Introduction to CMI-12:

The twelfth annual meeting of the Carbon Mitigation Initiative

Steve Pacala and Rob Socolow

April 16, 2013

Goals of CMI-12

The goals of CMI-12 are:

- to review the current program
- to discuss the CMI research frontier, which now extends to 2020!

CMI-12 Two-day agenda

Today: Science and Policy

Tomorrow: Climate, Academia, and the Future

Agenda today: Science and Policy

Morning
Steve Pacala, Robert Socolow: Introduction to CMI-12

Keith Dixon, Gabriel Lau, Gabriel Vecchi (GFDL) First Deep Dive: Attribution and Extreme Events

Noon: Group Photo
Lunch and review of posters

Afternoon
Michael Oppenheimer: "What has science got to do with policy, anyway?"

D. Hawkins, N. Keohane: Second Deep Dive: The Washington scene

David Nagel and Ellen Williams: BP Review of 2012

Evening (Prospect House): Reception, Announcement of 2013 Best Paper Award

Dinner: Steven E. Koonin "Promise of Urban Science"

Agenda tomorrow
Climate, Academia, and the Future

Morning
Emily Carter, Lynn Orr: Institutional Development

Bob Williams, Mike Celia, Henry Lee: Fossil Energy in a Carbon-Constrained World

Pablo Debenedetti: Molecular modeling of hydrates and brines

Noon: Lunch and review of posters

Afternoon
Jorge Sarmiento: Southern Ocean research

Advisory Committee

3:00 pm Adjourn

Posters – on display at noon, both days

SCIENCE
Thomas Froelicher: “The dominance of the Southern Ocean in oceanic heat and carbon uptake”

John Higgins, Andrei Kurbatove, Elle Chimiak, Nicole Spaulding, Paul Mayewski, and Michael Bender: “Million-year old ice core samples from the Allan Hills, Antarctica”

Joseph Majkut: “Historical and Future Changes to Ocean Fluxes of CO_2”

CAPTURE Robert Williams: “A First Step Toward Understanding the FOAK to NOAK Cost Transition for CO_2 EOR-Coupled Energy Conversion Systems”

STORAGE Zhong Zheng, Ivan Christov and Howard A. Stone: “Similarity solutions for viscous gravity currents in heterogeneous systems”

POLICY Christopher Little: “Toward probabilistic sea level projections”

OUTREACH Roberta Hotinski: "A LEGO Simulation of CMI's Stabilization Wedges"

Read our Annual Report

Current Roster

19 professor-level investigators

68 post-docs, graduate students, and support staff

CMI Mission Statement

The mission of CMI is to lead the way to a compelling and sustainable solution of the carbon and climate change problem. By combining the unique and complementary strengths of the CMI parties – a premier academic institution and an influential global company – CMI participants seek to attain a novel synergy across fundamental science, technology development, and business principles that accelerates the pace from discovery, through proof of concept, to scalable solution.

CMI's Carbon Commitment

CMI will sustain its leadership in the integration of science, technology, and policy related to climate change.

CMI will remain a "steward" of the climate change problem, so that when attention is refocused, the CMI partners will be ready.

CMI Structure

Research Groups:
Science
Low-carbon energy
Fluids and energy
Integration and policy

Co-Directors:
S. Pacala
R. Socolow

BP:
D. Eyton
D. Nagel
G. Hill

Collaborators:
GFDL, Princeton NJ
Tsinghua University
Politecnico di Milano
University of Bergen
Climate Central, Princeton

Advisory Council:
D. Burtraw, Resources for the Future
D. Hawkins, Natural Resources Defense Council
D. Keith, Harvard
M. Levi, Council on Foreign Relations
S. Benson/F. Orr, Stanford
S.Long /C.Somerville, EBI, Berkeley CA

Elsewhere on the campus

The Andlinger Laboratory is taking shape. It is an ambitious complex of three interconnected buildings providing more than 125,000 square feet of laboratory, cleanroom, classroom and lecture hall, and faculty and student space. (*Take a look : it is a few hundred feet east of here.*)

A University-funded research effort, "Communicating Uncertainty," with special attention to climate change, is in its second of three years. It links faculty across natural science, engineering, economics, politics, psychology, and ethics. It has just held a workshop on Ethics of Risk and Climate Change.

The Climate and Energy Challenge has been refunded by Princeton University under PEI. It fosters innovative faculty-led enhancements of the undergraduate research experience.

CMI leaders: Low-C energy

Low-Carbon Energy Group (formerly, Capture Group):
Left to right: Arnold / Kreutz / Larson / Socolow / Williams

Arnold: Mechanical stresses and battery life. *Deep dive, CMI-11.*

Kreutz, Larson, Williams: coal/gas/biomass to fuel/power with CO2 capture/EOR; China ties, costing. *Talk tomorrow. Poster.*

Frontier: Low-C energy

Core areas

Fossil fuel concepts for a low-carbon world (with Tsinghua, Politecnico di Milano)

Polygeneration of fuels and power

Biomass co-firing

Biofuels via chemical energy conversion

CO_2 use (enhanced oil recovery, CO_2 feedstock for synfuels)

Physics of batteries

Coupling of mechanics and electrochemistry

Constraints on charge and discharge rates

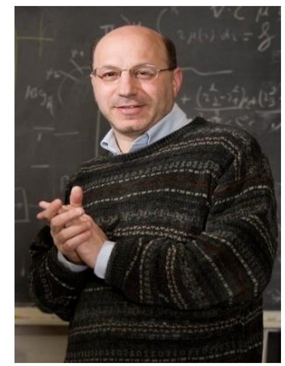
On the radar screen

Joint studies of conceptual issues in cost estimation

First of a kind (FOAK) and Nth of a kind (NOAK)

CMI leaders: Fluids

Fluids and Energy Group (formerly, Storage Group):
Left to right: Celia / Debenedetti / Panagiotopoulos / Prevost / Stone / Tromp

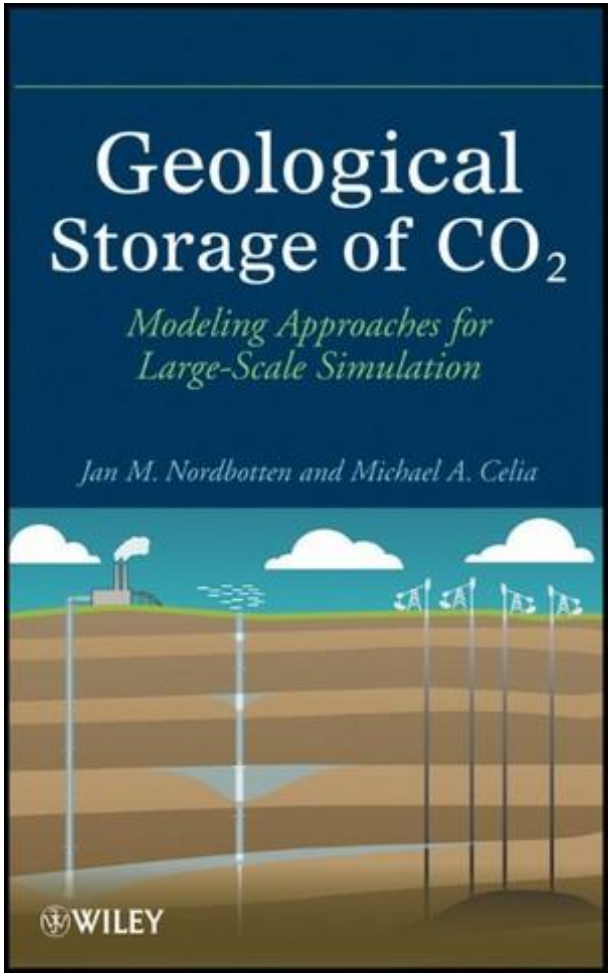
Celia: CO_2 basin modeling. *Talk tomorrow.*

Debenedetti, Panagiotopoulos, Tromp. Molecular modeing. *New program, 2011. Talk tomorrow.*

Prevost: Modeling CO_2 below ground. *Best paper prize (Gennady Gor)*

Stone: Fluids *Poster tomorrow*

New book: *Geological Storage of CO_2*



Jan M. Nordbotten and Michael Celia

"We have focused the book on basic concepts needed to understand subsurface storage of CO_2, with a focus on mathematical models used to describe storage operations." (from the Preface)

http://www.wiley-vch.de/publish/en/books/ISBN978-0-470-88946-6

Research frontier: Fluids

Core areas

CO_2 storage

Modeling from pore scale to basin scale
Active brine management
Field studies of well-bore integrity (re-enter wells, with BP)
Technical back-up for regulations
e.g., EPA: "area of review," "zone of endangering influence"
Table-top exploration of fundamentals (Hele-Shaw cells)

Molecular modeling of hydrates and CO_2-hydrocarbon systems

Formation and melting of CO_2-H_2O-salt hydrate systems
Mixed-hydrate desalination
Physical chemistry of enhanced oil recovery
Methane hydrates: stability, CO_2-for-CH_4 storage/production

On the radar screen

Climate-change adaptation

Coupling SFDL storm-surge models to damage reduction

CMI leaders: Integration

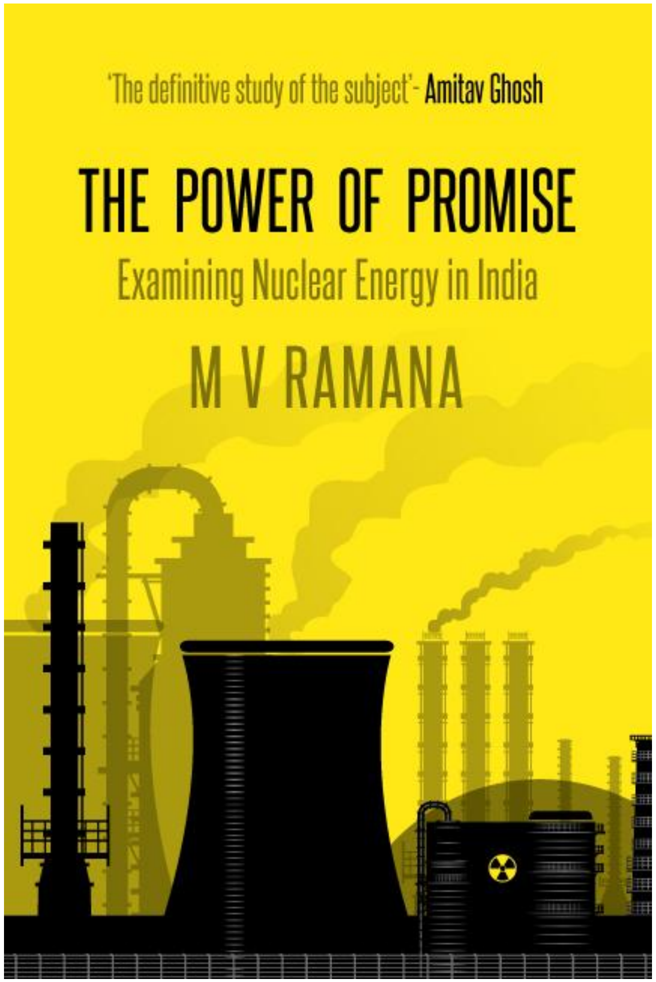
Policy and Integration Group:
Left to right: Glaser / Oppenheimer / Pacala / Socolow

Glaser: Small nuclear reactors *New program, 2011.*

Oppenheimer: Science and policy. *Talk today*, *poster*.

