Metrics to assess the mitigation of global warming by carbon capture and storage

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Motivation:

- How do we quantify the benefits of leaky reservoirs/temporary storage?

Approach of study and outline of talk:

- Generic model study
- Choose reference scenario and sequestration cases
- Generate results and compare different metrics
- Discuss applicability and future developments

Reference: Peter M. Haugan and Fortunat Joos 2004. Metrics to assess the mitigation of global warming by carbon capture and storage in the ocean and in geological reservoirs. *Geophysical Research Letters* 31, L18202, doi:10.1029/2004GL020295.

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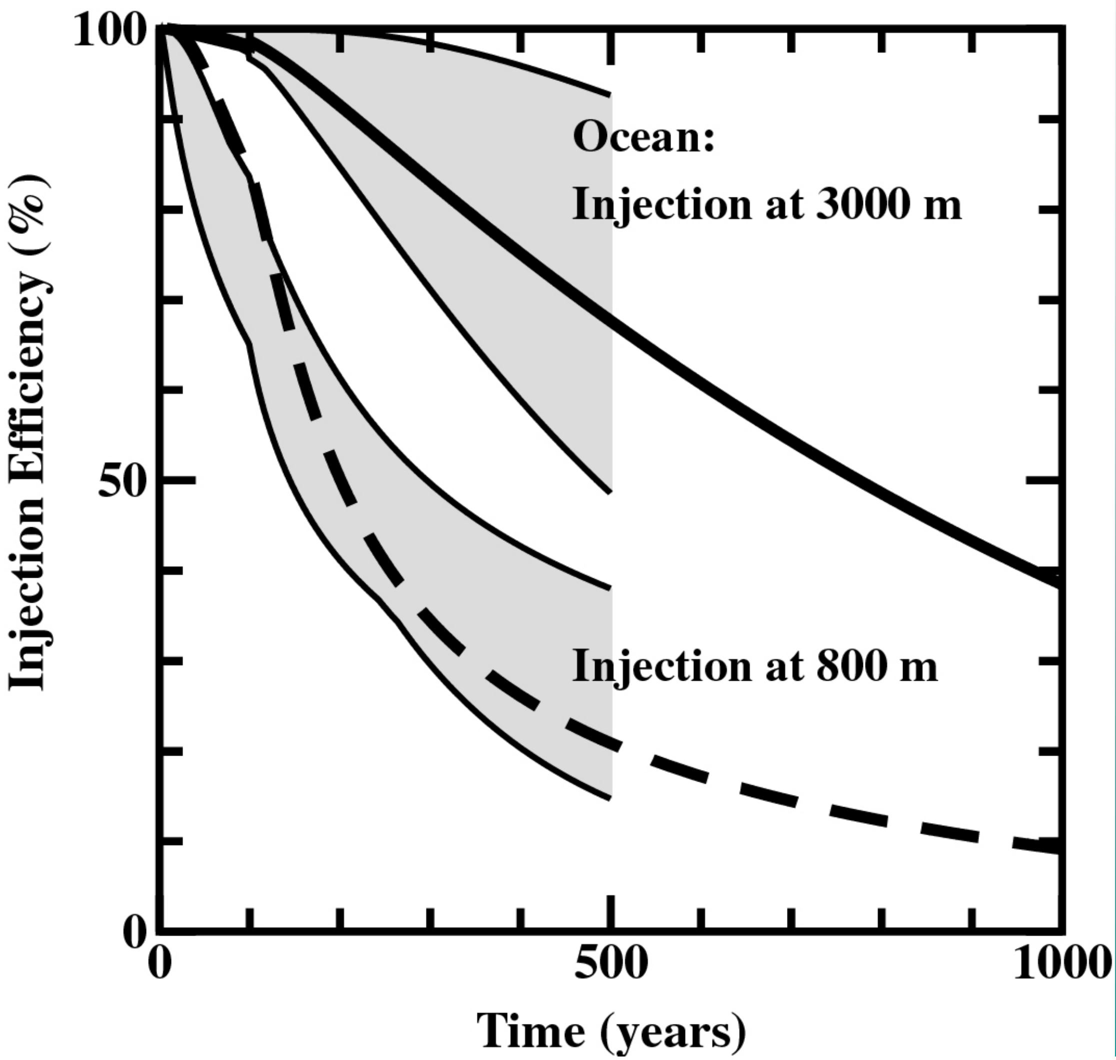
Approach

