ARC CENTRE OF EXCELLENCE FOR CLIMATE SYSTEM SCIENCE

MONASH University

Conceptual Understanding of Climate Change with a Simple Climate Model

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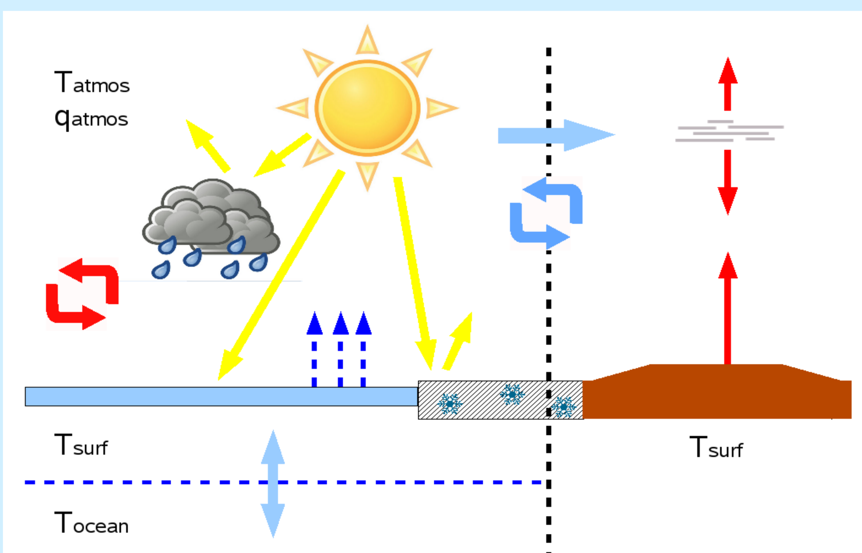
A very simple globally resolved energy balance (GREB) climate model is introduced, which is based on strongly simplified physical processes. The model is capable of simulating the main regional characteristics in response to external forcings. It shall give a bridge between the 1-dimensional energy balance models and the fully coupled 4-dimensional complex GCMs. The climate sensitivity and the spatial structure of the warming pattern of the simple model is within the uncertainties of the IPCC AR4 model simulations. The presentation will discuss the mechanisms causing the main features of global warming, as estimated from the deconstruction of feedbacks and processes in the simple model.

Model description



Physical processes:

- solar insolation
- thermal radiation including greenhouse effect
- evaporation, precipitation and latent heat flux
- sensible heat flux
- atmospheric transport of heat and moisture
- sea ice and albedo change
- heat exchange with deep ocean

Prognostic Variables:

- atmospheric humidity:
- atmospheric temperature:
- surface temperature:
- deep ocean temperature:

$$\gamma_{surf}\frac{dT_{surf}}{dt} = F_{solar} + F_{thermal} + F_{latent} + F_{sense} + F_{ocean} + F_{correct}$$

$$\frac{dq_{air}}{dt} = \Delta q_{eva} + \Delta q_{precip} + \kappa\cdot\nabla^2 q_{atmos} - \vec{u}\cdot\nabla q_{atmos} + \Delta q_{correct}$$

$$\gamma_{atmos}\frac{dT_{atmos}}{dt} = -F_{sense} + Q_{latent} + \gamma_{atmos}(\kappa\cdot\nabla^2 T_{atmos} - \vec{u}\cdot\nabla T_{atmos})$$

$$\frac{dT_{ocean}}{dt} = \frac{1}{\Delta t}\Delta To_{entrain} + \frac{1}{\gamma_{ocean}-\gamma_{surf}} Fo_{sense} + Fo_{correct}$$

