Estimation of climate sensitivity

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References

- Aldrin, M., Holden, M., Guttorp, P., Skeie, R.B., Myhre, G. and Berntsen, T.K. (2012).
  Bayesian estimation of climate sensitivity based on a simple climate model fitted to observations of hemispheric temperatures an global ocean heat content.
  Environmetrics, vol. 23, p. 253-271.

- Skeie, R.B., Berntsen, T., Aldrin, M., Holden, M., Myhre, M. (2014).
  A lower and more constrained estimate of climate sensitivity using updated observations and detailed radiative forcing time series.
  Earth System Dynamics, vol. 5, p. 139-175.

Climate sensitivity S

Definition:

Climate sensitivity $= S$
$=$ The temperature increase due to a doubling of CO_2 concentrations compared to pre-industrial time (1750), when all else is constant

Today: 40 % increase in CO_2 concentrations
Estimate from IPCC AR4 (2007): 3°C, 90 % C.I. =(2.0-4.5)
Estimate from IPCC AR5 (2013): 2.5°C, 90 % C.I. =(1.5-4.5)

Radiative forcing

- CO_2 is only one of several factors that affect the global temperature
- Radiative forcing = The change in net irradiance into the earth relative to 1750
- Measured in Watts per square meter
- The global temperature depends on the radiative forcing
- The climate sensitivity measures the strength of this dependency

Aim of study

To estimate the climate sensitivity

- by modelling the relationship between
  - estimates of radiative forcing since 1750 and
  - estimates of hemispheric temperature based on measurements since 1850
  - estimates of global ocean heat content based on measurements since about 1950
- using a climate model based on physical laws

Climate model

Could use

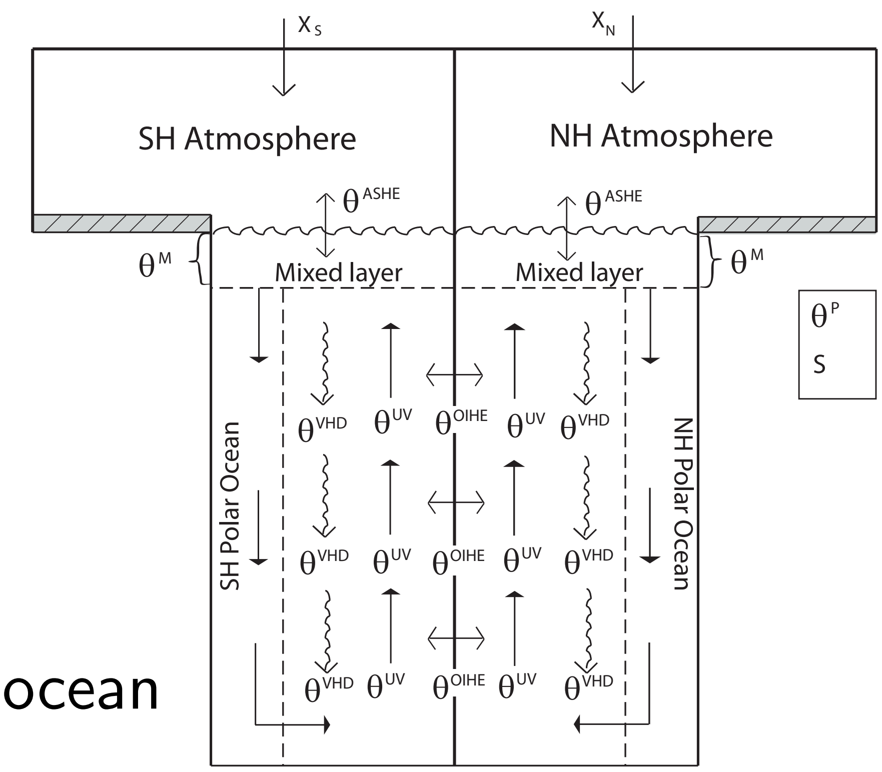
- an Atmospheric Ocean General Circulation Model, but complex and very computer intensive
- an approximation to an AOGCM, an emulator
- a simple climate model, our approach

The "true" global state of the earth in year t

- TNH_t - Temperature at the northern hemisphere
- TSH_t - Temperature at the southern hemisphere
- OHC_t - Ocean heat content

Simple climate model

- Deterministic computer model (Schlesinger et al., 1992)
- based on
  - energy balance
  - upwelling diffusion ocean
- where the earth is divided into
  - atmosphere and ocean
  - northern and southern hemisphere
- with
  - radiative forcing into the system
  - energy mixing
    - between the atmosphere and the ocean
    - within the ocean



Simple climate model cont.

