Coastal and marine ecosystems: Greenhouse gas sources, sinks and reservoirs: Results from research by the ESSP on coastal and marine ecosystems-related research

Rik Leemans, Martin Rice, Ghassem Asnar,
Bruce Campbell, Pep Canadell, Anantha K. Duraiappah
Rob Jackson, Anne Larigauderie, Sybil Seitzinger, Barbara
Solich and Ruben Zondervan

UNFCCC-SBSTA meeting Bonn
19-5-2012

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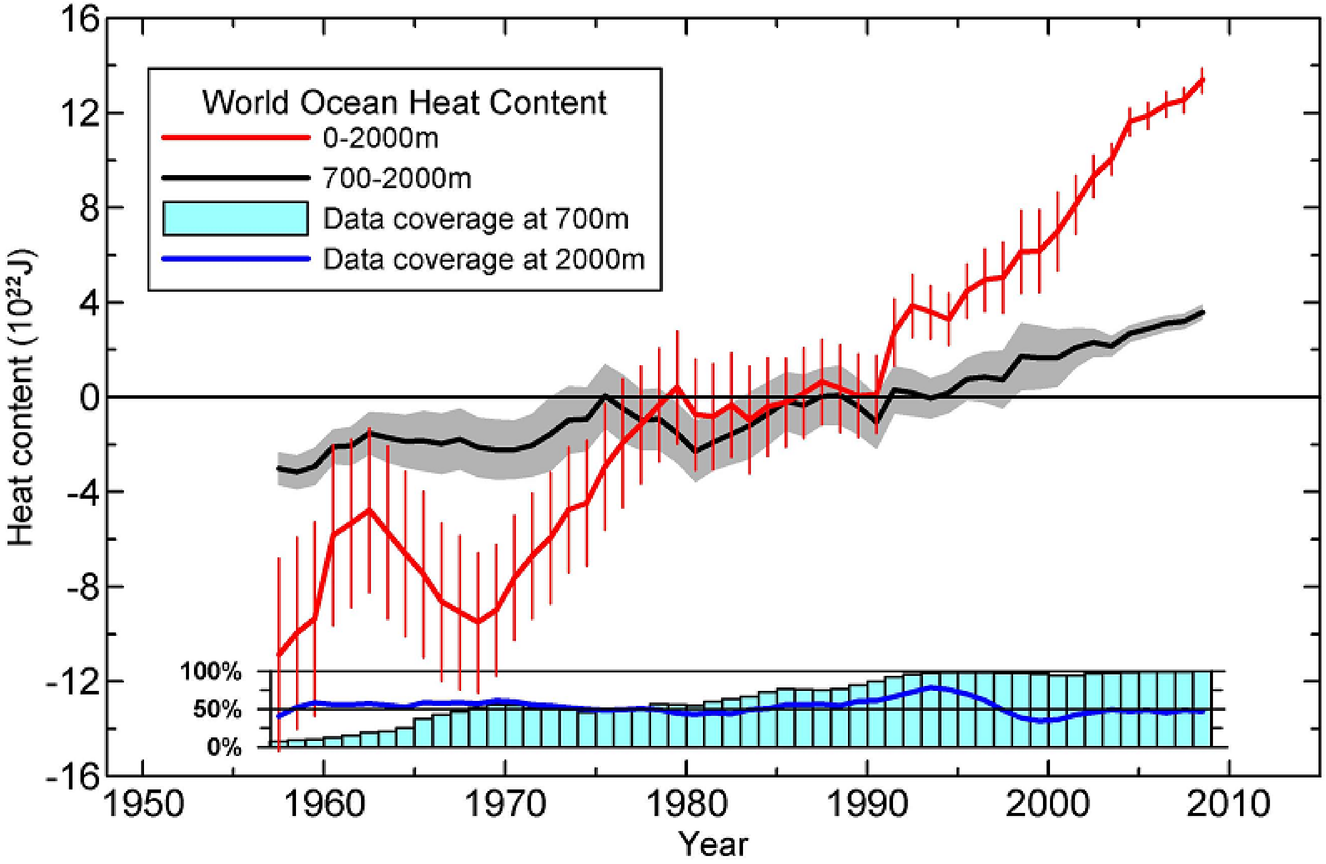
The oceans have warmed since 1955 due to GHG increase



- ○ A strong positive linear trend is observed in oceans' heat content since 1955
- ○ One third of the warming occurs in the deeper ocean.
- ○ The warming can only be explained by the increase in atmospheric GHG.

Levitus et al. 2012. World ocean heat content and thermosteric sea level change (0-2000), 1955-2010. GEOPHYSICAL RESEARCH LETTERS, doi:10.1029/2012GL051106

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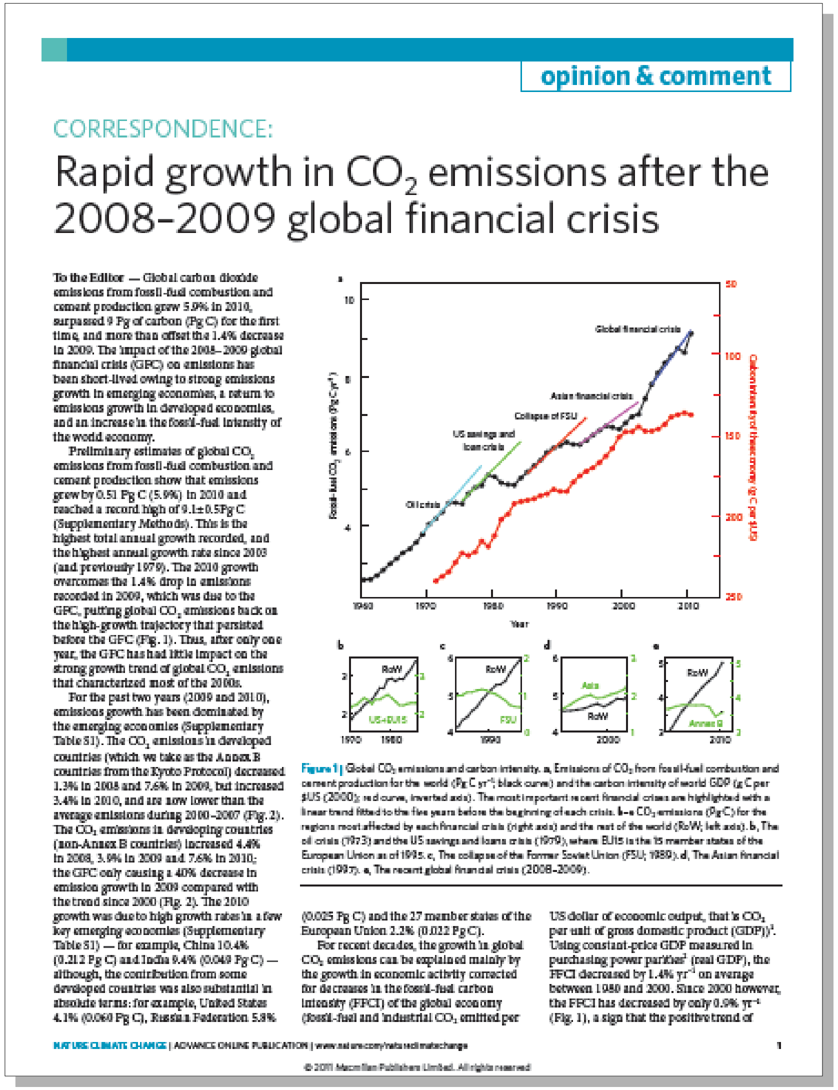
Carbon Budget 2010



opinion & comment

CORRESPONDENCE:

Rapid growth in CO_2 emissions after the 2008–2009 global financial crisis

To the Editor — Global carbon dioxide emissions from fossil-fuel combustion and cement production grew 5.9% in 2010, surpassed 9 Pg of carbon (Pg C) for the first time, and more than offset the 1.4% decrease in 2009. The impact of the 2008–2009 global financial crisis (GFC) on emissions has been short-lived owing to strong emissions growth in emerging economies, a return to emissions growth in developed economies, and an increase in the fossil-fuel intensity of the world economy.

