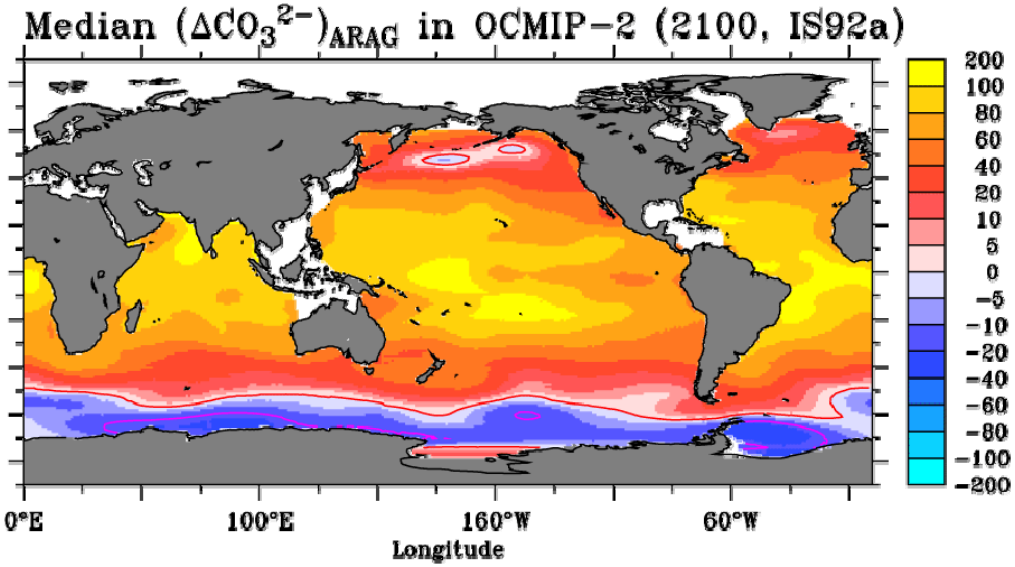
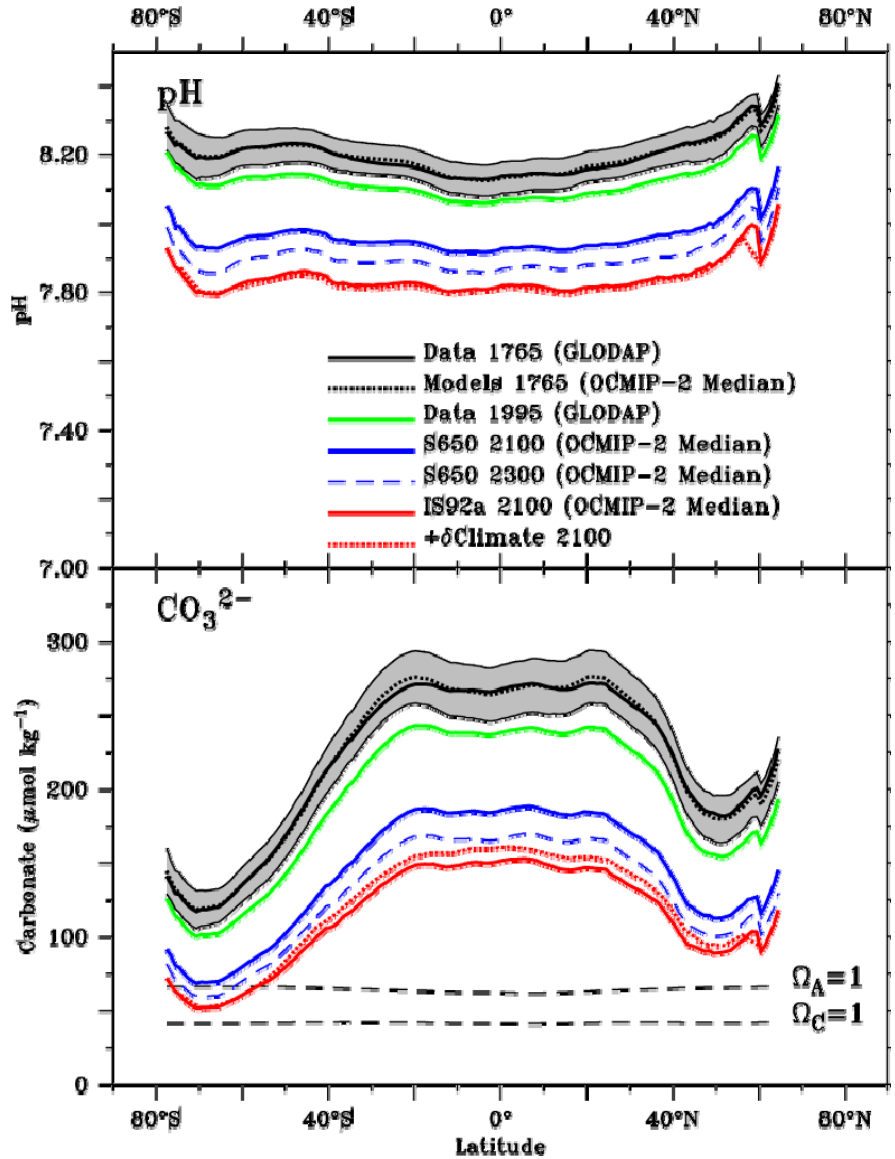
Aragonite Undersaturation in the Surface Southern Ocean by 2100

Orr et al. (poster)





IS92a "Business-as-Usual" pathway

The Oceans in a High-CO_2 World
10-12 May 2004
Paris

Ocean model predictions of changes in ocean *p*H and calcite saturation

Ken Caldeira and Mike Wickett
Energy and Environment Directorate
Lawrence Livermore National Laboratory

Caveats

- We estimate ocean chemistry changes without considering
  - climate change
  - ocean circulation change
  - marine biology
  - land biosphere
  - carbonate dissolution

    - Consideration of these factors would affect numerical results, but would not affect basic qualitative conclusions
      - *LLNL coupled climate/carbon model yields ~1400 ppm instead of ~1940 ppm at year 2300 for emission pathway in Caldeira and Wickett (2004)*

Simulations

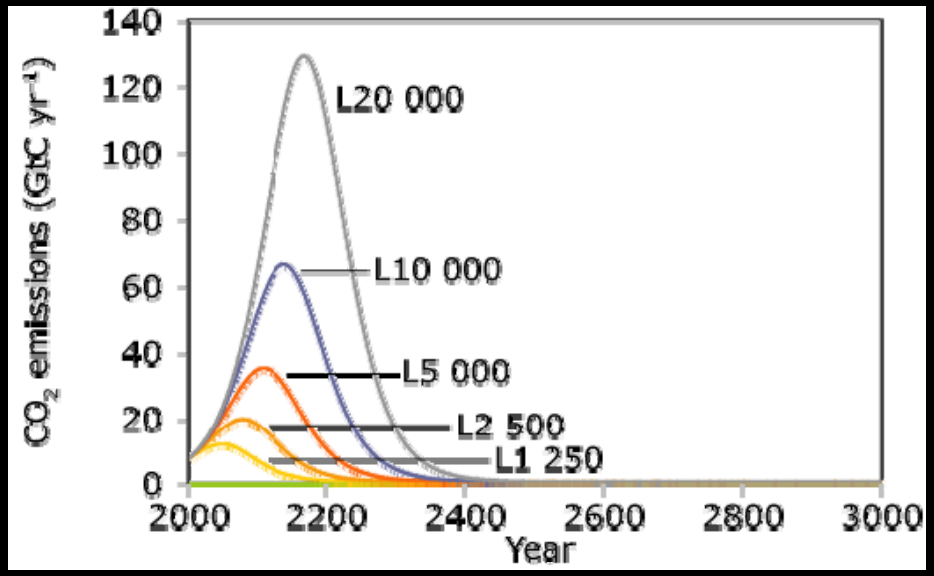
- CO_2-emissions pathways
  - SRES A1, A2, B1, B2 (Year 2000 to 2100)
  - Logistic pathways:
    1 250, 2 500, 5 000, 10 000, and 20 000 GtC
- CO_2-stabilization pathways
  - WRE 450, 550, 650, 750, and 1000 ppm
- CO_2 release to ocean interior
  - Use of ocean to provide all or some of abatement needed to move from emissions pathway to stabilization stabilization