$\mathbf{m}_t(\mathbf{x}_{1750:t}, S, \boldsymbol{\theta})$

- Yearly time resolution
- Output
  - temperature northern hemisphere
  - temperature southern hemisphere
  - ocean heat content
- Input
  - $\mathbf{x}_{1750:t}$ - yearly radiative forcing from 1750 until year t, separate for northern and southern hemisphere
  - S - the climate sensitivity, the parameter of interest
  - $\boldsymbol{\theta}$ - 6 other physical parameters

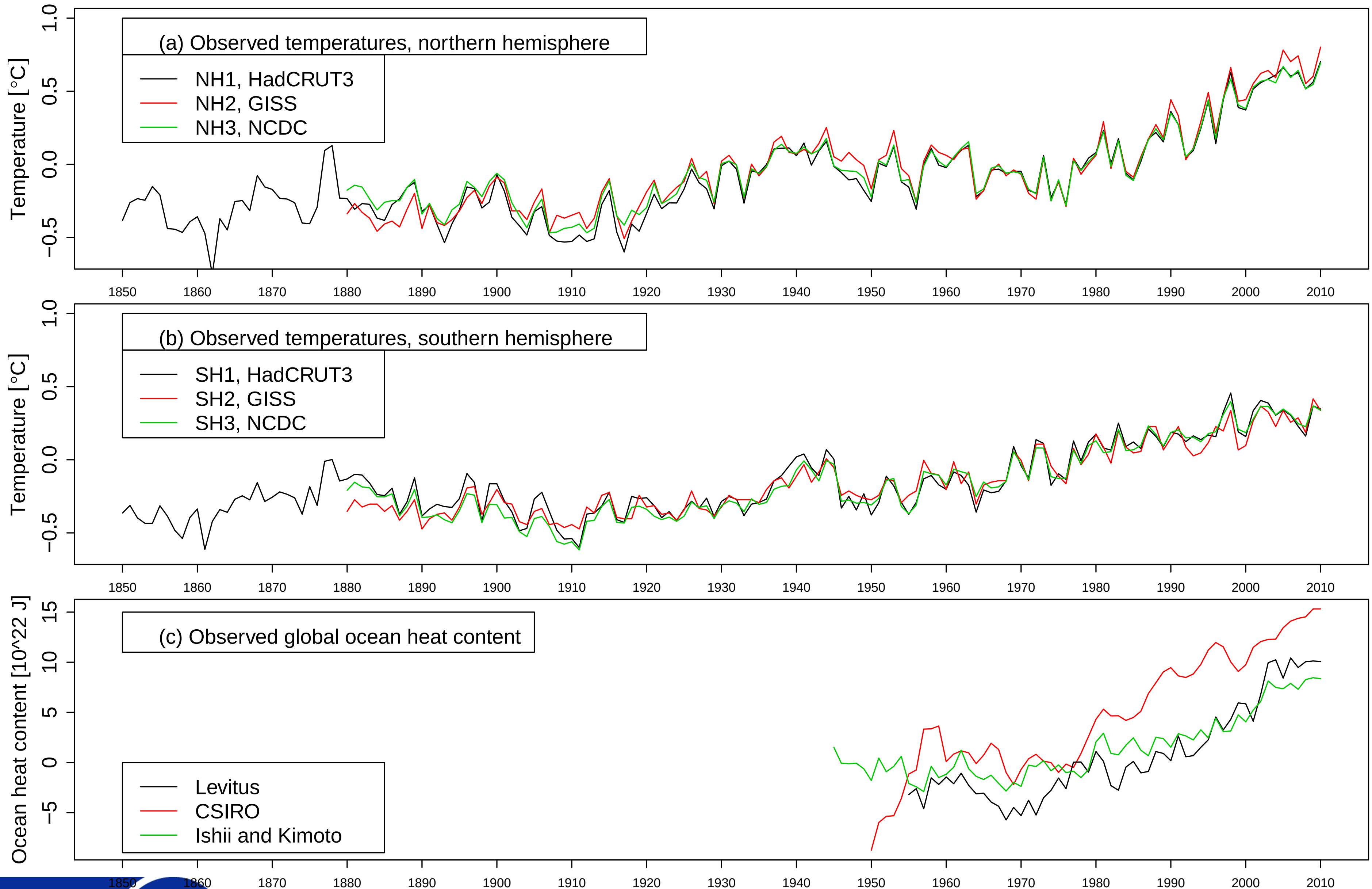
Response data

- $\mathbf{y}_t$ - 9-dimensional vector with yearly observed temperatures and ocean heat content

- Three pairs of series with temperature measurements for northern and southern hemisphere
  - 1850-2010 (HadCRUT3, Brohan et al.,2006)
  - 1880-2010 (GISS, Hansen et al. 2006)
  - 1880-2010 (NCDC, Smith and Reynolds 2005)

- Three series with ocean heat content measurements 0-700m
  - 1955-2010 (Levitus et al. 2009)
  - 1950-2010 (Domingues et al. 2008; Church et a. 2011)
  - 1945-2010 (Ishii and Kimoto 2009)

