IPCC-class climate models: Issues for fisheries applications

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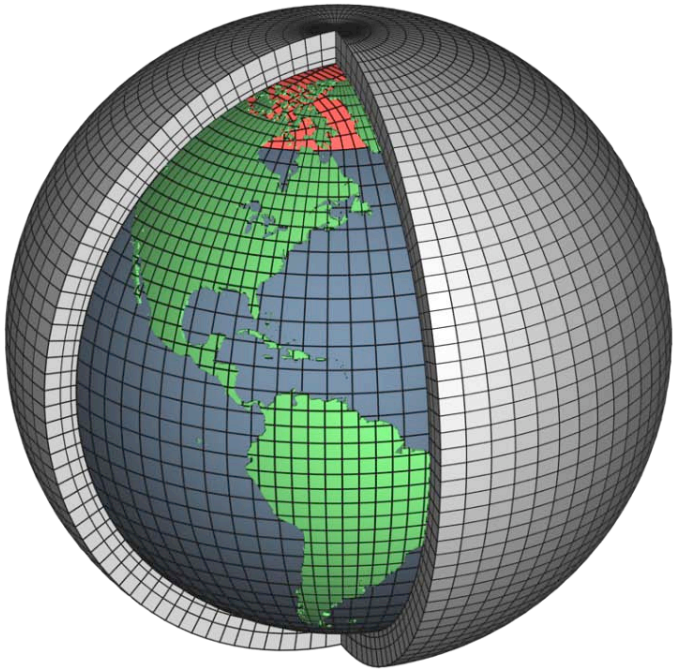
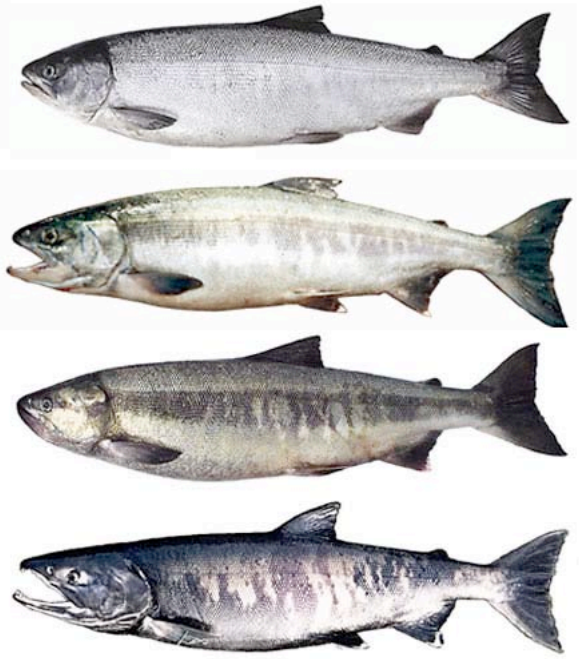




Salmon images: wdfw.wa.gov

Outline

- Introduction

From IPCC-class models to the fish, issues:

- Resolution
- Inter-model spread
- Internal variability
- Summary

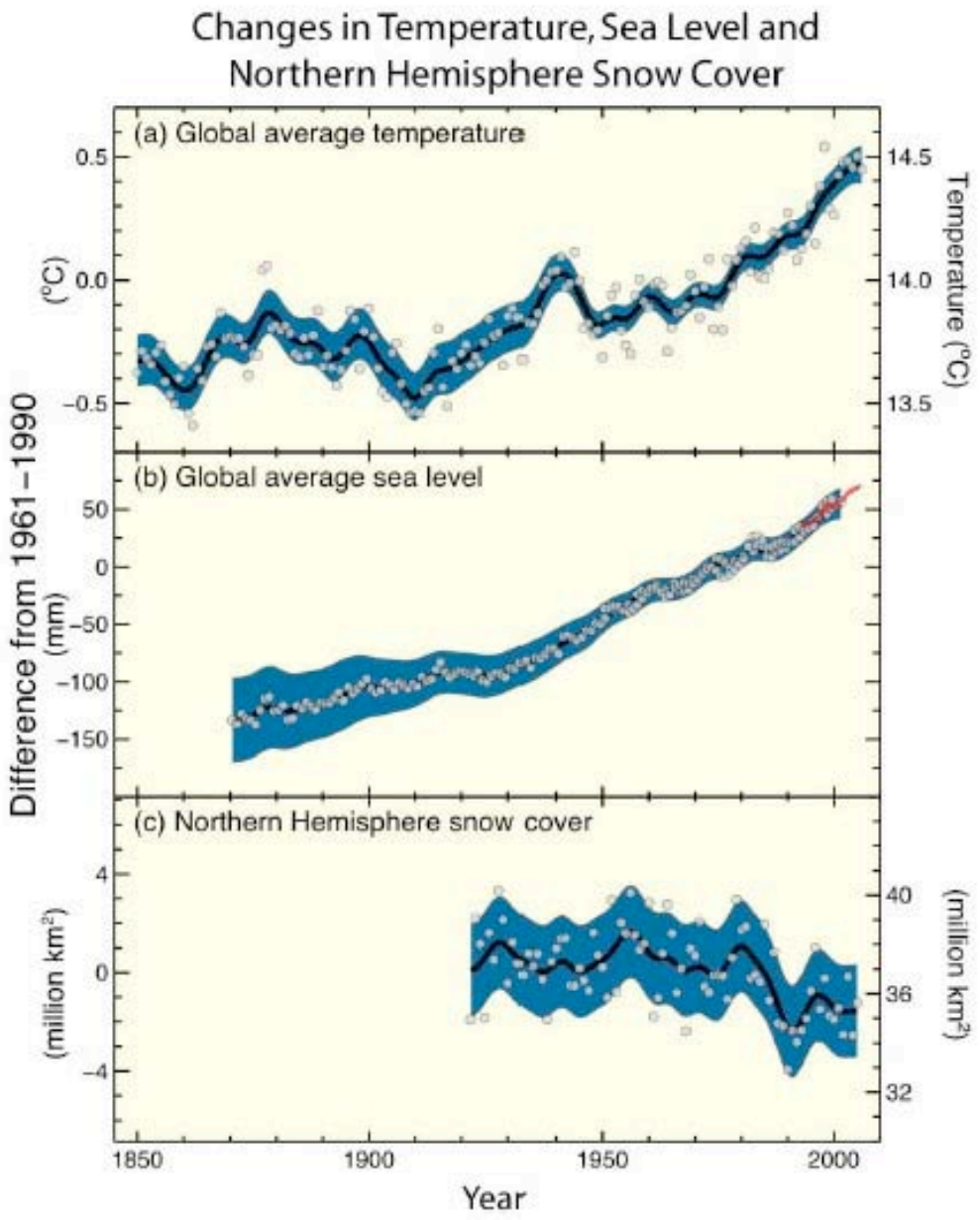
Observational Evidence:

Sfc Air Temp. Warming

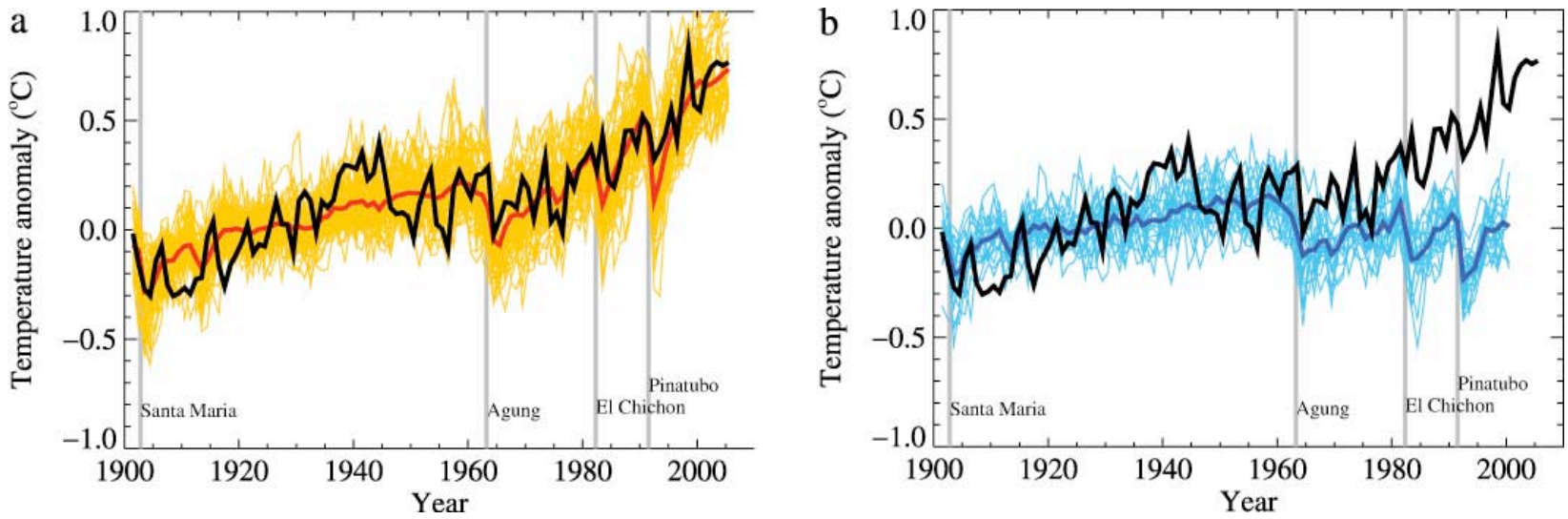
Global Avg. Sea Level Rising

N.H. Snow Cover Decreasing

Significance of trends determined from obs & modeled internal varibility

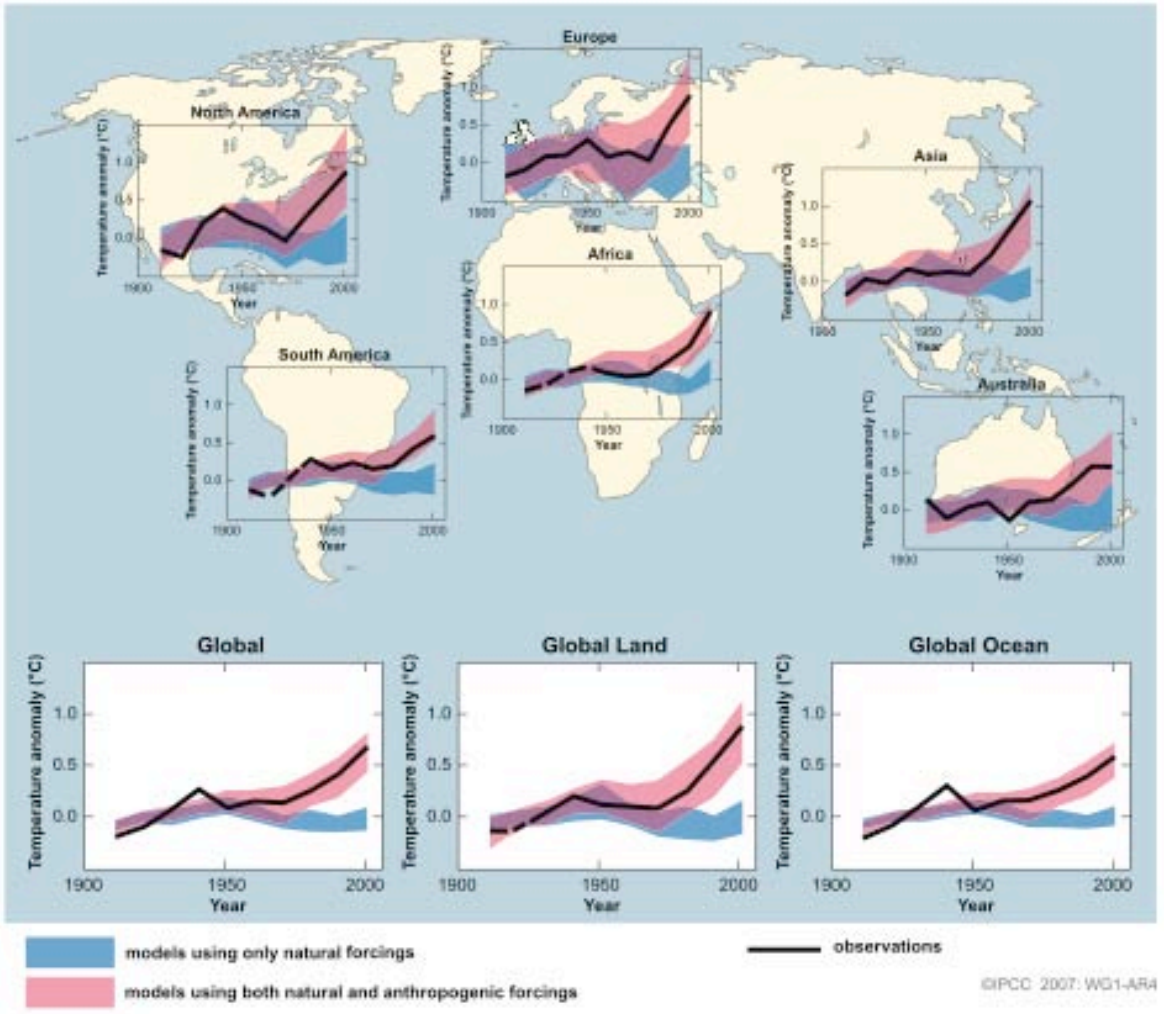


Historical global temperature changes radiatively forced: long-term warming largely anthropogenic



IPCC-AR4 (2007)

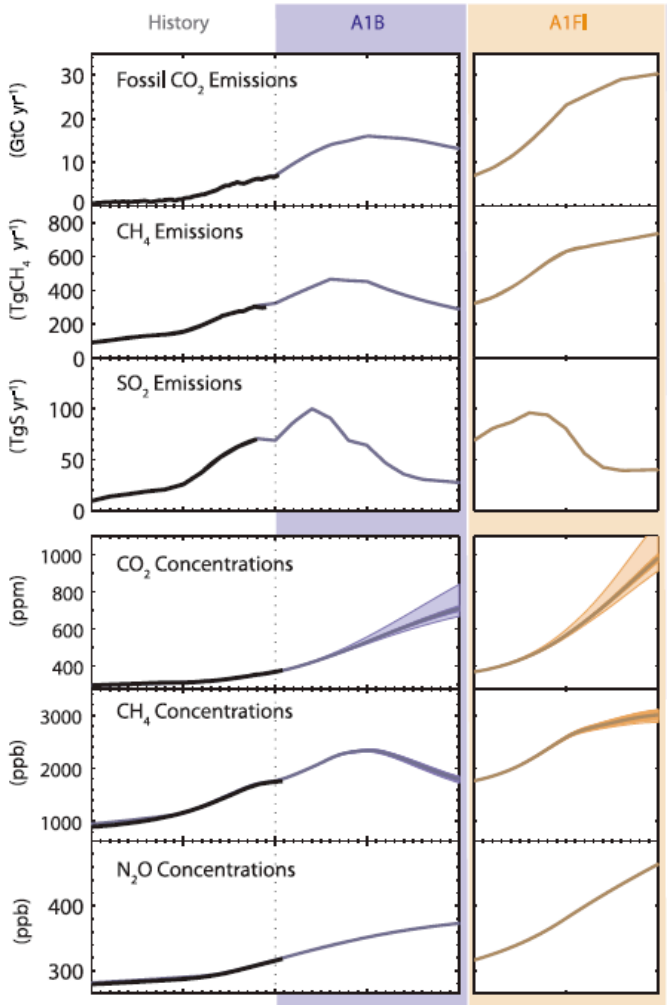
Regional SAT Warming Radiatively Forced



IPCC-AR4 (2007)

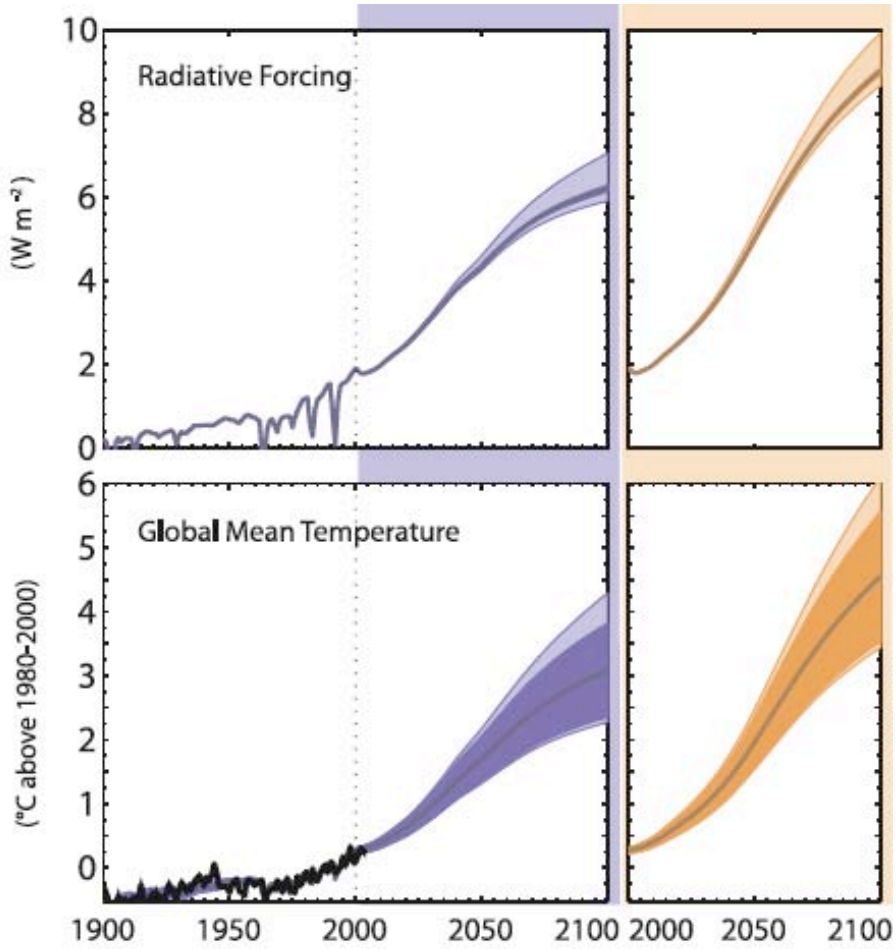
Radiative forcing and global temperature

Greenhouse gas emiss.



