



# Emerging research findings: How to achieve the long-term climate-change goal of 2°C?

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Solich and Ruben Zondervan

UNFCCC-SBSTA meeting Bonn  
19-5-2012

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World Climate Research Programme

**GLOBAL**  
**IGBP** International  
Geosphere-Biosphere  
Programme  
**CHANGE**

**DIVERSITAS**  
an international programme  
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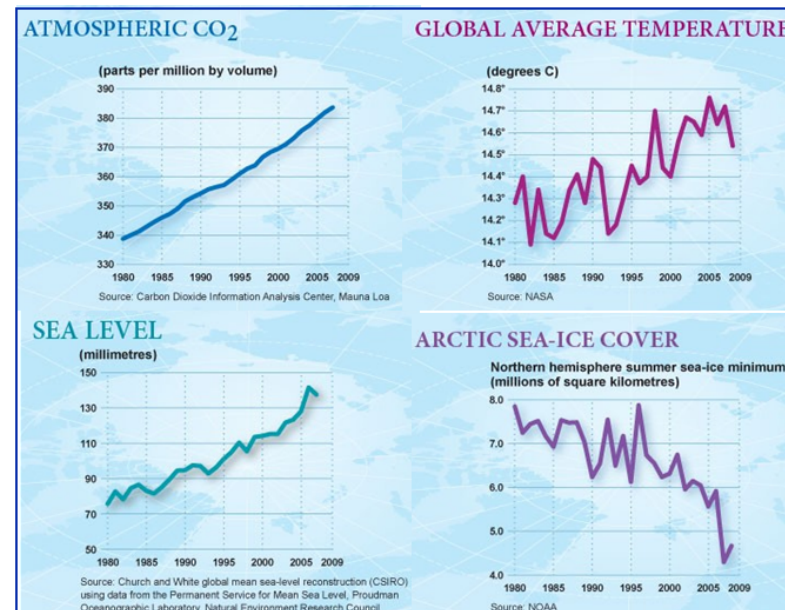


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# The Global Environmental Change Programmes and ESSP provide timely policy relevant information and scientific understanding to deal with climate change.



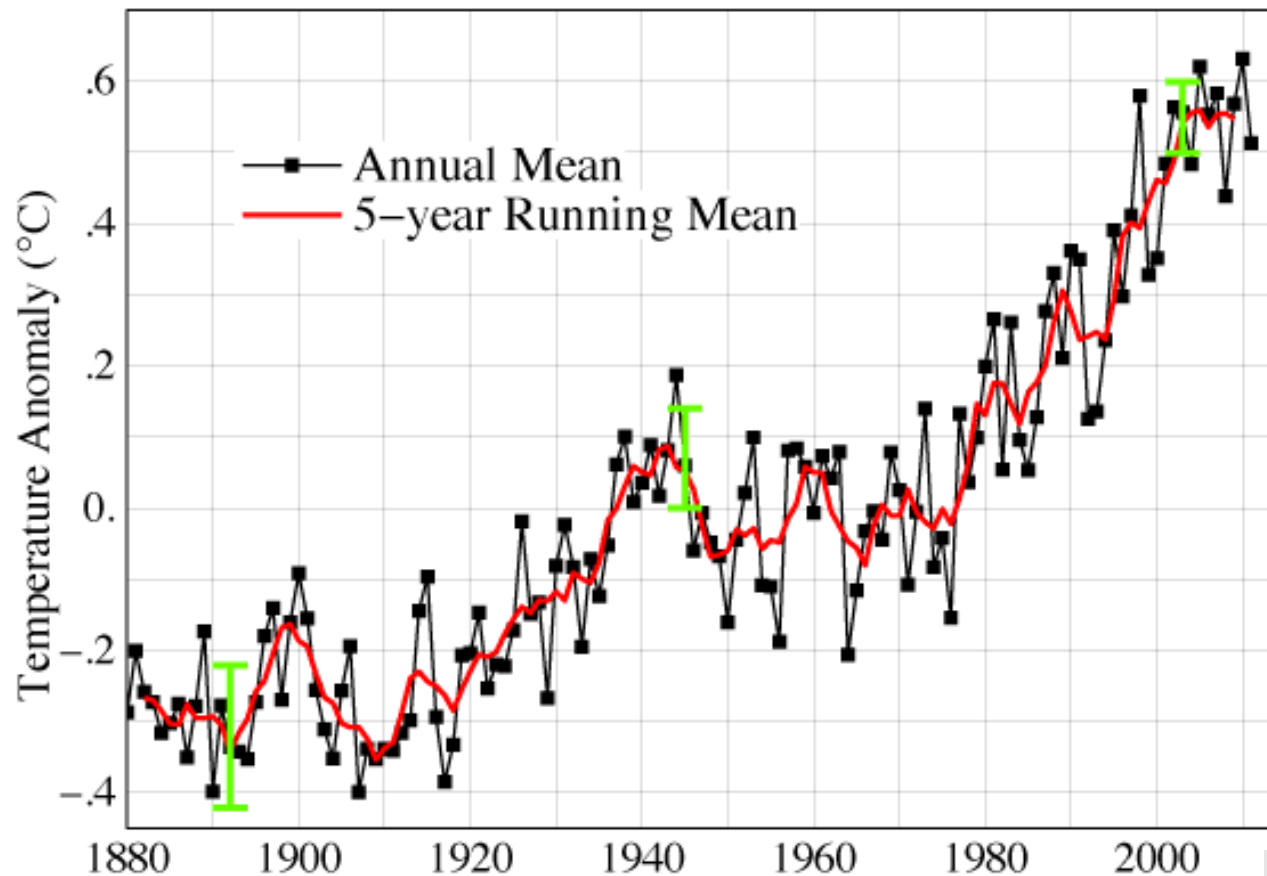
**This is illustrated by the IGBP climate-change index**, which It combines key indicators for CO<sub>2</sub>, temperature, sea level and sea ice. The index rises steadily and its change is unequivocal, it is global, and, significantly, it is in one direction.