Observations

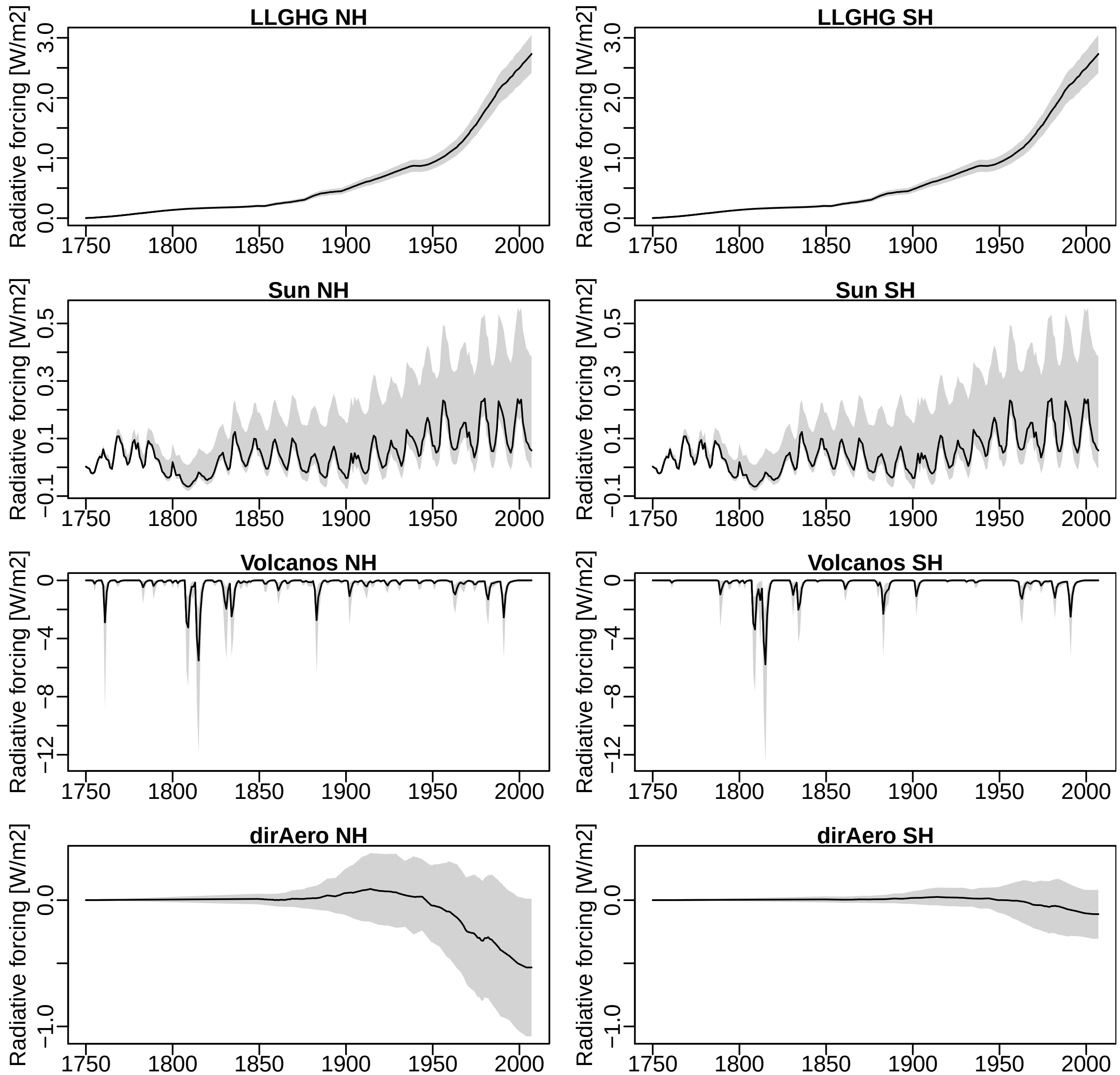


Radiative forcing

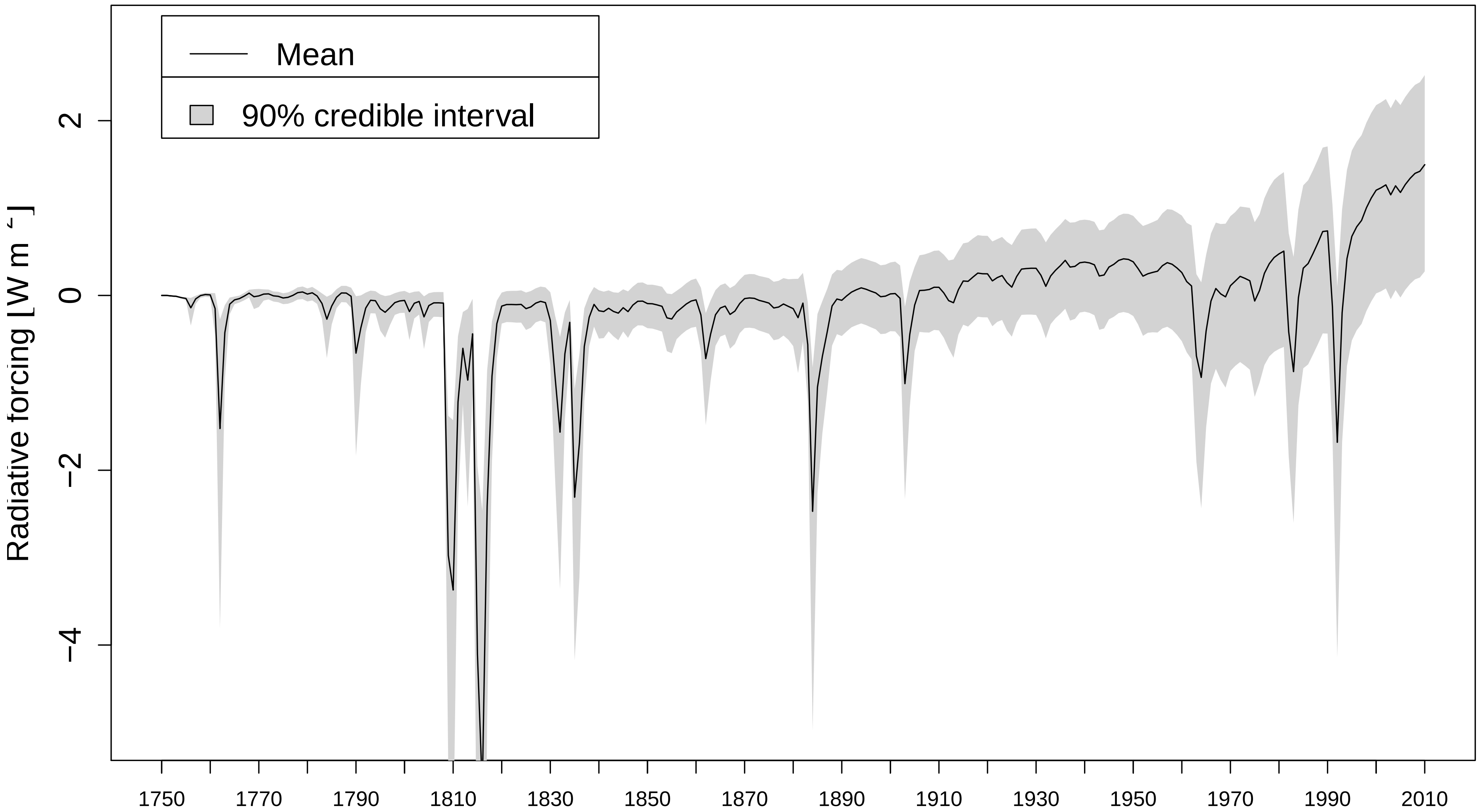
- We will specify our best knowledge about historical radiative forcing as prior distributions of 11 independent components, based on temperature-independent estimates of each component, including uncertainties
  - long-lived greenhouse gases
  - direct aerosols
  - indirect aerosols
  - solar radiation
  - volcanoes
  - land use
  - ...

