(sfi)^2 Statistics for Innovation

Of what use is a statistician in climate modeling?

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Outline

- Difference between weather and climate
- Modeling climate
- Analyzing trends
- Looking at extremes
- Comparing climate models to weather data

Weather and climate

- **Climate is**
  - **–average weather**
    - **WMO 30 years (1961-1990)**
  - **–marginal distribution of weather**
    - **temperature**
    - **wind**
    - **precipitation**
  - **–classification of weather type**
    - **state of the climate system**
- **Weather is**
  - **–current activity in troposphere**

Models of climate and weather

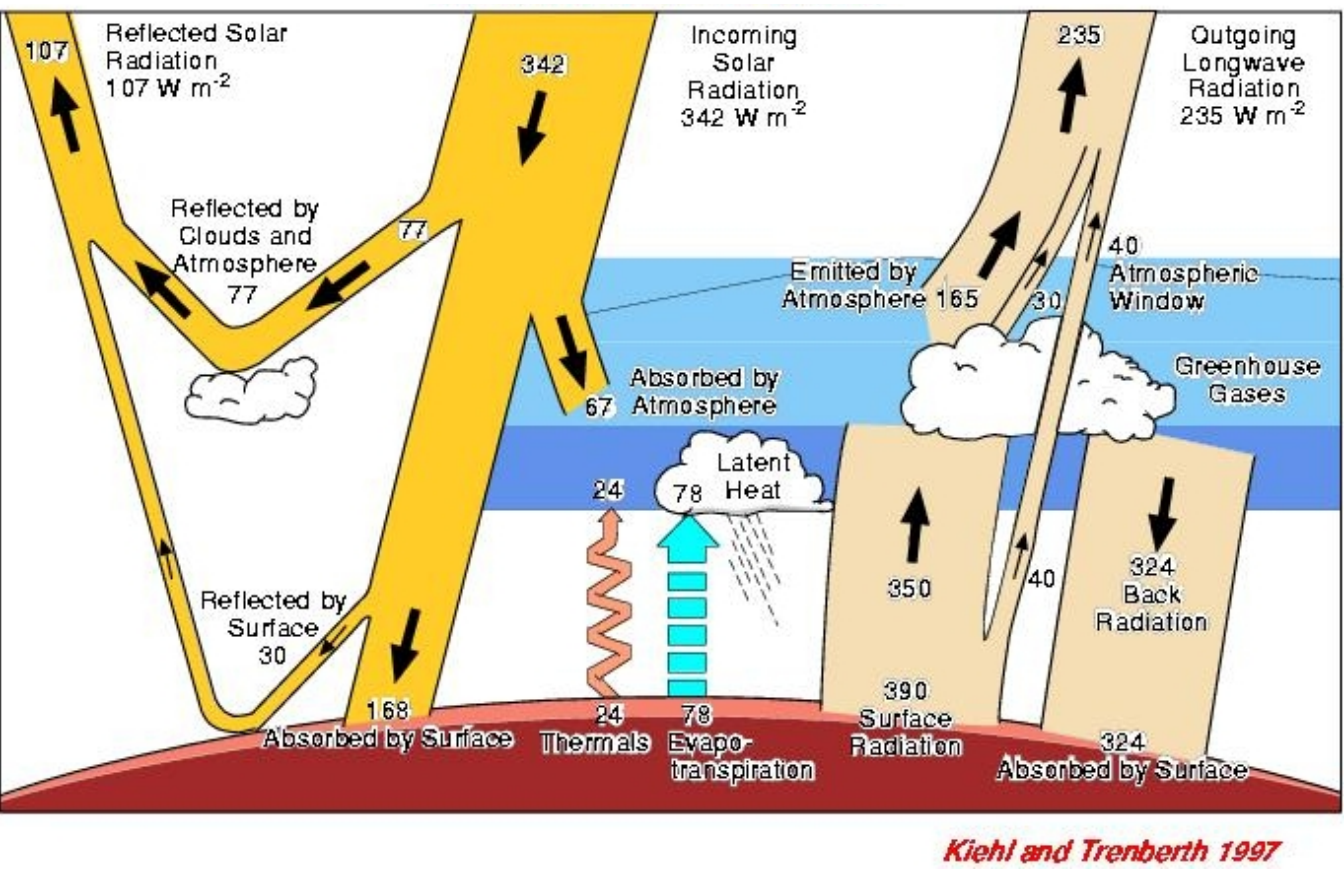
Numerical weather prediction:

- **Initial state is critical**
- **Don't care about entire distribution, just most likely event**
- **Need not conserve mass and energy**