Greenhouse gas conc.

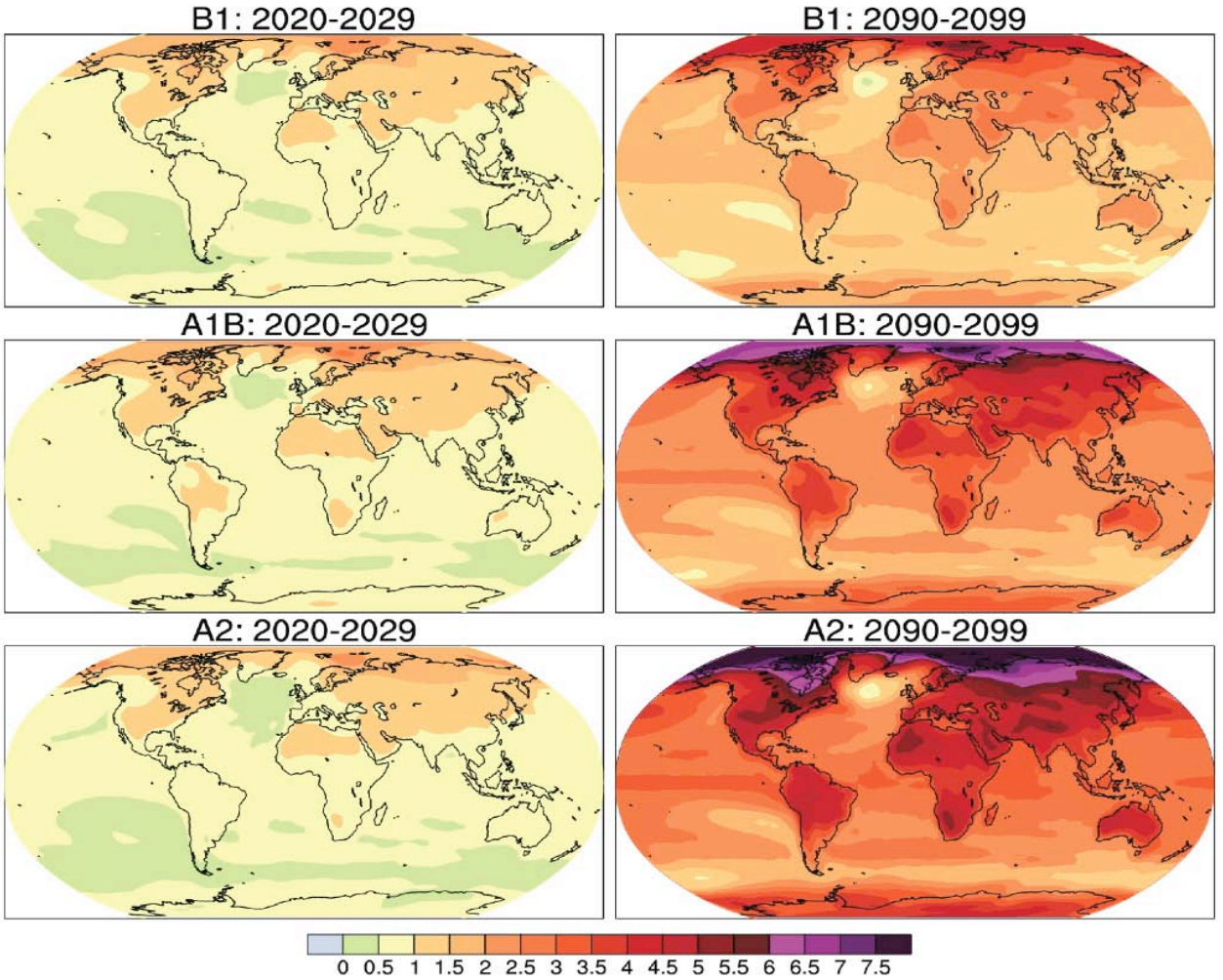
Radiative forcing



Temperature response

Projections of Future Changes in Climate

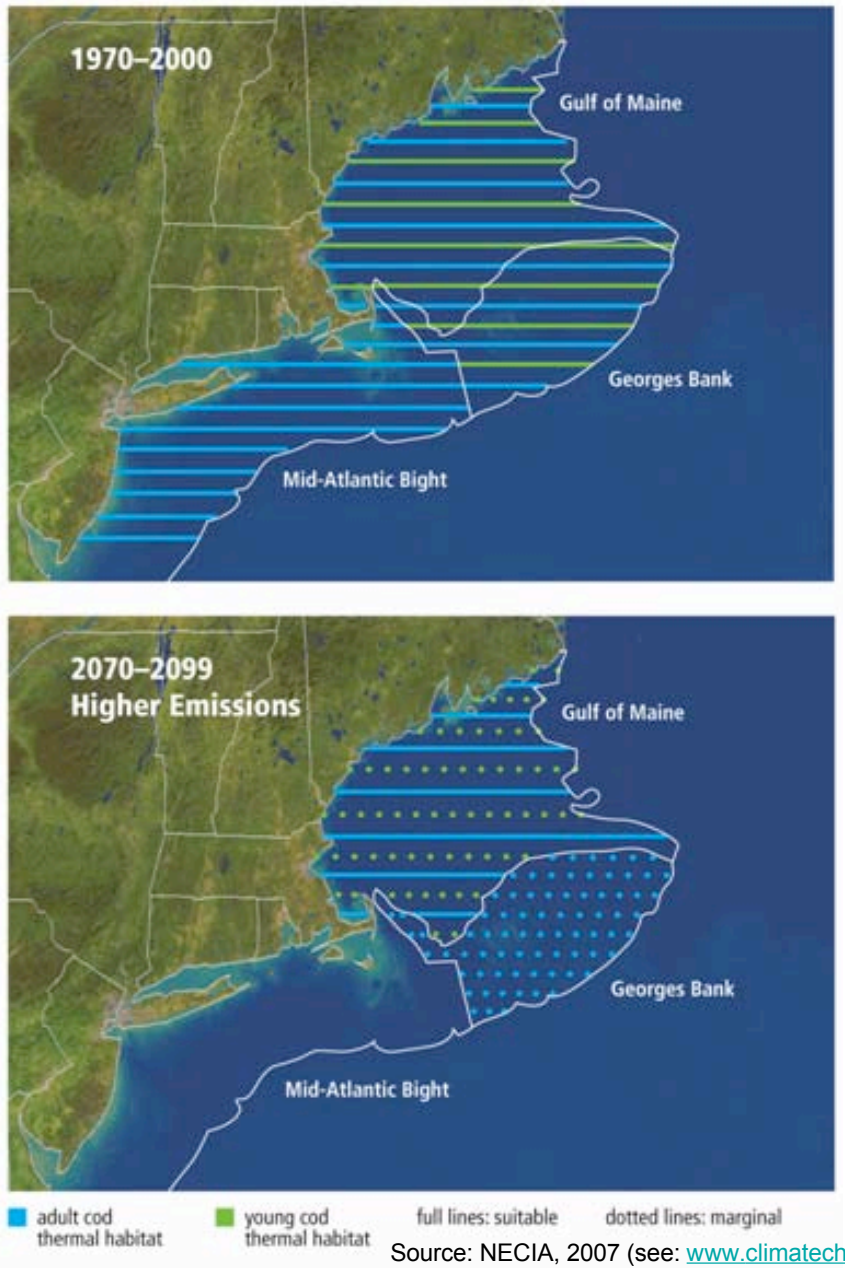
Projected warming in 21st century expected to be greatest over land and at most high northern latitudes and least over the Southern Ocean and parts of the North Atlantic Ocean



Source: IPCC 4th Assessment Report. Used with permission.

How can IPCC-type models best be used to guide our long-term outlook on fisheries?

Example:
Statistical Projection of Cod Habitat Based on Water Temperatures Suitable for Cod



Source: NECIA, 2007 (see: www.climatechoices.org/

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Image Credit: Jeff Schmaltz,
MODIS Rapid Response Team, NASA/GSFC

Resolution of GFDL-CM2.1 Ocean

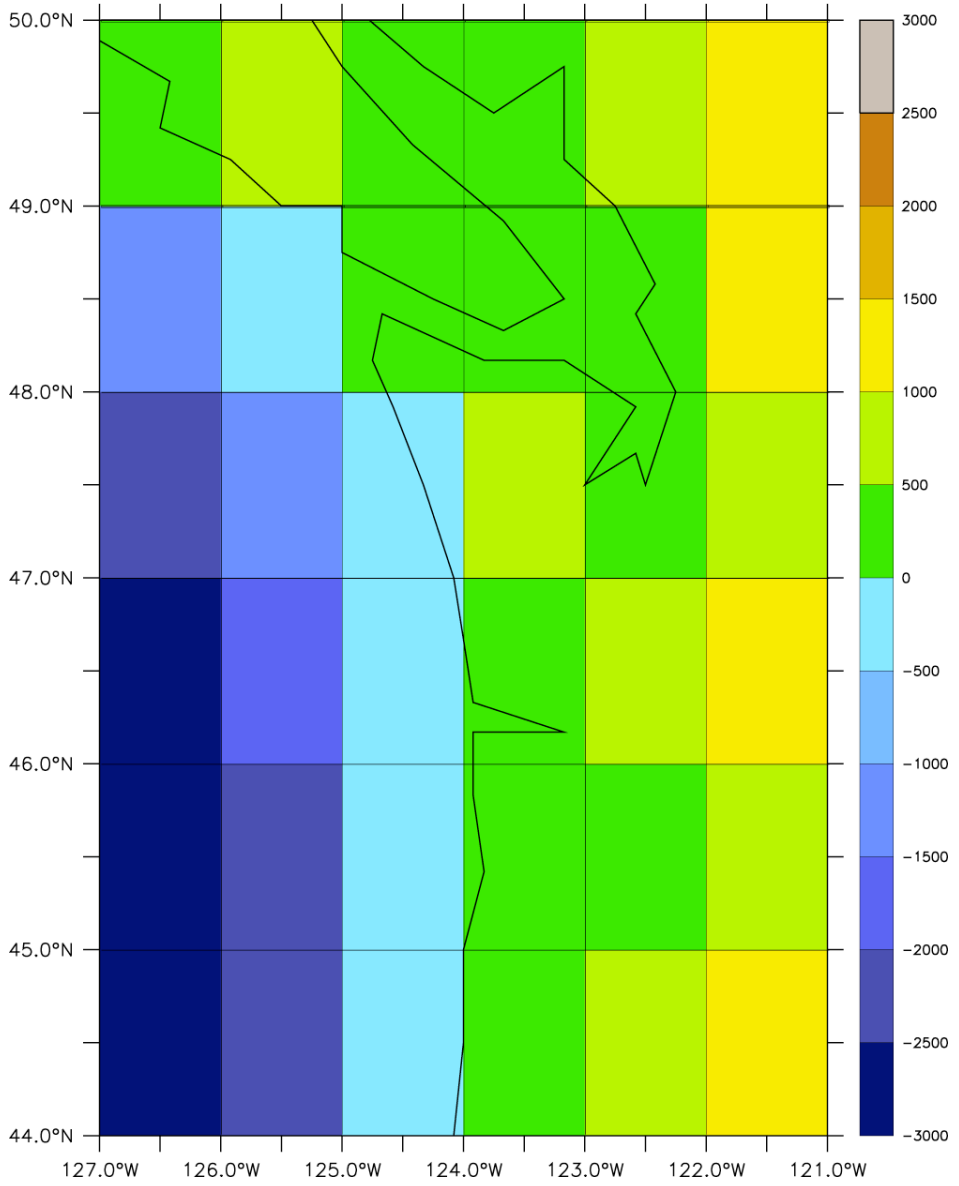
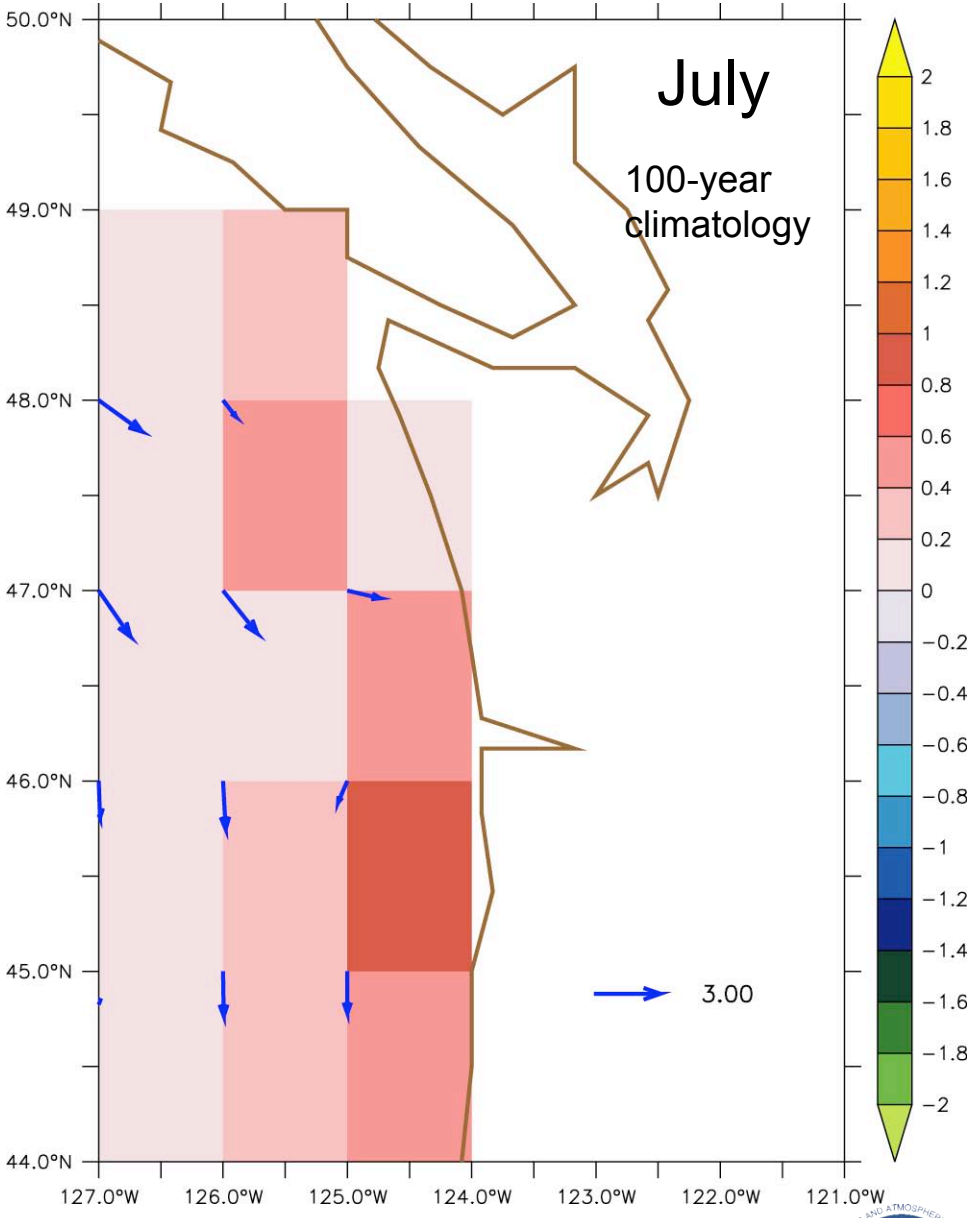
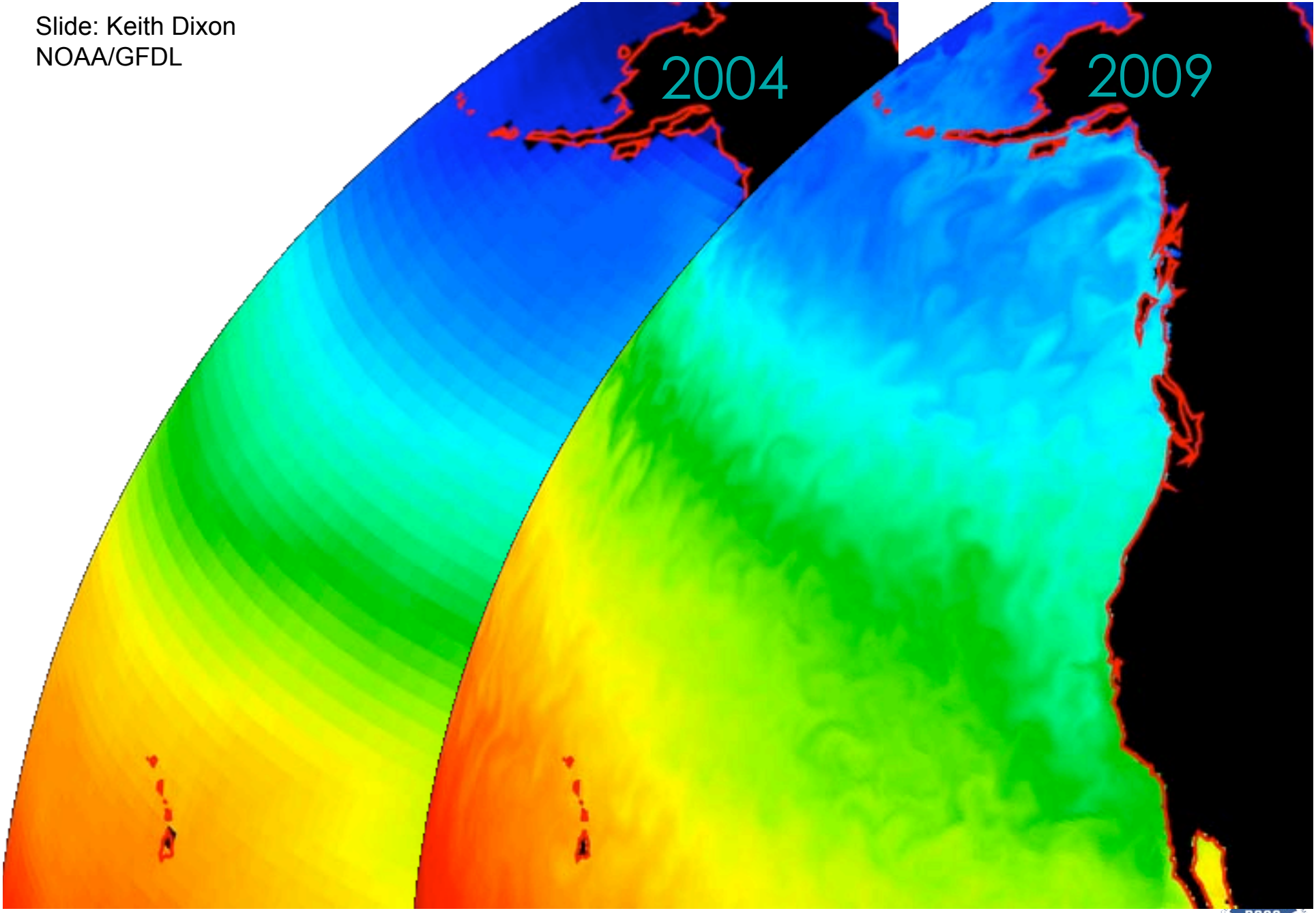