Ocean model

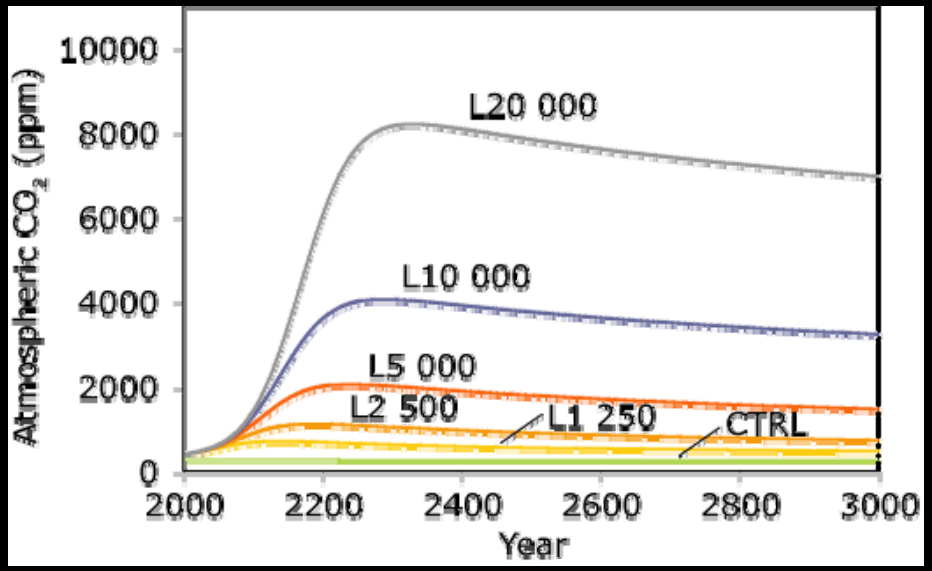
- LLNL ocean GCM
  - coarse resolution (4° x 2°)
  - variant of GFDL MOM model
  - Gent-McWilliams
  - Oberhuber ice model
- Differs slightly from LLNL OCMIP2 submission
  - $k_{iso} = 10^{-7}$ cm^2 s^{-1}
  - 24 horizontal layers
  - NCEP climatology wind-stress and heat forcing

