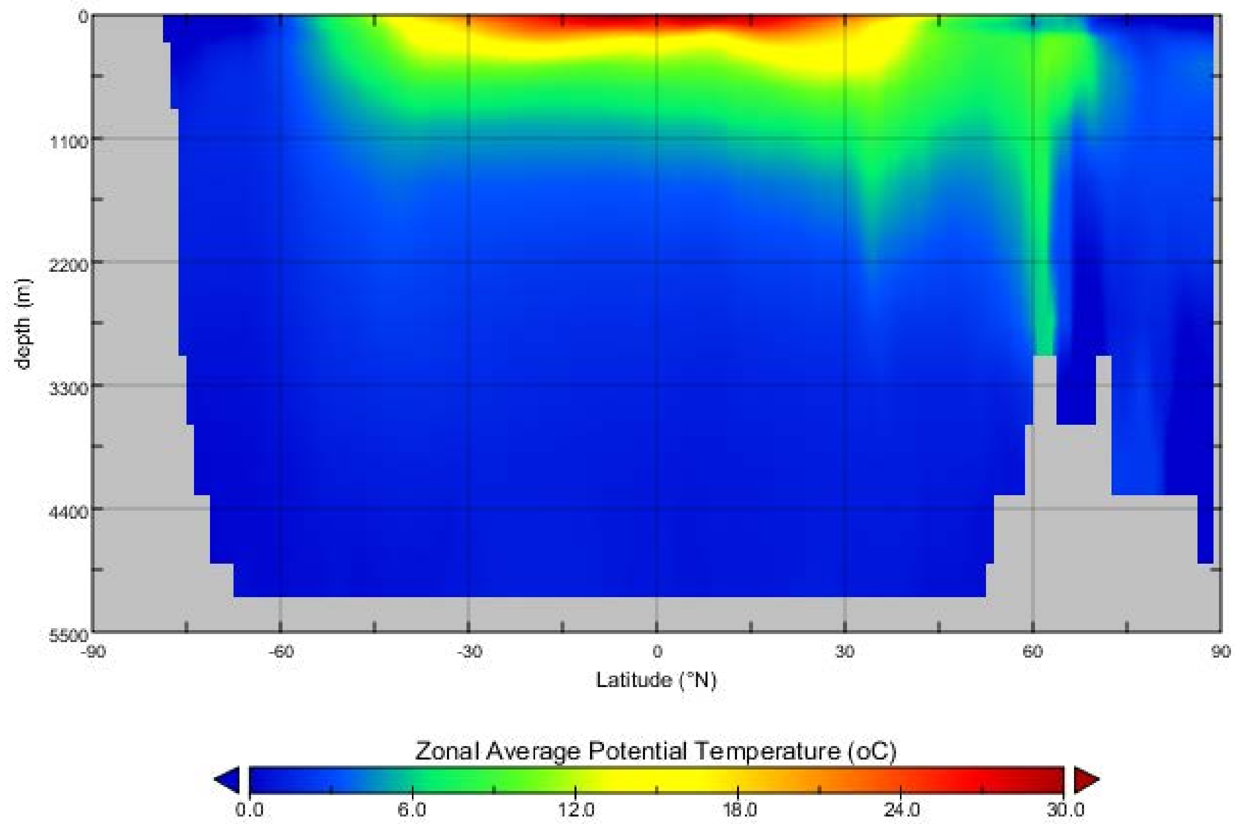
Vertical mixing and the ocean circulation

Chris Brierley,
Postdoc Luncheon, 14th April 2010

- Vertical mixing – what and why
- What is its global impact?
  - Mean climate
  - Climate change
- Changing sources of mixing
  - Hurricanes
  - Tidal dissipation

Outline

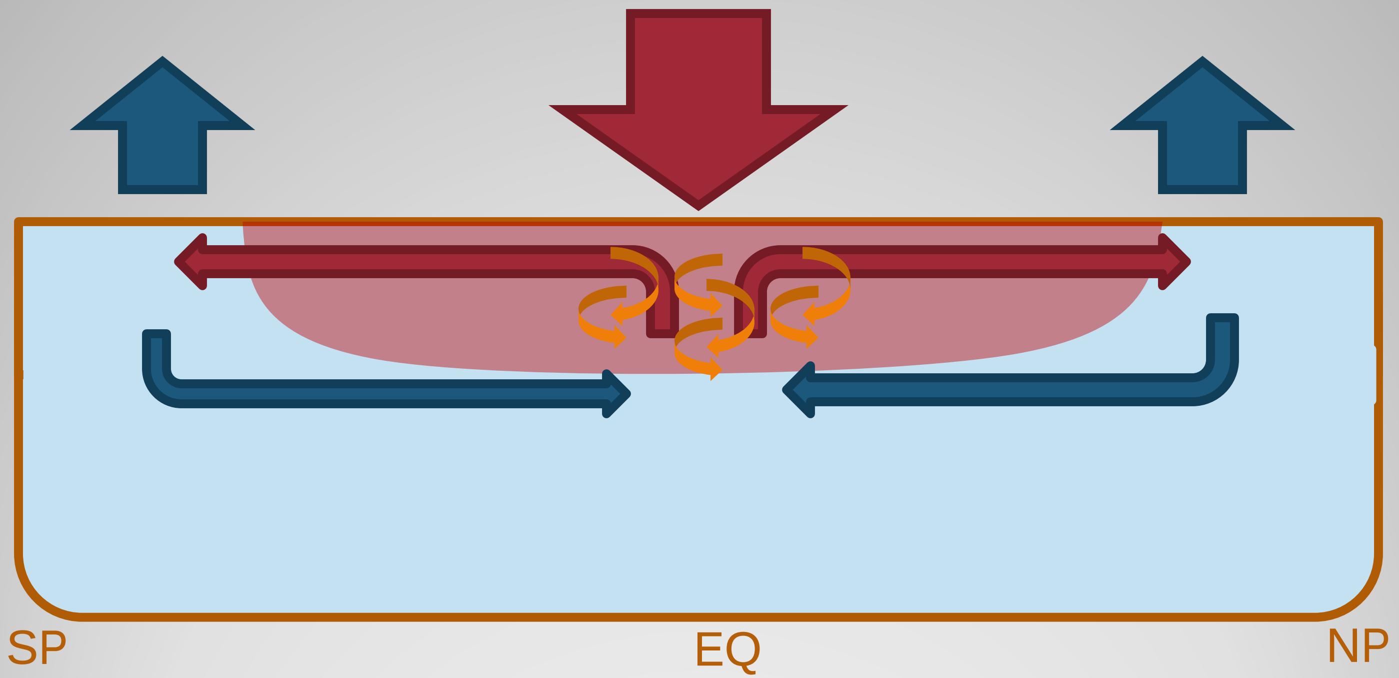


Zonal Mean Ocean Temperature

- *A circulation cannot be driven unless heat is input at a lower depth than it is lost at*

Sandström's Theorem

- Vertical mixing leads to smearing of water properties
- Effectively different vertical levels.



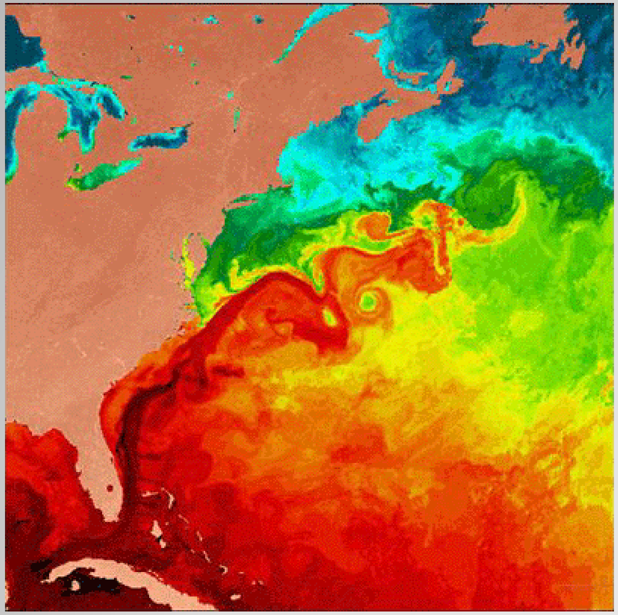
Mixing's impact

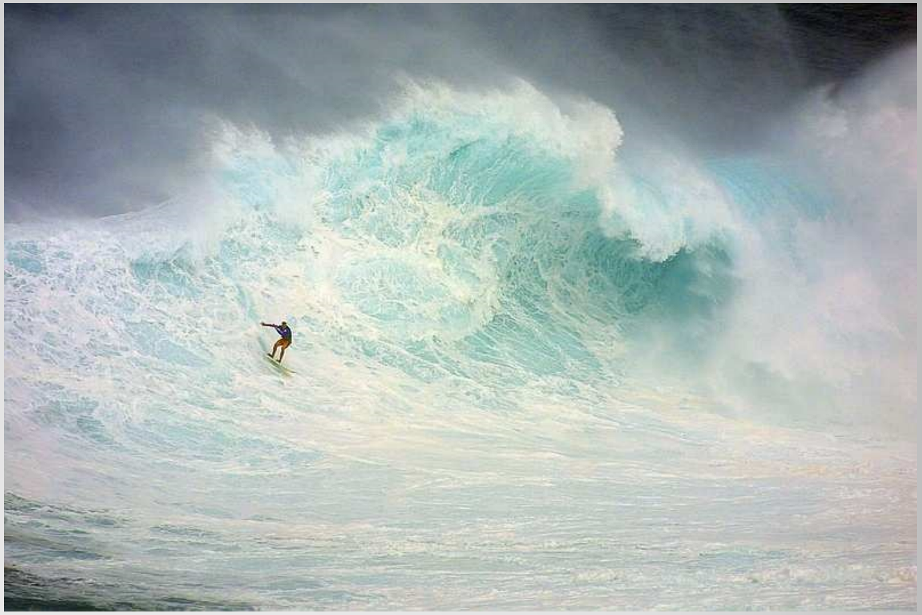
- What are the sources of mixing in the ocean?
  - Wind-driven stirring
  - Tidal generation of internal waves
  - *Biota*
  - *Hurricanes*

