The role and potential impacts of using Carbon Dioxide Removal to achieve the Paris Agreement goals

Earth system modelling in support of the Paris Agreement

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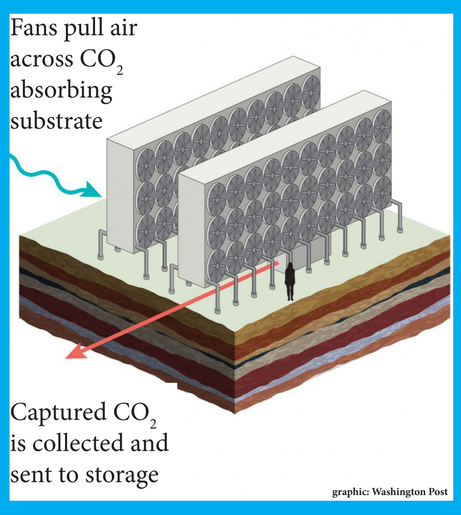
Carbon Dioxide Removal (CDR) or "negative emissions" is required in all scenarios that limit warming to 1.5°C and plays a major role in most < 2°C scenarios (IPCC SR 1.5). However, little is understood about how the climate and Earth system may respond to CDR. The **Carbon Dioxide Removal Model Intercomparison Project** (**CDRMIP**; Keller et al., 2018) is coordinating Earth system modelling research to investigate the potential, risks, and challenges of different types of proposed CDR.

Find out more at: www.kiel-earth-institute.de/CDR_Model_Intercomparison_Project.html

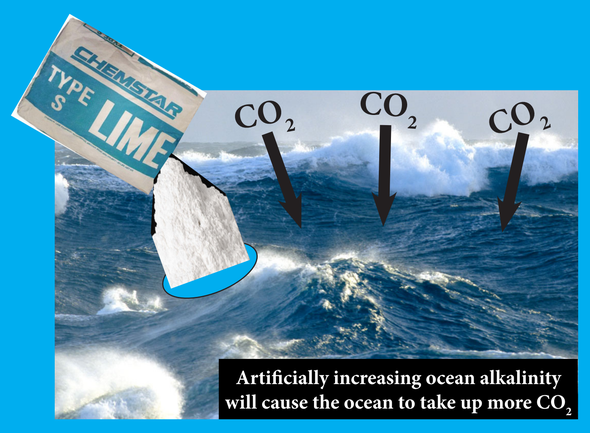
Multi-model simulations of carbon dioxide removal methods*

Direct air capture (with storage)



Large-scale afforestation/reforestation

Artificial ocean alkalinization



Needed Future Investigations	• Other CDR methods, e.g. bioenergy with carbon capture and storage (BECCS) • Combinations of CDR methods

*Individual models have simulated other CDR methods such as BECCS, but many CDR methods are difficult to simulate with multiple models

CDRMIP research

How efficient is carbon dioxide removal?

Implications

The amount of CDR that is needed

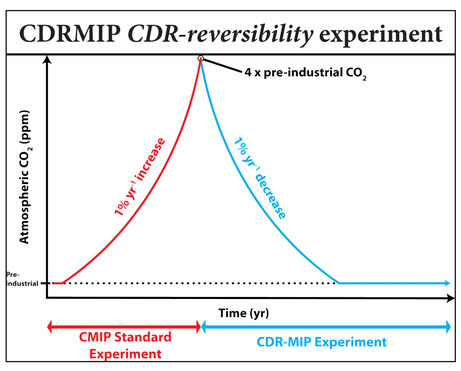
Sustainable/safe levels of CDR

What are the positive and negative impacts (side effects) of CDR?

What does this mean for transformation of energy and other sectoral systems?

- Implications for the energy requirements of CDR
- Effects on/implications for agricultural systems
  - e.g., the scale and location of bioenergy plantations
- Effects on/implications for infrastructure
  - e.g., construction and location of carbon capture and storage facilities

Is climate change reversible if CDR is used after overshooting a temperature target?



It is easier to warm the climate by adding CO_2 than it is to cool the climate by removing CO_2

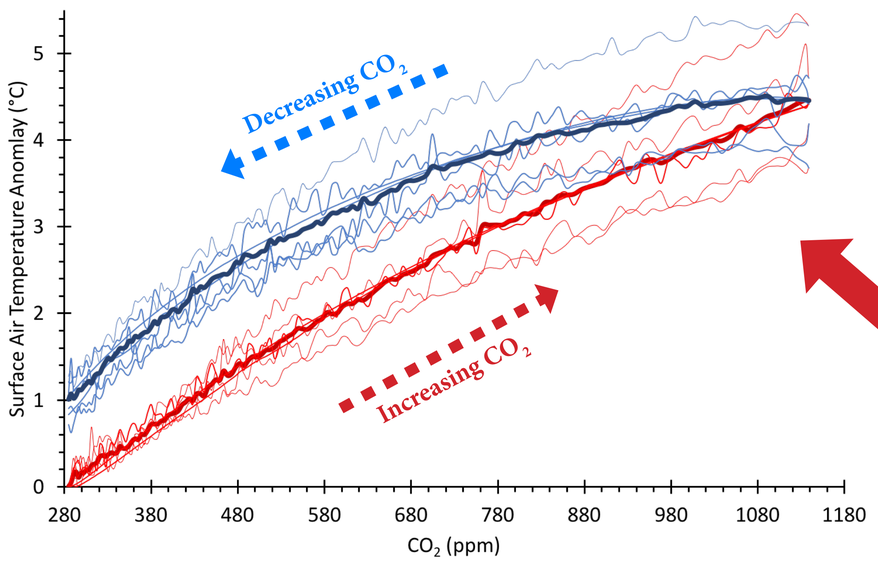


Figure 1. Preliminary *CDR-reversibility* simulation results from 6 models. Multi-model mean (thick lines) and individual simulations (thin lines) are shown for increasing CO_2 (red) and decreasing CO_2 (blue). Only the ramp-up and ramp-down portion of the simulations is shown, i.e., a 280 year time period.

