Pattern scaling for climate and socio- economic scenarios

Ronald J Stouffer
GFDL/NOAA

Outline

- Pattern scaling of climate change
- Role of natural variability in projections of future climate

Methods of Downscaling Climate Model Information

- Statistical
- Pattern scaling
- Dynamical Models
  - Global
  - Regional

Pattern Scaling

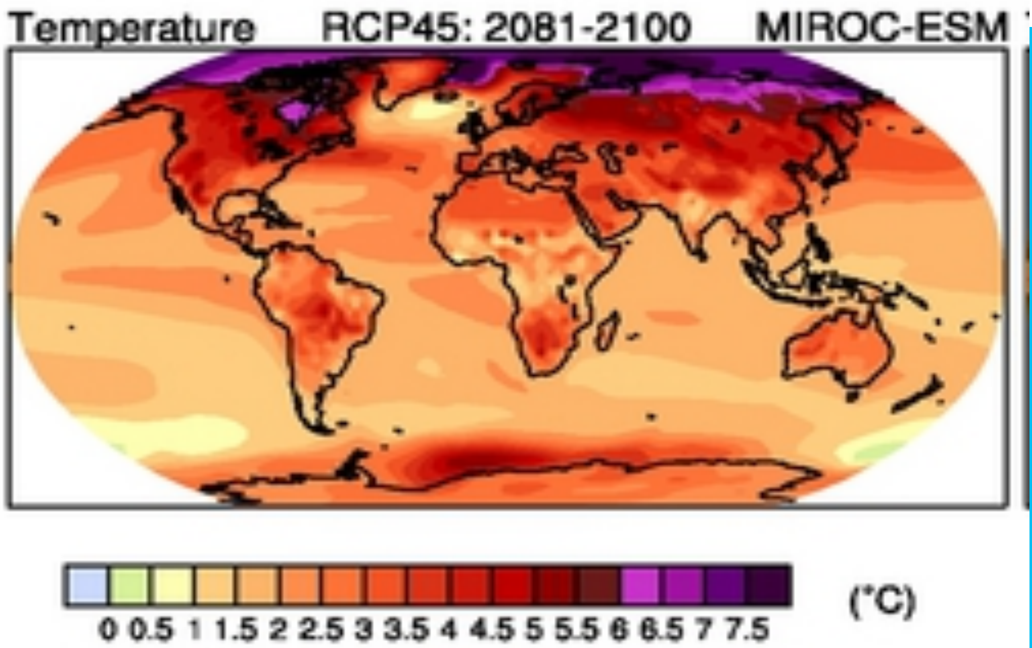
For a given variable of interest:

- Find or define a signal over some time period
- Interpolate to any point in given period
- Extrapolate beyond end of period

Finding a Stable Pattern

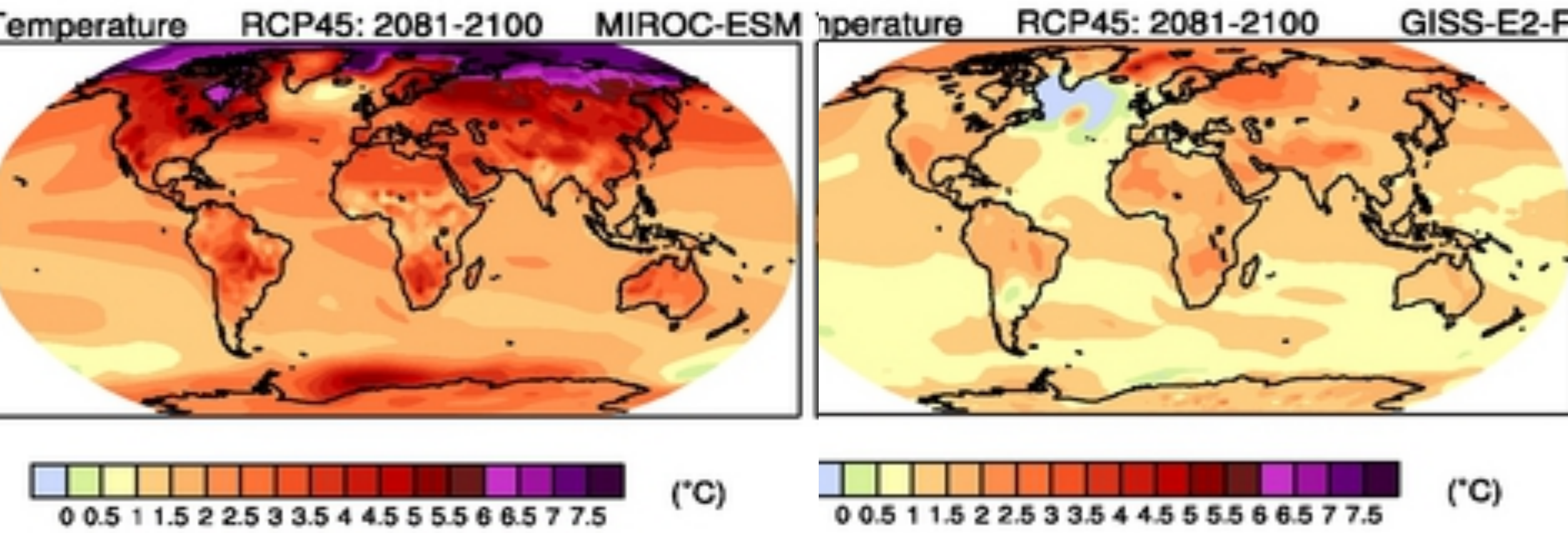
- If one has an infinite number of ensemble members, what is that pattern?
- Usually want to compute pattern over long time period to maximize signal
- Experience has shown that large scale pattern can be seen early in runs (few decades)
  - But pattern varies from model to model and even ensemble member to ensemble member in a given model
  - In practice, use large multi-model ensemble

Finding a Stable Pattern



- High lats warmer than lower lats
- Land warmer than adjacent ocean

Finding a Stable Pattern



- High lats warmer than lower lats
- Land warmer than adjacent ocean
- BUT pattern very different between models

Finding a Stable Pattern

- How small a scale can pattern scaling be trusted?
  - A function of number of ensemble members
    - Minimize "noise" in signal
  - A function of S/N ratio of given variable
- Modelers typically think in terms of relatively large scales
  - E.g. Western US, Western Europe, or larger
  - Smaller scales can have issue (more later)