Preliminary estimates of global CO_2 emissions from fossil-fuel combustion and cement production show that emissions grew by 0.51 Pg C (5.9%) in 2010 and reached a record high of 9.1±0.5 Pg C (Supplementary Methods). This is the highest total annual growth recorded, and the highest annual growth rate since 2003 (and previously 1979). The 2010 growth overcomes the 1.4% drop in emissions recorded in 2009, which was due to the GFC, putting global CO_2 emissions back on the high-growth trajectory that persisted before the GFC (Fig. 1). Thus, after only one year, the GFC has had little impact on the strong growth trend of global CO_2 emissions that characterized most of the 2000s.

For the past two years (2009 and 2010), emissions growth has been dominated by the emerging economies (Supplementary Table S1). The CO_2 emissions in developed countries (which we take as the Annex B countries from the Kyoto Protocol) decreased 1.3% in 2008 and 7.6% in 2009, but increased 3.4% in 2010, and are now lower than the average emissions during 2000–2007 (Fig. 2). The CO_2 emissions in developing countries (non-Annex B countries) increased 4.4% in 2008, 3.9% in 2009 and 7.6% in 2010; the GFC only causing a 40% decrease in emission growth in 2009 compared with the trend since 2000 (Fig. 2). The 2010 growth was due to high growth rates in a few key emerging economies (Supplementary Table S1) — for example, China 10.4% (0.212 Pg C) and India 9.4% (0.049 Pg C) — although, the contribution from some developed countries was also substantial in absolute terms: for example, United States 4.1% (0.060 Pg C), Russian Federation 5.8% (0.025 Pg C) and the 27 member states of the European Union 2.2% (0.022 Pg C).

For recent decades, the growth in global CO_2 emissions can be explained mainly by the growth in economic activity corrected for decreases in the fossil-fuel carbon intensity (FFCI) of the global economy (fossil-fuel and industrial CO_2 emitted per US dollar of economic output, that is CO_2 per unit of gross domestic product (GDP))[1]. Using constant-price GDP measured in purchasing power parities[2] (real GDP), the FFCI decreased by 1.4% yr^{-1} on average between 1980 and 2000. Since 2000 however, the FFCI has decreased by only 0.9% yr^{-1} (Fig. 1), a sign that the positive trend of

Figure 1 | Global CO_2 emissions and carbon intensity. a, Emissions of CO_2 from fossil-fuel combustion and cement production for the world (Pg C yr^{-1}; black curve) and the carbon intensity of world GDP (g C per \$US (2000); red curve, inverted axis). The most important recent financial crises are highlighted with a linear trend fitted to the five years before the beginning of each crisis. b–e CO_2 emissions (Pg C) for the regions most affected by each financial crisis (right axis) and the rest of the world (RoW; left axis). b, The oil crisis (1973) and the US savings and loans crisis (1979), where EU15 is the 15 member states of the European Union as of 1995. c, The collapse of the Former Soviet Union (FSU; 1989). d, The Asian financial crisis (1997). e, The recent global financial crisis (2008–2009).

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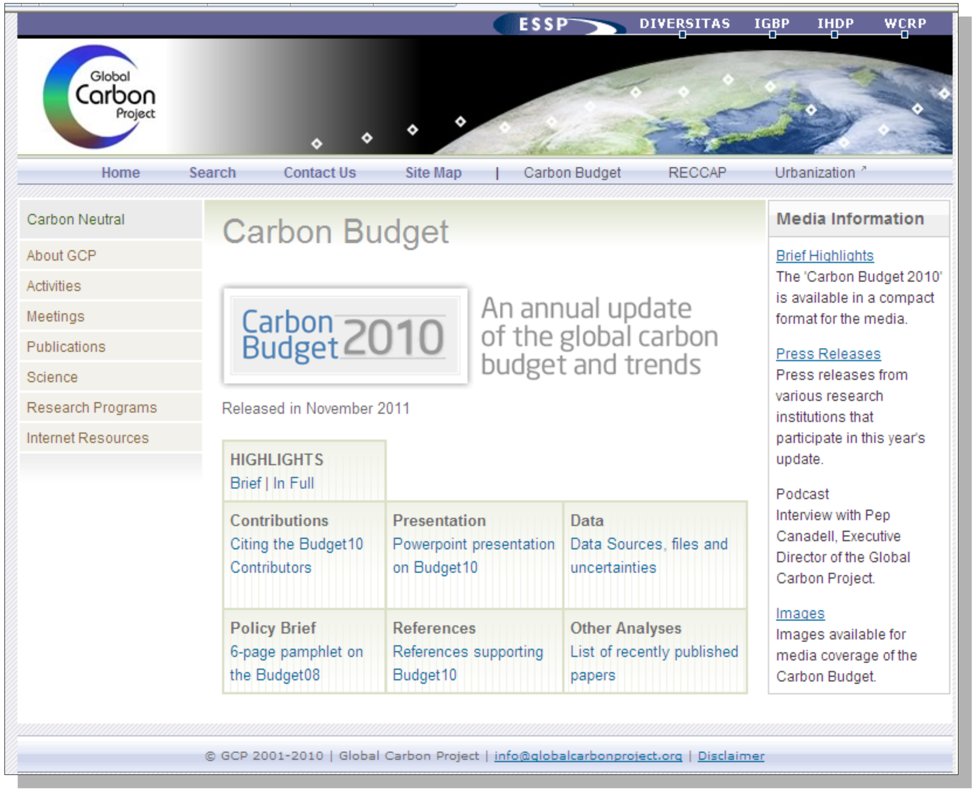

Carbon Budget

Carbon Budget 2010

An annual update of the global carbon budget and trends

Released in November 2011

HIGHLIGHTS Brief | In Full		
Contributions Citing the Budget10 Contributors	Presentation Powerpoint presentation on Budget10	Data Data Sources, files and uncertainties
Policy Brief 6-page pamphlet on the Budget08	References References supporting Budget10	Other Analyses List of recently published papers

Media Information

Brief Highlights
The 'Carbon Budget 2010' is available in a compact format for the media.

Press Releases
Press releases from various research institutions that participate in this year's update.

Podcast
Interview with Pep Canadell, Executive Director of the Global Carbon Project.

Images
Images available for media coverage of the Carbon Budget.

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http://www.globalcarbonproject.org/carbonbudget

Peters GP, Marland G, Le Quéré C, Boden T, Canadell JG, Raupach MR (2011) Rapid growth in CO_2 emissions after the 2008-2009 global financial crisis. Nature Climate Change, doi. 10.1038/nclimate1332.