Sources of Ocean Mixing

Nasa

- Wind-driven stirring
- Tidal generation of internal waves
- *Biota*
- *Hurricanes*





Sources of Ocean Mixing

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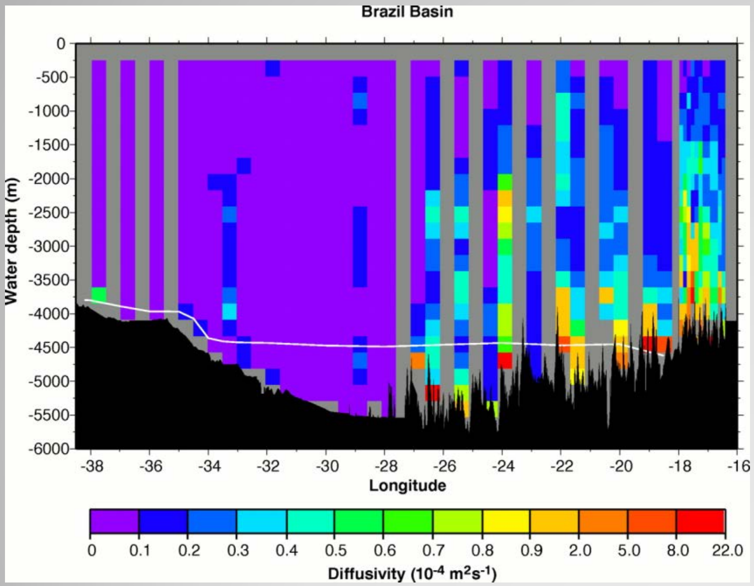
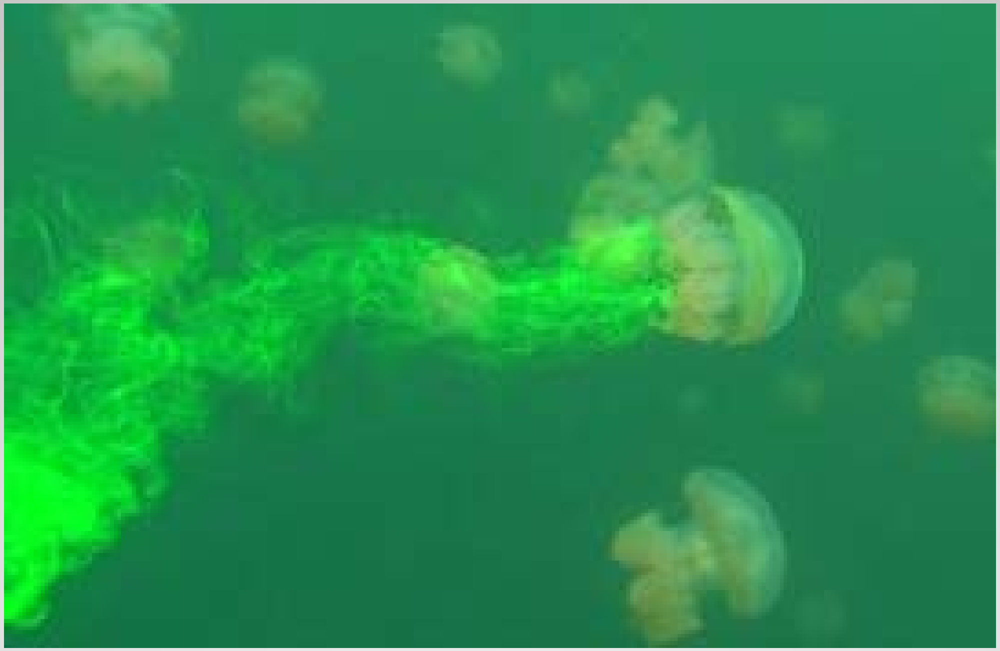


Sources of Vertical Mixing

Polzin et al; Aaron Feinberg

- Wind-driven stirring
- Tidal generation of internal waves
- *Biota*
- *Hurricanes*



Sources of Vertical Mixing

Katija & Dabiri, 2009

Sources of Vertical Mixing

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- Tidal generation of internal waves
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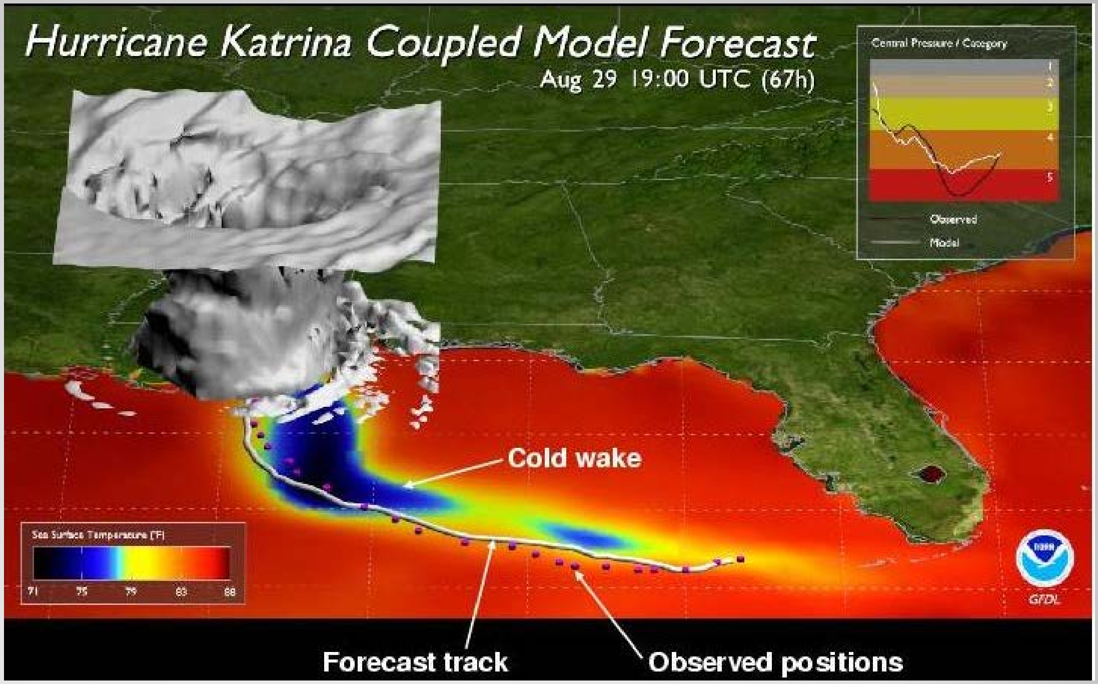


Eddy Diffusivity

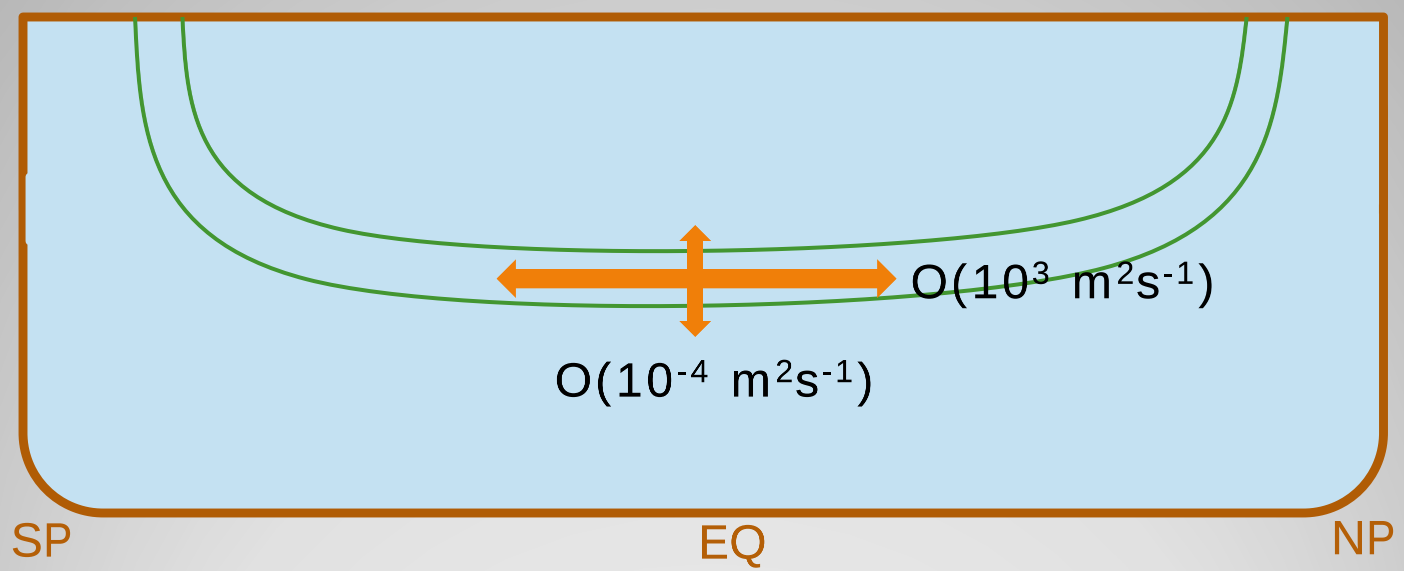
- Irrespective of the source can treat process as diffusion
  - Heat flux is proportional to temperature difference