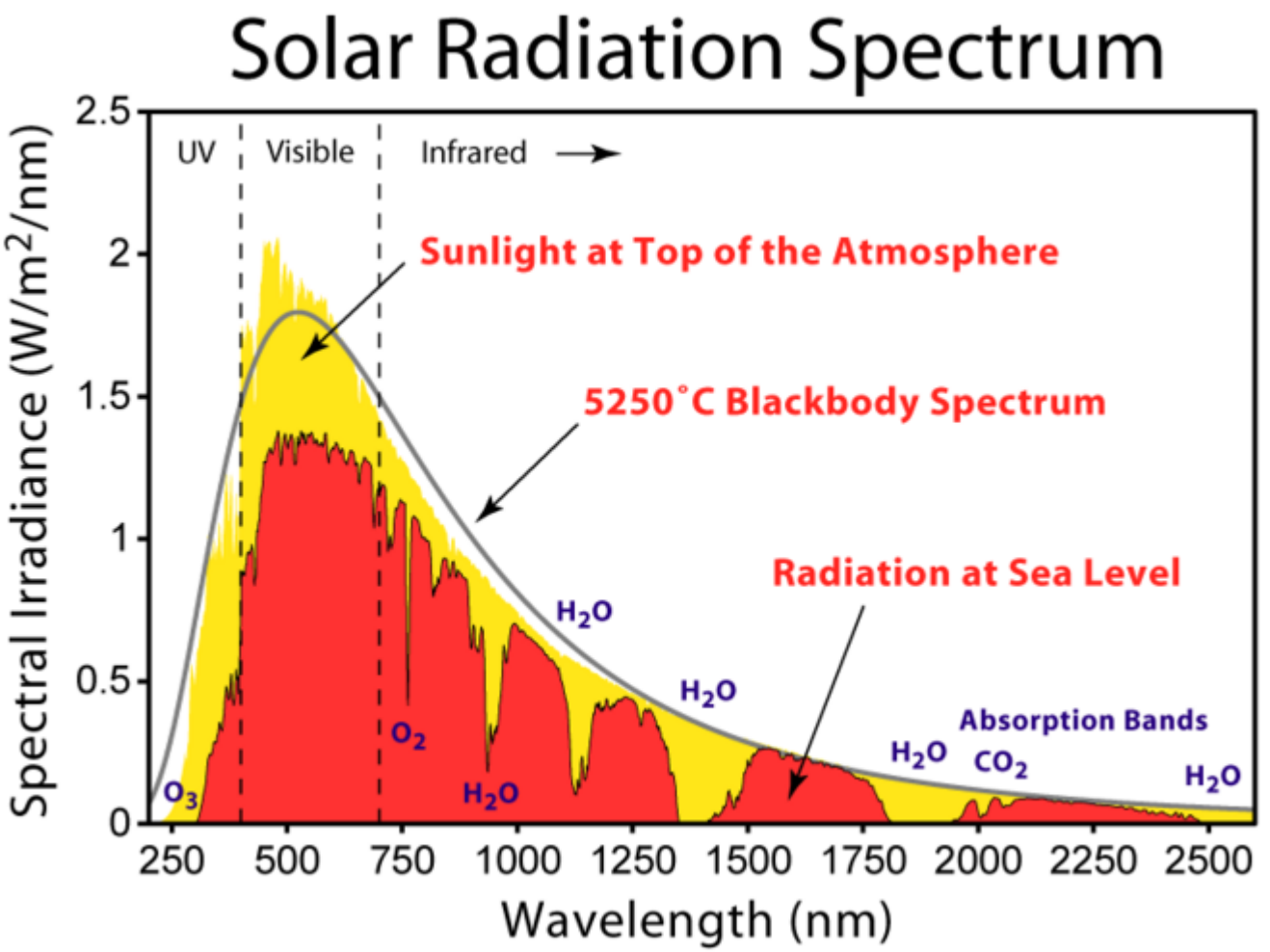
Climate models:

- **Independent of initial state**
- **Need to get distribution of weather right**
- **Critical to conserve mass and energy**

The heat engine



Greenhouse effect



A simple climate model

What comes in

$$S\pi r^2(1-a)$$

Solar constant
1367 W/m^2

Earth's albedo
0.3

must go out

$$4\pi r^2 \varepsilon \sigma T^4$$

Effective emissivity
(greenhouse, clouds)
0.64

Stefan's constant
5.67×10^{-8} W/(K^4·m^2)

Solution

Average earth temperature is T=285K (12° C)

One degree Celsius change in average earth temperature is obtained by changing

solar constant by 1.4%

Earth's albedo by 3.3%

effective emissivity by 1.4%

But in reality…

The solar constant is not constant

The albedo changes with land use changes, ice melting and cloudiness

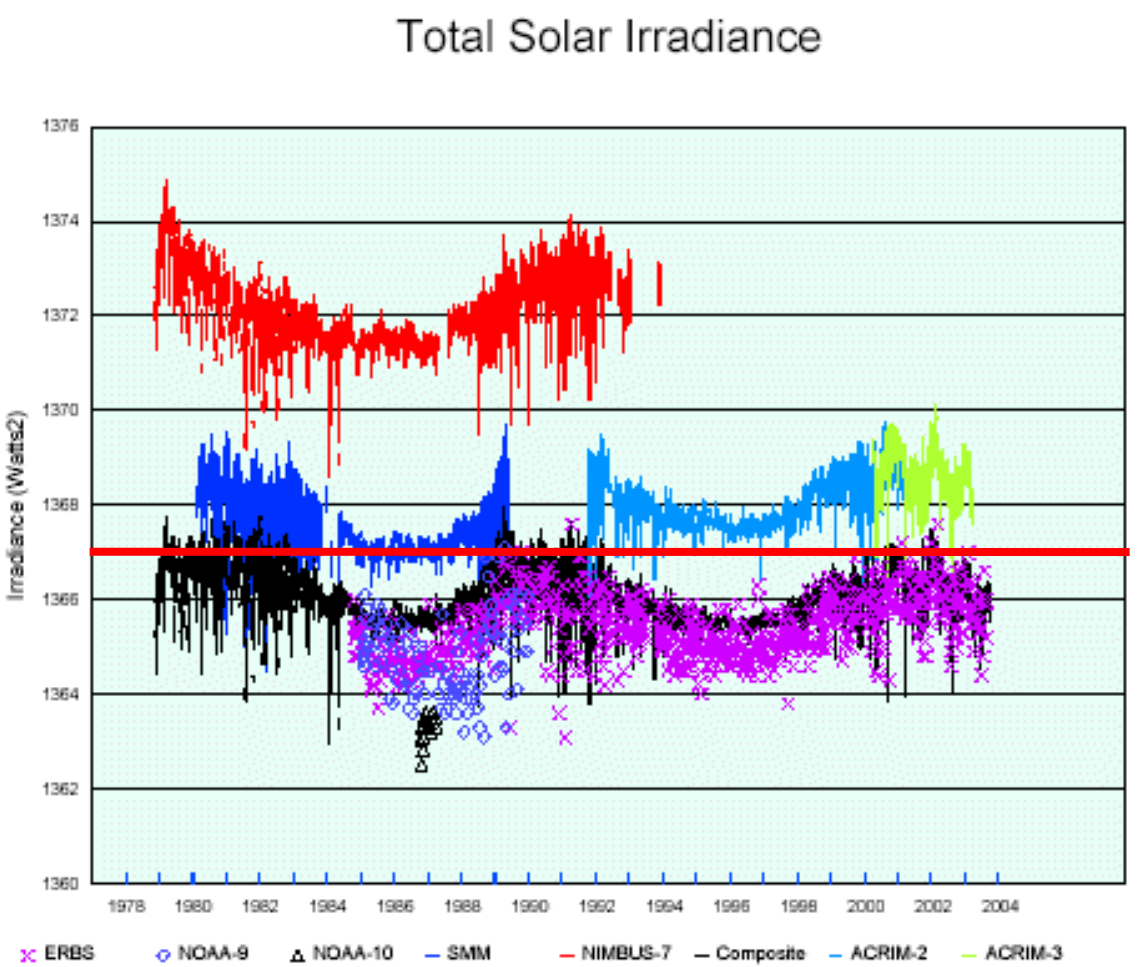
The emissivity changes with greenhouse gas changes and cloudiness

Need to model the three-dimensional (at least) atmosphere

But the atmosphere interacts with land surfaces…

…and with oceans!

