Optimising parameter values in Climate Models: Observational/model synthesis

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1. Abstract

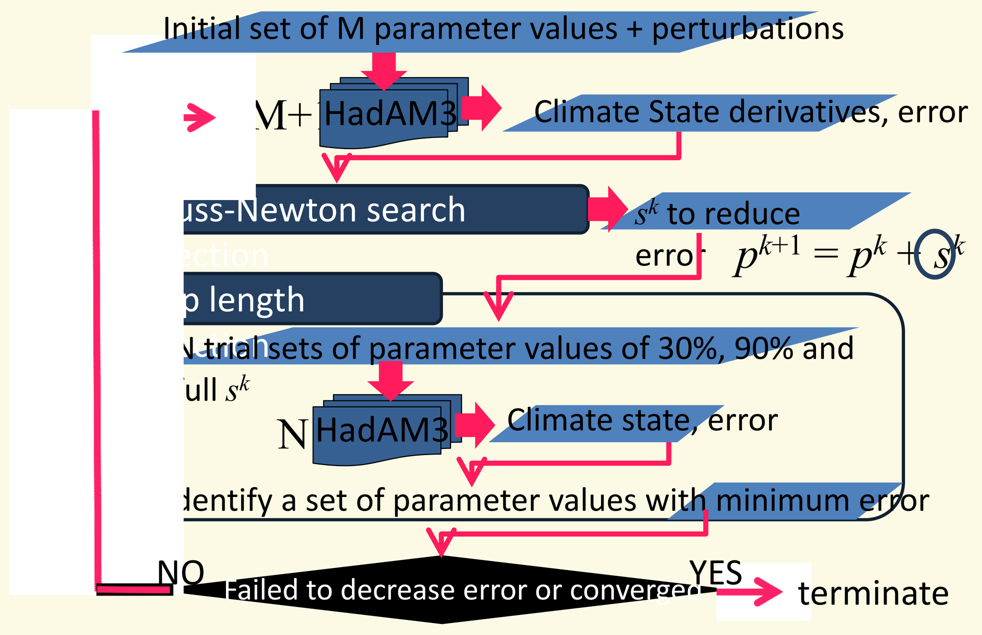
Climate models need to represent unresolvable, small-scale processes with parameterisations. The values of these parameters are estimated from nature but are quite uncertain so their ranges are normally determined by expert scientists in the field. Parameter uncertainty, even within the solicited ranges, can lead to a large spread in the model's response to changes in greenhouse gases.

We have been experimenting with the application of relatively simple optimisation methods to the problem of making climate models consistent with observations. This we consider as a possible method to synthesise observations and physically based models. The challenges we face is that climate models are chaotic and computing derivatives can only be done numerically. We report results based on: Case 1) tuning the atmospheric component of a climate model to several different observations and Case 2) the ice parameters of a coupled atmosphere/ocean model to observations of the seasonal-cycle of sea-ice.

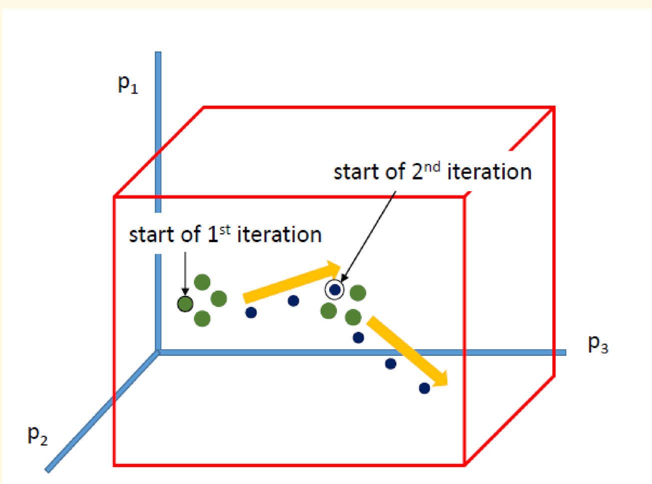
2. Methods

A combined framework of Global Climate Model (GCM) simulations alternated with optimisation to determine optimal parameter values for HadAM3 atmosphere GCM (Case 1) and HadCM3 coupled ocean-atmosphere GCM (Case 2).

- Optimisation
  - Find parameter values that minimise error between chosen *simulated* and *observed* (i.e. target) climate variables.
  - Gauss-Newton algorithm.
  - Derivatives unknown so estimate by finite differencing.