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# Globally averaged increase in temperature anomaly (°C from 1951-80)

Global Land–Ocean Temperature Index



2011 was the 11th warmest since records began in 1850. This is in spite of a cooling La Niña.

Hansen, J., R. Ruedy, M. Sato, and K. Lo. 2010. Global surface temperature change. *Review Geophysics* 48:RG4004.

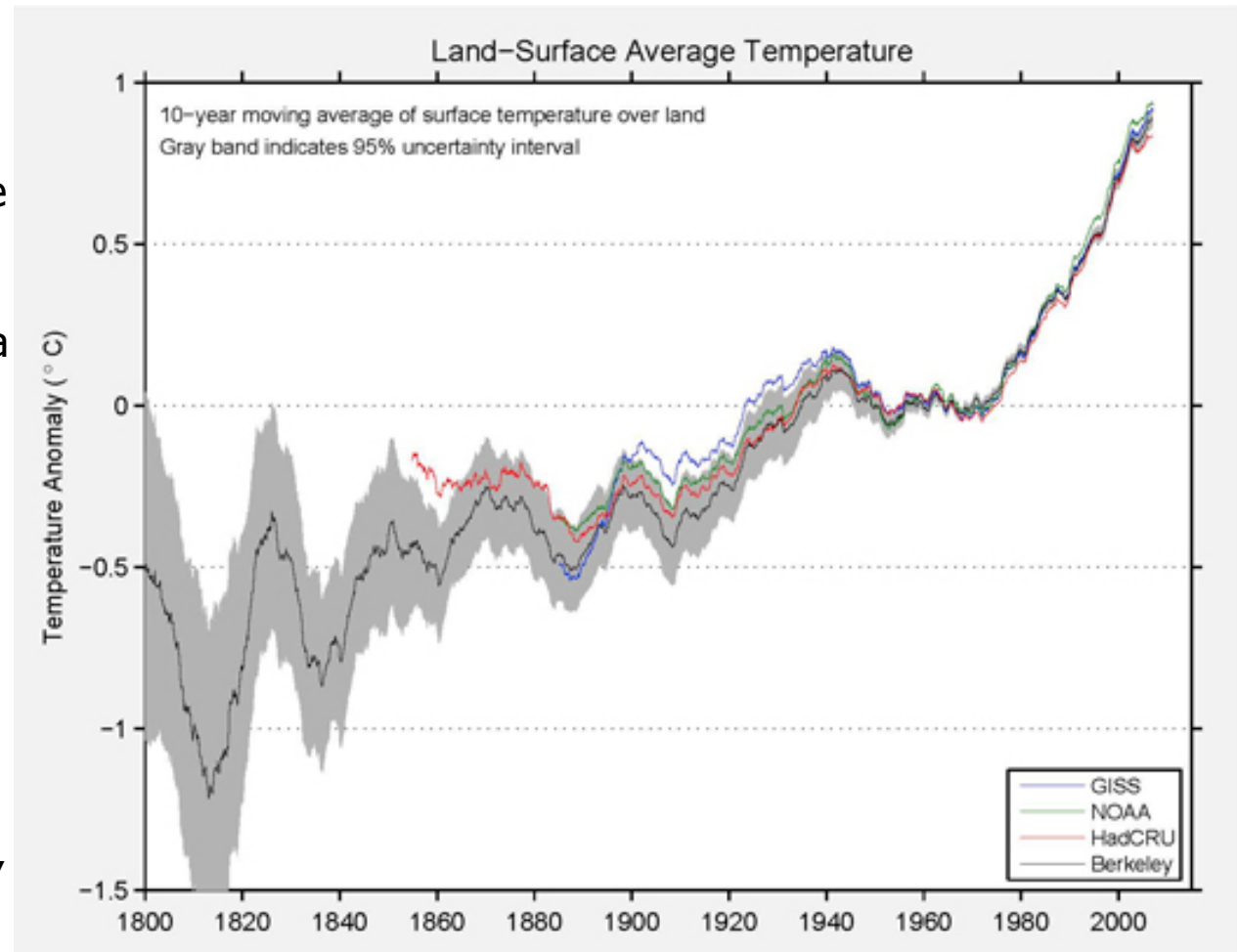


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# A new assessment of global temperatures: The Berkeley Earth Surface Temperature Study (BEST)