Image Credit: Jeff Schmaltz,
MODIS Rapid Response Team, NASA/GSFC

GFDL-CM2.1 40-m upwelling and currents



Slide: Keith Dixon
NOAA/GFDL



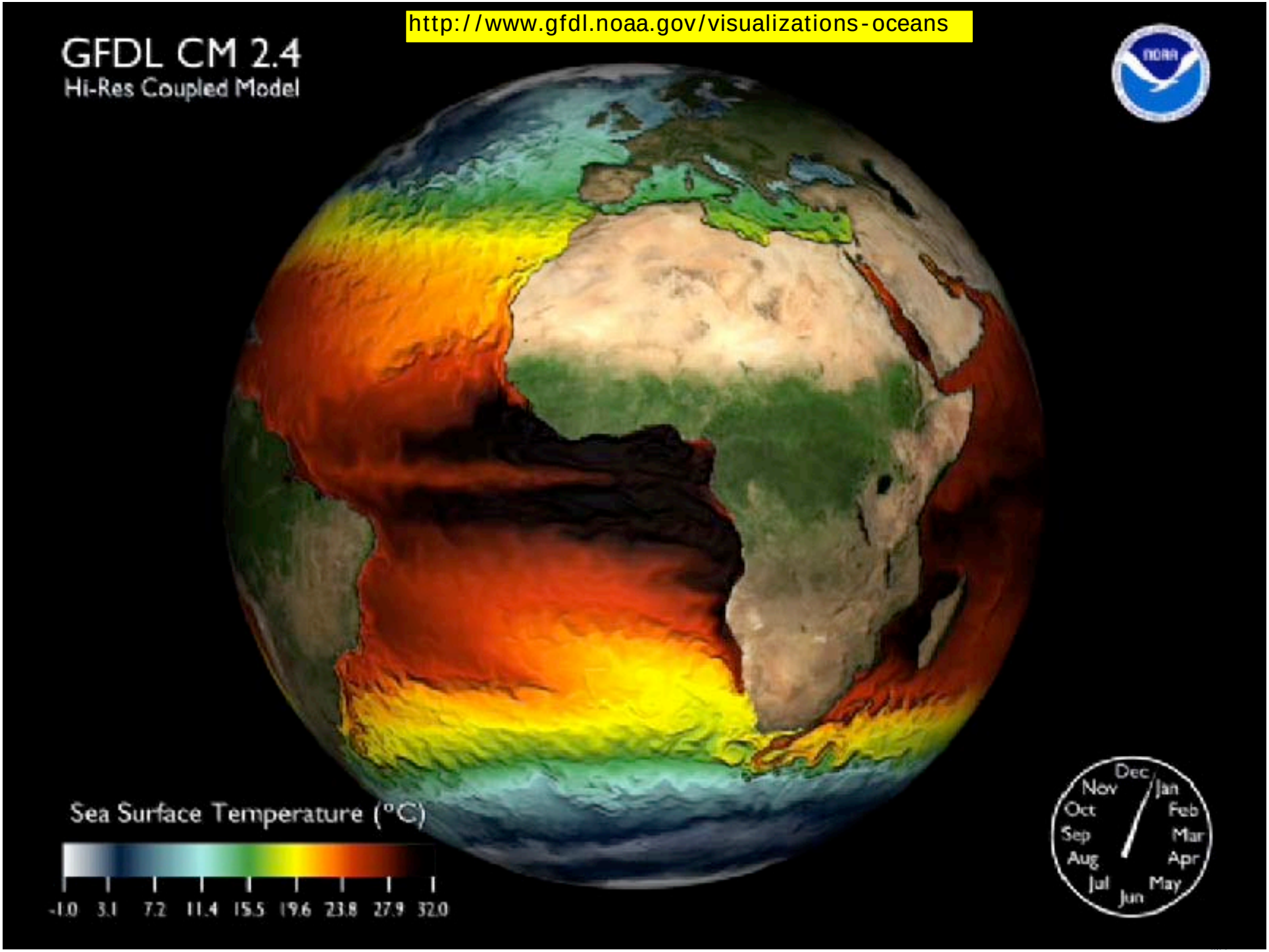
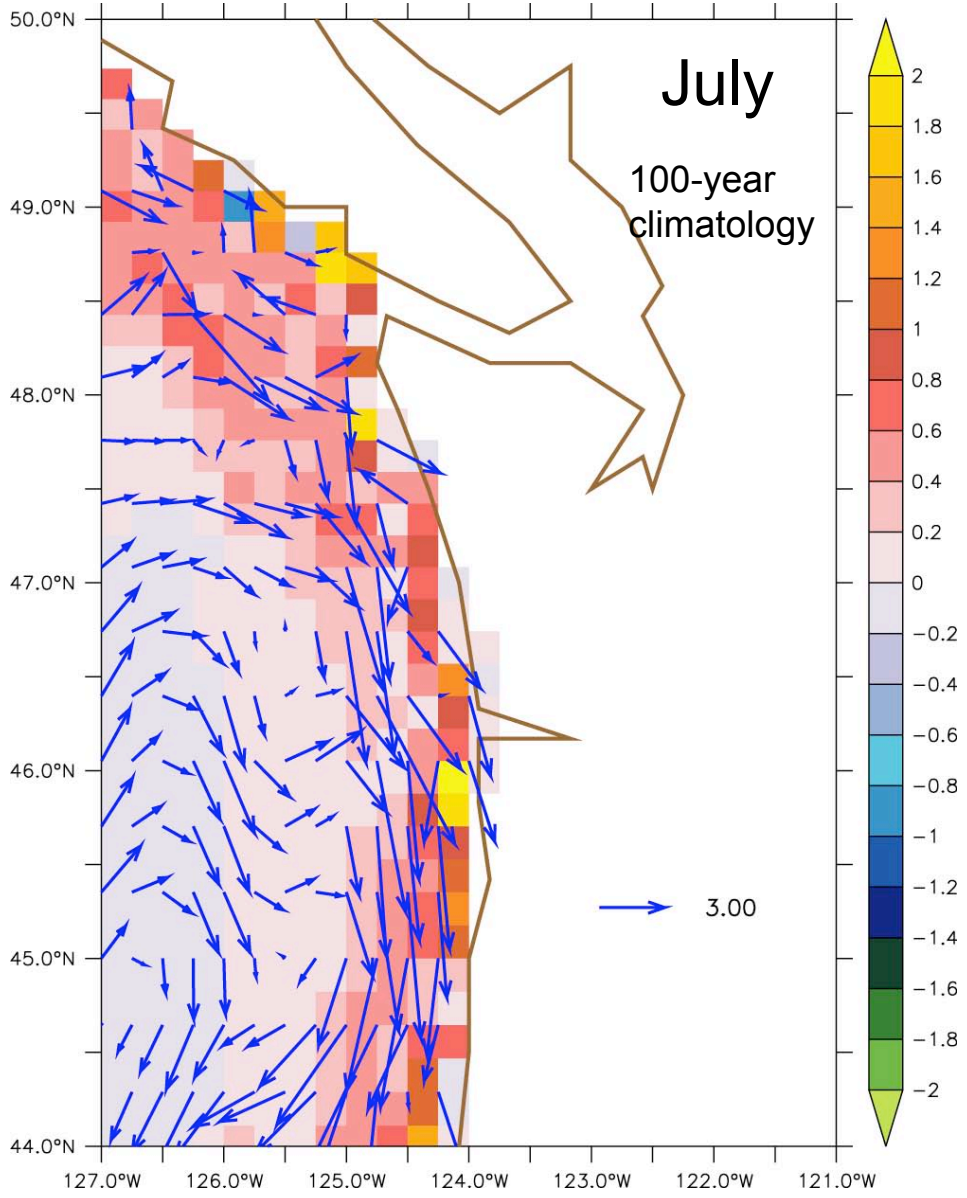
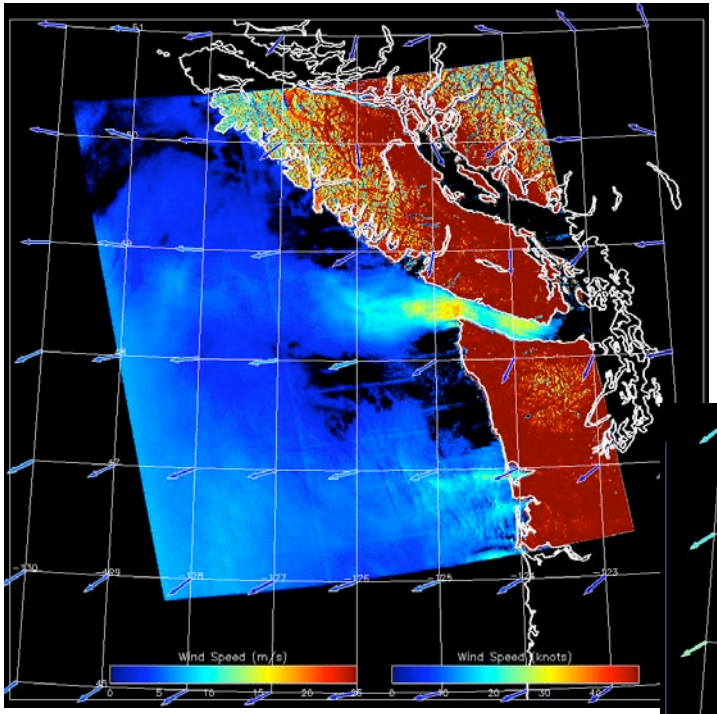

http://www.gfdl.noaa.gov/visualizations-oceans
GFDL CM 2.4
Hi-Res Coupled Model
Sea Surface Temperature (°C)
-1.0 3.1 7.2 11.4 15.5 19.6 23.8 27.9 32.0
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov

Image Credit: Jeff Schmaltz,
MODIS Rapid Response Team, NASA/GSFC

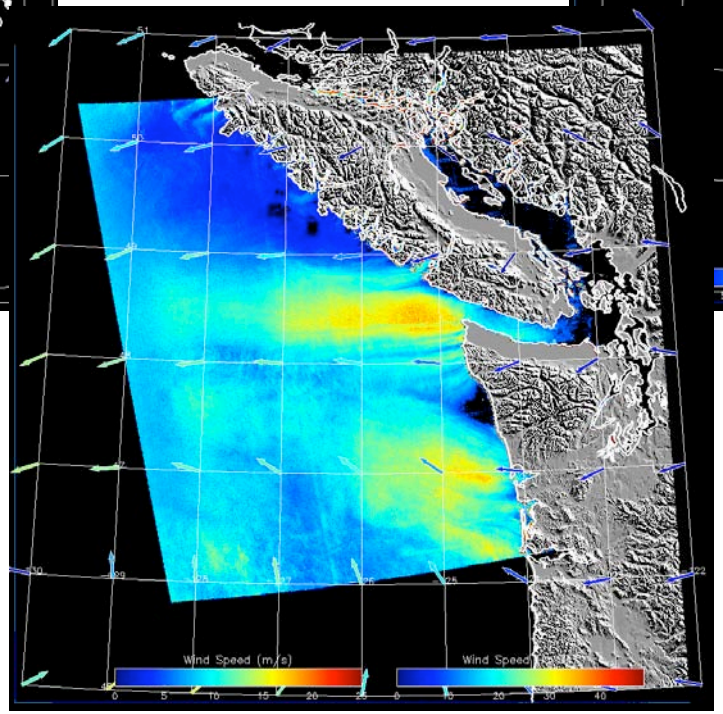
GFDL-CM2.4 40-m upwelling and currents



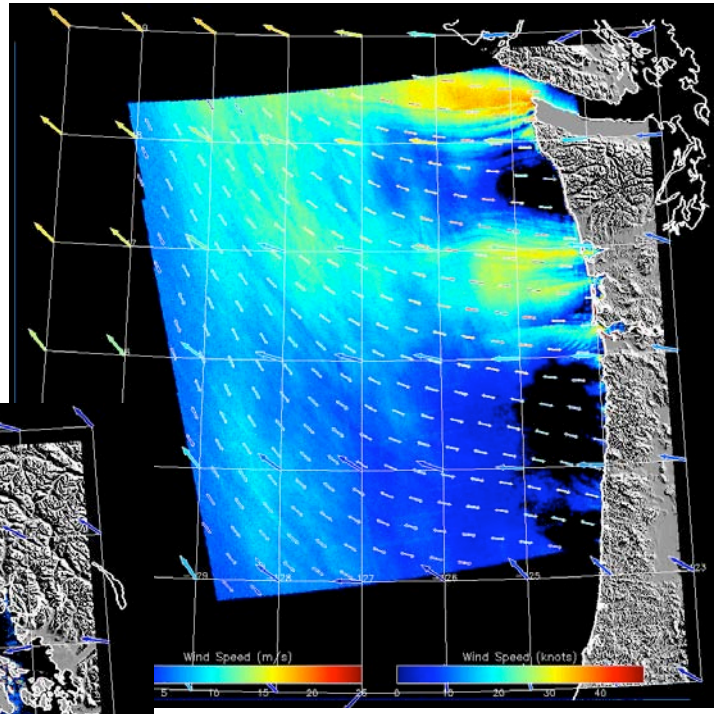
Observed wind (SAR)



27 Dec 1999



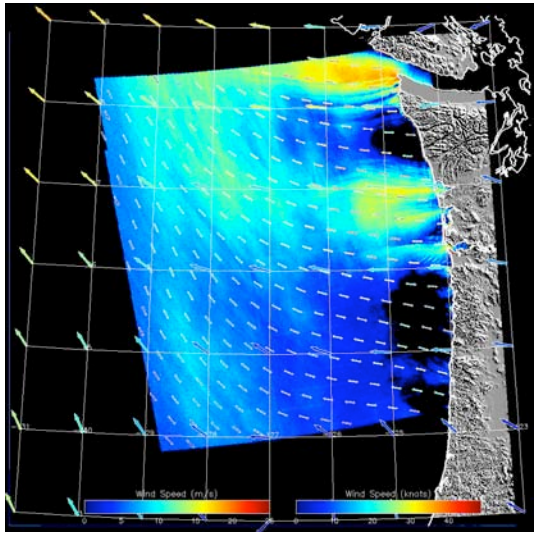
20 Jan 2000



7 Jan 2001

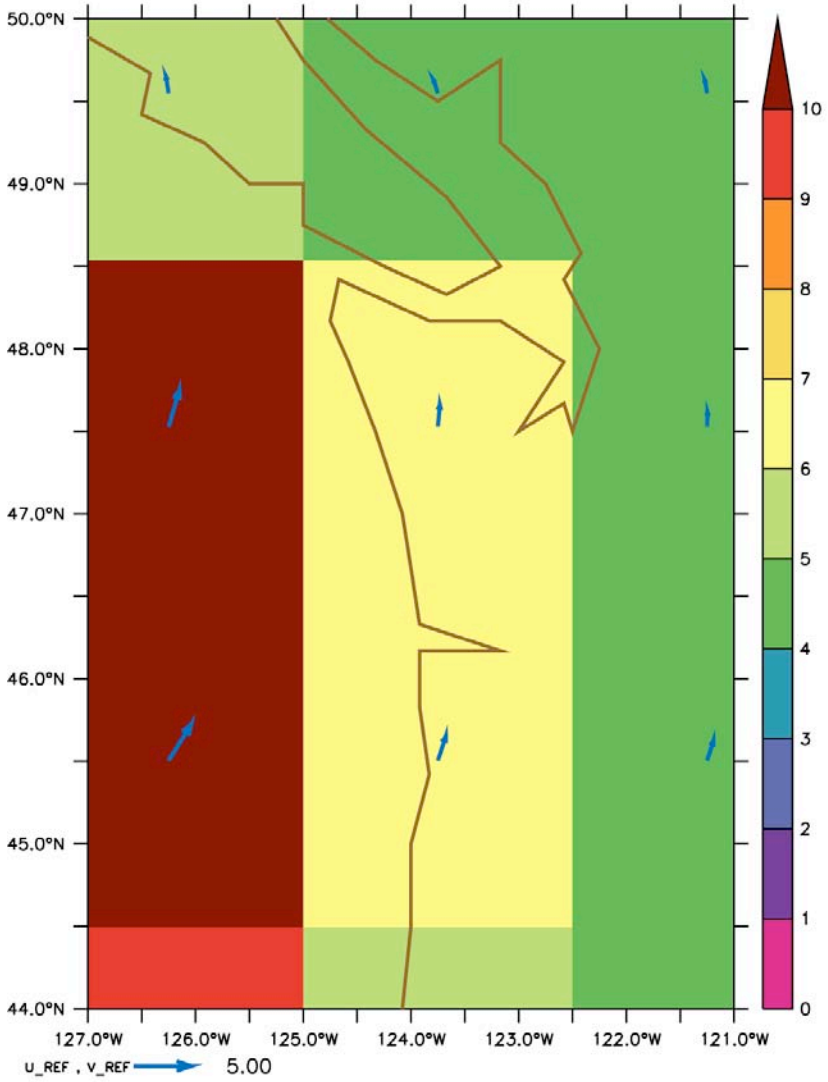
Figures from Cliff Mass,
U. Washington Atmos. Sci.