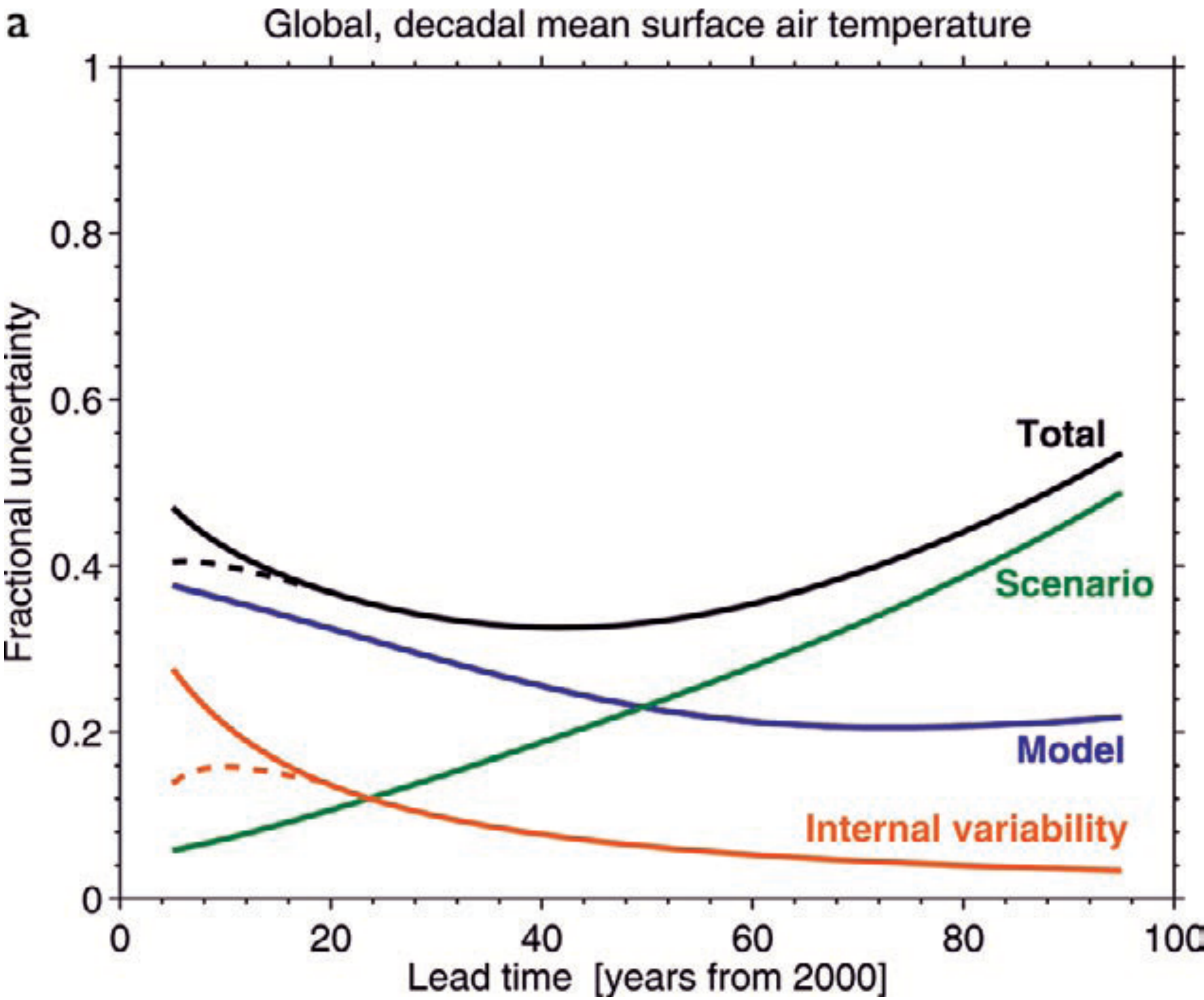
Pattern Scaling

- Pluses
  - Once pattern is computed:
    - Easy to apply to any time period
    - Cheap
    - Works fairly well at large time (big signals) and space (continental) scales
- Cons
  - Computing pattern can be data intensive
  - If signal contains too much noise, pattern is very miss leading <= hard to know
  - At small scales, local forcings may produce signal larger than large scale pattern signal
    - Aerosols, land use changes are examples

Natural variability role in climate science

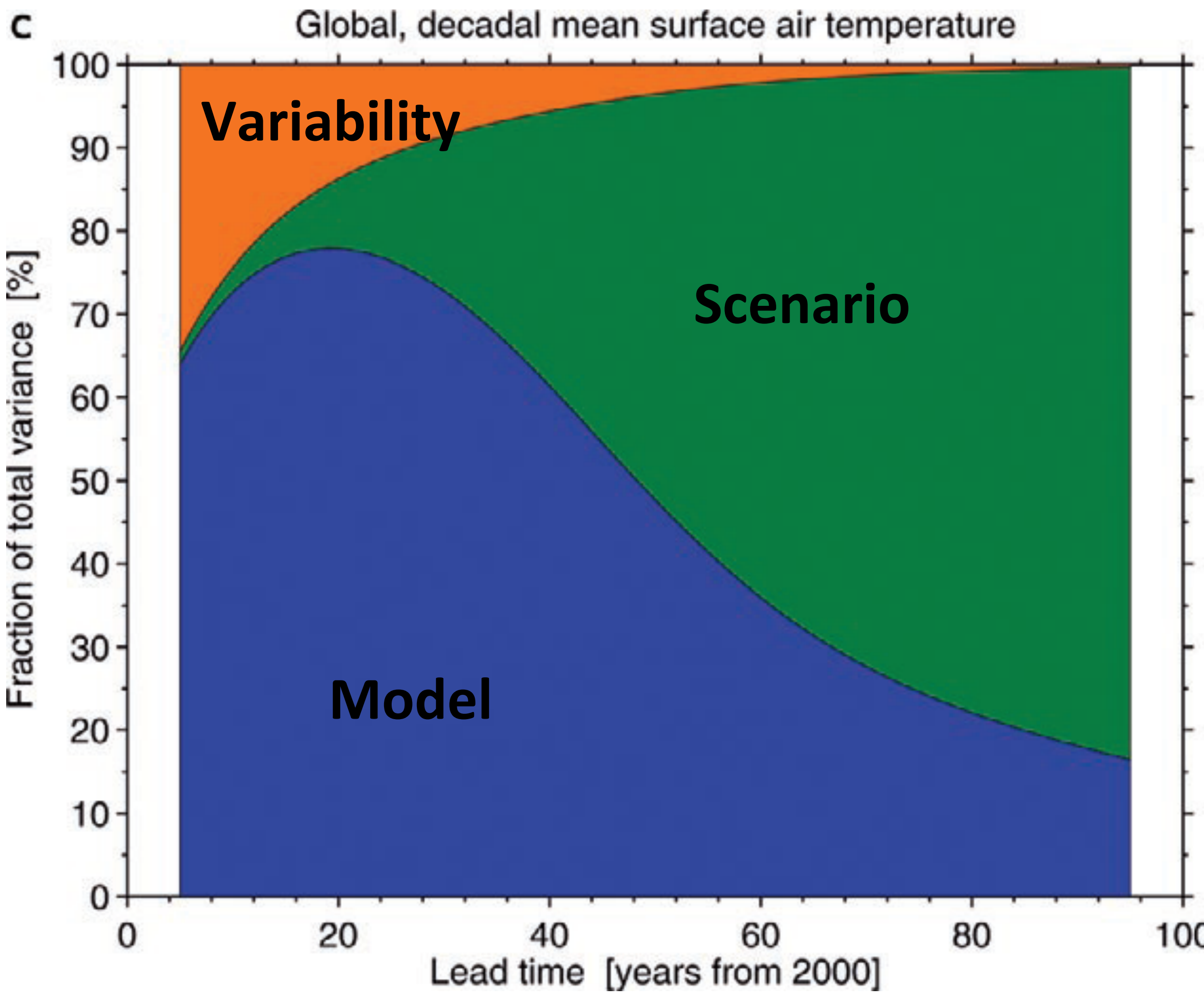
- More than just sampling issue
- Importance relative to other uncertainties
  - Scenario
  - Model
- Use Hawkins and Sutton 2009 BAMS paper to frame discussion