Flowchart of optimisation



Schematic of optimisation with three parameters

3. Case 1 Results

Case 1: Atmosphere model experiment

① Experimental Design

- Optimisation period : 2000-2005
- Parameters to optimise : 7 atmospheric parameters (5 cloud, 1 radiation, 1 convection)
- Climate state variables to optimise to: 20 atmospheric variables (7 variables × 3 regions – 1)
  - Variables: top-of-atmosphere radiation fluxes, land surface temperature, land precipitation, mean sea level pressure, temperature at 500 hPa, relative humidity at 500 hPa
- Regions: Northern Hemisphere (NH) (30N-90N), Tropics (30S-30N), Southern Hemisphere (SH)(60S-30S)

Error has decreased.

Some climate state variables have improved; some have not. Perhaps due to parameter/variable choice.

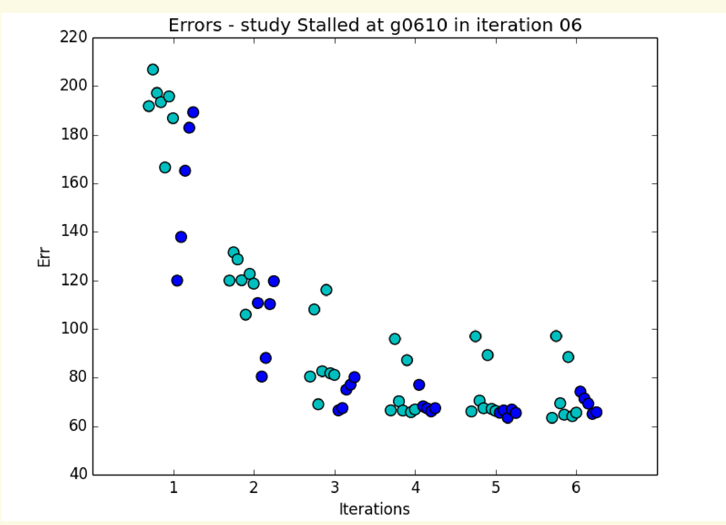


Figure 2: Normalised total residual between simulated and observed climate state variables. The residual decreases with iteration as optimisation progresses. Optimisation stops when there is no improvement.

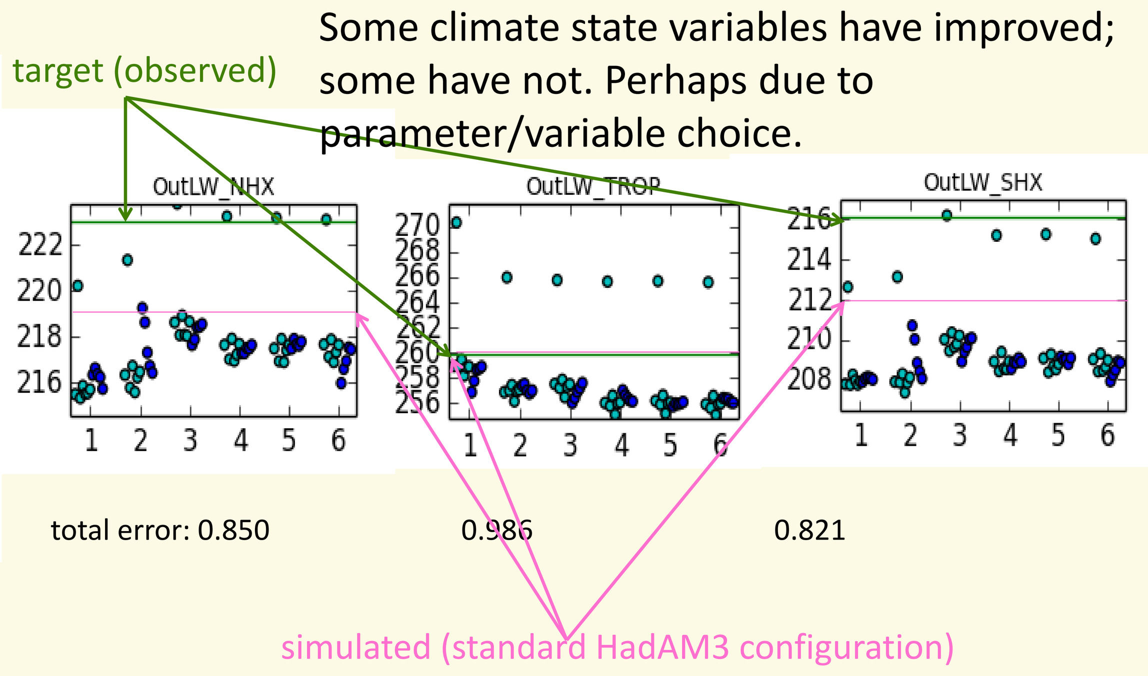


Figure 3: Simulated outgoing longwave radiation (OLR). There are improvements in NH- and SH-mean OLR compared with the standard parameter configuration of HadAM3.