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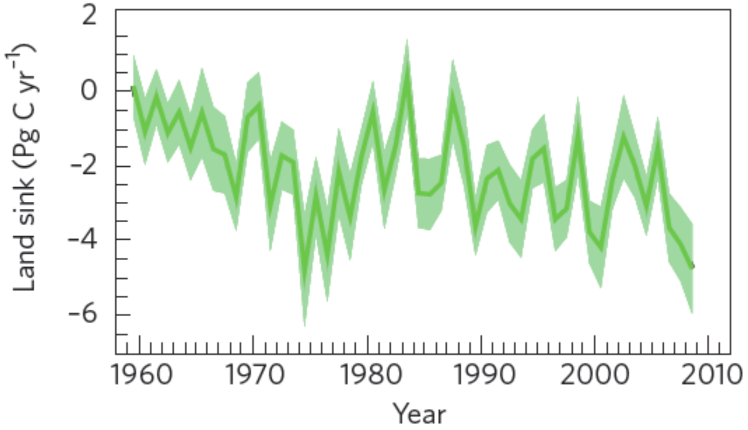
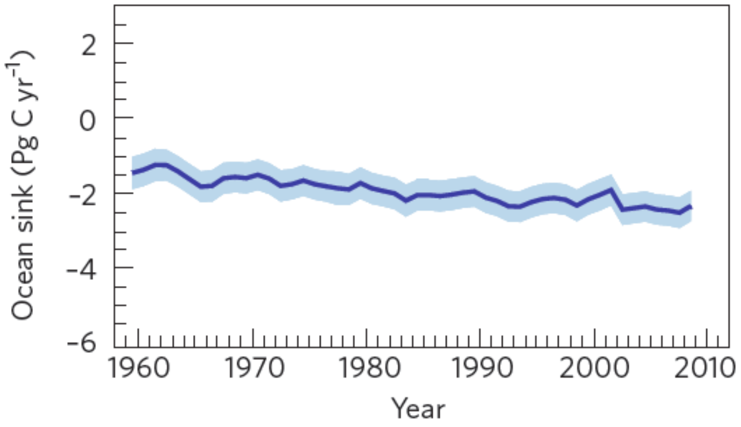
Trends in sinks of carbon





nature geoscience
FOCUS | PROGRESS ARTICLES
PUBLISHED ONLINE: 17 NOVEMBER 2009 | DOI: 10.1038/NGEO689

Trends in the sources and sinks of carbon dioxide

Corinne Le Quéré, Michael R. Raupach, Josep G. Canadell, Gregg Marland *et al.**

Efforts to control climate change require the stabilization of atmospheric CO_2 concentrations. This can only be achieved through a drastic reduction of global CO_2 emissions. Yet fossil fuel emissions increased by 29% between 2000 and 2008, in conjunction with increased contributions from emerging economies, from the production and international trade of goods and services, and from the use of coal as a fuel source. In contrast, emissions from land-use changes were nearly constant. Between 1959 and 2008, 43% of each year's CO_2 emissions remained in the atmosphere on average; the rest was absorbed by carbon sinks on land and in the oceans. In the past 50 years, the fraction of CO_2 emissions that remains in the atmosphere each year has likely increased, from about 40% to 45%, and models suggest that this trend was caused by a decrease in the uptake of CO_2 by the carbon sinks in response to climate change and variability. Changes in the CO_2 sinks are highly uncertain, but they could have a significant influence on future atmospheric CO_2 levels. It is therefore crucial to reduce the uncertainties.

Atmospheric measurements of CO_2 concentration are highly precise and provide an accurate, reliable measure of the increase of CO_2 in the atmosphere every year[1]. Yet these measurements cannot at present be used to verify global CO_2 emissions estimated from energy data, because the uptake of CO_2 by the land and ocean CO_2 sinks are not quantified with high enough accuracy. Understanding the difference in amount between anthropogenic CO_2 emissions and changes in atmospheric CO_2 concentration requires good estimates of the sinks and good attribution of the causes of changes, both for the emissions and for their partitioning between the natural reservoirs.

Global CO_2 emissions and their partitioning between the atmosphere and the land and ocean CO_2 sinks can be established using a wide range of geophysical and economic data. We have constructed a global CO_2 budget for each year during 1959–2008 and analysed the underlying drivers of each component. The global increase in atmospheric CO_2 was determined directly from measurements. CO_2 emissions from fossil fuel combustion were estimated on the basis of countries' energy statistics. CO_2 emissions from land-use change (LUC) were estimated using deforestation and other land-use data, fire observations from space, and assumptions on the carbon density of vegetation and soils and the fate of carbon. The time evolution of the land and ocean CO_2 sinks, however, cannot be estimated directly from observations. For these terms, we used state-of-the-art models on which we imposed the observed meteorological conditions of the past few decades. The resulting global CO_2 budget provides insight into the global carbon cycle and the emerging trends.

Fossil fuel CO_2 emissions

CO_2 emissions from fossil fuel combustion, including small contributions from cement production and gas flaring, were 8.7±0.5 Pg C yr^{-1} in 2008, an increase of 2.0% on 2007, 29% on 2000 and 41% above emissions in 1990 (Supplementary Table 1; see Methods). Emissions increased at a rate of 3.4% yr^{-1} between 2000 and 2008, compared with 1.0% yr^{-1} in the 1990s (Fig. 1). Emissions continued to track the average of the most carbon-intensive family of scenarios put forward by the Intergovernmental Panel on Climate Change[13] (IPCC; scenario A1FI in Fig. 1a). Since 1990, the growth in fossil fuel CO_2 emissions has been dominated by countries that do not have emissions limitations in the so-called non-Annex B of the Kyoto Protocol (mostly emerging economies in developing countries), where emissions have more than doubled in that time (Fig. 1b). Among Annex B countries (mostly advanced economies with emissions limitations), growth in some has been offset by declines in others. This recent growth in CO_2 emissions parallels a shift in the largest fuel emission source from oil to coal. Coal contributed 40% of the fossil fuel CO_2 emissions in 2008, compared with 37% for 1990–2000, whereas the contribution of oil changed from 41% for 1990–2000 to 36% in 2008 (Fig. 1c). This shift in the dominant source of fossil fuel emissions has reversed the prevalence of oil since 1968. The growth in emissions since 2000 was also accompanied by an increase in the world per-capita emissions from 1.1 metric tons of carbon in 2000 (Fig. 1d) to an all-time high of 1.3 metric tons of carbon in 2008.

There is growing evidence that the rapid growth in international trade[4–10] and a shift of Annex B economic activity towards services[8] were significant in driving non-Annex B CO_2 emission increases due to fossil fuels. Several recent studies provide indicators of the magnitude and time evolution of the share of non-Annex B emission growth that was due to production of manufactured products exported and consumed in Annex B countries. In 2001, the equivalent of 0.22 Pg C was emitted in non-Annex B countries to produce internationally traded products consumed in Annex B countries[4]. In China alone, 30% of the growth in emissions between 1990 and 2002 was attributable to the production of exports from China that were consumed in other countries[6], and the share of the growth increased to 50% between 2002 and 2005 (ref. 7). In 1990, 16% of Chinese emissions were from the production of exports, increasing to 30% in 2005. Over half of the exported products were destined for Annex B countries[6,7]. Complementary studies in some Annex B countries showed that consumption-based emissions (that is, emissions including imported products from non-Annex B countries, but excluding goods and services) were increasing faster than emissions from domestic production[8,9]. In the UK, for instance, within-country emissions decreased by 5% between 1992 and 2004, whereas consumption-based emissions increased by 12% (ref. 8). In the USA, within-country emissions increased by 6% between 1997 and 2004, whereas consumption-based emissions increased by 17% (ref. 9). In both cases, a key factor driving the growth in consumption-based emissions was the import of manufactured products from China[4–9]. Taken together, these studies imply that a considerable share of the growth of emissions from non-Annex B countries was associated with international trade. This explained around one-quarter of the growth in non-Annex B emissions since 2000.

The growth in the world gross domestic product (GDP) was a key driver in the recent increase in CO_2 emissions[2]. Consequently,

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* A full list of authors and their affiliations appears at the end of the paper.

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The fraction of CO_2 emissions that remains in the atmosphere has likely increased from about 40% to 45%. Models suggest that this trend was caused by a decrease in the uptake of CO_2 by carbon sinks in response to climate change and variability.

