Using millennial AOGCM simulation as a laboratory to derive and test hypotheses

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Overview

1. General philosophy
2. The millennial simulation(s)
3. Example of deriving hypotheses
   – variability of coastal currents and coastal upwelling
4. Examples of testing hypotheses
   - Linkage link between hemispheric temperature and regional upwelling
   - Linkage between thermal expansion of sea level and temperature variations

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General philosophy

Two major problems in climate science are:

1) Hypotheses are tested with the same data, from which they are derived (Mexican hat paradoxon).

2) Time series of observational data often do not cover multiples of the involved characteristic time scales.

AOGCM millennial simulations are useful tools to overcome these problems:

- Hypotheses derived from observational evidence may be tested with independent simulation data.
- Hypotheses about dynamical links may be derived from time series much longer than the time scales involved.

General philosophy

Problem:

Simulations may be “false”

- in terms of the forcing administered or its experimental design
- in their descriptions of timing, intensity, response characteristics to external forcing etc.
- in terms of the model’s internal dynamics.

But inconsistencies between hypotheses derived from empirical evidence and simulations point to a problem which needs to be examined in more detail.

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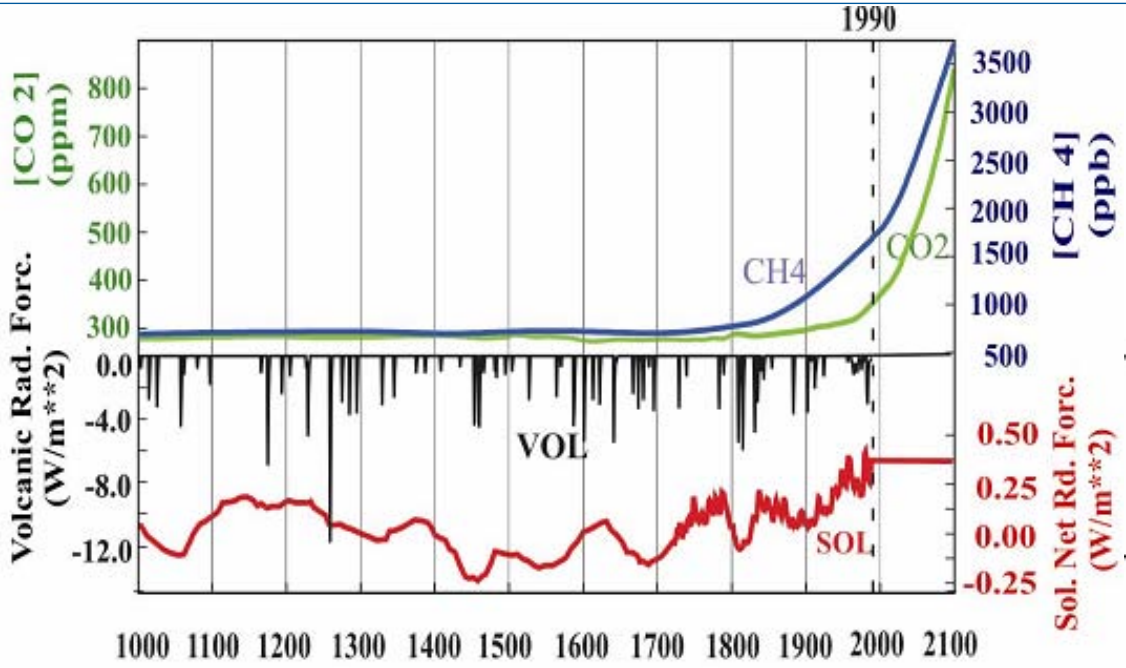
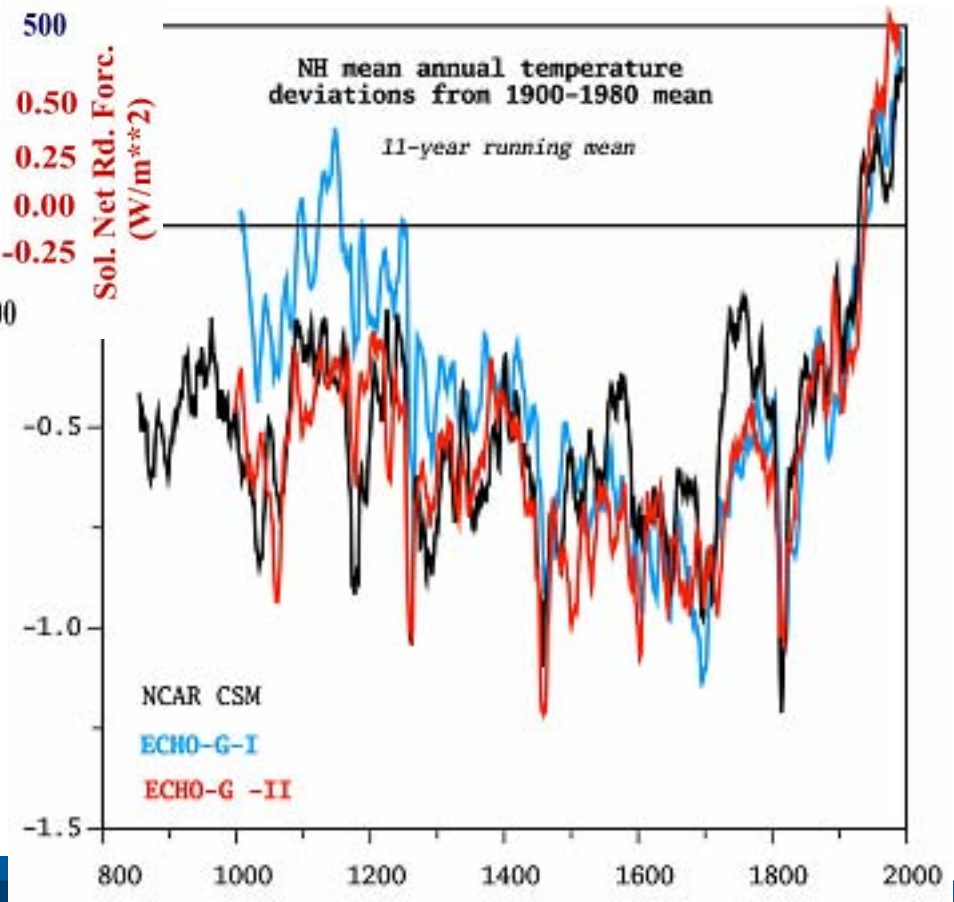
Millennial simulations with ECHO-G: “Erik” (1 and 2)