Logistic CO_2 emission pathways

Prescribed CO_2 emissions

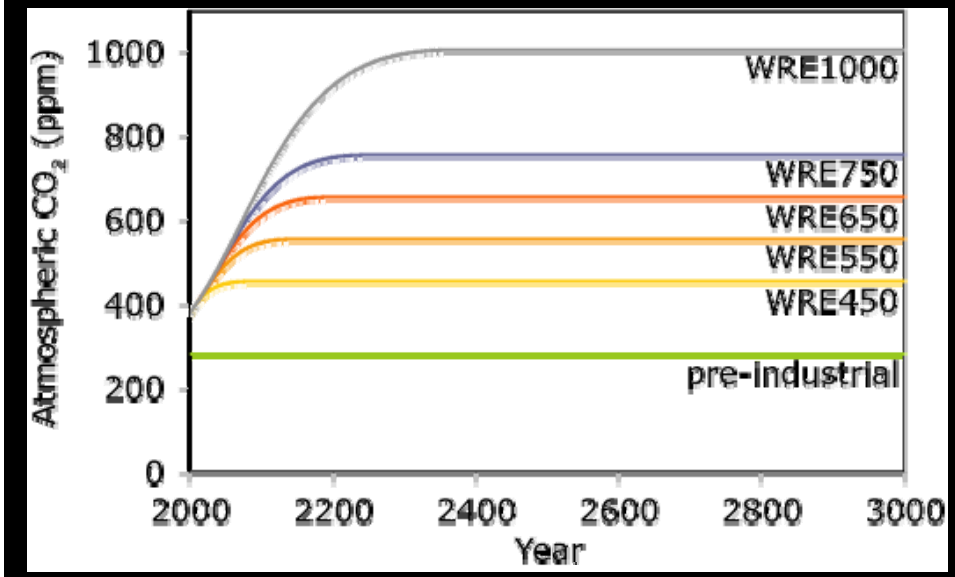


Computed atmospheric CO_2

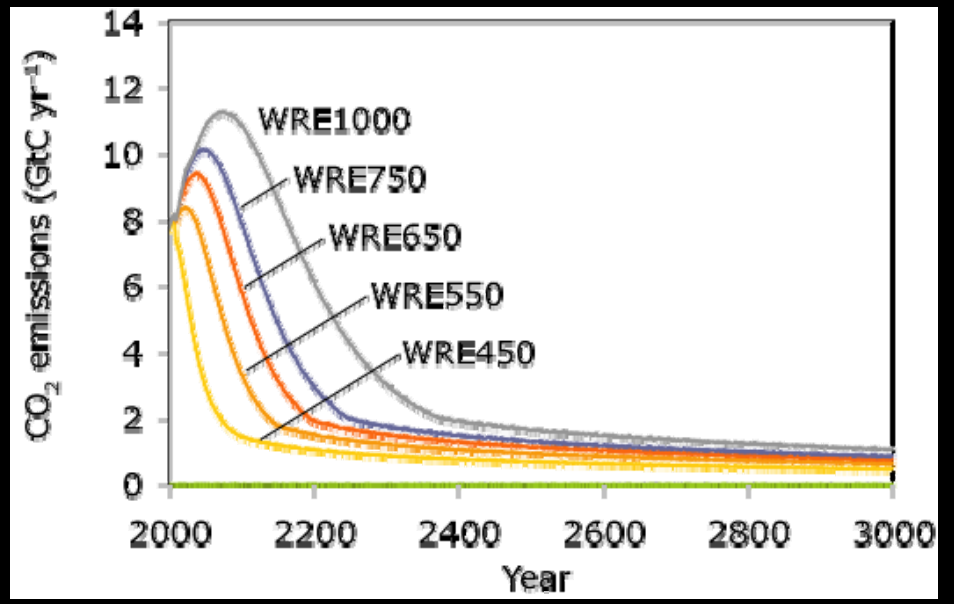


WRE CO_2 stabilization pathways

Prescribed atmospheric CO_2

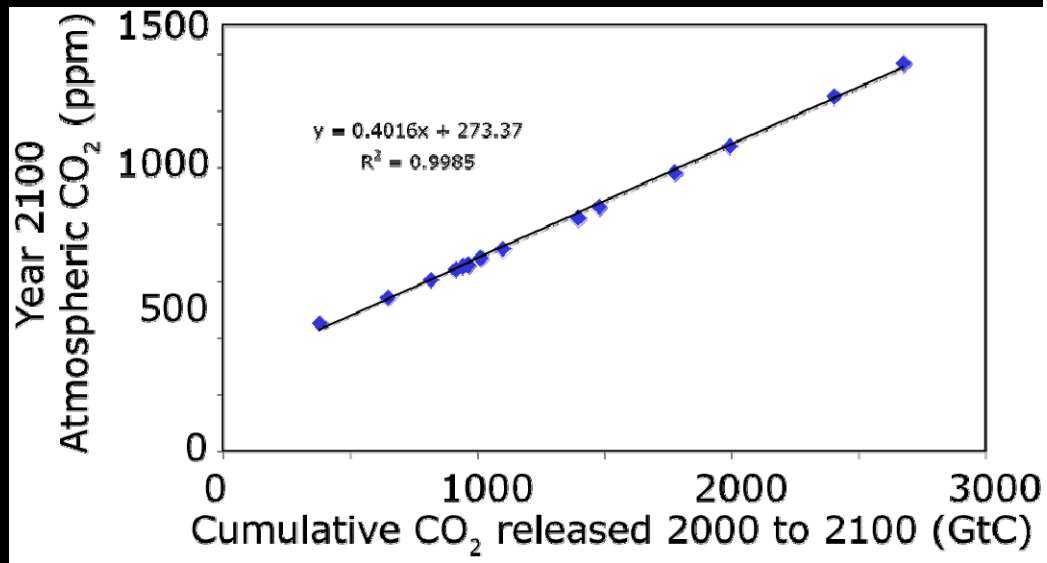


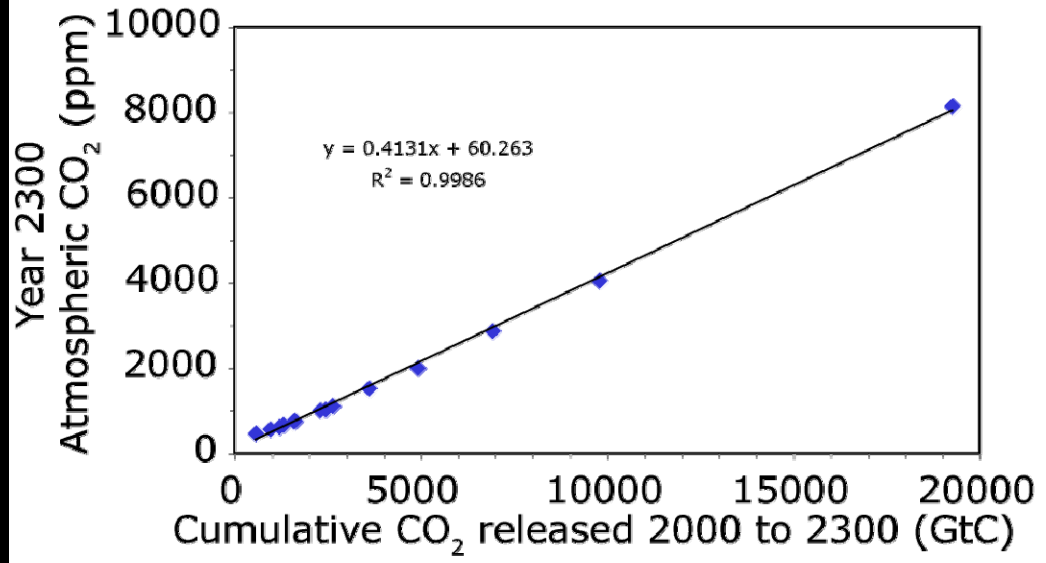
Computed CO_2 emissions



Basic results for atmosphere

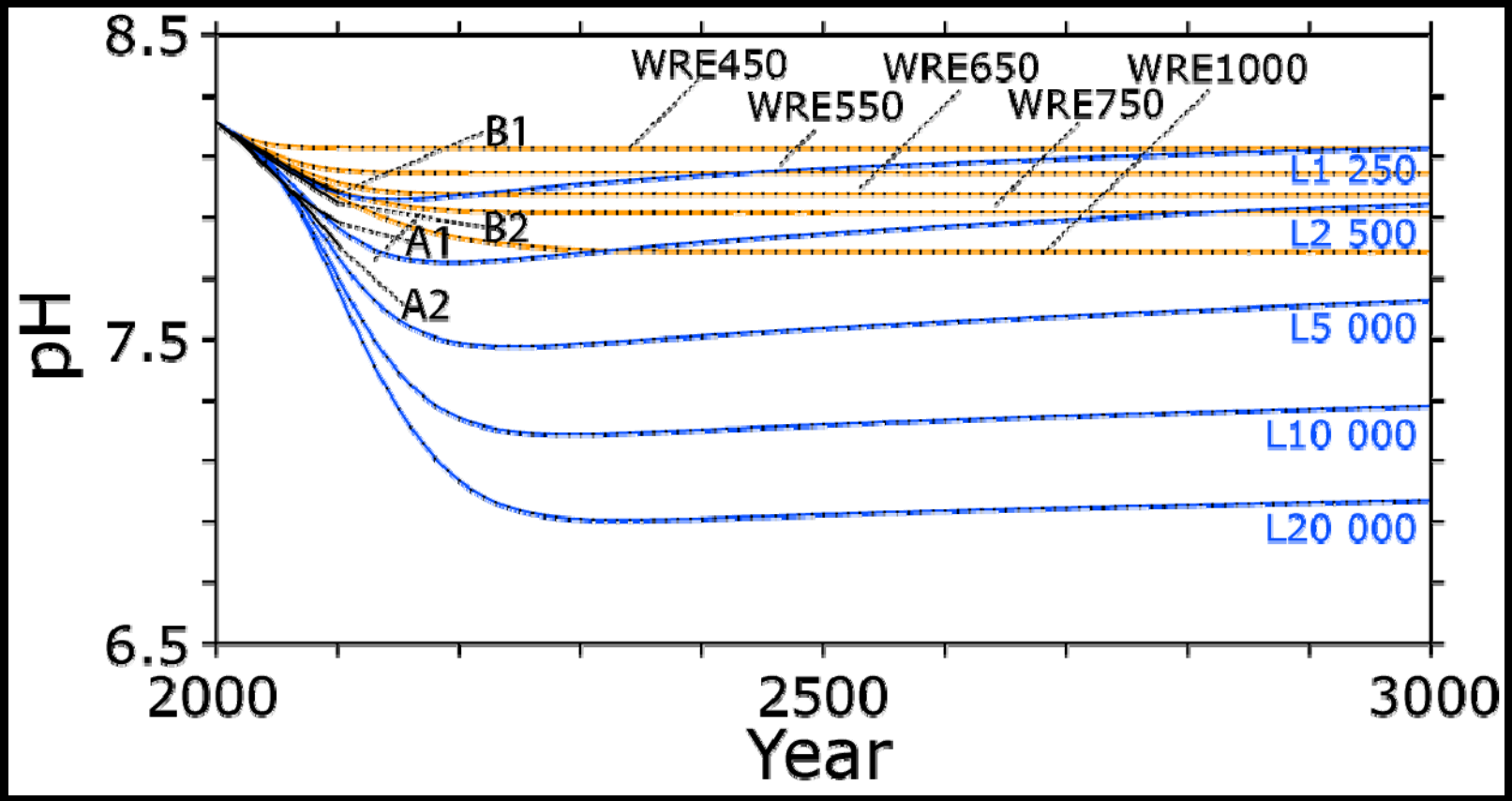
- For these emissions pathways, atmospheric pCO_2 is closely related to cumulative CO_2 emissions