The most important indicator of global warming, the temperature record has been criticized for the choice of stations and the methods for correcting systematic errors. The BEST study did a new analysis of the surface temperature record to address these criticisms. They used over 39,000 unique stations and advanced interpolations schemes.

**BEST found similar warming and patterns, comparable to all other studies.**

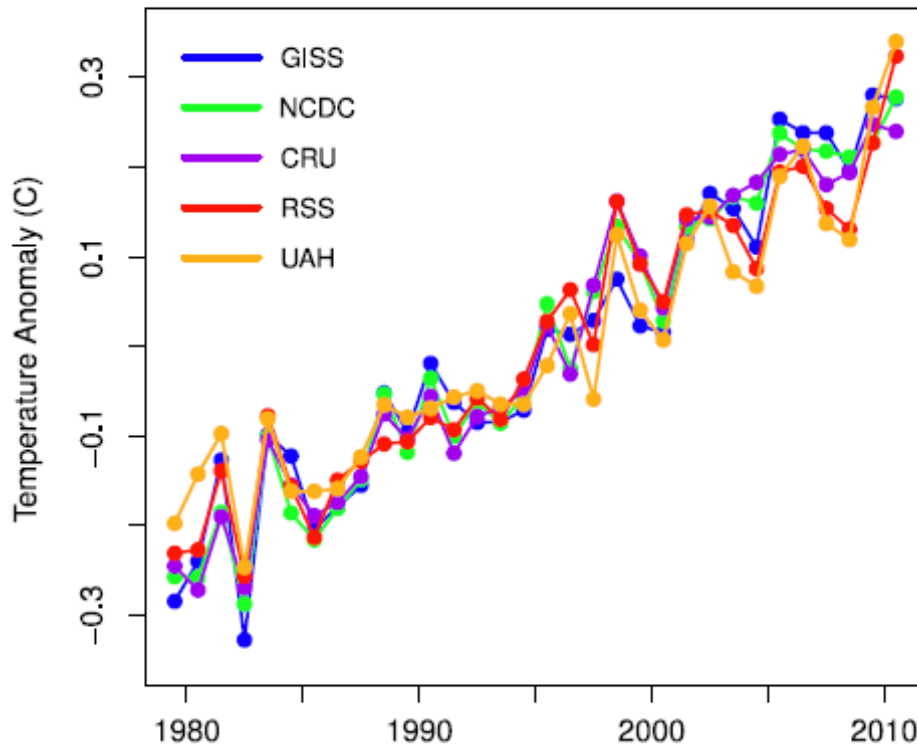




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# Removing non-GHG factors from temperature records