$$\partial_z\left(K_v \partial_z T\right)$$

- K_v is a vertical eddy diffusivity

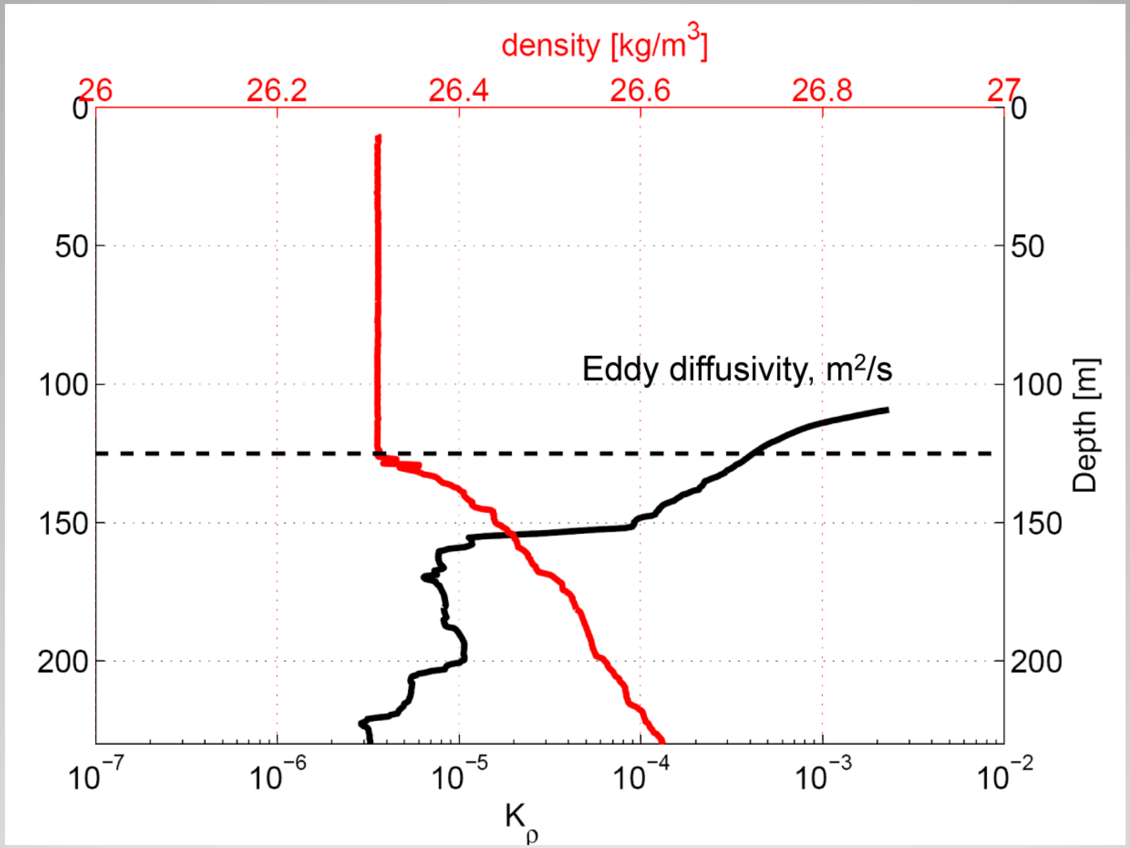
Diapycnal vs. Isopycnal

- It is much easier to move along isopycnals than across them (diapycnal)



$K_I / K_V = O(10^7)$

Observations

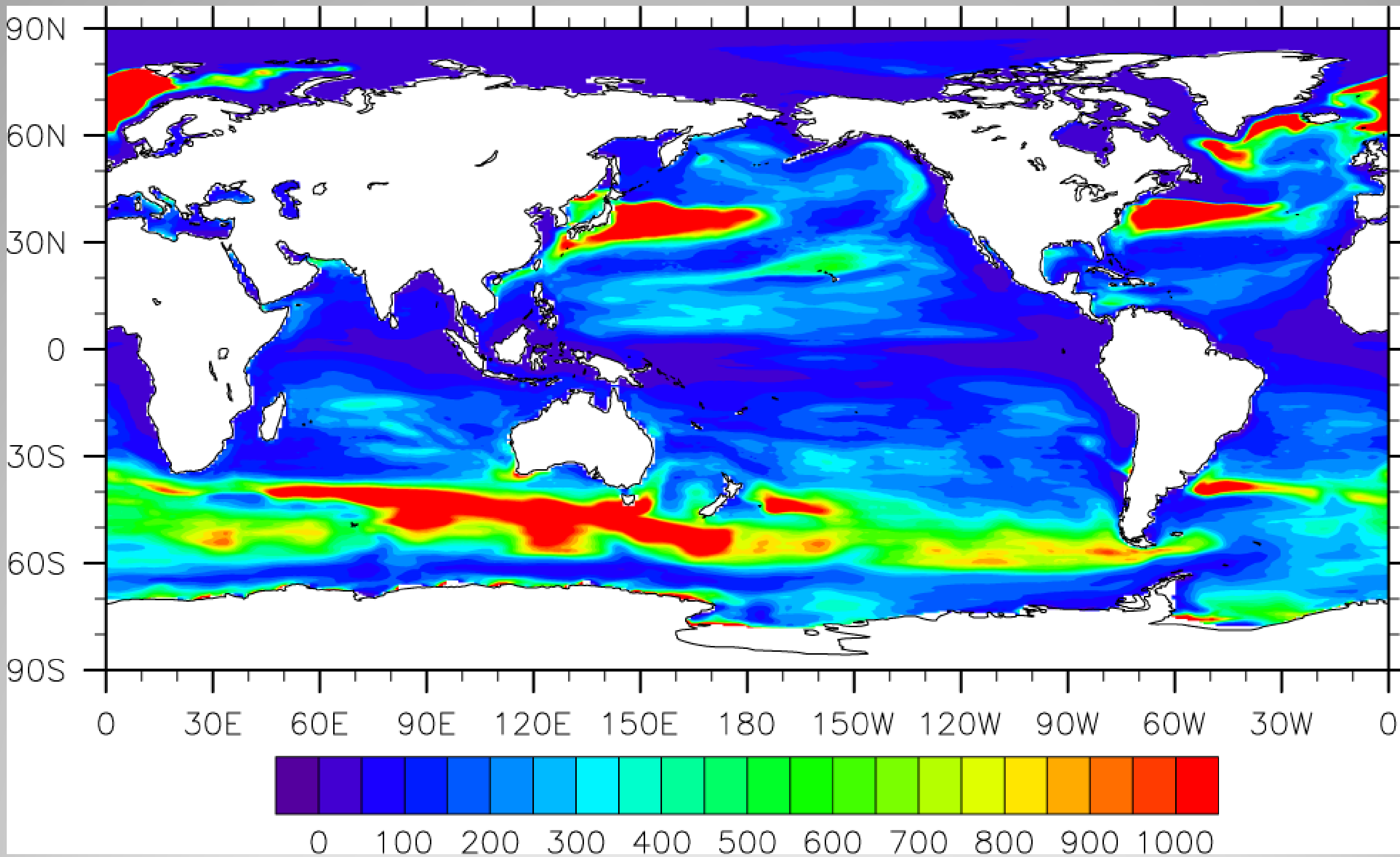


Results from the North Atlantic Tracer Release Experiment

Mixing changes with depth and stratification

Parameterisation of vertical mixing in a GCM

- Philander & Pacanowksi, 1981 (K-Theory)
  - Vertical diffusion depends on Richardson Number, therefore stratification dependent
- KPP Scheme (Large et al., 1994)
  - Based off boundary layer principles learnt in meteorology
- Prescribed global background component
  - Increases with depth
  - Required for
    - numerical stability
    - fill gaps left by other parameterisations



Average calculated K_V in top 100m (10^{-4} m^2s^{-1})

Vertical mixing field in a GCM

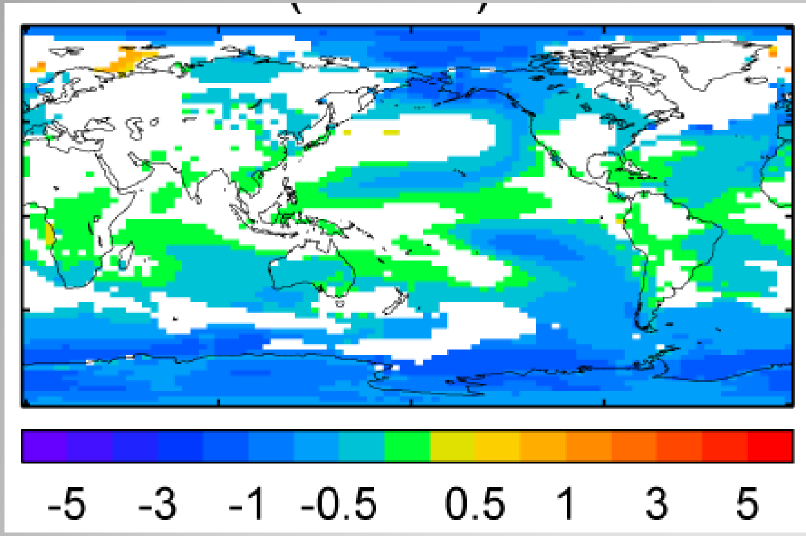
- The observations give a range of values of K_V for the ocean interior, but models use a single profile for the whole globe
- What impact would this uncertainty have on climate?