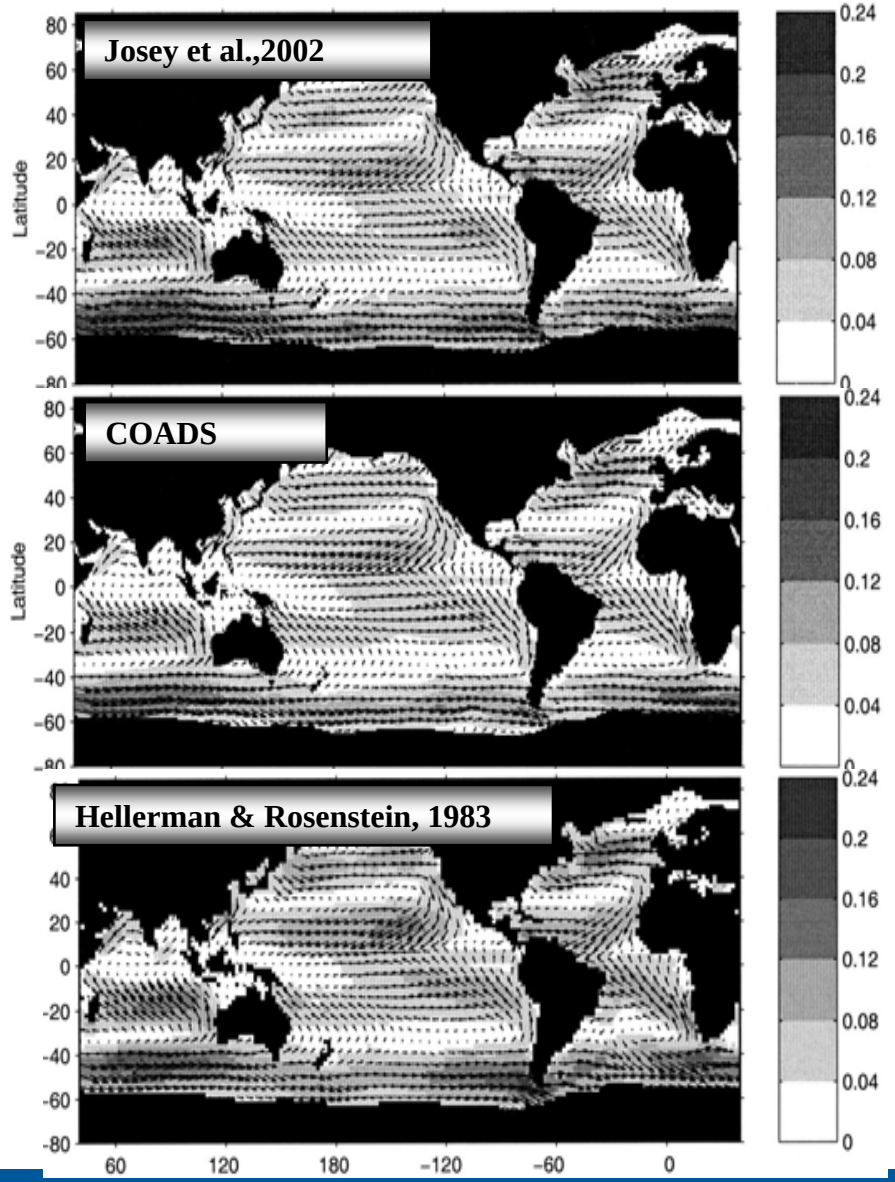


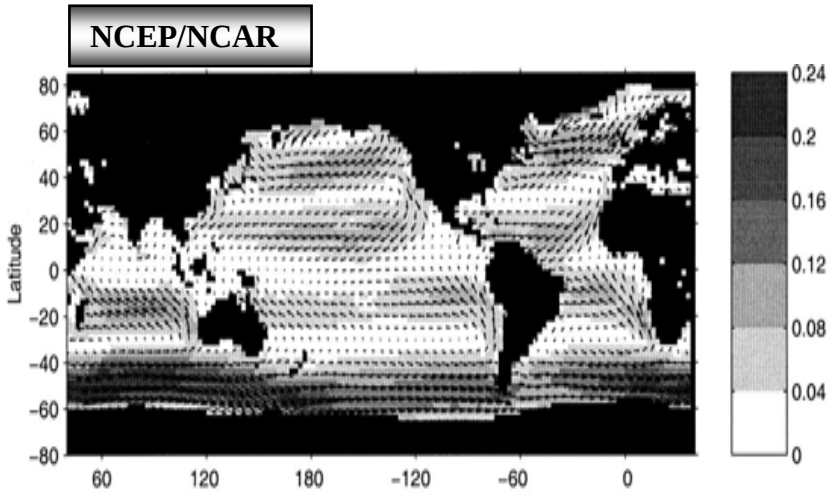
Millennial simulations with ECHO-G (ECHAM 4 T30, HOPE-G T42),

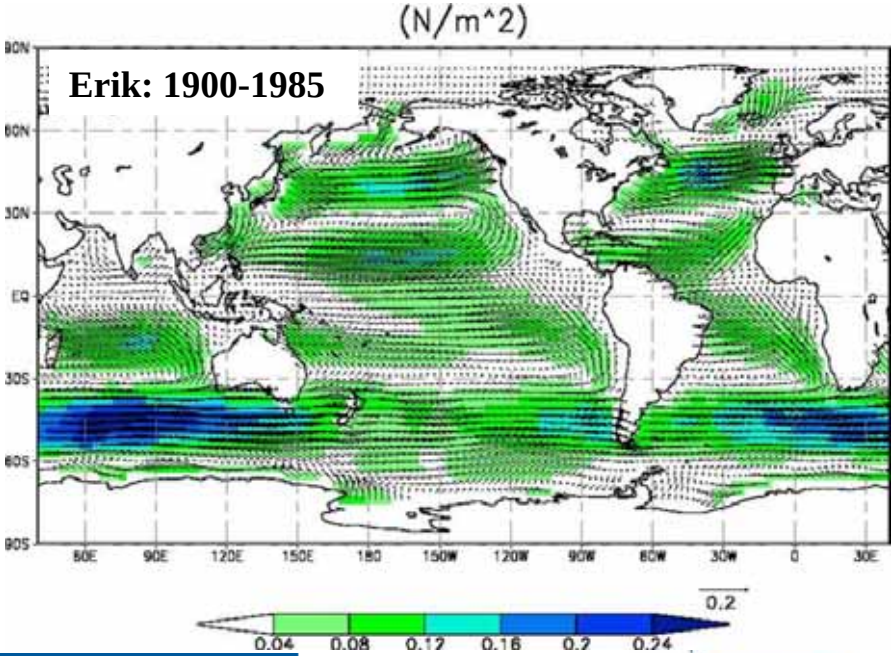
Run with estimated volcanic, solar and GHG forcings.