The solar constant



Sources of uncertainty

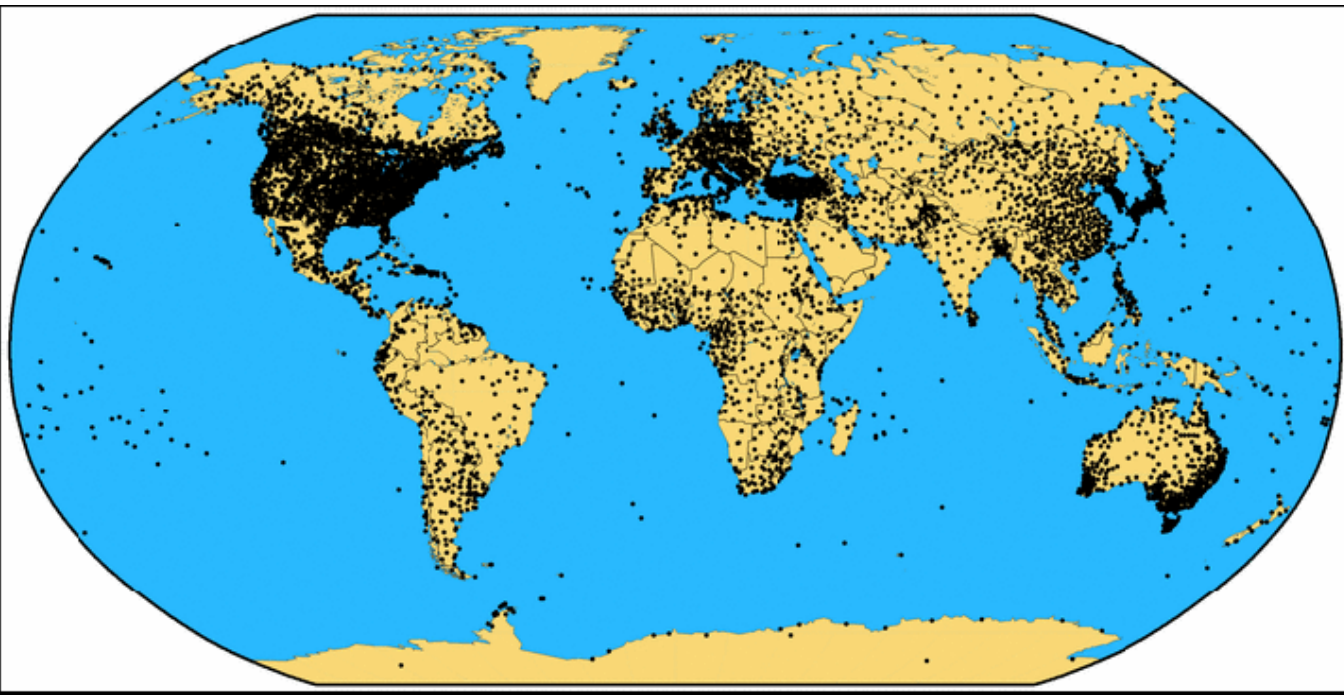
Forcings

- **Sea surface temperature is uncertain, especially for early years**
- **Greenhouse gases vague estimates for early part**

Data

- **Global mean temperature is not measured**
- **Uncertainty in estimates may be as big as 1° C**

Estimating global mean temperature

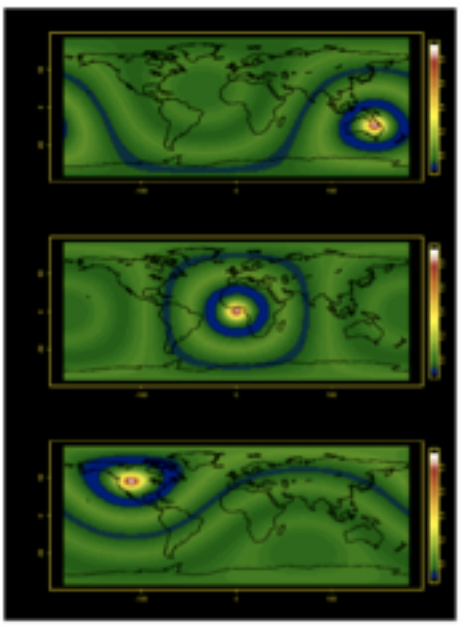


Global Historical Climatology Network

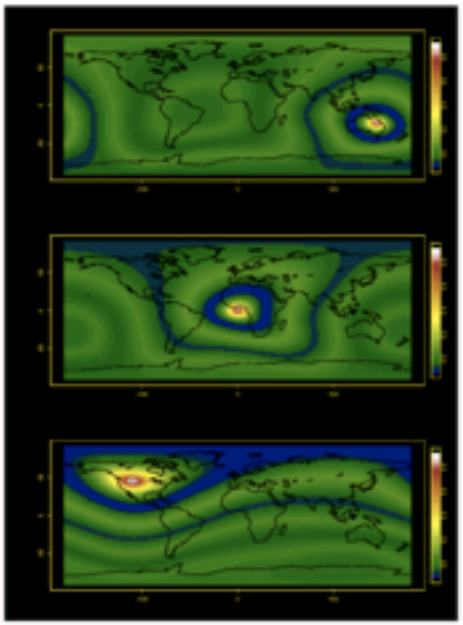
5206 stations with homogenized data of at least 20 years