7 Jan 2001



SAR Figure from
Cliff Mass,
U. Wash. Atmos. Sci.

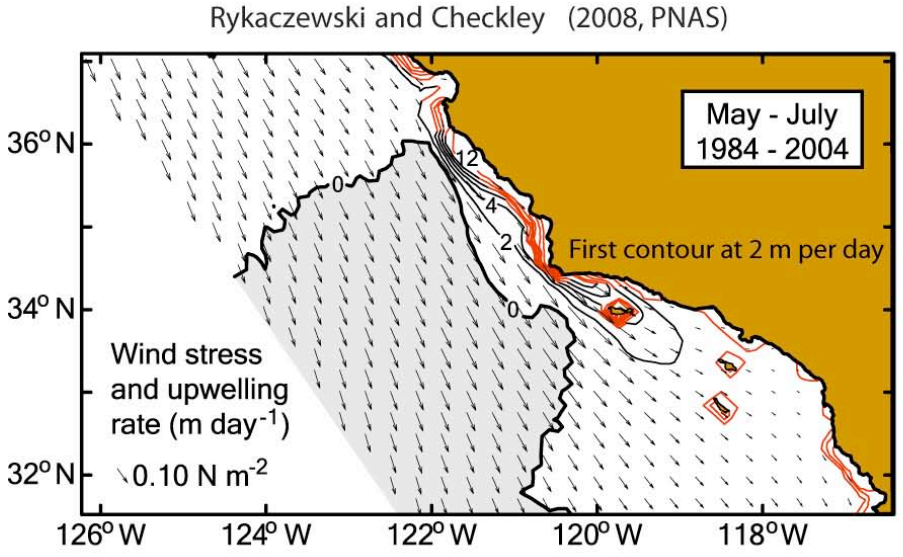
GFDL CM2.1
Atmospheric Resolution

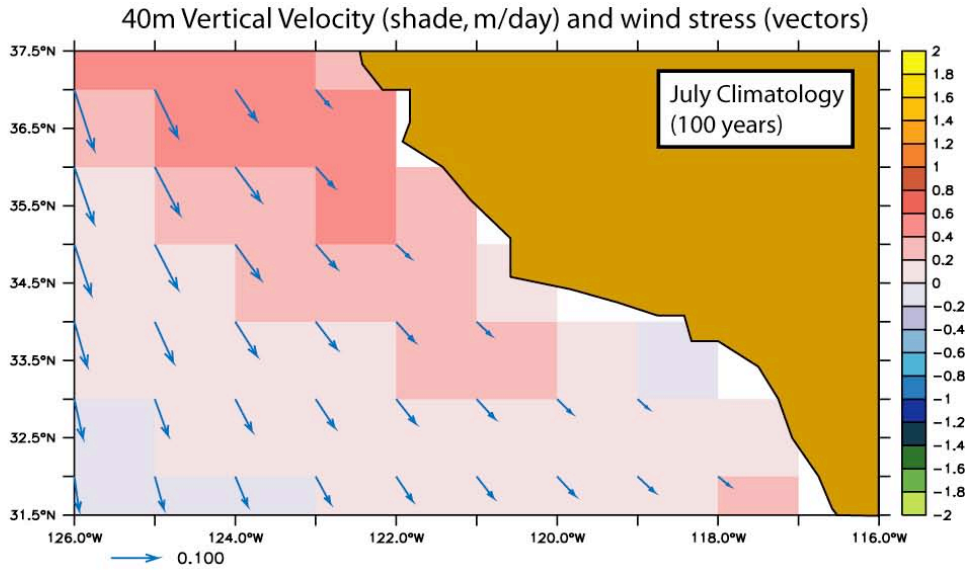


Wind speed (shaded) and wind velocity (vectors)

100-year Dec. Climatology

California Coastal Ecosystem upwelling and wind





Observed upwelling:

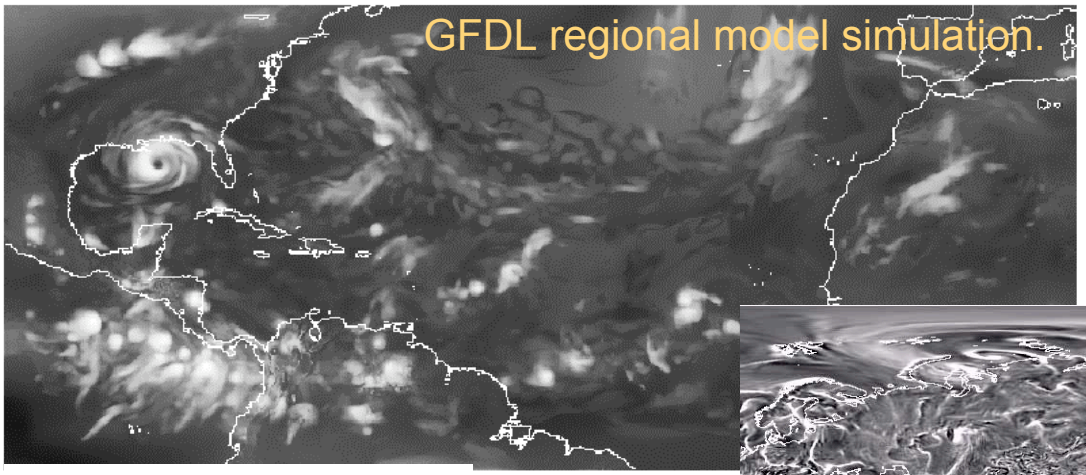
Curl-driven upwelling has influenced pelagic fisheries (sardines).

Model upwelling:

CGCM winds do not drive strong upwelling.

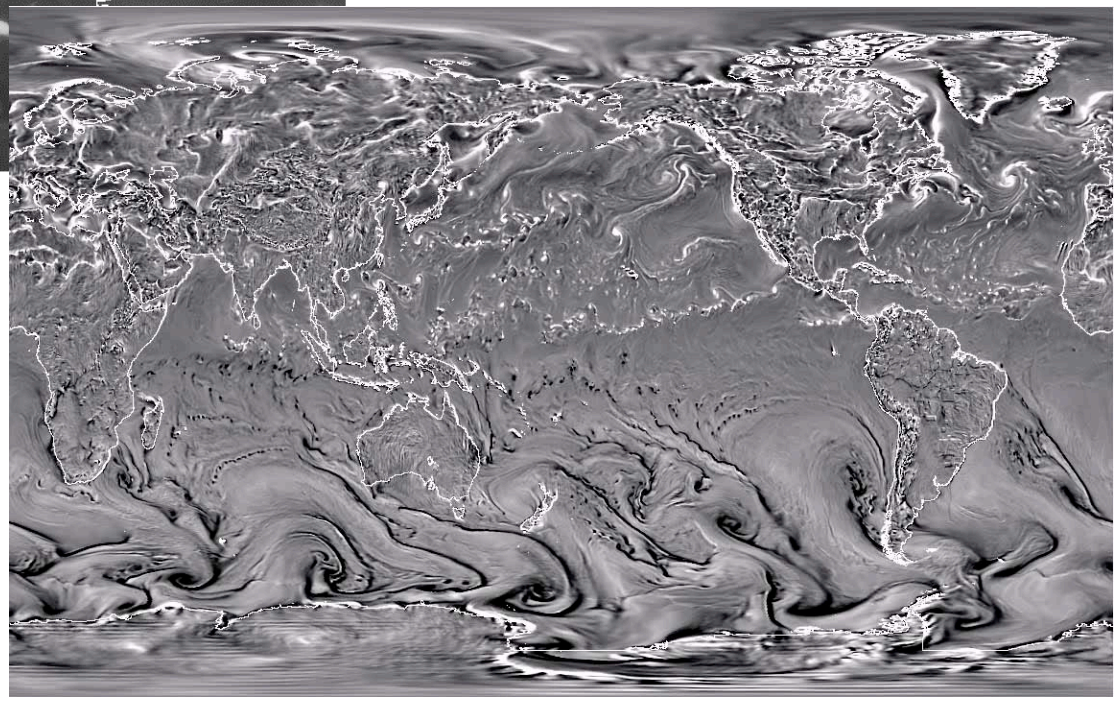
High-resolution atmospheric models

Regional and global atmospheric models at higher resolution being developed and improved.



Knutson et al (2007, BAMS)

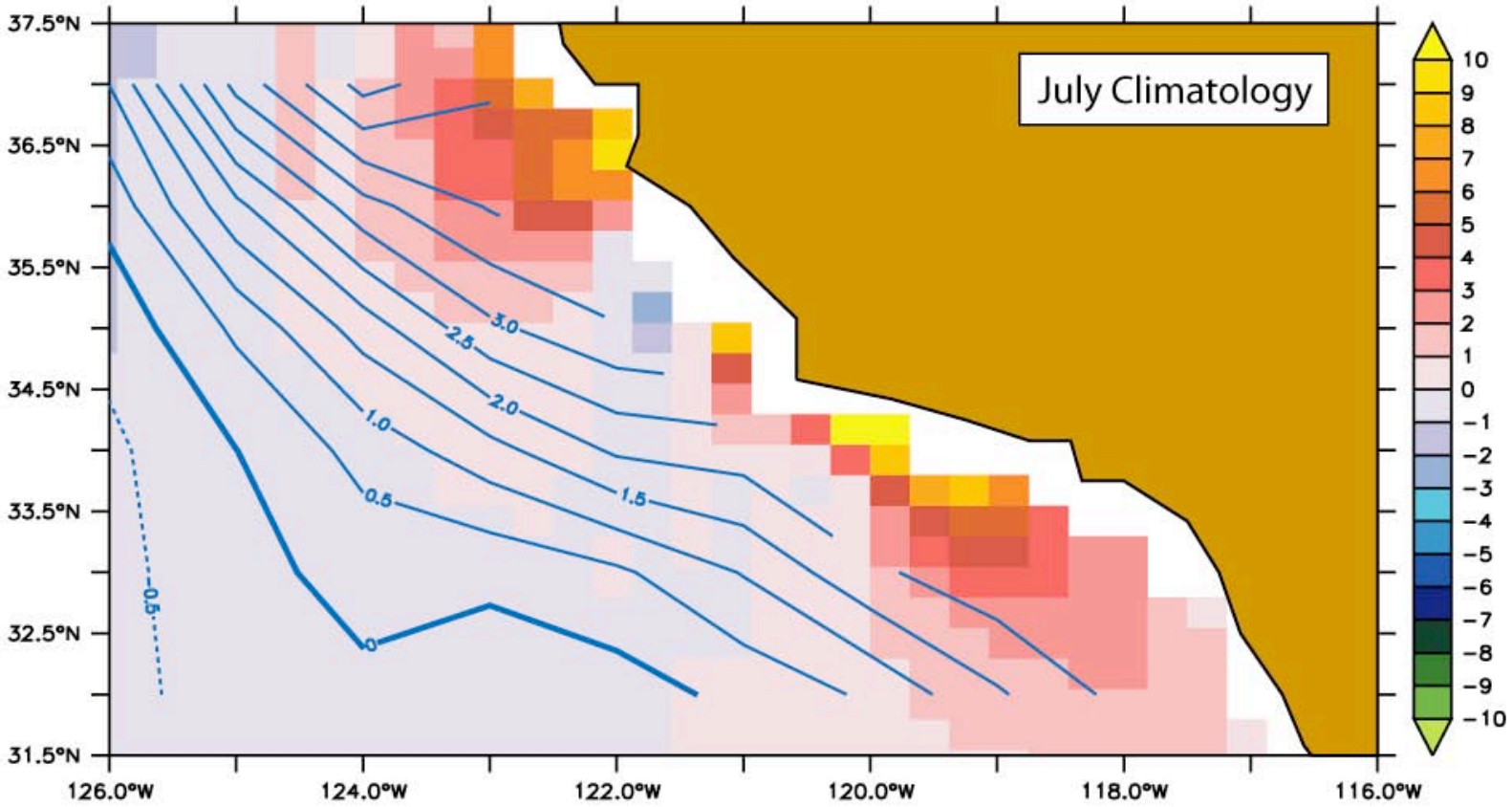
Models ranging in 100km to 18km resolution.



Zhao et al. (2009, J. Climate)

GFDL global model simulation.

Prototype higher resolution AGCM gives stronger wind stress curl.

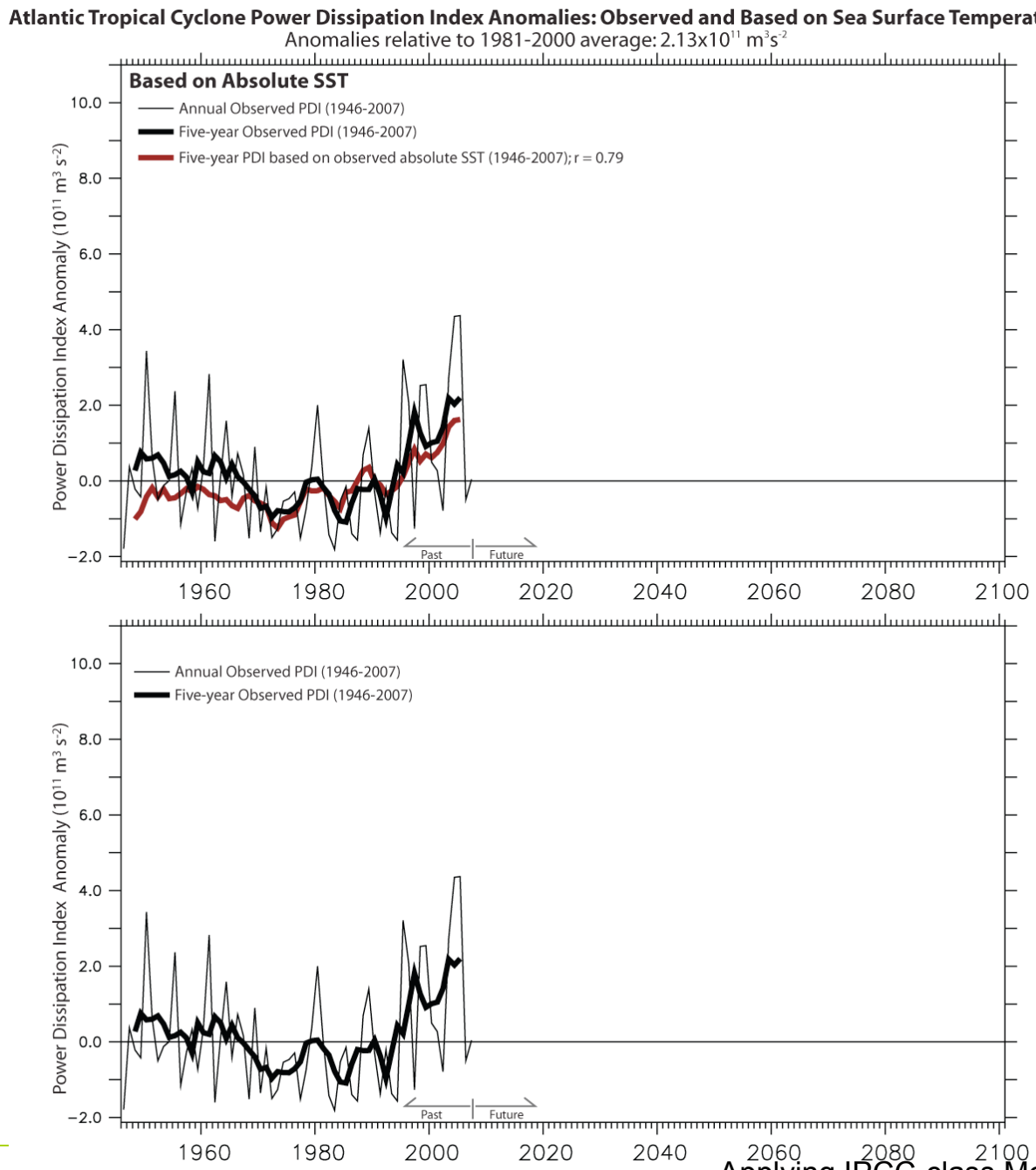


Wind-stress curl from GFDL CM2.1 (contour) and from prototype 25km global atmospheric model (shade, cf. Zhao et al 2009)