Started with different initial conditions

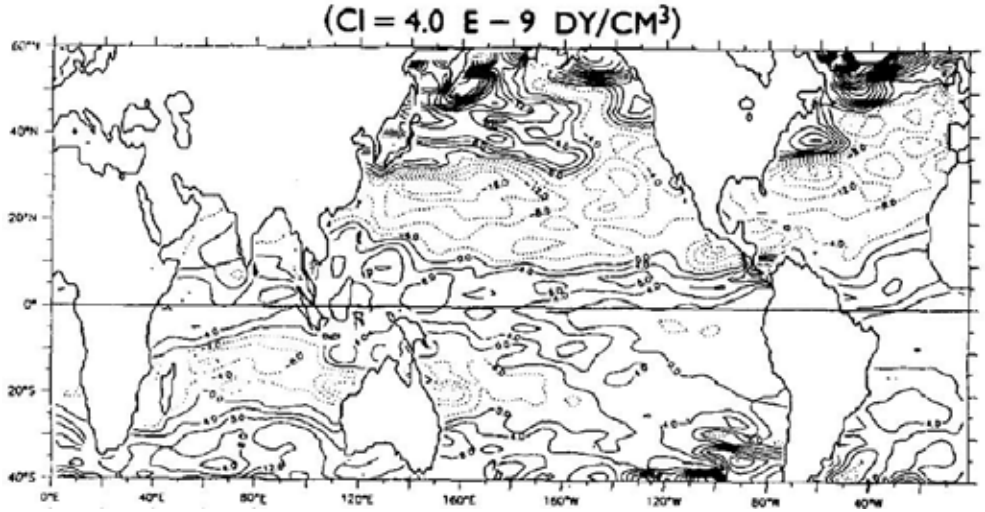
Climatological annual mean wind stress



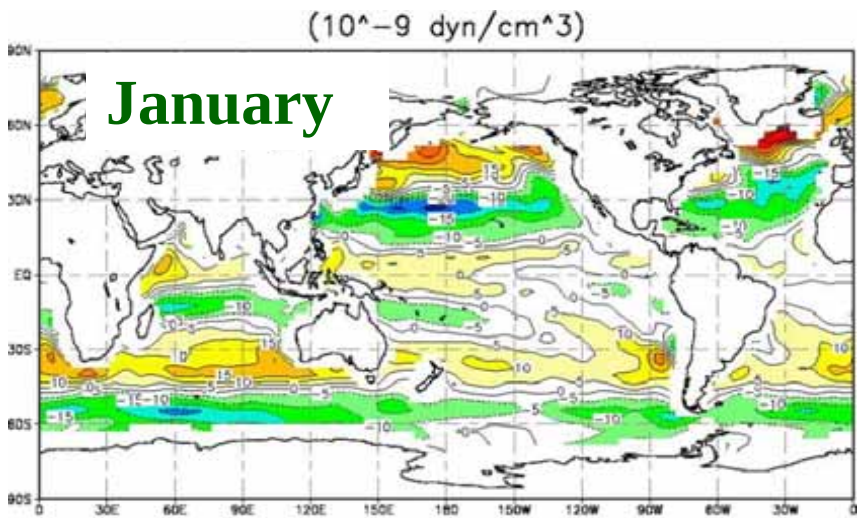




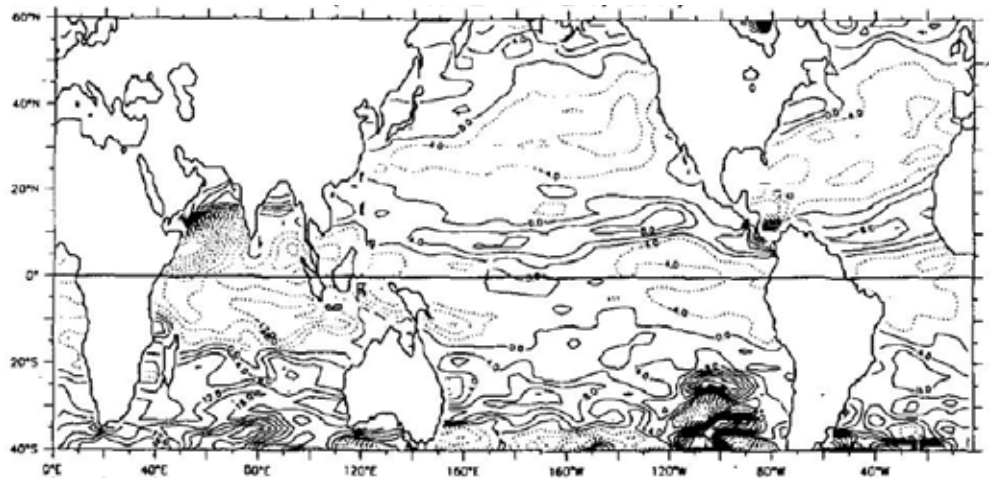
Climatological annual mean wind stress curl

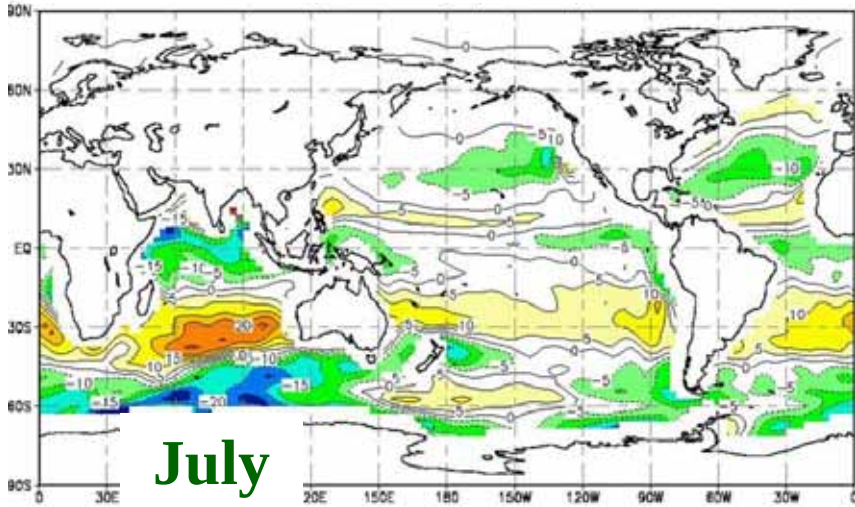


Harrison, 1989



ECHO-G: 1900-1985





Model shows no massive, first order deviations from empirically derived atmospheric statistics.

But: Coastal resolution insufficient in the ocean model!

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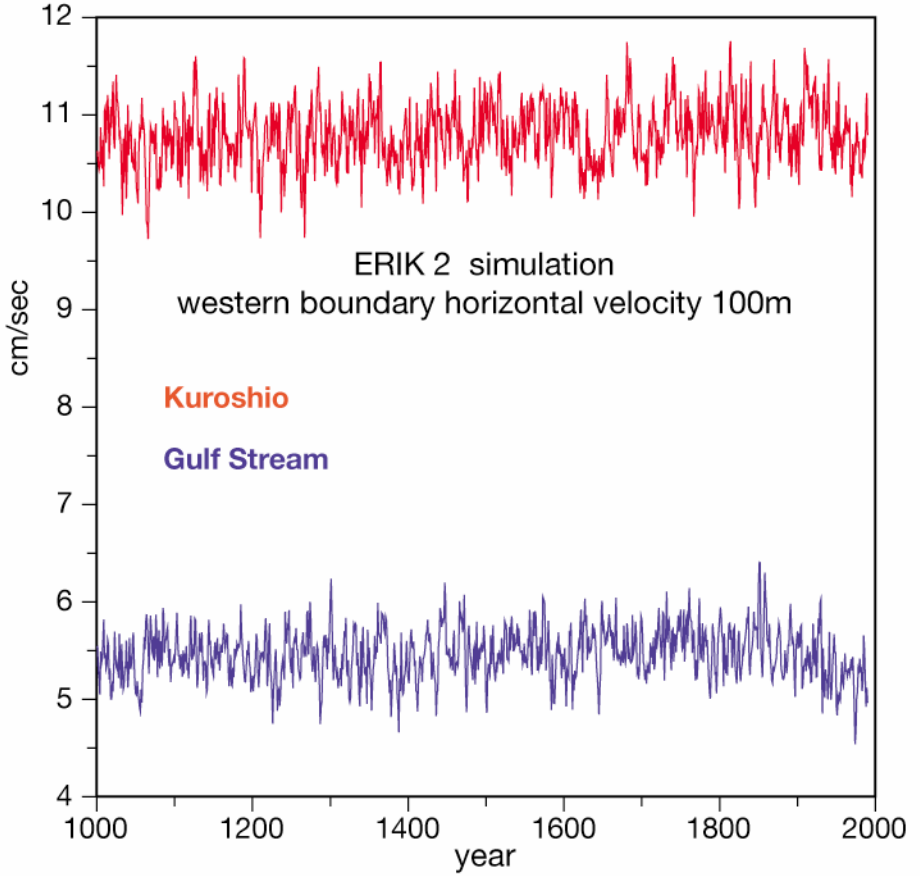
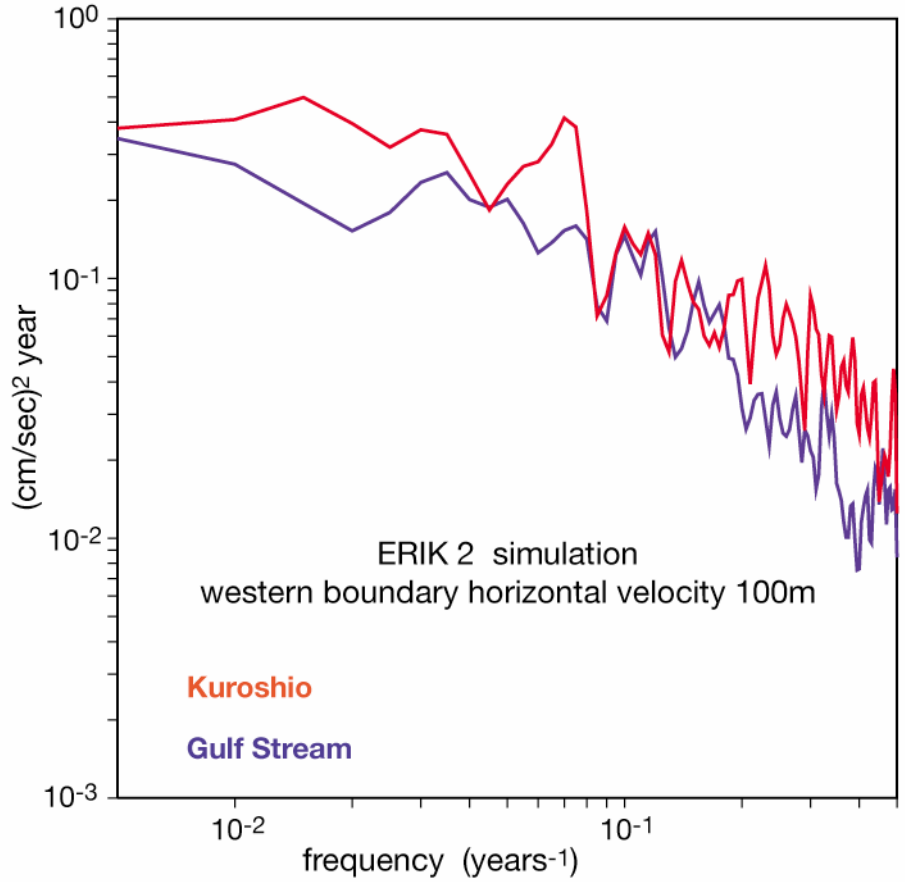
Coastal Currents