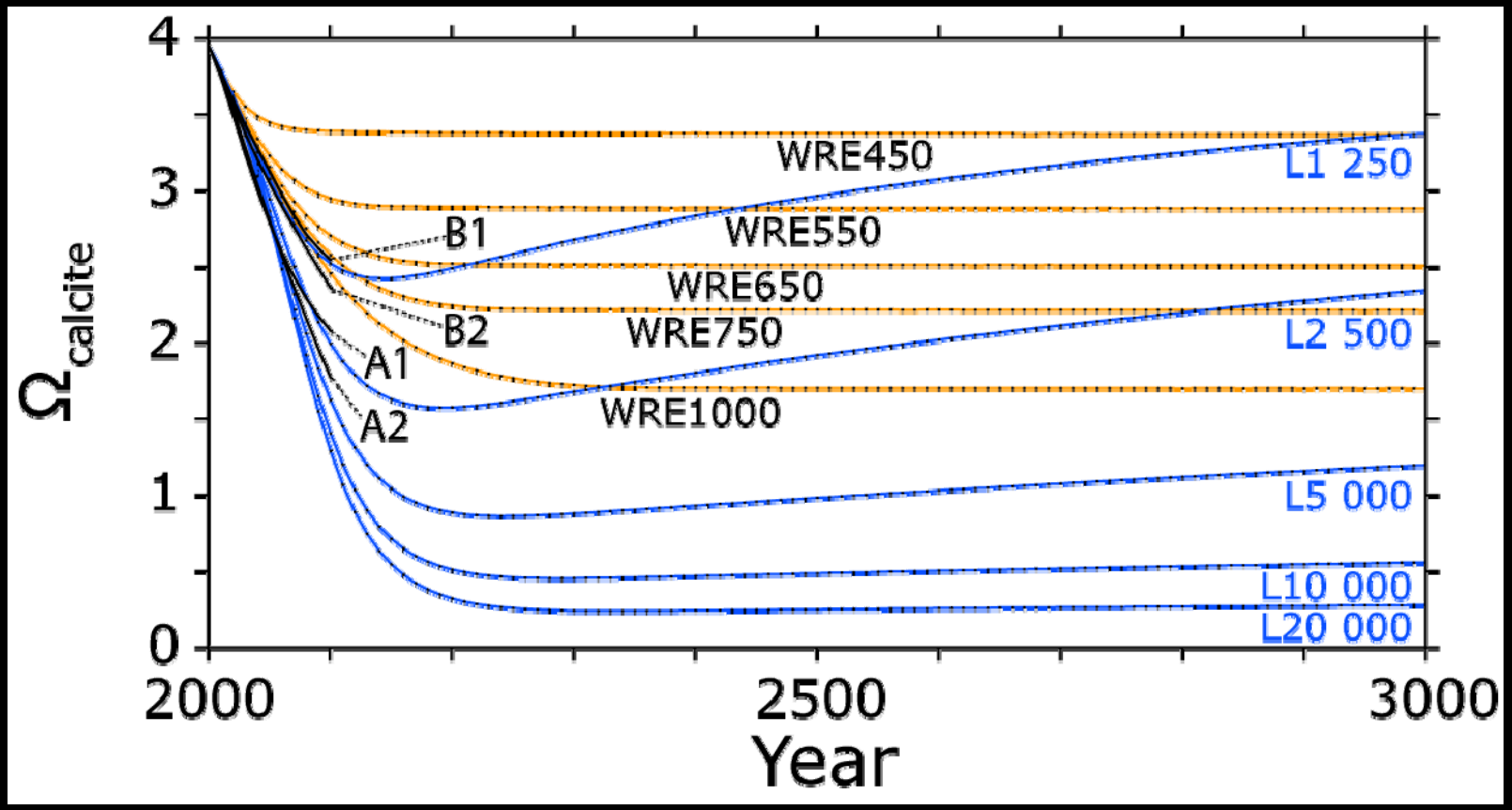
Basic results for surface ocean

- Surface ocean pH changes

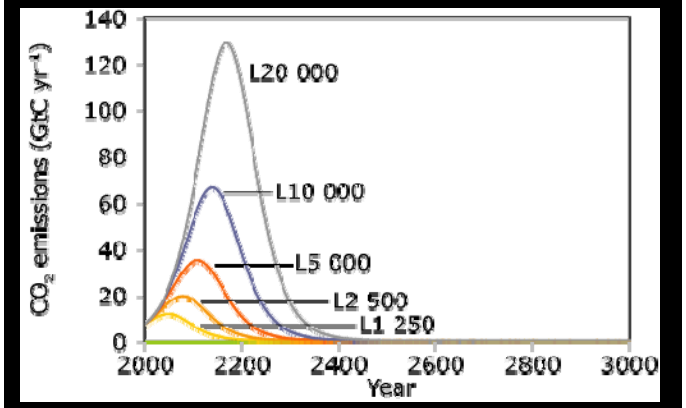


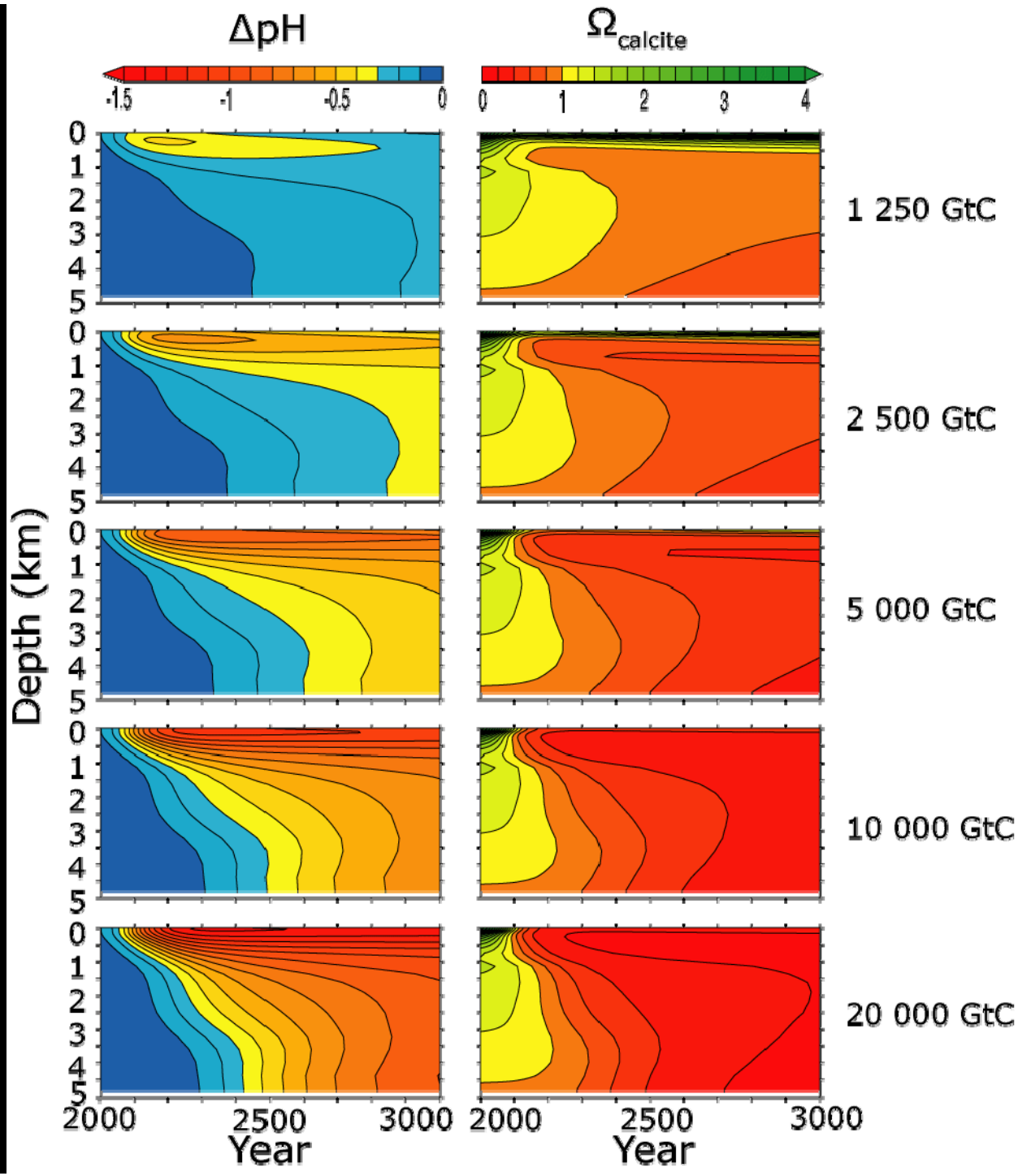
Basic results for surface ocean

- Surface ocean calcite saturation changes

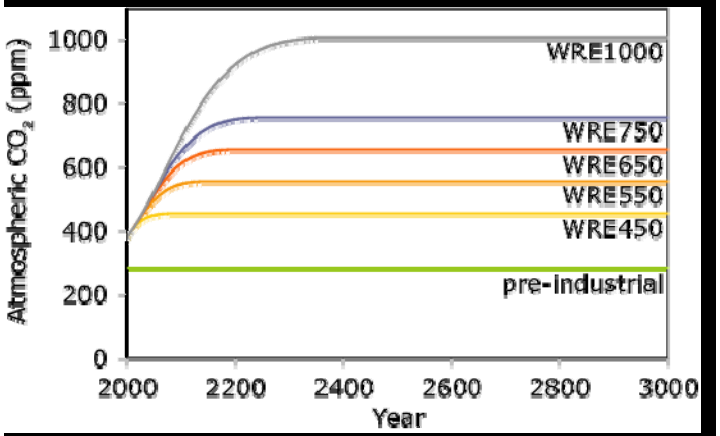


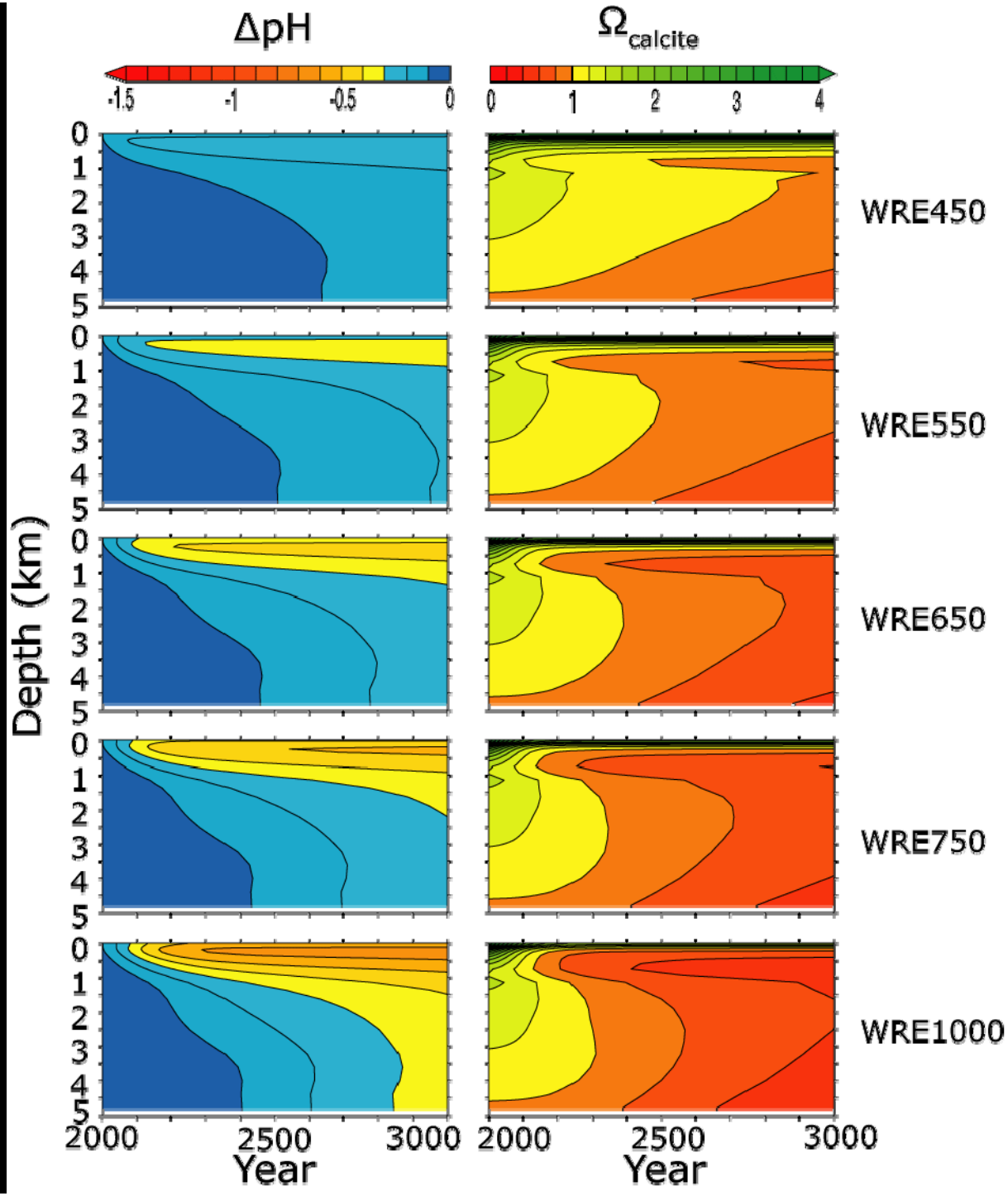
Logistic emission pathways





WRE stabilization pathways



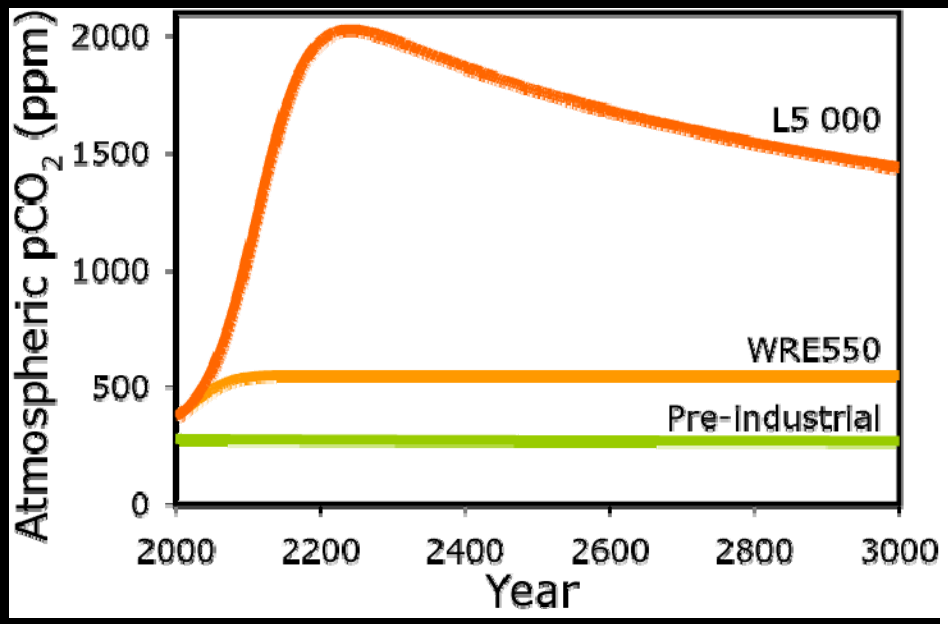


Summary (Part I)

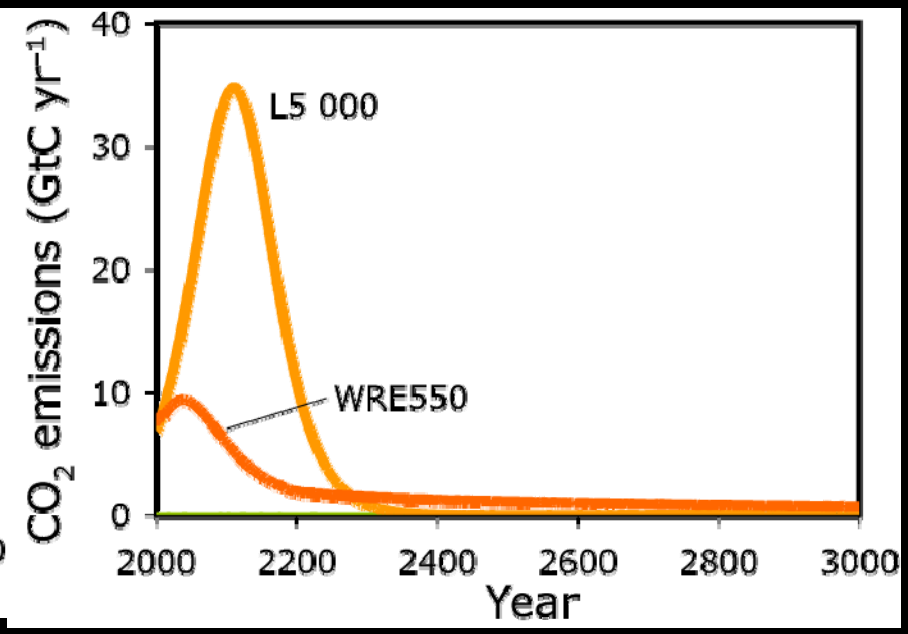
- To a first approximation
  - Atmospheric pCO_2 increase is proportional to integrated emissions
  - Surface ocean pCO_2 tracks atmospheric pCO_2
  - Ocean pH change scales with log pCO_2
    - Ocean pH change scales with log of integrated emissions
- Calcite lysocline to <500 m depth, even with
  - WRE550 stabilization (e.g., 2 x CO2)
  - Atmospheric emission of only 25% of IPCC estimated fossil-fuel resources (i.e., 1250 GtC)

A closer look at L5000, WRE550, and the use of ocean storage to get from one to the other