Other possible solution to unresolved scales: statistical downscaling

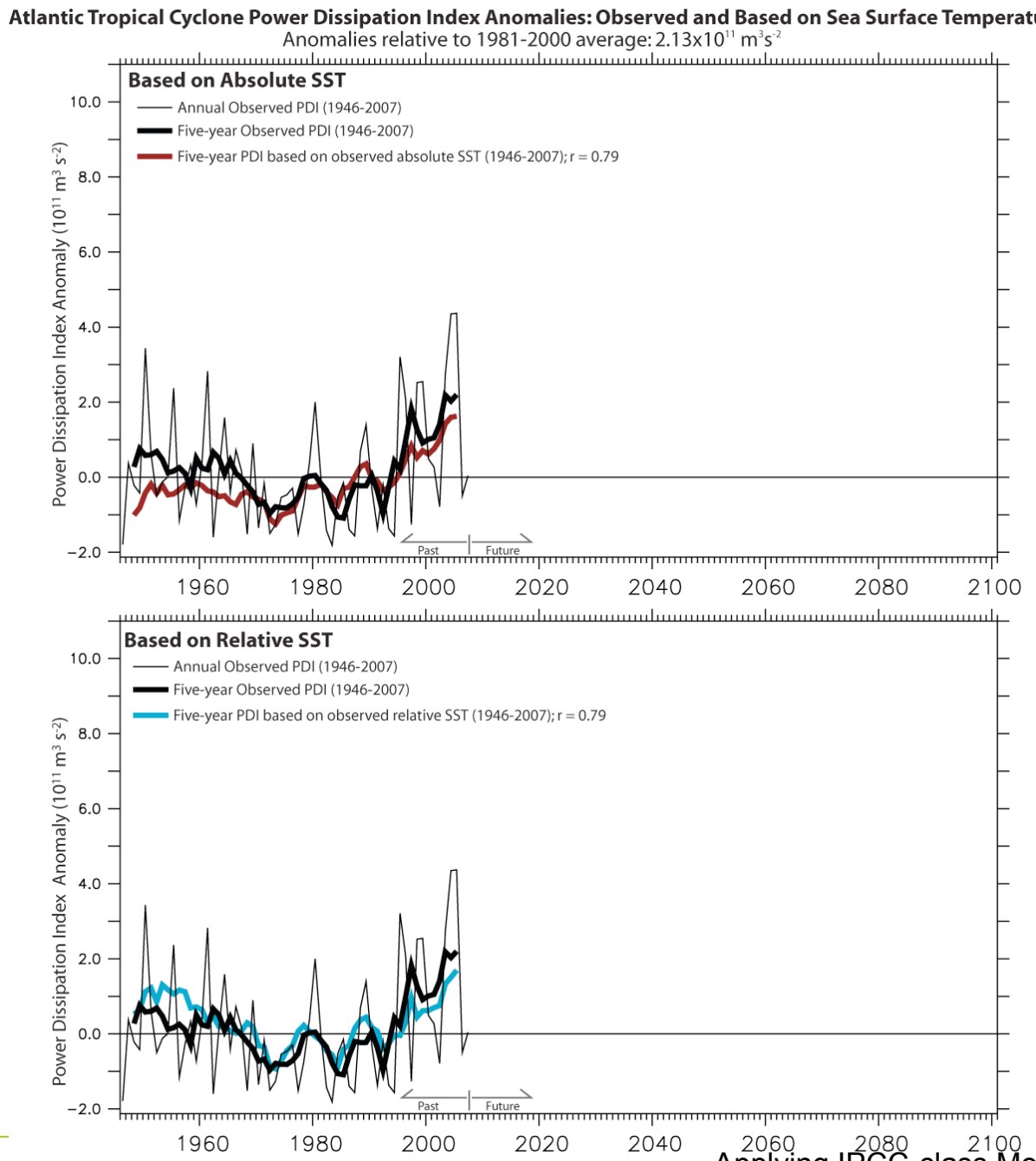
- Develop a empirical relationship between a set of predictors on the large (model-resolved) scales, and the desired variables on the smaller scale.
- Apply empirical relationship to model projections and other runs.
- Choice of predictors can influence projection.

  Cautionary tale #1 from hurricane downscaling



Observed Activity
Absolute MDR SST

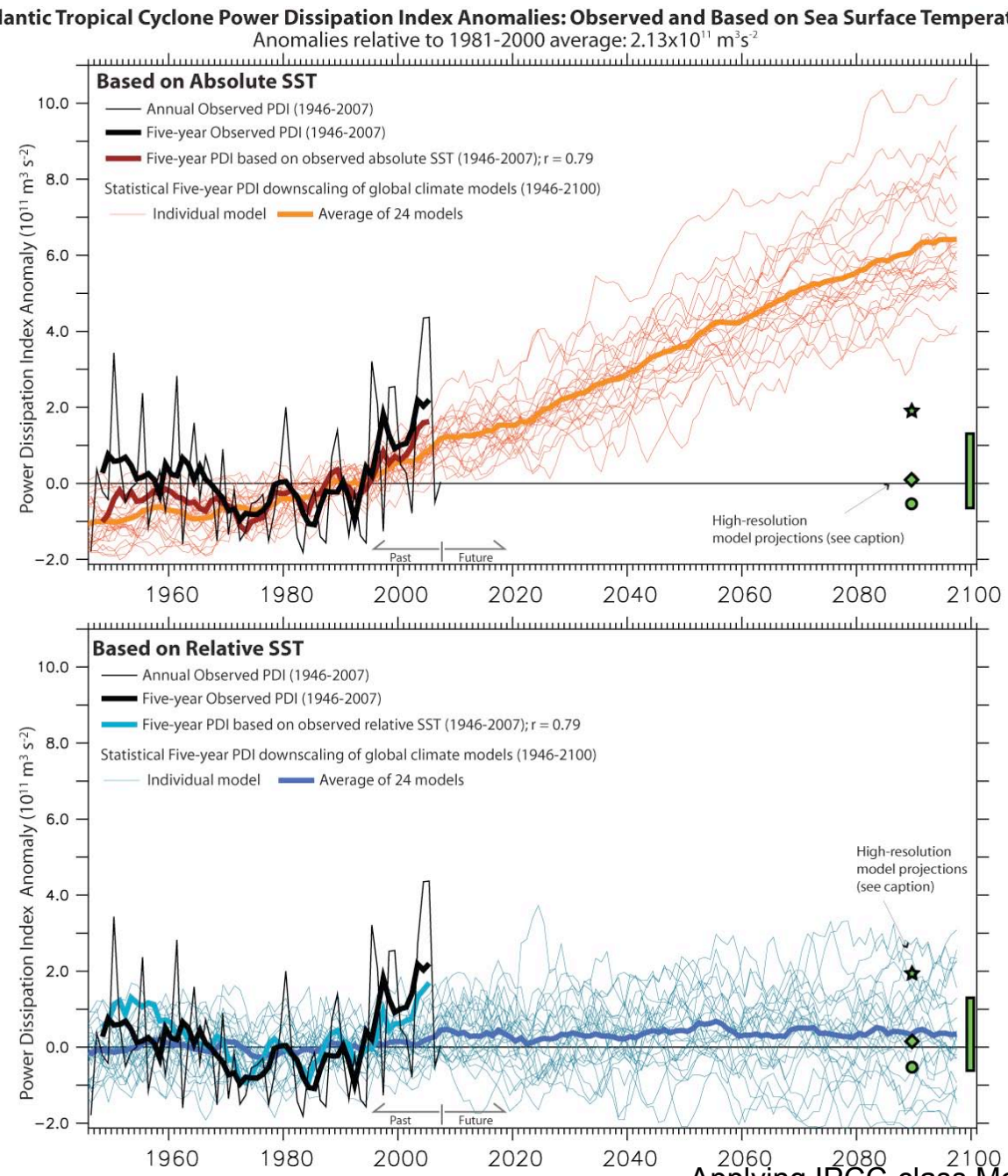
Vecchi, Swanson and Soden (2008, Science)



Observed Activity
Absolute MDR SST

Relative MDR SST

Vecchi, Swanson and Soden (2008, Science)



Observed Activity

Absolute SST

Model Abs. SST

Relative SST

Model Rel. SST

Vecchi, Swanson and Soden (2008, Science)

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Inter-model differences

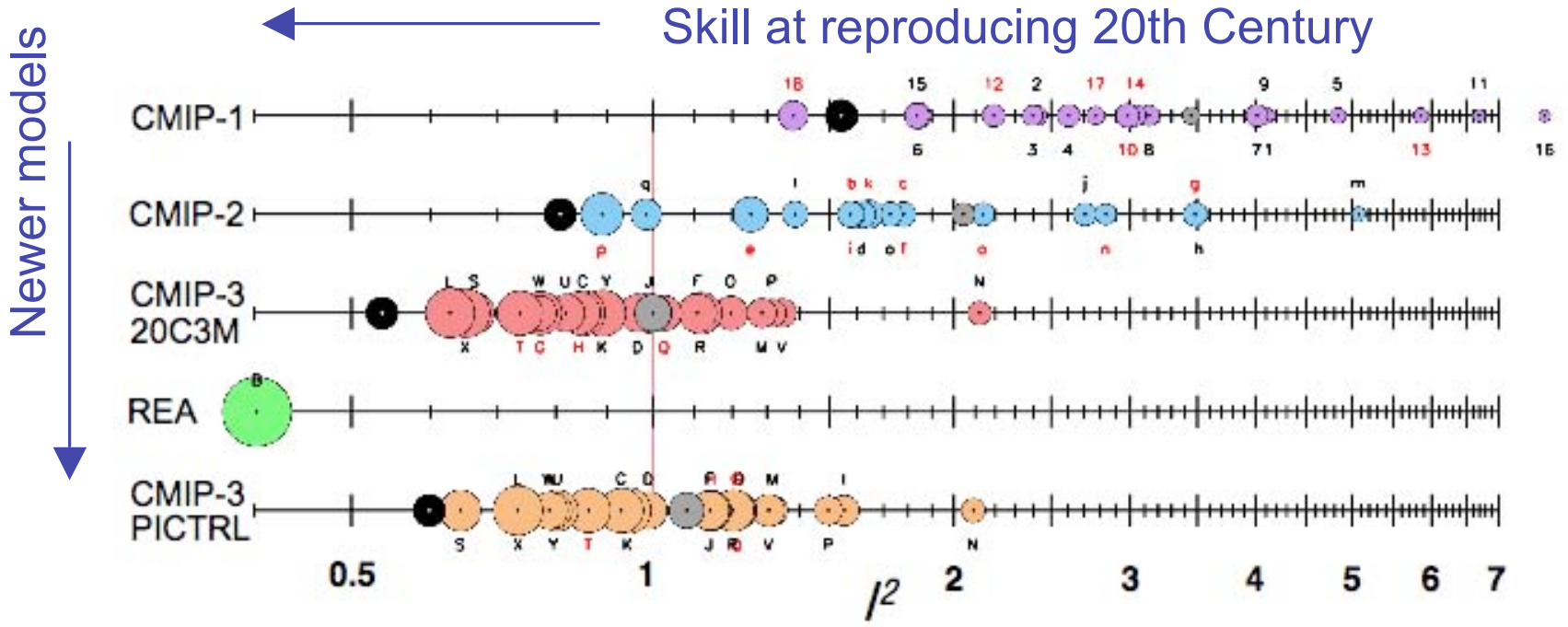
- Many “IPCC-class” models exist in the world.
  25 models in IPCC-AR4 archive.

- Can differ in many ways:
  - Ocean, atmosphere, ice, land models
  - Sub-gridscale parameterizations and parameter choices
  - Forcing used, etc.…

- Differ in ability to reproduce climatology:
  - Ability to reproduce climatology not necessarily test of model’s ability to project future.
  - Each model’s projection has some plausibility.
  - Cannot exclude a model’s projection solely because the projection is an outlier

- Modest inter-model differences in large-scale can lead to big differences in downscaled result
  Cautionary tale #2 from hurricanes downscaling.

Ability to reproduce climatology differs between models



Reichler and Kim (2008, BAMS)

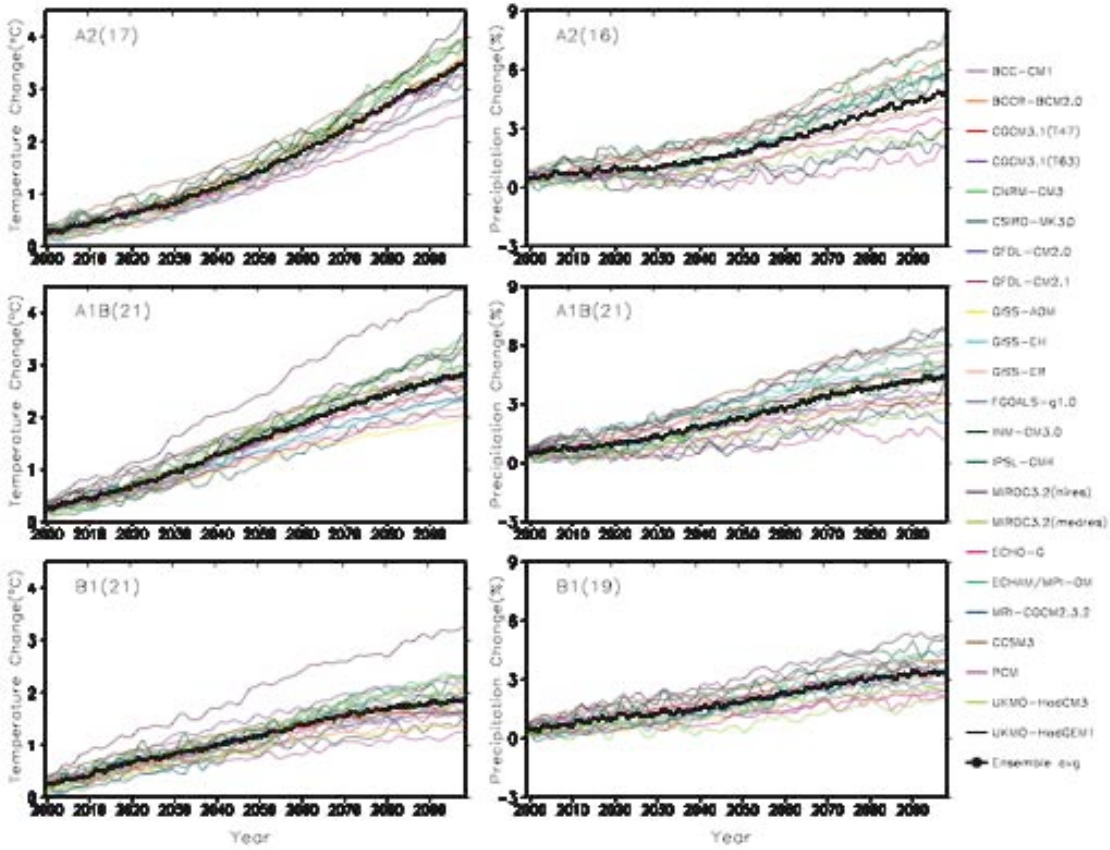
- Skill increasing with time
- Multi-model average better than any individual model
- Ability to reproduce climatology not necessarily projection skill

Inter-model spread on global temperature and precipitation sensitivity

Temperature Precipitation

Stronger forcing

Weaker forcing



IPCC-AR4 (2007)

Change in El Niño activity

IPCC-AR4 (2007)