- Use reduced form carbon cycle climate model in millennium time scale runs: HIgh Latitude Diffusion-Advection (HILDA) ocean model coupled to a 4-box biosphere model and an energy balance model (Joos et al., 1996, Joos and Bruno, 1996, IPCC reports)
- Check the ability of the model to simulate the injection efficiency of direct ocean storage
- Choose stabilization reference scenarios: WRE 550, 450 and 1000
- Capture and store 30 % of emissions after a ramp-up period 2010-2035
- Investigate effects of
  - Perfect storage *PS* (no leakage)
  - Geological storage with 0.01 annual leakage to the atmosphere
  - Geological storage with 0.001 annual leakage to the atmosphere
  - Storage in the ocean at 800m depth
  - Storage in the ocean at 3000m depth
- Include energy penalty of 20% and 5%

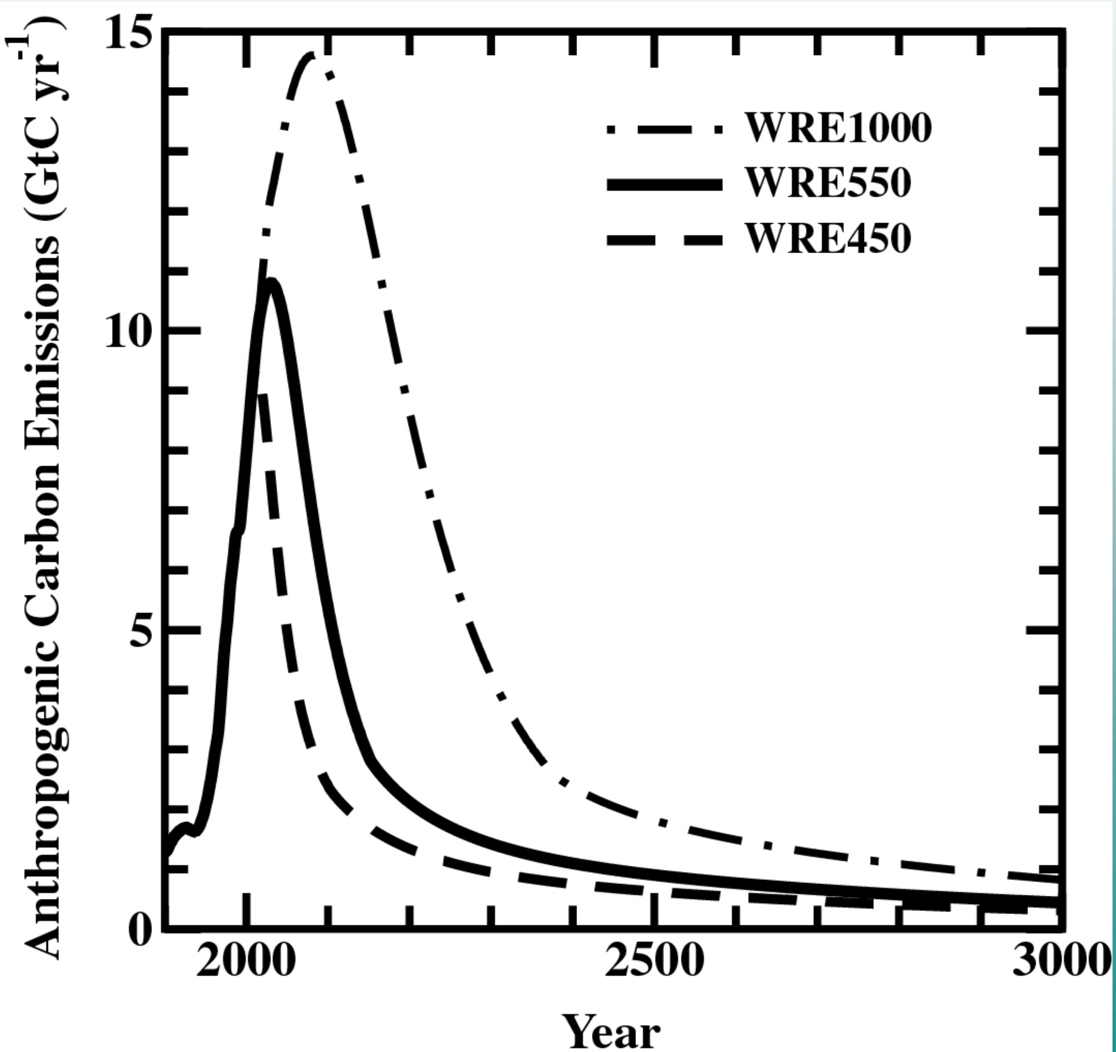
Validation of model for ocean storage cases