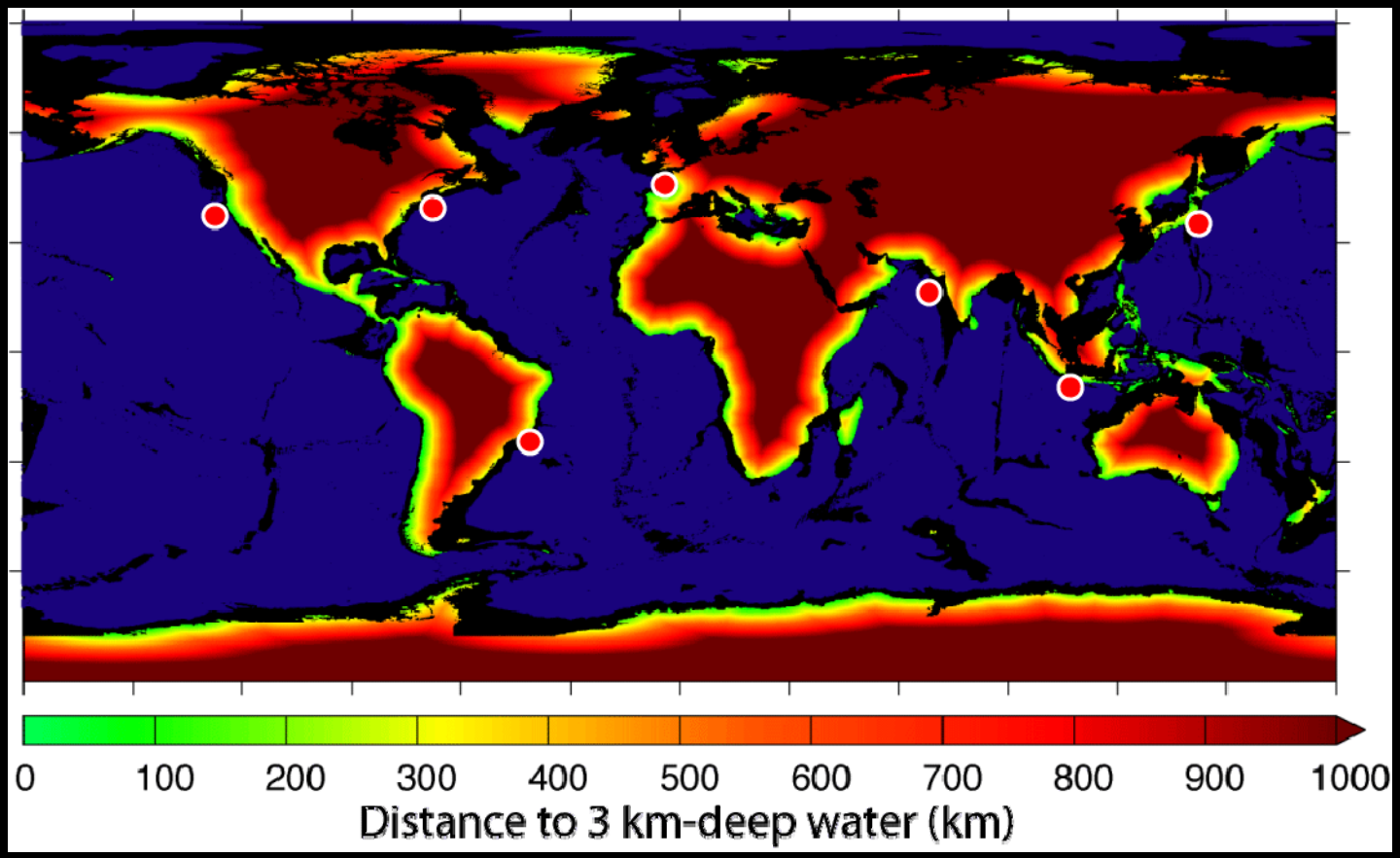
Atmospheric pCO_2



CO_2 emissions



OCMIP-2 injection locations

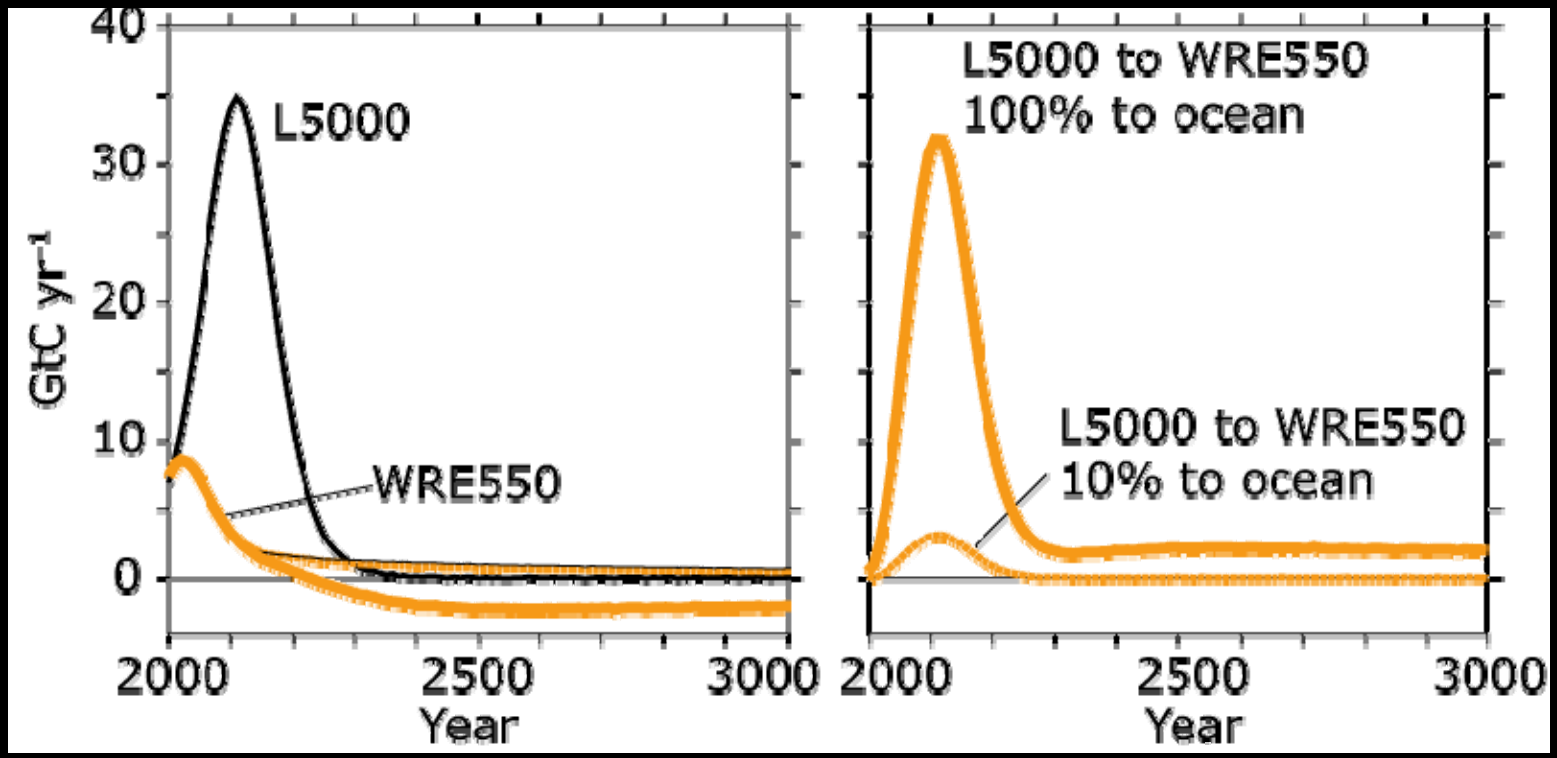


In the simulations presented here, injections are at 3 km depth.

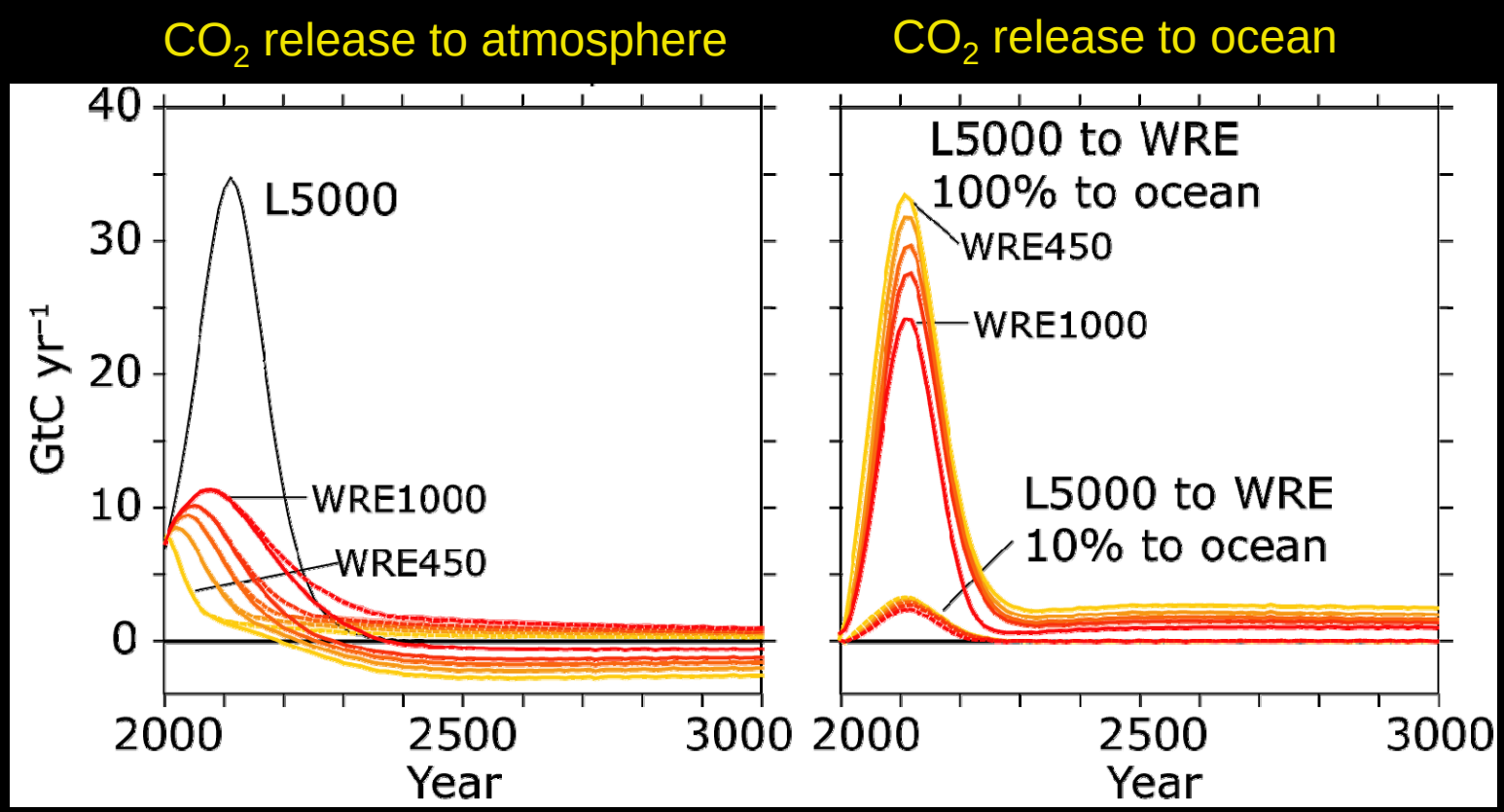
A closer look at L5000, WRE550, and the use of ocean storage to get from one to the other