New book: Nuclear Energy in India



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Published by Penguin Books, India, December 2012

http://www.us.penguingroup.com/nf/Book/BookDisplay/0,,9780670081707,00.html?The_Power_of_Promise_M._V._Ramana

Tavoni-Socolow: CDR special issue

CDR: Carbon dioxide removal from the atmosphere, deliberately.

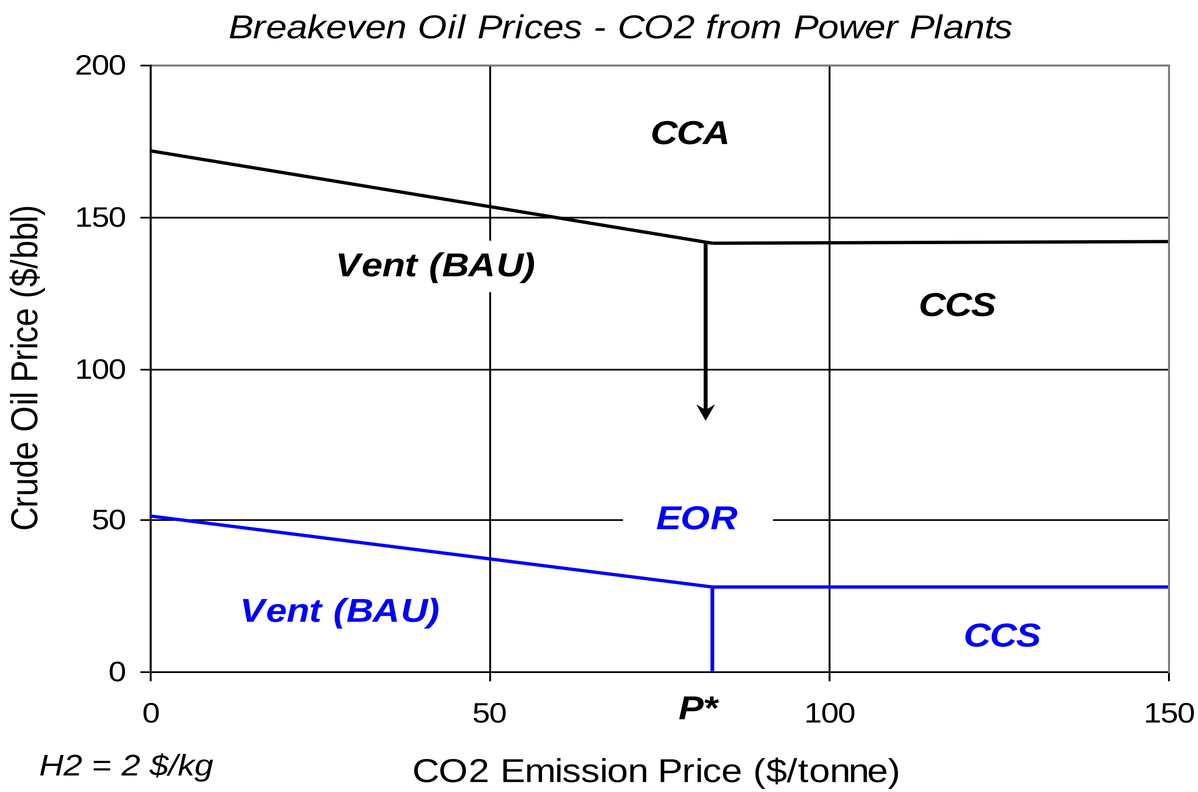
Special issue of *Climatic Change*, ten articles, available electronically already, hard copy soon. Co-editor: Massimo Tavoni, FEEM (Milan) – former CMI staff and participant in Energy Sustainability Challenge.

Strategies include afforestation, biopower with CO_2 capture and storage, and direct capture with chemicals. CDR enables “overshoot” trajectories. Modeling and science are on parallel tracks!

Articles include:

- Marco Mazzotti, Renato Baciocchi, Michael J. Desmond, and Robert H. Socolow, “Direct air capture of CO_2 with chemicals: optimization of a two-loop hydroxide-carbonate system using a countercurrent air-liquid contactor.” http://rd.springer.com/article/10.1007/s10584-012-0679-y.

CO_2 Activation (with Tom Kreutz)



CO2 “activation “ (CCA) is obtained by a reverse shift reactor,

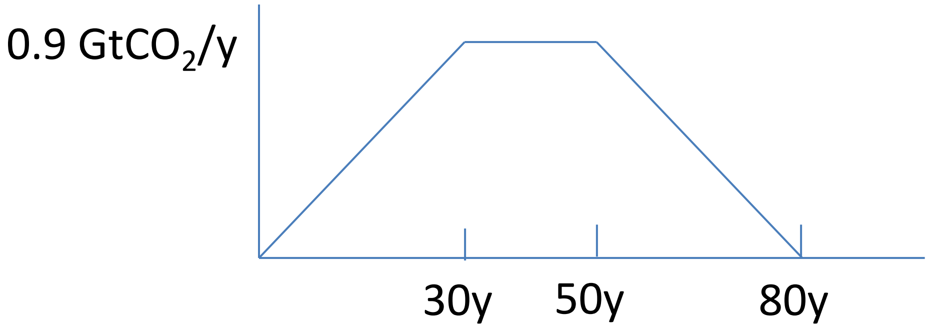
captured CO_2 + external $H_2 \rightarrow CO + H_2O$,

followed by Fischer-Tropsch synthesis.

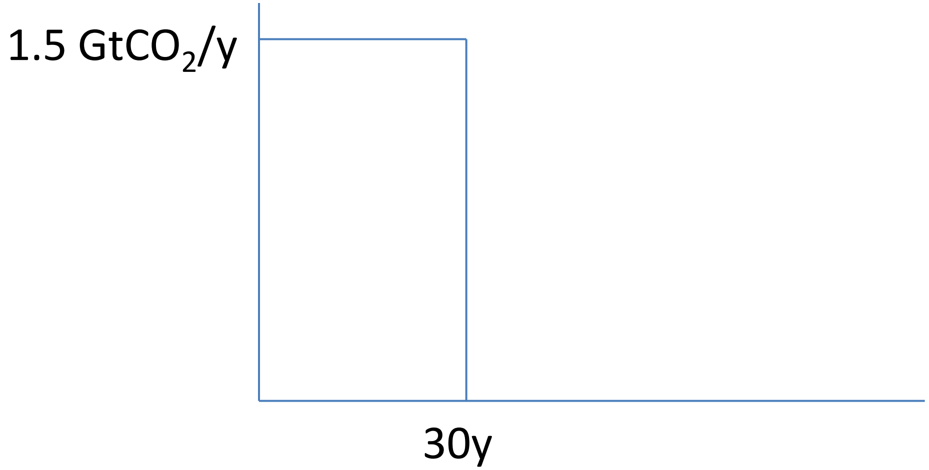
Commitment accounting (w. Steve Davis)

Imagine a project to build 10 GW of natural gas combined-cycle power every year for 30 years, with CO_2 emissions of 3 $MtCO_2$/GW-year, and power plant life of 50 years. There are two ways of thinking about the project's 45 $GtCO_2$ of emissions.

1. Emissions over time

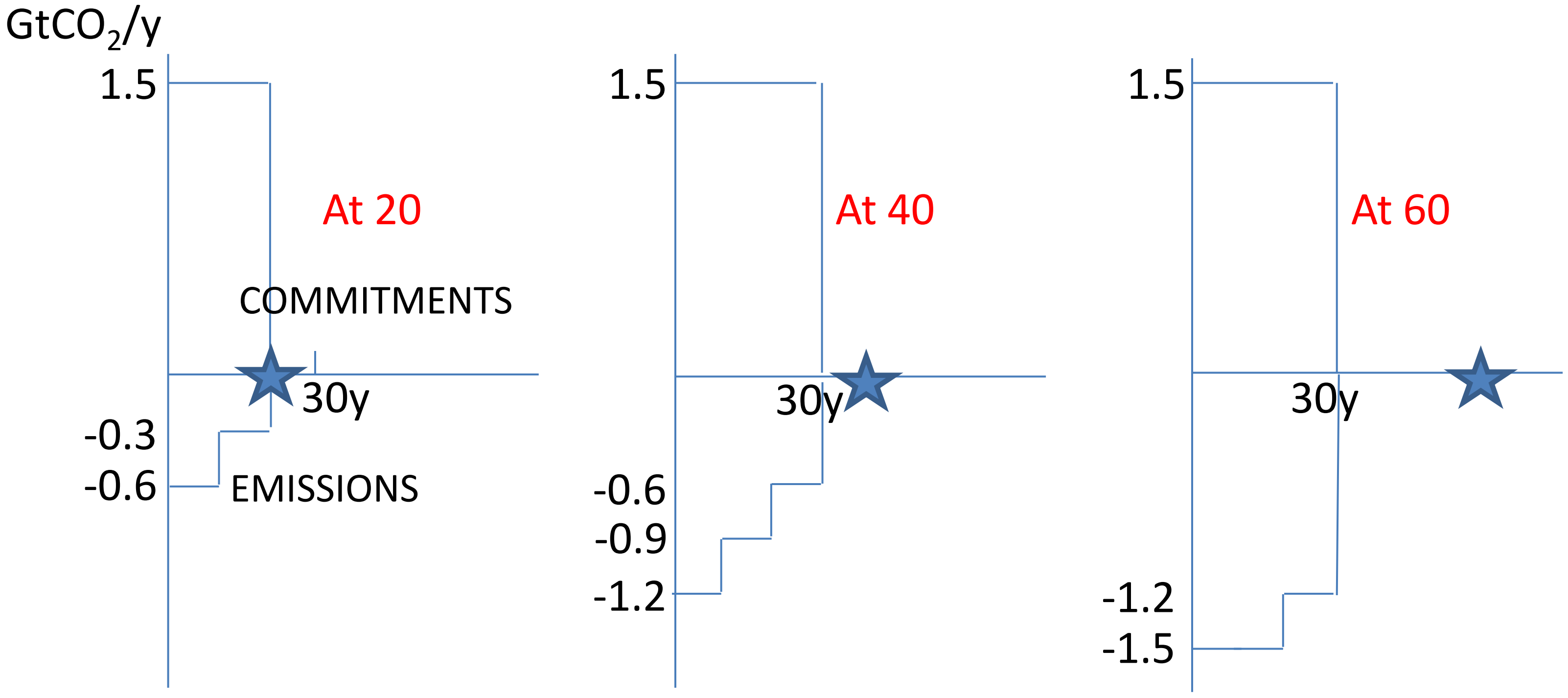


2. New commitments over time
Each plant is a commitment to emit 150 $MtCO_2$.



Credit David Hawkins for the original idea, ca. 2005.