Global covariance

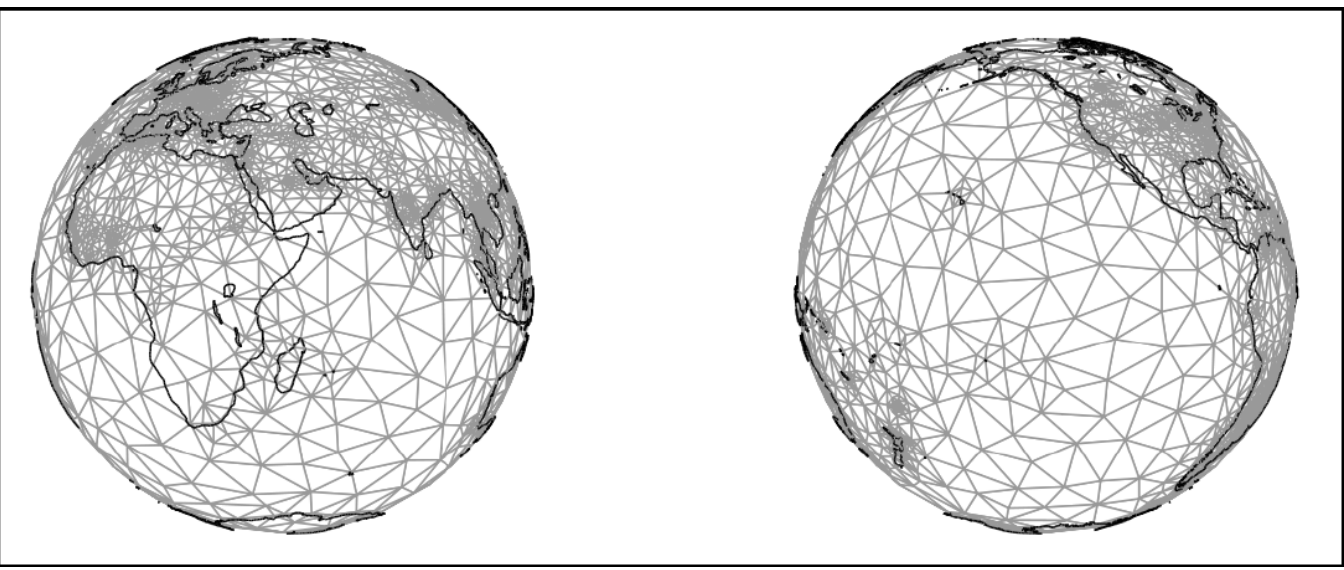
Isotropic



Anisotropic



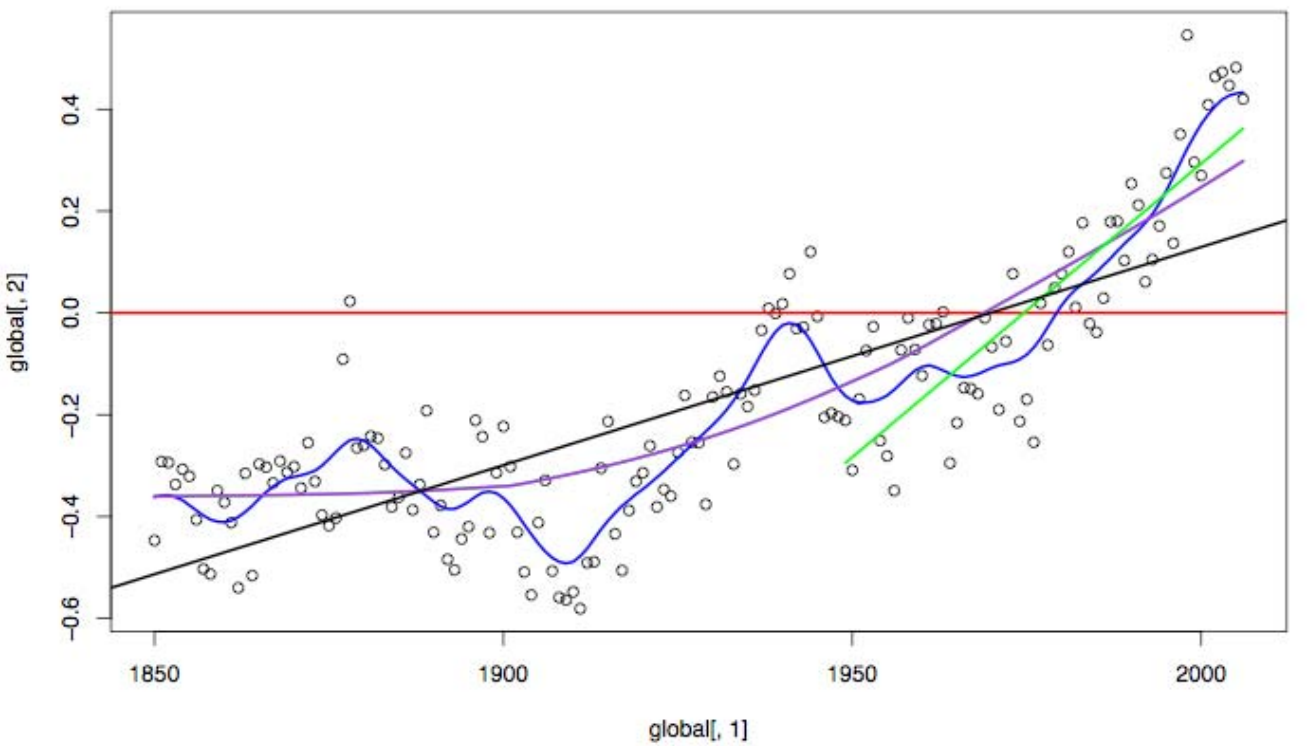
The MRF approach



$$\left(\kappa^2(s) - \Delta\right)^{\alpha/2} x(s) = \varepsilon(s)$$

Solve this stochastic differential equation on a triangulation. Covariance is nonstationary Matérn on the manifold.

