Interactions of Climate Change with Acidic Deposition in a Forest Watershed over the 21st. Century Using a Dynamic Biogeochemical Model (PnET-BGC)

NADP Annual Meeting and Scientific Symposium
Saratoga Springs, New York
October 6 – 8, 2009

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Outline

- Introduction
  - Global Climate Models / Downscaling
  - Future Scenarios
  - Model PnET-BGC
- Objectives/Methods
- Results
  - Without CO_2 Fertilization
  - With CO_2 Fertilization
  - Atmospheric Deposition and Climate Change
- Conclusion
- Future Research Plans
- Question and Answer

Global Climate Models

Atmosphere-ocean general circulation models (AOGCMs):

➔Large, three-dimensional coupled models that incorporate the latest understanding of the physical processes at work in the atmosphere, oceans, and Earth's surface.

Output➔ Geographic grid-based projections of precipitation, temperature, solar radiation, cloud cover, humidity, and a host of other climate variables at daily, monthly, and annual scales. There are 17 models from different countries but we used only 3:

- **HadCM3: The United Kingdom Meteorological Office's Hadley Centre Climate Model, version 3,**
- **GFDL CM2.1: The U.S. National Atmospheric and Oceanic Administration's Geophysical Fluid Dynamics Laboratory, and**
- **PCM: The National Center for Atmospheric Research's Parallel Climate Model.**

Downscaling AOGCMs

With a course resolution (80 to 400 km), AOGCMs are unable to predict detailed regional climate change, therefore:

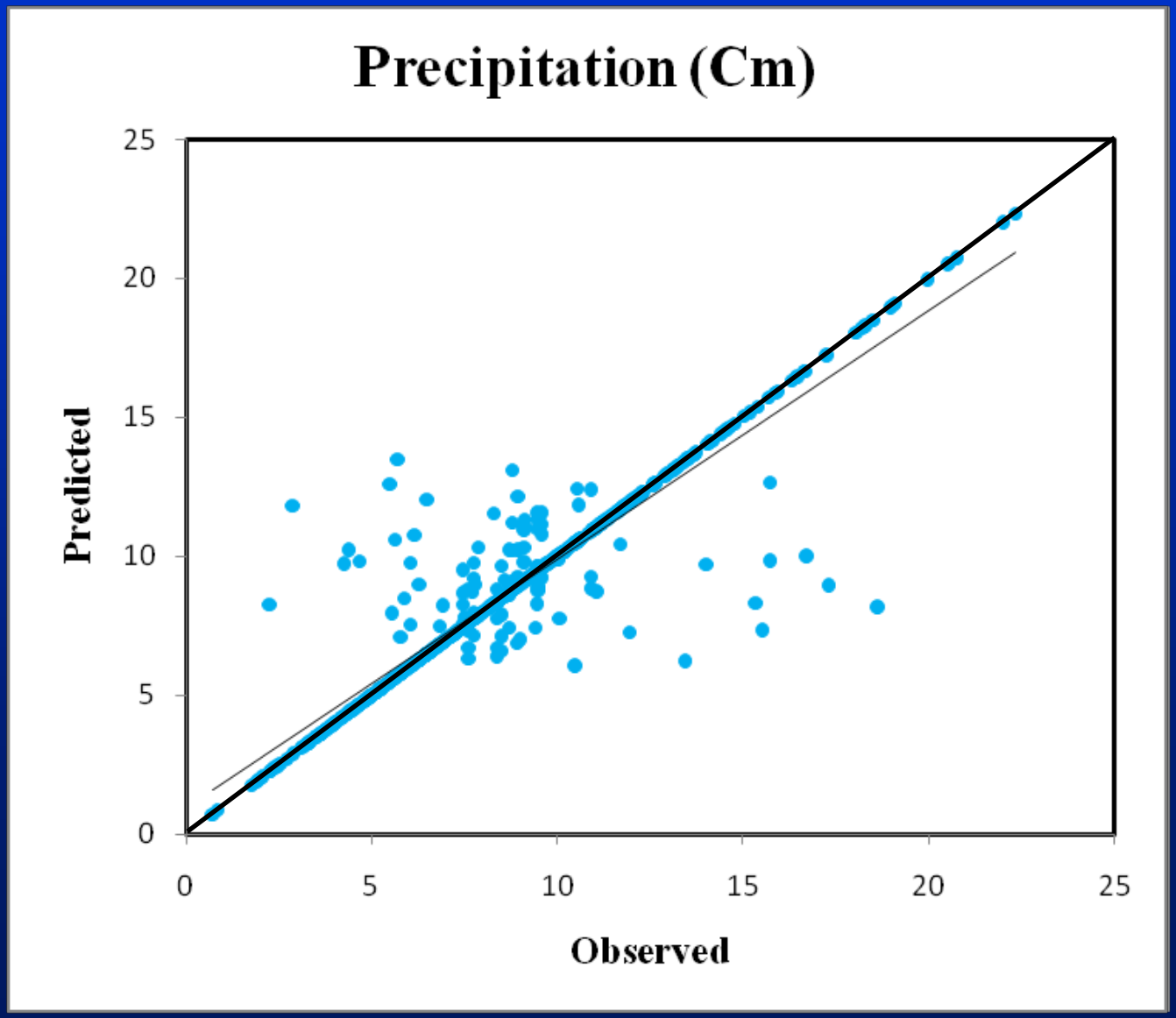
Coarse-resolution global climate model outputs ➔ Downscaled to high-resolution local temperature and precipitation projections.

Downscaling methods:

- **Dynamical: Use physically based models with finer spatial resolution than the original global model, e.g. Regional Climate Model (RCM).**
- **Statistical (SD): Use statistical relationships (usually some form of regression equation) where a fine-scale predictand is related to a set of course-resolution predictors.**