Adjusted data



**Global temperature evolution 1979–2010**

Grant Foster<sup>1</sup> and Stefan Rahmstorf<sup>2</sup>

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**Abstract**  
 We analyze five prominent time series of global temperature (over land and ocean) for their common time interval since 1979: three surface temperature records (from NASA/GISS, NOAA/NCDC and HadCRU) and two lower-troposphere (LT) temperature records based on satellite microwave sensors (from RSS and UAH). All five series show consistent global warming trends ranging from 0.014 to 0.018 K yr<sup>-1</sup>. When the data are adjusted to remove the estimated impact of known factors on short-term temperature variations (El Niño/southern oscillation, volcanic aerosols and solar variability), the global warming signal becomes even more evident as noise is reduced. Lower-troposphere temperature responds more strongly to El Niño/southern oscillation and to volcanic forcing than surface temperature data. The adjusted data show warming at very similar rates to the unadjusted data, with smaller probable errors, and the warming rate is steady over the whole time interval. In all adjusted series, the two hottest years are 2009 and 2010.

**Keywords:** climate, global warming, El Niño/southern oscillation, solar cycles

**1. Introduction**

The prime indicator of global warming is, by definition, global mean temperature. Time series of global temperature show a well-known rise since the early 20th century and most notably since the late 1970s. This widespread temperature increase is corroborated by a range of warming-related impacts: shrinking mountain glaciers, accelerating ice loss from ice sheets in Greenland and Antarctica, shrinking Arctic sea ice extent, sea level rise, and a number of well-documented biospheric changes like earlier bud burst and blossoming times in spring (IPCC 2007).

Despite the unequivocal signs of global warming, some public (and to a much lesser extent, scientific) debate has arisen over discrepancies between the different global temperature records, and over the exact magnitude of, and possible recent changes in, warming rates (Peterson and Baringer 2009). To clarify these issues, we analyze the five leading quasi-global temperature data sets up to and including the year 2010. We focus on the period since 1979, since satellite microwave data are available and the warming trend since that time is at least approximately linear.

Much of the variability during that time span can be related to three known causes of short-term temperature variations: El Niño/southern oscillation (ENSO), an internal quasi-oscillatory mode of the ocean-atmosphere system (Newell and Weare 1976, Angell 1981, Trenberth *et al* 2002), volcanic eruptions (IPCC 2007), and solar variations including the solar cycle (IPCC 2007, Lean and Rind 2008, 2009). This complicates both comparison and trend analysis of the temperature records. Since independent measures of these variations are available, their influence can to a large extent be removed, leading to adjusted, less noisy global temperature data sets. Therefore we will remove the influence of these factors on the temperature data sets, not only to isolate the longer-term changes, but also to identify whether different data sets show meaningful differences in their response to these factors. The influence of exogenous factors will be approximated by multiple regression of temperature against ENSO, volcanic influence, total solar irradiance (TSI) and a linear time trend to approximate the global warming that has occurred during the 32 years subject to analysis.

Lean and Rind (2008) performed a multivariate correlation analysis for the period 1889–2006 using the CRU temperature data (Brohan *et al* 2006), and found that they could explain 76% of the temperature variance over this period from anthropogenic forcing, El Niño, volcanic aerosols and solar variability. The long-term warming trend almost exclusively stems from anthropogenic forcing. They

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When the estimated impact of El Niño/SO, volcanic aerosols and solar variability are removed, the global warming signal becomes even more evident. The adjusted data show warming at very similar rates to the unadjusted data with smaller probable errors but the warming rate is steady over the whole time interval. The two hottest years are 2009 and 2010.