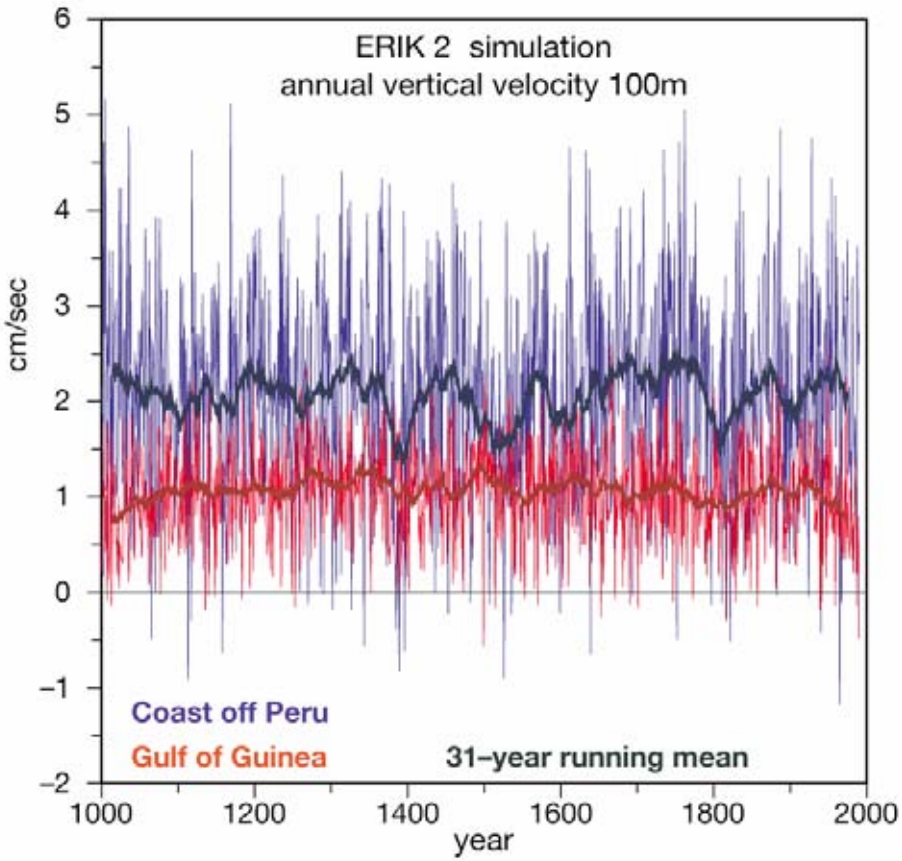


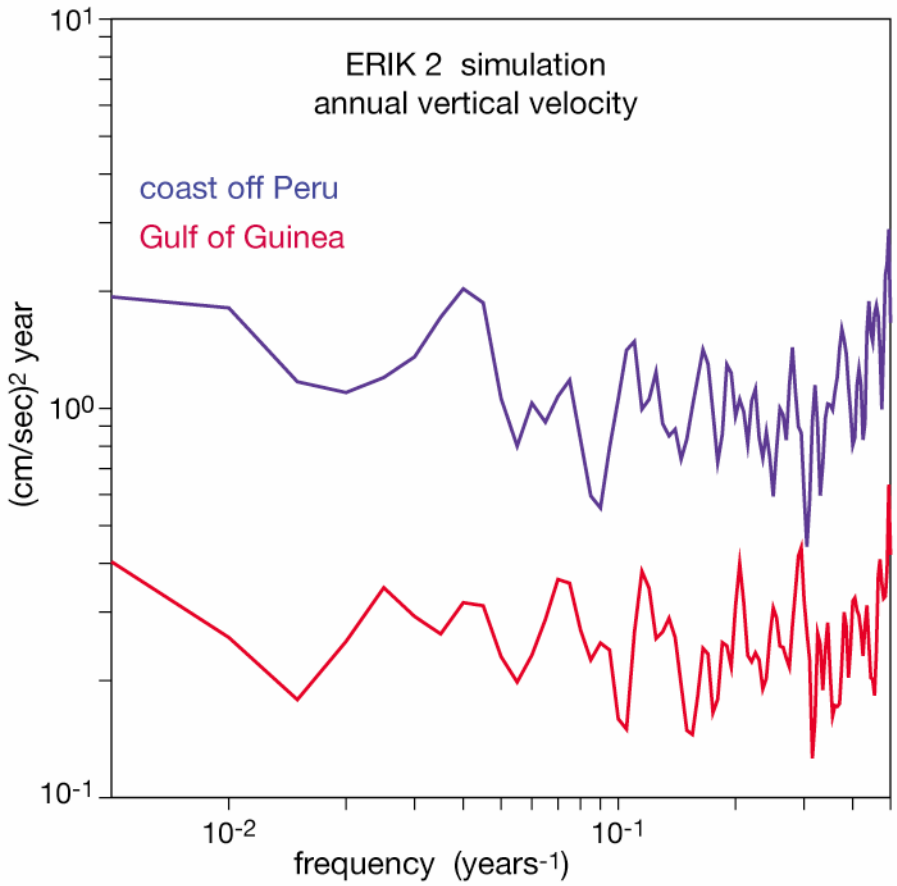


Stochastic climate model at work?

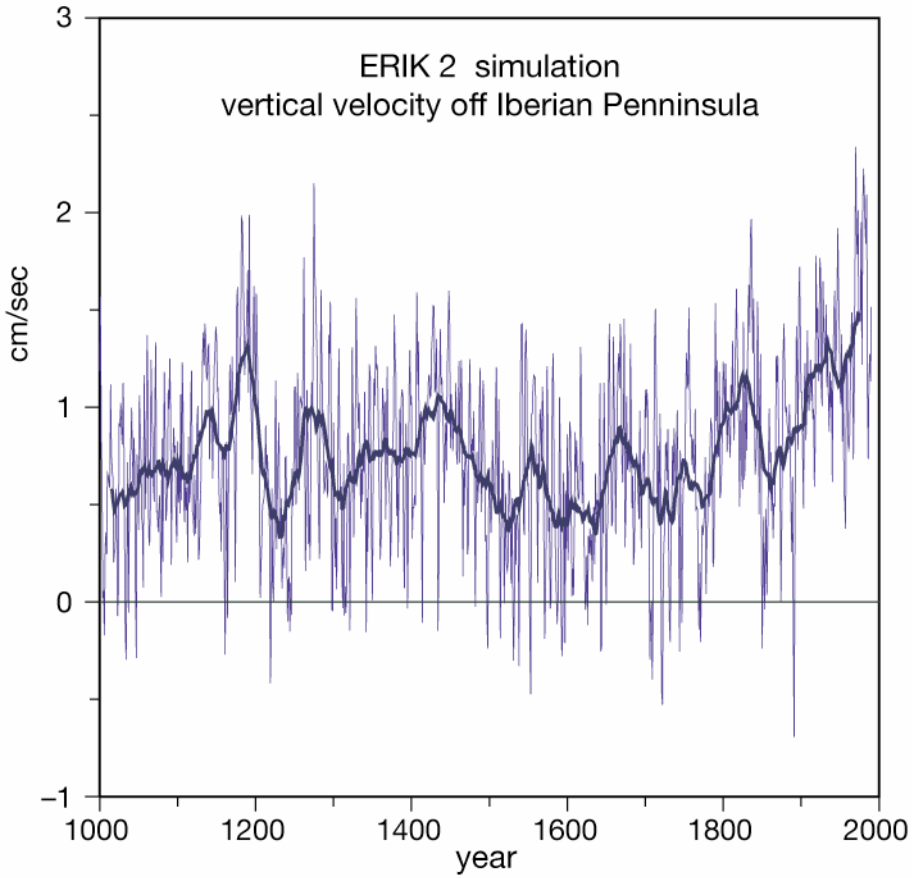
Hasselmann, K., 1976: Stochastic climate models. Part I. Theory. Tellus 28, 473-485