Temperature trends



Is the trend significant?

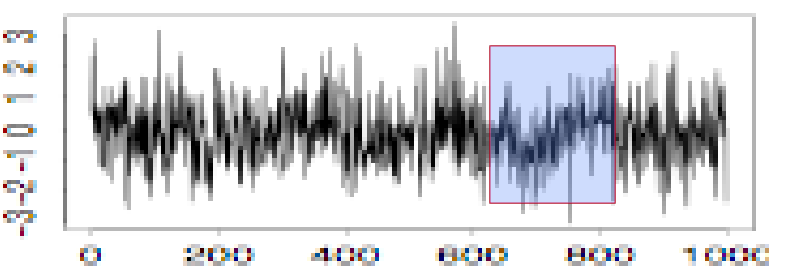
Many analyses use OLS

More sophisticated use AR(1)

Annual averages show evidence of long-term dependence:

$$f(\lambda) \propto b\lambda^{-2d}, \lambda \to 0$$

Thus standard errors from simple time series model can seriously overstate significance



d=0.4

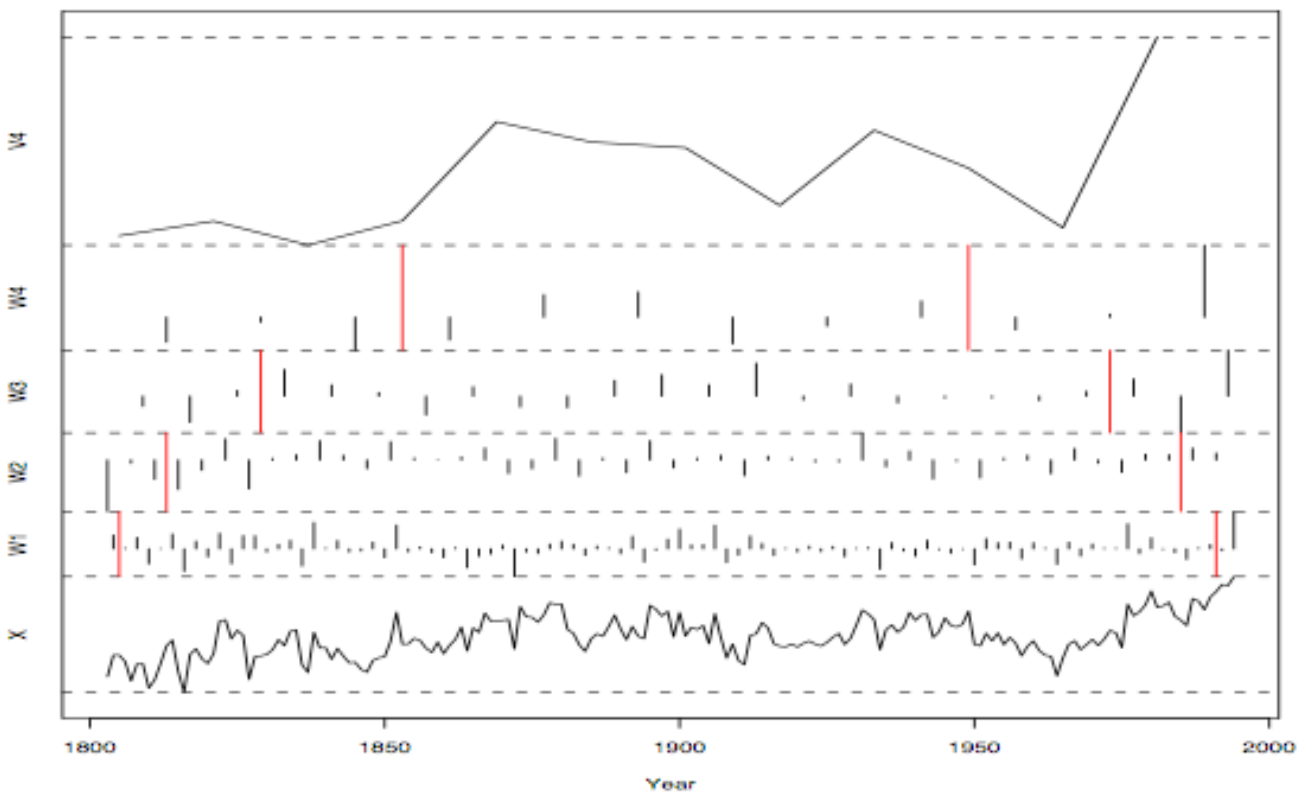
Oxygen isotope in coral cores at Malindi, Kenya

Cole et al. (Science, 2000): 194 yrs of monthly δ^{18}O-values in coral core.

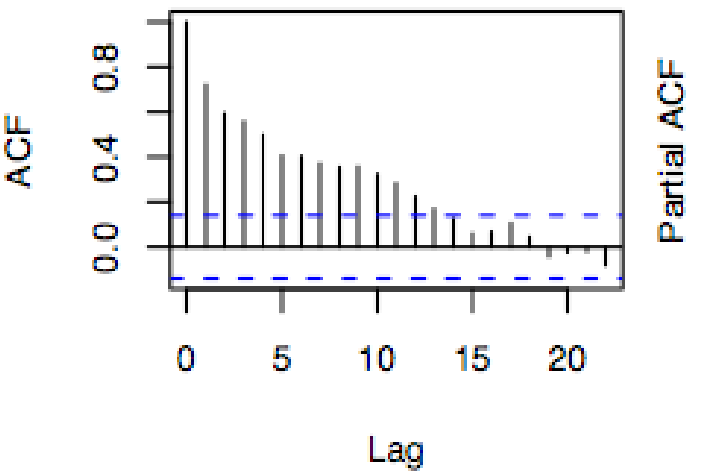
Decreased oxygen corresponds to increased sea surface temperature

