Earth System Modeling

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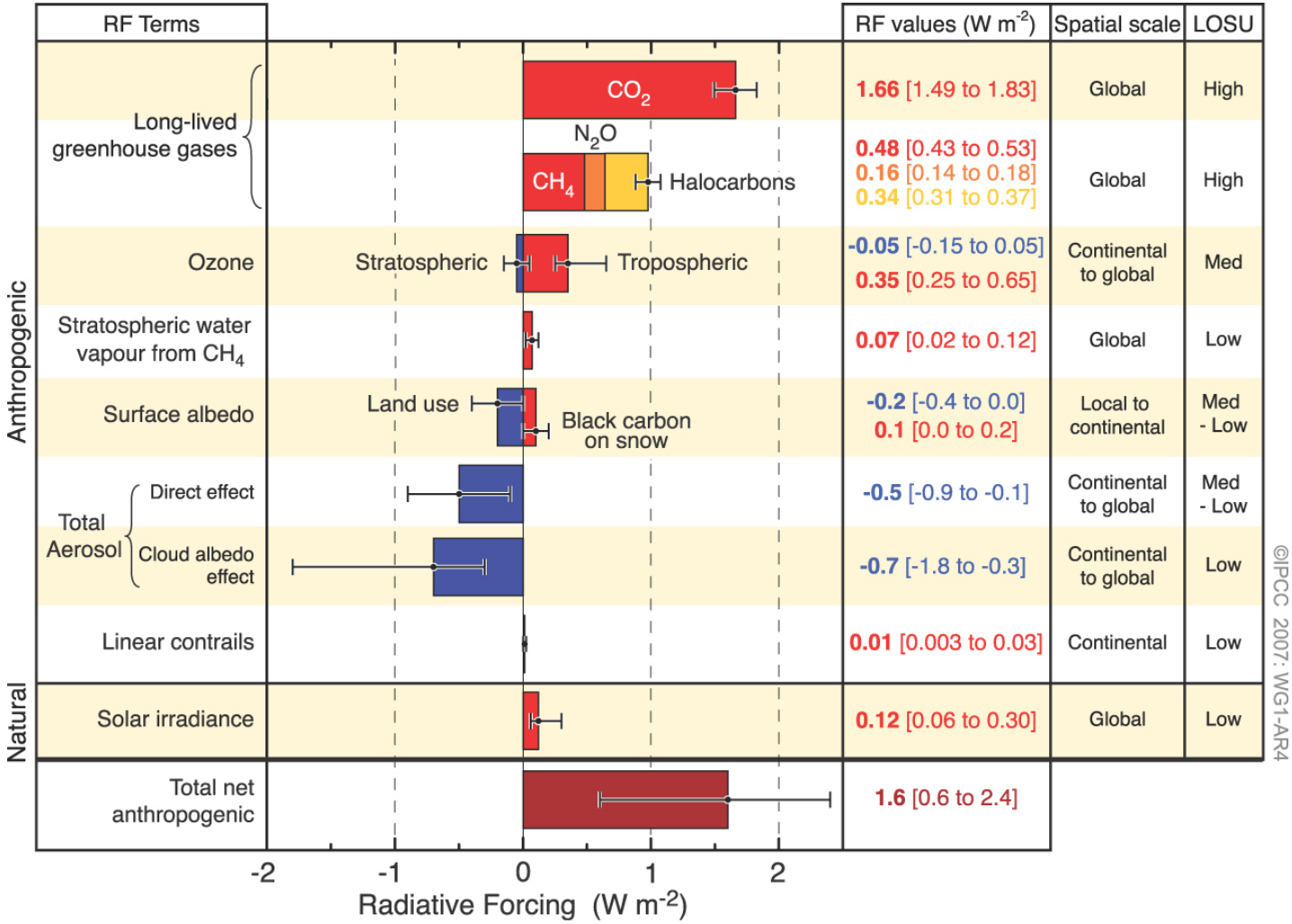
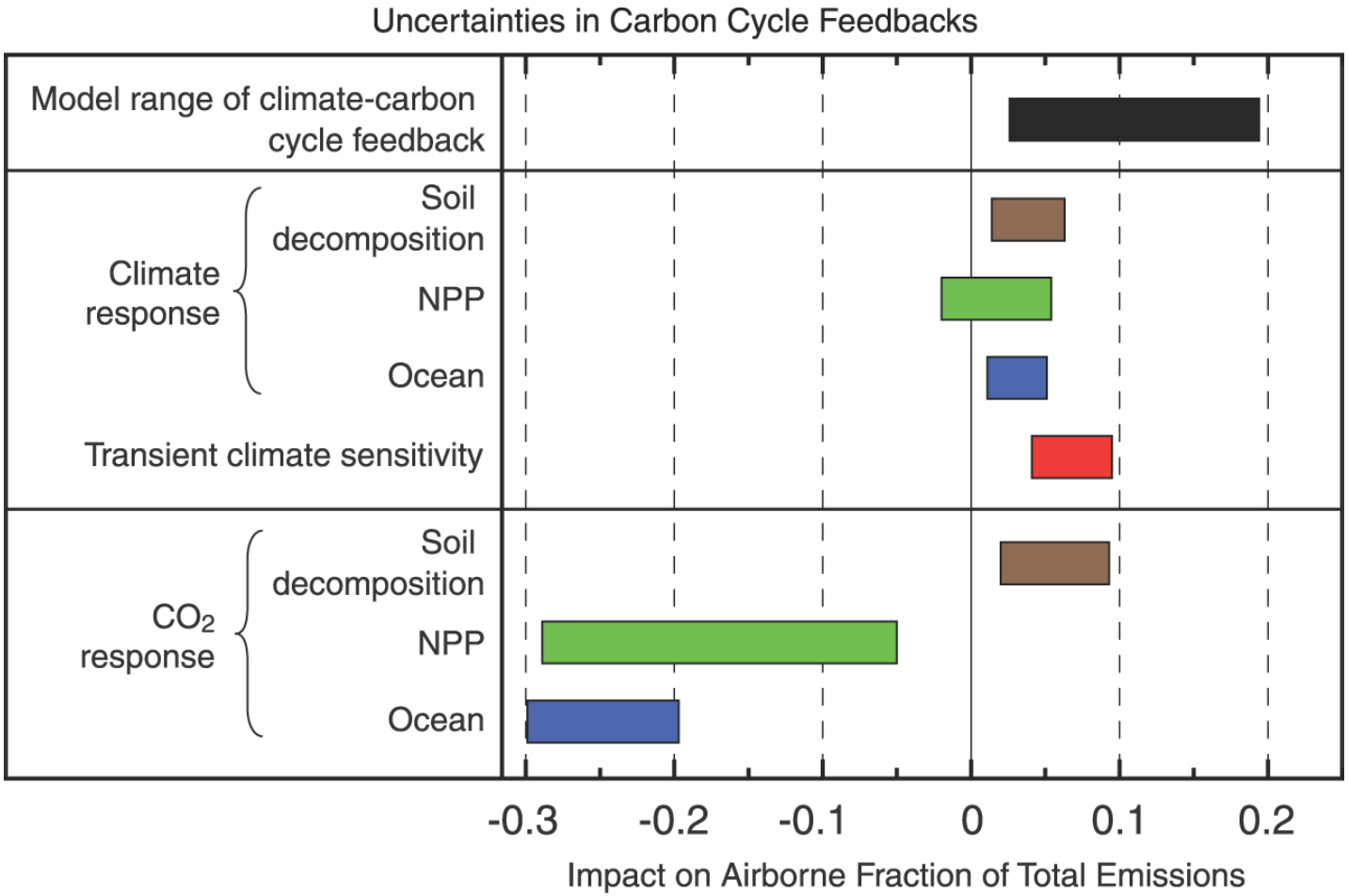
GO Amazon 2014 Workshop, 26-27 July 2011