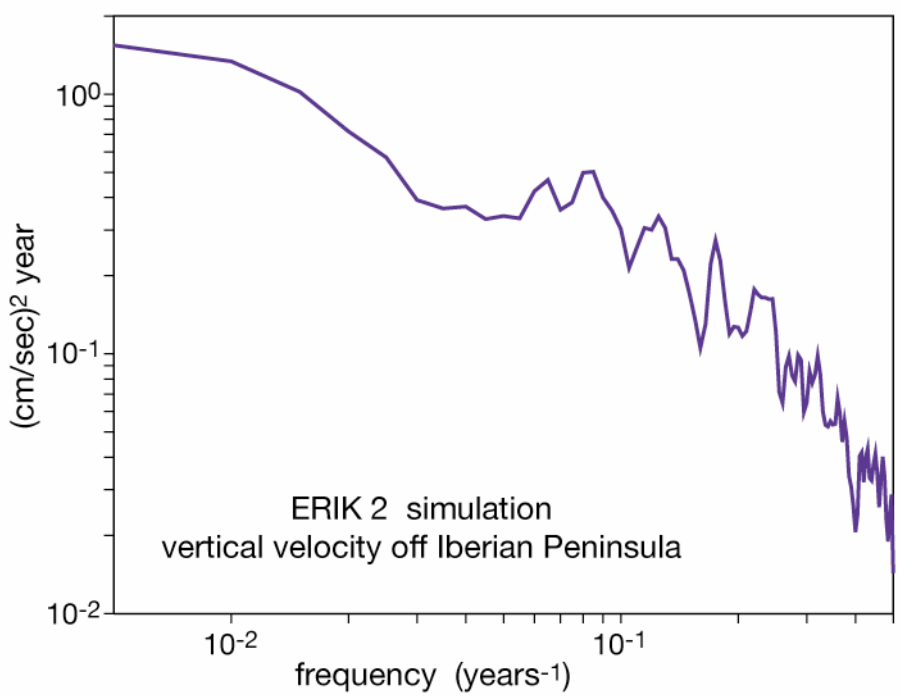
Upwelling at lower latitudes





Upwelling at midlatitudes





Result of integrating winds?

See also: Frankignoul, Müller and Zorita, 1997: A Simple Model of the Decadal Response of the Ocean to Stochastic Wind Forcing, J. Phys. Oceano. 27:1533-1546

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Mc Gregor et al., 2007 on Marocco coast

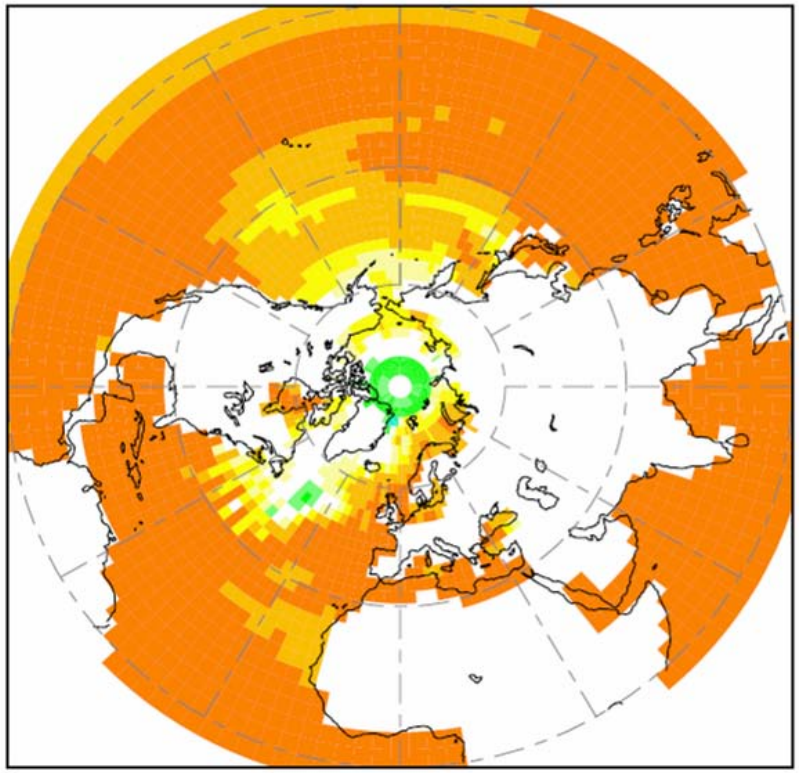
Upwelling-driven SSTs also vary out of phase with millennial-scale changes in Northern Hemisphere temperature anomalies (NHTAs).

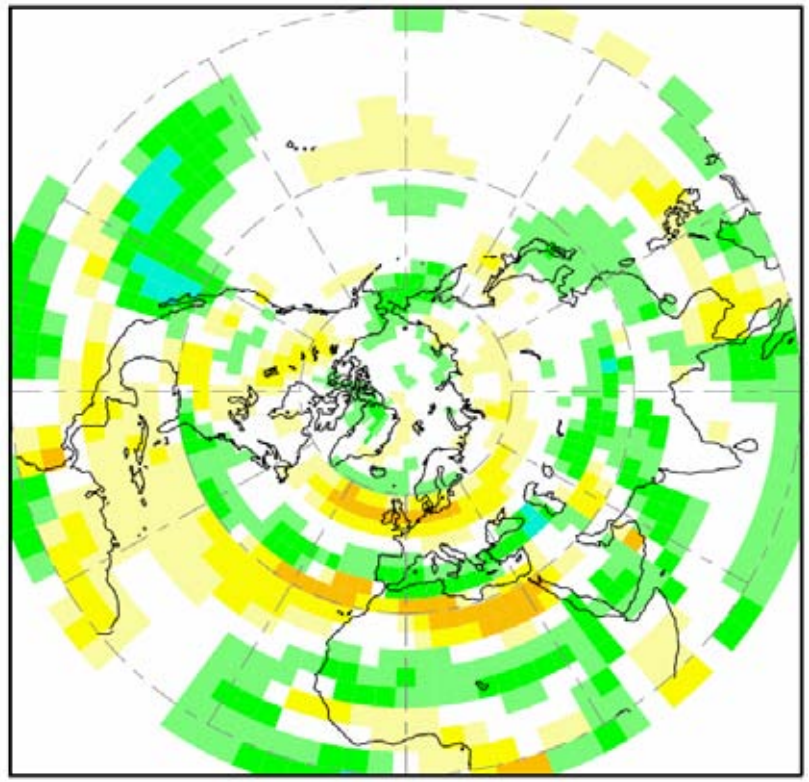
… results suggest that coastal upwelling varies with NHTAs and that upwelling off northwest Africa may continue to intensify as global warming … increase.

Black et al 1999 focus on Cariaco Basis. They argue that the trade winds enhance upwelling and local cooling. Hemispheric warming would be anti-correlated with local SST.