Global decadal mean SAT



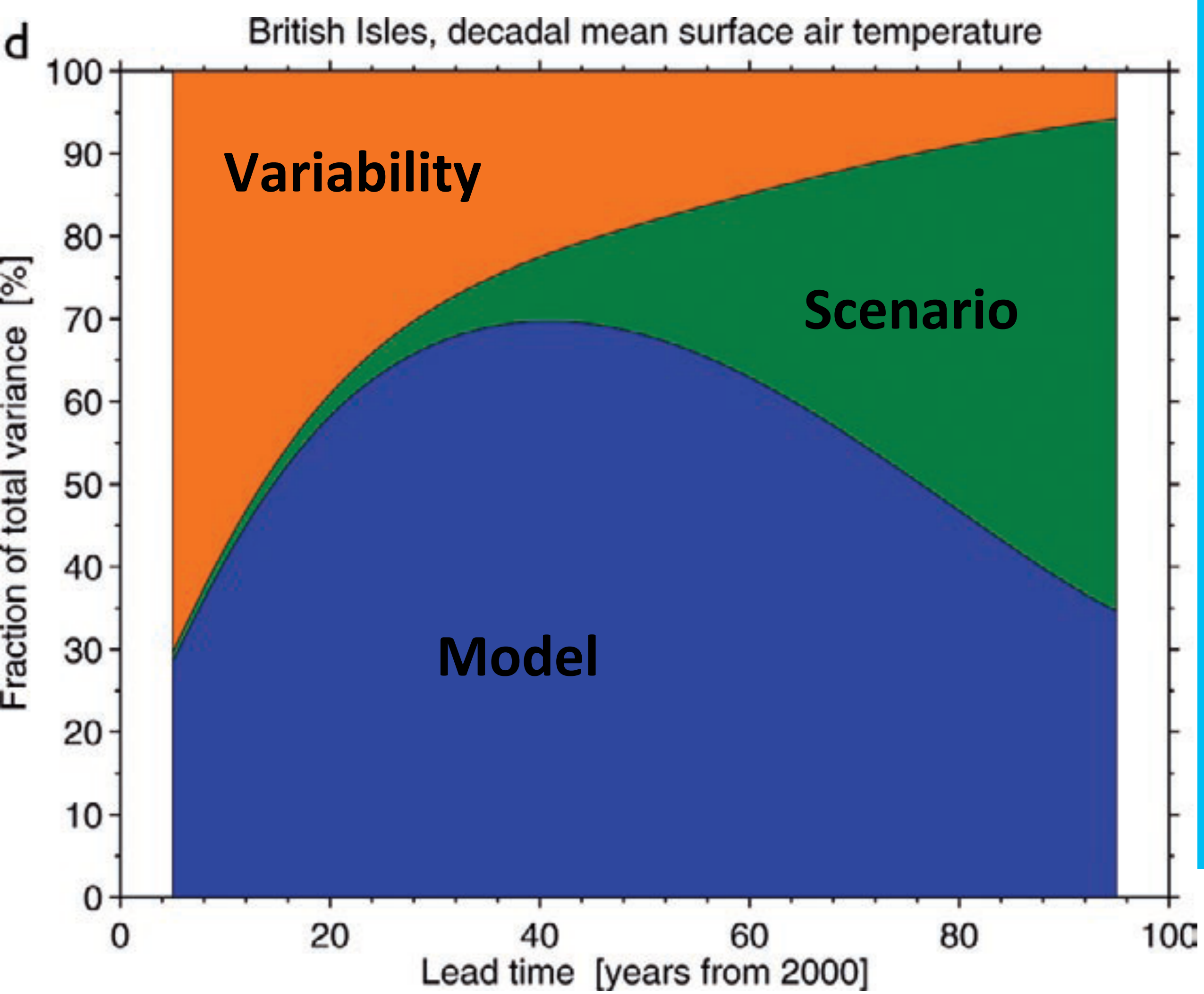
- Looked at span of CMIP3 model results
- Scenario are AR4 SRES WG1's
- 1995 to 2100
- Decadal means!

Global decadal mean SAT



- Scenario uncertainty most important on longer scales
- Model uncertainty most important on shorter time scales
- Variability not a big player

UK decadal mean SAT



- Large role for natural variability on short to medium time scales
- Model/scenario uncertainty most important near 2100