Major climate change forcing uncertainty: clouds and aerosols



From: Summary for Policymakers, IPCC AR4, WGI, 2007.

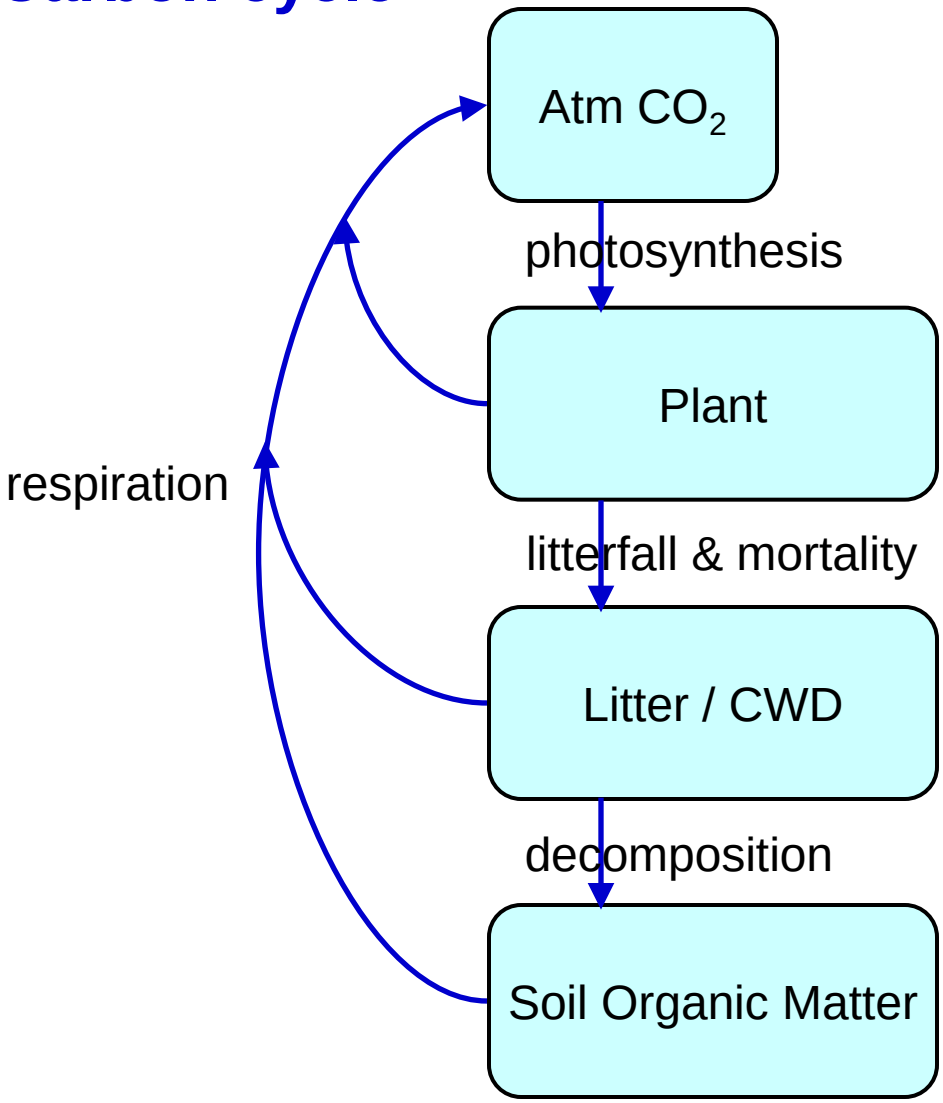
Major climate change feedback uncertainty: carbon and ecosystems