Injection efficiency = Additional mass in the ocean relative to reference divided by the total injected



The range spanned by the results of seven ocean circulation models used in the Ocean Model Intercomparison Project (OCMIP, Orr et al., 2001) and run until year 2500, shown in gray, HILDA ocean model run until year 3000. Annual injection of 0.7 GtC at 800 m (dashed) and 3000 m (solid) with S650 atmosphere.

Deduce emissions corresponding to the reference (stabilization) scenarios when no carbon is stored



Anthropogenic carbon emissions for the WRE450, WRE550, and WRE1000 stabilization scenarios.

Use model to investigate effects of capture and storage of 30 % of these emissions (*ref*)

Output parameters to look at for storage cases (*s*):

– Atmospheric CO_2

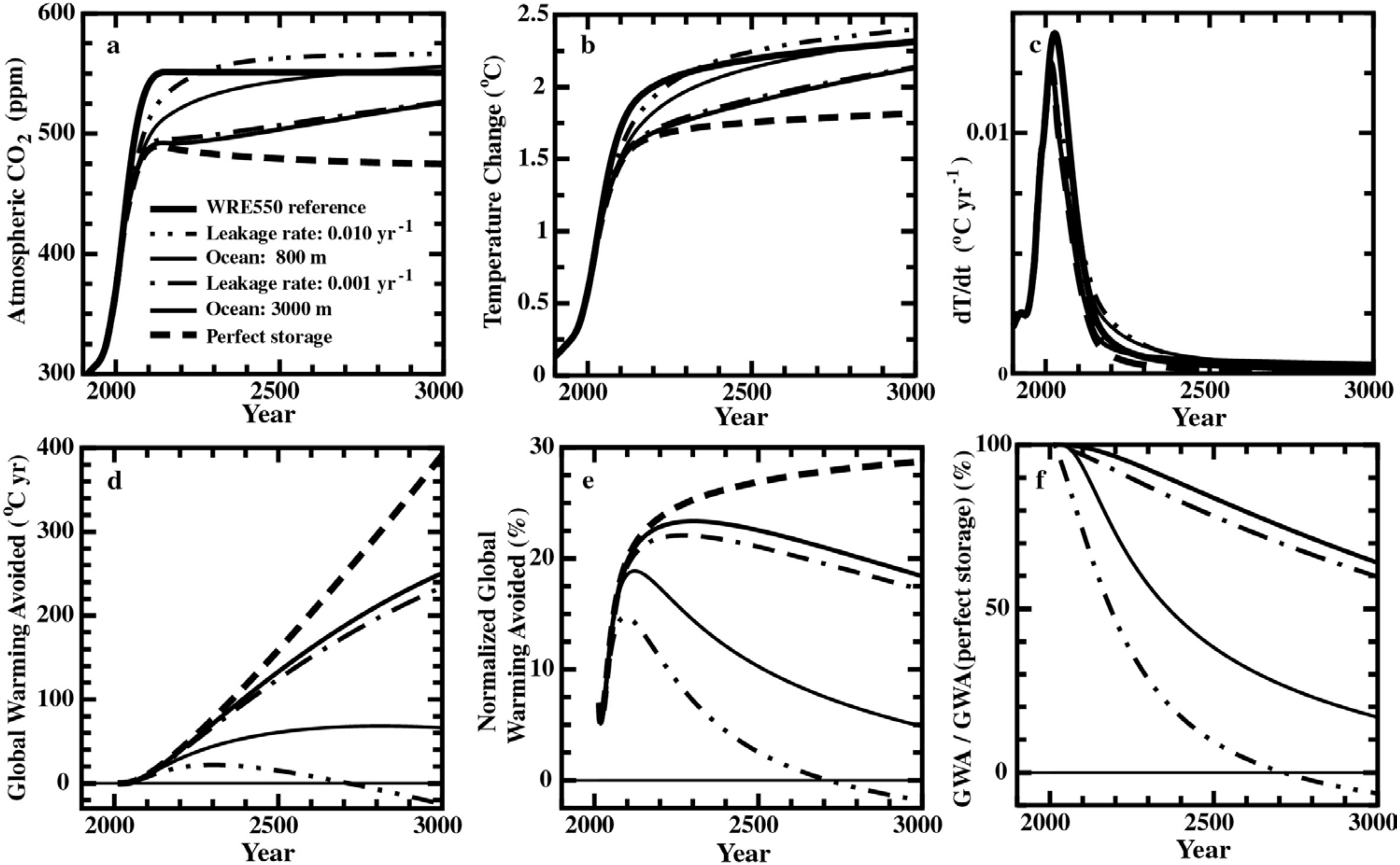
– Surface air temperature *T*

– Rate of change of surface air temperature

– Global Warming Avoided (GWA):

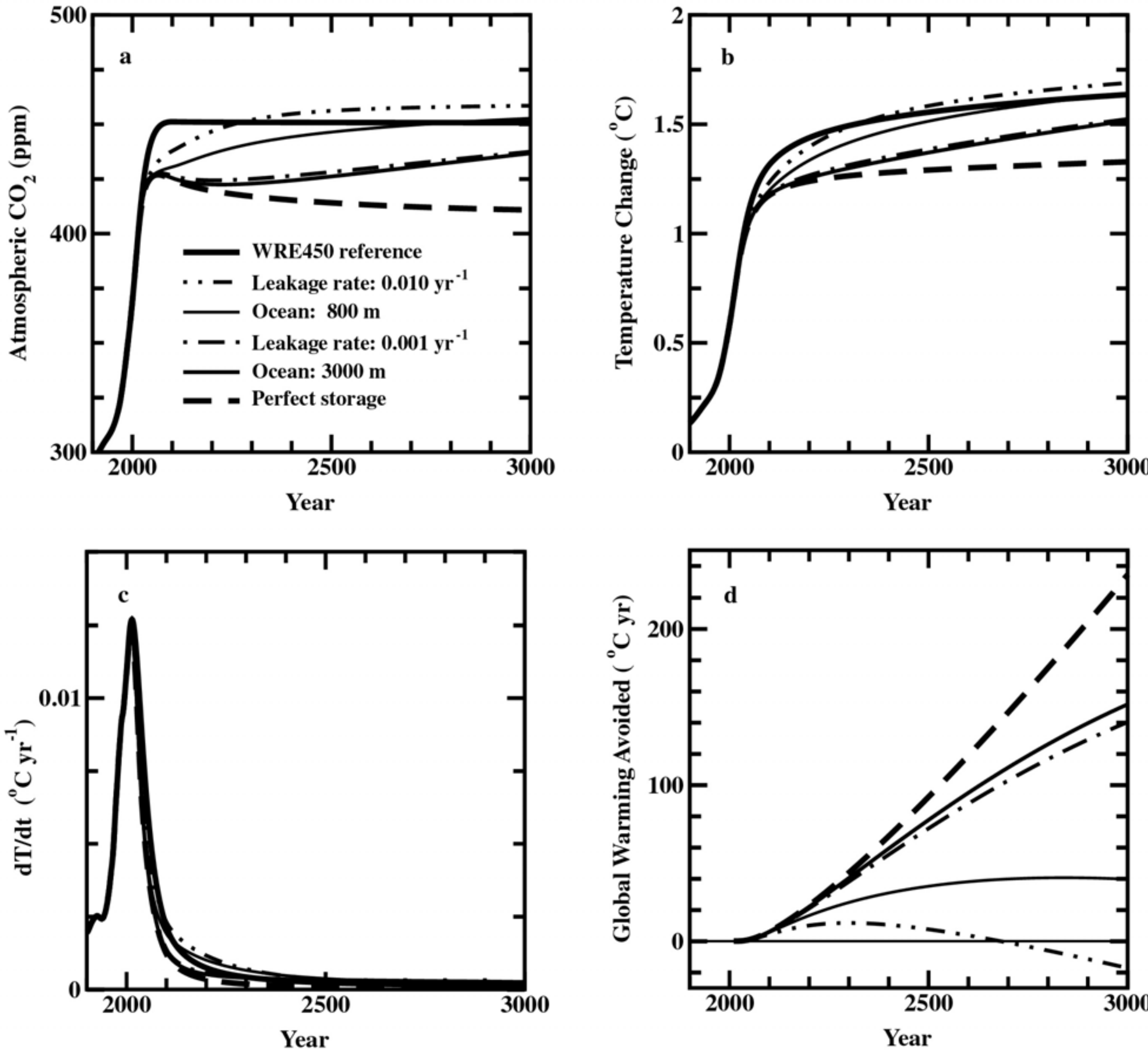
$$GWA(t) = \int_{t_0}^{t} (T_{ref} - T_s)\,dt \qquad GWA_{Norm}(t) = \frac{\int_{t_0}^{t} (T_{ref} - T_s)\,dt}{\int_{t_0}^{t} (T_{ref} - T_0)\,dt}$$