Priors of components of radiative forcing

Figure not updated



Prior of total radiative forcing



Model for "true" global state of the earth

$$\mathbf{g}_t = (TNH_t, TSH_t, OHC_t)^T$$

Combined deterministic + stochastic model

$$\mathbf{g}_t = \mathbf{m}_t(\mathbf{x}_{t:1750}, S, \boldsymbol{\theta}) + \mathbf{n}_t^{siv} + \mathbf{n}_t^{liv} + \mathbf{n}_t^{m}$$

- $\mathbf{n}_t^{siv}$: short-term internal variation, related to El Ninõ episodes
- $\mathbf{n}_t^{liv}$: long-term internal variation, estimated from an AOGCM
- $\mathbf{n}_t^{m}$: model error, VAR(1)
- All terms have dimension 3

Model for observations

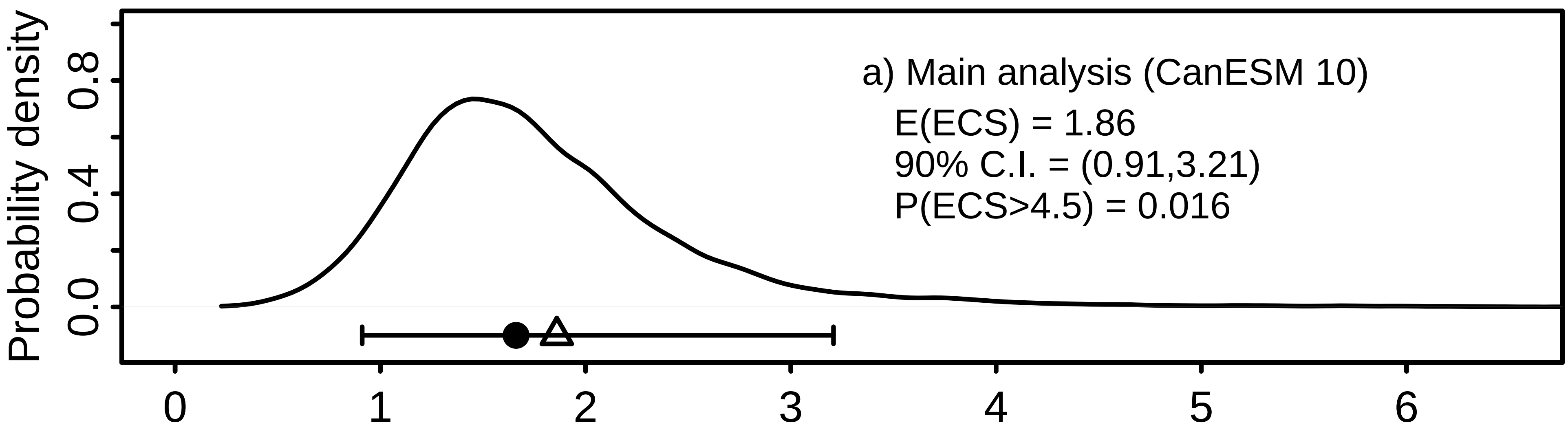
$$\mathbf{y}_t = \mathbf{A}\mathbf{g}_t + \mathbf{n}_t^o$$

- $\mathbf{A}$: 9x3 matrix copying each data series 3 times, to compare model values with observations
- $\mathbf{n}_t^o$: observational (measurement) error, dimension 9, VAR(1)