Grid resolution: 3.75ºx3.75º

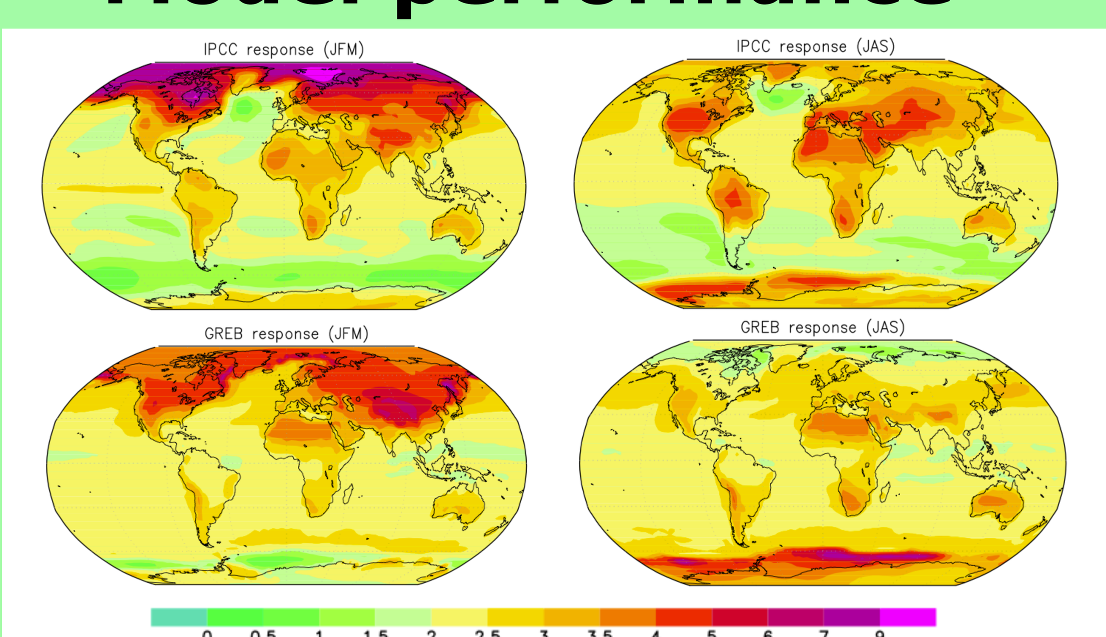
Benchmark (standard PC) : 2yrs/sec or 100,000yrs/day

Model performance

IPCC

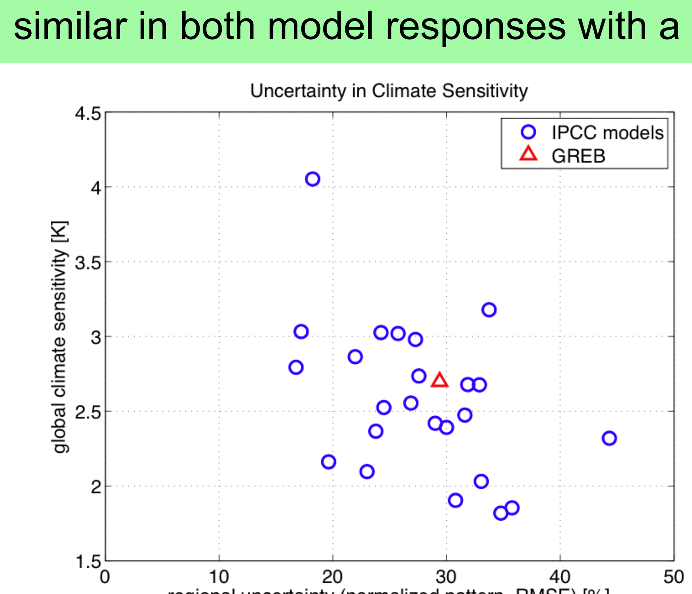
vs.

GREB



A1B-scenario surface temperature response (K) for winter (JFM) and summer (JAS) in IPCC and for the GREB model.

The GREB Model captures the large-scale features of the ensemble mean IPCC response pattern. A stronger warming over land (land-sea contrast), a polar amplification and a stronger warming on the northern compared to the southern hemisphere are clearly evident. The seasonal differences are also similar in both model responses with a stronger warming in the cold season.



Intercomparison of the IPCC AR4 model ensemble and the GREB Model by their climate sensitivities, which is the global and annual mean temperature response for the A1B-scenario, and the RMS error of the surface response pattern if compared to the IPCC ensemble mean pattern.

The GREB model lies well within the uncertainties of the IPCC models, suggesting that the major feedback mechanisms included into the simple model are sufficient in order to reproduce the large scale features of the climate predictions made by state-of-the-art Global Circulation Models.