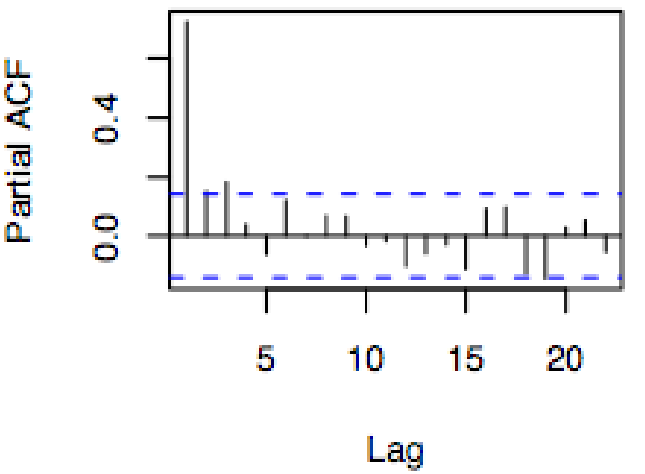
Decadal variability related to monsoon activity

Multiscale analysis of coral data



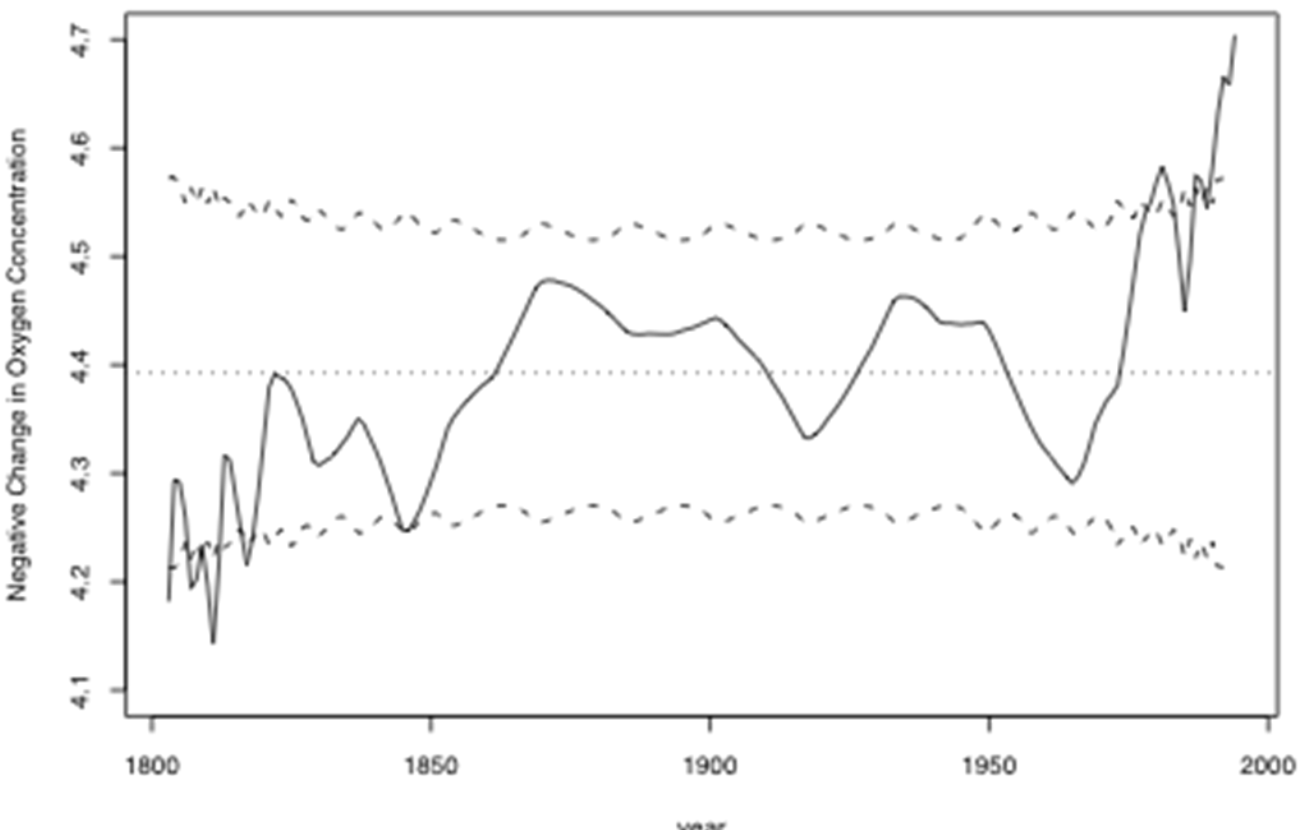
Coral data correlation





$\hat{d} = 0.359$ (CI [0.143,0.597])

Malindi trend



Finding climate change effects in extreme temperatures

Climate model runs indicate increasing minimum temperatures, decreasing range of temperatures at mid latitudes

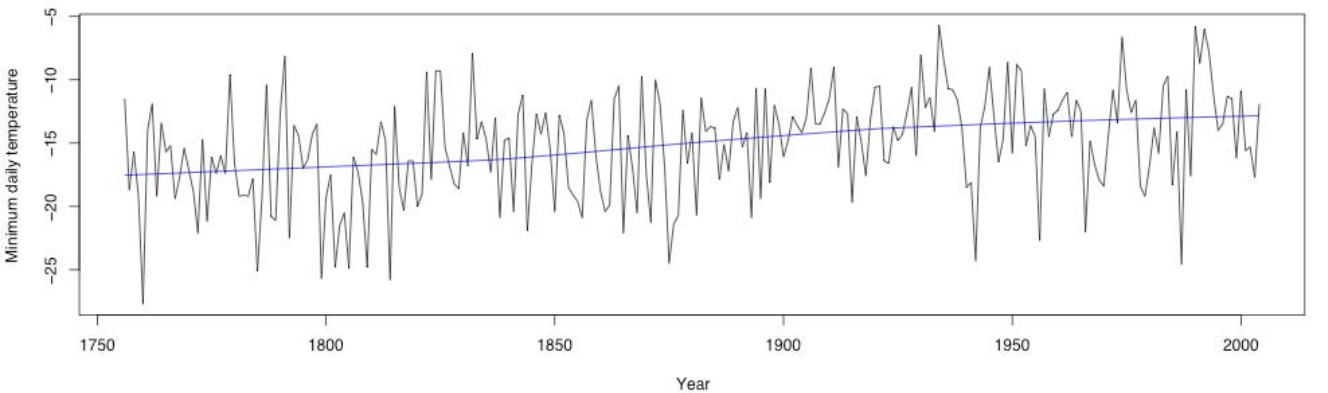
Can we see this in long temperature series?