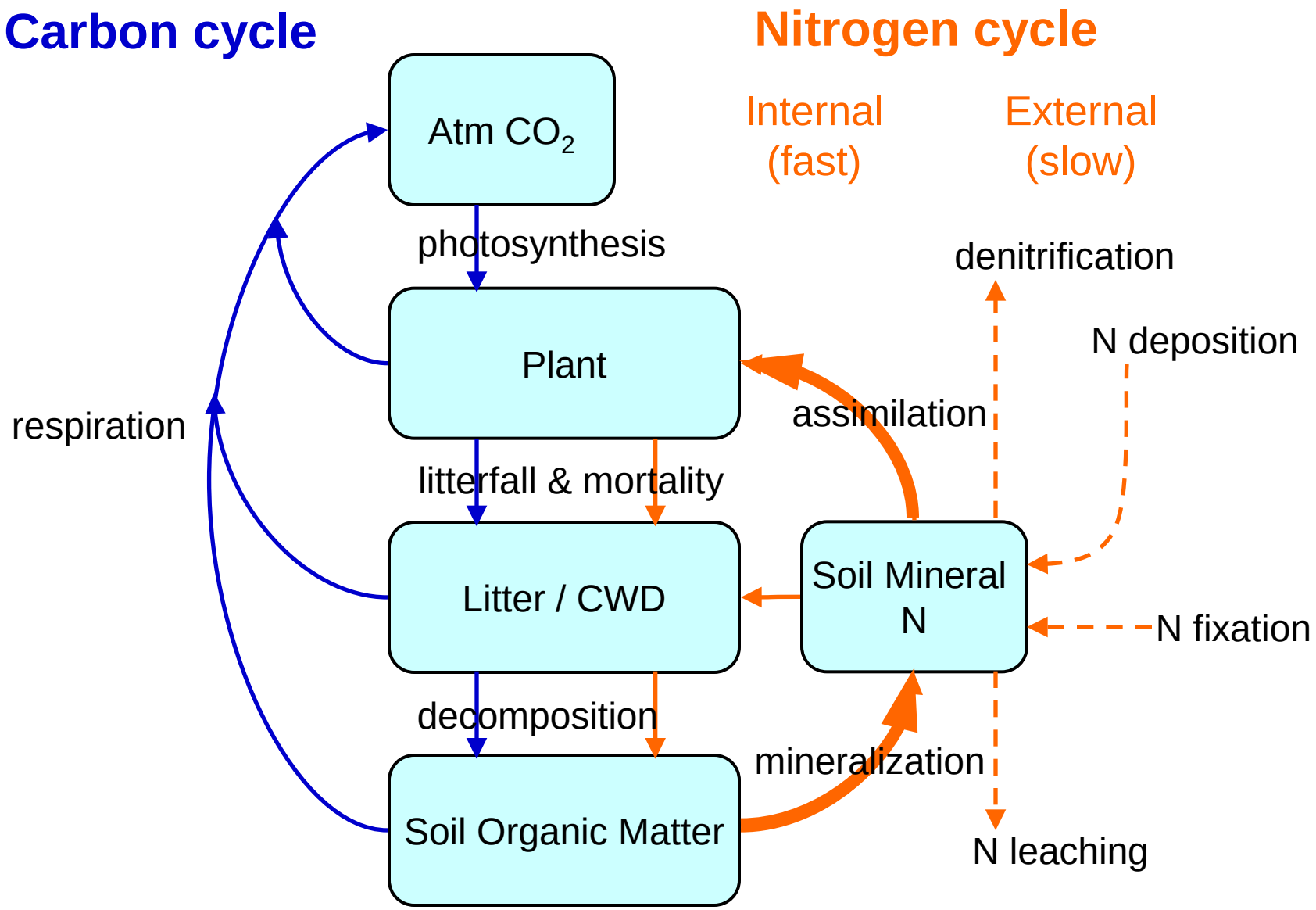
From: Chapter 7, IPCC AR4, WGI, 2007.

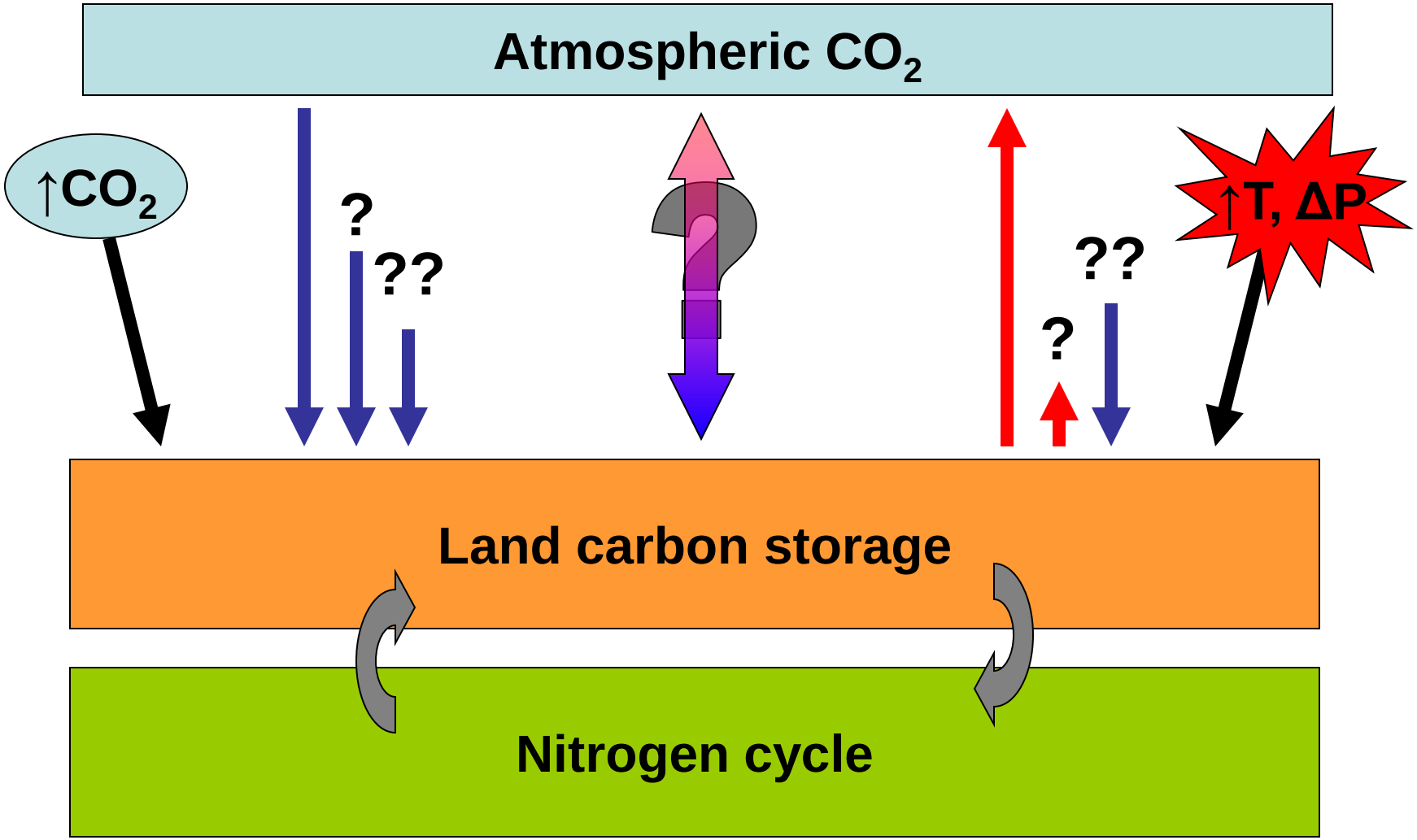
Carbon cycle

Summary of land carbon cycle representation for IPCC AR4 (ca. 2007)



- Strong CO_2 fertilization effect
- Strong positive feedback with warming
- Overall positive gain for the carbon-climate feedback (considering both land and ocean)
- Conclusion: “warming feeds the warming” is a robust result from AR4 generation of climate system models


Carbon cycle
Nitrogen cycle
Internal
(fast)
External
(slow)
Atm CO_2
photosynthesis
Plant
respiration
litterfall & mortality
Litter / CWD
decomposition
Soil Organic Matter
denitrification
N deposition
assimilation
Soil Mineral
N
N fixation
mineralization
N leaching