McGregor et al 2007 & Black et al 1999

Link NHTA – trade winds ?





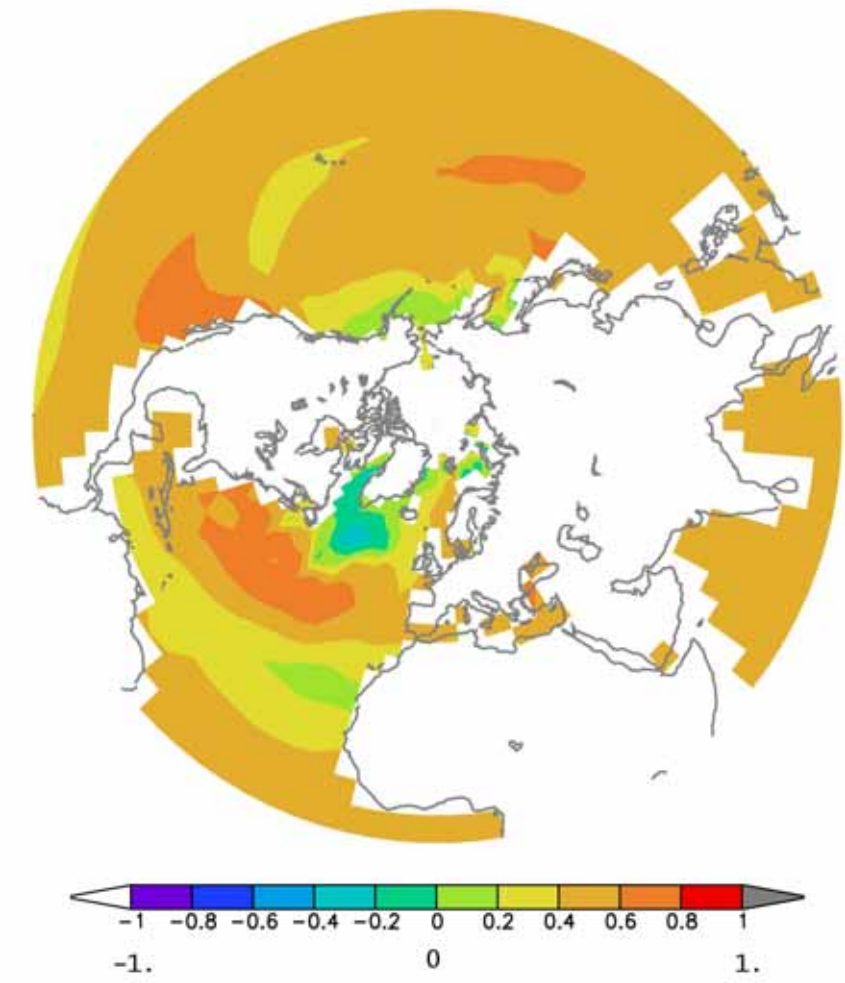
X = SST

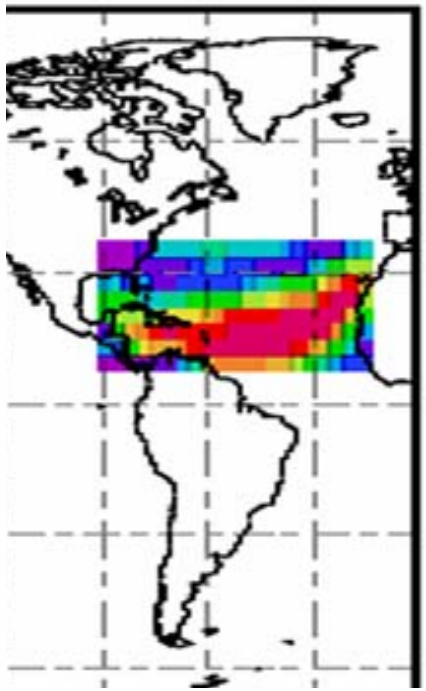
X = wind speed (10 m)

Correlations of NH air temperature and X.
21yr low pass filtered annual data from Erik 2 (1000-2000)

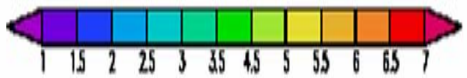
Link regional trade winds – SST?

Correlation of 21 year running mean regional SST and Atlantic trade wind speed (averaged across region shown)