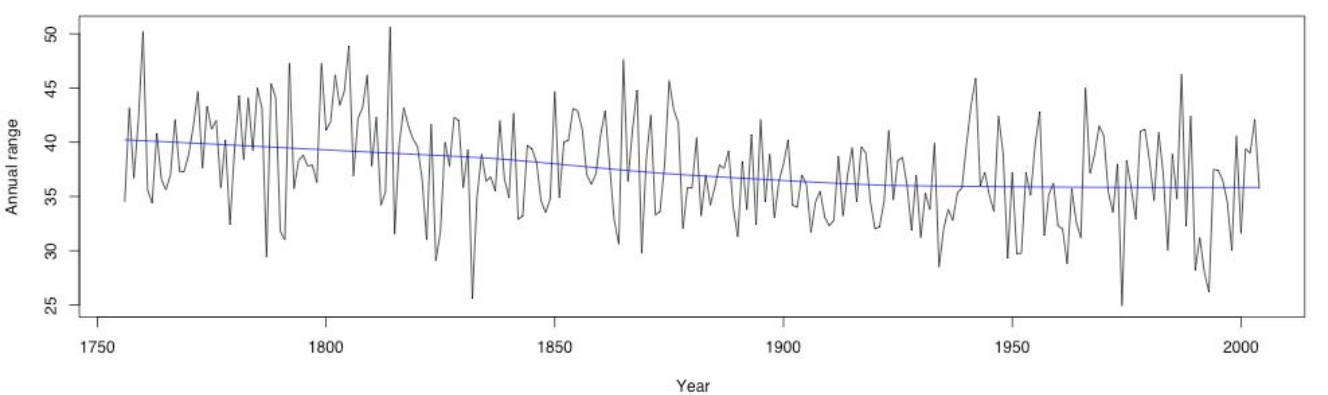
Stockholm daily 1756-2004

Moberg et al. (2002)

***Clim. Sci.* 53: 171-212**

Annual minimum temperature and range

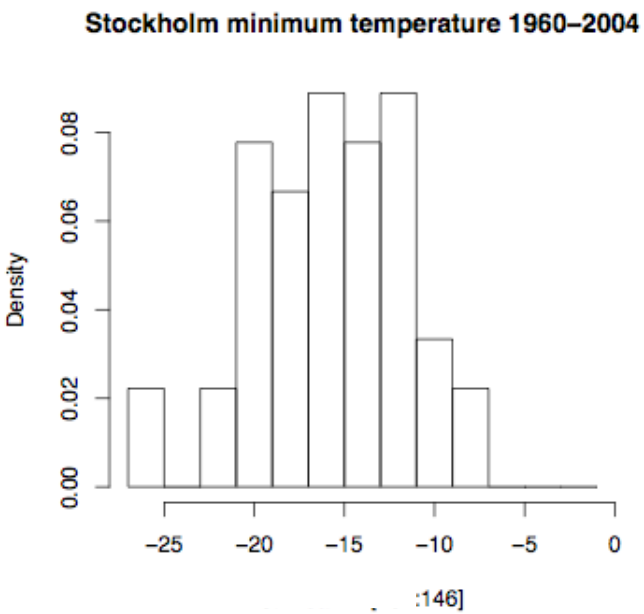


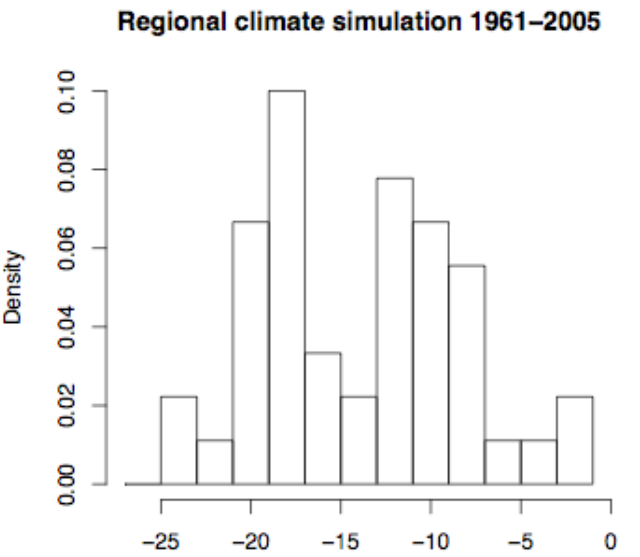


Comparing climate model output to weather data

- Global models are very coarse
- Regional models are driven by boundary conditions given by global model runs
- In either case, describe distribution of weather, not actual weather
- Consider a regional model driven by “actual weather”
- Stockholm 50 km x 50 km grid, 3 hr resolution (SMHI-RCA3; ERA40)

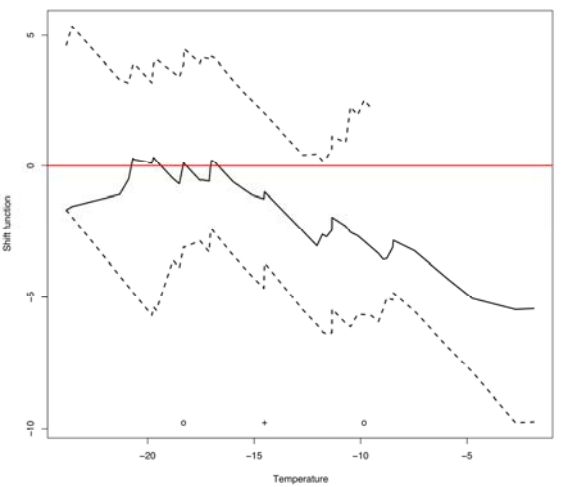
How well does the climate model reproduce data?