Components of Climate-Carbon cycle feedback

Climate-carbon cycle feedback analysis: "Does the warming feed the warming?"

$$\textbf{Gain} \approx -\alpha\,(\gamma_L + \gamma_O) / (1 + \beta_L + \beta_O)$$

($K\ ppm^{-1}$) α = transient climate sensitivity to CO_2

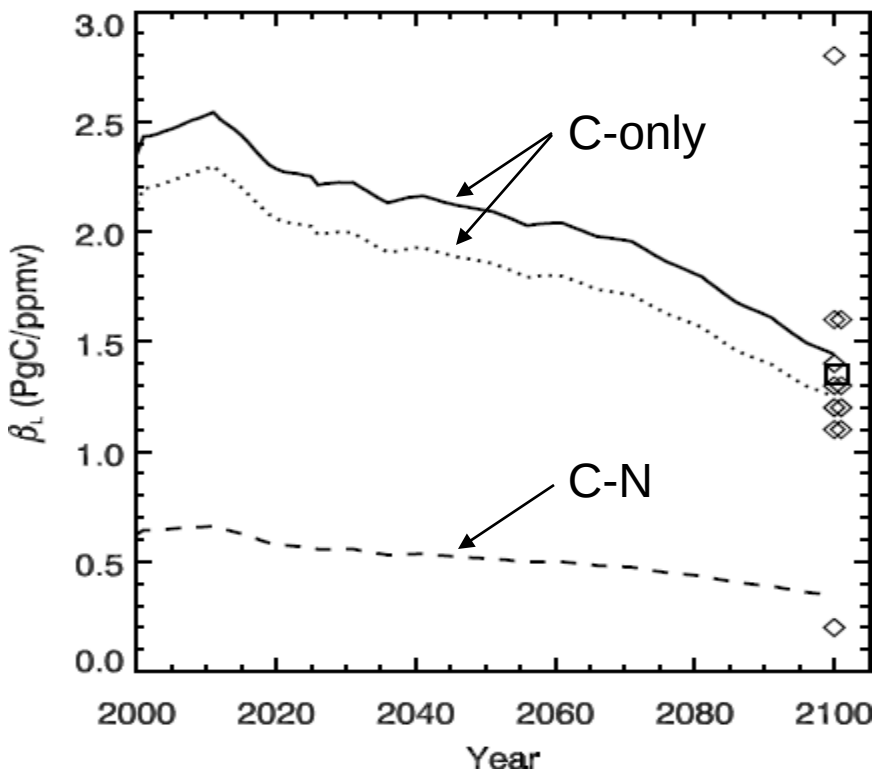
($PgC\ ppm^{-1}$) β = (land or ocean) carbon storage sensitivity to CO_2