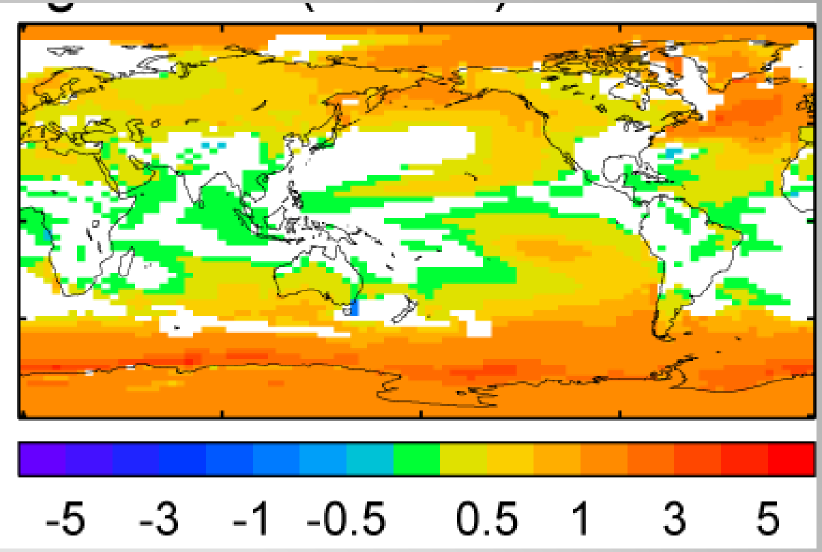
Climate Model Experiments

K_V (m^2s^{-1})	Low K_V Run	Standard K_V	High K_V Run
Surface	0.5×10^{-5}	1×10^{-5}	2×10^{-5}
Bottom	4×10^{-5}	15×10^{-5}	50×10^{-5}

Test of Uncertainty

Low K_V **High K_V**

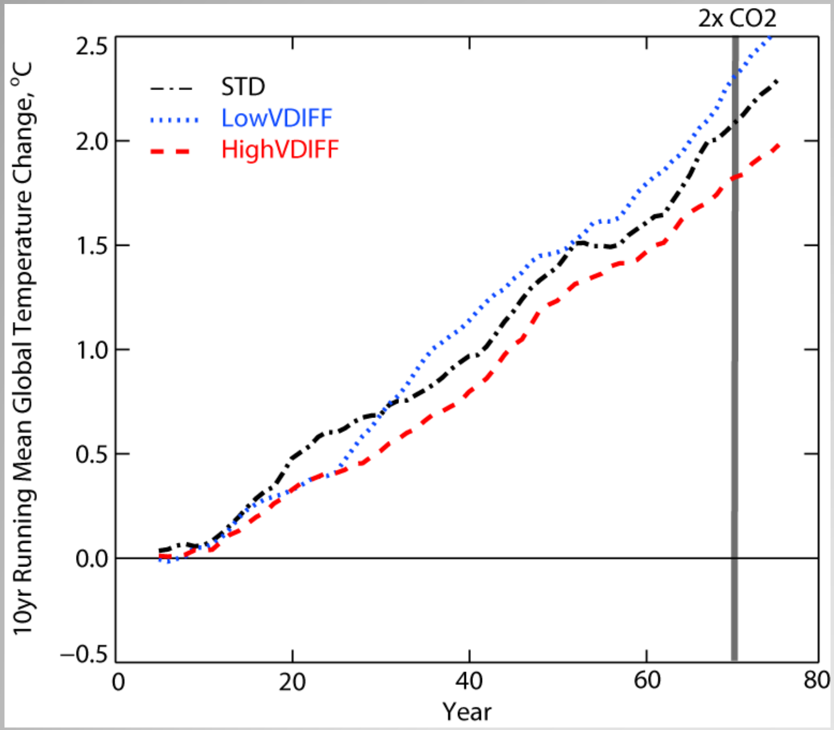




Higher mixing leads to stronger ocean circulation
(c.f. with Sandström thoughts from earlier)

Impact on Mean Climate (0.8°C)

Impact on Climate Projections



Run	Transient Climate Response (ºC)
Low K_v	2.3
Standard	2.1
High K_v	1.8

- Transient response opposite from equilibrium one
- Higher mixing means better draw down of heat from the ocean surface

- Uncertainty in K_v leads to significant uncertainty in climate models and their projections of climate change
- How can we constrain that uncertainty?
  - Look at individual sources of mixing
    - Determine their impact
    - Observe the sources directly rather than attempt to measure uncertainty
  - *Think about using paleoclimates*

Making a more certain world

- What are the sources of mixing in the ocean?
  - Wind-driven stirring
    - *Relatively well constrained*
    - *Already parameterised in climate models*
  - Tidal generation of internal waves
  - Biota
  - Hurricanes

Sources of Ocean Mixing

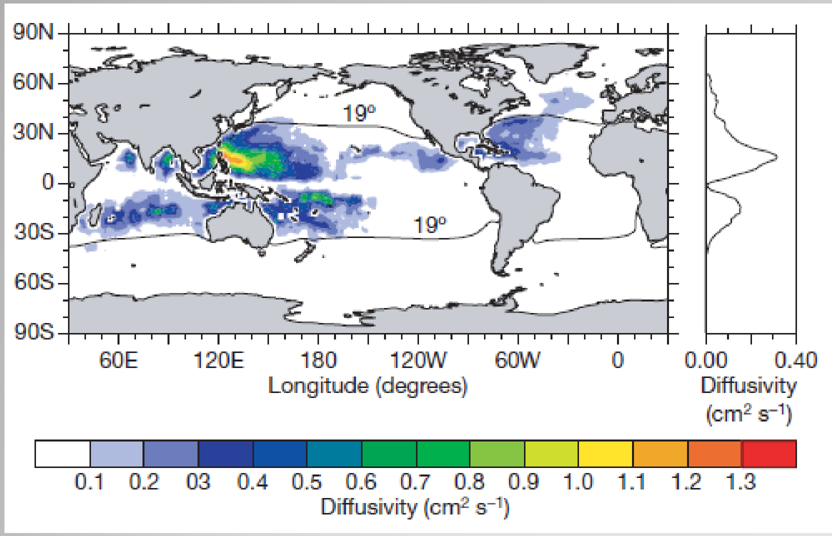
Nasa

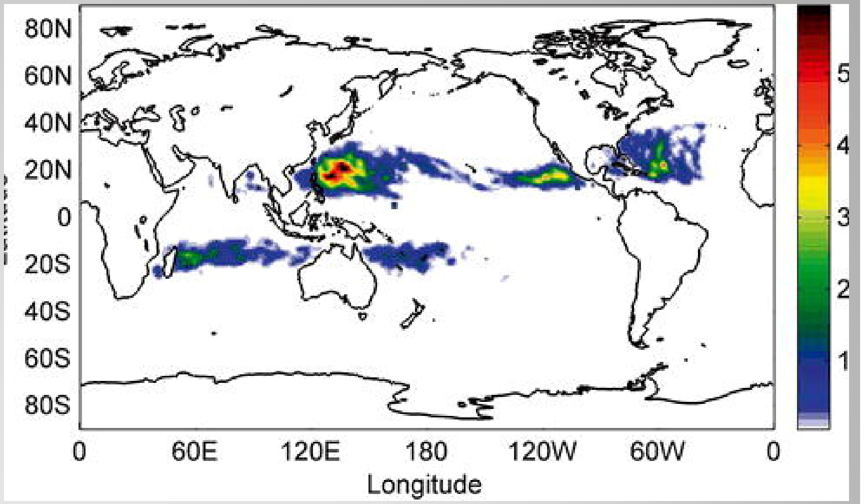
Hurricanes

Tropical Cyclones (hurricanes, typhoons etc)