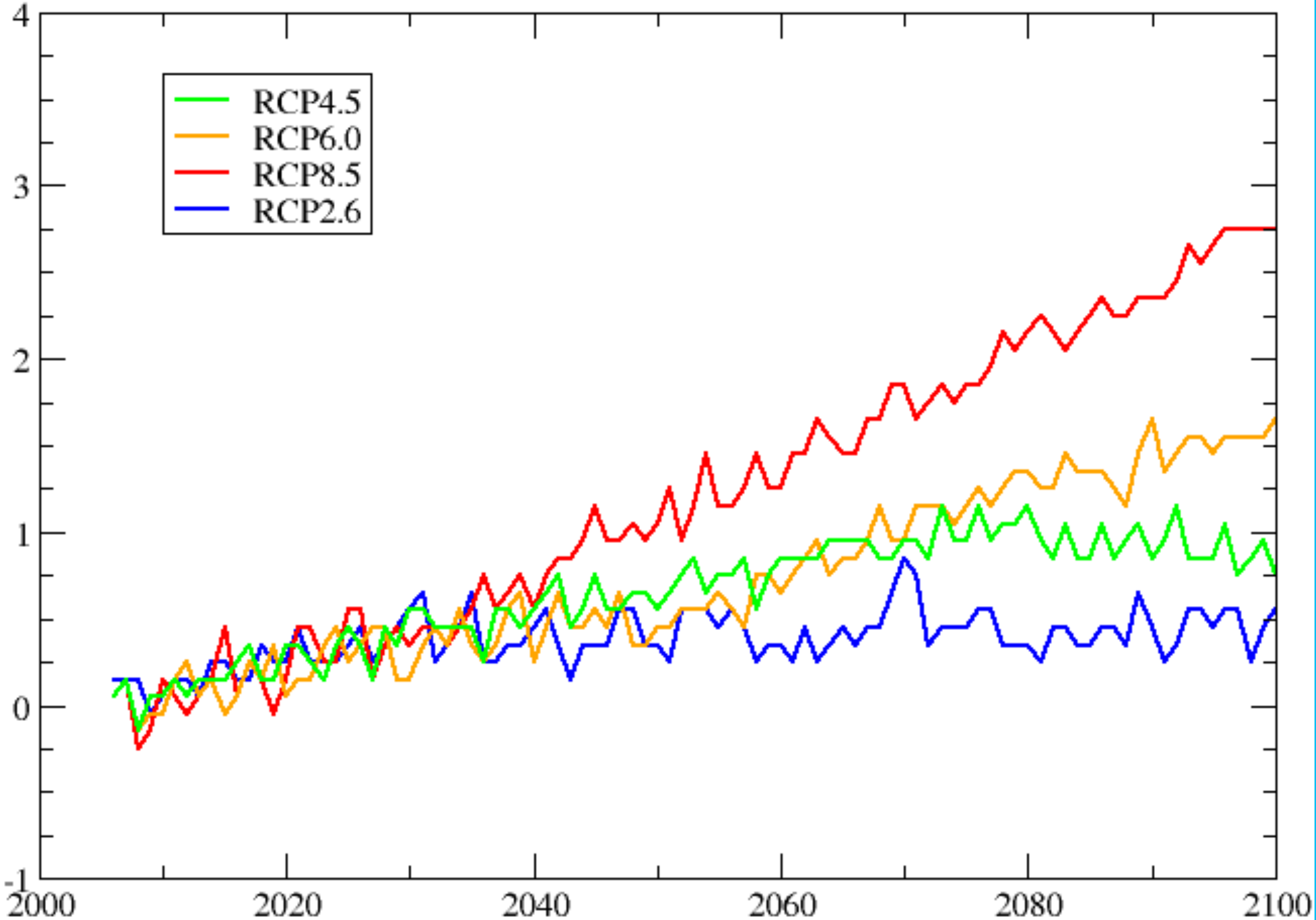
Notes

- Analysis on present day models and scenarios
  - If models improve **or**
  - If scenarios radiative forcing range changes
  - Then pictures may change
- Analysis based on **decadal** mean data
  - Role for natural variability larger on shorter time scales
- Analysis based on global and UK data
  - Smaller space and shorter time scale will have larger role for natural variability

An example using RCP’s

- GFDL ESM2M model
  - GFDL AR5 Earth System Model
  - ESM based on GFDL CM2.1 AR4 AOGCM
  - 2 deg atmosphere
  - 1 deg ocean
  - Closes carbon cycle using land and ocean bio-geo-chemical components
  - Looked at 2005 to 2100 annual mean data

Global SAT

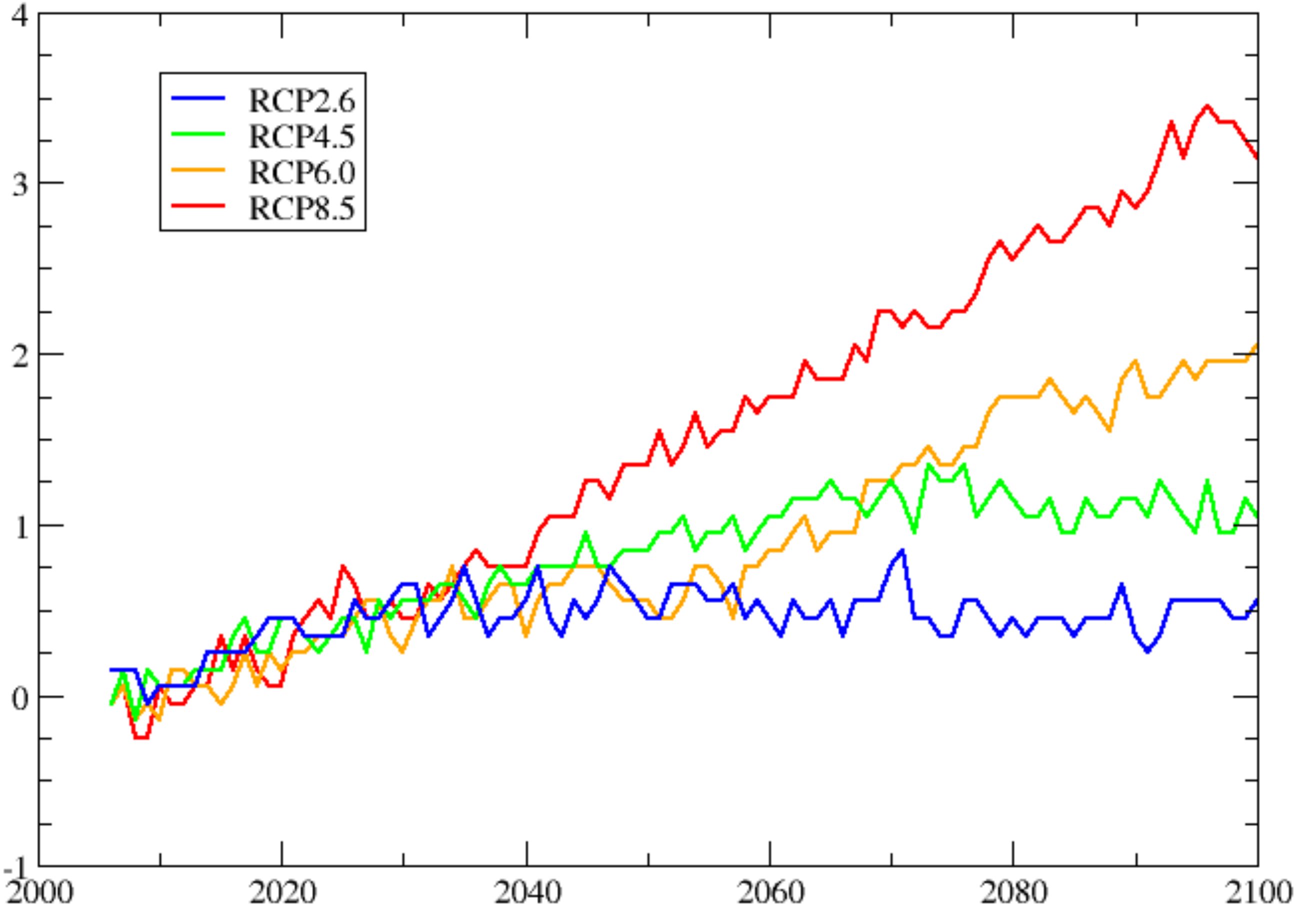


4 slides with same X and Y axis.
GFDL ESM2M –
1 member for each RCP

Points:

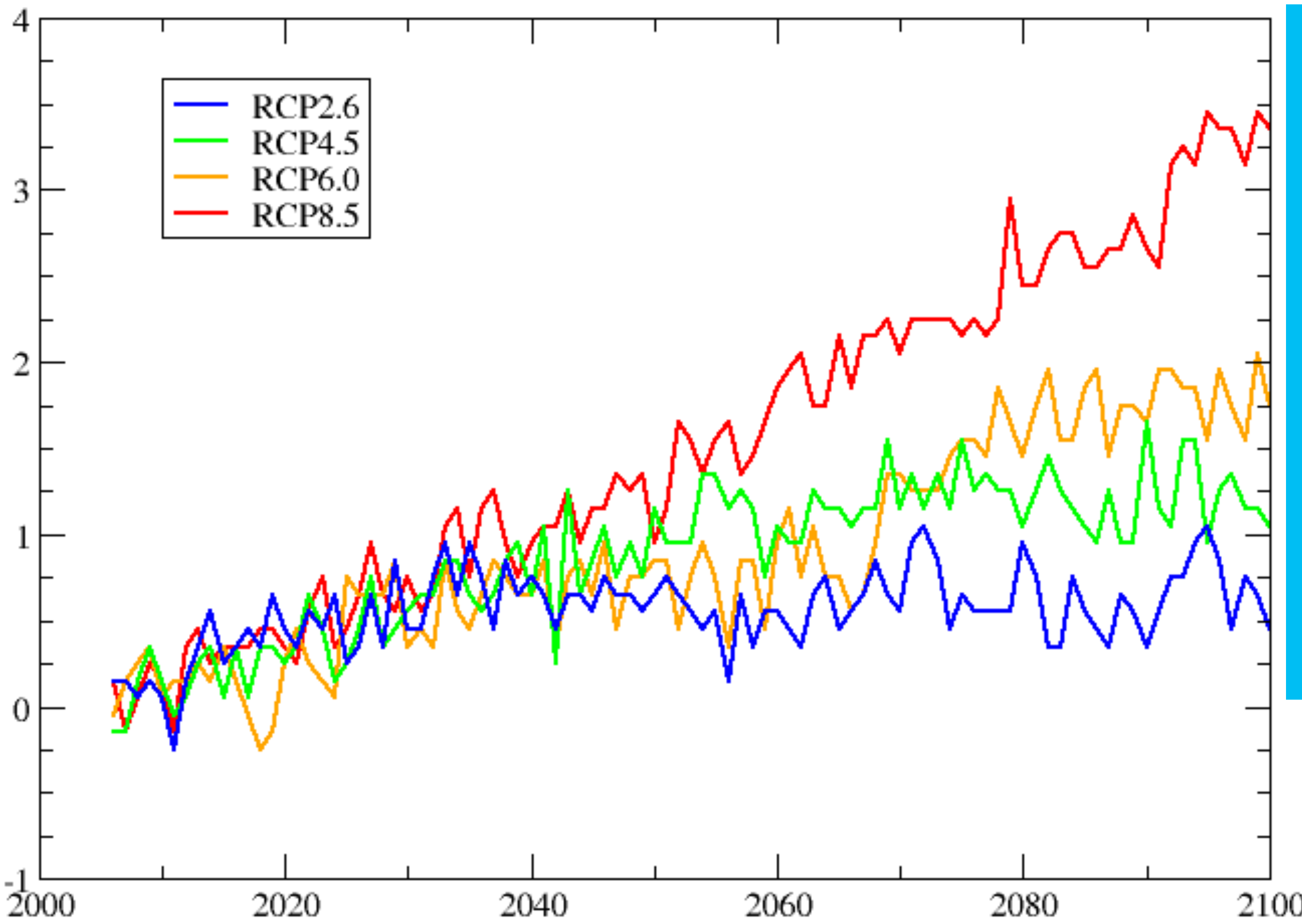
1. RCP8.5 clearly warmer than others by 2040.
2. RCP2.6 clearly cooler than others by 2060.
3. RCP4.5 and 6.0 split around 2070.

Northern Hemisphere SAT



Points:
1. Signal is slightly larger than global.
2. Noise is a little larger too.
3. But global points still apply.

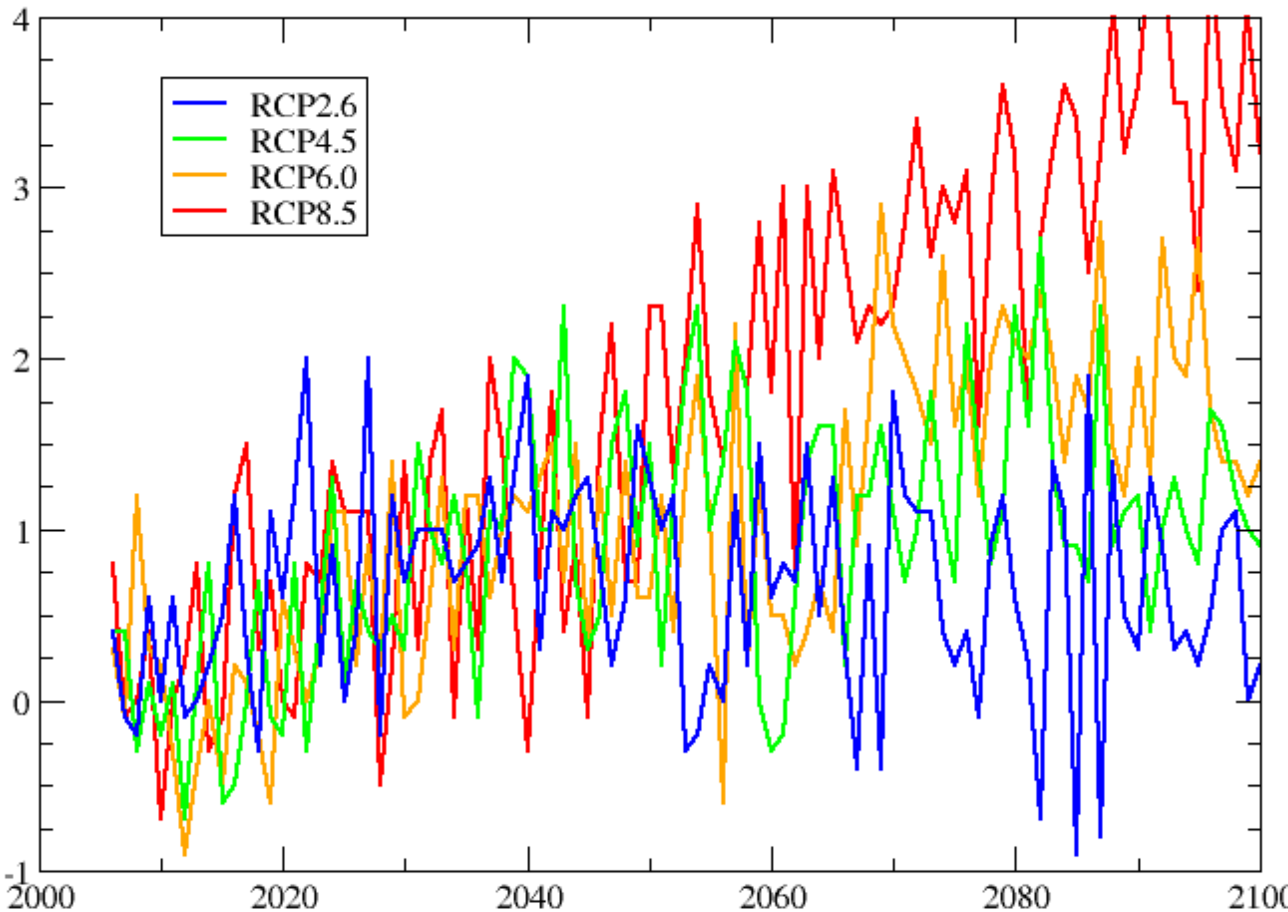
Contiguous United States SAT



Points:

1. Signal is about the same as NH.
2. Noise is larger again.
3. Divergence of curves not as clear and later in time series.