For many indicators climate change appears reversible...but with a time lag

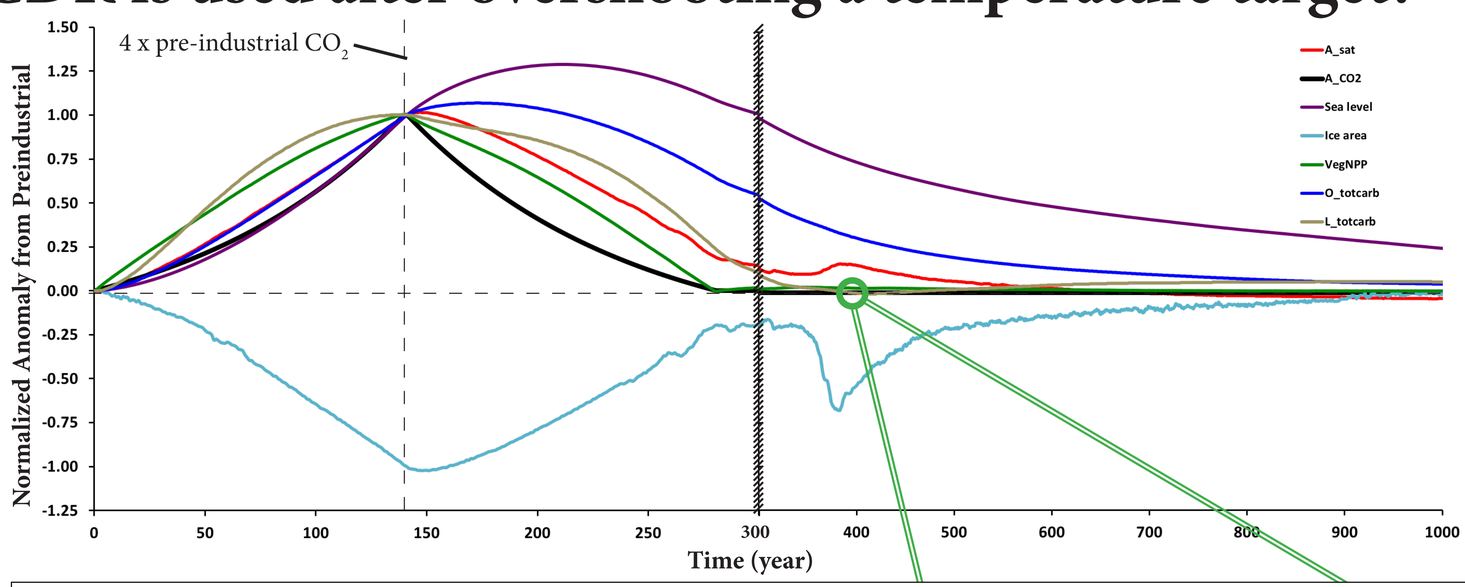
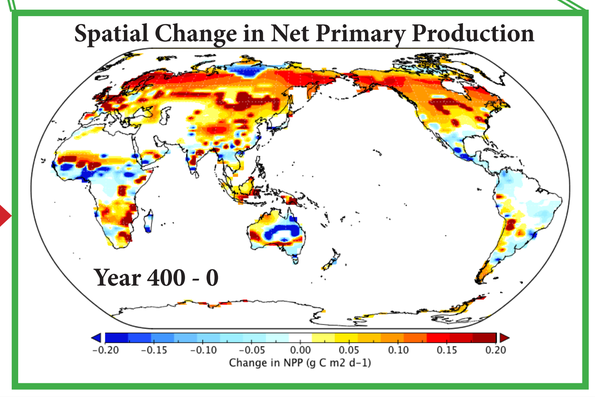


Figure 2. Example *CDR-reversibility* simulation conducted with the University of Victoria Earth System Climate Model of intermediate complexity. Lines depict global annual mean values normalized to the initial preindustrial steady state value. Black line [A_CO2]: CO_2 forcing as prescribed by the C1 protocol; Red line [A_sat]: surface air temperature; Purple line [Sea level]: Thermosteric sea level change relative to pre-industrial; Light blue line [Ice area]: Arctic and Antarctic sea-ice areal extent; Green line [VegNPP]: terrestrial vegetation net primary productivity; Dark blue line [O_totcarb]: Ocean carbon; Tan line [L_totcarb]: terrestrial carbon content.

However, annual global mean metrics may be misleading when evaluating reversibility



References:
Keller, D. P., Lenton, A., Scott, V., Vaughan, N. E., Bauer, N., Ji, D., Jones, C. D., Kravitz, B., Muri, H. and Zickfeld, K.: (2018) The Carbon Dioxide Removal Model Intercomparison Project (CDRMIP): Rationale and experimental protocol for CMIP6, Geosci. Model Dev., 11(3), doi:10.5194/gmd-11-1133-2018.

Global warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [V. Masson-Delmotte, P. Zhai, H. O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, A. Pirani, W. Moufouma-Okia, C. Péan, R. Pidcock, S. Connors, J. B. R. Matthews, Y. Chen, X. Zhou, M. I. Gomis, E. Lonnoy, T. Maycock, M. Tignor, T. Water eld (eds.)].