Impact on ocean circulation is debated, as they are short, transient features

Sriver & Huber, 2007 Liu et al, 2008

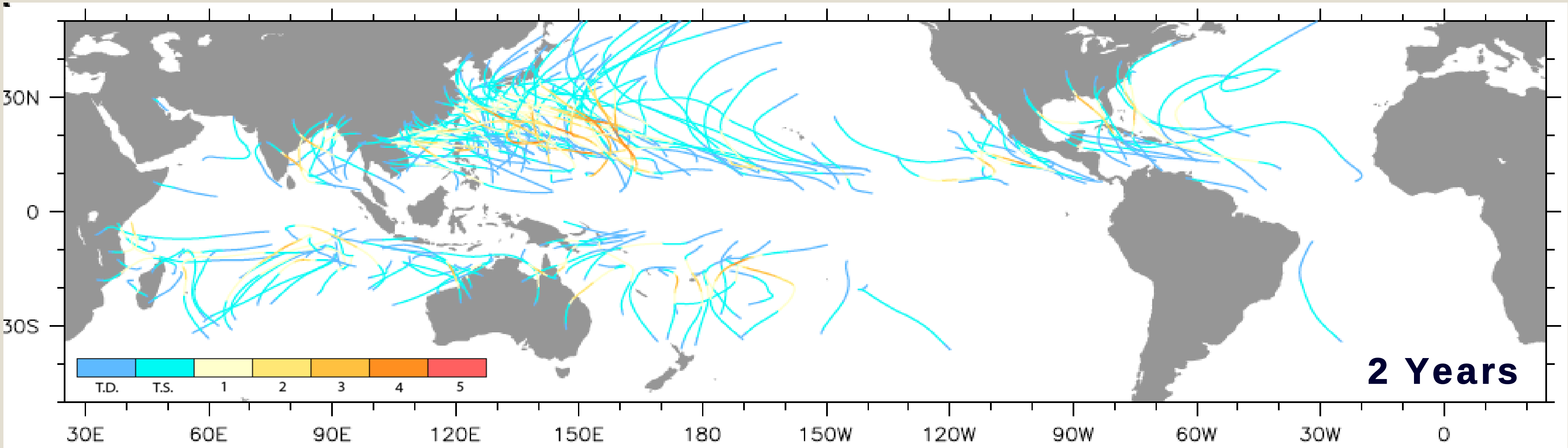


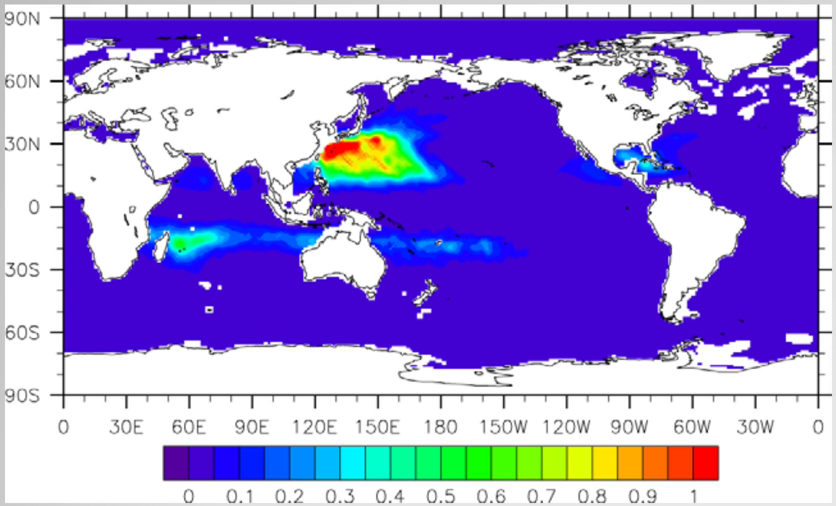


Maximum of $10^{-4} m^2 s^{-1}$

Maximum of $5 \times 10^{-4} m^2 s^{-1}$

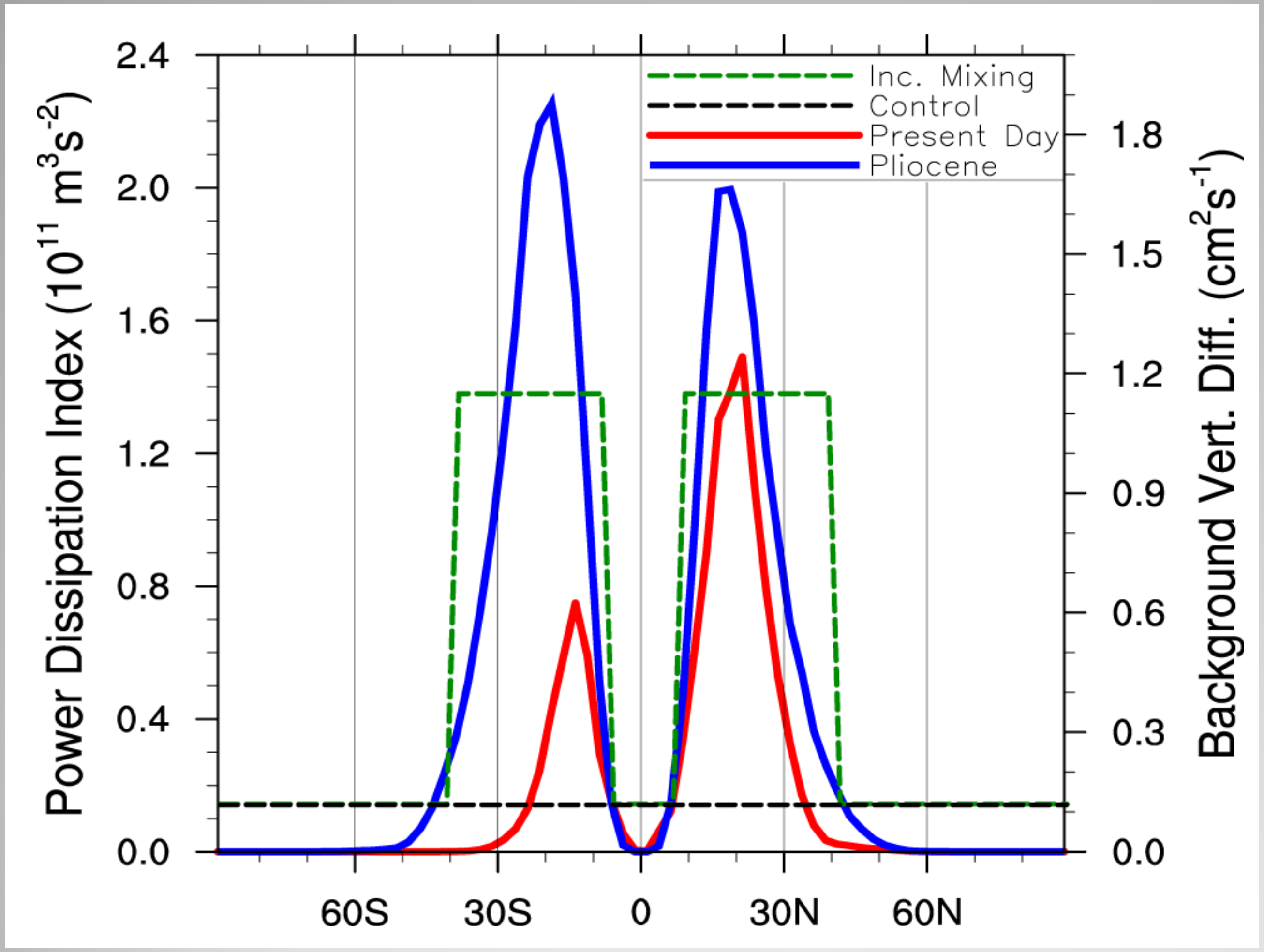
Hurricane K_v Fields - Observed





Calculate diffusivity from energy balance of mixed layer (Georgy)
Maximum of $10^{-4} m^2 s^{-1}$