Washington DC SAT



Points:

1. Signal is about the same as NH and CONUS.
2. Noise is much larger.
3. RCP8.5 clearly warmer than others by 2060.
4. RCP2.6 probably cooler than others.
5. Hard to see difference between RCP4.5 and RCP6.0.

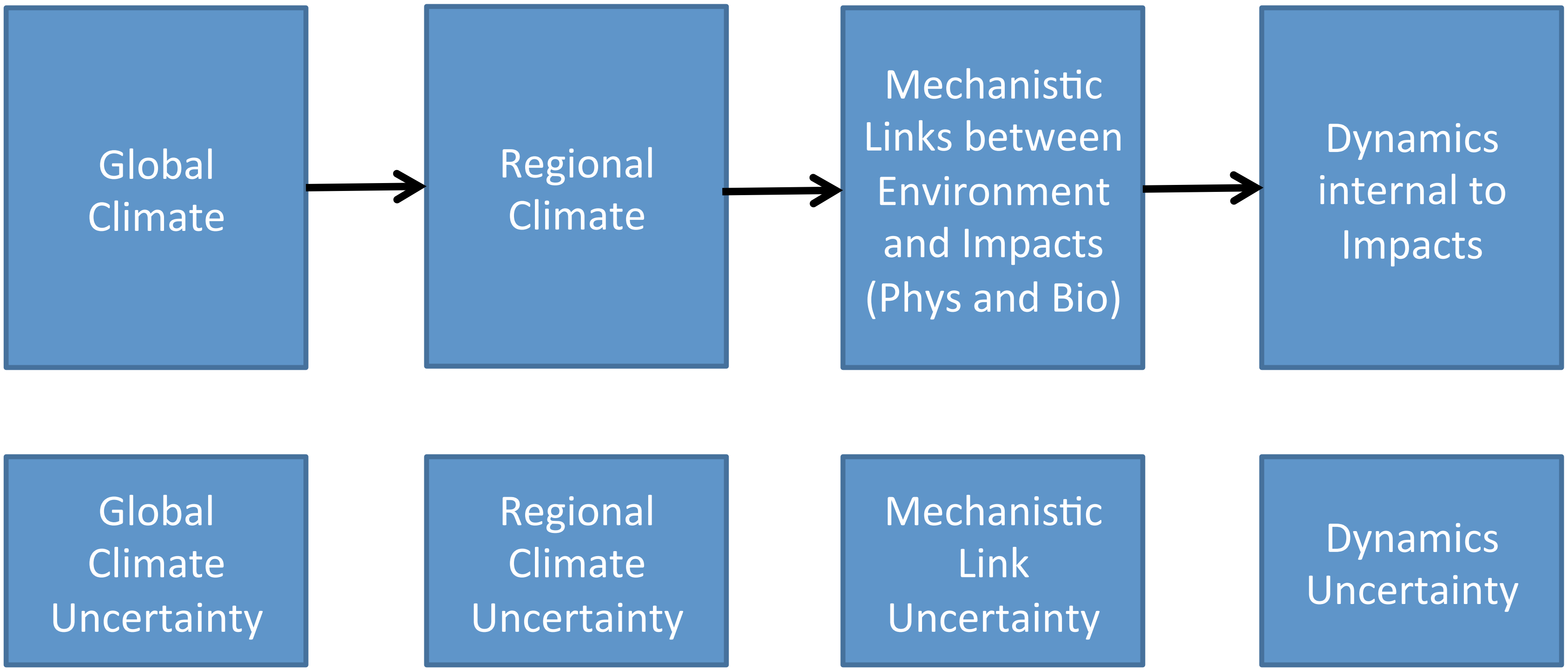
Summary of Signal to Noise Discussion

- While signal does not change much going from long time scales to short or large space scales to small (<2X), noise changes a lot (~10X+).
- Aerosols and other regional forcings play a role in this discussion but variability (noise) is primary factor.
- Implications for analyzing individual model runs and comparing models to real world.
- Precipitation S/N ratio much smaller than SAT

An Example: Making Climate impact statements for Fisheries

- Downscaling climate model data
- Building Living Marine Resource models for climate change impacts projections
- Suggestions on a path forward

Steps to an Impact Study



- Uncertainty tends to be additive as one goes from step to step

Statistical downscaling

- Rely on statistical relationships between resolved, larger-scale features and unresolved finer-scale features.
- Relatively low computational cost but:
  - Must assume stationarity in the statistical relationship
  - Selecting relevant predictors can be difficult – multiple predictors may work equally well (e.g., Vecchi et al, 2008, Science).
  - Requires long observational time series to establish relationships

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Is it sensible to add the projected changes from a coarse climate model to finer-scale regional climatologies when assessing the magnitude and direction of potential climate changes?

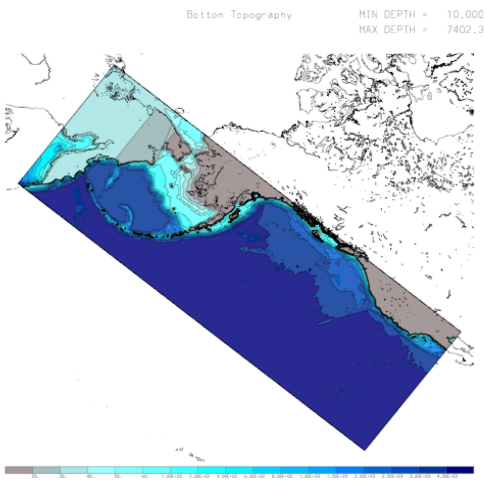
- Projected change can be thought as the product of two things:
  - A large-scale signal driven by radiative changes linked to greenhouse gases and aerosols
  - Changes in local dynamics
- Climate models can capture the first part, but have very limited representations of the second.

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Key question:

Is there a significant regional-scale dynamical feedback that may significantly alter (or reverse) changes resulting from perturbations to the large-scale radiative forcing?

Dynamical downscaling to translate basin-scale dynamics to shelf responses



- One-way nesting decouples regional and global, two-way allows feedbacks
- Still subject to large-scale global model biases
- Biogeochemical Boundary conditions are dynamic (Rykaczewski et al. Science)
- Inconsistencies between nested and global runs complicate interpretation
- Two-way nesting creates a new climate model.

Slide courtesy of K. Hedstrom, E. Curchitser

LMRs are complex climate integrators

- Environmental conditions affect LMRs in many ways and effects propagate through complex food webs
- Interactions occur over a large range of interacting scales
- Potential for evolutionary responses that are not well understood
- Responses are often neither gradual nor linear



Botsford et al., Science, Vol. 277, 509-515.

Why do we trust climate model projections?

"There is considerable confidence that climate models provide credible quantitative estimates of future climate change, particularly at continental scales and above. This confidence comes from the foundation of the models in accepted physical principles and from their ability to reproduce observed features of the current and past climate changes."