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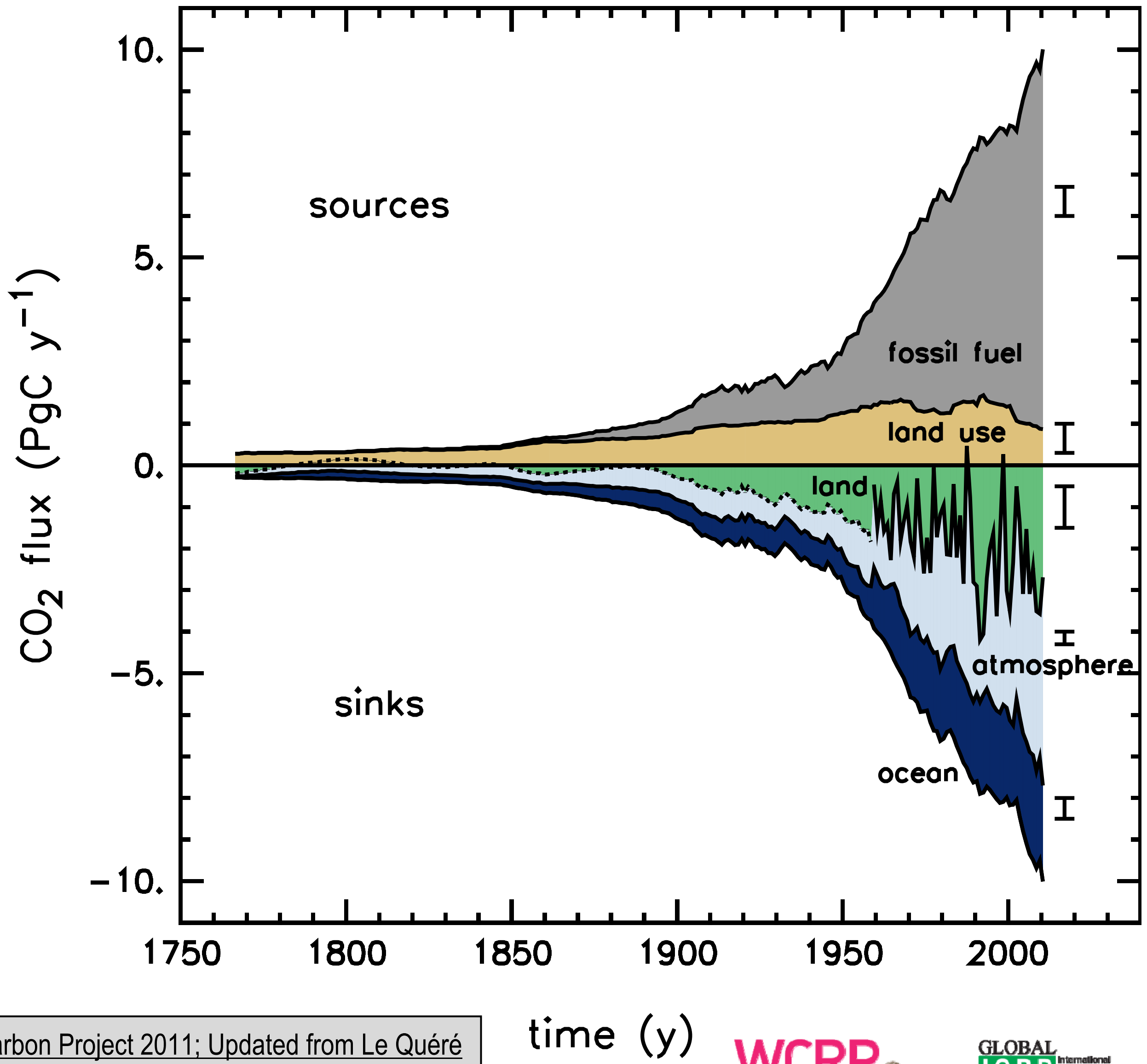
Human Perturbation of the Global Carbon Budget



2000-2010

(PgC y^{-1})

7.9±0.5

1.0±0.7

2.5±1.0

(Residual)

4.1±0.2

2.3±0.5

(5 models)

Global Carbon Project 2011; Updated from Le Quéré et al. 2009, Nature G; Canadell et al. 2007, PNAS

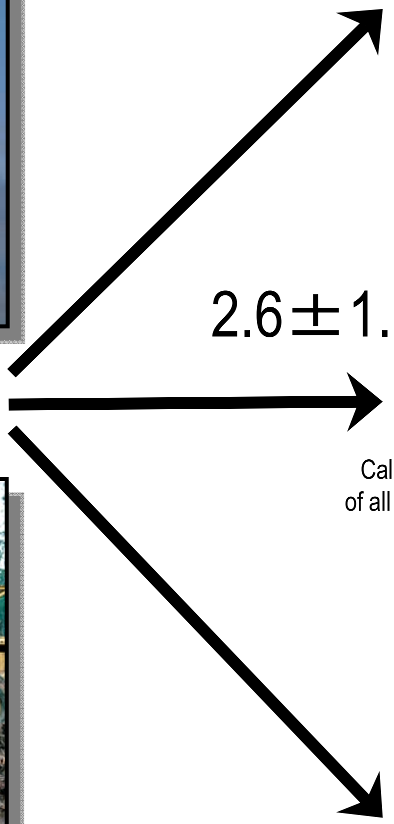
Fate of Anthropogenic CO2 Emissions (2010)

9.1 ± 0.5 PgC y^{-1}

+

0.9 ± 0.7 PgC y^{-1}

Global Carbon Project 2010; Updated from
Le Quéré et al. 2009, Nature Geoscience;
Canadell et al. 2007, PNAS



5.0 ± 0.2 PgC y^{-1}

50%

2.6 ± 1.0 PgC y^{-1}

26%

Calculated as the residual
of all other flux components

24%

2.4 ± 0.5 PgC y^{-1}

Average of 5 models

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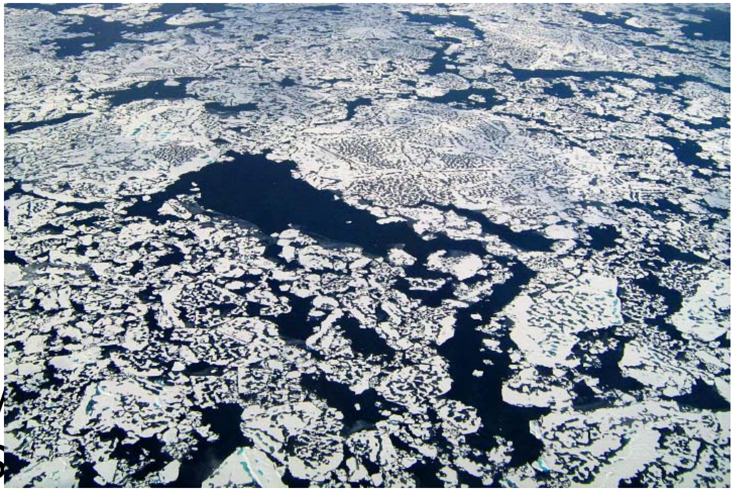
Large-scale carbon release as warming feedback (generally included in climate-model runs)

- **High northern latitude permafrost thawing** leads to carbon release (CO_2 and methane)
  - **By 2100** under high business-as-usual: release of carbon estimated at 120-420 $GtCO_2$ ➔ 0.04-0.23° C additional warming
- **"Frozen methane" below sea floor**: possible **destabilization** due to warming and be released (recorded in geological past)
  - Could lead to a slow, chronic release of methane from ocean hydrates ➔ blocking warming to return to lower levels for millennia



An observation: Kort et al (2012) measured increased methane levels while flying at lo altitudes above the Chukchi and Beaufort S

Schneider von Deimling et al (2011); Schuur and Abbott (2011); Archer et al (2009), Kort, E.A., et al (2012) Atmospheric observations of Arctic Ocean methane emissions up to 82° north. Nature Geoscience 5, 318–321

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ESSP-GWSP on vulnerability of rivers and water security

nature

THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

RIVERS IN CRISIS

Mapping dual threats to water security for biodiversity and humans PAGES 534 & 555