Predicted* vs. observed climate for 1960-2007

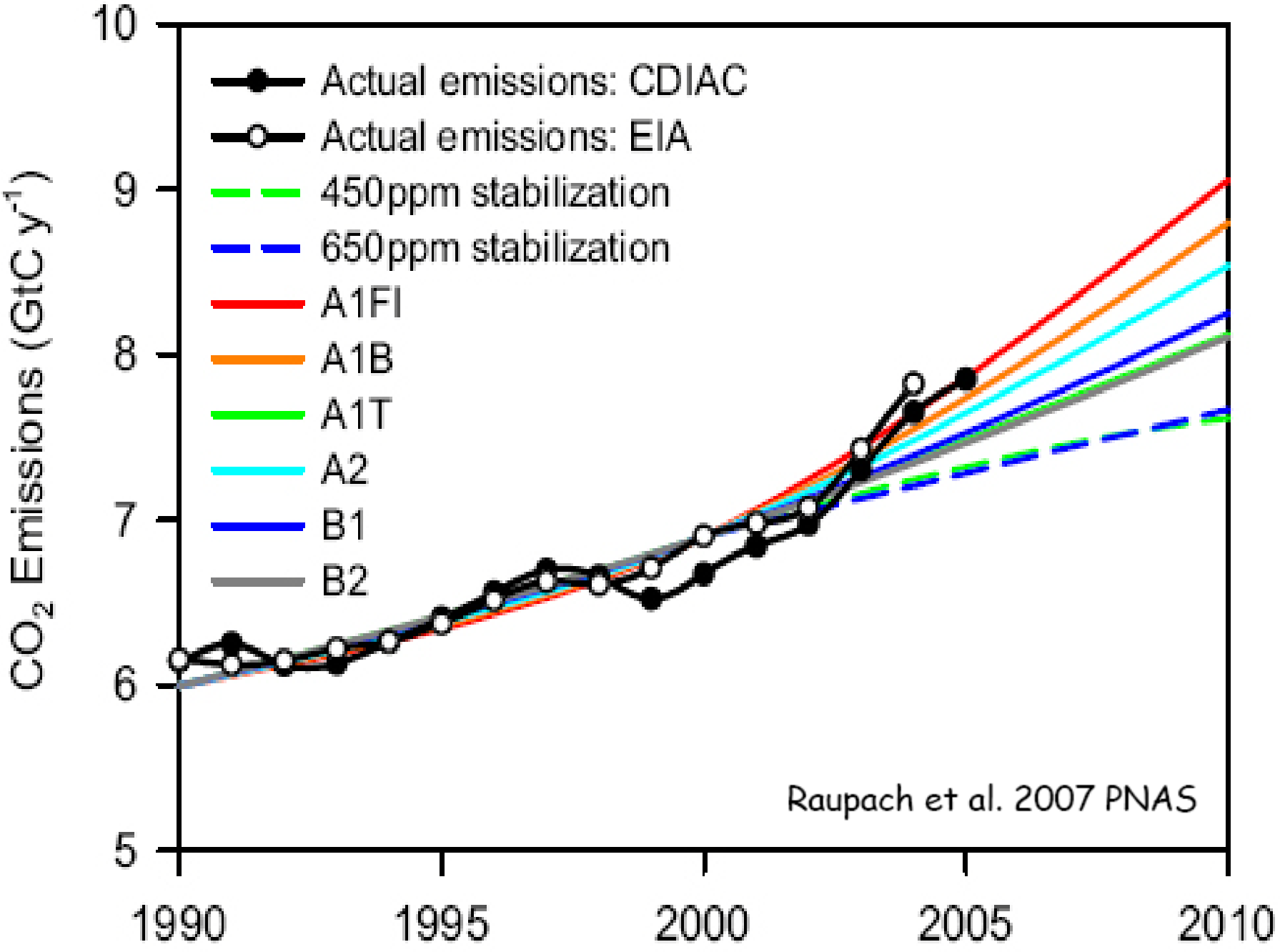
*Average of all 6 Scenarios

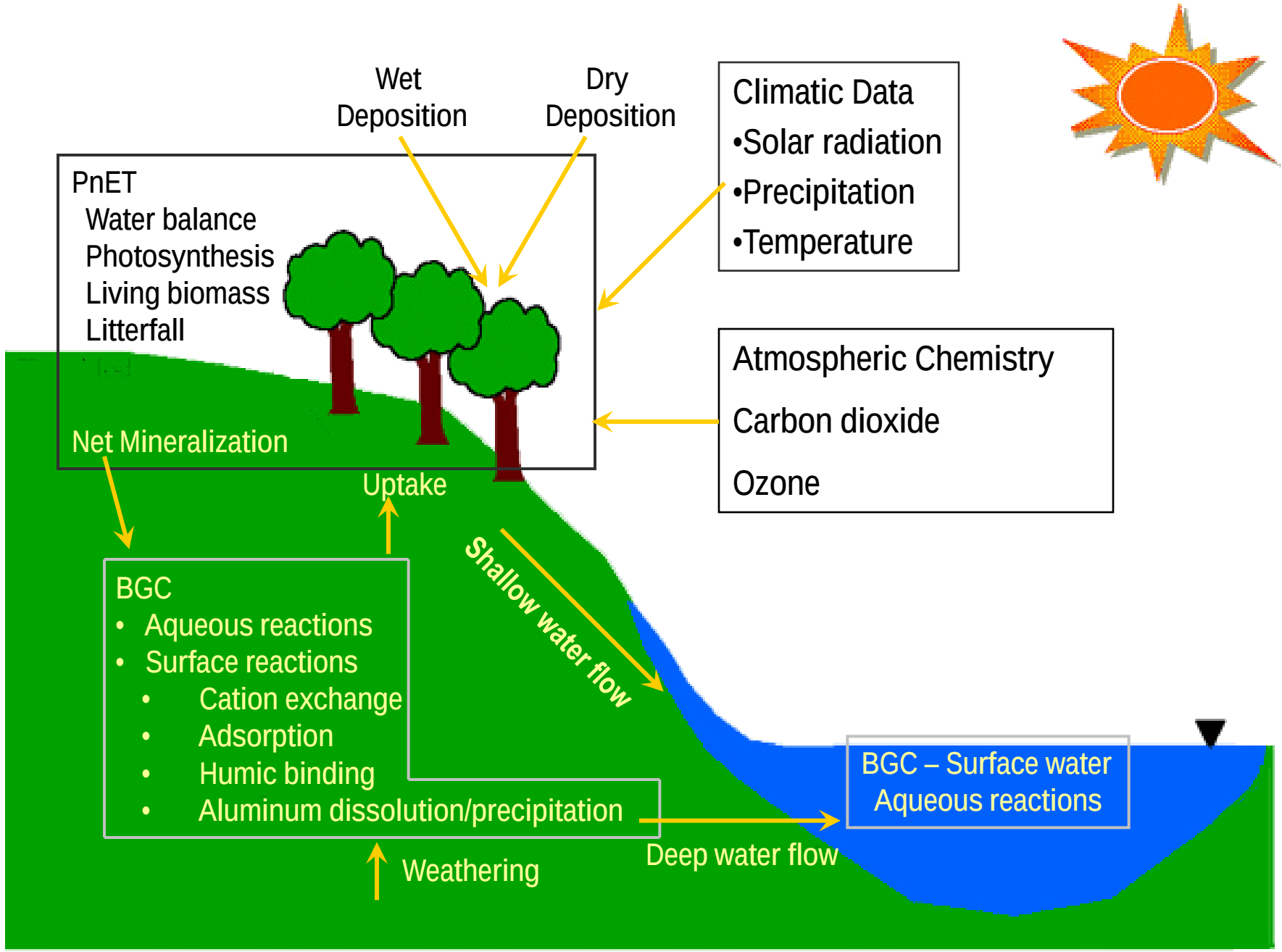


Future Scenarios

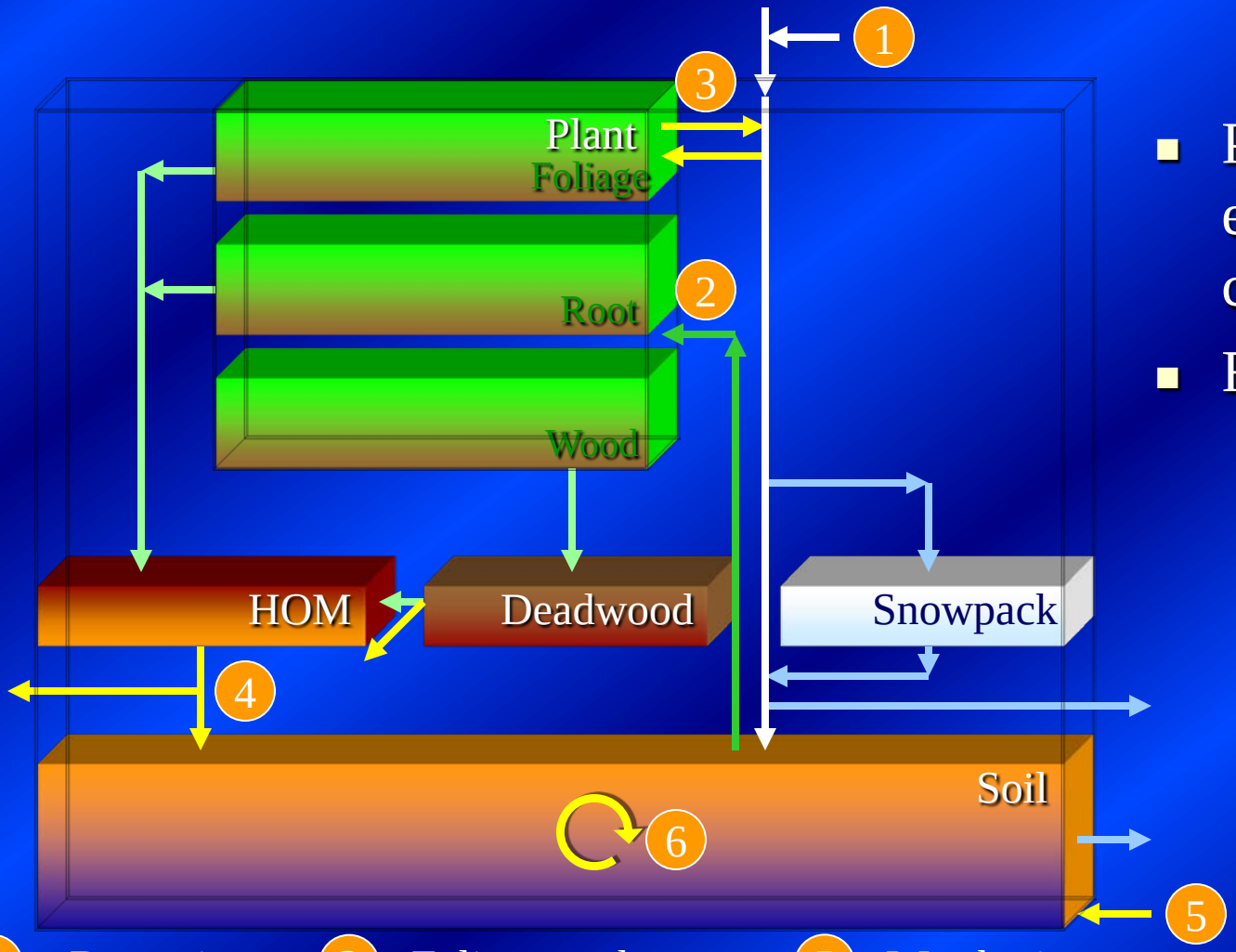
To estimate future changes in climate, we use:

- **Global emissions scenarios that project future emissions resulting from alternative pathways of population growth, energy use, economic development, and technology.**
- **IPCC AR4 (2007)➔Future emissions scenario estimates known as SRES (Special Report on Emissions Scenarios)**
  - **SRES A1fi (fossil fuel-intensive) and B1 scenarios ➔ possible higher (970 ppm) and lower (550 ppm) emissions choices, for future scenarios (2008-2099).**


Actual emissions: CDIAC
Actual emissions: EIA
450ppm stabilization
650ppm stabilization
A1FI
A1B
A1T
A2
B1
B2
CO_2 Emissions ($GtC\ y^{-1}$)
10
9
8
7
6
5
1990
1995
2000
2005
2010
Raupach et al. 2007 PNAS


Wet Deposition
Dry Deposition
Climatic Data
•Solar radiation