Randall et al., 2007 (Chapter 8 of IPCC WG1 Report)

Why should we trust ecosystem projections?

- Foundation of models on accepted ecological and physiological principles

- Ability of models to reproduce observed features of the LMR response to current climate and past climate changes

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Steps toward more robust LMR (Impact) models for climate/LMR (Impact) projections:

- More mechanistic LMR models rooted in physiological and ecological principles
- Correlative relationships should have strong mechanistic underpinnings that can be assessed under different climate conditions.
- It may be necessary to consider multiple plausible models (i.e., an LMR model ensemble)
- Sustained time-series and focused process studies are needed to build and test models

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Support a two-pronged approach articulated by Hollowed et al. (2009):

- Progress can be made by incorporating climate information into existing simple to intermediate-complexity LMR (impact) models (being particularly mindful to avoid highly-empirical relationships w/o mechanistic underpinnings)
- Continued efforts to develop, constrain, and couple comprehensive end-to-end models with climate models

Hollowed et al., a framework for modeling fish and shellfish Responses to future climate change, ICES J of MS 66, 1584-1594

Predicting climate change impacts multiple decades into the future is an uncertain business….

- Any climate-ecosystem impacts study will be subject to criticism on grounds of uncertainty.
- Desire for greater certainty must be balanced against the need for incremental progress.
- Scientific merit must be gaged relative to the extent of previous knowledge and frank acknowledgement and discussions of uncertainties where they exist.

Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Why can’t WG1 provide data I want?

- Mechanical
- Physical
- Communication

Why can't WG1 provide data I want?

- Mechanical
  - Archival aspects – too much data!
  - Space and time (frequency) are problems
    - Finer spatial resolution => more data
    - Higher frequency => more data
  - CMIP3 - ~100 tb total
  - CMIP5 - ~2-4 pb total
    - Factor of 20-40 increase

Why can’t WG1 provide data I want?

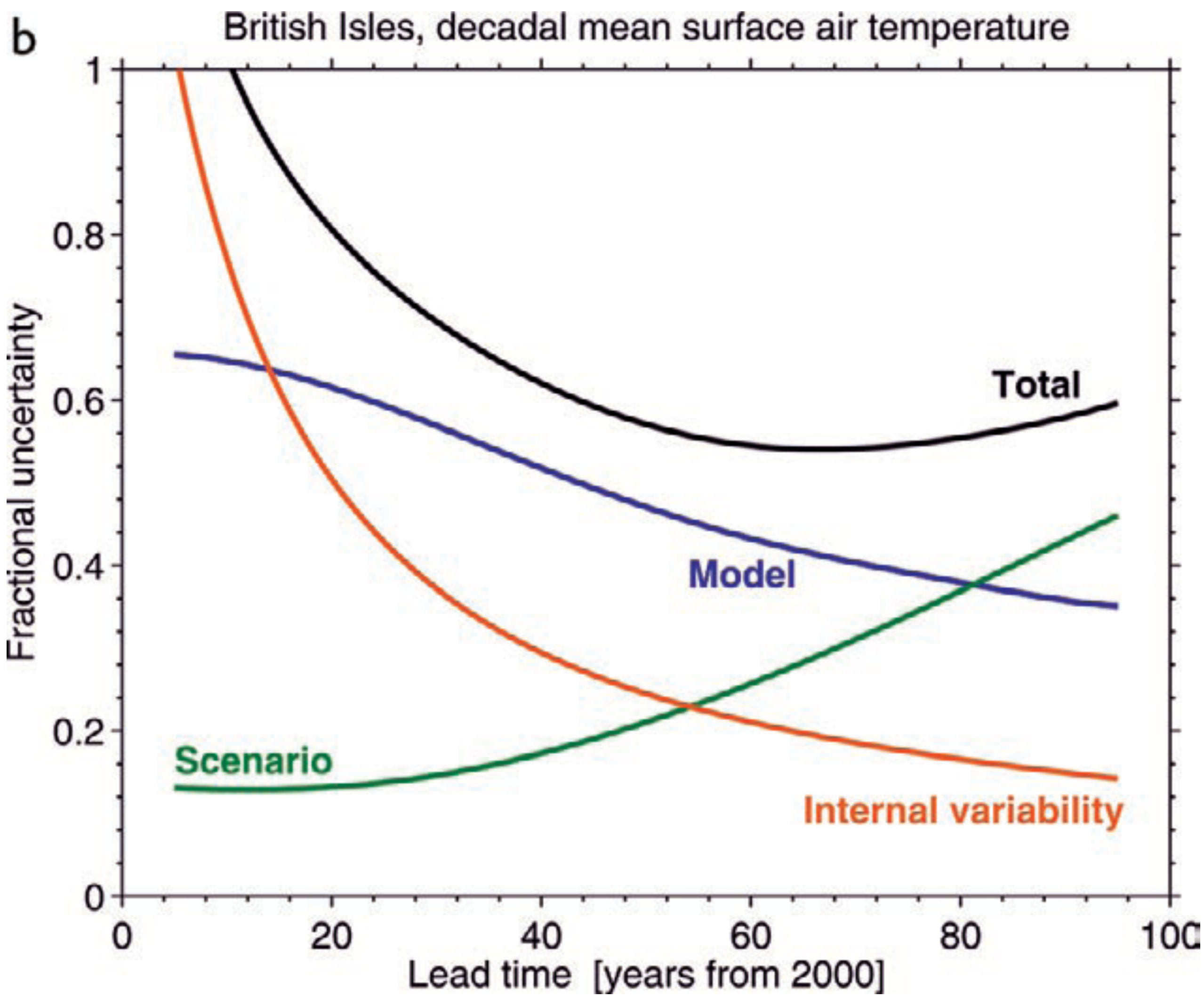
- Physical
  - Models physical parameterizations do not allow/ simulate variable
    - Example – Diurnal in model with no diurnal cycle
    - Becoming smaller issue with time
  - Variable not prognostic
    - Need statistics or other model to provide variable
    - Example - downscaling

Why can't WG1 provide data I want?