ANTICANCER THERAPY

THE DOUBLE HELIX

LABORATORY ETHICS

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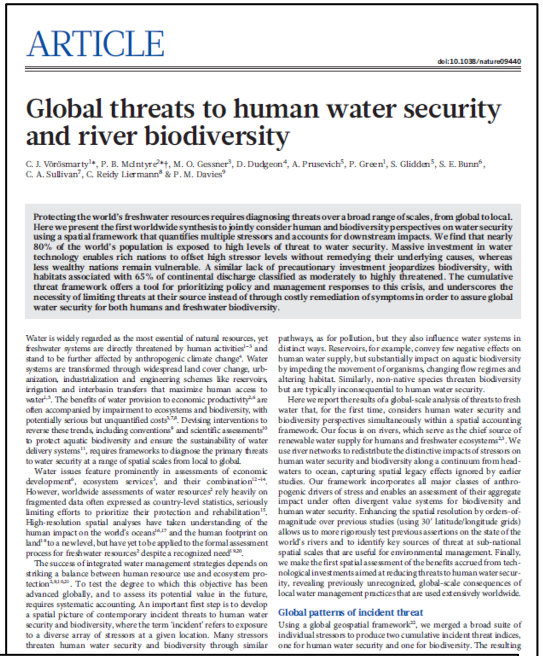


ARTICLE

doi:10.1038/nature09440

Global threats to human water security and river biodiversity

C. J. Vörösmarty[1]*, P. B. McIntyre[2]*†, M. O. Gessner[3], D. Dudgeon[4], A. Prusevich[5], P. Green[1], S. Glidden[5], S. E. Bunn[6], C. A. Sullivan[7], C. Reidy Liermann[8] & P. M. Davies[9]

Protecting the world's freshwater resources requires diagnosing threats over a broad range of scales, from global to local. Here we present the first worldwide synthesis to jointly consider human and biodiversity perspectives on water security using a spatial framework that quantifies multiple stressors and accounts for downstream impacts. We find that nearly 80% of the world's population is exposed to high levels of threat to water security. Massive investment in water technology enables rich nations to offset high stressor levels without remedying their underlying causes, whereas less wealthy nations remain vulnerable. A similar lack of precautionary investment jeopardizes biodiversity, with habitats associated with 65% of continental discharge classified as moderately to highly threatened. The cumulative threat framework offers a tool for prioritizing policy and management responses to this crisis, and underscores the necessity of limiting threats at their source instead of through costly remediation of symptoms in order to assure global water security for both humans and freshwater biodiversity.

Water is widely regarded as the most essential of natural resources, yet freshwater systems are directly threatened by human activities[1–3] and stand to be further affected by anthropogenic climate change[4]. Water systems are transformed through widespread land cover change, urbanization, industrialization and engineering schemes like reservoirs, irrigation and interbasin transfers that maximize human access to water[1,5]. The benefits of water provision to economic productivity[2,6] are often accompanied by impairment to ecosystems and biodiversity, with potentially serious but unquantified costs[3,7,8]. Devising interventions to reverse these trends, including conventions[9] and scientific assessments[10] to protect aquatic biodiversity and ensure the sustainability of water delivery systems[11], requires frameworks to diagnose the primary threats to water security at a range of spatial scales from local to global.

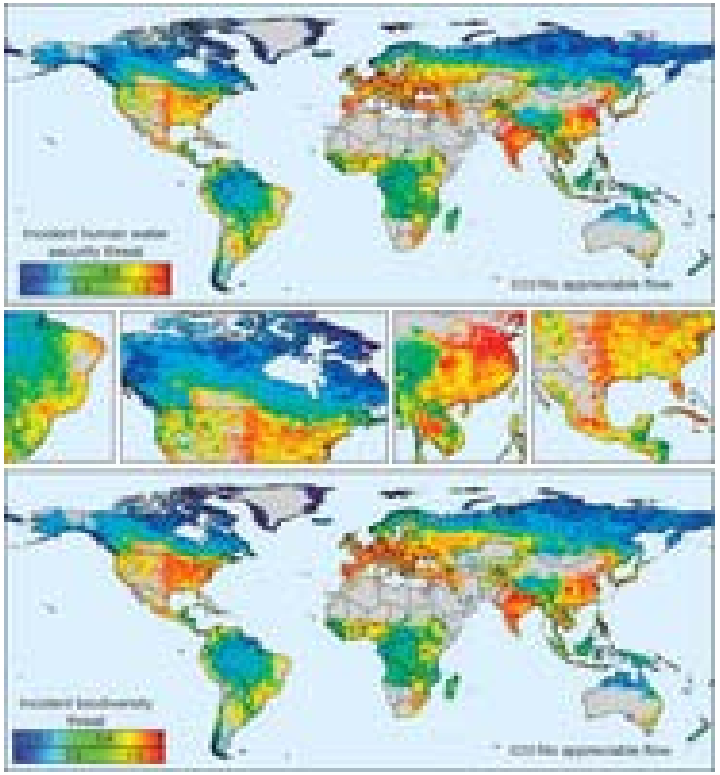
Water issues feature prominently in assessments of economic development[6], ecosystem services[3], and their combination[12–14]. However, worldwide assessments of water resources[2] rely heavily on fragmented data often expressed as country-level statistics, seriously limiting efforts to prioritize their protection and rehabilitation[15]. High-resolution spatial analyses have taken understanding of the human impact on the world's oceans[16,17] and the human footprint on land[18] to a new level, but have yet to be applied to the formal assessment process for freshwater resources[2] despite a recognized need[19,20].

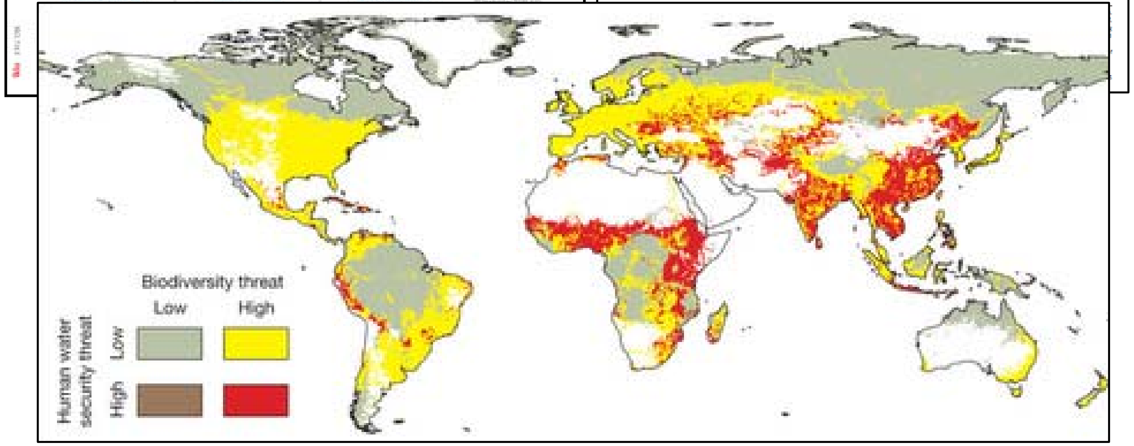
The success of integrated water management strategies depends on striking a balance between human resource use and ecosystem protection[2,9,10,21]. To test the degree to which this objective has been advanced globally, and to assess its potential value in the future, requires systematic accounting. An important first step is to develop a spatial picture of contemporary incident threats to human water security and biodiversity, where the term 'incident' refers to exposure to a diverse array of stressors at a given location. Many stressors threaten human water security and biodiversity through similar pathways, as for pollution, but they also influence water systems in distinct ways. Reservoirs, for example, convey few negative effects on human water supply, but substantially impact on aquatic biodiversity by impeding the movement of organisms, changing flow regimes and altering habitat. Similarly, non-native species threaten biodiversity but are typically inconsequential to human water security.