($PgC\ K^{-1}$) γ = (land or ocean) carbon storage sensitivity to climate

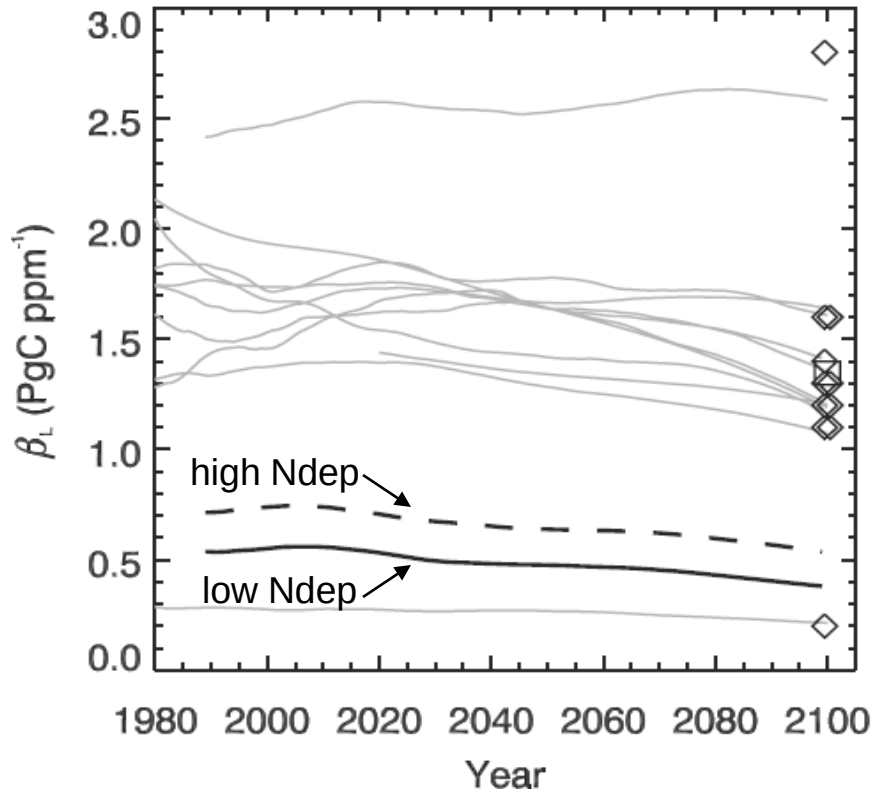
Following Friedlingstein et al. 2006

Land carbon cycle sensitivity to increasing atmospheric CO_2

Offline CLM-CN



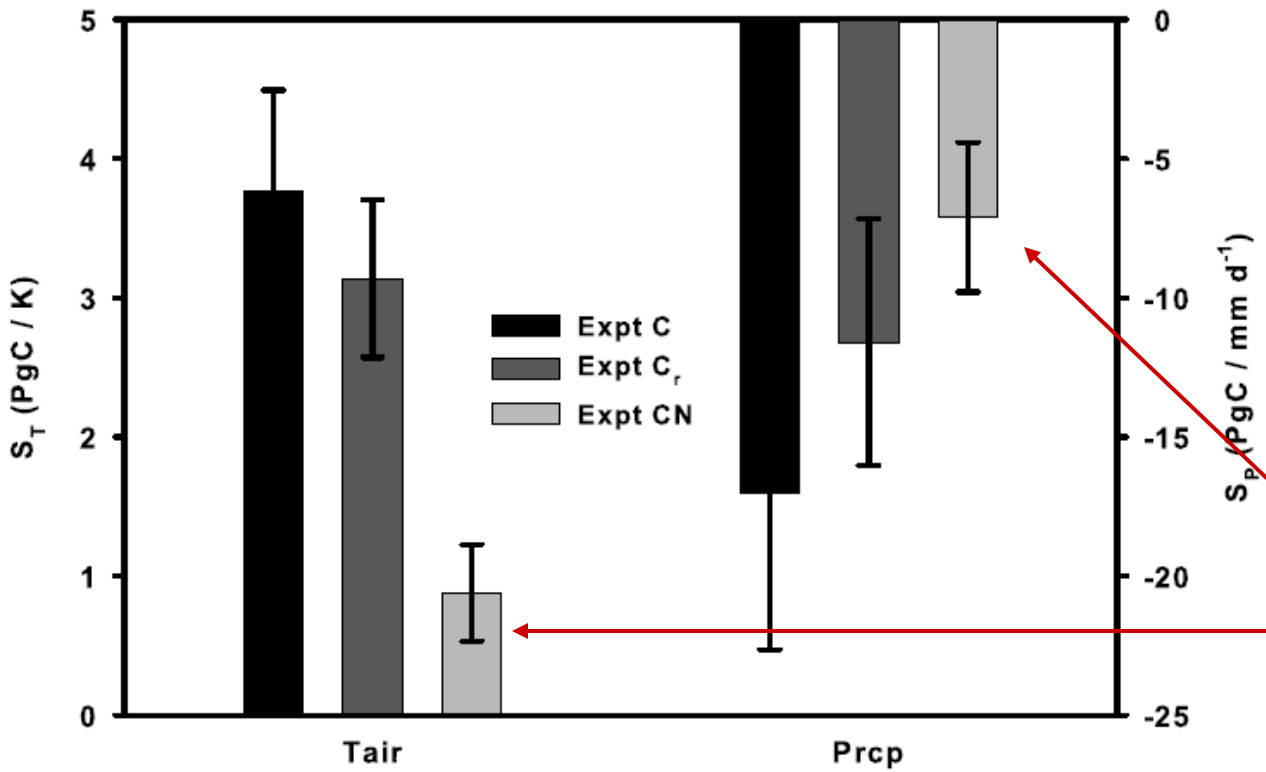
Fully-coupled CCSM3.1



Effect of C-N coupling is to **increase** atmospheric CO_2 by about **150 ppm** by 2100, compared to previous model results

Thornton et al., 2007 (left), and Thornton et al., 2009 (right)

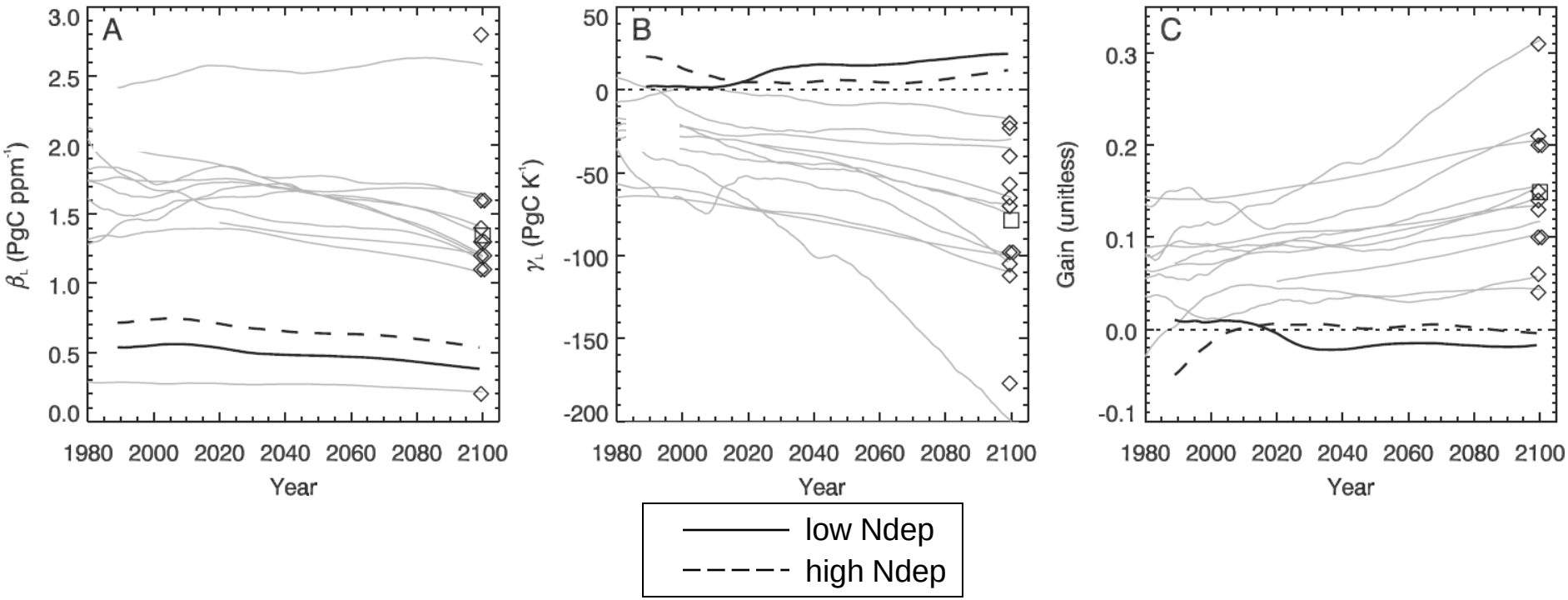
Carbon cycle response to climate variation: interannual time scales (offline model)



Nutrient dynamics suppress the response of carbon cycle to interannual variation in precipitation and temperature