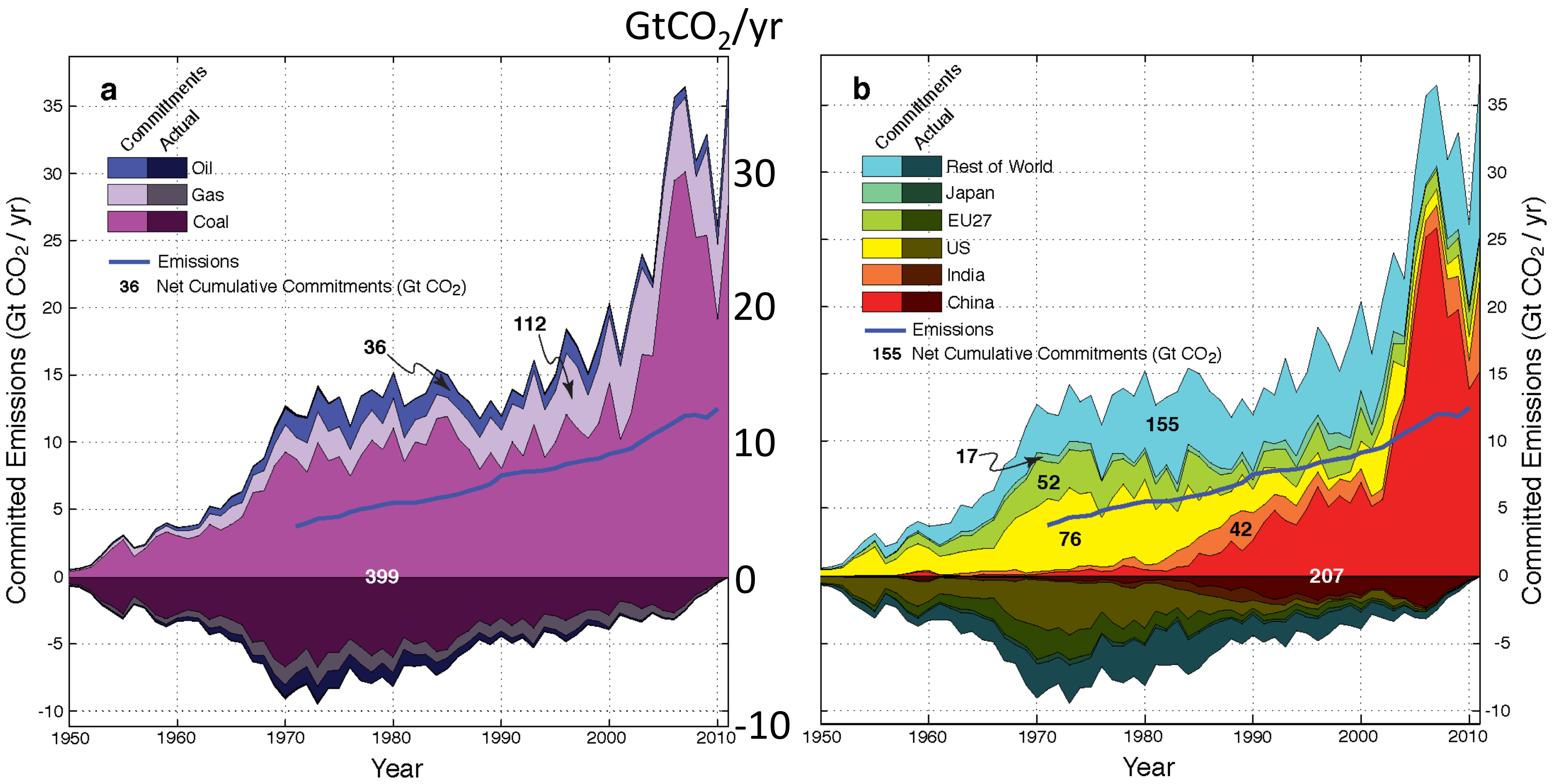
Dynamic view



Commitments – Realized emissions = Residual commitment

Commitments from global electricity, 1950-2010

Preliminary



Research frontier: Integration

Core areas

Policy restart: getting real

Communication of uncertainty

Pace: How fast can things change?

Carbon dioxide removal from the atmosphere (with M. Desmond)

Sea level rise assessment

The future of nuclear power

Small nuclear reactors (weapons-coupling, safety)

Outreach

Making climate change vivid (with Climate Central); Wedges popularization

On the radar screen

Biocarbon

Coupling science models with integrated assessment models (IAMs)

Adaptation: a structured discussion

CMI leaders: Science

Science Group:
Left to right: Bender / Hedin / Medvigy / Morel / Pacala / Sarmiento

Bender: Very old ice. *Poster.*
Hedin and Medvigy: Amazon *New start, 2011*.
Morel: Ocean acidification. *This talk.*
Sarmiento: Southern ocean. *Talk tomorrow, two posters.*

Highlights:

Controls on the Terrestrial Carbon Sink

•A new analysis shows that, in the absence of a historical CO_2 fertilization sink, the concentration of atmospheric CO_2 would have been 80% greater than observed, and warming would have been 40% larger.

•New models are explaining how nutrient limitation and nitrogen fixation affect CO_2 fertilization, and predict that CO_2 enhancement of the terrestrial carbon sink will continue.

Quantifying the Ocean Carbon Sink

•A new set of climate models indicates that Southern Ocean south of 30°S took up 71 ± 24% of the excess heat and 43 ± 3% of anthropogenic carbon over the period 1861 to 2005.

•A new instrument for continuous, high precision measurements of the dissolved inorganic carbon concentration (DIC) of surface seawater has been deployed and validated.

New modeling tools

•Simulation of ocean carbon cycling has been enhanced by a new model of bacterial cycling for global circulation models.

•A new model explains how drought leads to tree mortality, which has been one of the largest sources of uncertainty in the carbon cycle.

•A new model of fire in terrestrial systems is the first to effectively separate natural and anthropogenic fires at global scales.

Fate of Anthropogenic CO_2 Emissions (2000-2008)

1.4 PgC y^{-1}

+

7.7 PgC y^{-1}

4.1 PgC y^{-1}

45%

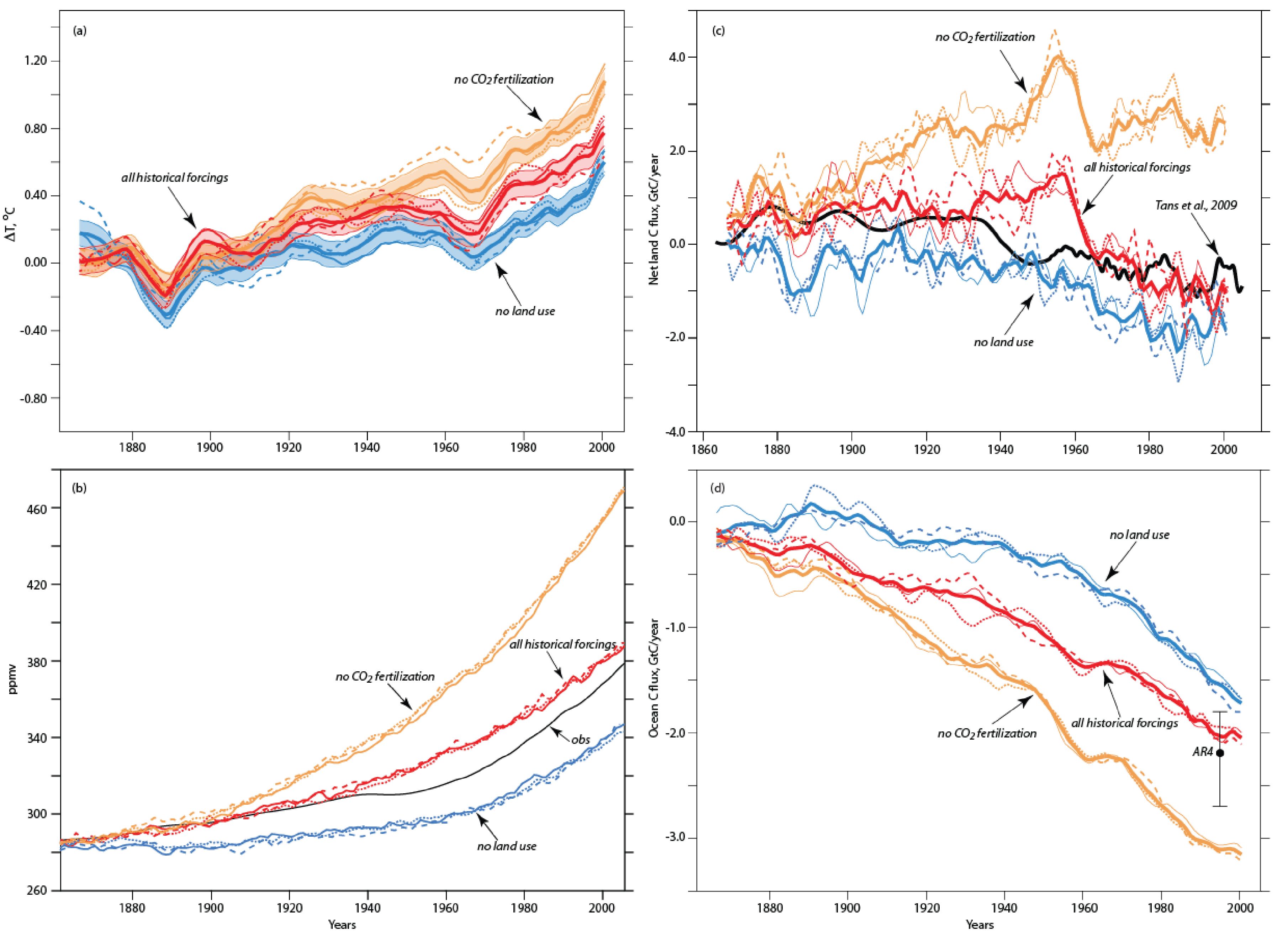
3.0 PgC y^{-1}

29%

26%

2.3 PgC y^{-1}

Le Quéré et al. 2009, Nature Geoscience; Canadell et al. 2007, PNAS, updated



(a)
1.20
0.80
0.40
0.00
-0.40
-0.80
ΔT, °C
no CO_2 fertilization
all historical forcings
no land use
1880
1900
1920
1940
1960
1980
2000
(b)
460
420
380
340
300
260
ppmv
no CO_2 fertilization
all historical forcings
obs
no land use
Years
(c)
4.0
2.0
0.0
-2.0
-4.0
Net land C flux, GtC/year
no CO_2 fertilization
all historical forcings
Tans et al., 2009
no land use
1860
(d)
0.0
-1.0
-2.0
-3.0
Ocean C flux, GtC/year
no land use
all historical forcings
no CO_2 fertilization
AR4