Storage effectiveness $EFF(t) = GWA(t) / GWA_{PS}(t)$



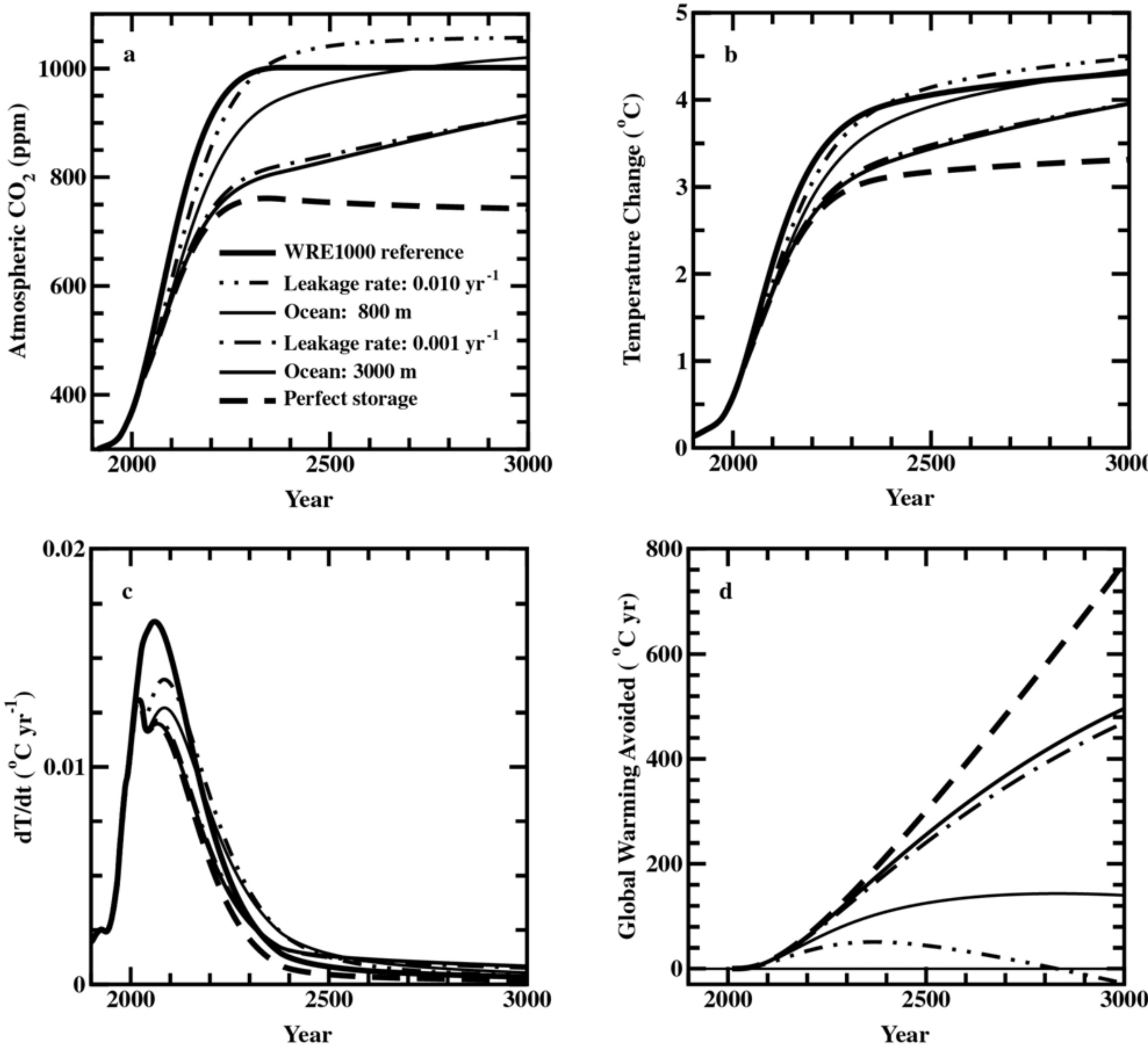
(a) atmospheric CO_2, (b) global average surface temperature change, (c) rate of global average surface temperature change, and GWA (d) in °C year, (e) in percent of the cumulative warming of the reference case, and (f) relative to the perfect storage case for WRE550.