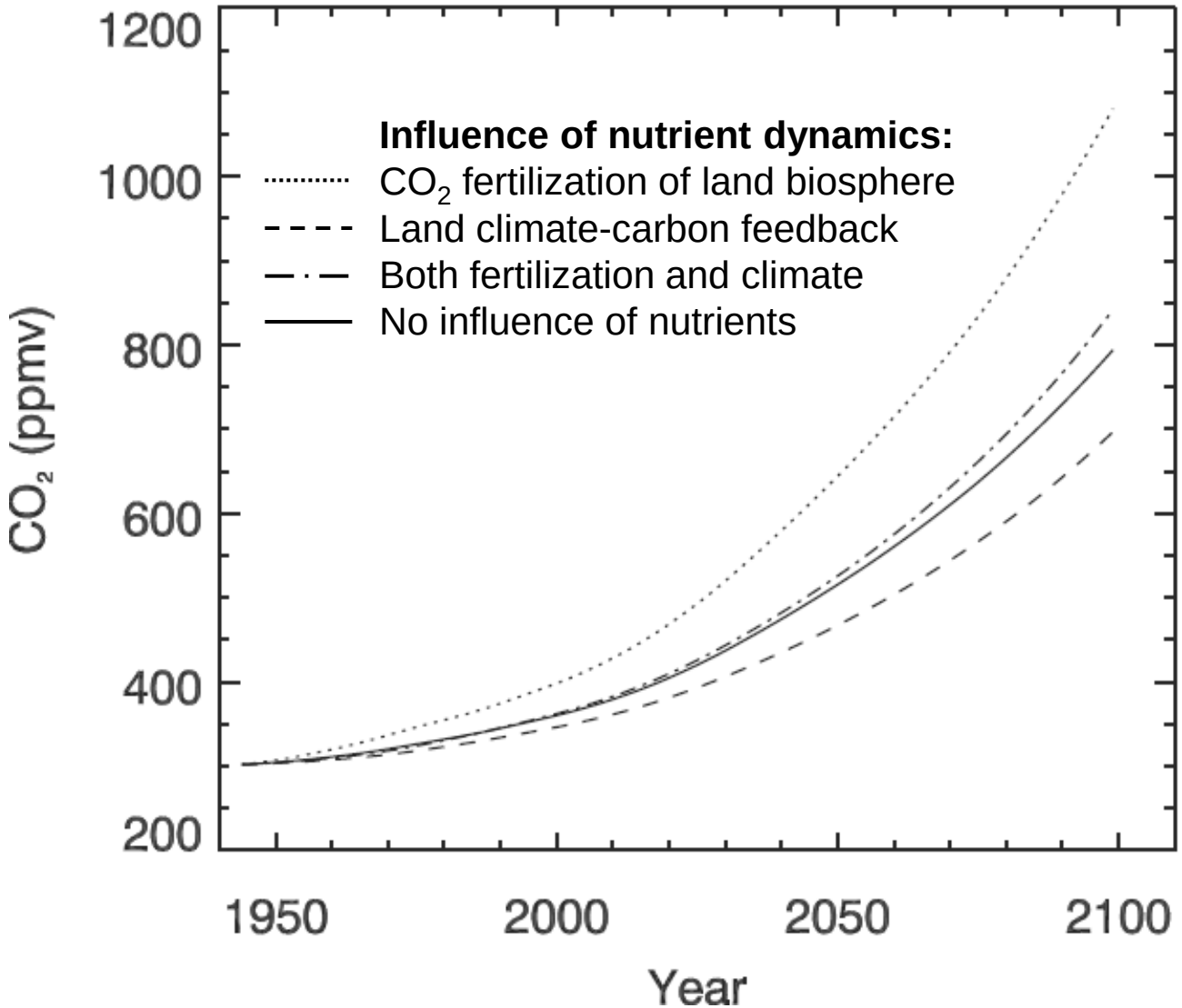
From Thornton et al., 2007

Carbon cycle response to climate variation: century time scales (coupled model)



- Effect of C-N coupling on gamma_land is to **reduce** atmospheric CO2 by about **130 ppm** by 2100, compared to previous model results
- Net climate-carbon cycle feedback gain (including ocean response) is nearly neutral or negative, compared to positive feedback for previous models.

Thornton et al., 2009



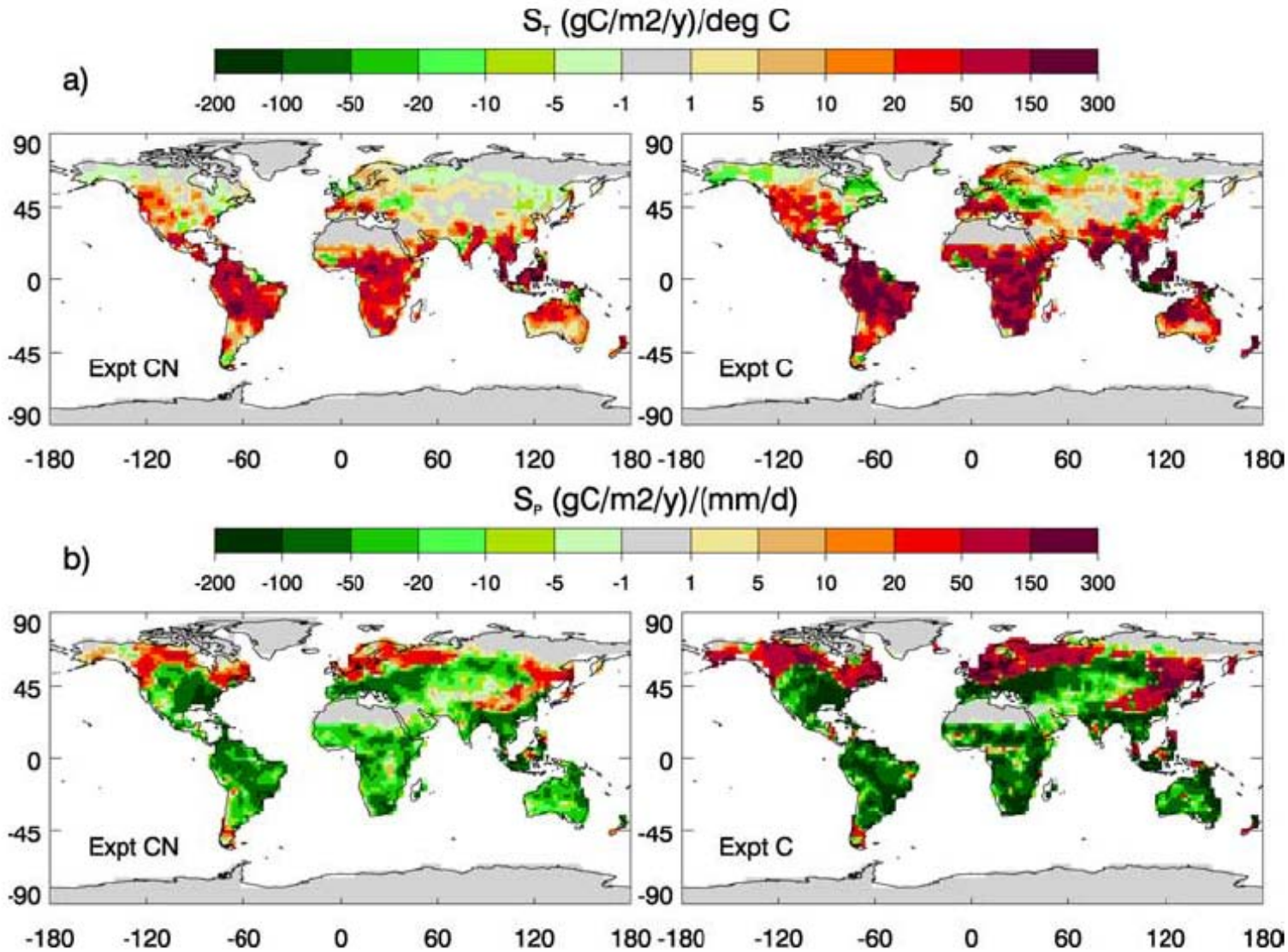
Range of uncertainty: We don't know how these C-N interactions will be expressed over time