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CO_2 from More than a Trillion Tons of Heated Peat Enters the Atmosphere

~2050

2012

1995

850

800

750

550

500

450

400

350

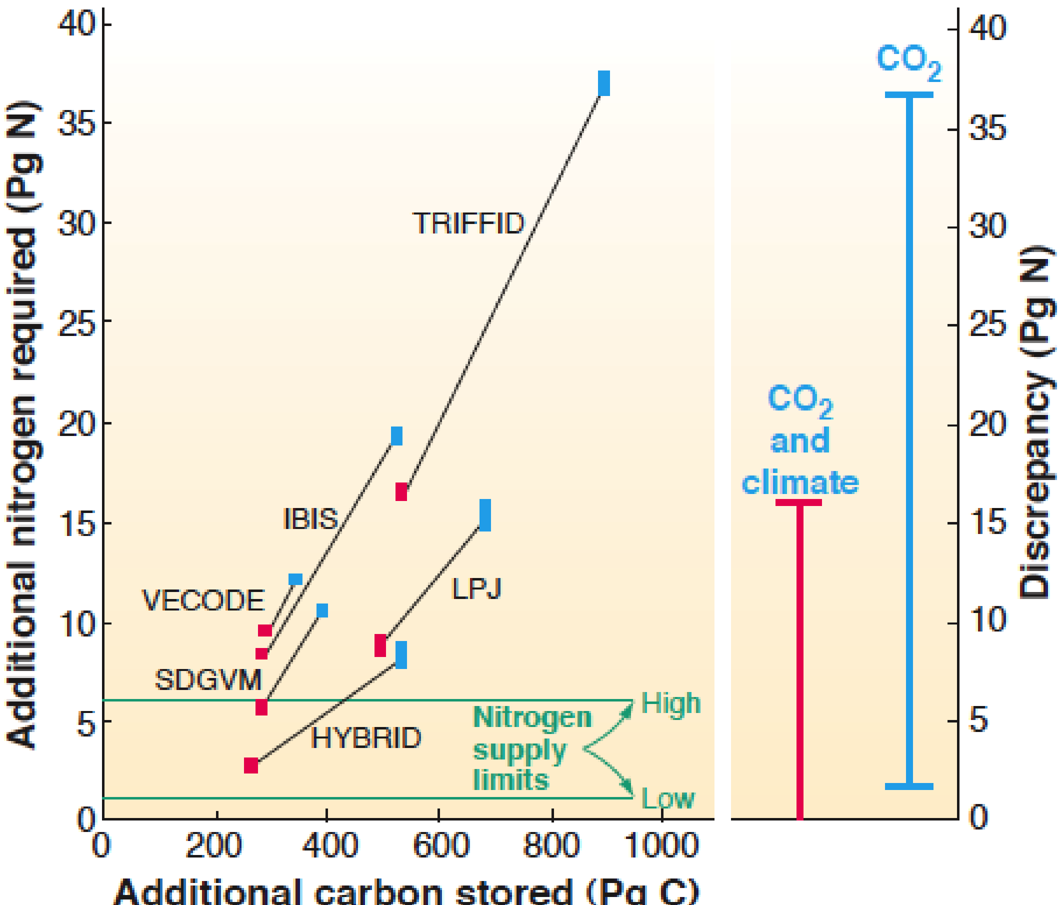
300

- Deglaciation and Loss of Coastal Cities
- Mass Extinction
- Deep Sea Circulation Stops
- Tropical Famine

If the CO_2 fertilization sink fails:

- Parts per Million in the Atmosphere

Liebig's Law of the Minimum and the Future of the Carbon Sink

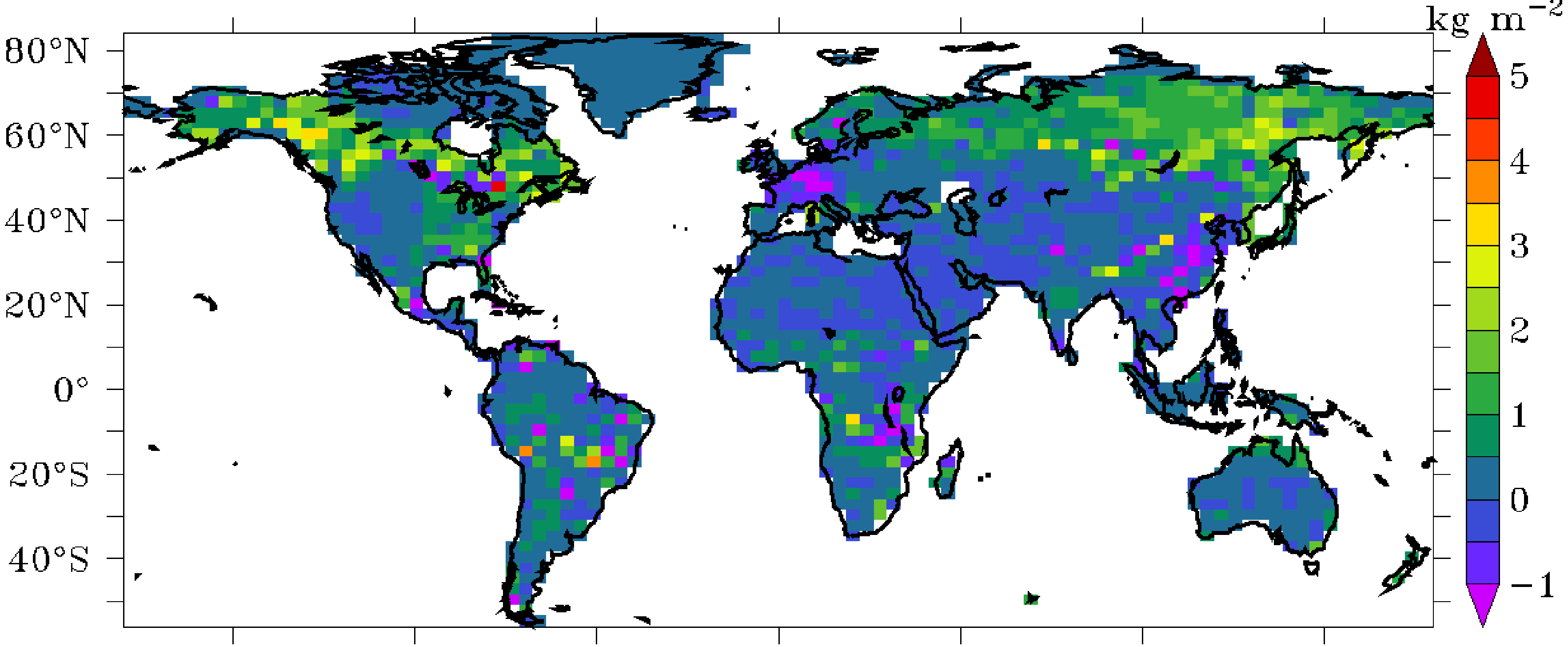


Hungate et al. 2003.
Science 302: 1512-1513

The C/N of vegetation is ~35.

No new N = No new C.

Current global models with an N cycle predict a weakening sink because of Liebig's Law, where N-fixing trees are absent.