•Precipitation
•Temperature
PnET
Water balance
Photosynthesis
Living biomass
Litterfall
Net Mineralization
Uptake
Atmospheric Chemistry
Carbon dioxide
Ozone
Shallow water flow
BGC
• Aqueous reactions
• Surface reactions
• Cation exchange
• Adsorption
• Humic binding
• Aluminum dissolution/precipitation
BGC – Surface water
Aqueous reactions
Deep water flow
Weathering

PnET-BGC in detail - Elements



- Pools with element composition
- Fluxes driven by
  - Atmospheric deposition
  - Water fluxes
  - Biomass fluxes
  - Pool composition
  - Transformation processes

1 Depostion
2 Plant uptake
3 Foliage exchange
4 Mineralization
5 Weathering
6 Soil & soil solution interaction / nitrification

Climate Projections (HWF)

	1970-1999	Mean Change 2070-2099					
		PCM B1	PCM A1	Had B1	Had A1	GFDL B1	GFDL A1
Temperature (ºC)	4.4	+1.4	+3.2	+2. 9	+6.3	+2.1	+4.7
Annual Precipitation (cm)	101	+21.2	+15.4	+25.2	+30.4	+20.3	+21.8
PAR (mmol m^{-2} s^{-1})	618	+21.0	-18.3	+13.1	-4.9	-22.5	+18.8