Here we report the results of a global-scale analysis of threats to fresh water that, for the first time, considers human water security and biodiversity perspectives simultaneously within a spatial accounting framework. Our focus is on rivers, which serve as the chief source of renewable water supply for humans and freshwater ecosystems[2,3]. We use river networks to redistribute the distinctive impacts of stressors on human water security and biodiversity along a continuum from headwaters to ocean, capturing spatial legacy effects ignored by earlier studies. Our framework incorporates all major classes of anthropogenic drivers of stress and enables an assessment of their aggregate impact under often divergent value systems for biodiversity and human water security. Enhancing the spatial resolution by orders-of-magnitude over previous studies (using 30′ latitude/longitude grids) allows us to more rigorously test previous assertions on the state of the world's rivers and to identify key sources of threat at sub-national spatial scales that are useful for environmental management. Finally, we make the first spatial assessment of the benefits accrued from technological investments aimed at reducing threats to human water security, revealing previously unrecognized, global-scale consequences of local water management practices that are used extensively worldwide.

Global patterns of incident threat

Using a global geospatial framework[22], we merged a broad suite of individual stressors to produce two cumulative incident threat indices, one for human water security and one for biodiversity. The resulting





Vorosmarty, C. J., P. B. McIntyre, M. O. Gessner, D. Dudgeon, A. Prusevich, P. Green, S. Glidden, S. E. Bunn, C. A. Sullivan, C. R. Liermann, and P. M. Davies. 2010. Global threats to human water security and river biodiversity. Nature 467:555-561.

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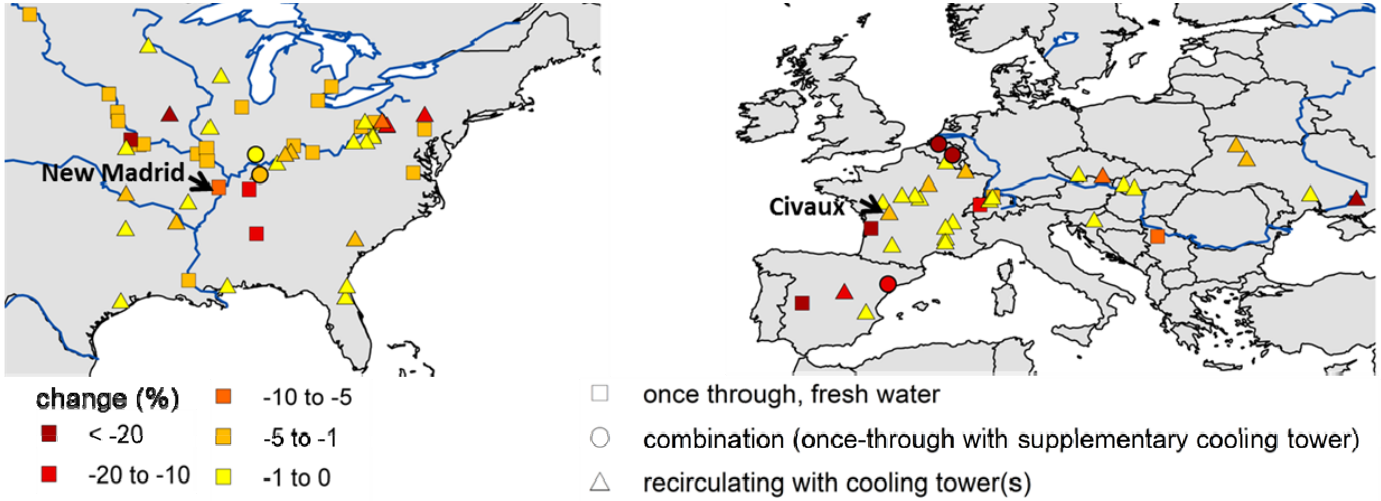
Vulnerability of US and European electricity supply to climate change



- Thermoelectric (nuclear and fossil fueled) power plants currently produce 91% of all electricity in the US and 78% in Europe
- Directly depend on availability and temperature of water resources for cooling
- Mean capacity decrease of 6.3-19% (Europe) and 4.4-16% (US) depending on cooling system type and climate scenario
- **Strong need for improved climate adaptation strategies in the thermoelectric power sector to assure future energy security**.

van Vliet et al., in press Nature climate change

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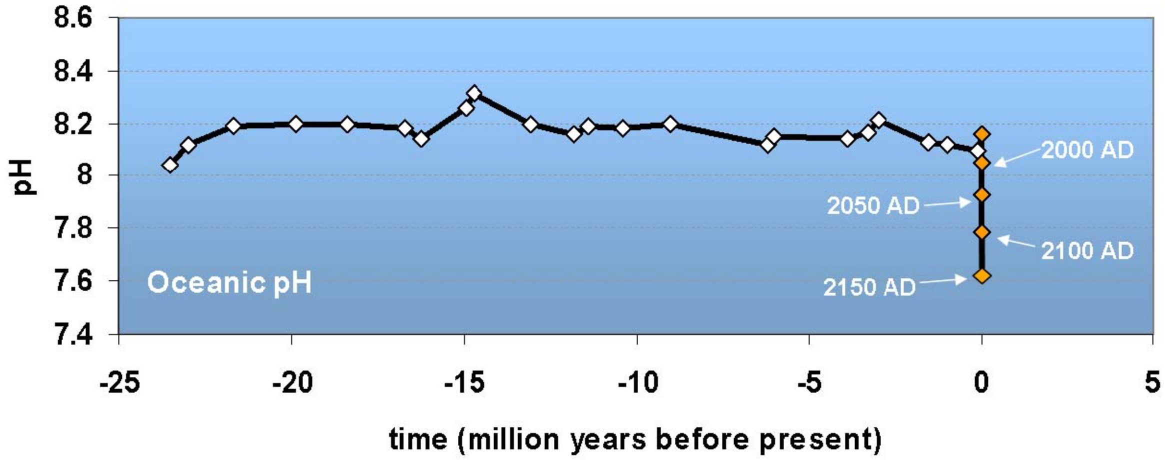
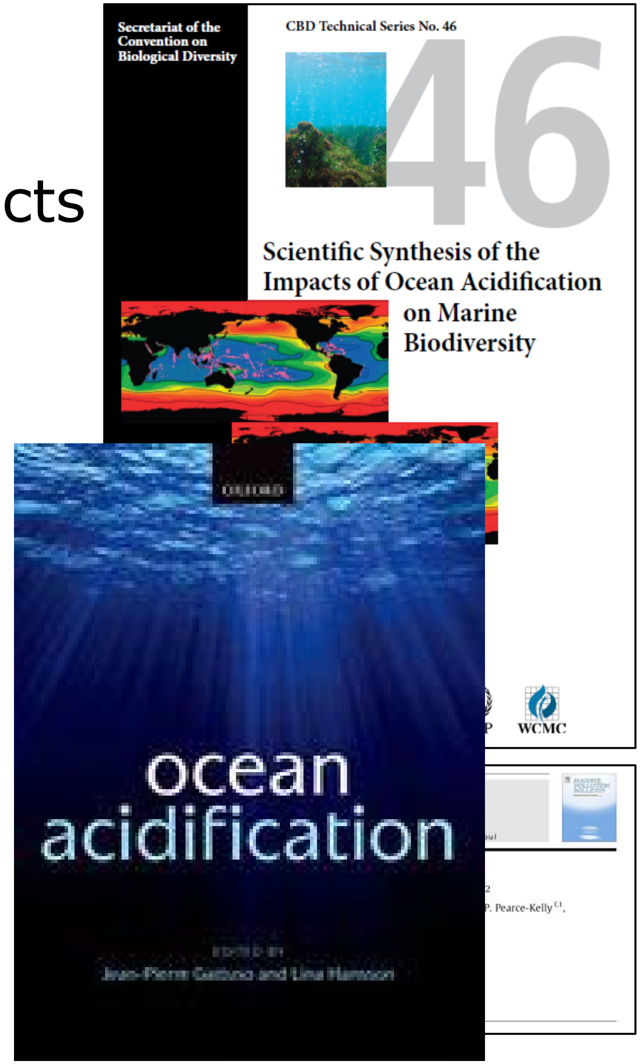
Coral Reefs: CO_2 and Ocean acidification