Warm Colors = Annual Carbon Sink Eliminated by Nitrogen Shortage at 550 PPM

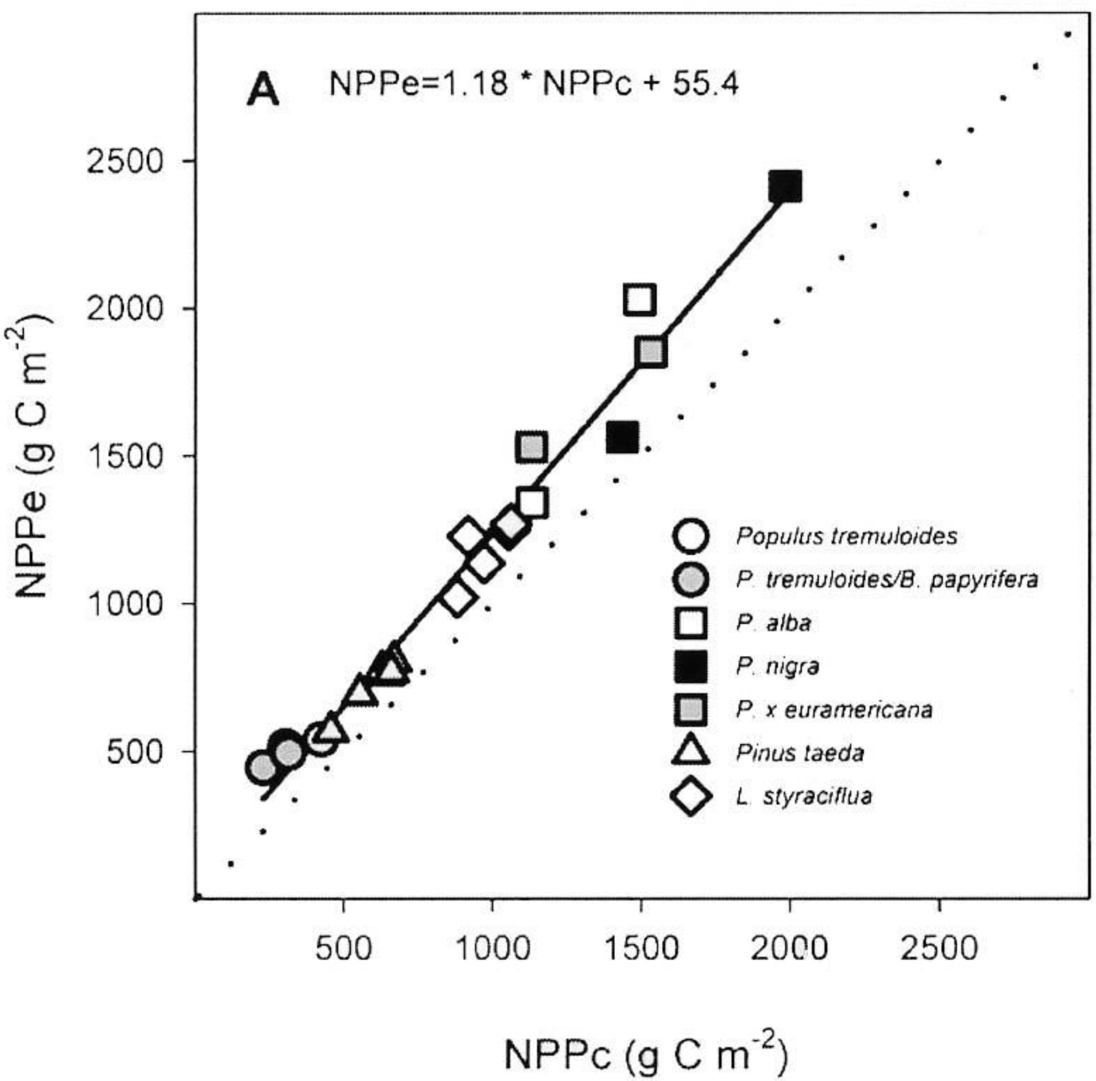
Gerber et al. GBC 2009.

Will the sink fail?

Consider its basic physiology.

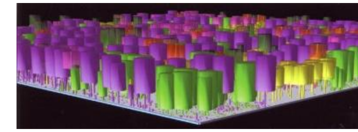
Le Chatelier's principle:

$$6CO_2 + 6H_2O \;\underset{\longleftarrow}{\overset{\longrightarrow}{N}}\; C_6H_{12}O_6 + 6O_2$$



FACE experiments show trees increased NPP despite N limitation.

Norby et al. (2006)

Face Results 	New Model Predictions 
No site sees N limitation ala Liebig’s law.	No N limitation ala Liebig’s law.
NPP always increases as though not N limited.	NPP always increases as though not N limited.
% allocation to wood stays the same.	% allocation to wood stays the same.
% allocation belowground increases.	% allocation to fine roots increases.
% allocation to leaves decreases.	% allocation to leaves decreases.
Tissue C/N increases.	Tissue C/N increases.

Will the CO_2 fertilization sink fail?

No, we predict a 100-year terrestrial sink.

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- Ocean acidification may decrease the fixation of nitrogen in the open ocean by decreasing the bioavailability of iron to nitrogen-fixing organisms.

- New model studies predict a 20% reduction in fish size and likely tuna habitat reduction due to climate change and ocean warming.

Long-Term Climate Variability

- Trends in the airborne fraction of anthropogenic CO_2 are shown to be within the noise level when accounting for the decadal-scale influence of explosive volcanic eruptions, indicating that natural sinks are not decreasing as previous studies have found.

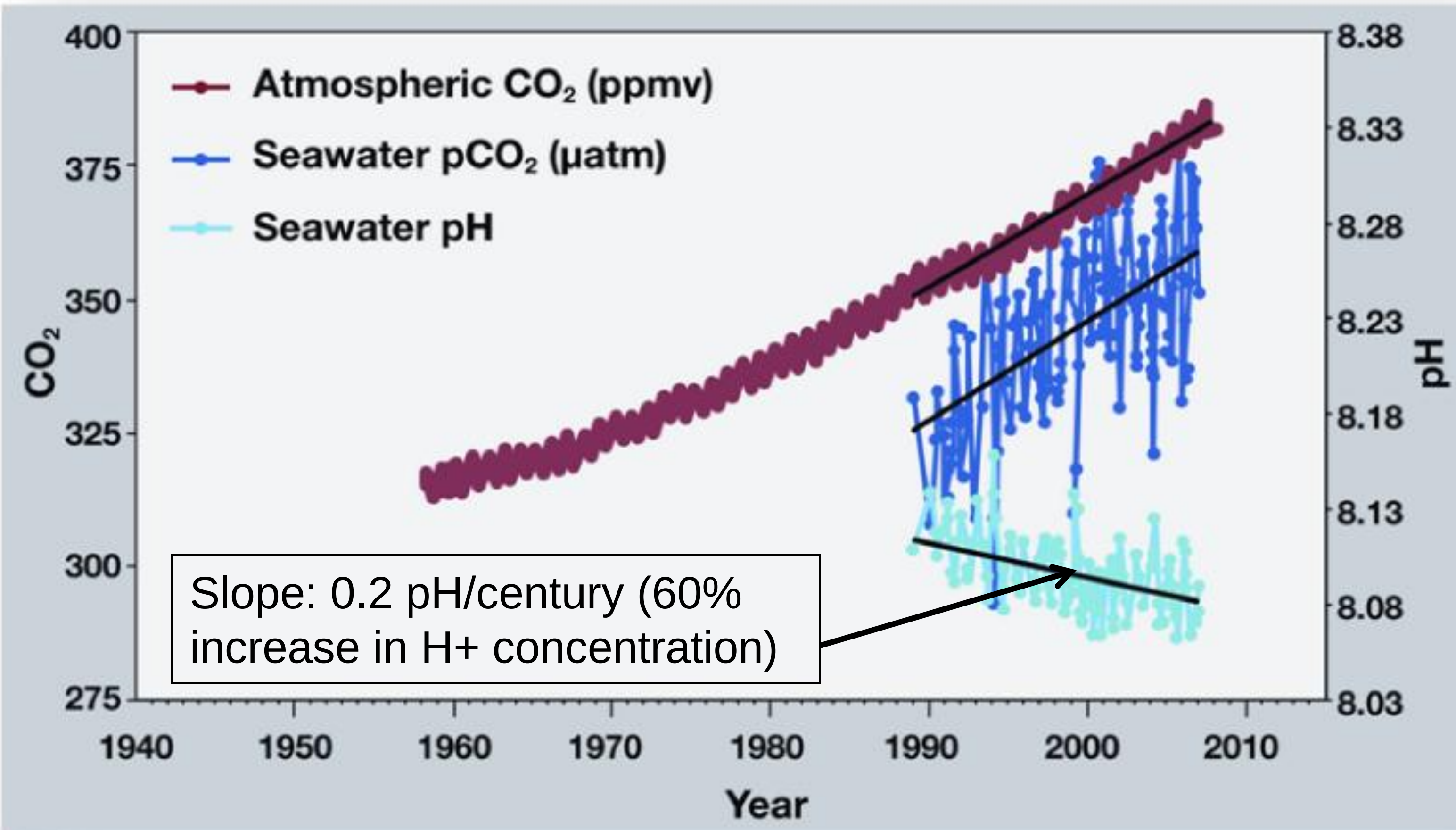
- Million year-old ice from Antarctica is extending the ice core record of climate, and researchers are looking for even older ice.

New Initiatives

- The Sarmiento group prepared a large proposal for the National Science Foundation to form a Center for Southern Ocean Biogeochemical Observations and Modeling.

- A new BP-sponsored initiative will build Science Group's capacity to analyze, predict and attribute changes in climate over the next 25 years.

Ocean pH time series



CO_2 level in atmosphere at Mauna Loa; CO_2 level and pH in nearby ocean at Station Aloha.

Modified after R.A. Feely, Bulletin of the American Meteorological society, July 2008. *Website*: Pacific Marine Environmental Laboratory, NOAA, http://pmel.noaa.gov/co2/files/hitimeseries2.jpg

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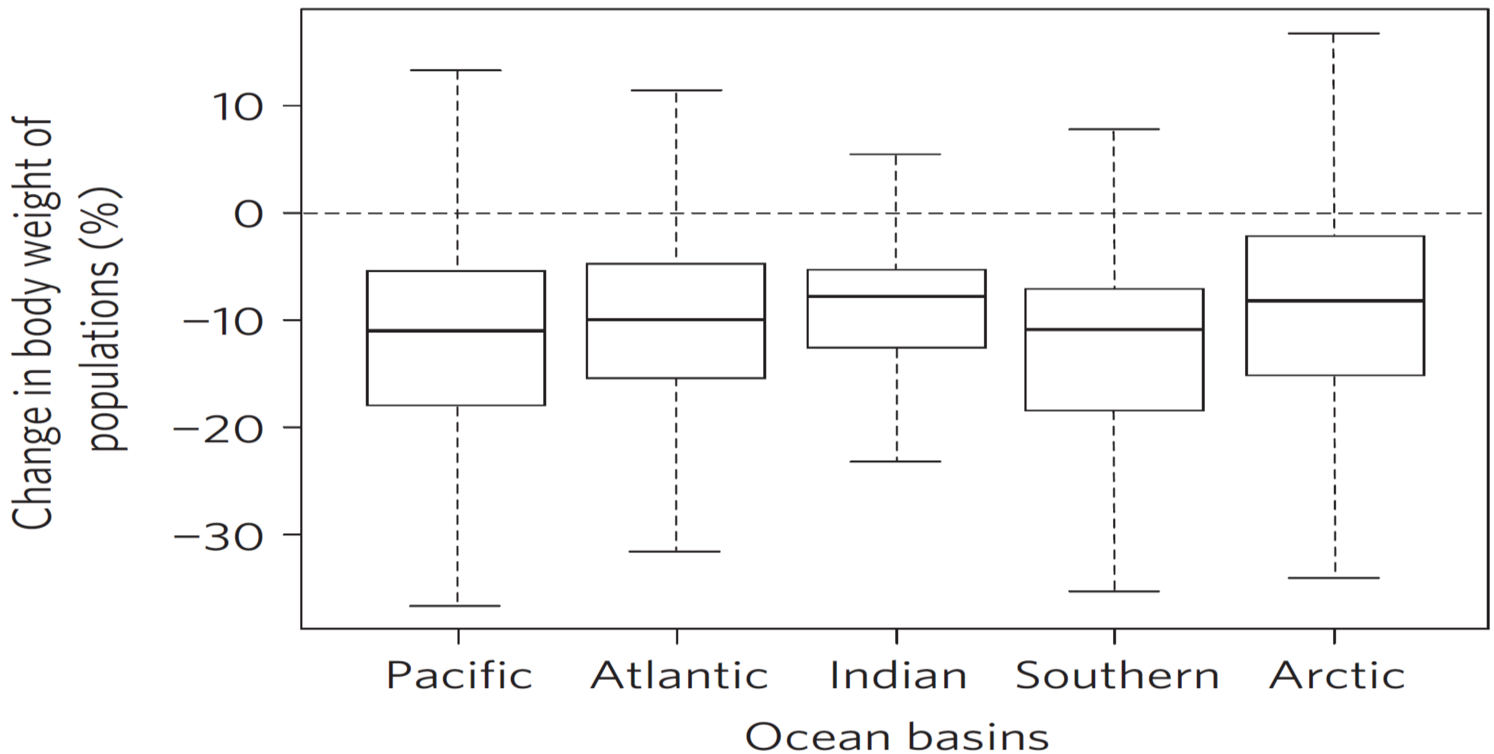

Figure X: Change in individual-level body size of fishes in different ocean basins from 2000 (averages of 1991-2010) to 2050 (averages of 2041-2060). The thick black lines represent median values, the upper and lower boundaries of the box represents 75 and 25 percentiles and the vertical dotted lines represent upper and lower limits.