4. Case 2 Results

Case 2: Coupled model experiment

① Experimental design

- Optimisation period : 1980-1990
- Parameters to optimise : 4 ocean parameters (3 sea-ice, 1 ocean mixing)
- Climate state variables to optimise to: 4 ocean variables (2 variables 2 regions)
  - Variables: maximum sea-ice extent maximum, minimum sea-ice extent
  - Regions: Northern Hemisphere, Southern Hemisphere

② Results

Optimisation works!

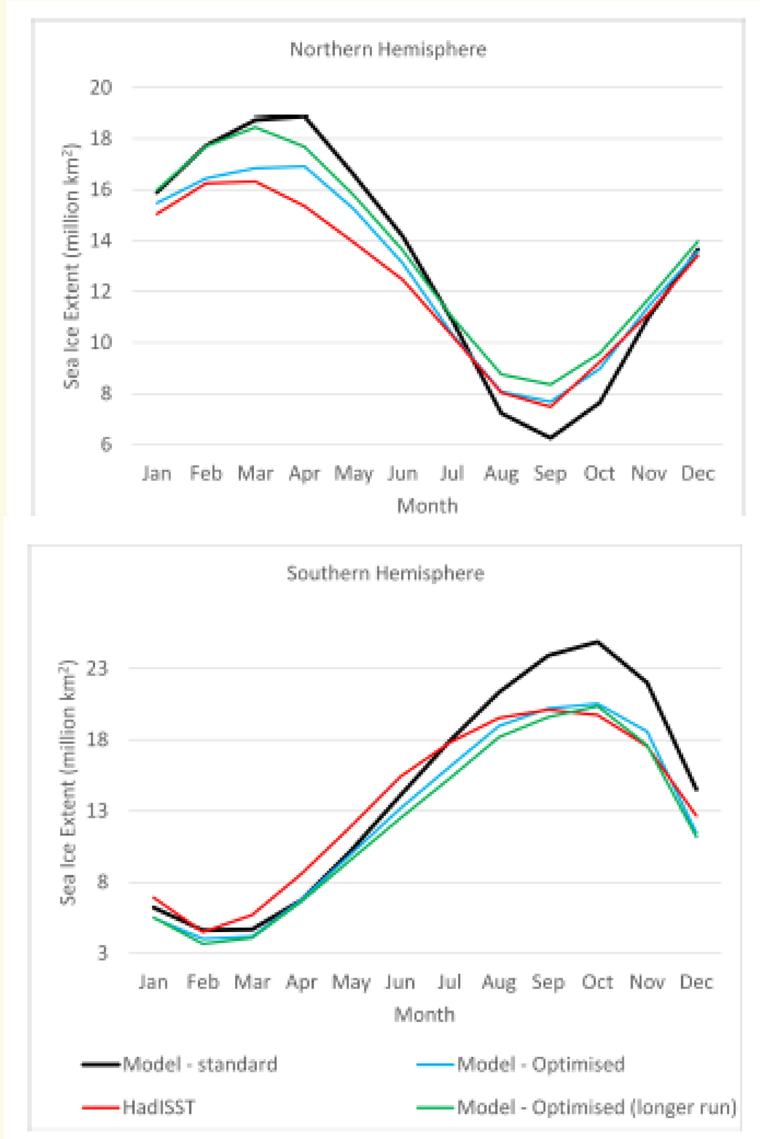


Figure 4: The mean monthly cycle of sea ice extent for the Northern and Southern Hemispheres for 1980 to 1990. The optimised model (red) agrees much better with the HadISST observations (blue) than the standard model (black). Also shown in green is the monthly cycle averaged over 1980 to 1990 from a simulation begun in 1940 using the optimised parameter configuration; this shows less agreement with the observations in the Northern Hemisphere.