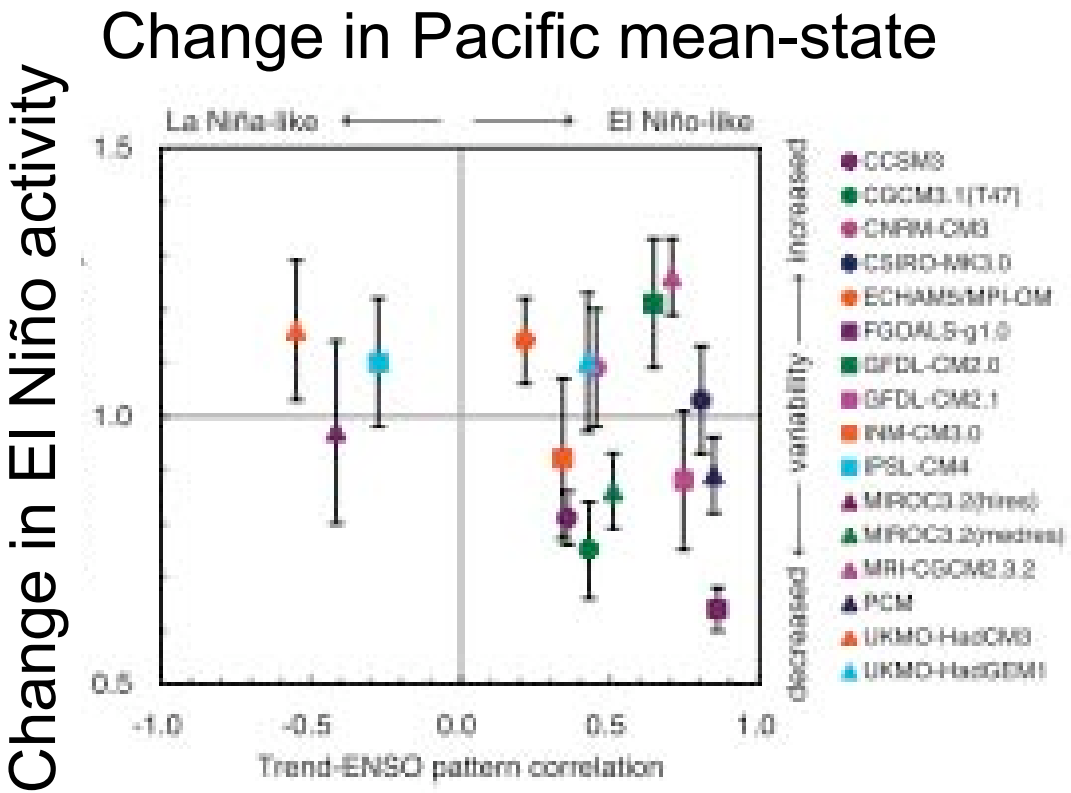
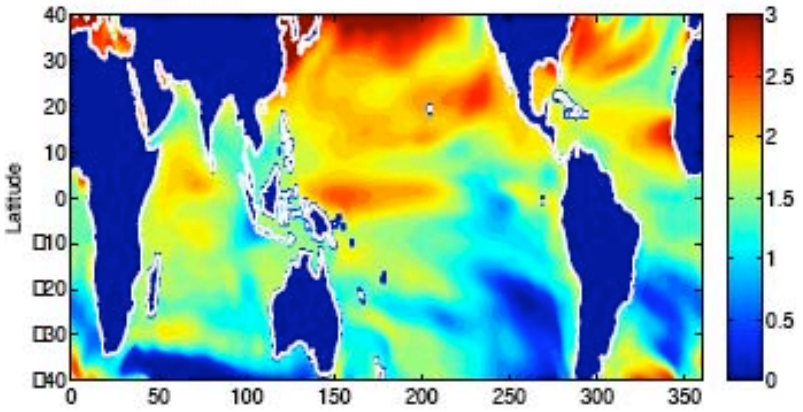


Figure 10.16. *Base state change in average tropical Pacific SSTs and change in El Niño variability simulated by AOGCMs (see Table 8.1 for model details). The base*

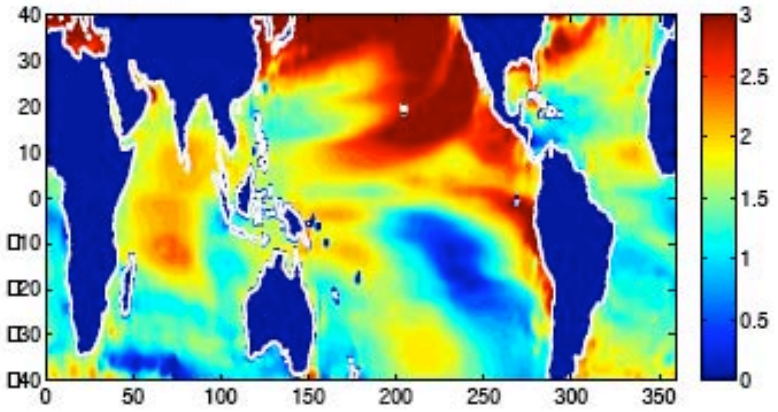
No general consensus on the change of El Niño amplitude.

21st Century projections of SST change

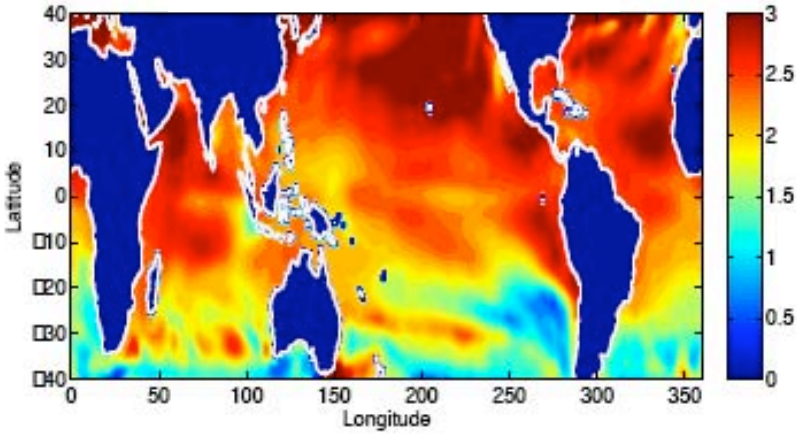
GFDL-CM2.1



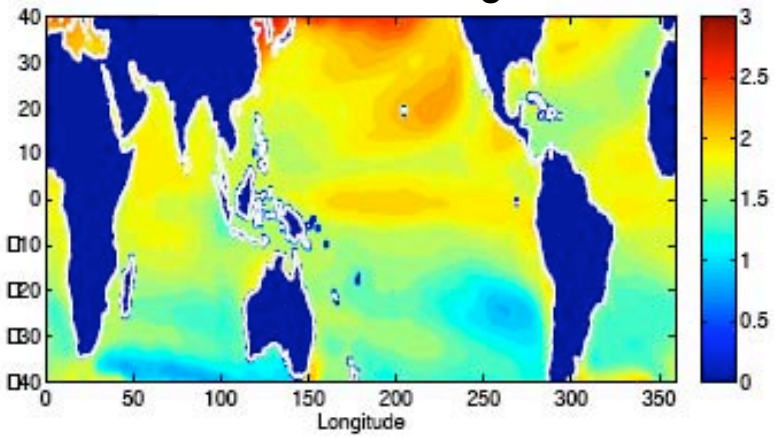
UKMet. HadCM3



Max Planck-ECHAM5



18-Model Average



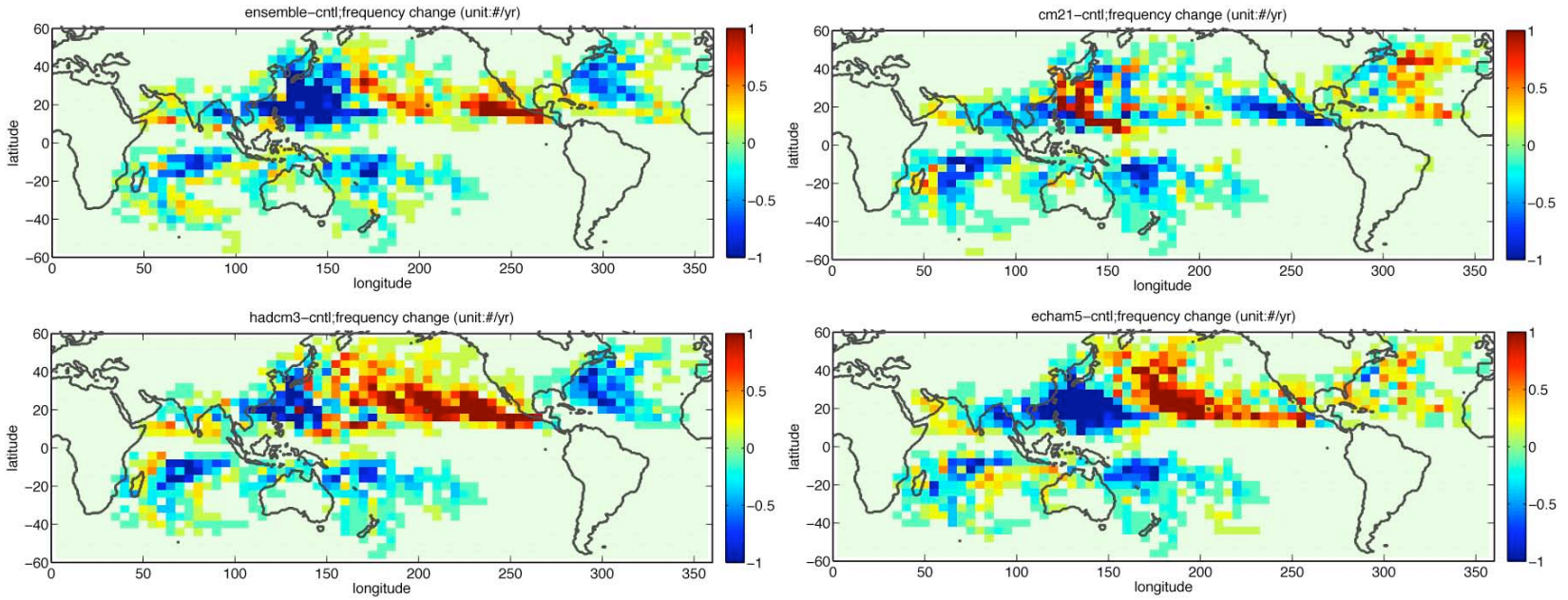
Zhao et al (2009, J. Climate)

Each model indicates warming.

The structure of warming differs considerably between models.

21st Century Hurricane Activity Change

Based on four projections of 21st Century Ocean temperatures.



Red/yellow = increase
Blue/green = decrease

Adapted from Zhao et al. (2009, J. Climate)

Details of ocean temperature change can changes sign of response.

Identify changes consistent across models, range of solutions, and mechanisms controlling the solution.

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Internal variability

- Change a superposition of forced response and internal variability.
  - Variability can offset or amplify forced change.
  - Largest extremes in change occur from a constructive superposition of variability and change.

- Forcing tends to dominate the longer the space/time-scale

  conversely

- Variability tends to dominate the shorter the space/time-scale

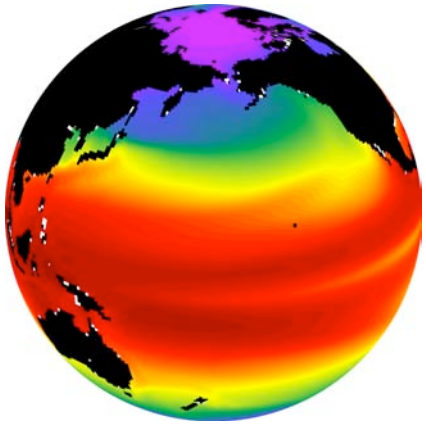
- IPCC-AR4 runs **NOT** initialized, so no attempt to project/predict internal variations

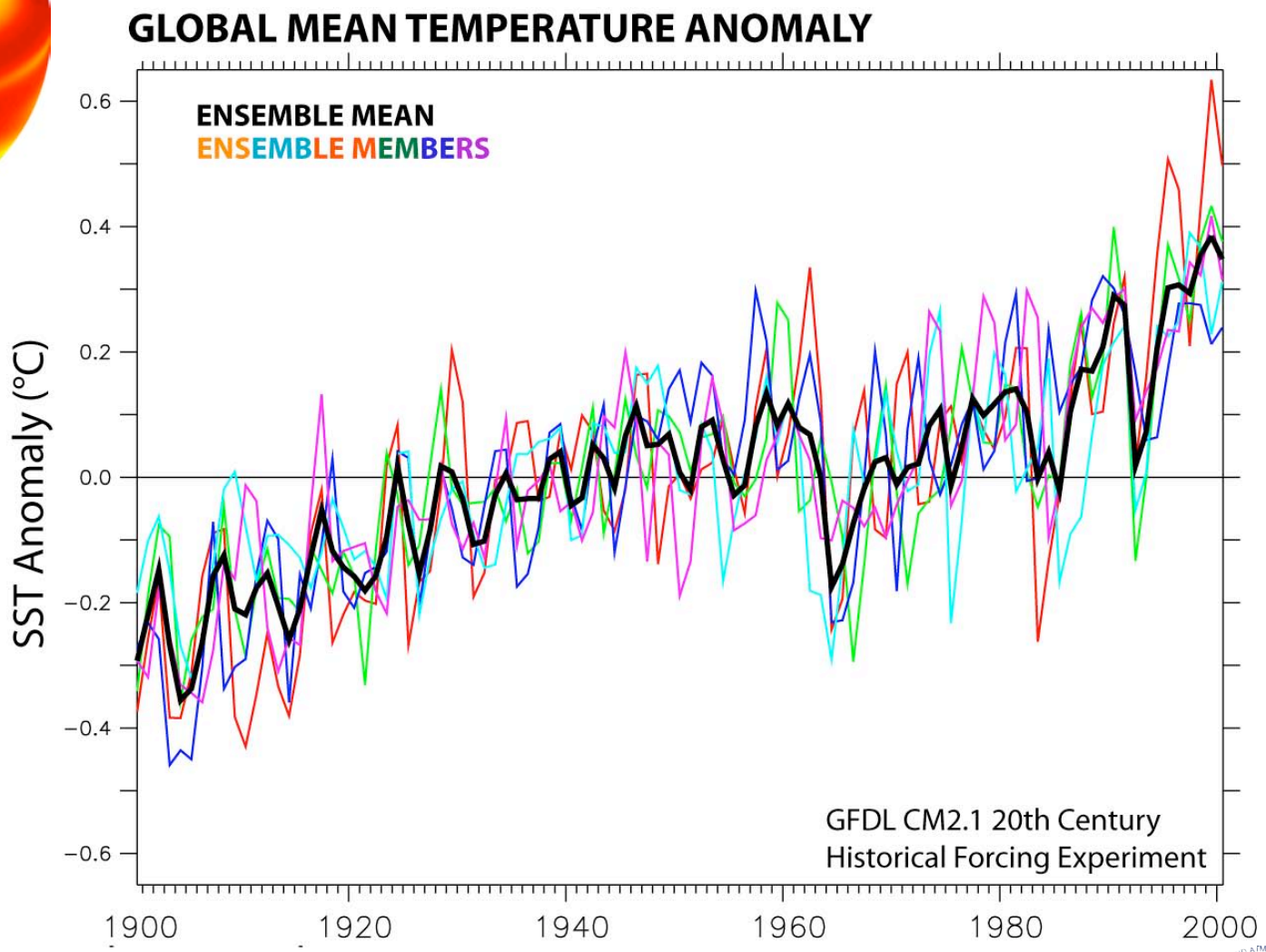
  wiggles shouldn't match

- IPCC-AR5 will include a component to explore initialized decadal predictions

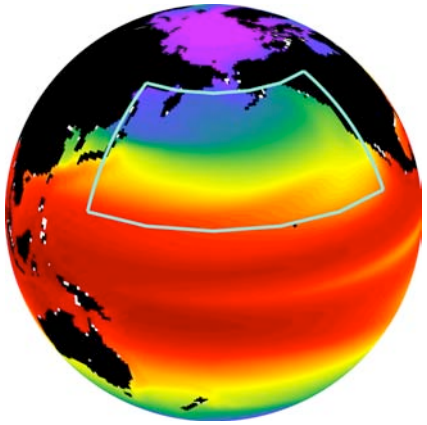
  some wiggles could match: *cf.* Tom Delworth on Wed.