WRE 450 reference case results



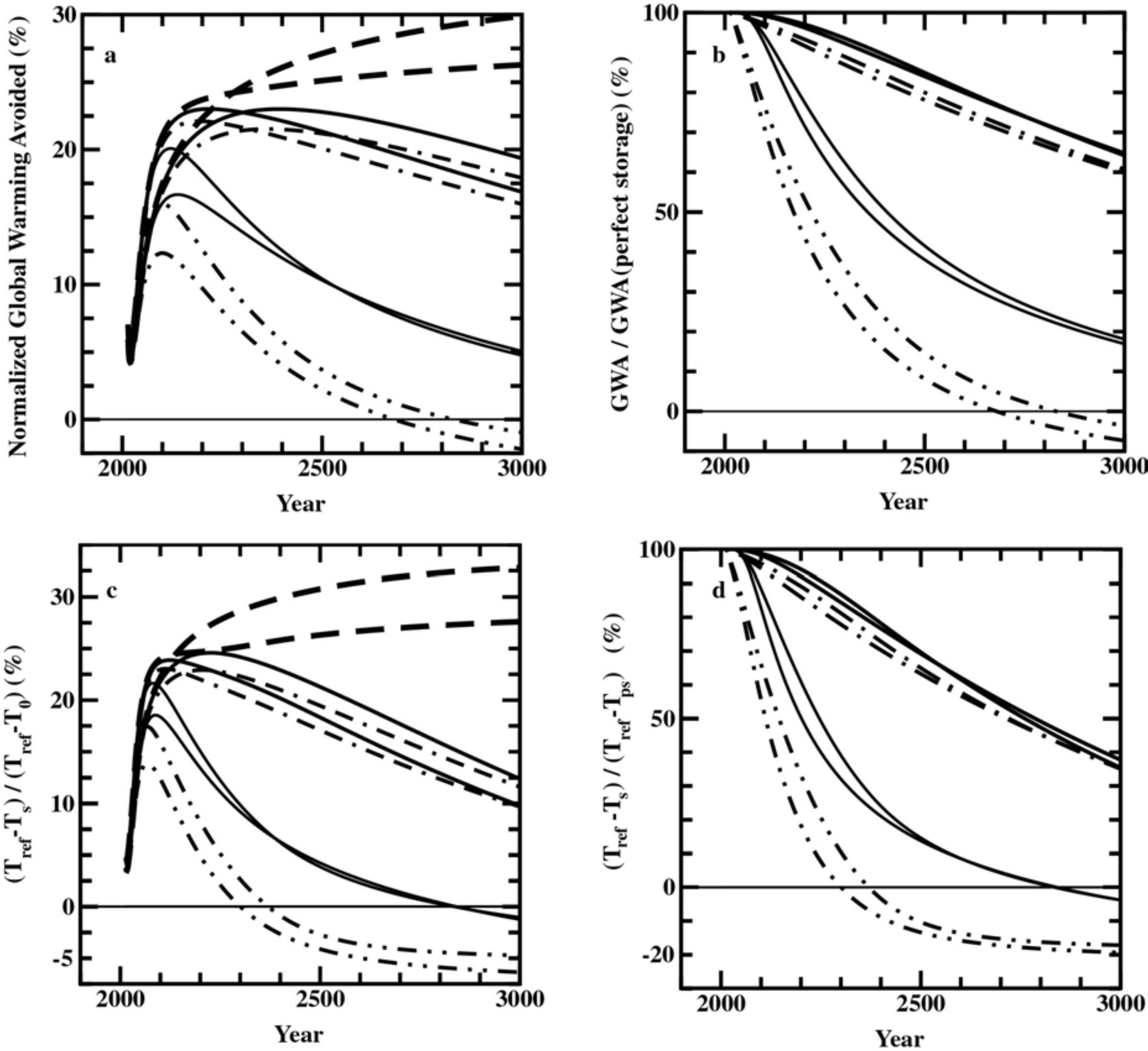
(a) atmospheric CO_2,
(b) global average surface temperature change,
(c) rate of global average surface temperature change,
(d) GWA in °C year

WRE 1000 reference case results



(a) atmospheric CO_2,
(b) global average surface temperature change
(c) rate of global average surface temperature change,
(d) GWA in °C year