Estimation

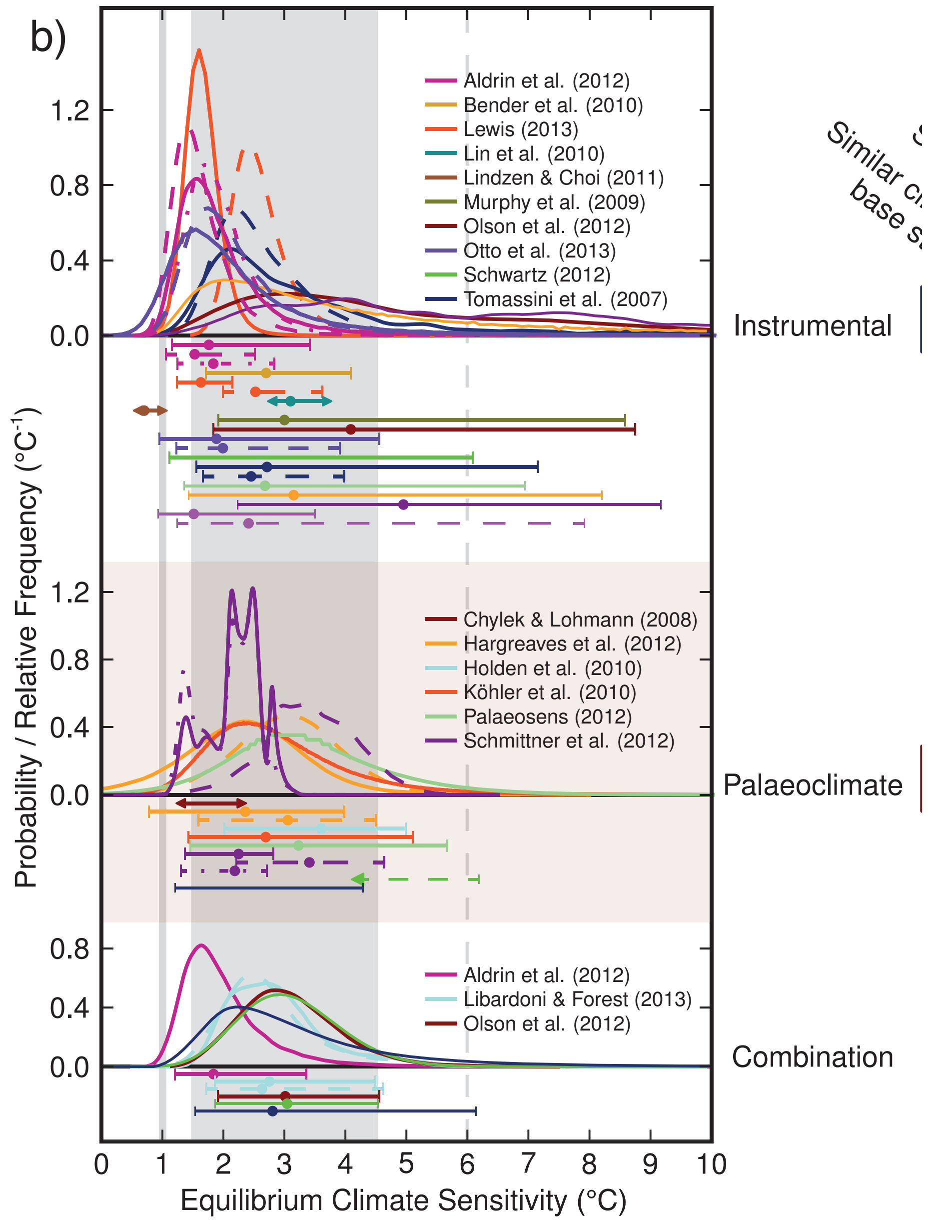
- Bayesian approach (Kennedy and O'Hagan 2001), using MCMC
- Vague prior for S
- Informative priors for $\mathbf{x}_{t:1750}$ and $\boldsymbol{\theta}$
- Vague priors for other parameters