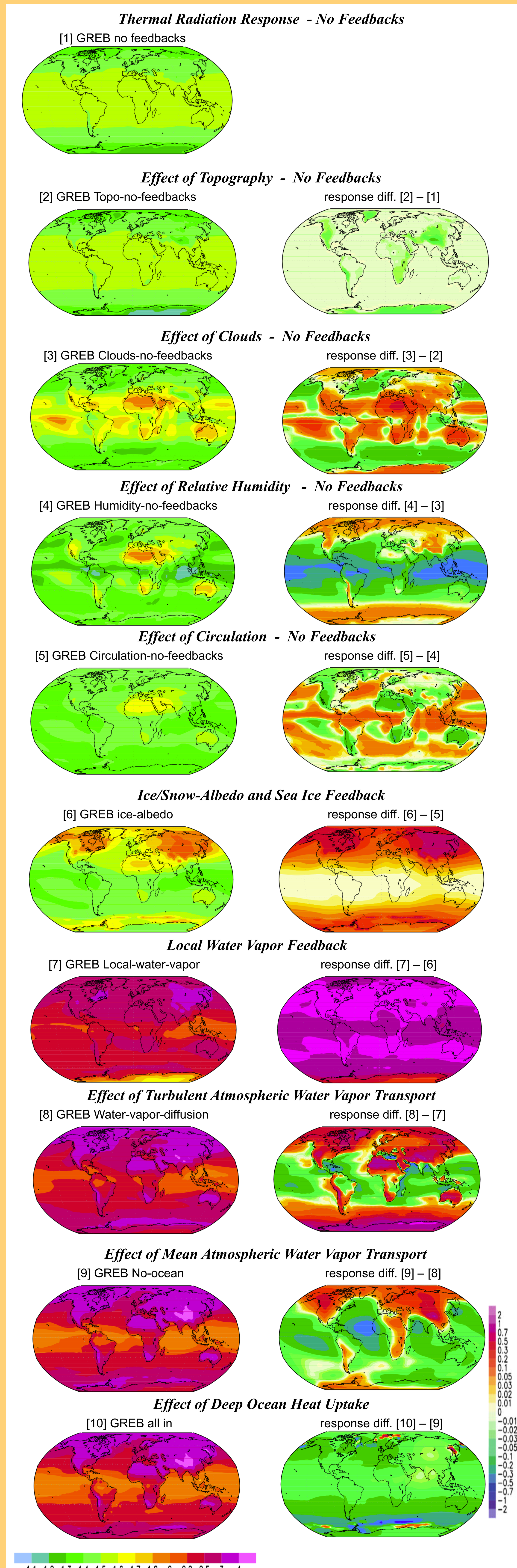
Conclusions

✧The simple GREB climate model is a decent model for simulating the response to external forcing. It can compute the IPCC A1B scenario in 2min on a standard PC. It is a fast and easy to understand climate model.

✧The IPCC prediction can roughly be understood by the interaction of some simple feedback processes. Much of the large scale structure can be understood by the regional differences in water vapor and snow/ice cover.

Reference: Climate Dynamics, in press, 2011.

Deconstructing Climate Change



The GREB model response in a series of sensitivity experiments. On the left hand side of each row the response in T_{surf} to 2xCO_2 is shown, whereas on the right hand side the response difference between two successive sensitivity experiments is illustrated. From top to bottom the number of included processes increases and gives the complete global warming pattern in the last row.

If regional differences in cloud cover, humidity and topography are neglected, a response in water vapor or ice/snow cover is not allowed, and the deep ocean is not taking up heat, than the response in T_{surf} to doubling of CO_2 is relatively uniform. The pattern is weakly monotonically increasing with the mean T_{surf}

Including surface topography reduces the effective emissivity of the atmosphere over high-altitude regions. This will eventually reduce the local response to a CO_2 increase.

Regional differences in the mean cloud cover changes the effective forcing of CO_2 and it changes the sensitivity of T_{surf}. Regions with less cloud cover will warm more strongly than regions with strong cloud cover.

The atmospheric water vapor reduces the effective forcing of CO_2, due to overlapping absorption bands. It further increases the sensitivity of T_{surf} to external forcings. In sum regions with large mean atmospheric water vapor will warm less in response to local CO_2 forcing.

The atmospheric circulation will, by horizontal advection and turbulent diffusion, transport heat around the world and will thereby reduce gradients in the response pattern.

The first main feedback considered is the response in snow and sea ice, which have a positive feedback on the solar radiation absorption and the seasonal heat uptake/loss over sea ice. This leads to a strong amplification of the response over the northern hemisphere.

Allowing atmospheric water vapor content to response locally to changes in surface temperature (no atmospheric transport of water vapor) makes the strongest positive feedback and leads to a strong amplification of the response pattern globally.

Including turbulent diffusion of water vapor within the atmosphere leads to a further amplification of the response in high-latitude, desert and high-altitude regions, whereas in the tropics the signal is reduced by mean dry-air convergence.

Additionally taking the water vapor transport by the mean atmospheric circulation into account leads to a pronounced warming over northern hemisphere continents and the arctic region.

In completing the ensemble of the GGEB model´s physical processes the heat exchange with the deeper ocean is included. On the time scale of a 2xCO_2 scenario the deep ocean acts as a sink for additional energy inputs at the surface and thus has a dampening effect on the global surface temperature response.

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