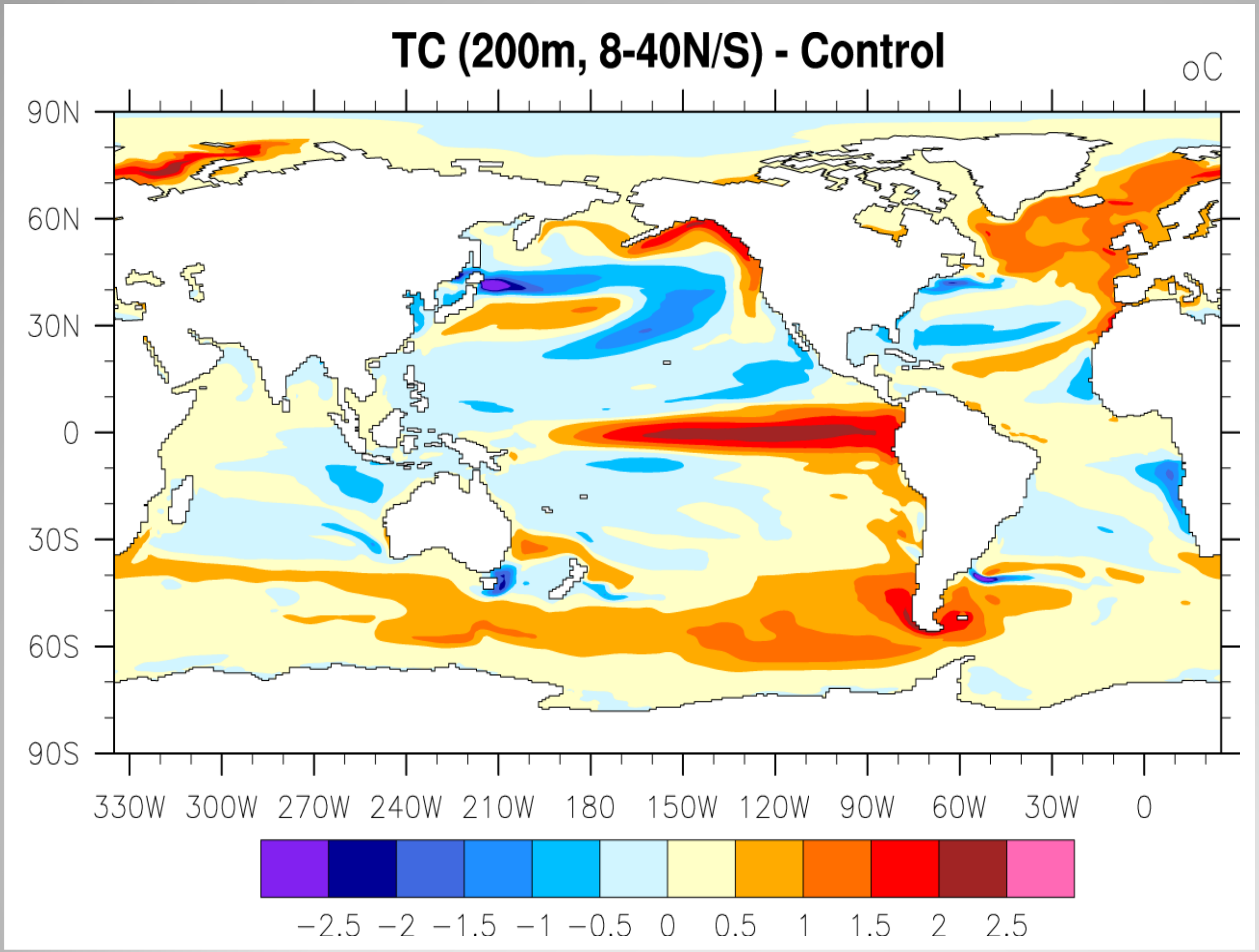
Reconstructed Hurricanes



Include hurricanes as two stripes of extra mixing in their common latitudes

Use 10x normal background mixing to test sensitivity

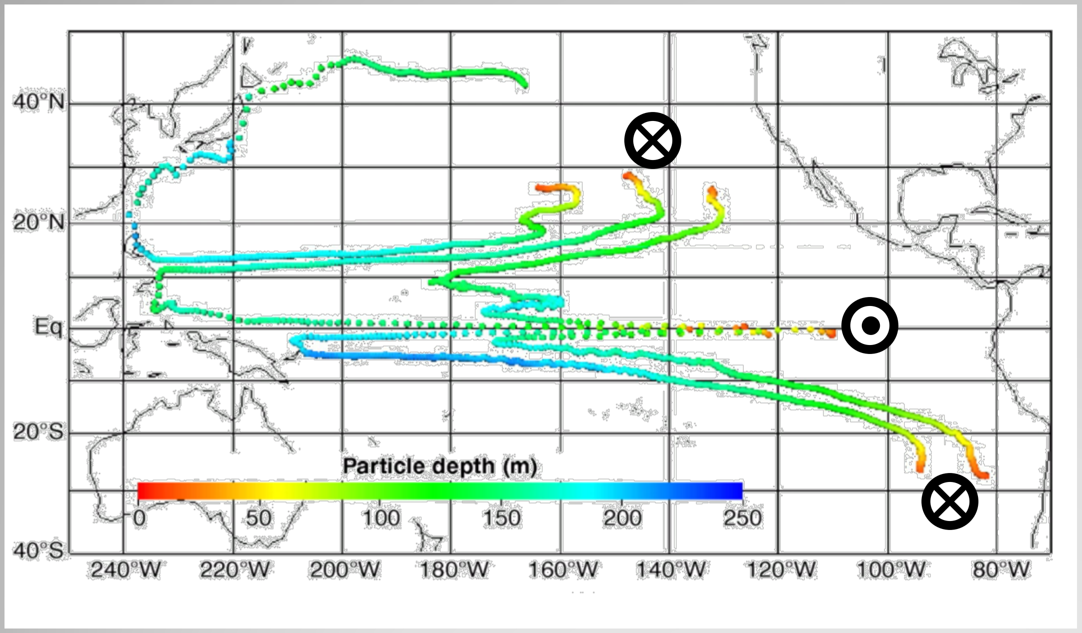
Including hurricanes in a GCM



Inclusion of hurricanes in coupled climate model causes up to 2.5°C

El Nino region is most strongly affected

Significant surface warming

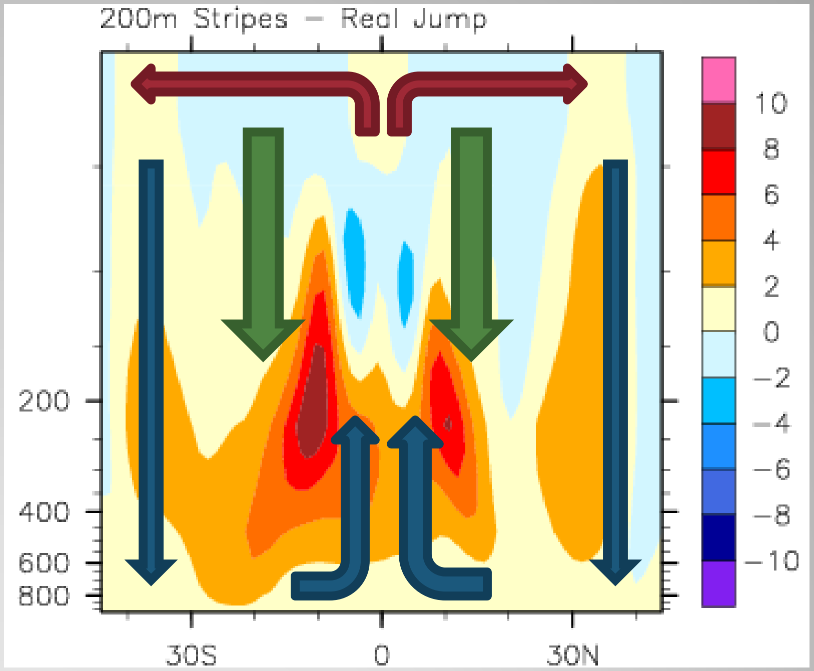


- Water is subducted in subtropical East Pacific
- Travels west towards warm pool
- Catches EUC and upwells in cold tongue
- From Gu & Philander '97

The Wind-driven Subtropical Cell

Mechanism of hurricane warmth

- Hurricanes act to mix warm water from surface to ~200m
- Warms the return flow of the cell

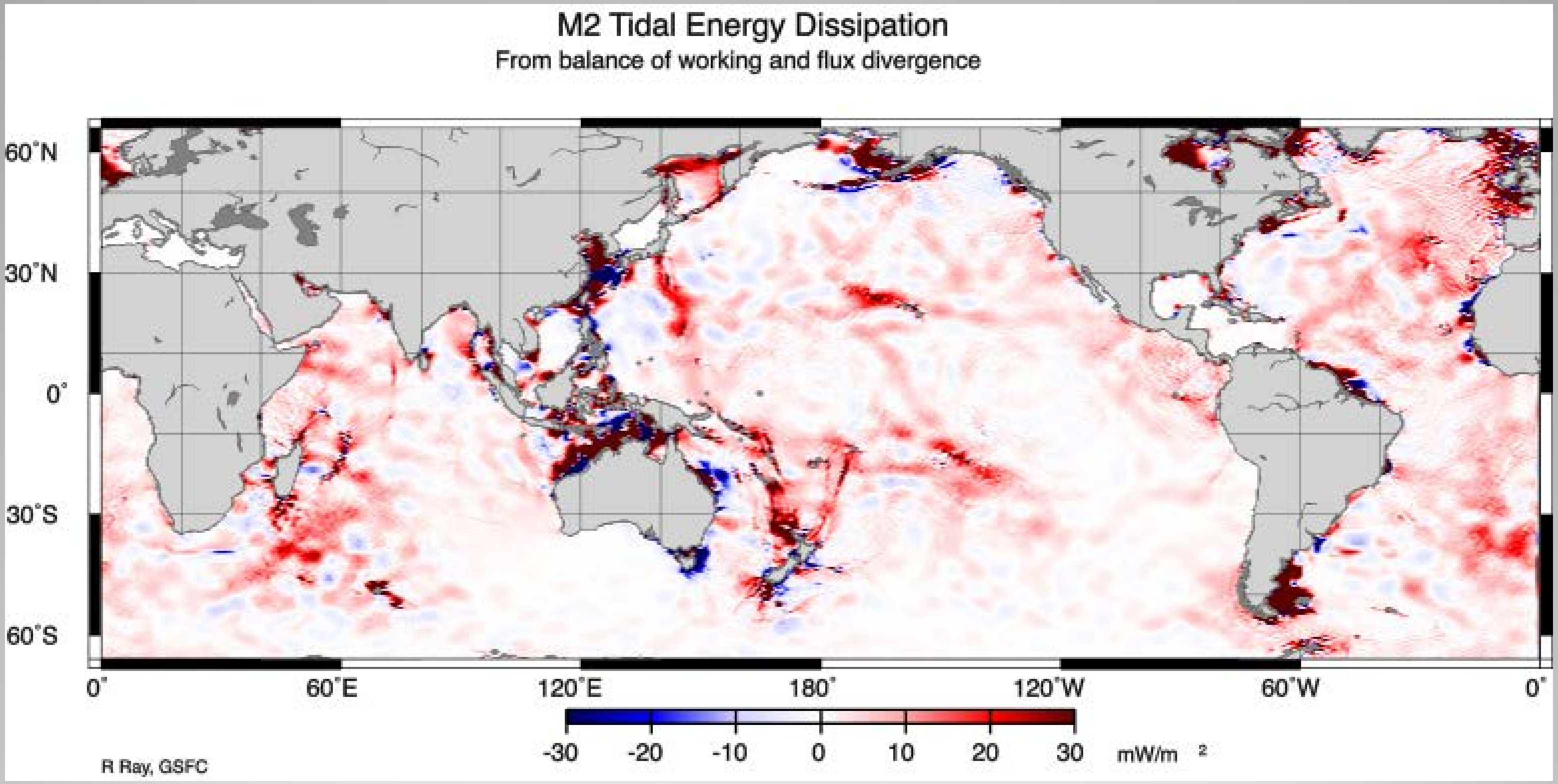


Cross section at 180º
(before EUC hits the surface)

Sources of Ocean Mixing

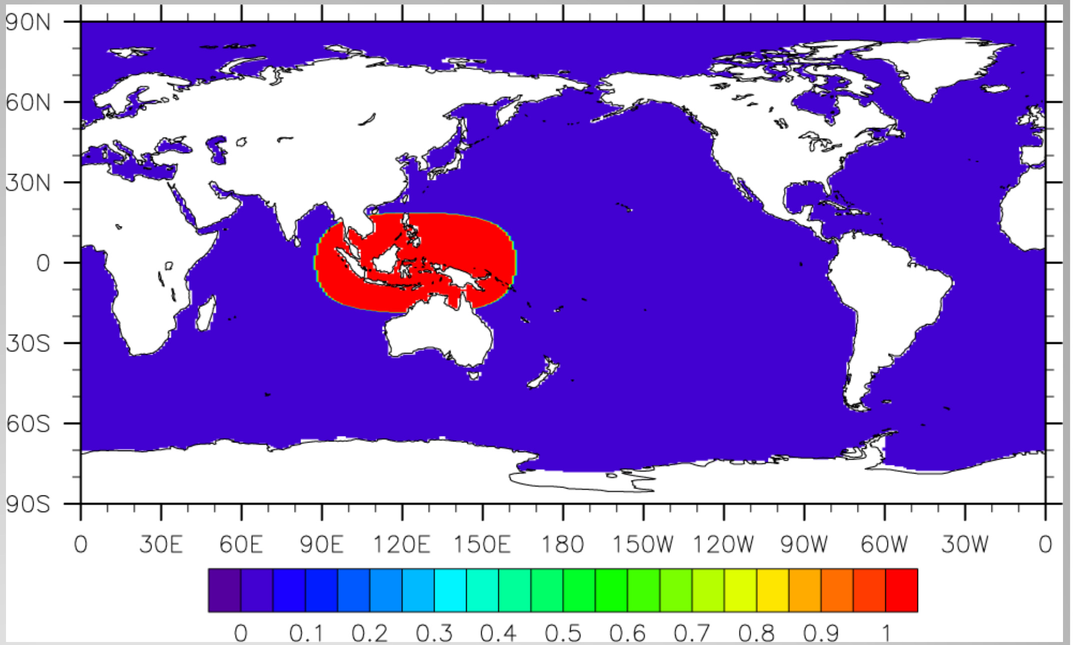
- What are the sources of mixing in the ocean?
  - Wind-driven stirring
    - *Relatively well constrained*
    - *Already parameterised in climate models*
  - Tidal generation of internal waves
  - Biota
  - Hurricanes
    - *Could be important*
    - *Needs a lot of work – get a grad student to do it*