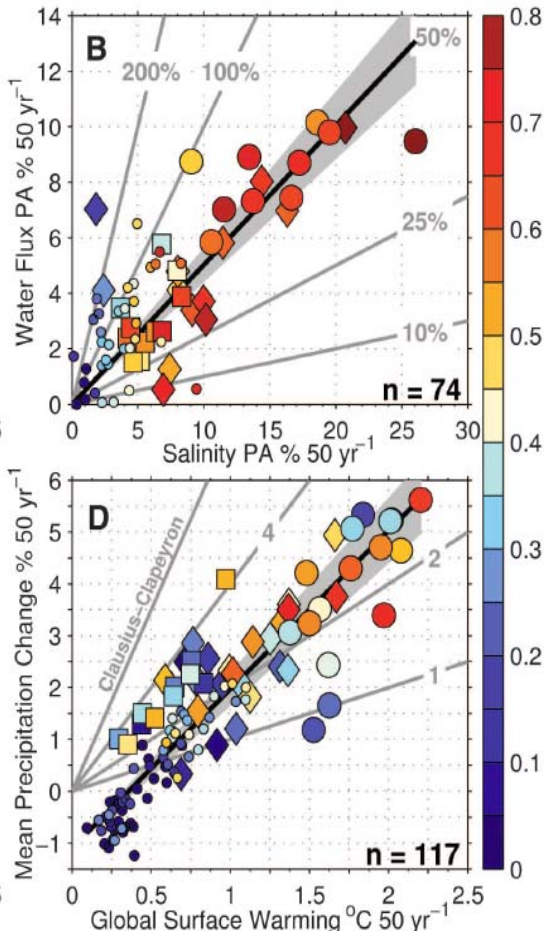




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# Proof of intensification of the global water cycle

Fundamental thermodynamics and climate models suggest that dry regions will become drier and wet regions will become wetter in response to warming. Our 50-year observed global surface salinity changes, combined with changes from global climate models, present **robust** evidence of an intensified global water cycle at a rate of  $8 \pm 5\%$  per degree warming. This rate is double the response projected by climate models and suggests that a 16 to 24% intensification of the global water cycle will occur in a future  $2^\circ$  to  $3^\circ$  warmer world.



## Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000

Paul J. Durack,<sup>1,2,3,4</sup> Susan E. Wijffels,<sup>3,5</sup> Richard J. Matear<sup>3,6</sup>

Fundamental thermodynamics and climate models suggest that dry regions will become drier and wet regions will become wetter in response to warming. Efforts to detect this long-term response in sparse surface observations of rainfall and evaporation remain ambiguous. We show that ocean salinity patterns express an identifiable fingerprint of an intensifying water cycle. Our 50-year observed global surface salinity changes, combined with changes from global climate models, present robust evidence of an intensified global water cycle at a rate of  $8 \pm 5\%$  per degree of surface warming. This rate is double the response projected by current-generation climate models and suggests that a substantial (16 to 24%) intensification of the global water cycle will occur in a future  $2^\circ$  to  $3^\circ$  warmer world.

**A** warming of the global surface and lower atmosphere is expected to strengthen the water cycle (*1-3*), largely driven by the ability of warmer air to hold and to redistribute more moisture. This intensification is expressed as an enhancement in the pattern of surface water fluxes [evaporation and precipitation (E-P)] and, as a consequence, ocean surface salinity patterns. According to the Clausius-Clapeyron (CC) relation and assuming a fixed relative humidity, we expect a  $\sim 7\%$  increase in atmospheric moisture content for every degree of warming of Earth's lower troposphere (*2*). Of greatest importance to society, and the focus of this work, is the strength of the regional pattern of E-P, which in climate models scales approximately with CC, whereas global precipitation changes more slowly at a rate of 2 to 3%  $^\circ\text{C}^{-1}$ , limited by tropospheric energy constraints (*4, 5*).

An intensification of existing patterns of global mean surface E-P is found along with enhancements to extreme events such as droughts and floods (*1, 3*) in available 21st-century climate projections, forced by anthropogenic greenhouse gases (GHGs) from the Coupled Model Intercomparison Project Phase 3 (CMIP3) (*6*). This has been labeled the "rich get richer" mechanism, where wet areas (compared with the global mean) get wetter and dry regions drier (*7*). There is, however, little consistency

in the seasonal changes provided by model projections and poor agreement when compared with regional observational estimates (*8*). Additionally, atmospheric aerosols included in these projections can regionally counteract the GHG-driven warming and act to suppress the local water cycle through dynamical changes (*9, 10*).