CO_2 release to atmosphere

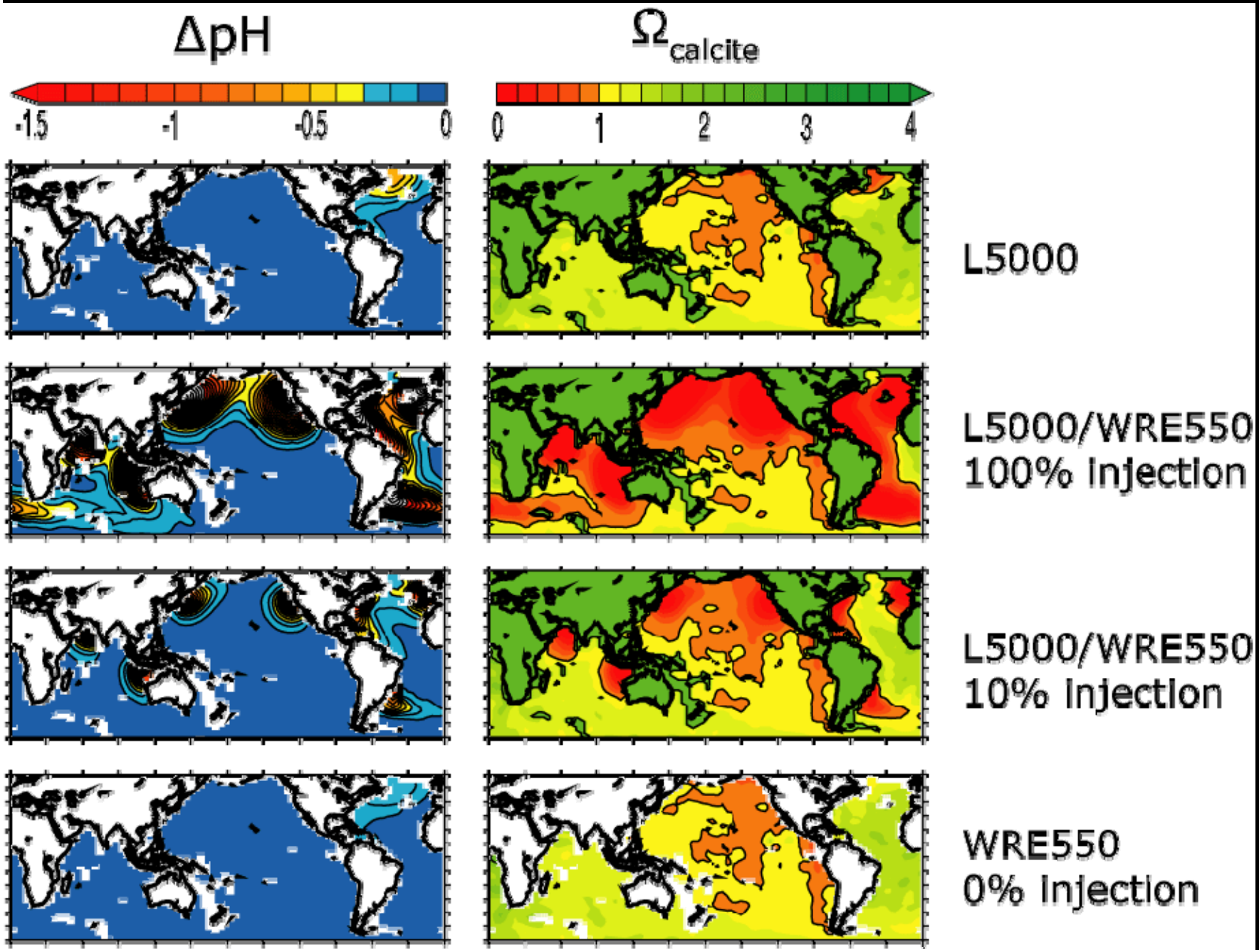
CO_2 release to ocean



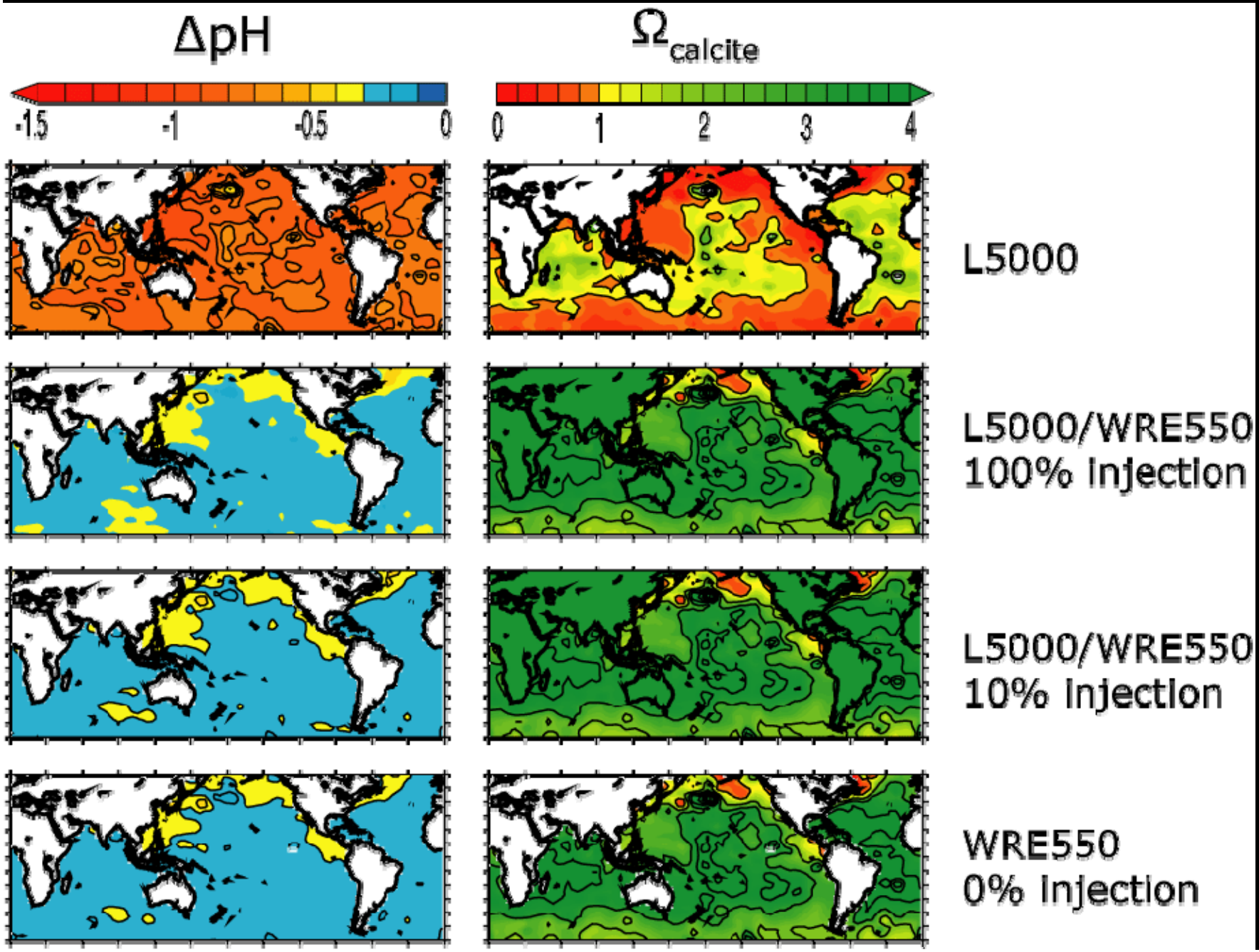
A closer look at L5000, WRE550, and the use of ocean storage to get from one to the other