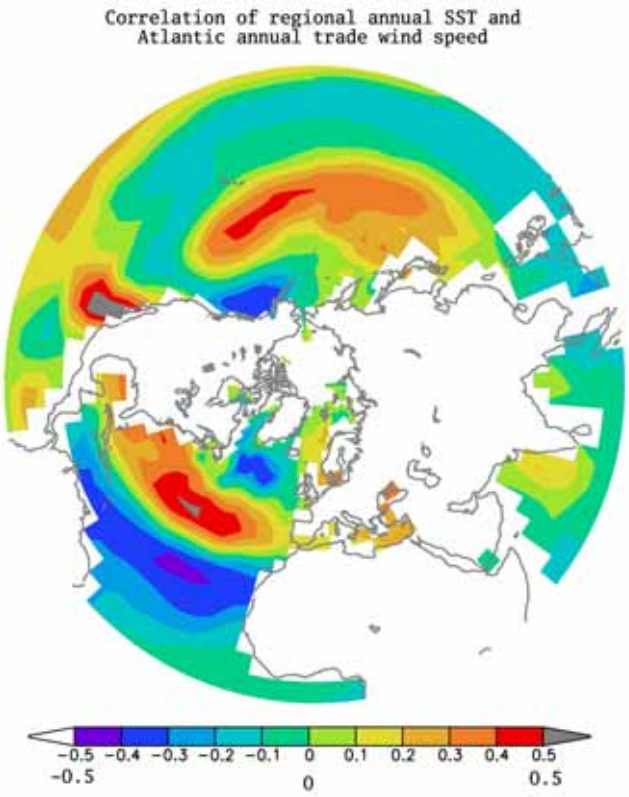


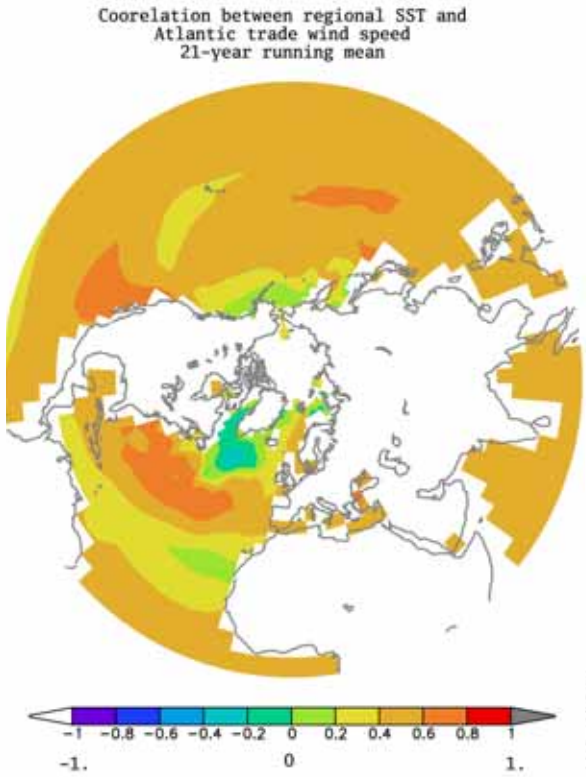


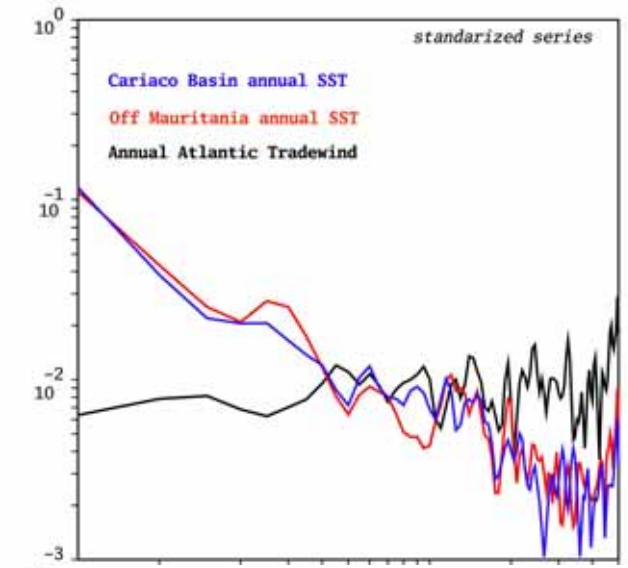
Mean trade wind speed

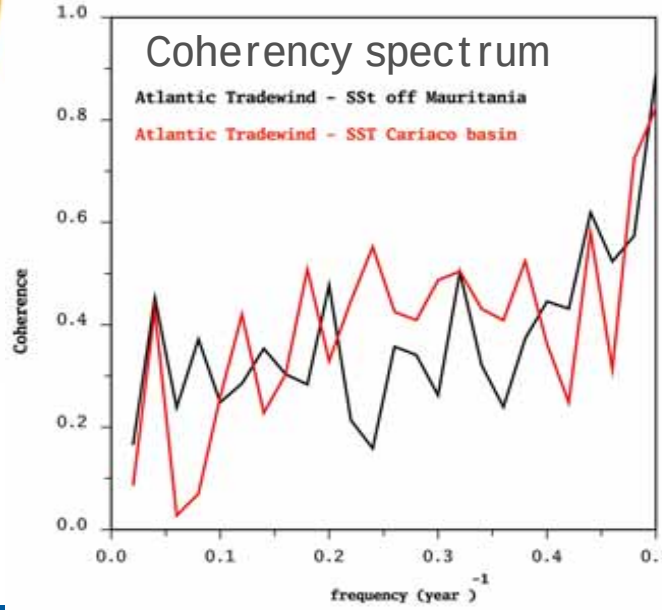


Time scale dependent link regional trade winds – SST?









Correlation of regional SST and Atlantic trade wind speed

Conclusion

McGregor et al (and, to some extent, Black et al) suggests

a) Link NHTA – trade wind system: positive correlation

b) Link trade wind – regional SST: negative correlation

In ECHO-G

a) weak link

b) strongly depend on time scale; on short time scale direct link; on longer time scales – stochastic climate model at work (white > red).

Significance of hypothesized links not supported in AOGCM laboratory.