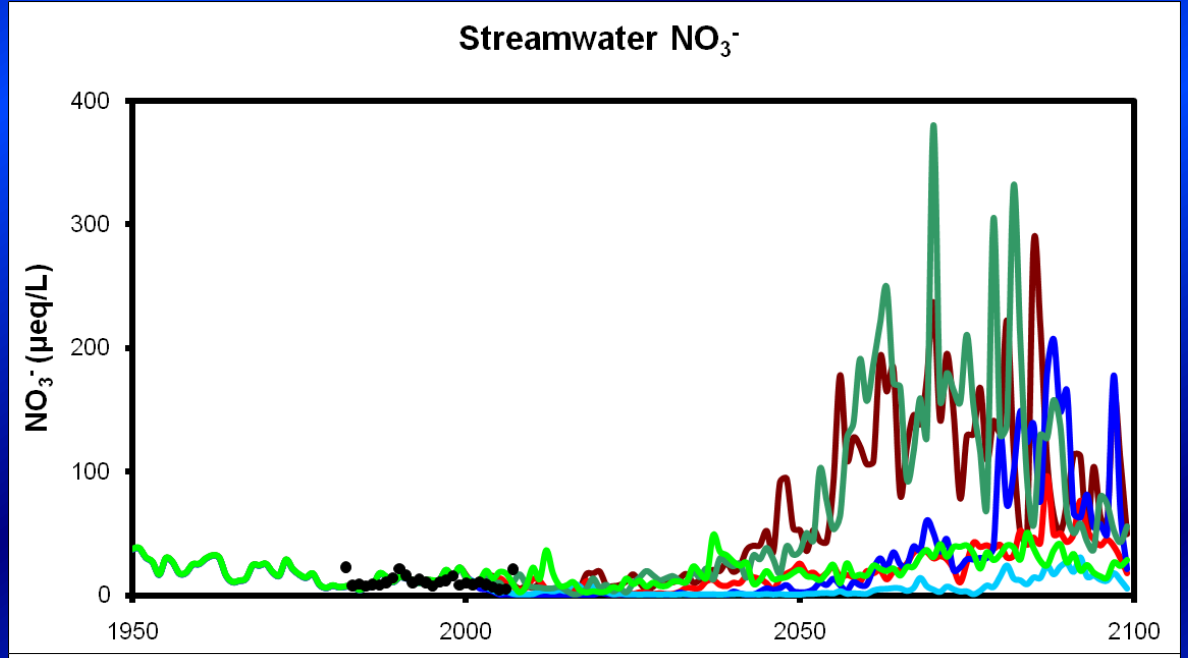
Low CO_2 = 550 ppm by 2100

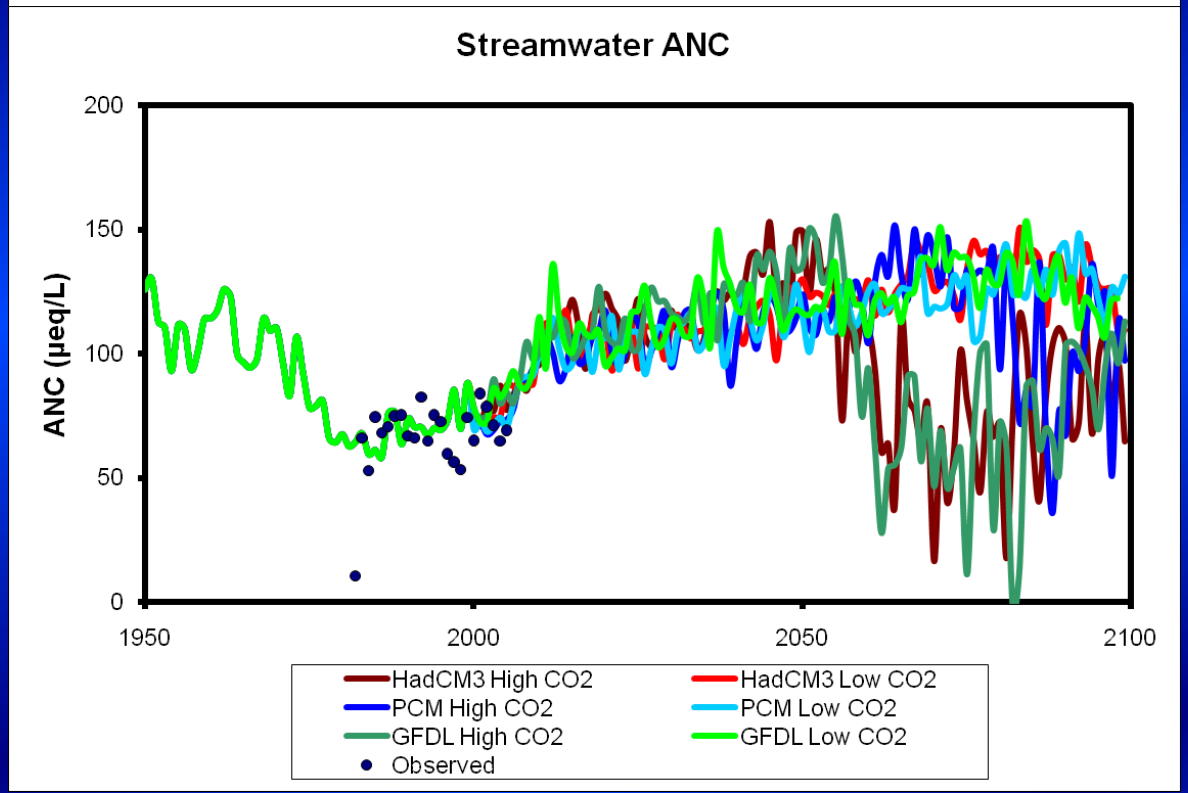
High CO_2 = 970 ppm by 2100

Current CO_2 = 370 ppm

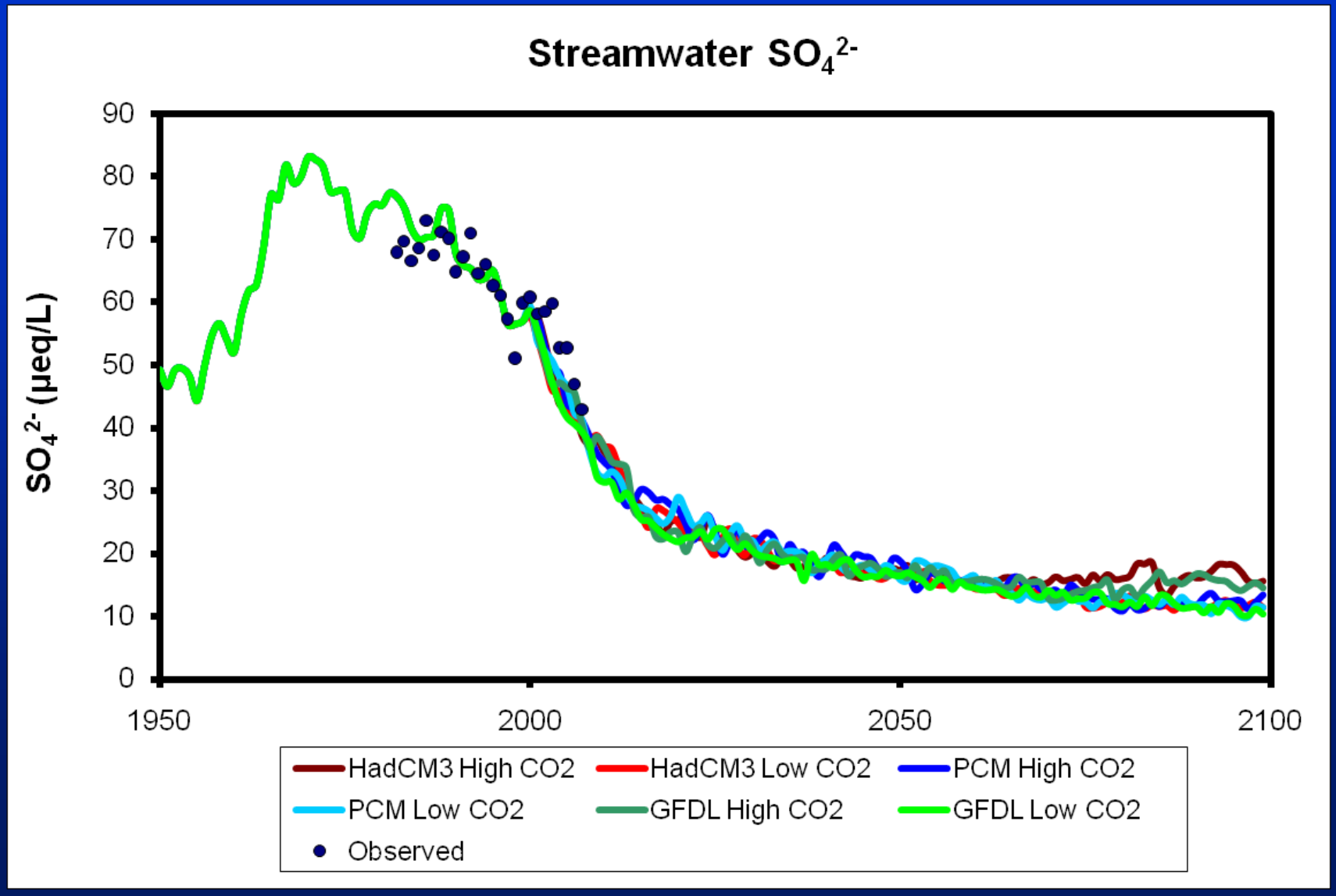
In 1800 CO_2 = 280 ppm