Global SST

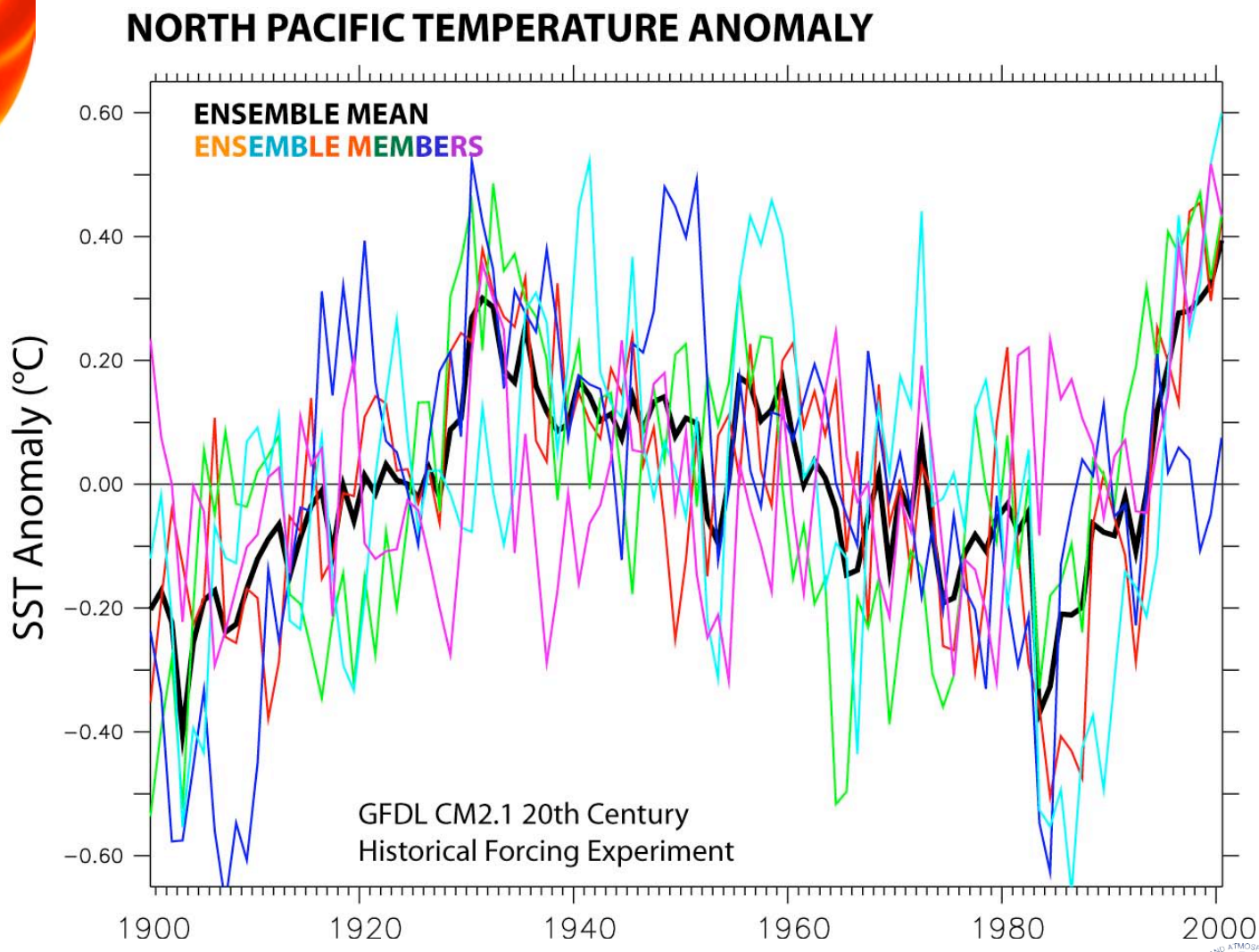




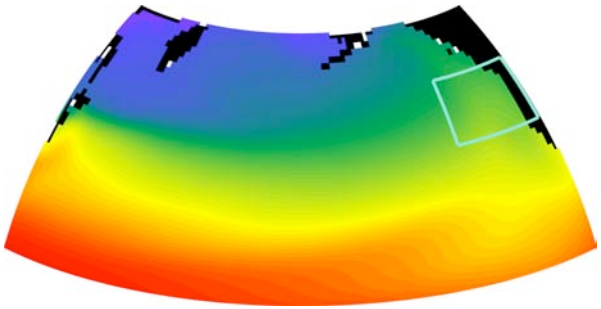
Forced signal clear

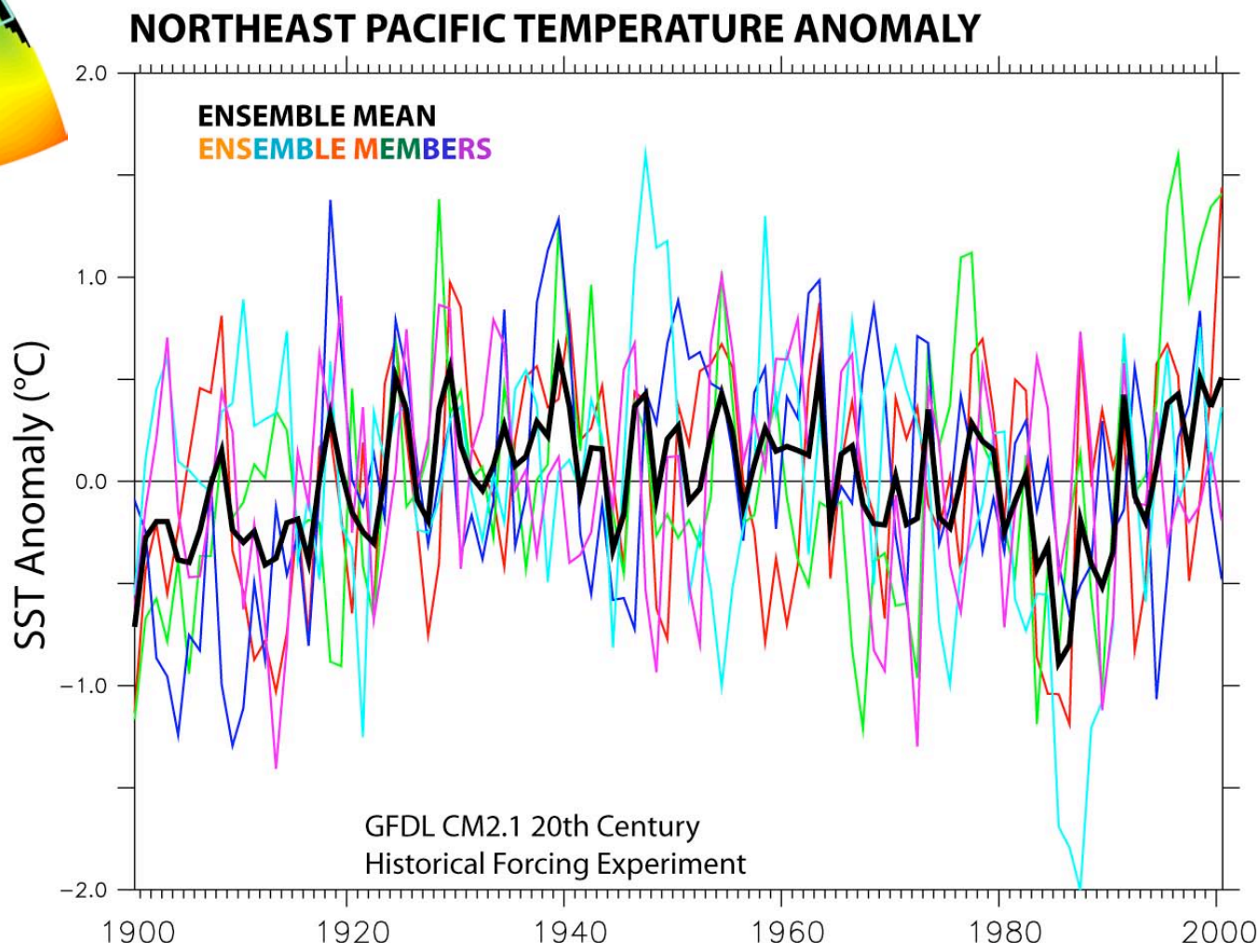


North Pacific SST

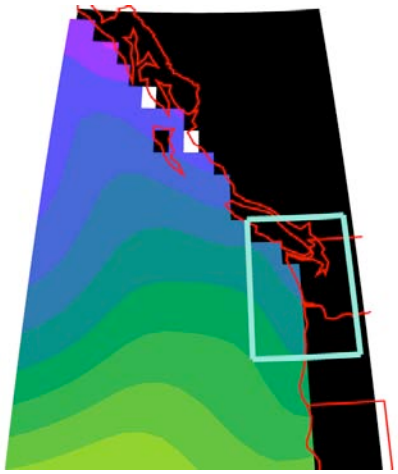


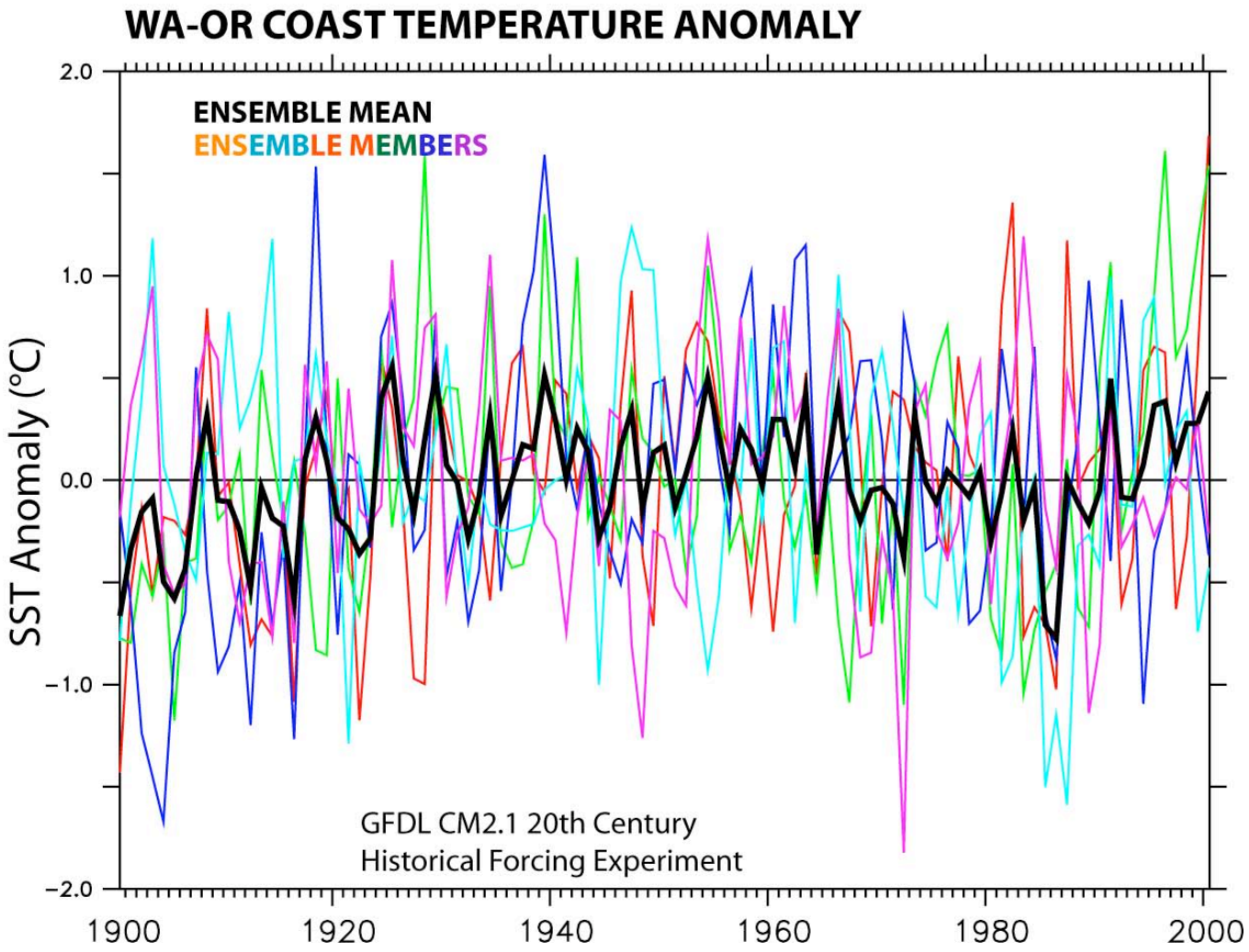
Northeast Pacific SST





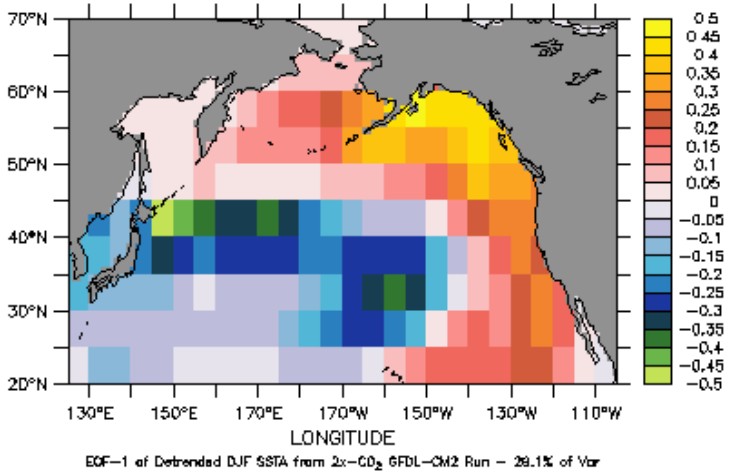
WA-OR Shelf SST



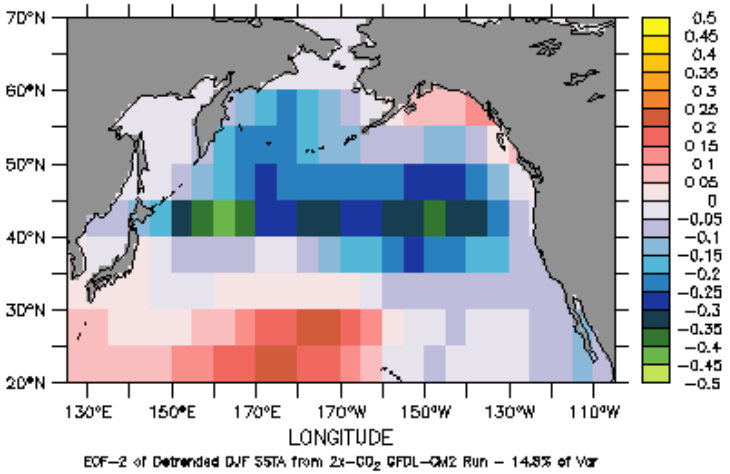


EOFs of decadal SST in GFDL CM2.0

1% to 2xCO2 run

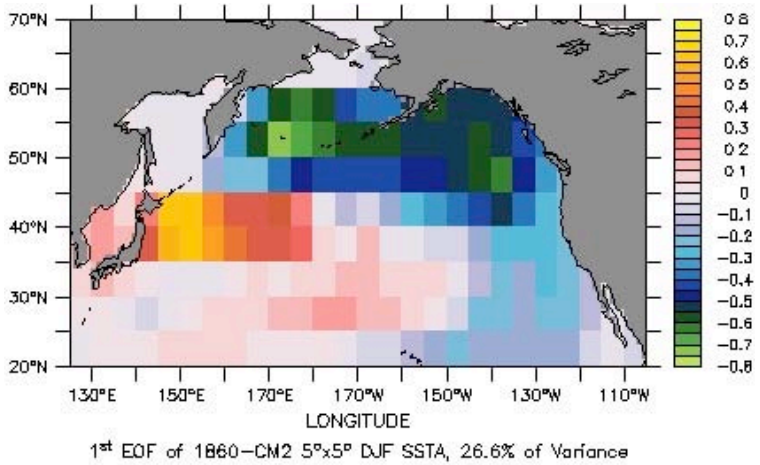


EOF–1 of Detrended DJF SSTA from 2x–CO_2 GFDL–CM2 Run – 29.1% of Var

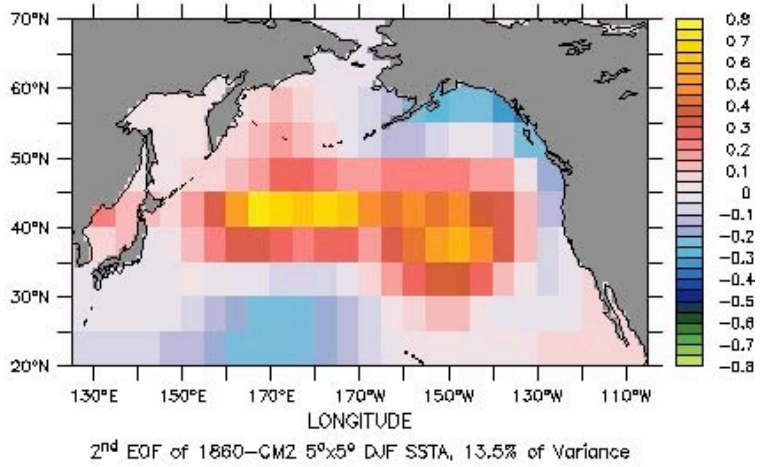


EOF–2 of Detrended DJF SSTA from 2x–CO_2 GFDL–CM2 Run – 14.8% of Var

1860 Control



1st EOF of 1860–CM2 5°x5° DJF SSTA, 26.6% of Variance



2nd EOF of 1860–CM2 5°x5° DJF SSTA, 13.5% of Variance

Patterns of EOF resemble those in observations.

Internal Variability

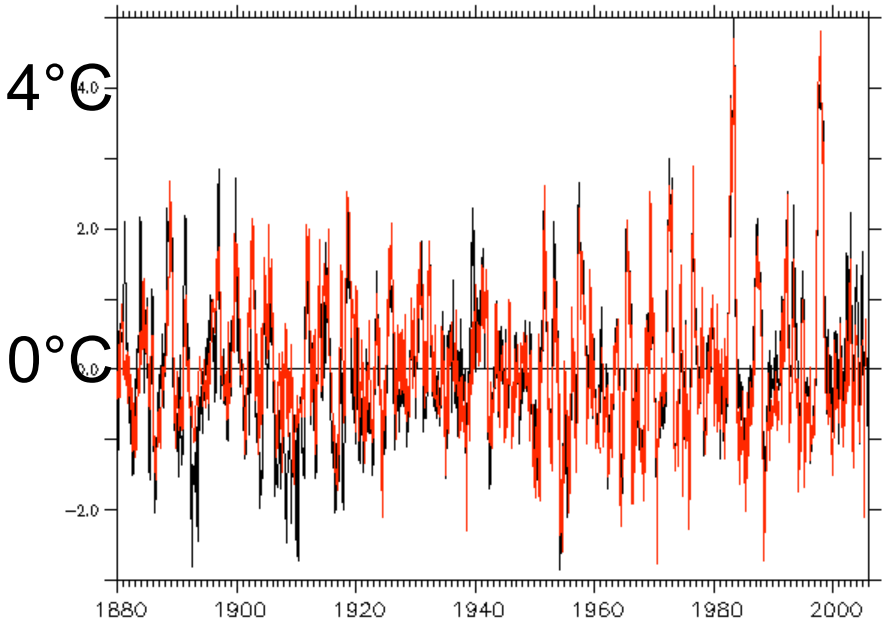
- Rule of thumb: the smaller the space/time scale the larger the influence of internal variability.

  Radiative forcing signals tend to dominate at longer time/space scales.