Increasing CO_2 concentration acidifying the world oceans

- ○ Likely to have wide ranging adverse effects
- ○ 550 ppm CO_2 coral reefs dissolve (reached by 2050s)
- ○ 450 ppm CO_2 coral stop growing (reached by 2030s)
- ○ Below 350 ppm CO_2 appears to be 'safe'





Secretariat of the Convention on Biological Diversity

CBD Technical Series No. 46

46

Scientific Synthesis of the Impacts of Ocean Acidification on Marine Biodiversity

WCMC

OXFORD

ocean acidification

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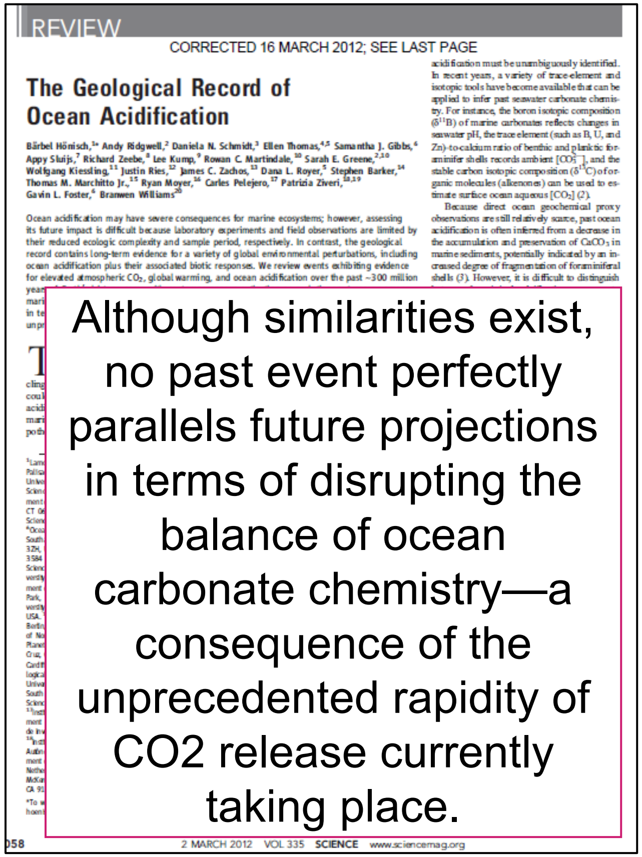
Much better insights in ocean acidification impacts



REVIEW

CORRECTED 16 MARCH 2012; SEE LAST PAGE

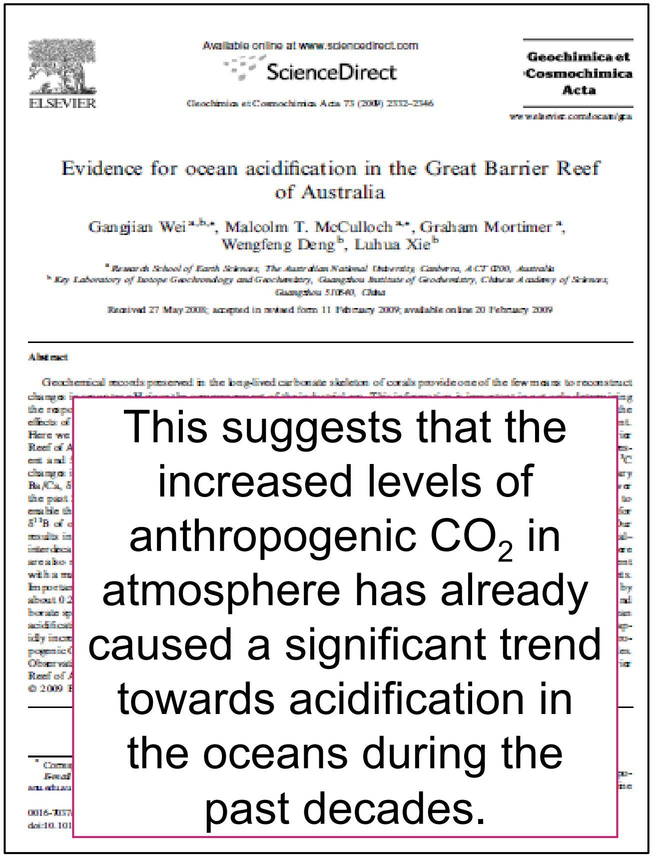
The Geological Record of Ocean Acidification

Bärbel Hönisch,[1]* Andy Ridgwell,[2] Daniela N. Schmidt,[3] Ellen Thomas,[4,5] Samantha J. Gibbs,[6] Appy Sluijs,[7] Richard Zeebe,[8] Lee Kump,[9] Rowan C. Martindale,[10] Sarah E. Greene,[2,10] Wolfgang Kiessling,[11] Justin Ries,[12] James C. Zachos,[13] Dana L. Royer,[5] Stephen Barker,[14] Thomas M. Marchitto Jr.,[15] Ryan Moyer,[16] Carles Pelejero,[17] Patrizia Ziveri,[18,19] Gavin L. Foster,[6] Branwen Williams[20]

Ocean acidification may have severe consequences for marine ecosystems; however, assessing its future impact is difficult because laboratory experiments and field observations are limited by their reduced ecologic complexity and sample period, respectively. In contrast, the geological record contains long-term evidence for a variety of global environmental perturbations, including ocean acidification plus their associated biotic responses. We review events exhibiting evidence for elevated atmospheric CO_2, global warming, and ocean acidification over the past ~300 million

2 MARCH 2012 VOL 335 SCIENCE www.sciencemag.org

Although similarities exist, no past event perfectly parallels future projections in terms of disrupting the balance of ocean carbonate chemistry—a consequence of the unprecedented rapidity of CO2 release currently taking place.



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Geochimica et Cosmochimica Acta 73 (2009) 2332–2346

Geochimica et Cosmochimica Acta

Evidence for ocean acidification in the Great Barrier Reef of Australia

Gangjian Wei[a,b,*], Malcolm T. McCulloch[a,*], Graham Mortimer[a], Wengfeng Deng[b], Luhua Xie[b]

Abstract

Geochemical records preserved in the long-lived carbonate skeleton of corals provide one of the few means to reconstruct

This suggests that the increased levels of anthropogenic CO_2 in atmosphere has already caused a significant trend towards acidification in the oceans during the past decades.

REPORTS

www.sciencemag.org SCIENCE VOL 335 3 FEBRUARY 2012 593

Increasing calcification rates on reefs off Western Australia contrast with the decline of Australia’s Great Barrier Reef and provide additional evidence that recent changes in coral calcification are responses to temperature rather than ocean acidification

Hönisch, B., A. Ridgwell, D. N. Schmidt, E. Thomas, S. J. Gibbs, A. Sluijs, R. Zeebe, L. Kump, R. C. Martindale, S. E. Greene, W. Kiessling, J. Ries, J. C. Zachos, D. L. Royer, S. Barker, T. M. Marchitto, R. Moyer, C. Pelejero, P. Ziveri, G. L. Foster, B. Williams. 2012. The Geological Record of Ocean Acidification. Science 335:1058-1063.

Wei, G., M. T. McCulloch, G. Mortimer, W. Deng, and L. Xie. 2009. Evidence for ocean acidification in the Great Barrier Reef of Australia. Geochimica et Cosmochimica Acta 73:2332-2346.

Cooper, T. F., R. A. O’Leary, and J. M. Lough. 2012. Growth of Western Australian Corals in the Anthropocene. Science 335:593-596.