- Dynamics not yet adequately constrained by experimentation

From globe to region…

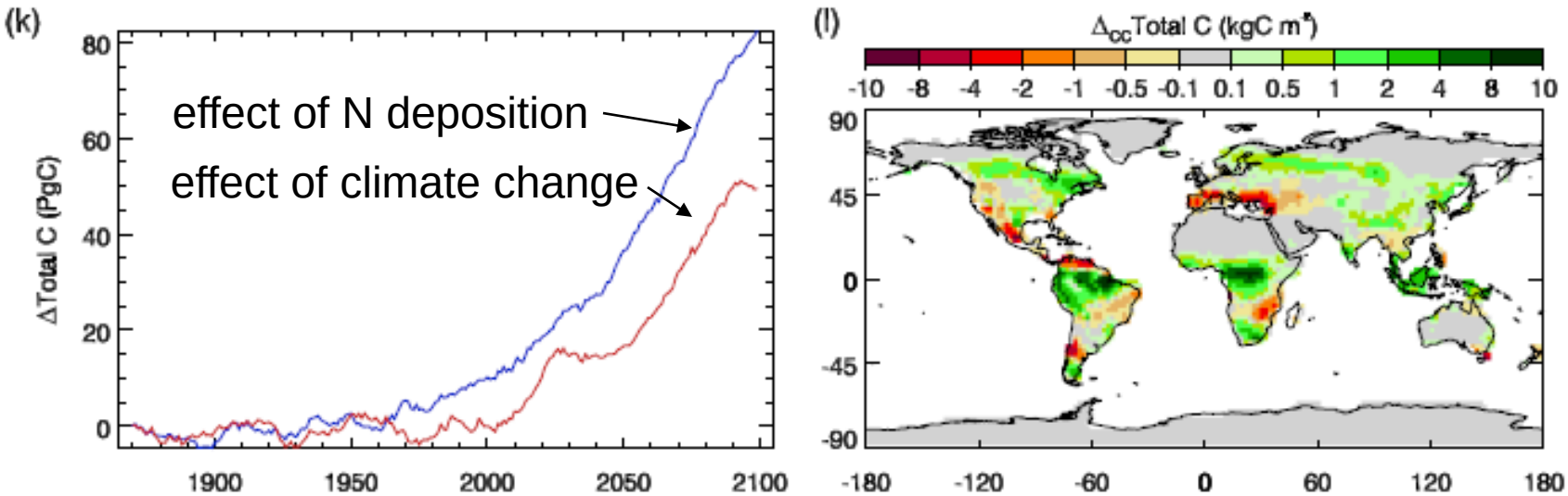
- Carbon-climate feedback uncertainty important at global scale
- Processes driving the feedback play out at the local scale
- Different processes are more/less important in different regions
- Characteristic differences in Arctic, temperate, and tropical ecosystems

Regional variation in carbon cycle sensitivity to interannual climate variability



From Thornton et al., 2007

Regional variation in carbon cycle sensitivity to century-scale climate variability



- A large fraction of predicted carbon uptake due to radiatively forced climate warming over the coming century is occurring in tropical forests.
- The validity of this prediction depends in part on the carbon-nutrient interactions in real tropical forests compared to model representation
- Model includes nitrogen but ignores phosphorus – what are the consequences??

Models need new observational constraints:

- Testable hypotheses for tropical forest feedbacks have been generated, but many remain to be tested
- Collaborations between tropical forest experimentalists and modelers are developing, but more integration is required
- Some model-data intercomparison efforts underway (e.g. LBA MIP), but models need to be evaluated against many independent observational constraints to reduce uncertainty
- Some recent examples, and a suggestion…