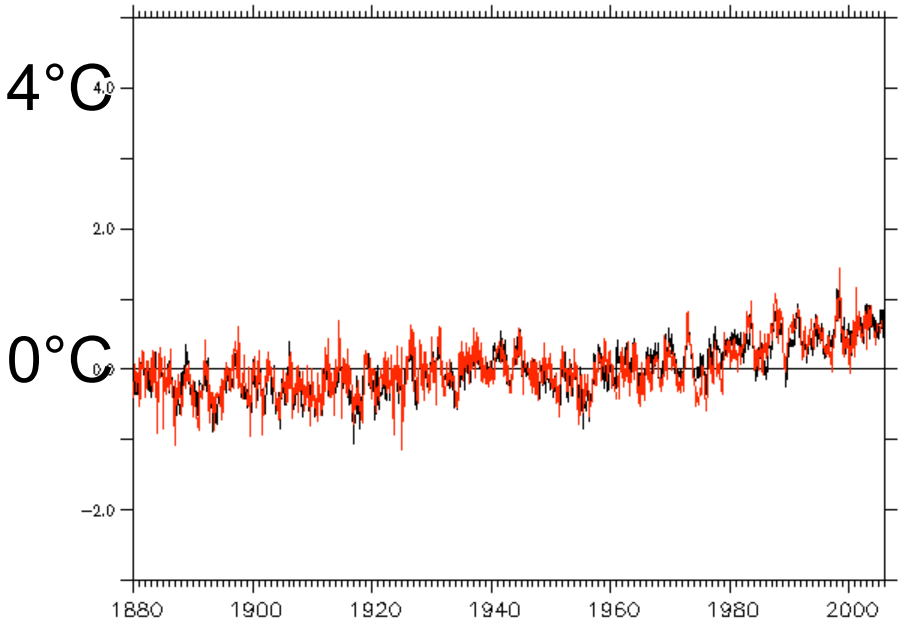
- However, exceptions exist….
  - Some places more variable than others
  - Radiative forcing impacts structure of some features more strongly than mean (*e.g.*, sea surface salinity).

Observed Sea Surface Temperature

Eastern Eq. Pacific (90°O,0°N)

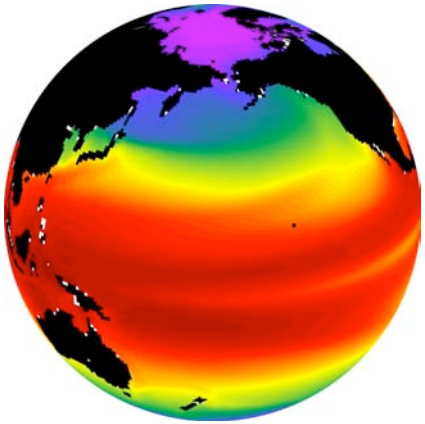


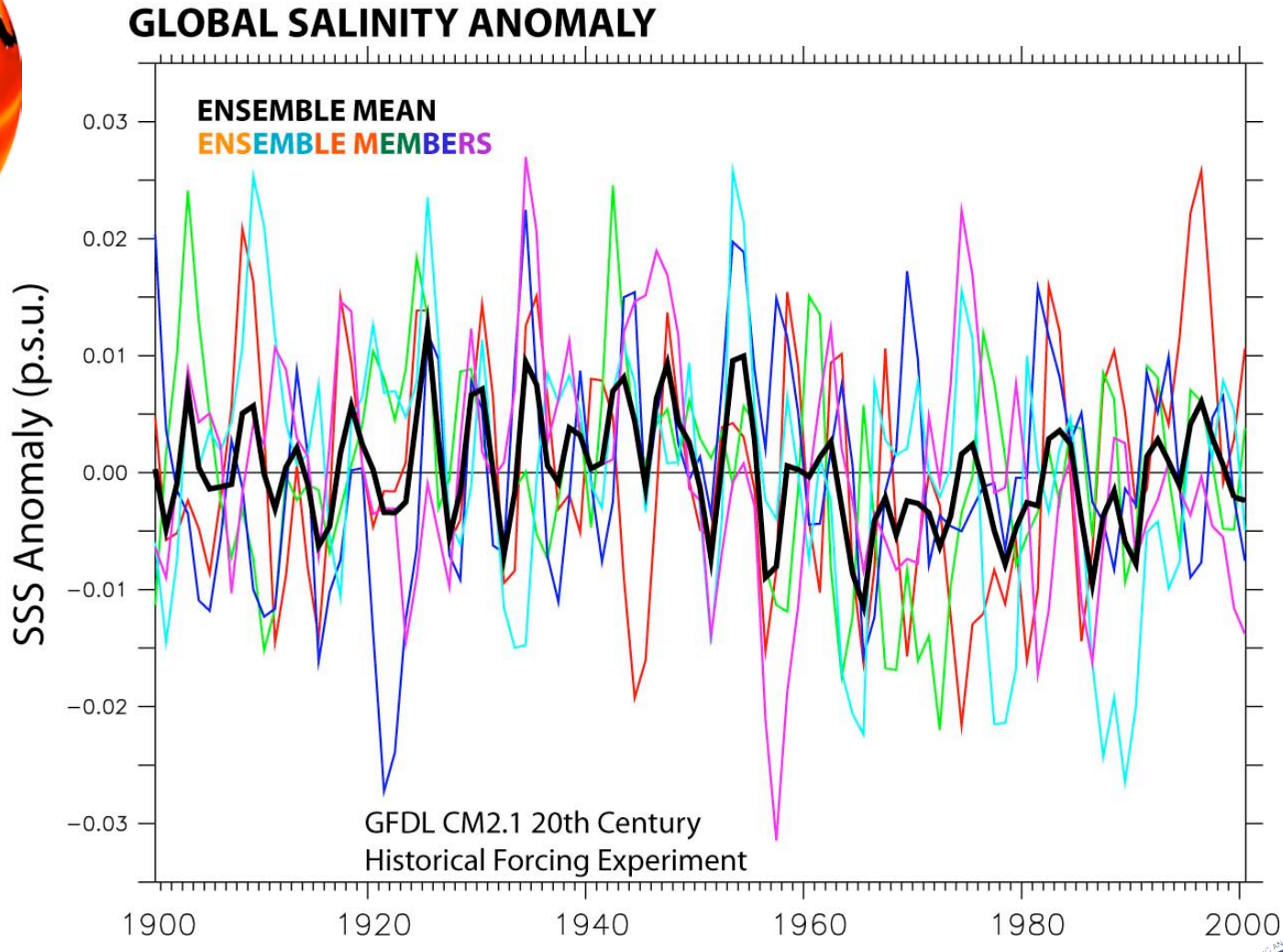
Equatorial Indian (70°E,0°N)



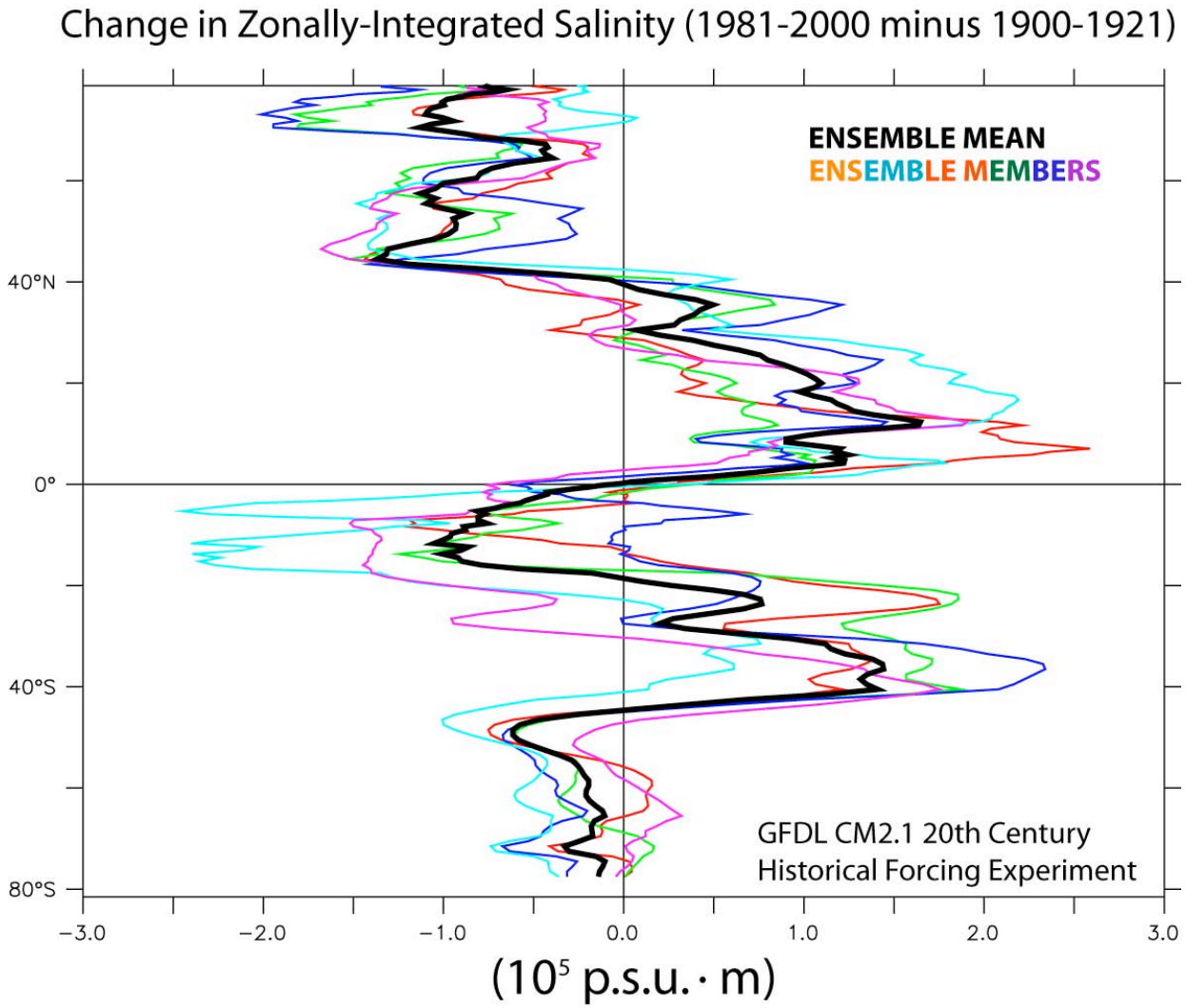
- EEqPacific dominated by internal variability.
  - Long-term trend is not obvious
- Long-term trend clear in Indian Ocean.

Global-mean Sea Surface Salinity





Longitudinally integrated SSS



FRESH

SALTY

FRESH

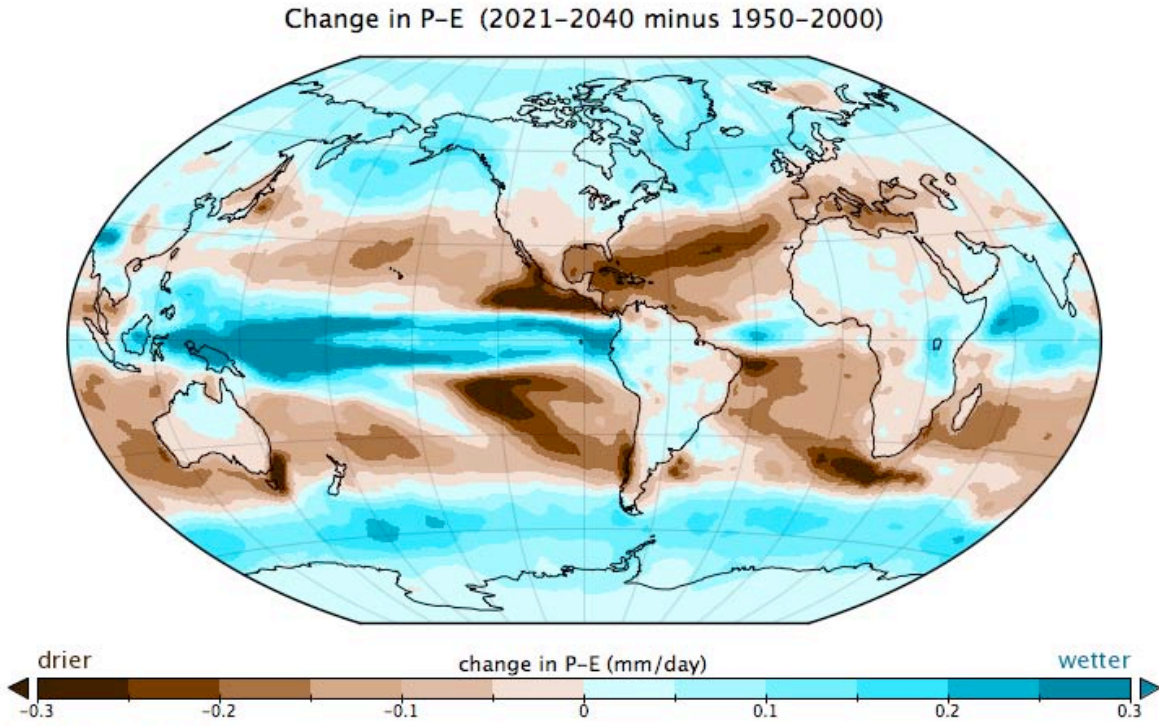
SALTY

FRESH

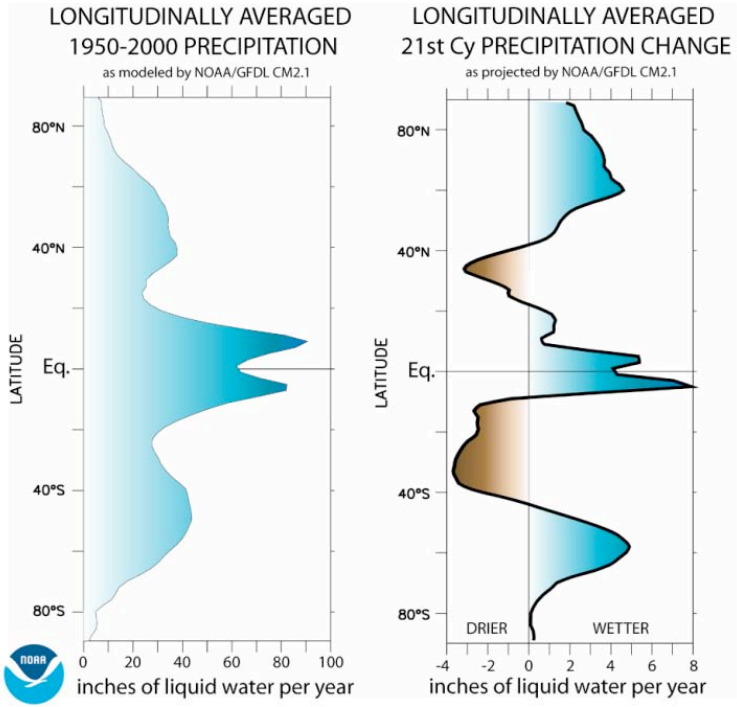
“Wet-get-wetter, dry-get-drier”

Thermodynamic Control:

Warming (increase q_{sat}) -> increase atmospheric moisture. -> increase moisture flux divergence/convergence.



Adapted from Held and Soden (2006, J. Clim.)
Figure by N. Naik., LDEO/Columbia



Adapted from Held and Soden (2006, J. Clim.)

Summary

Application of GCMs to fisheries (or other localized, complex problem) constrained by:

- Resolution of global projections
  - Statistical adjustment a possible solution (caution)
  - Higher resolution global models in the pipeline

- Inter-model spread within global projections
  - Models agree on gross features (sign of regrional and global changes)
  - Models disagree on magnitude of changes (and relative magnitude)
  - Uncertainty can have profound impacts on downscaling
  - Explore multiple models to get sense of spread, understand mechanisms

- Internal variability
  - More dominant at small time/space-scales
  - Climate change that happens combination of forced and internal
  - How much is predictable?

References

Delworth, T.L. et al. (2006):2006: GFDL's CM2 Global Coupled Climate Models. Part I: Formulation and Simulation Characteristics. *J. Climate*, 19(5), doi:10.1175/JCLI3629.1.

Gnanadesikan, A. et al., (2006): GFDL's CM2 global coupled climate models - Part 2: The baseline ocean simulation, *J. Climate.*, v.19, pp.675-697.

Held, I., and B.J. Soden, 2006: Robust responses of the hydrological cycle to global warming. *J. Climate*, 19(21), doi:10.1175/JCLI3990.1

IPCC, 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 996 pp.

Knutson, T.R., J.J. Sirutis, S.T. Garner, G.A. Vecchi and I.M. Held (2008): Simulated reduction in Atlantic hurricane frequency under twenty-first-century warming conditions, *Nature Geoscience*, doi:10.1038/ngeo202

Reichler, T., and J. Kim (2008): How Well do Coupled Models Simulate Today's Climate? *Bull. Amer. Meteor. Soc.*, 89, 303-311.

Stouffer, R.J. et al. (2006): GFDL's CM2 Global Coupled Climate Models. Part IV: Idealized Climate Response. *J. Climate*, 19(5), doi:10.1175/JCLI3632.1.

Vecchi, G.A., K.L. Swanson, and B.J. Soden (2008). Whither Hurricane Activity? *Science* 322 (5902), 687. DOI: 10.1126/science.1164396

Wittenberg, A.T., A. Rosati, N.-C. Lau, and J.J. Ploshay, 2006: GFDL's CM2 Global Coupled Climate Models. Part III: Tropical Pacific Climate and ENSO. *J. Climate*, 19(5), doi:10.1175/JCLI3631.1.

Zhao, M., I.M. Held, S.-J. Lin, and G.A. Vecchi (2009). Simulations of global hurricane climatology, interannual variability, and response to global warming using a 50km resolution GCM. *Submitted to J. Climate.*