Climate Change and "business as usual" Atmospheric Deposition (Without CO_2 Fertilization)

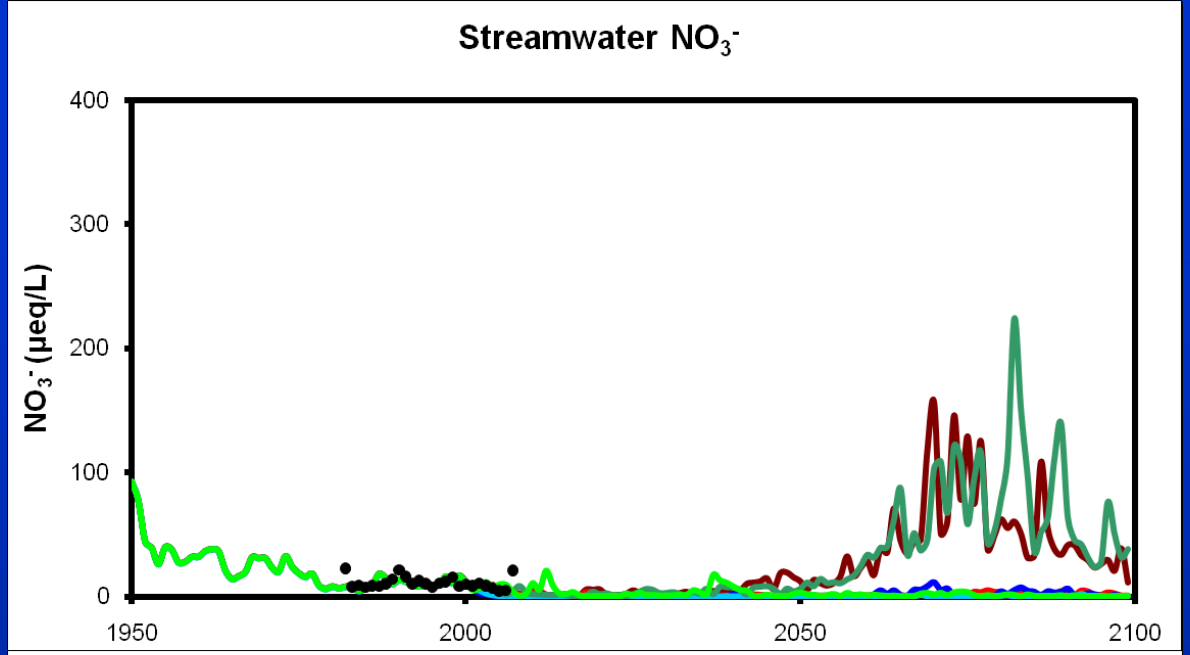


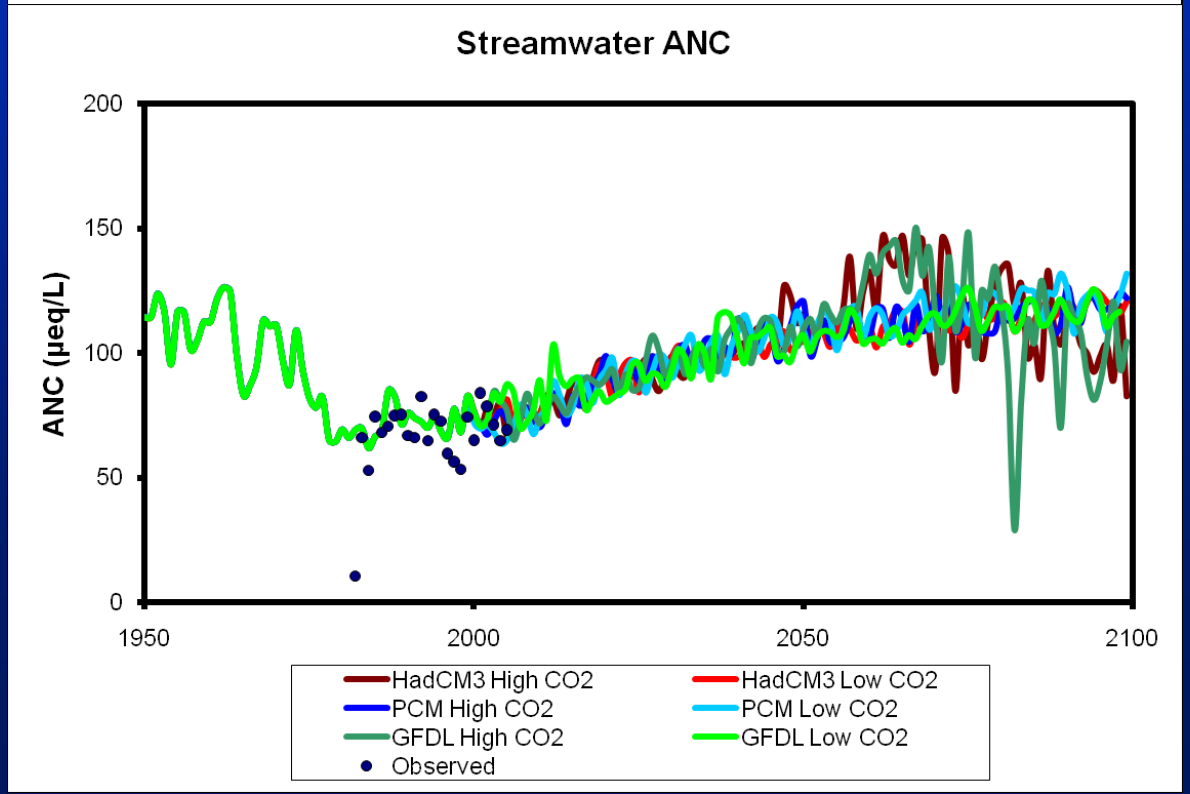


Streamwater SO_4^{2-} (Cont.)