Nasa



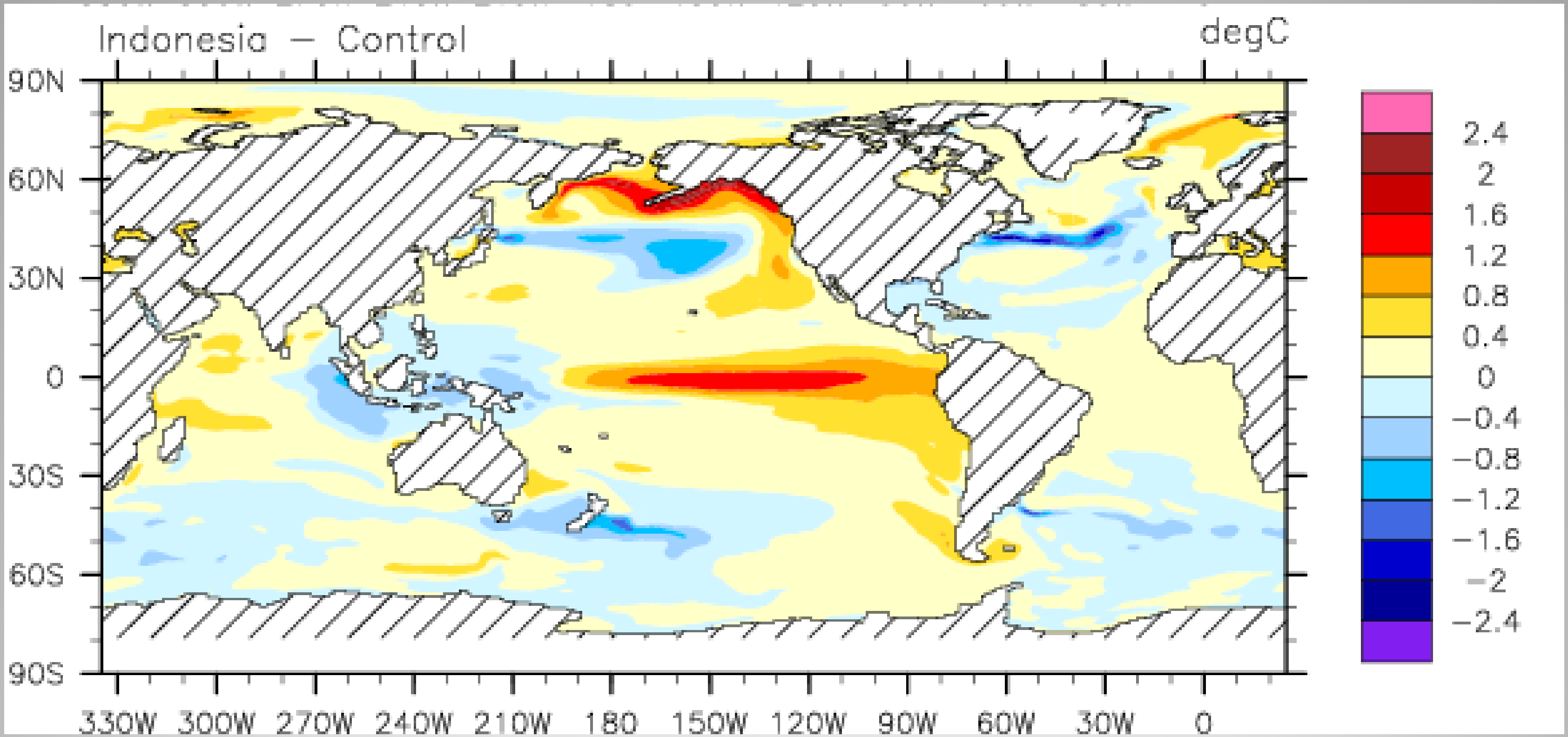
Spatial pattern of tidal energy

- Add area of increased mixing over Indonesia from surface to 200m
- 1/1000th of maximum calculated value



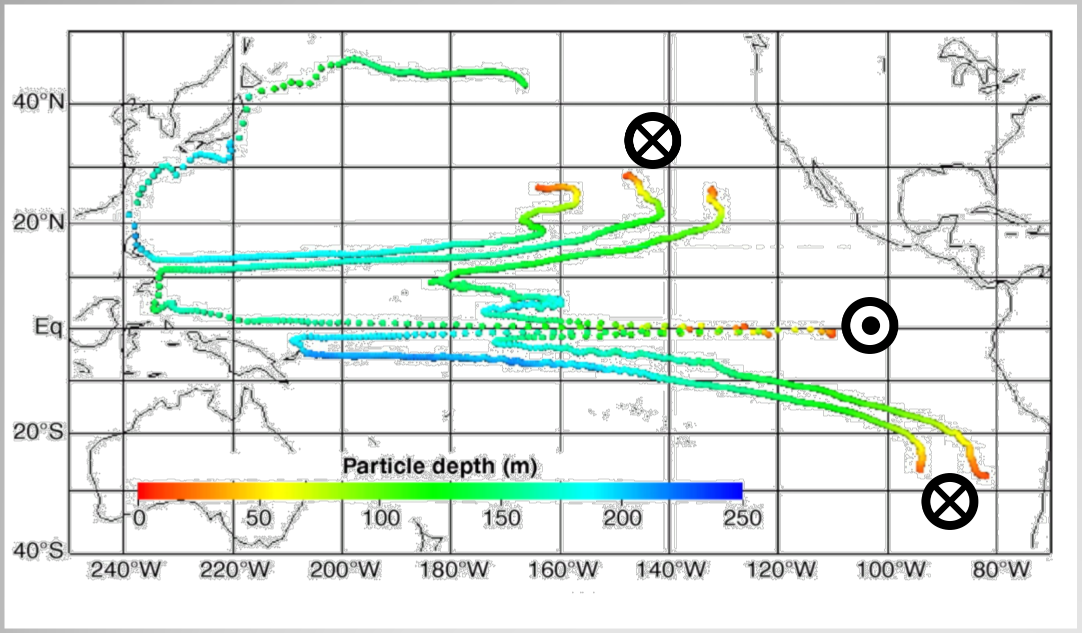
Additional imposed K_V averaged over top 100m (10^{-4} m^2s^{-1})

Is changing bathymetry important?



SST maximum in Tropics ~1.5°C (less than hurricanes)
Impacts in North Pacific, but run is not equilibrated yet

Impact on SST



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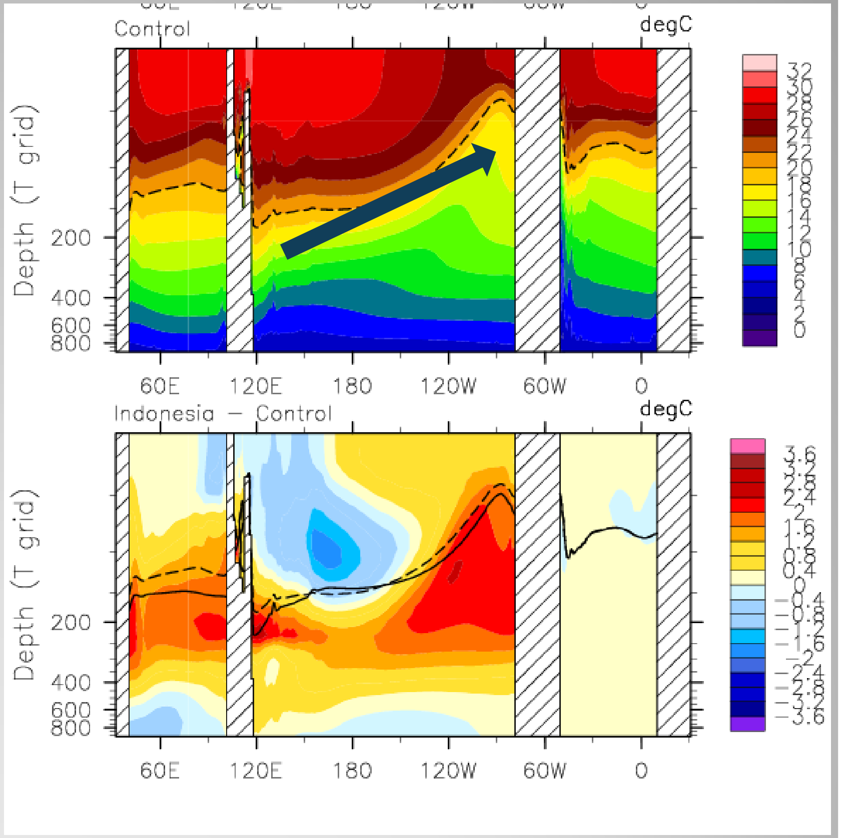
The Wind-driven Subtropical Cell