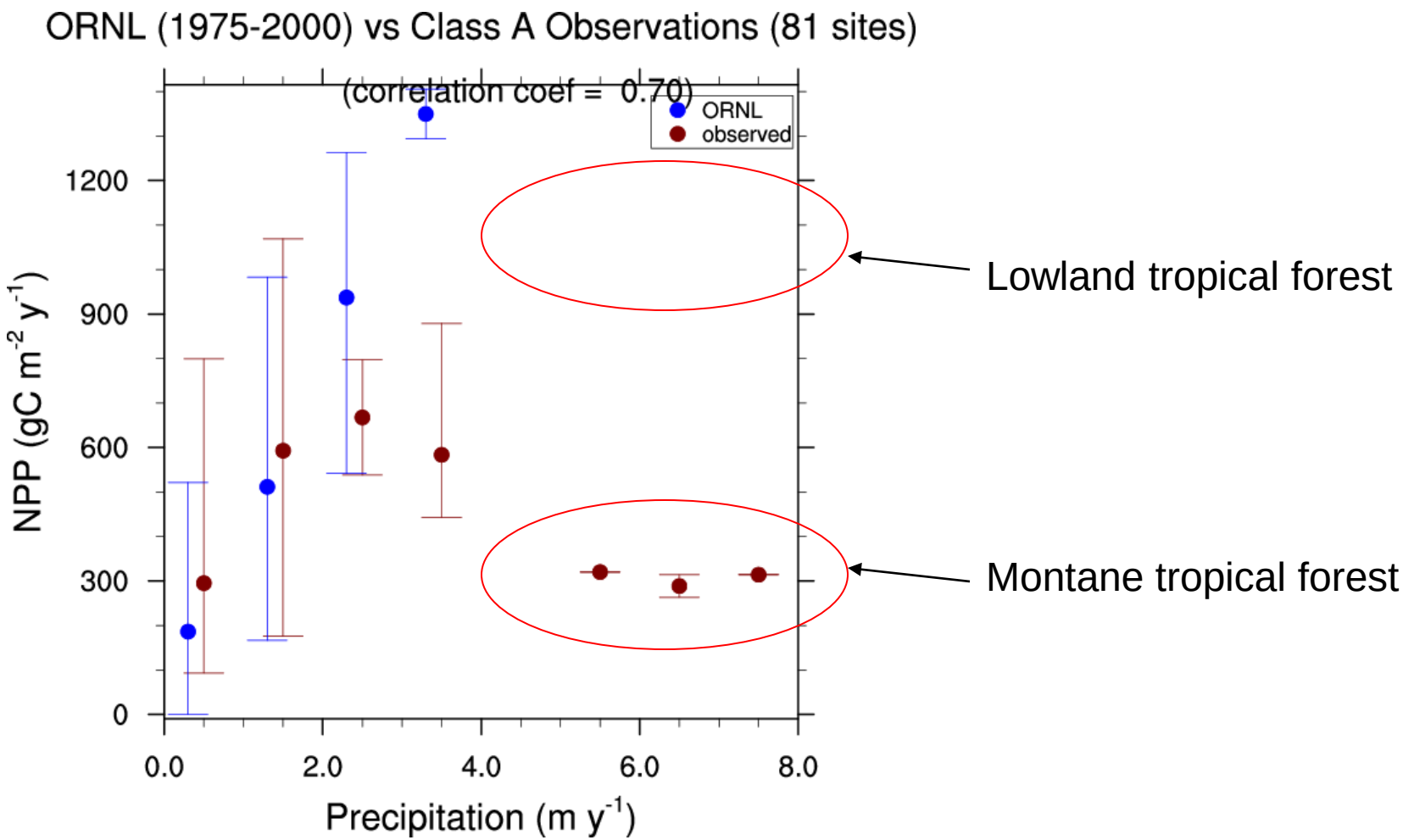
NCEAS tropical carbon-nutrient workshop

- Organizers:Cory Cleveland, Alan Townsend
- Synthesis of existing datasets
- Synthesis of previous and current experimentation
- Integration with models
- Development of new ideas for experimentation/modeling collaborations

ANPP database from NCEAS activity (P. Taylor, W. Wieder)

- Adding data from lowland tropical forest changes the shape of NPP vs. precipitation diagnostic (C-LAMP EMDI metric).
- Relating decomposition rates to ANPP and climate metrics.
- Higher estimate of tropical forest NPP than derived from either MODIS or Schuur-EMDI analysis.
- Evaluation of microbial respiration as a fraction of soil respiration.

Potential Update to EMDI NPP (C-LAMP)



Litter removal/addition experiment

- Ed Tanner, Emma Sayer, Cambridge Univ.
- Barro Colorado Island, Panama. Moist lowland tropical forest. Smithsonian Tropical Research Institute
- Paired-plot study, modifying nutrient dynamics by removing litter from one plot and placing it on adjacent plot.
- Manipulation for six years
- Lower production in removal vs. addition plots

“Stadium lights” experiment

- Eric Graham et al., PNAS, 2002.
- Parque Natural Metropolitano, near Panama City. Late successional lowland forest.
- Added light during cloudy periods for two canopy trees, compared to two control trees.
- Increased sap flow, increased photosynthetic potential, leaf carbohydrate concentrations, branch growth, and reproductive growth for illuminated branches.
- Suggests that interannual variability in tropical forest carbon flux may be influenced by radiation

Other experiments/datasets

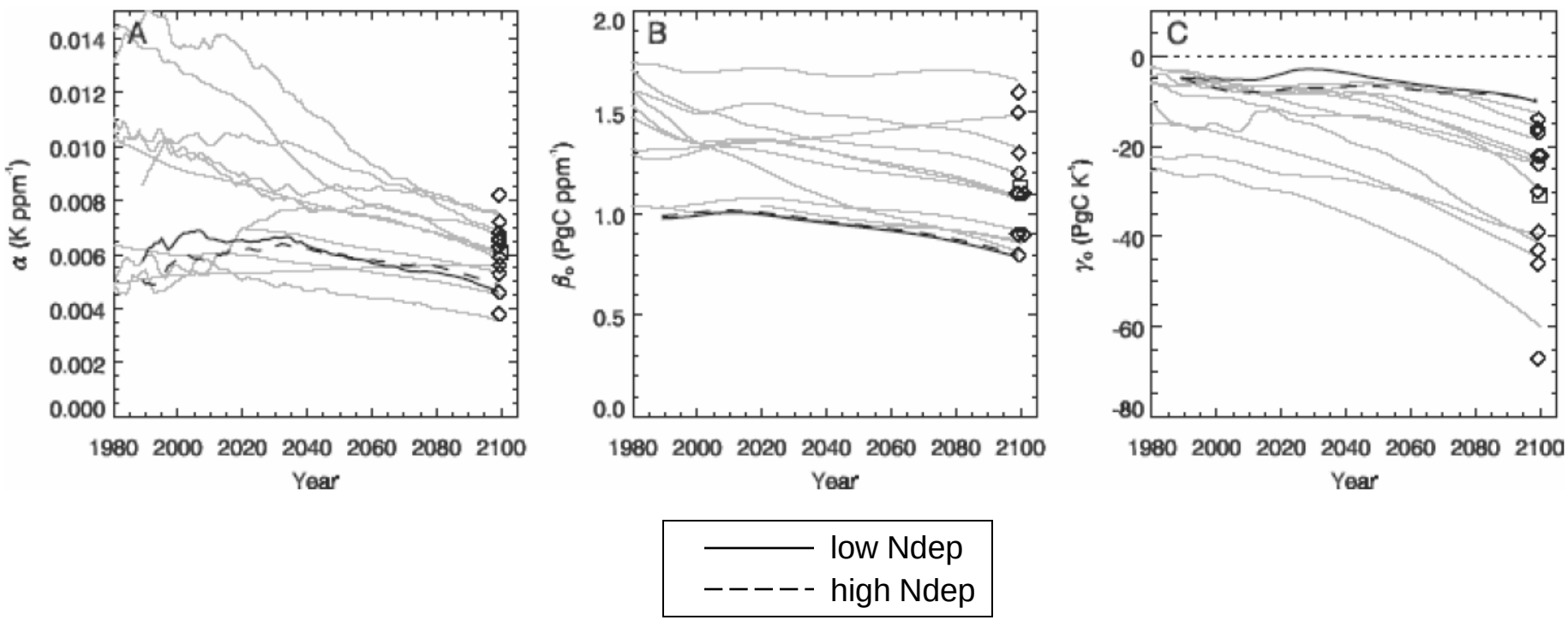
- N and P fertilization studies (BCI, Costa Rica)
- Canopy height (several sources)
- Biomass, mortality, NPP from RAINFOR

Model/data integration approach

- Develop global P database (Xiaojuan Yang, Mac Post)
- Implement C-N-P dynamics in global models
- Evaluate new model against observed ANPP, decomposition rates, biomass, belowground C stocks
- Replicate litter removal/addition experiment in models
- Replicate “stadium lights” experiment in models
- Try to convince experimentalists/funders to get a (soil?) warming experiment started in moist tropical forest.

extra slides…

Atmosphere and ocean components of climate-carbon cycle feedback



Thornton et al., 2009