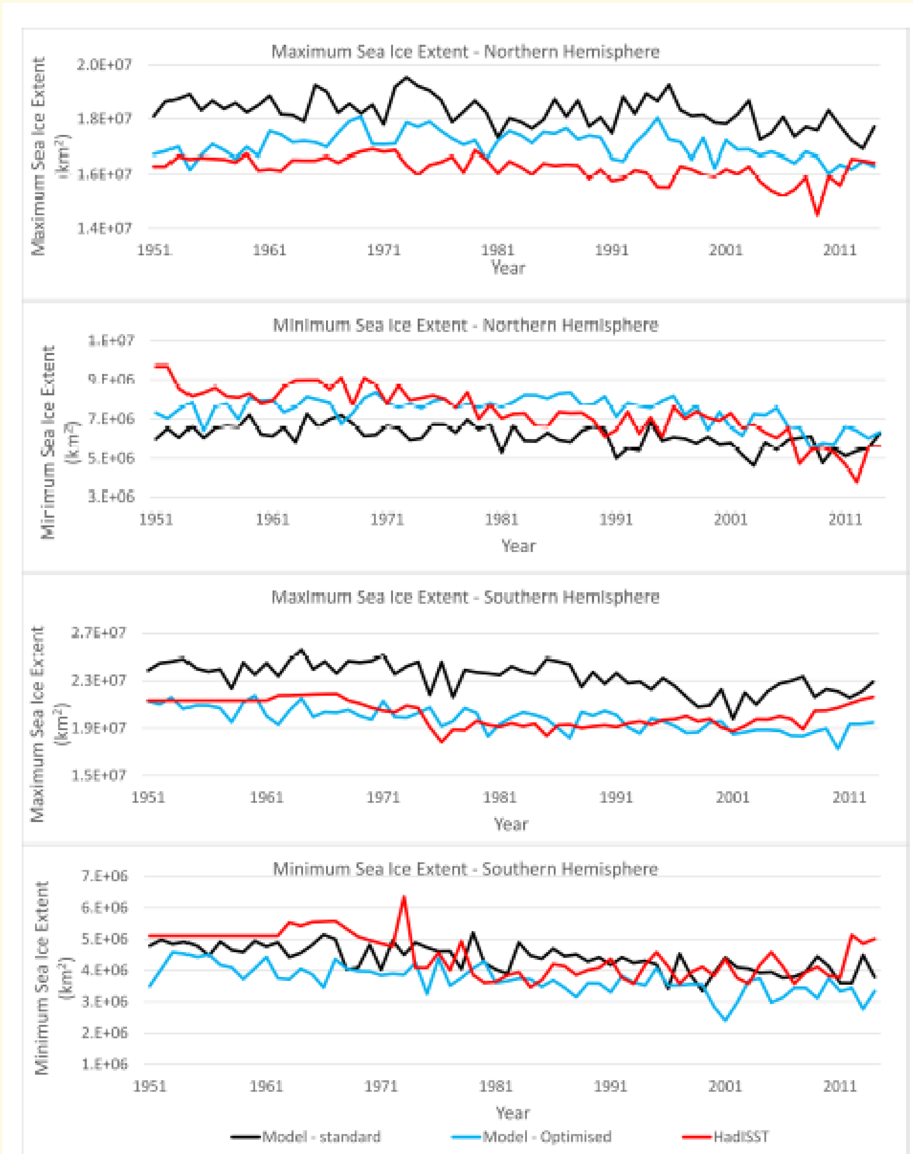


Figure 5: Time series of maximum and minimum sea ice extent each year for 1950 to 2014, simulated using the standard and optimised parameter configurations under observationally- based forcings for the Northern and Southern Hemisphere. Also shown are the equivalent HadISST observations. The optimised simulation shows an improvement on the standard simulation, which is most clearly seen in the maxima.

5. Challenges

- Chaos – climate system is chaotic so small changes mean system moves on a different trajectory.
- Represent this as signal + noise
- Which parameters and state variables to use in optimisation
- Parameters need to have an statistically significant effect
- Parameters chosen should be physically relevant to climate state variables to avoid getting right answer for wrong reasons.

6. Conclusions and Current Work

- ❑ Application of relatively simple optimisation algorithm to problem of making model consistent with observations promising.
- ❑ This has advantage of synthesising physical knowledge with observational knowledge.
- ❑ One challenge is chaos as that determines minimum size of perturbation needed.

7. References

Tett, S., M. Mineter, C. Cartis, D. Rowlands, and P. Liu (2013). Can top-of-atmosphere radiation measurements constrain climate predictions? part I: Tuning. Journal of Climate 26 (23), 9348–9366.