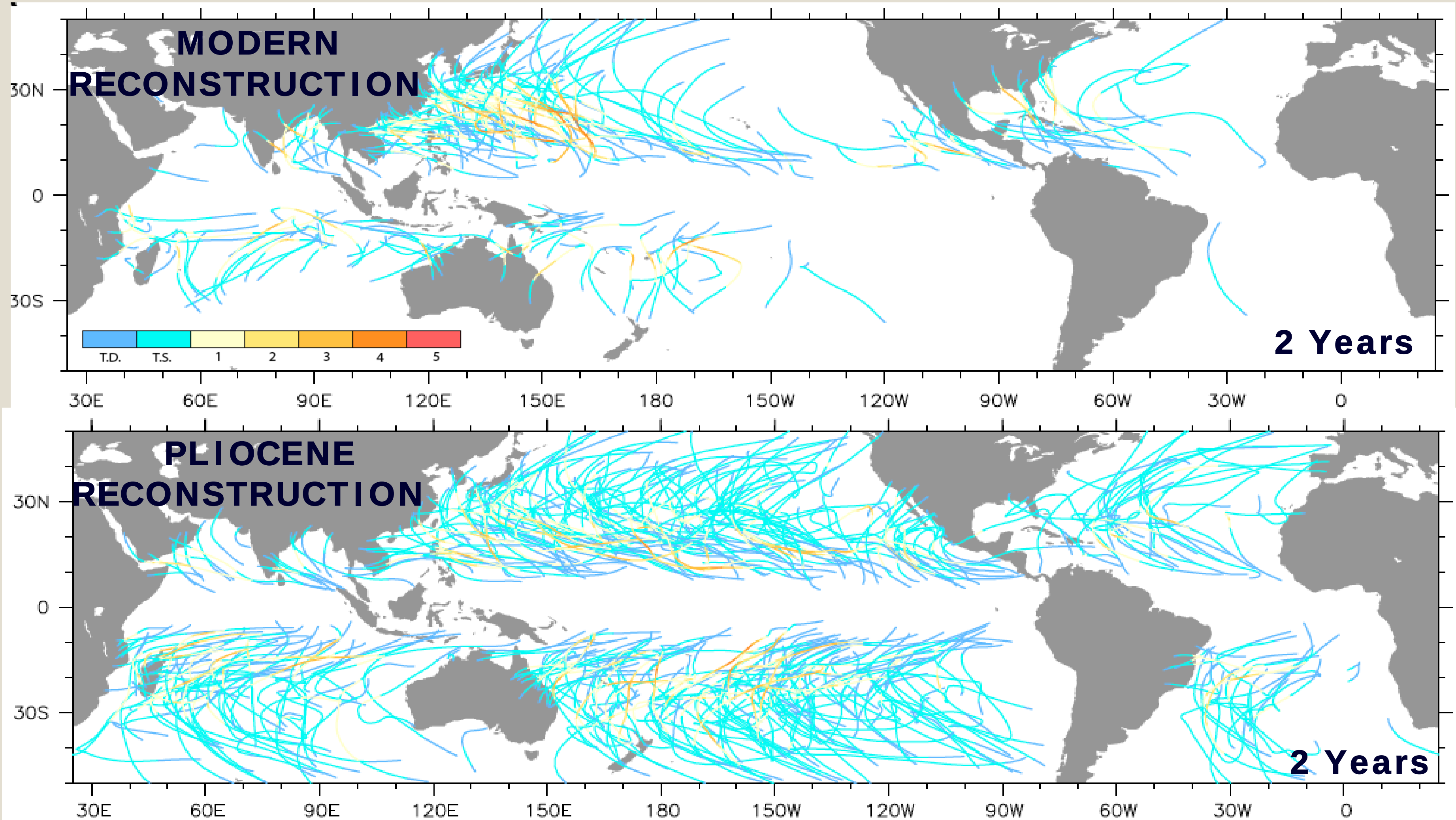
Mechanism of Tidal Warmth

- Tidal mixing over Indonesia deepens mixed layer
- More warmth enters EUC
- Warmer upwelling
- Only impacts top of EUC, which reaches surface further west



Conclusions

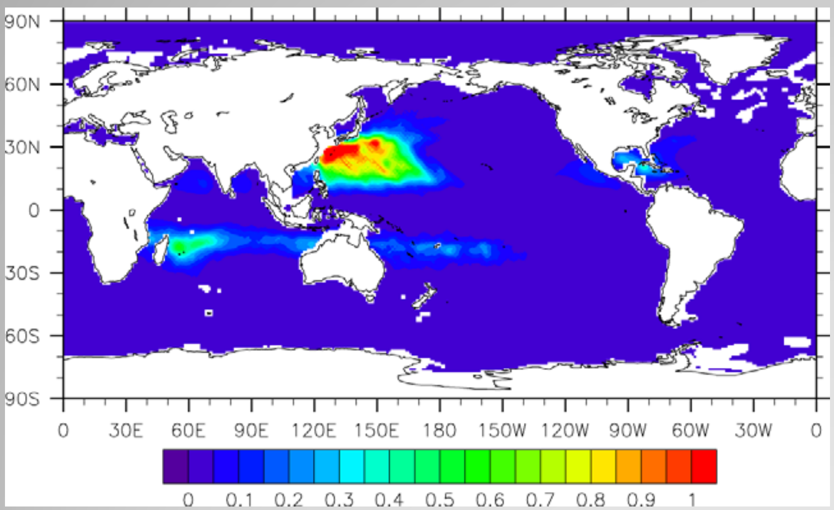
- There is vertical mixing in the ocean, which comes from a variety of sources
- Uncertainty & changes in vertical mixing in the ocean has climatic consequences
- Considering the sources individually may reduce that uncertainty (rather than having a single term do it all)
- Ocean could be sensitive to both tides and hurricanes



Reconstructed Hurricanes

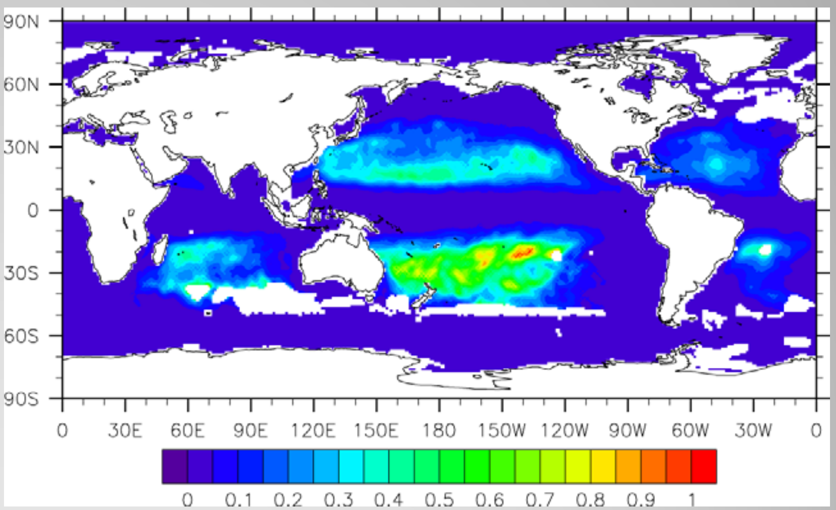
Hurricane K_V Fields - Modeled

Present Day



Maximum of $10^{-4}m^2s^{-1}$

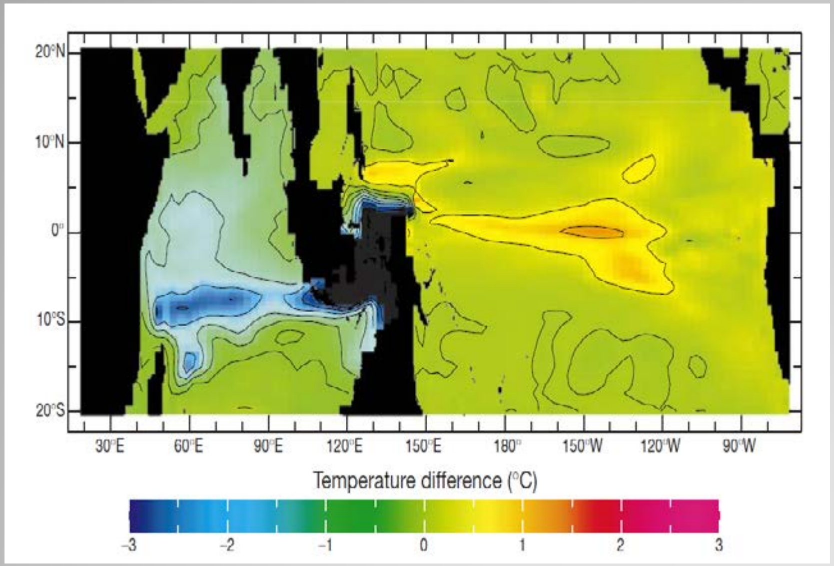
Pliocene



Maximum of $10^{-4}m^2s^{-1}$, much broader bands

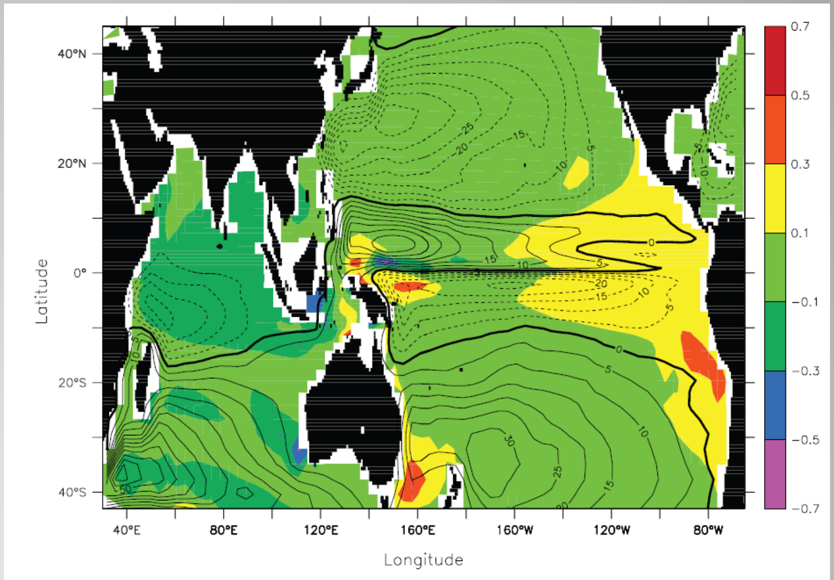
Climate simulations with altered Indonesian bathymetry

Cane & Molnar, 2001



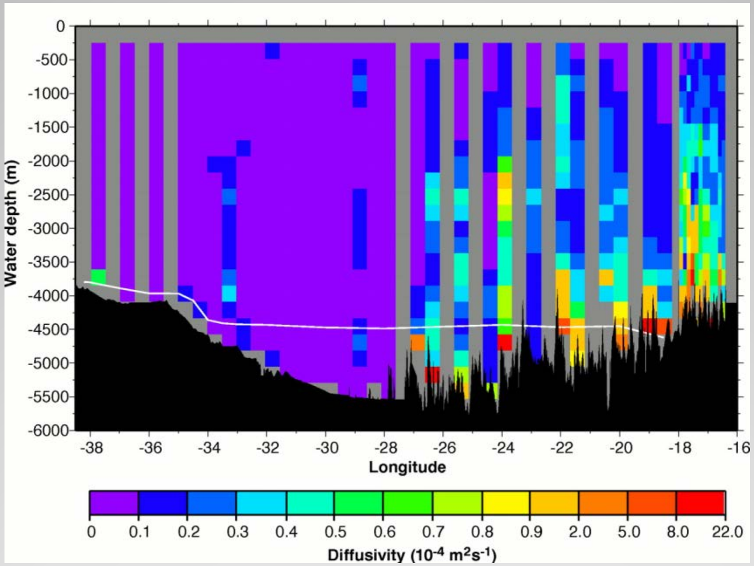
Maximum of 1°C at 100m

Jochum et al, 2009



Maximum of 0.1°C at 150m

- Moon’s Orbit is stable
- Roughness of the ocean bottom is not:



- Changes in Isthmus of Panama and Indonesia over past 5 Myrs

Changes in Tidal Mixing?