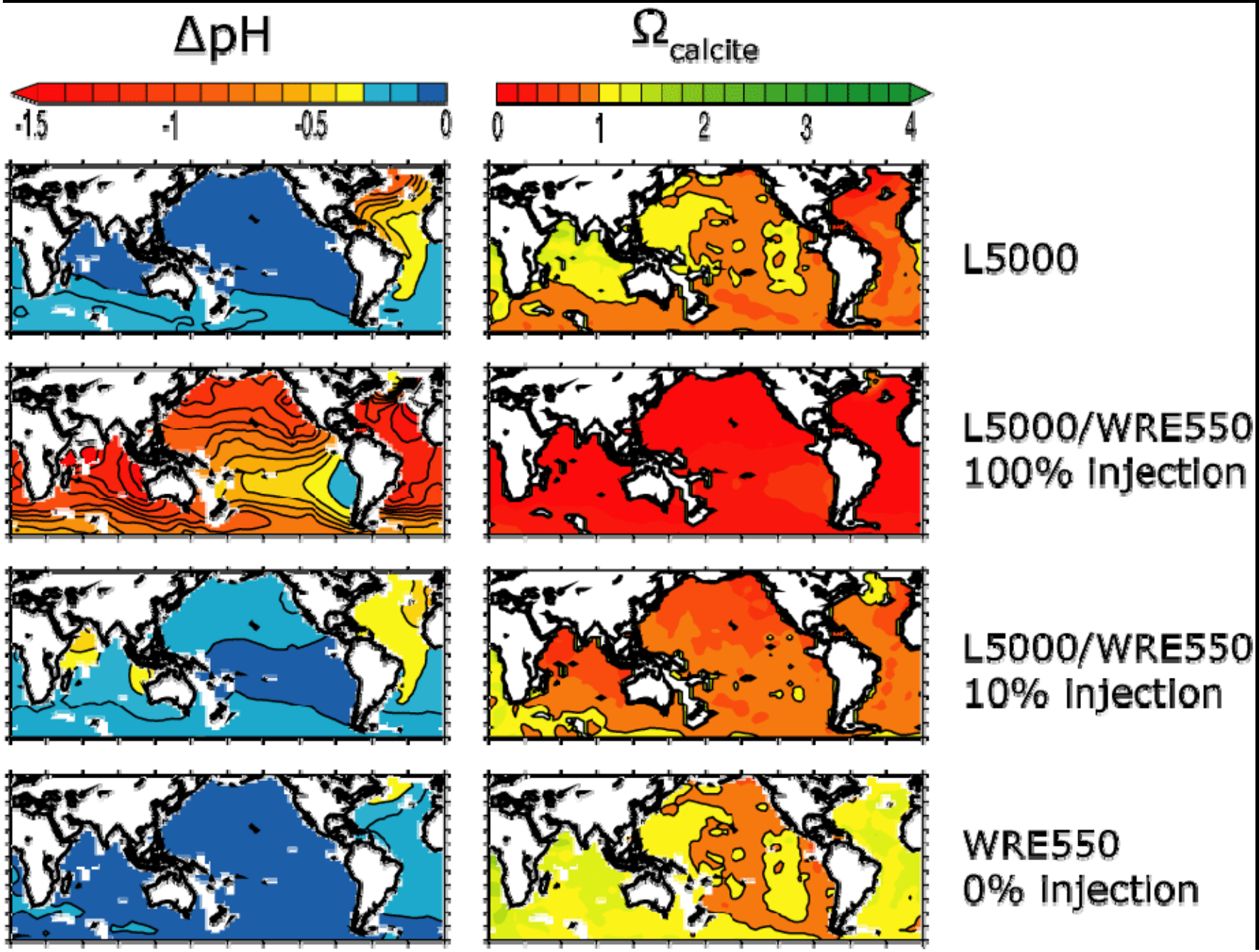
Year = 2100, Depth = 3 km



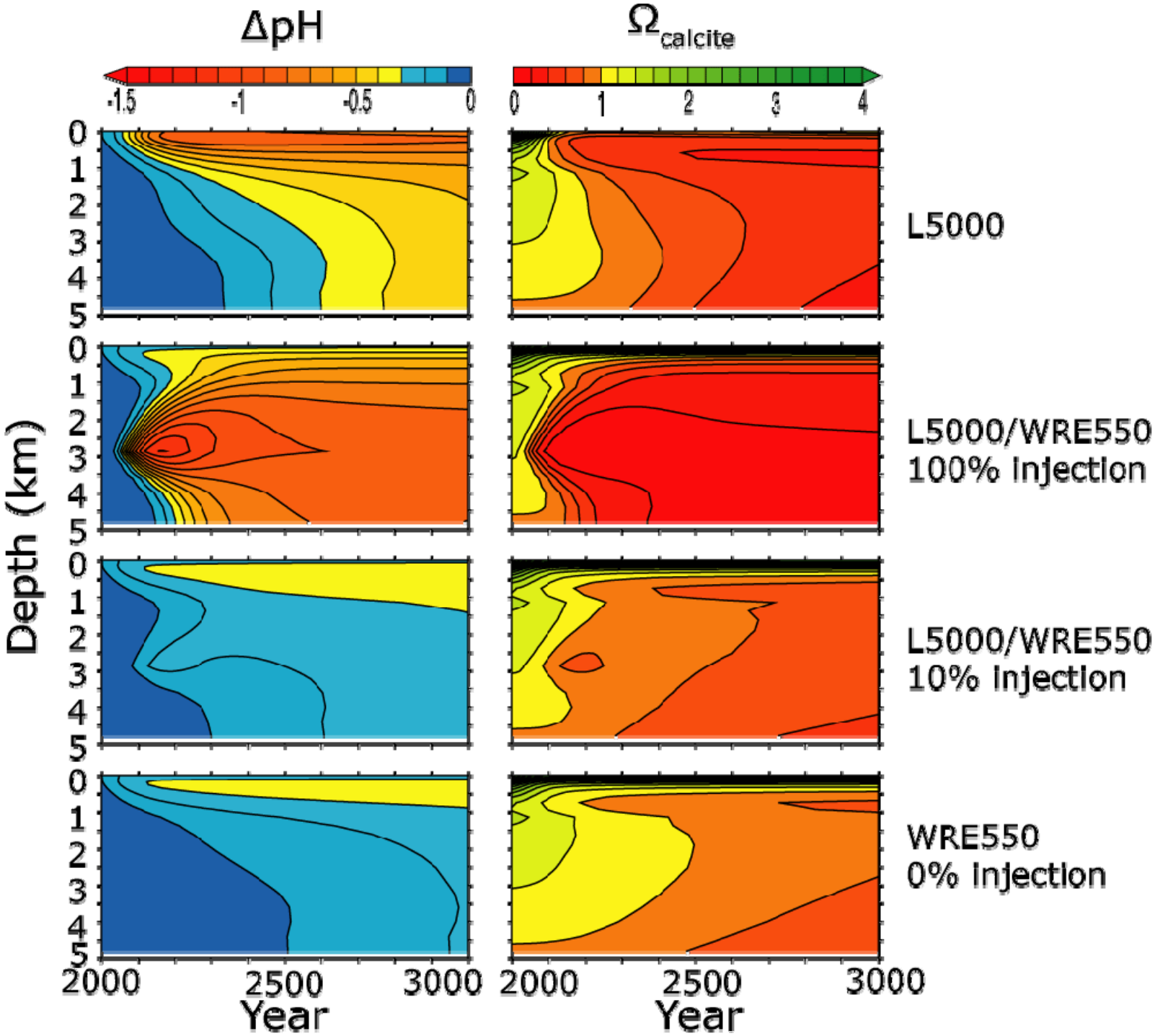
Year = 2300, Depth = surface



Year = 2300, Depth = 3 km



L5000, WRE550, and the use of ocean storage to get from one to the other



Summary (Part II)

- Direct CO_2 injection
  - Cannot solve entire problem
    - Would need active atmospheric CO_2 removal
  - Can contribute to mitigation
    - Does benefit of diminished atmosphere/upper ocean perturbation outweigh increased damage to deep ocean?
      - Is there a better option available?
      - Amount of abatement needed to go from unrestrained emission to WRE1000 is large relative to amount of abatement needed to go from WRE1000 to WRE450.