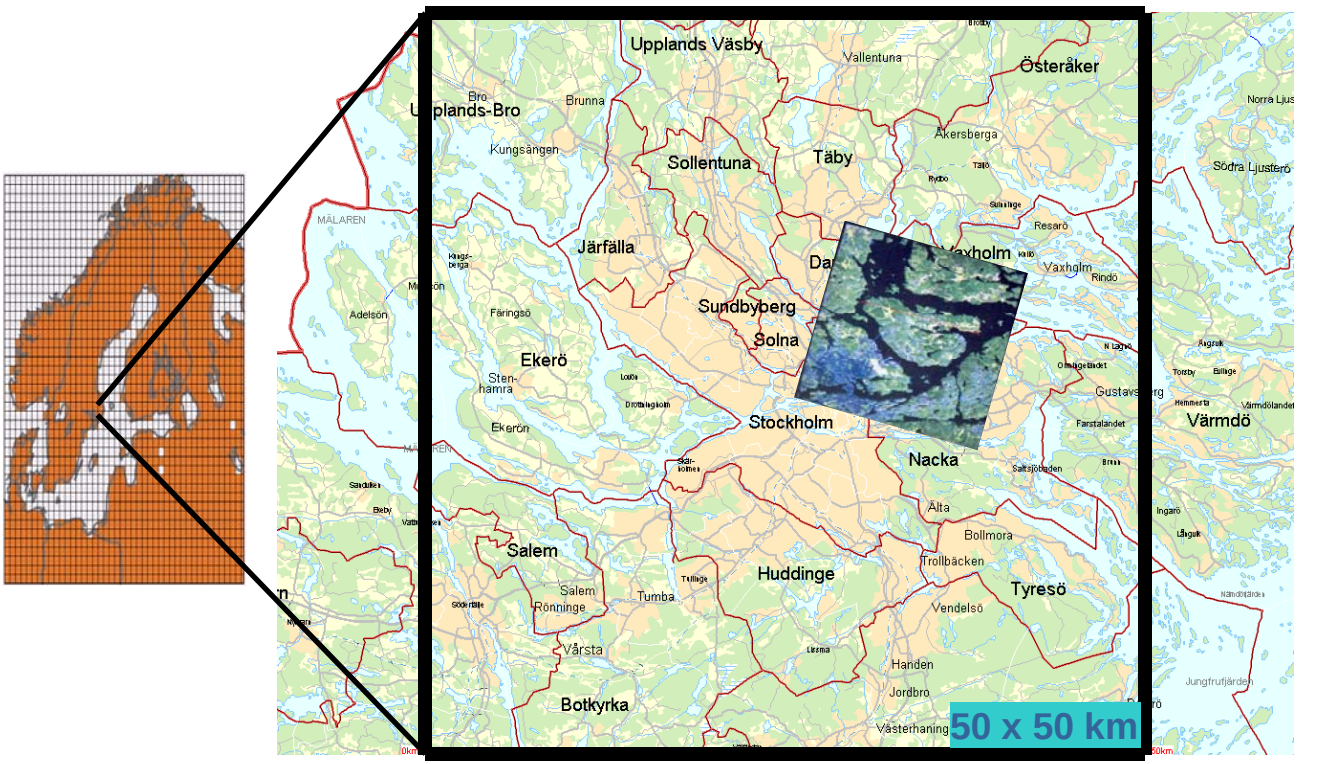


Shift function $\Delta(x)$

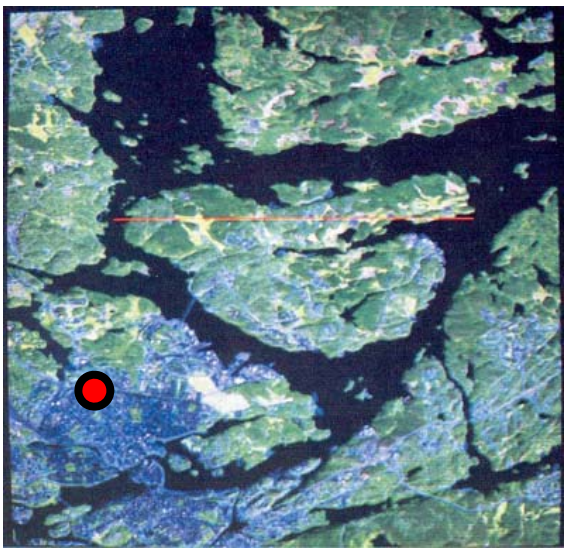
$$F(x+\Delta(x)) \overset{d}{=} G(x)$$

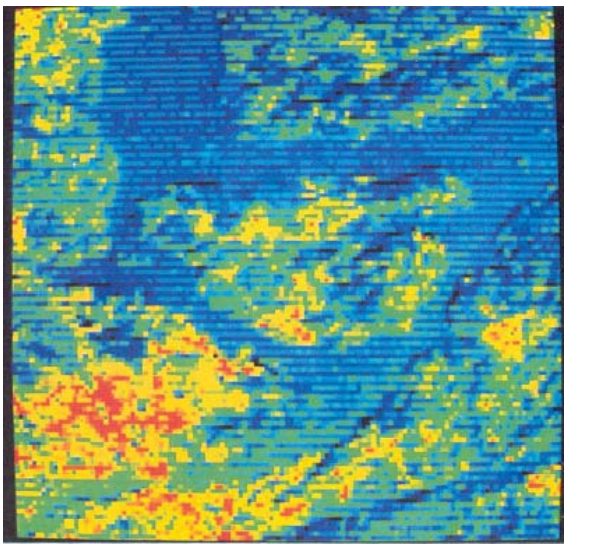


Resolution in a regional climate model



Microclimate





Model problem?

- Cloud water content
- Downward longwave radiation
- Mean annual temperature about 1.7° C higher in model than Stockholm series
- Correct comparison is to interpolation to same grid

Philosophical issues

How well must a model describe current climate in order to produce believable forecasts?

What is the probability model that allows ensemble methods?

Is there a selection bias in the models that are used in the IPCC assessments?