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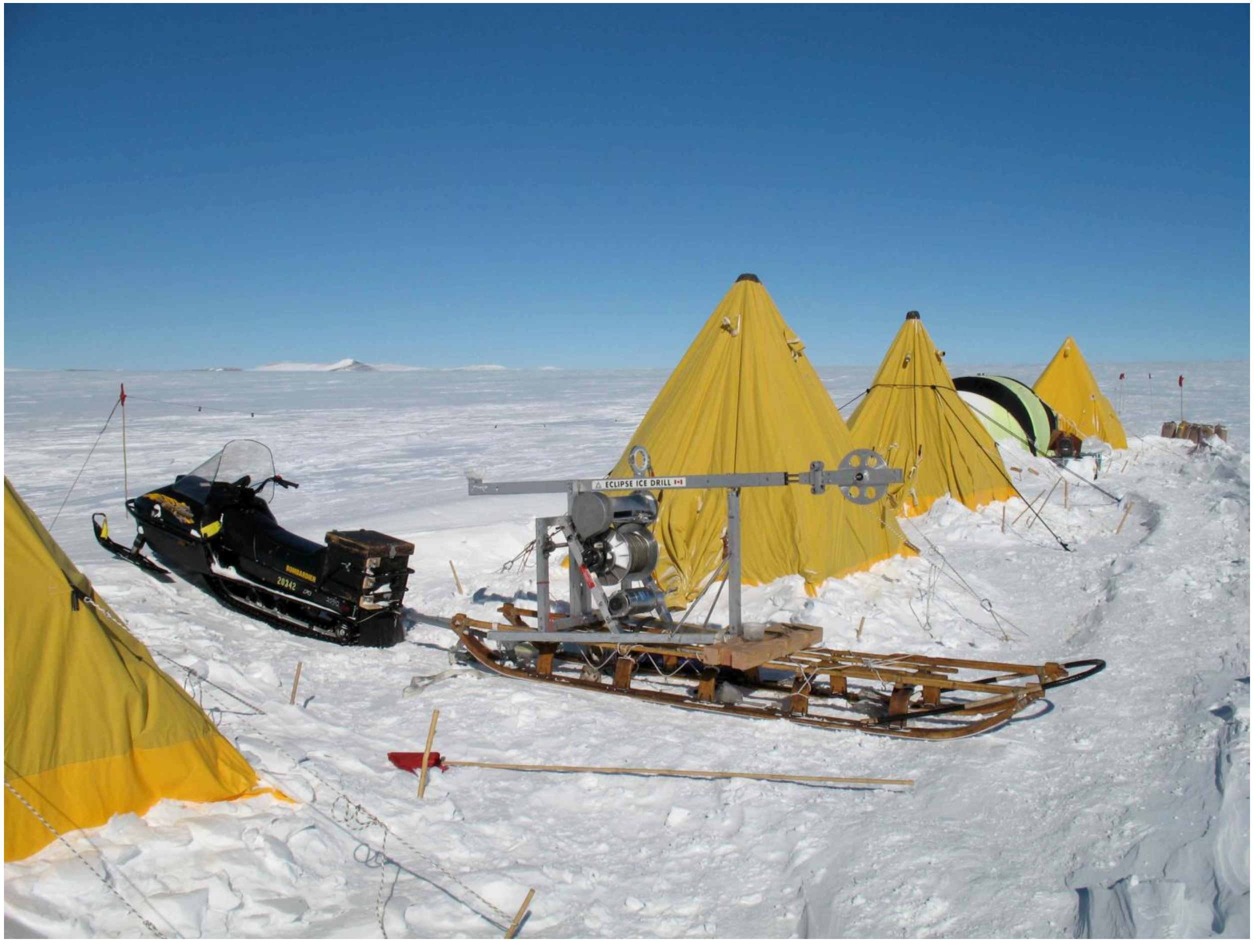

Figure X. Camp and ice core drill (on sled) in the Allan Hills where the Bender team is seeking even more ancient ice.

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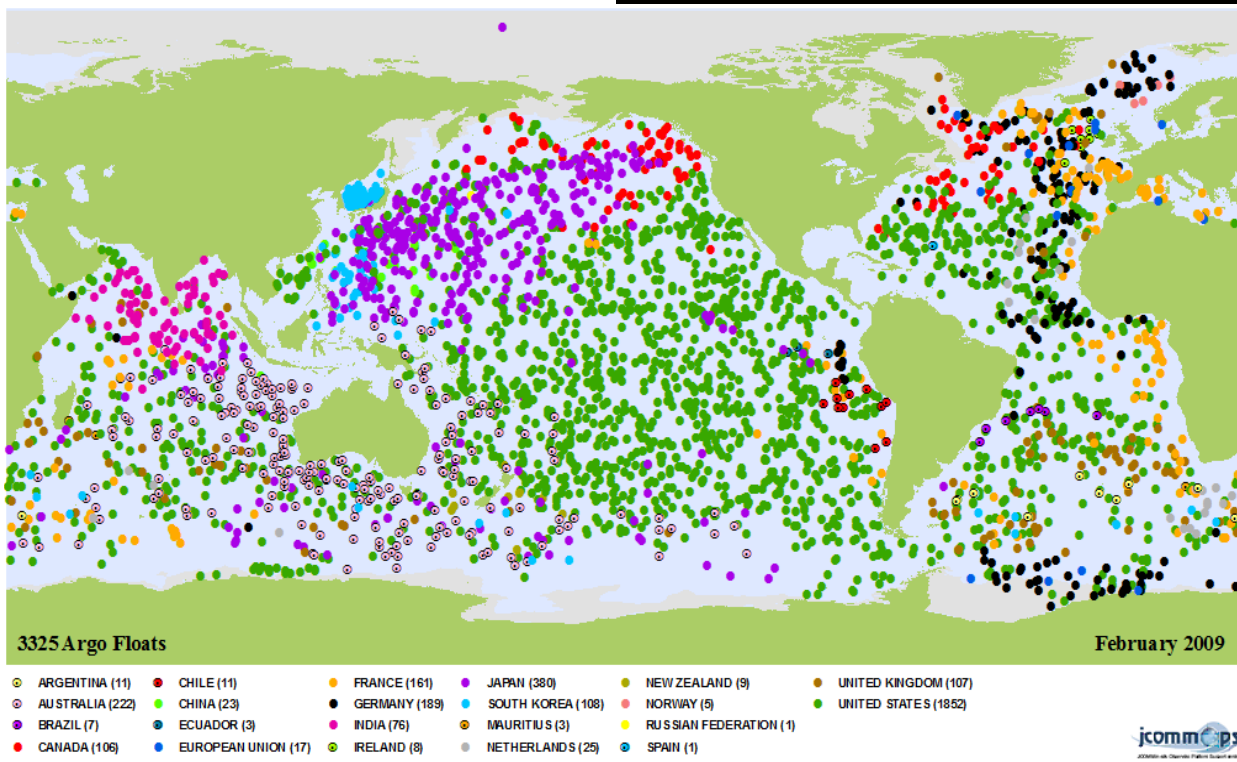
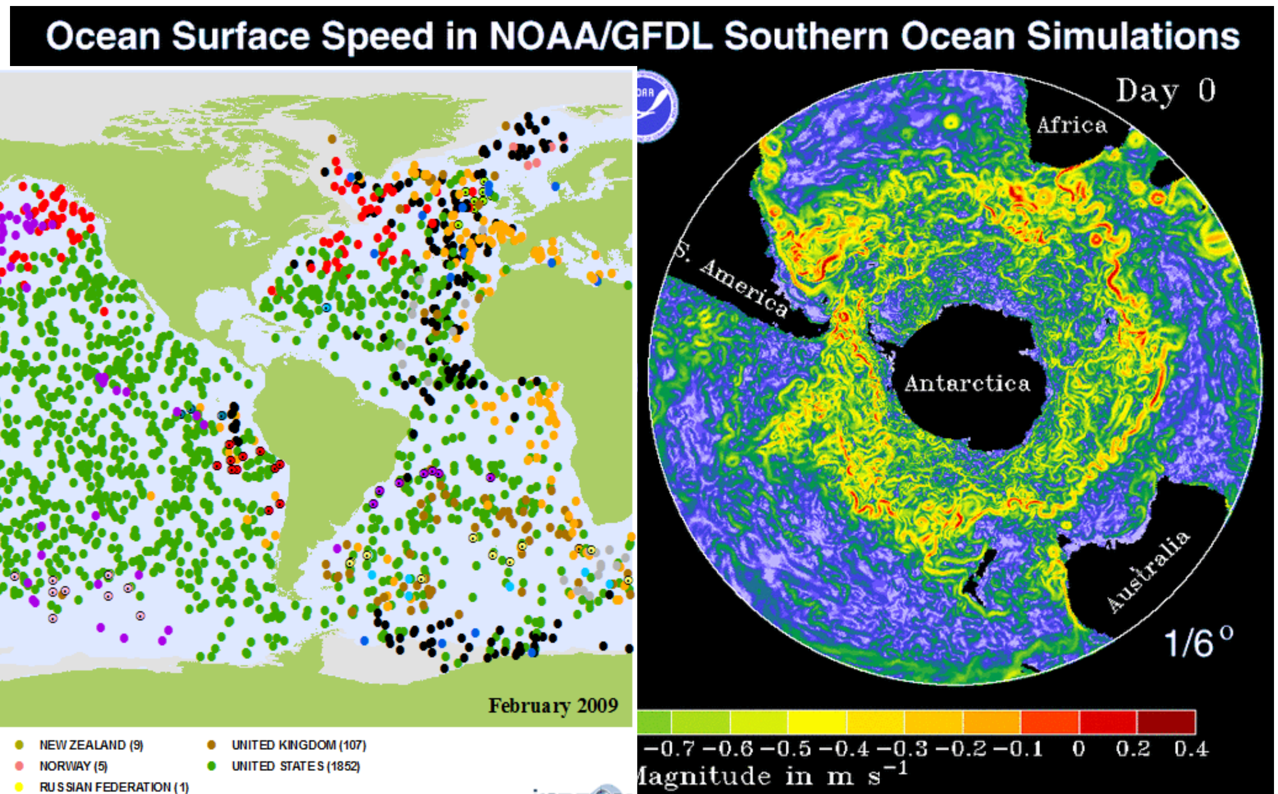
New Southern Ocean NSF Center
Headed by Jorge Sarmiento ($5M/y)