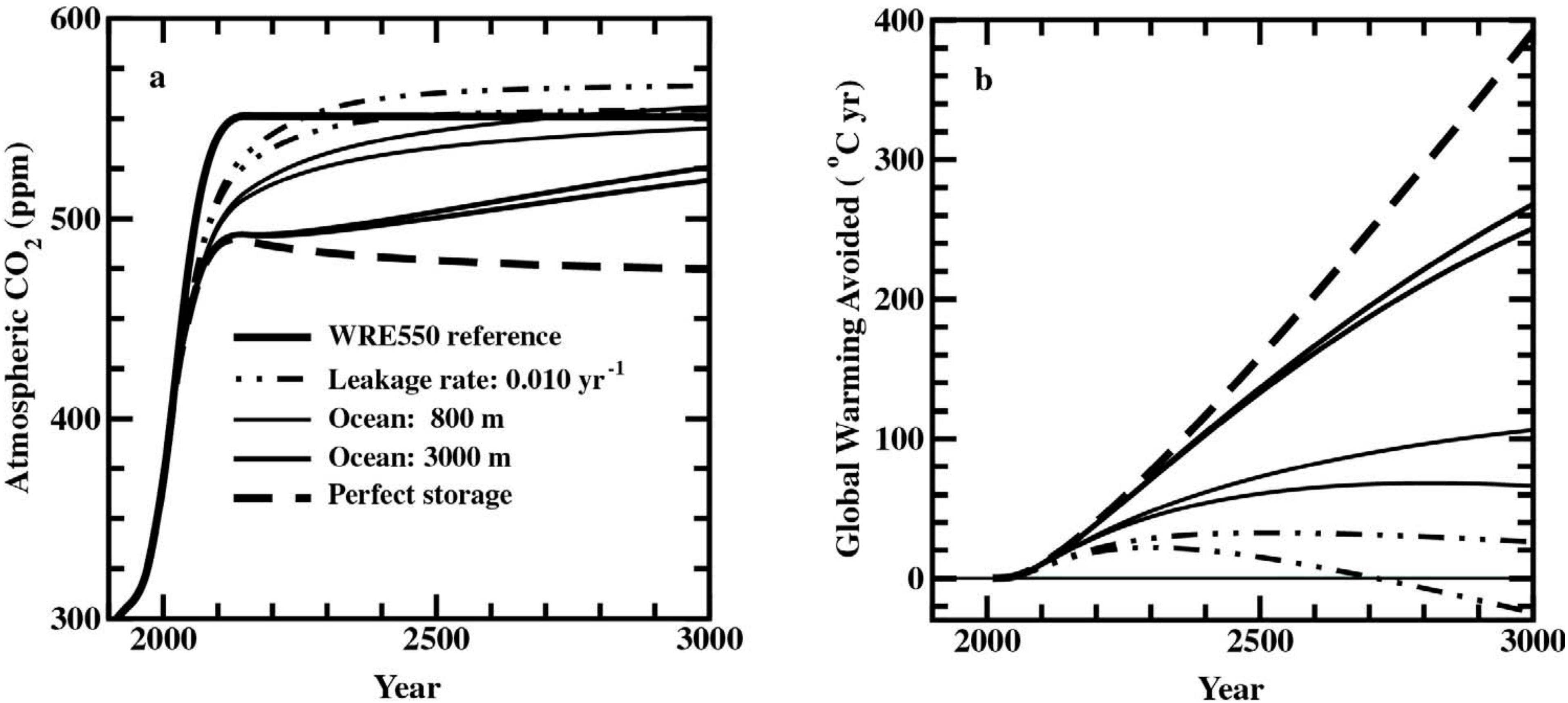
Further WRE 450 to WRE 1000 reference case results



Ranges spanned by WRE450 to WRE1000 of (a) Normalized GWA (b) Effectiveness, (c) temperature difference between the reference case (Tref) and an injection scenario (Ts) relative to the temperature change of the reference case (Tref- T0), and (d) the ratio of temperature differences between reference case and injection scenarios (Tref-Ts) to reference case and perfect storage scenario (Tref-Tps). The curves shown in panel c and d are related to the integrands of the GWAs shown in panel a and b, respectively.

Effects of changed energy penalty

(a) Atmospheric CO_2, and (b) GWA in °C year for WRE550 and an energy penalty of 5% (lower curves in (a), upper in (b)) and 20% (upper curves in (a), lower in (b)).



Summary of some of the results

Geological storage with 0.01 annual leakage fraction is less effective than shallow ocean storage (800m). Its effectiveness[1] for storing 30% of emissions peaks at 15 % and GWA gets negative after 6-700 years.

Geological storage with 0.001 annual leakage fraction has similar performance to deep ocean storage.

Maximum rates of change of temperature are not much affected by any of these carbon storage cases.

Normalized GWAs for a given storage case tend to collapse to similar values for different reference scenarios.

Reducing energy penalty from 20 to 5 % has limited effect.

[1]Storage effectiveness EFF(t) is defined here to be the fraction of the GWA obtained relative to that obtained by perfect storage.

Discussion

Global Warming Avoided (GWA) is offered as a metric of the value of storage schemes. It includes climate effects, not only carbon accounting, but avoids economic modeling. Normalization may remove some model dependency.

Perfect storage of 30 % of emissions approach 30% GWA over 1000 year time scale in the cases studied. Note that for higher background CO_2 levels, reducing atmospheric CO_2 will have smaller climate effects.

25 year ramp-up and storage of 30% is probably fast and large. Would require infrastructure similar to that for all fossil fuel.

Could use GWA concept for longer model runs and different models, and generalize to other damage than warming. Still require (political) decision on time horizon.

Deep ocean storage in lakes on the seafloor would perform better because of delayed mixing into the water column.