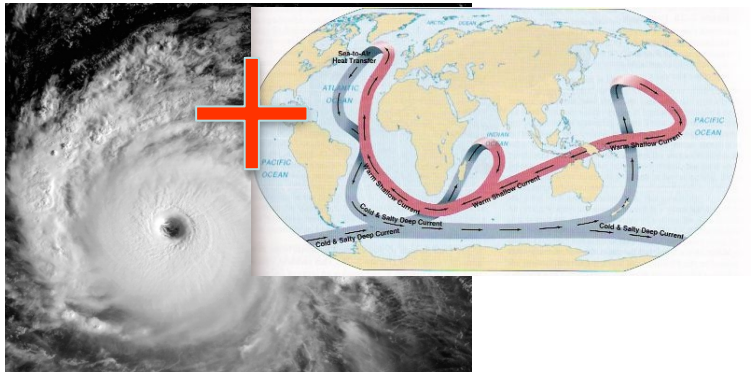
Equable climate ideas



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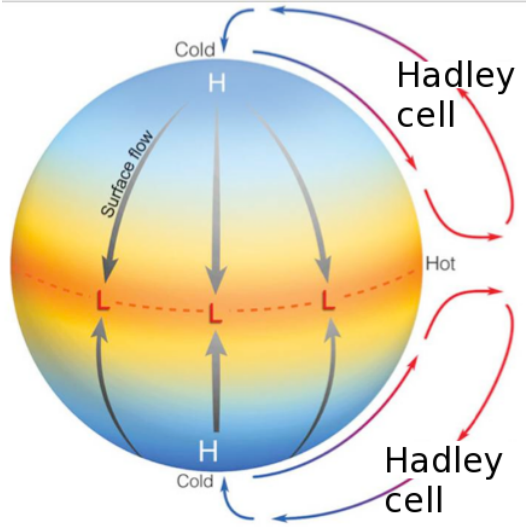

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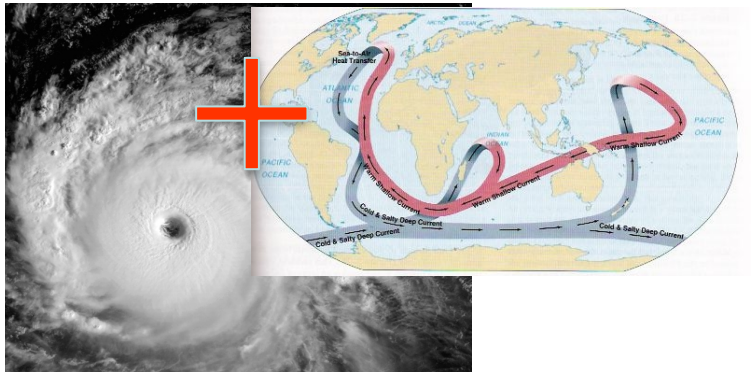

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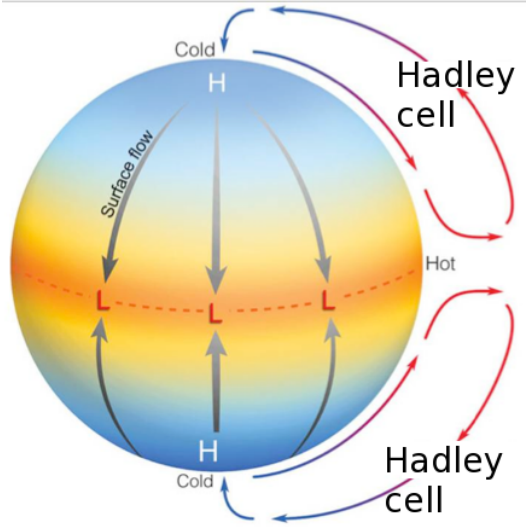

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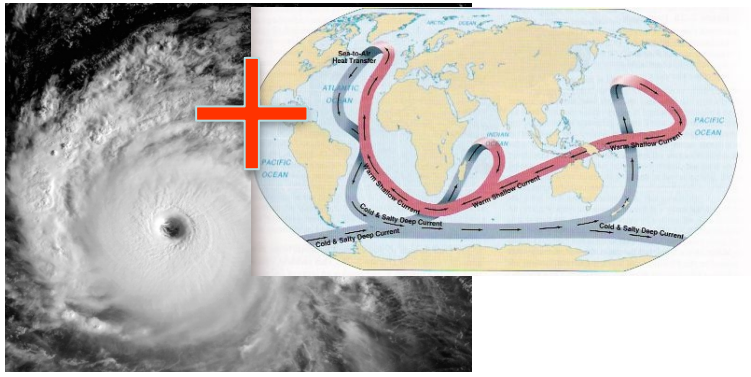

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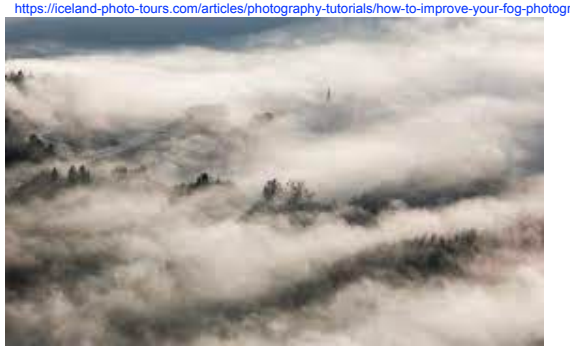
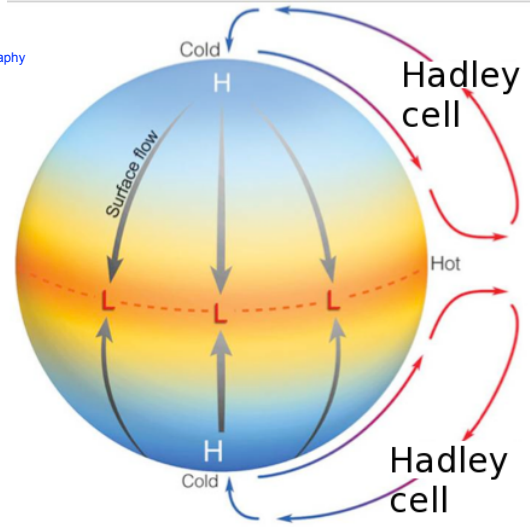
https://iceland-photo-tours.com/articles/photography-tutorials/how-to-improve-your-fog-photography



Low clouds suppress Arctic air formation (Cronin & Tziperman 2015)



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Let the fun begin…