With CO_2 Fertilization





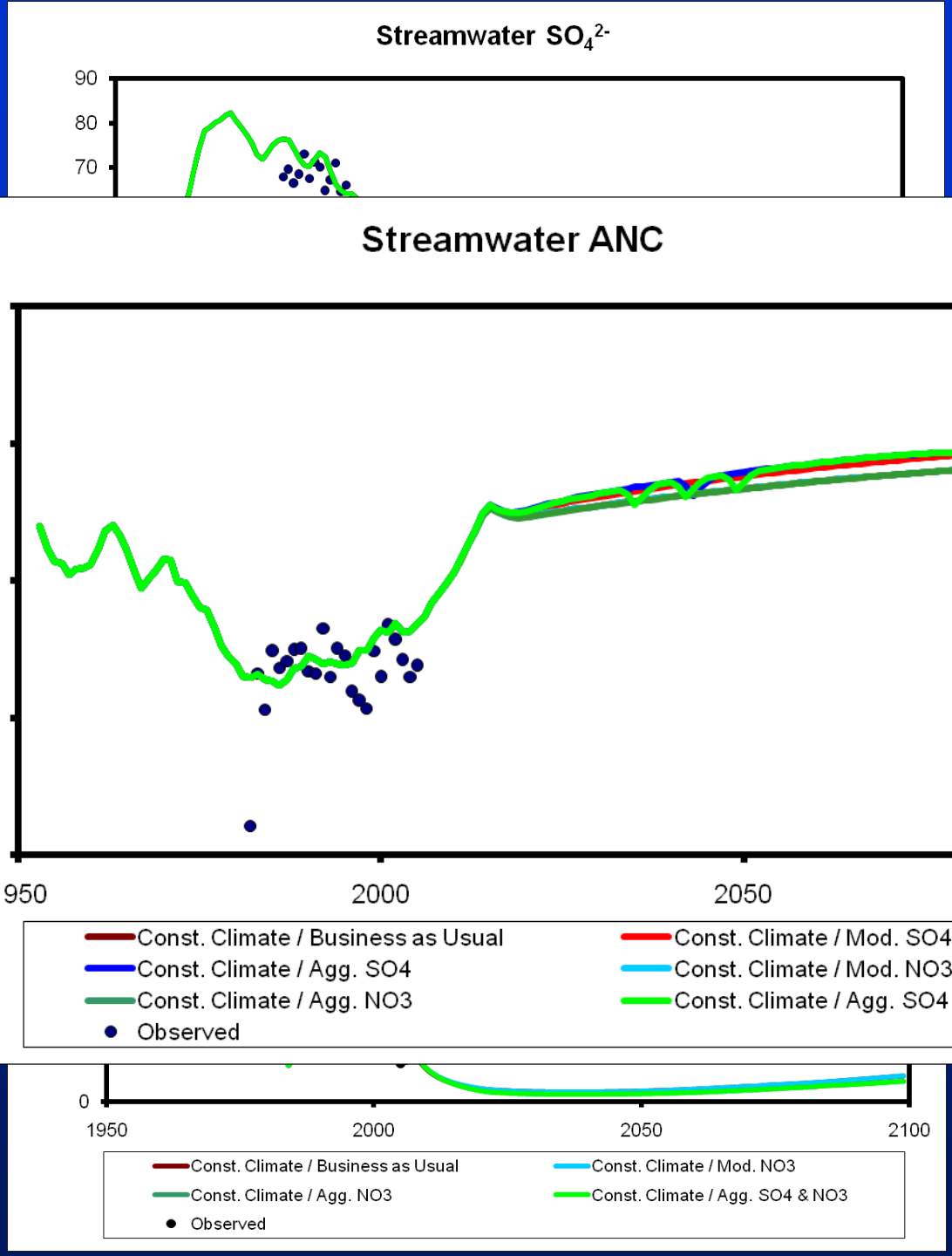
Time series Atmospheric Deposition

TABLE 2. Summary of Target Emissions of SO_2 and Percent Reduction in SO_2 and NO_x Emissions under Three Future Scenarios: Base Case, Moderate Control, and Aggressive Control Scenarios Based on Current Proposals on Emission Reductions

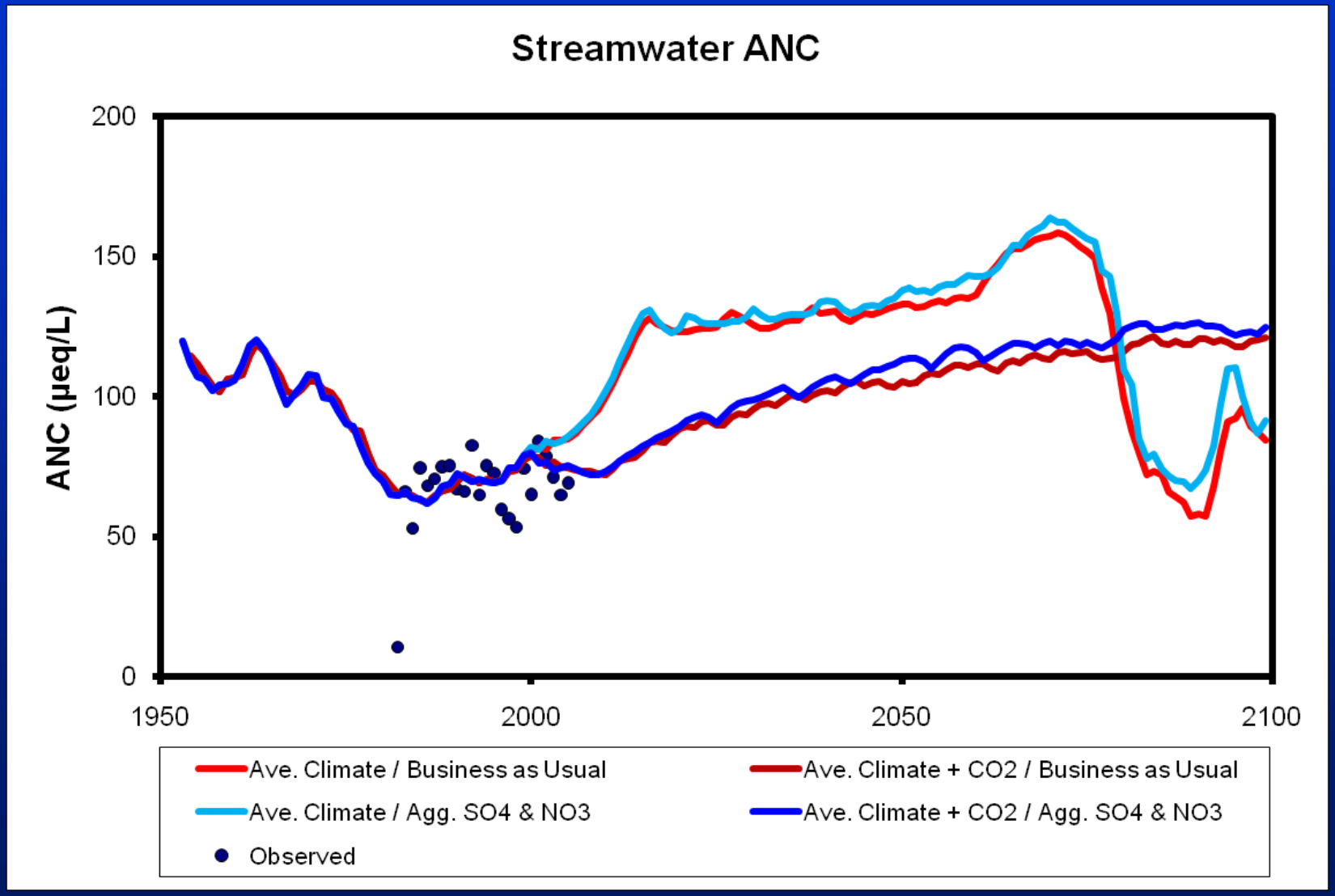
scenarios	utility SO_2 (million ton)	non-utility SO_2 (million ton)	reduction in SO_2[a] (%)	reduction in NO_x[a] (%)
1990 CAAA (base case)	8.95	5.6	~40	~5
moderate control	6	5.6	~55	~20
aggressive control	1	5.6	~75	~30