Posterior of the climate sensitivity S

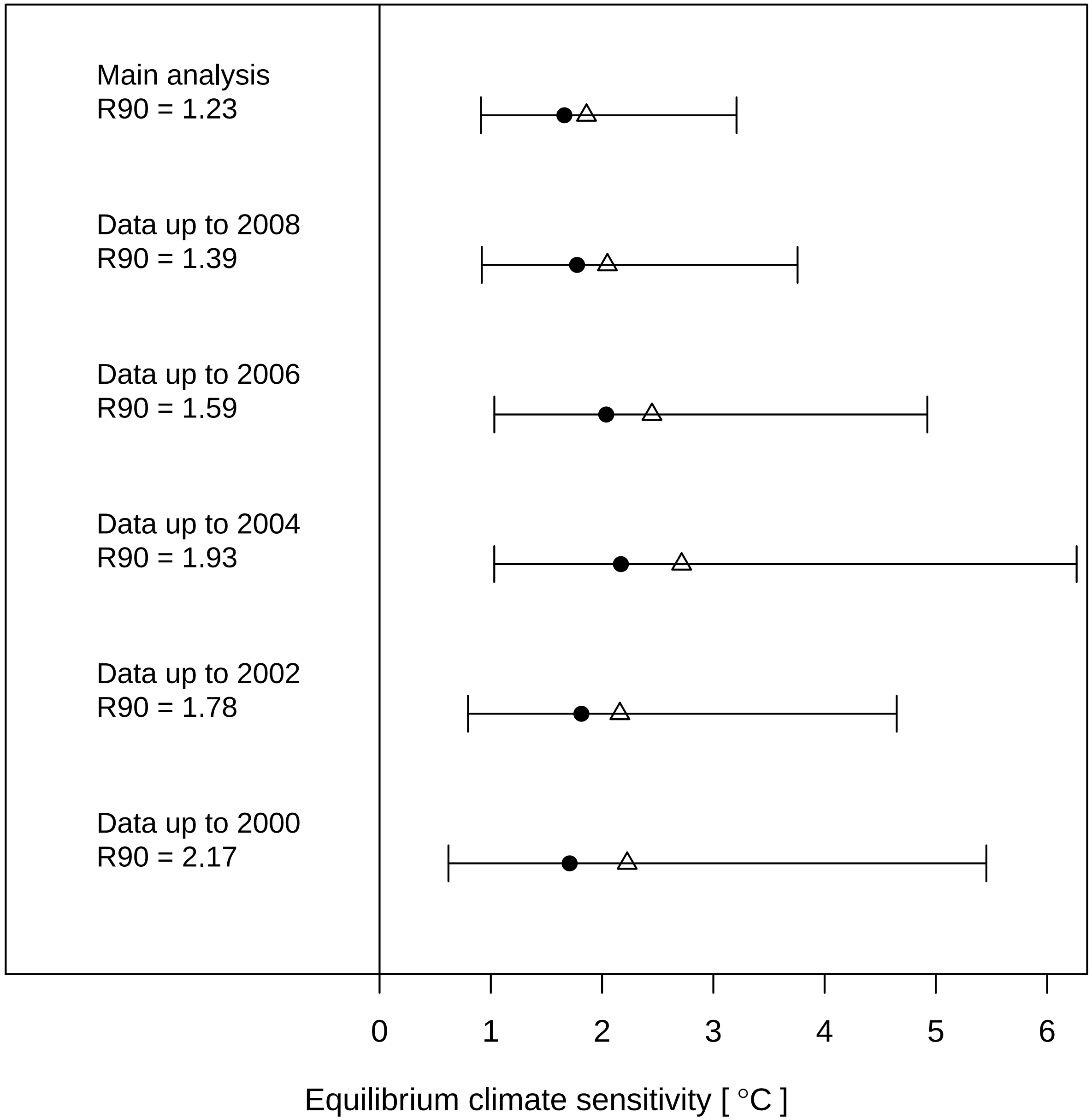


Degrees Celcius

From the 5th Assessment Report of IPCC



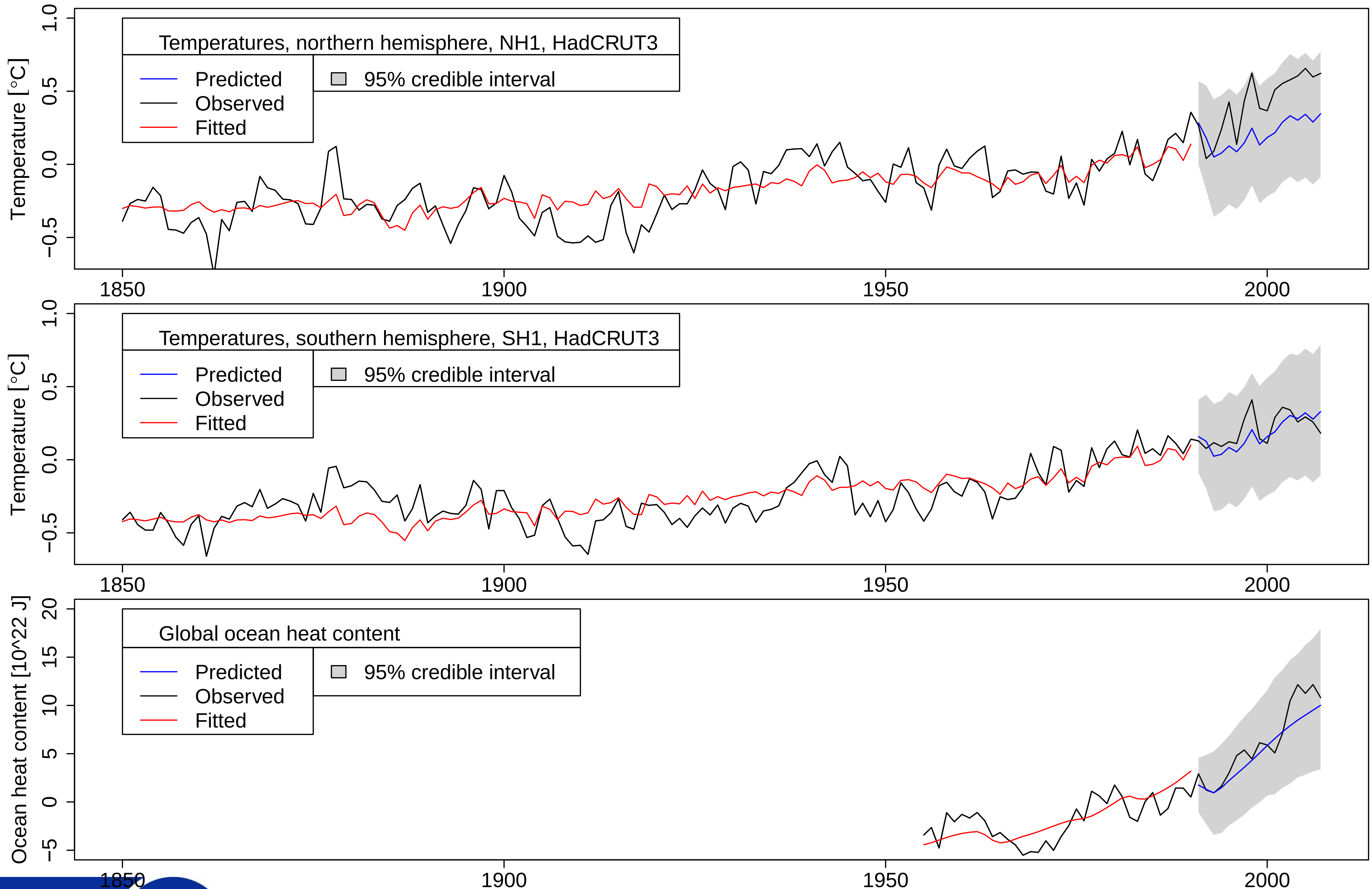
Effect of 10 more years of data



Validation

Based on only one OHC series

Re-estimation 1850-1990 + prediction 1991-2007