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New BP/Princeton/GFDL Climate Variability Project

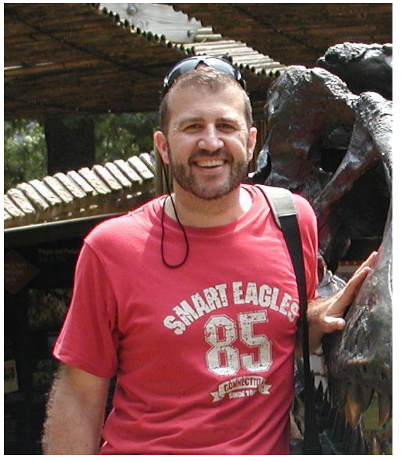
Pacala/Shevliakova/Bollasna/Barcikowski and the GFDL Climate Variability Group.

Climate variability and extreme events: drought, heat, extreme rainfall, windstorm.

Can we detect trends due to climate change?

Can we predict them over the next 25 years?

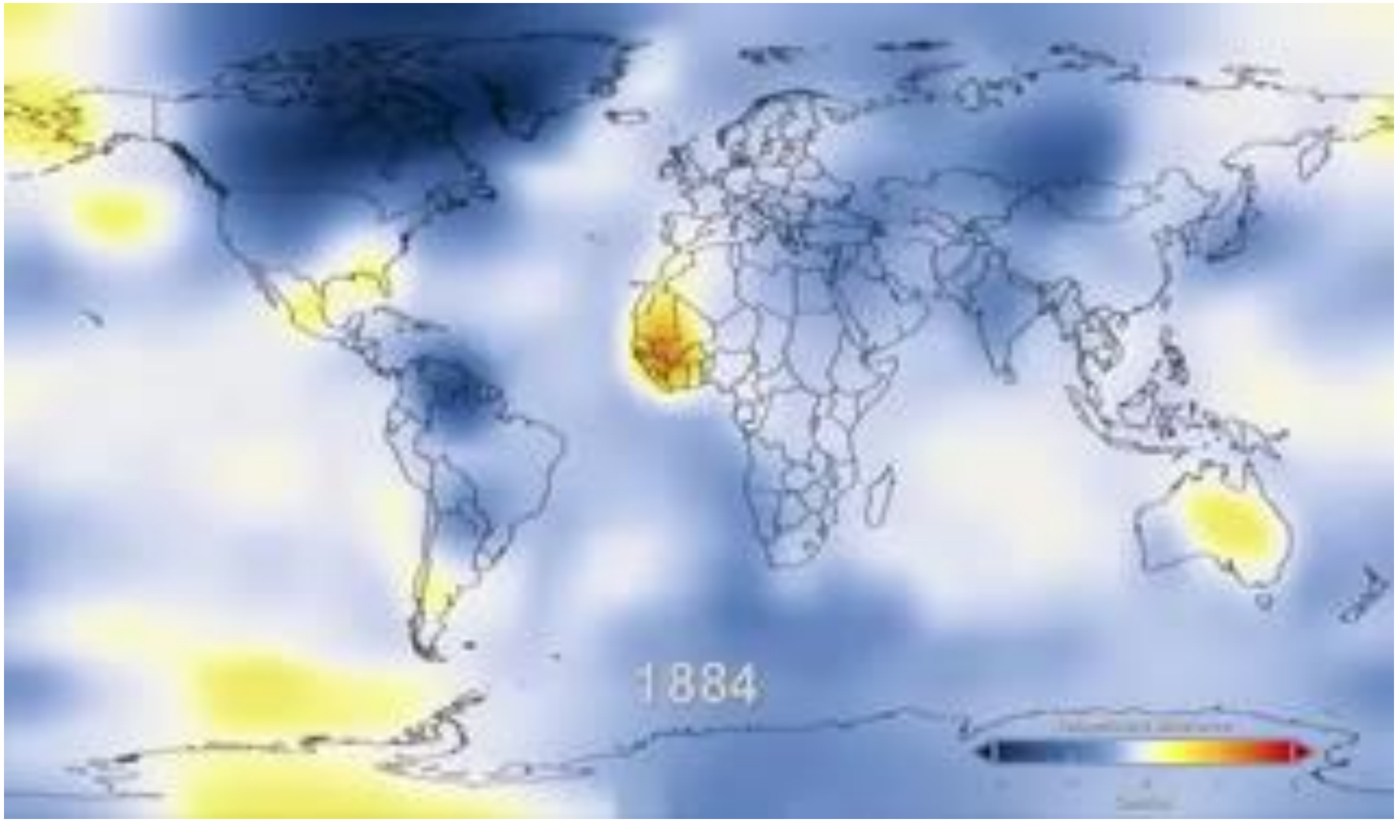
Climate Variability Postdocs



Massimo Bollasina

Monika Barcikowski

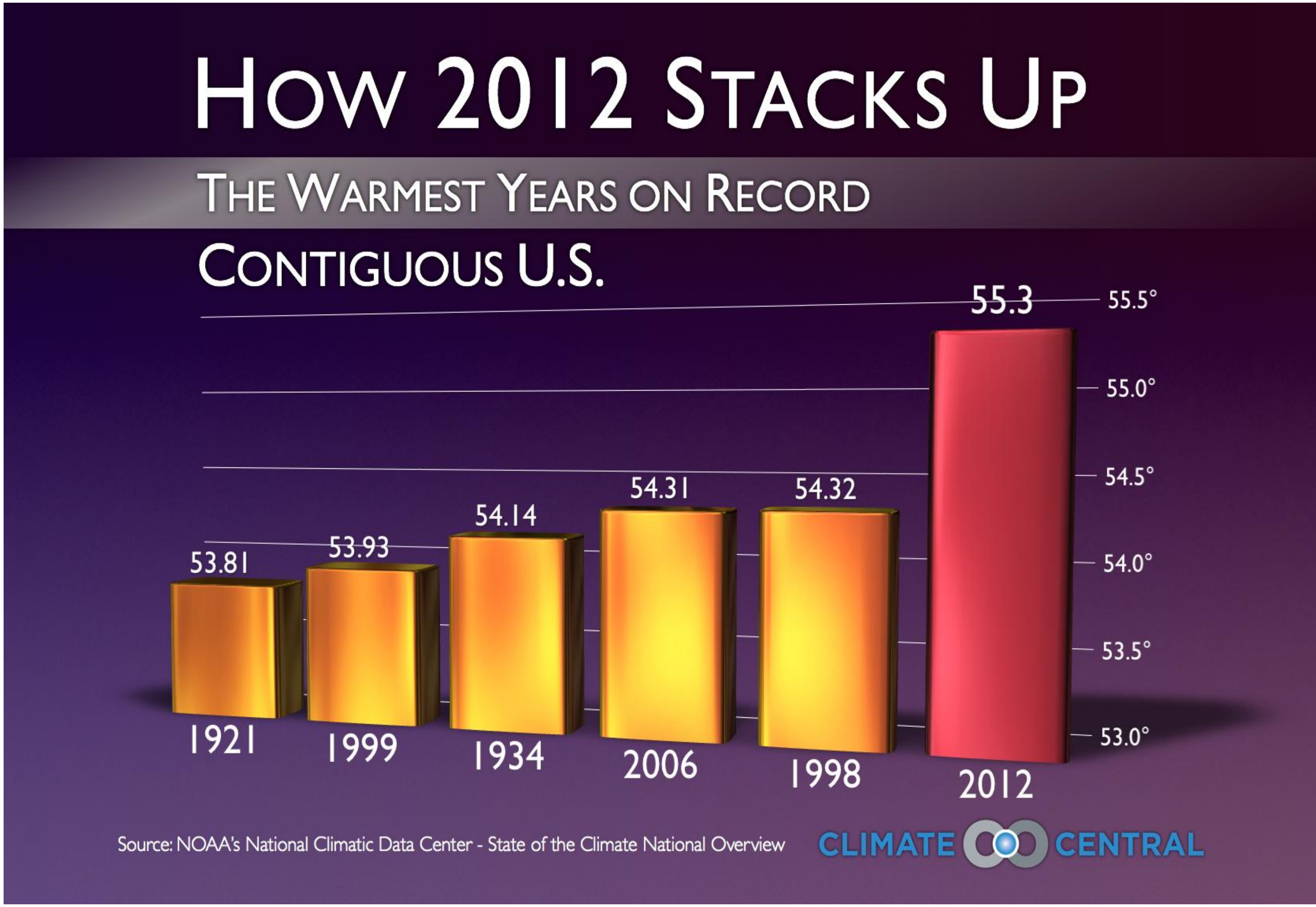
Global Warming

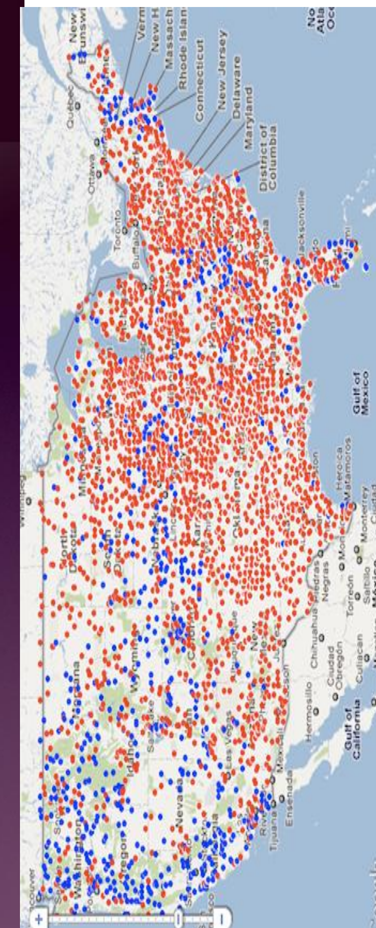


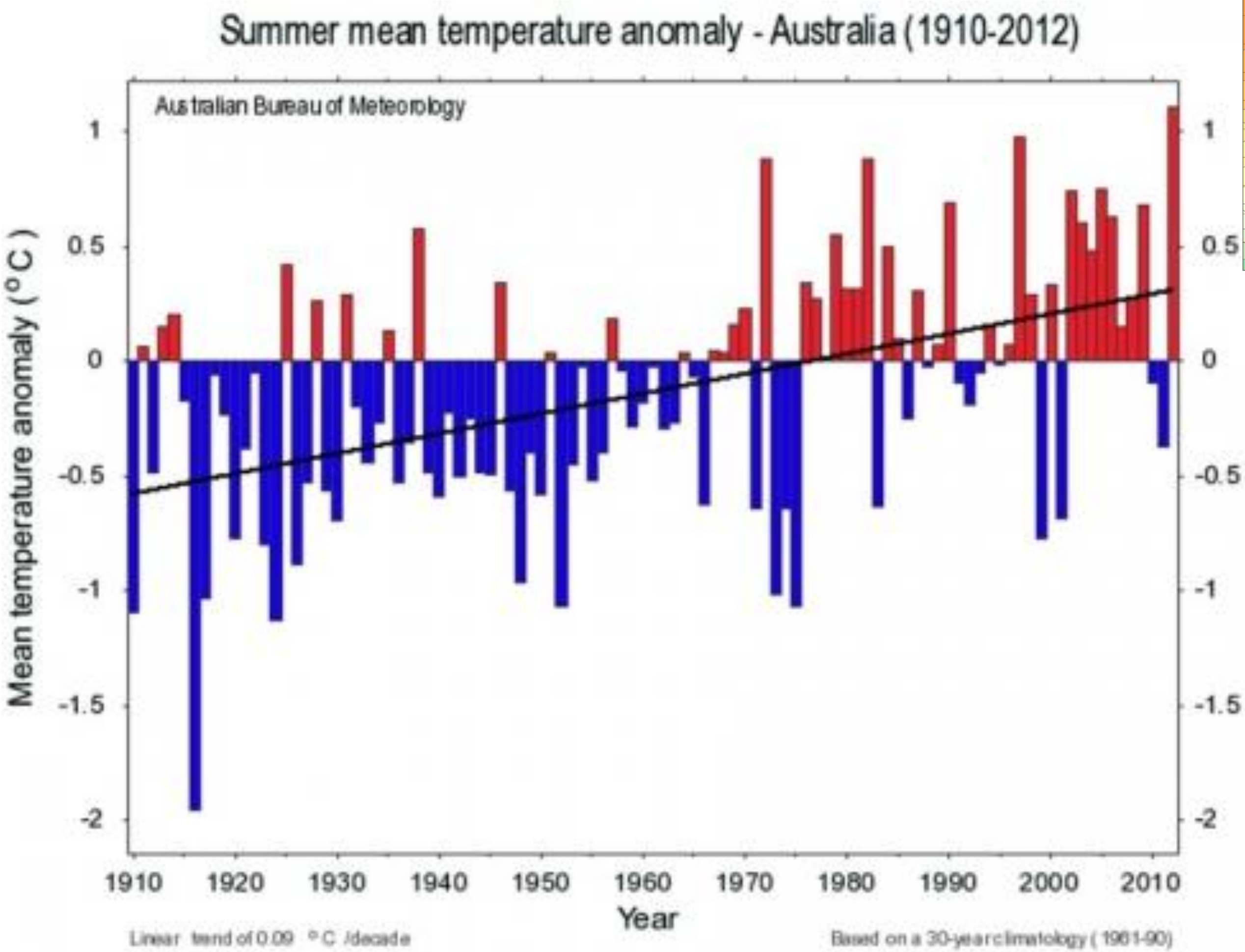
Weather Autopsy of 25,000-35,000 Deaths From the 2003 European Heat Wave

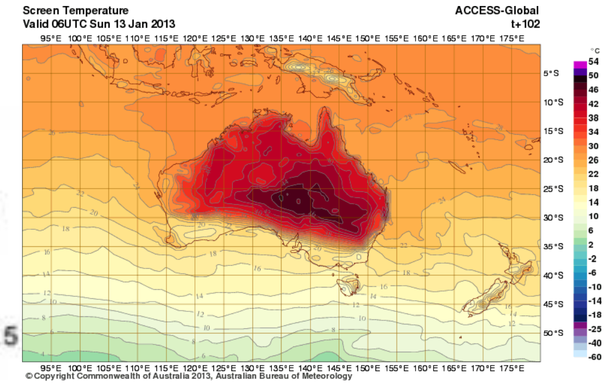
Human influence doubled the frequency of summers as hot as Europe’s 2003.

Models predict that by 2040 – a 2003-type summer every other year.


How 2012 Stacks Up
The Warmest Years on Record