[a] Percent reduction is relative to the 1990 values and would be achieved by 2020.

Atmospheric Deposition Reduction



Average of all 6 Scenarios (w/wo CO_2 Fertilization) / Aggressive Atmospheric Deposition Reduction



Preliminary Conclusions

- Under elevated temperature:
  - Later snowpack development, earlier snowmelt and greater ET.
  - Elevated mineralization of nitrogen, nitrate leaching and soil and surface water acidification.
- Under elevated temperature and CO_2 fertilization:
  - CO_2 effects on stomatal conductance and higher photosynthesis will decrease water yield and extend the growing season.
  - Increased plant uptake mitigates nitrate leaching and limits acidification.
  - Towards the end of the century under elevated temperature, plant uptake is unable to keep pace with accelerated mineralization resulting in elevated nitrate leaching.
  - Over the first half of the 21st. century CO_2 is the dominate driver of watershed responses to climate change while it shifts to temperature over the second half.
- Under elevated tem., CO_2 fertilization and Atm. Dep. Reduction:
  - Highest recovery rate will be achieved under reduction in atmospheric deposition of sulfate and nitrate if CO_2 fertilization effect occurs.

Future Work

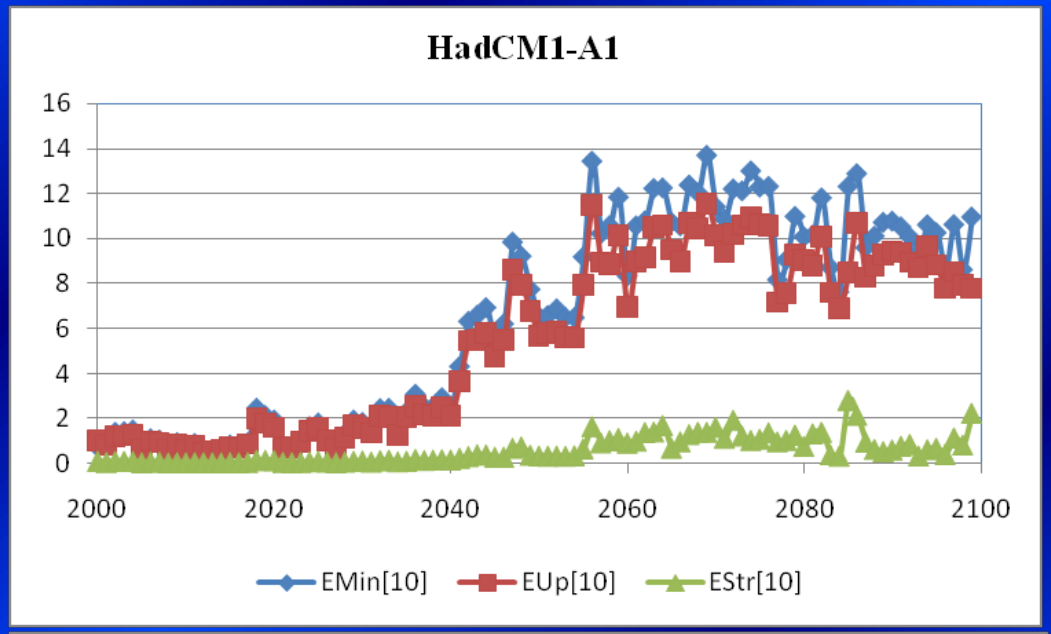
- Multi-layer soil model → compare the results with single layer
- Sensitivity and parametric study.
- Compare model calculations across high elevation watersheds in the U.S. with a range of climatic conditions.

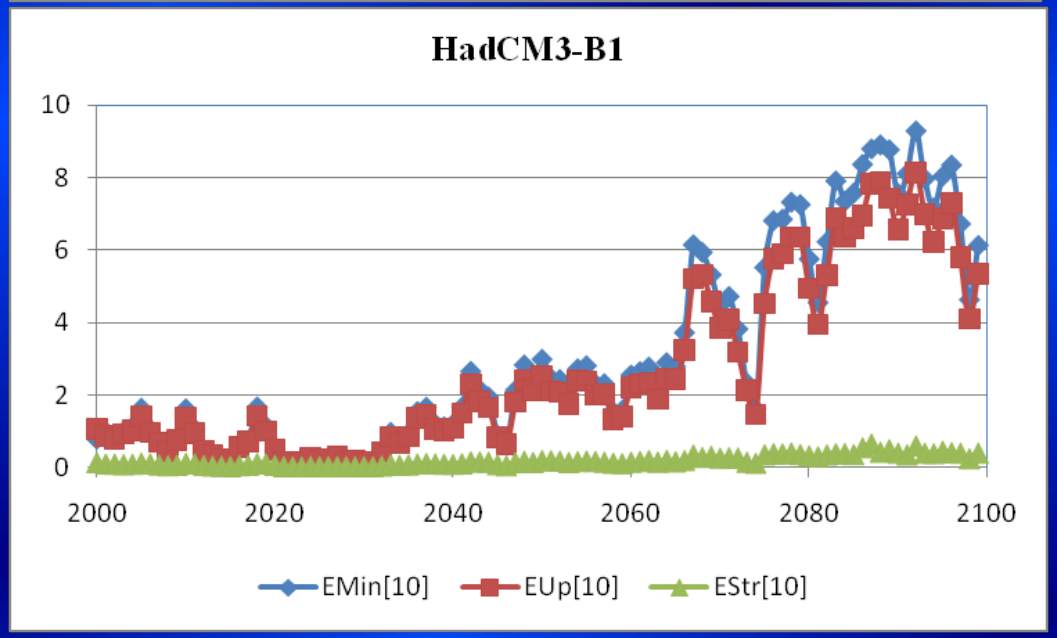
Question/Comments

The greatest uncertainty is what we are going to do about it.