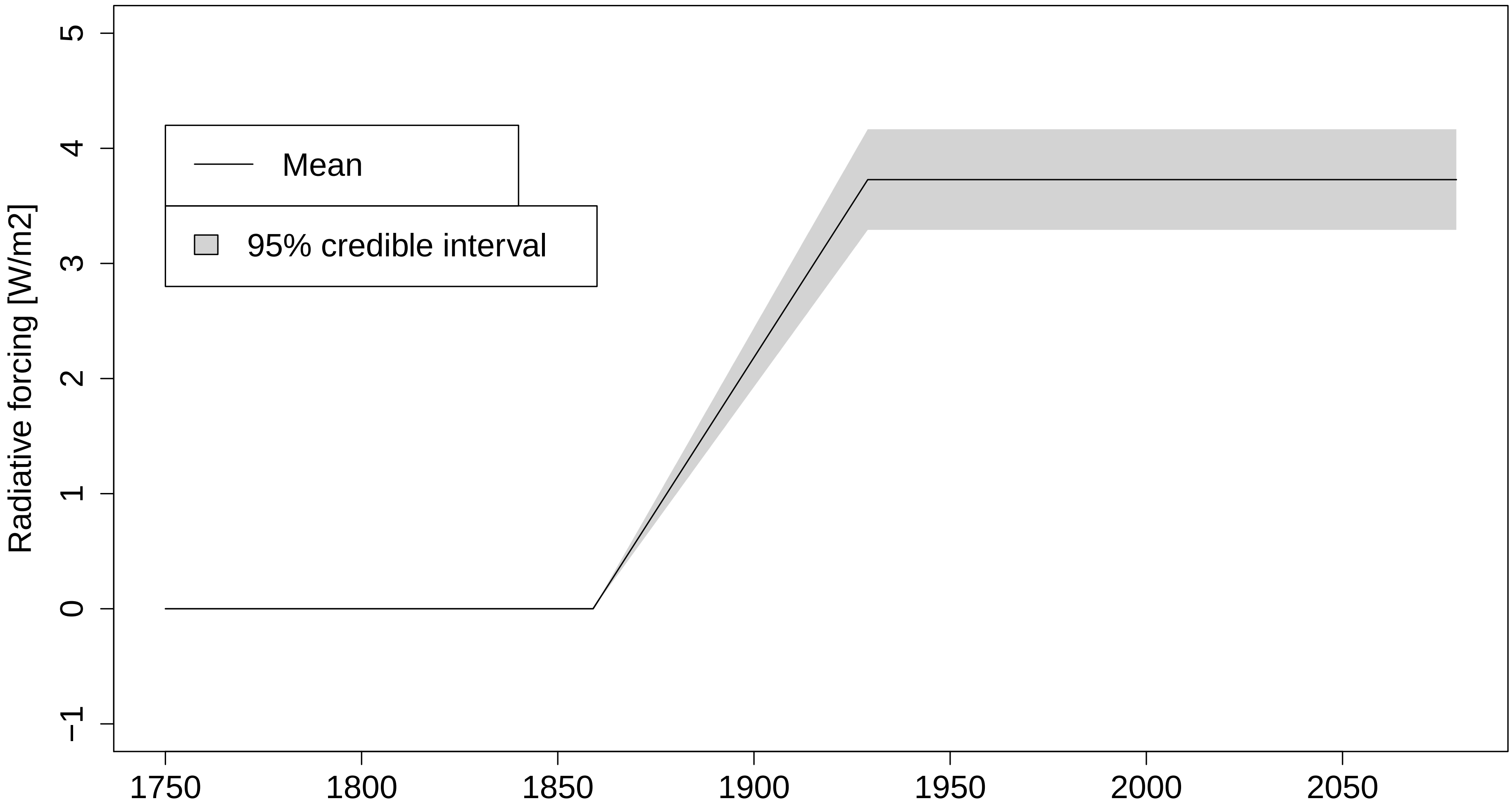
Validation on data from an AOGCM

- The reality is complex, but our model are simple
- Can we trust the posterior for the climate sensitivity?
- True S is unknown, can not validate on real data
- Validate on artificial data generated from an AOGCM