Link: Sea level - temperature

Testing

$H \approx aT$

$dH/dt \approx aT-T$

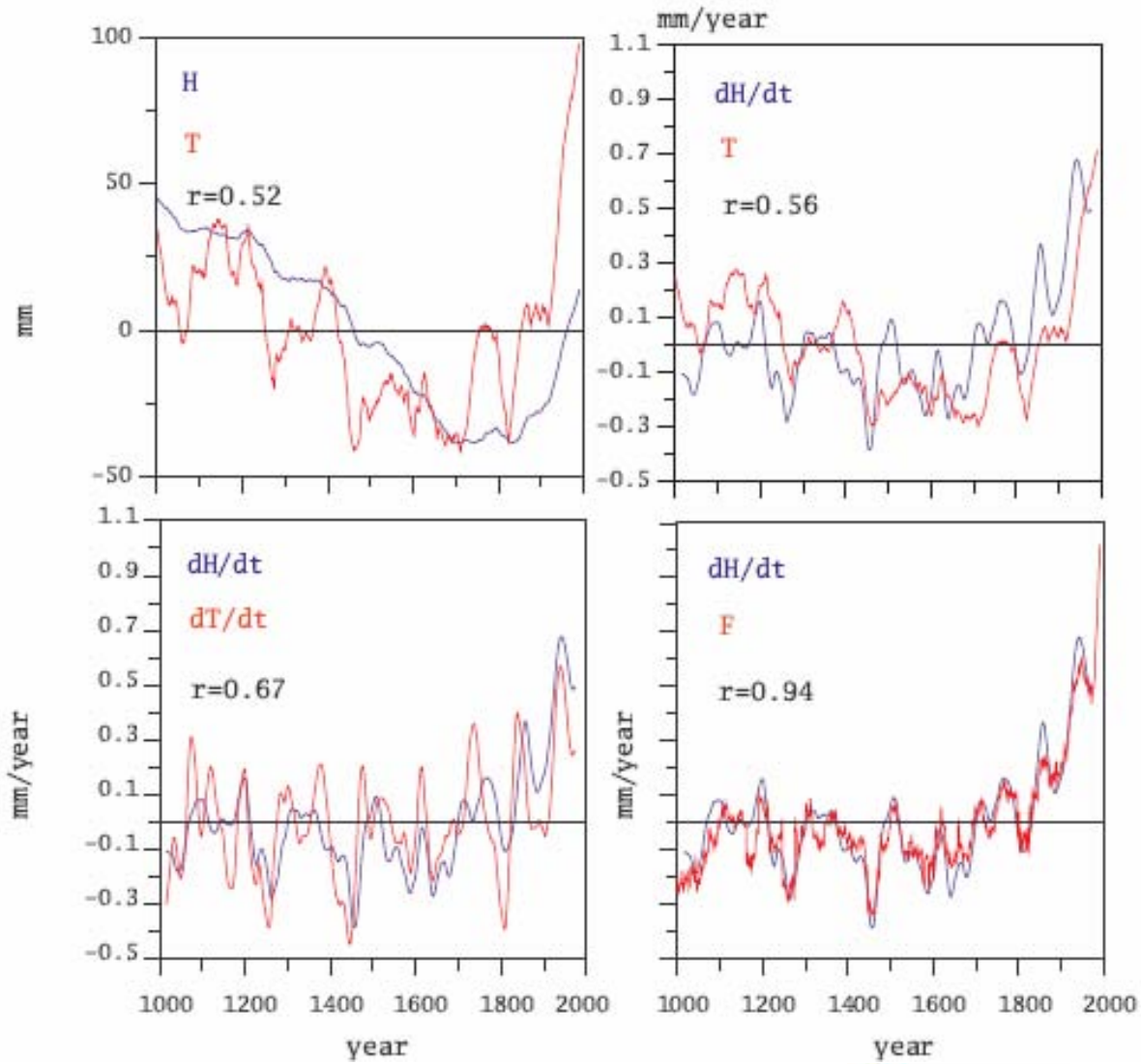
$dH/dt \approx dT/dt$

$dH/dt \approx F$

H sea level (thermal expansion) deviation from previous level H_o

T temperature deviation from previous level T_o

F heat flux

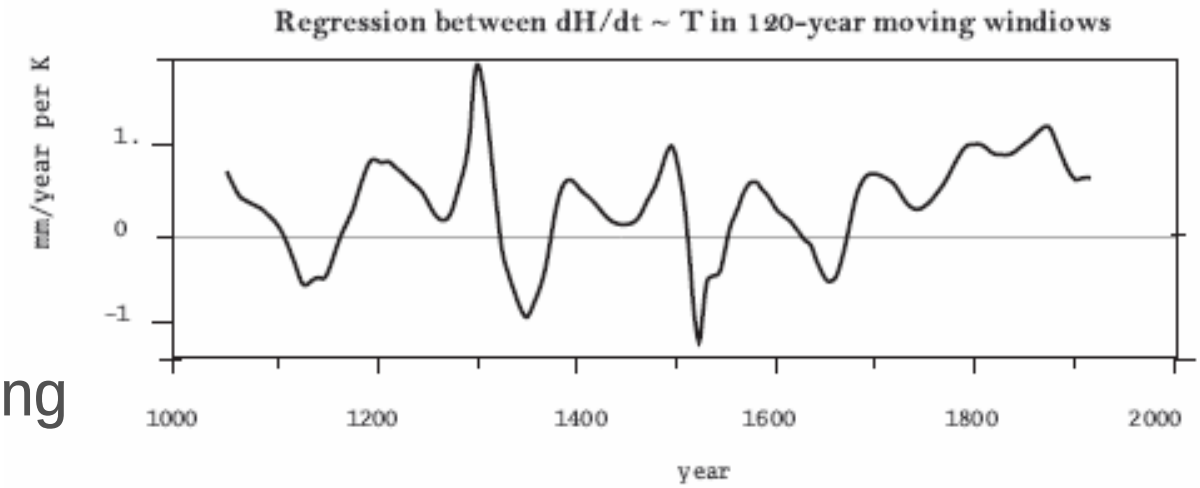


Link:
Sea level tendency- temperature

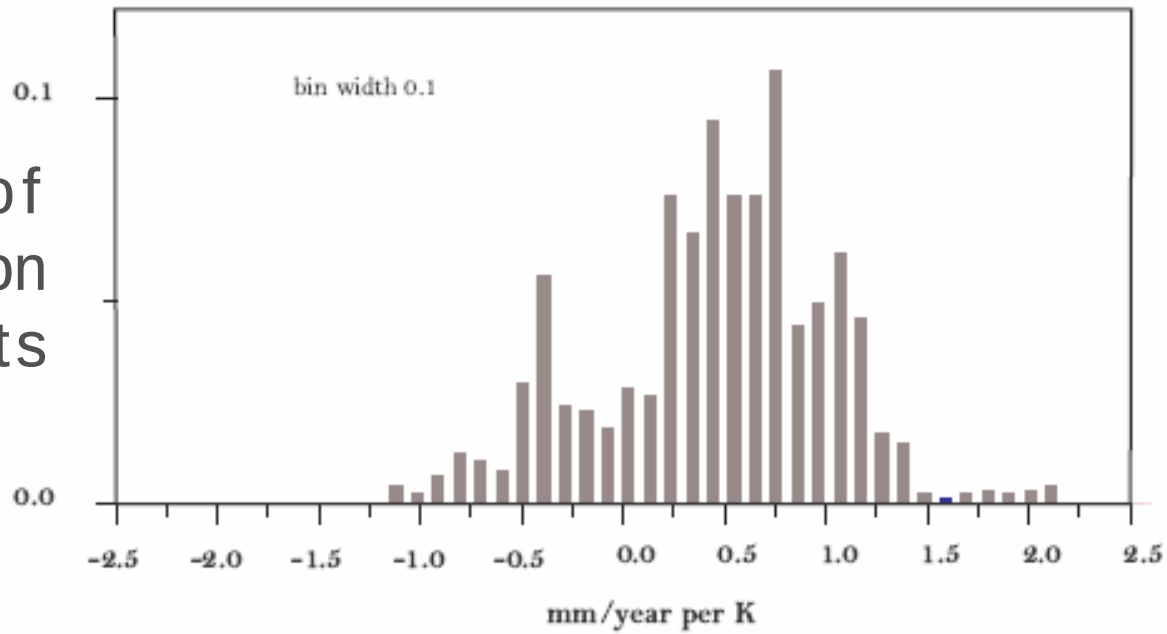
Fitting the model

$dH/dt \approx aT$

to data drawn from moving 120 year moving intervals.



Distribution of estimated regression coefficients



Not a stable estimate.

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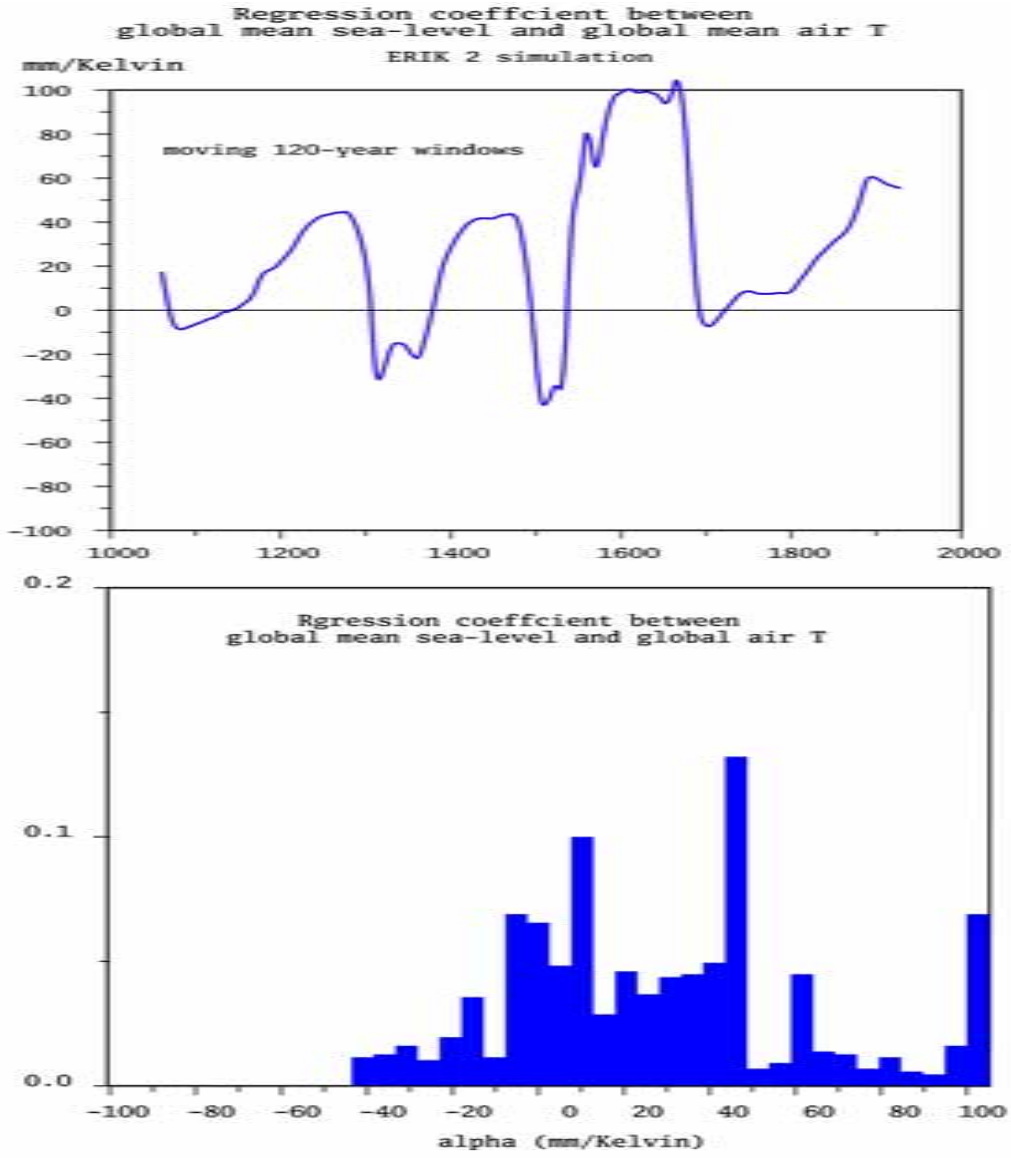

Conclusions

Many climatic studies, in particular when related to slow components of the climate system, suffer

- from too short time series

- which exhibit long memory or even instationarities.

Thus, many conclusions are drawn from comparing trends – which may be ok if a solid physical insight is backing the analysis.

Perspective: Use co-integration - when analysis has speculative character (as in case of the two examples).

See also comment by Schmith et al. (2007; comment on Rahmstorf's attempt to "improve" IPCC estimates for sea level rise)

Overall conclusions

1) Millennial (and longer) AOGCMs are good laboratories to test hypotheses,
   - which are sensitive to too short observational records, or
   – which are based on data with heavy overload of interpretation with respect to physical properties, timing, inhomogeneities (in particular proxies).

2) First order hypothesis on dynamical links may be derived from AOGCM simulations, and then tested by “real” data.

3) AOGCMs are not perfect. Some features are better resolved than others: Coastal features are badly resolved.

4) Several simulations, constructed with different AOGCMs and different forcing histories, should be used.