Extra Slides

Streamwater NO_3^-





Projected Globally Averaged Surface Warming and Sea-Level Rise at the End of the 21st Century

	Temperature Change (°F at 2090–2099 relative to 1980–1999)		Sea-Level Rise (inches at 2090–2099 relative to 1980–1999)
Case	Best estimate	Likely range	Model-based range excluding future rapid dynamical changes in ice flow
Constant Year 2000 concentrations	1.1	0.5 – 1.6	NA
B1 scenario	3.2	2.0 – 5.2	7.1 – 15.0
A1T scenario	4.3	2.5 – 6.8	7.9 – 17.7
B2 scenario	4.3	2.5 – 6.8	7.9 – 16.9
A1B scenario	5.0	3.1 – 7.9	8.3 – 18.9
A2 scenario	6.1	3.6 – 9.7	9.1 – 20.1
A1FI scenario	7.2	4.3 – 11.5	10.2 – 23.2

Source: Climate Change 2007: The Physical Science Basis—Summary for Policymakers.

Downscaling AOGCMs (Cont.)

Both methods give similar results (5% difference) , except when temperature is between 28 and 33°C and for relatively small precipitation events of <10mm/day.

In our study we used statistical downscaling (SD):

Monthly AOGCM temperature and precipitation fields for all three models and two future scenarios were statistically downscaled with a resolution of 1/8°.

Maps the probability density functions for modeled monthly precipitation and temperature for the climatological period (1961–1990)➔ mean and variability of monthly observations are reproduced by the climate model data.

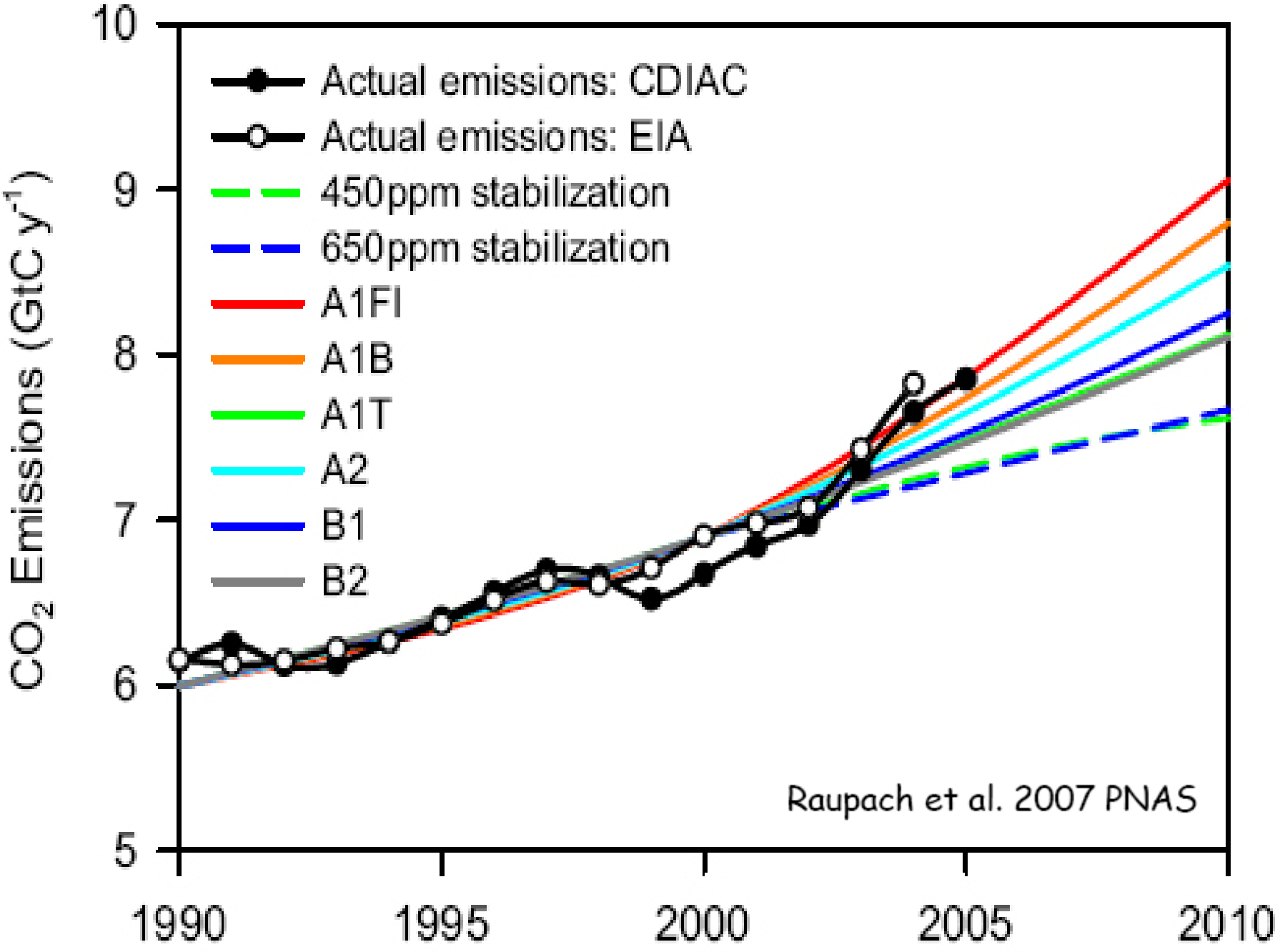
SD vs. RCM

Some disadvantages of statistical downscaling versus regional modeling are as follows.

- The major weakness of statistical downscaling is the assumption that observed links between large-scale predictors and local predictands will persist in a changed climate.
- A problem when applying statistical downscaling techniques to daily values is that the observed autocorrelation between the weather at consecutive time steps is not necessarily reproduced.
- Statistical downscaling does not necessarily reproduce a physically sound relationship between different climate elements. Using a downscaling method based on weather classification for several predictands can minimize this problem.
- Successful statistical downscaling depends on long, reliable observational series of predictors and predictands.

Some advantages of statistical downscaling versus regional modeling are as follows:

- Statistical downscaling is less technically demanding than regional modeling. It is thus possible to downscale from several GCMs and several different emissions scenarios relatively quickly and inexpensively.
- It is possible to tailor scenarios for specific localities, scales, and problems. The spatial resolution applied in regional climate modeling is still too coarse for many impact studies, and some variables are either not available or not realistically reproduced by regional models.
- In most cases, the development of statistical downscaling models includes an evaluation of AOGCM performance in simulating the climate of a specific region. Methods applied in statistical downscaling have been used to evaluate large-scale fields of single variables as well as the links between different fields. The stability of these links under global change has also been investigated. Such analyses can indicate which variables serve as the best predictors.


Actual emissions: CDIAC
Actual emissions: EIA
450ppm stabilization
650ppm stabilization
A1FI
A1B
A1T
A2
B1
B2
CO_2 Emissions ($GtC\ y^{-1}$)
10
9
8
7
6
5
1990
1995
2000
2005
2010
Raupach et al. 2007 PNAS