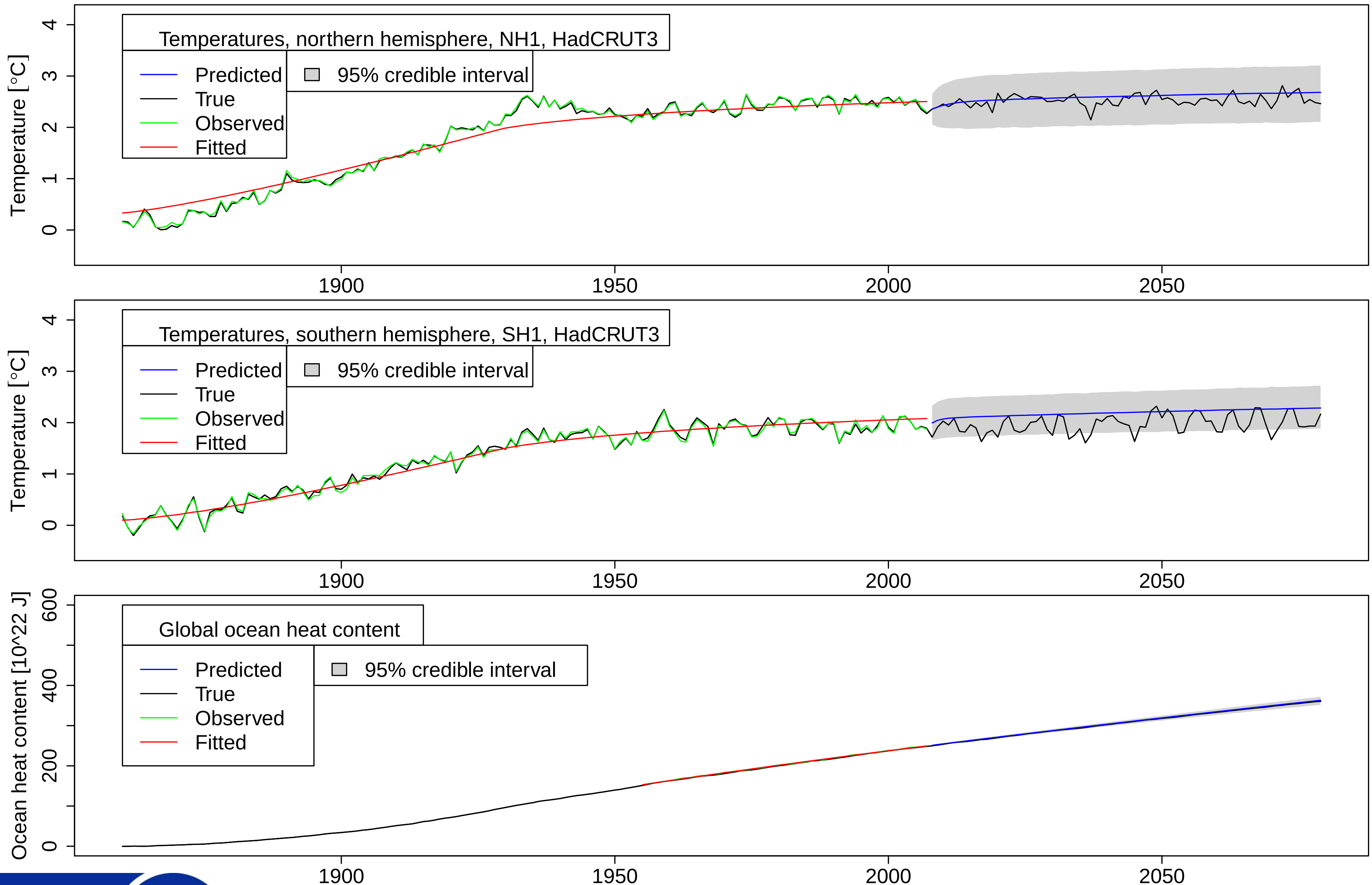
The CMIP3 experiment

- Coupled Model Intercomparison Project phase 3
- CO_2 increased by 1 % per year until a doubling in 1920, then constant
- Corresponding RF increased from 0 to 3.7 W/m^2
- (Deterministic) simulation 1859-2079 of temperature and OHC
- Our validation experiment, based on the Canadian CGCM3.1 model
  - "True" climate sensitivity $=$ 3.4°C
  - Training data: Temperatures 1860-2007, OHC 1955-2007

CMIP3 - Radiative forcing prior



CMIP3 - Data and predictions



CMIP3 - Posterior for climate sensitivity

- “True” climate sensitivity = 3.4°C
- Posterior mean 3.5°, CI=(2.4-5.3)

Further work

- Work in progress
  - Update model using data including 2013
  - Using updated RF prioirs from IPCC AR5
  - Including one more temperature series
  - Including one more OHC (above 700 m) series
  - Including data for OHC below 700 meters!
- Planned work
  - Improve the simple climate model
  - Using different simple climate models
  - Including other data types (ice melting, sea level, ...)

Thank you for your attention!