Given the above broad-scale model responses and the CC relationship, an intensification of  $\sim 4\%$  in the global water cycle (E-P) is expected to already have occurred in response to the observed  $0.5^\circ\text{C}$  warming of Earth's surface over the past 50 years (*11*). However, obtaining a global view of historical long-term rainfall pattern changes is made difficult because of the spatially sparse and short observational record. Long, high-quality land-based records are few and Northern Hemisphere-biased (*12*). Direct high-quality long-term rainfall estimates over oceans [which comprise 71% of the global surface area and receive over 80% of global rainfall (*13*) (fig. S1)] are very scarce, with most global observational products dependent on data contributions from satellites, themselves sensitive to error (*14, 15*). Additionally, because of the short temporal coverage ( $\sim 15$  to 30 years) by satellite missions, trends are likely affected by natural decadal modes of variability and may dominate much of the measured changes (*3*). This challenge is exacerbated by the spatially and temporally sporadic nature of rainfall, making the derivation of broad-scale averages of small multidecadal changes from a sparse network of observing stations error-prone (*16*). These difficulties are evident in the differing signs of long-term trends between reconstructed rainfall data sets (*17, 18*).

Discrepancies among air-sea evaporative flux products (*19*) undermine their use in resolving long-term water cycle changes. As a result, we do not yet have a definitive view on whether Earth's water cycle has intensified over the past

several decades from atmospheric observing networks (*12, 20*).

It has long been noted that the climatological mean sea surface salinity (SSS) spatial pattern is highly correlated with the long-term mean E-P spatial pattern (*21*) (Fig. 1, A and D), reflecting the balance between ocean advection and mixing processes and E-P forcing at the ocean surface (*21-23*). Several studies of multidecadal SSS changes reveal a clear pattern where increasing salinities are found in the equatorially-dominated midlatitudes and decreasing salinities in the rainfall-dominated regions such as the tropical atmospheric convergence zones and polar regions (*22, 24-28*). These previous studies have used optimally averaged pentadal historical ocean data (*24*) or the difference between pre-2000 and post-2000 climatologies (*27*), the latter period being strongly supported by the modern baseline provided by the Argo Programme (*29*) to investigate long-term salinity changes in the global ocean. By using a direct load fit of trends to historical and Argo data simultaneously (*25*), we map the multidecadal linear SSS trends back to 1950 (Fig. 1, D and G). Over the last 50 years, SSS changes reflect an intensification of the mean SSS patterns. This strong and coherent relationship is expressed through the high spatial pattern correlation coefficient (PC) of  $-0.7$  (fig. S2) between the mean SSS and independent estimates of long-term SSS change. Following the "rich get richer" mechanism (*7*), salty ocean regions (compared to the global mean) are getting saltier, whereas fresh regions are getting fresher (*24-28*). This robust intensification of the observed SSS pattern is qualitatively consistent with increased E-P if ocean mixing and circulation are largely unchanged.

In trying to quantitatively relate SSS changes and E-P changes, previous studies have made strong simplifying assumptions. One estimate of a global 3.3% E-P intensification from the 1970s to 2005 (*27*) is based on the assumption of an unchanging ocean mixing and advection field, with the additional assumption that no salt or freshwater exchange has occurred over this time with the ocean below 100 m. However, several studies have shown that subsurface salinity changes have occurred during the 20th century (*24, 25*), with many of the largest signals expressed at depths greater than 100 m. Another study used subsurface salinity changes on isopycnals to deduce E-P changes at the surface density outcrop (*26*). This approach is error-prone because broad-scale salinity changes on density surfaces can largely be explained by the subsidence of broad-scale warming and not E-P changes alone (*25*). To avoid such strong assumptions and explore the use of SSS pattern changes as a water cycle diagnostic, we used the most comprehensive simulations available to date of the historical and future global climate: the CMIP3 simulations of the 20th century (20C3M) and the Special Report on Emissions

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Durack, P. J., S. E. Wijffels, and R. J. Matear. 2012. Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000. *Science* 336:455-458.