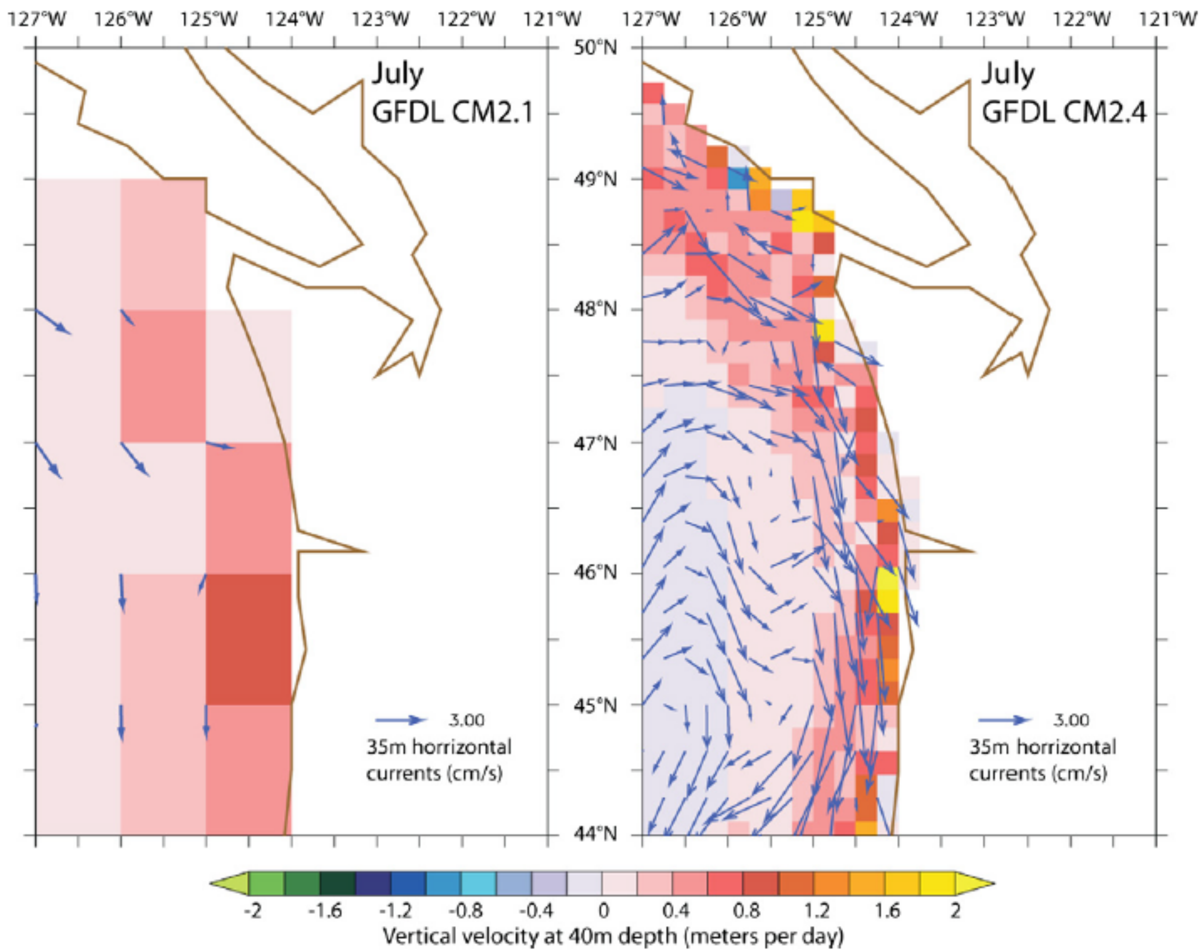
- Communication
  - Need for bi-directional communication
  - Many times issue is that impacts people do not have seat at table when variable lists developed
  - Who "owns" missing links?
    - Impacts or Modeling groups or ?
    - Examples – netCDF vs GIS, downscaling
  - Current problems

Why can't WG1 provide data I want?

- Communication
  - Current problems
    - Groups providing downscaled data
      - Little or no QC
      - Science information relating to data still missing
      - Typically available data developed with specific usage in mind => other uses may or may not fit into assumptions


b
British Isles, decadal mean surface air temperature
Fractional uncertainty
Lead time [years from 2000]
Total
Model
Scenario
Internal variability
0
0.2
0.4
0.6
0.8
1
0
20
40
60
80
100

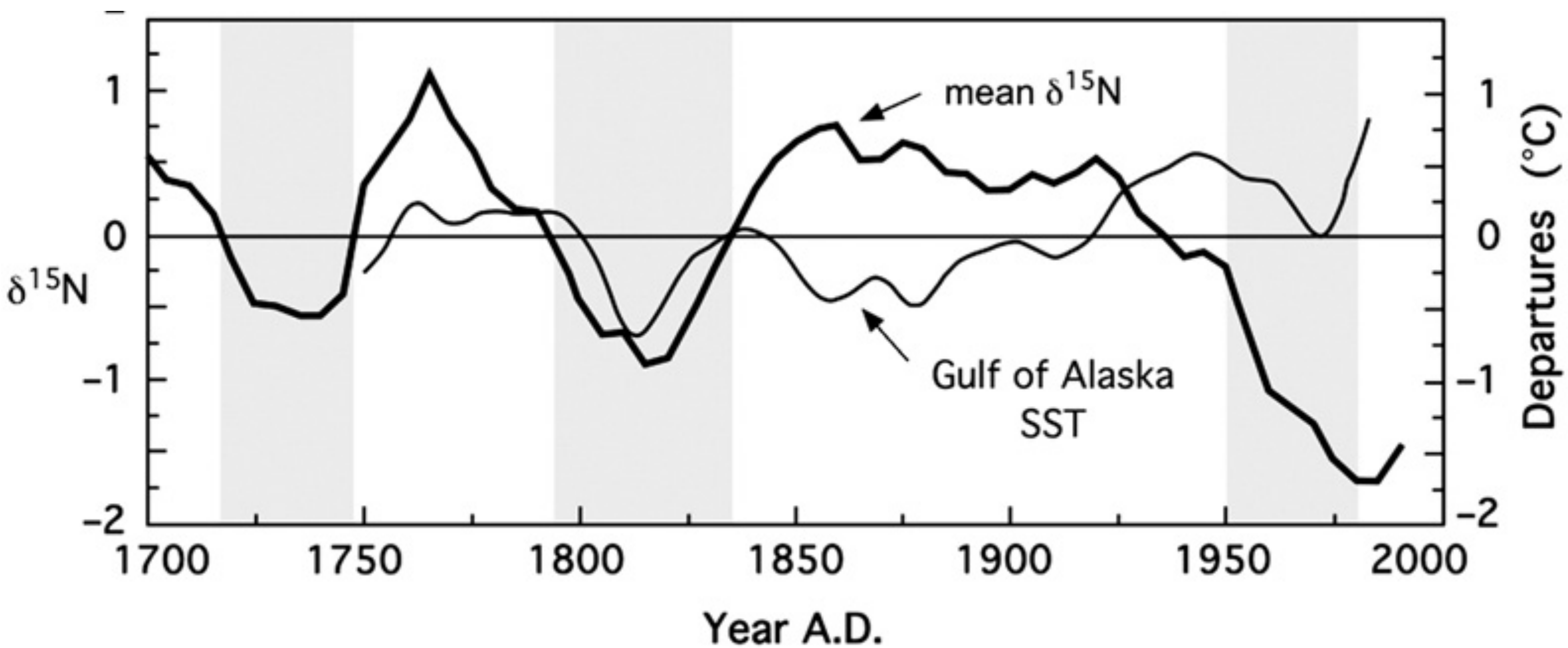
The ocean model resolution of most climate models is ~1-2 degrees; atmosphere is ~2-3 degrees



Stock et al., 2011, Prog. Oceanogr. 88, 1-27

Climate change will create conditions that will generally not have past analogs

Relationship Between Temperature and Sockeye Salmon in the Gulf of Alaska



Finney et al., 2010, Journal of Marine Systems, 79, 316-326