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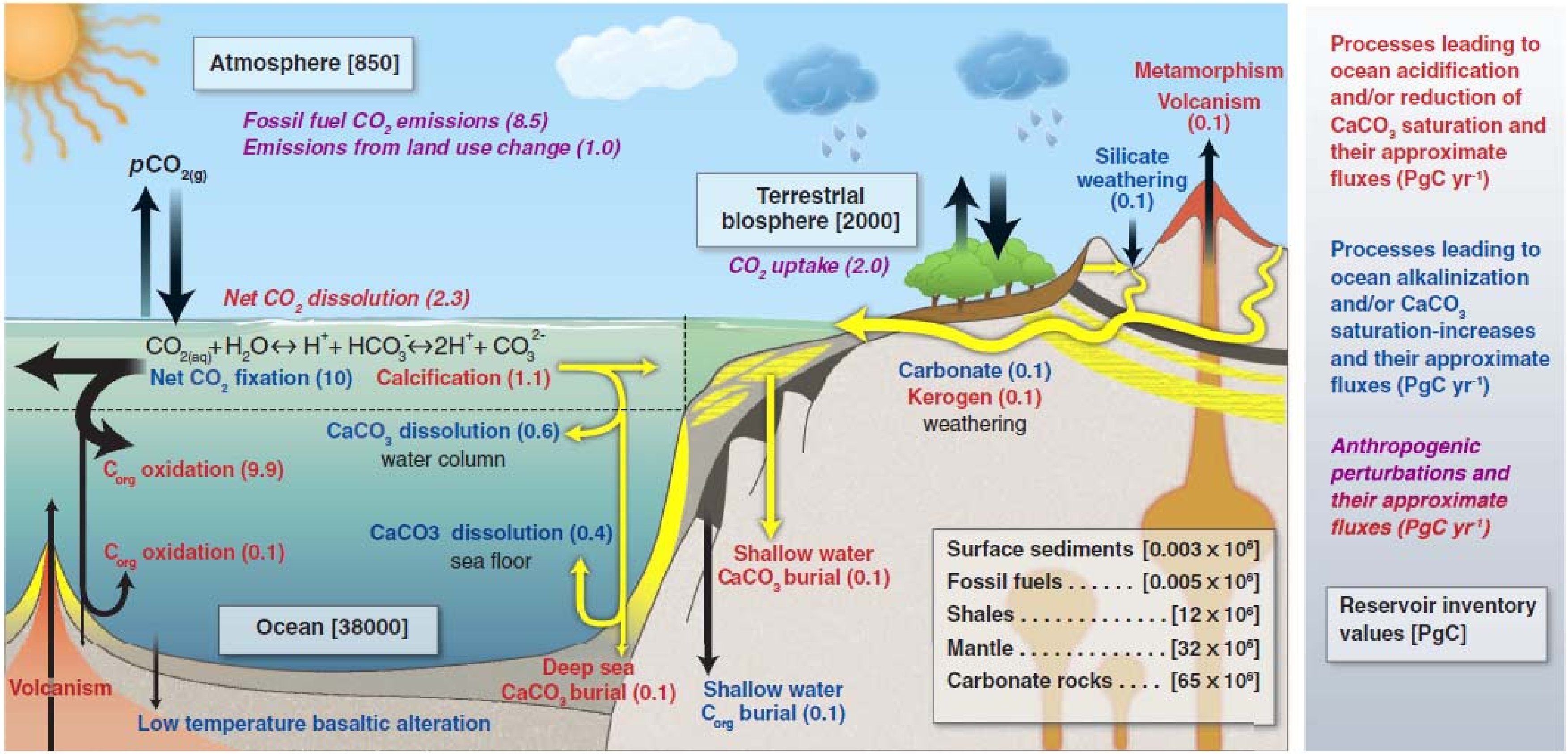
The process of ocean acidification



When CO_2 dissolves, it reacts with seawater to form carbonic acid, which then dissociates to bicarbonate, carbonate, and hydrogen ions. The hydrogen ions makes seawater acidic, but this process is buffered on long time scales by the interplay of seawater, seafloor carbonate sediments, and weathering on land. Shown are the major pathways of reduced carbon (**black**) and alkalinity (yellow). Ocean acidification or reduction of $CaCO_3$ saturation are indicated in **red**, and ocean alkalinization or $CaCO_3$ saturation increases are indicated in **blue**.

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Earth System
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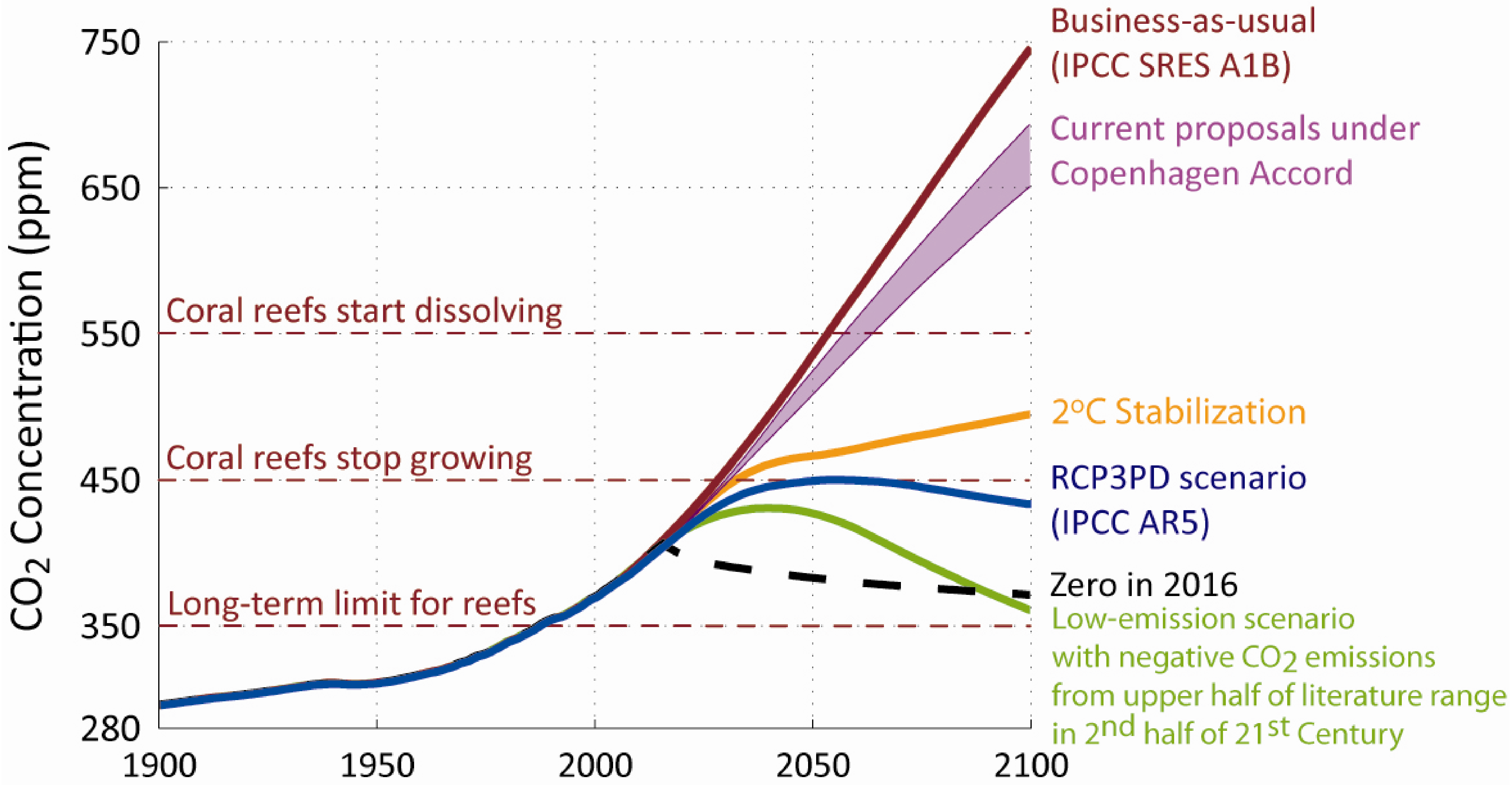
Latest scenario projections: Atmospheric CO_2 concentration (ppm)



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More information in our websites, newsletters and magazines:

Global Change
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