Contiguous U.S.
55.3
55.5°
55.0°
54.5°
54.0°
53.5°
53.0°
53.81
53.93
54.14
54.31
54.32
1921
1999
1934
2006
1998
2012
Source: NOAA's National Climatic Data Center - State of the Climate National Overview
CLIMATE CENTRAL




Summer mean temperature anomaly - Australia (1910-2012)
Australian Bureau of Meteorology
Mean temperature anomaly (°C)
1
0.5
0
-0.5
-1
-1.5
-2
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
Year
Linear trend of 0.09 °C /decade
Based on a 30-year climatology (1961-90)


Screen Temperature
Valid 06UTC Sun 13 Jan 2013
ACCESS-Global
t+102
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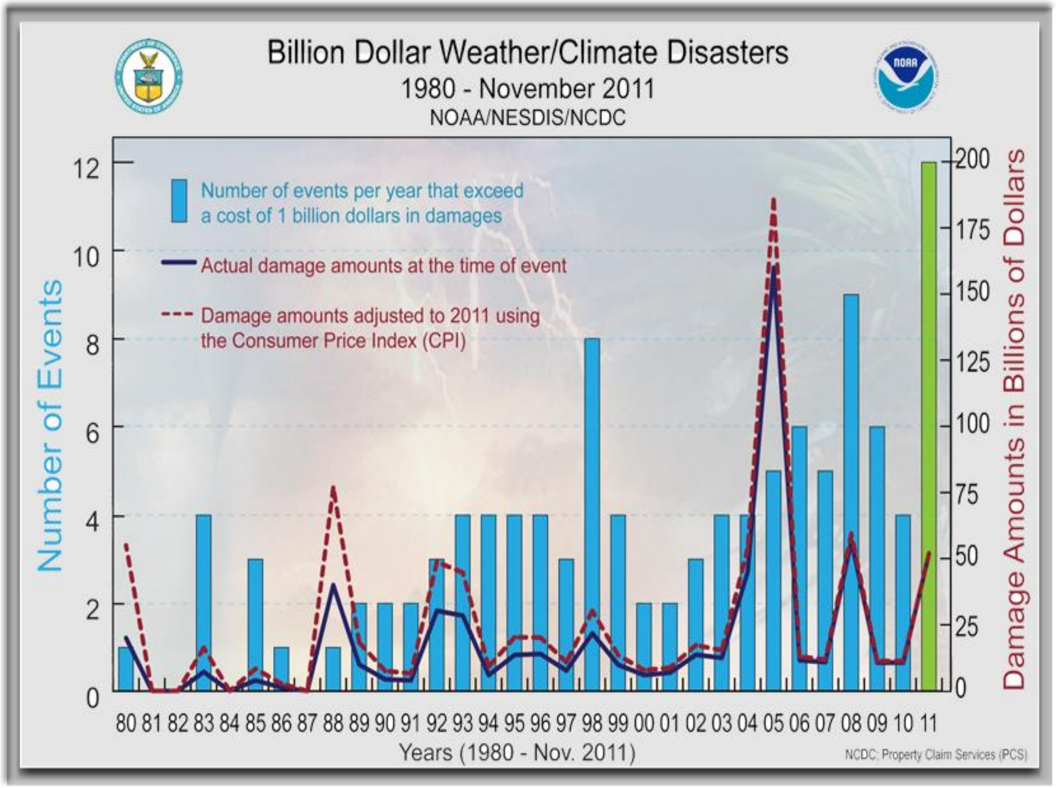
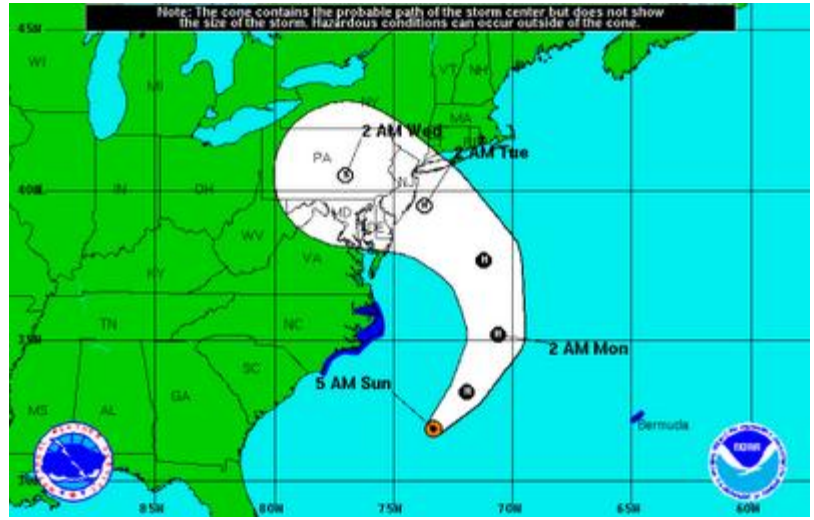
Extreme Weather






Global Warming Flood Risk
ClimateCentral.org
Odds of extreme coastal floods by 2030
Seattle
83%
San Francisco
Los Angeles
New York
23%
Boston
Baltimore
Norfolk
Charleston
New Orleans
Tampa
25%
Keys
With sea rise from warming
Without