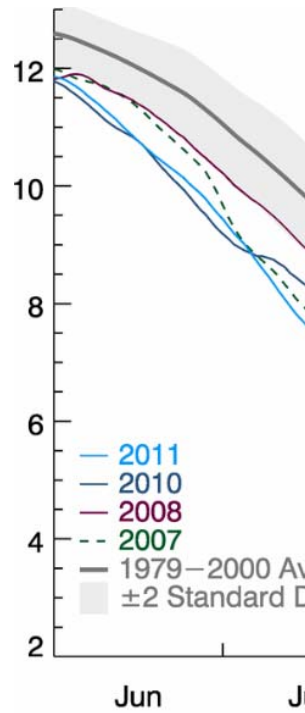
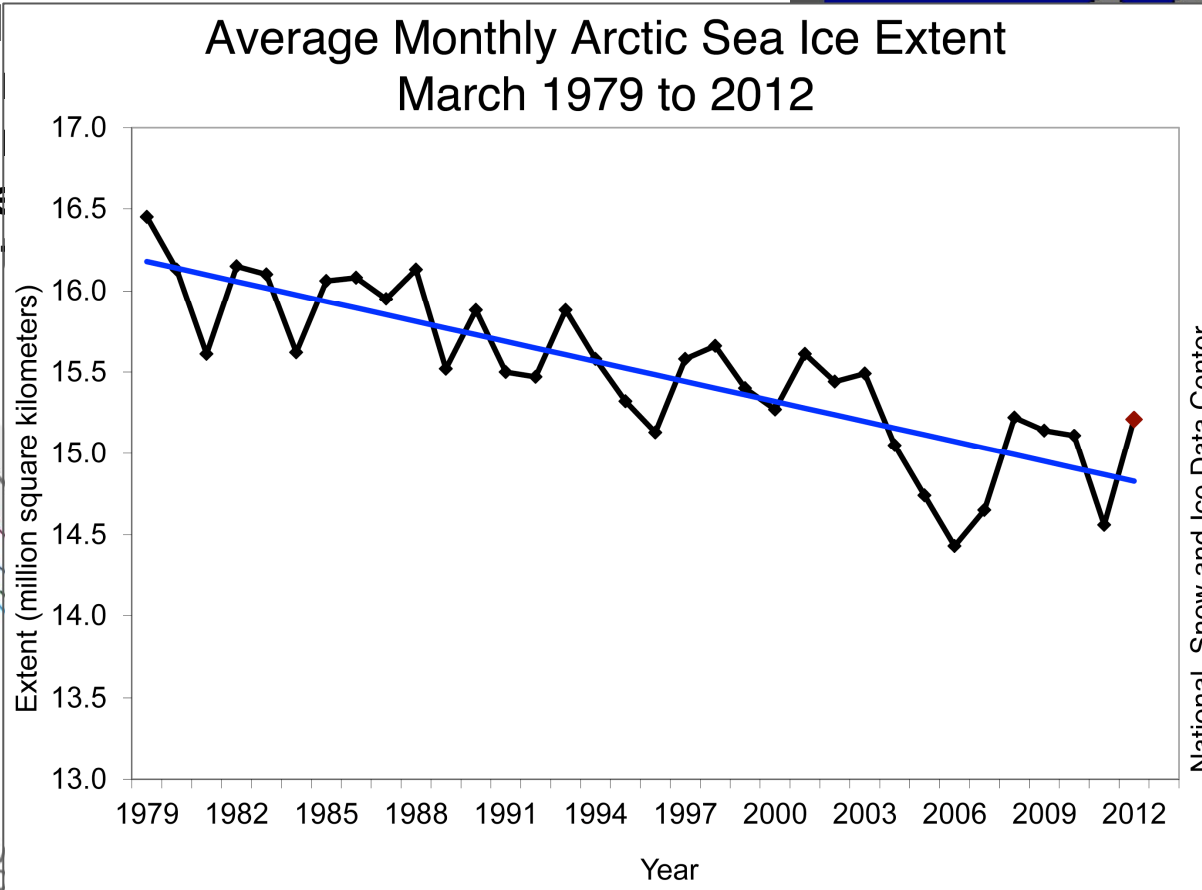


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# Minimum arctic sea ice extent (September)

The last five years have been the five lowest extents. While the record low 2007 had weather conditions that were not typical, 2011 had more typical conditions and the trend continued. This supports the hypothesis that the minimum ice cover is continuing to decrease.

Sea Ice Extent  
09/09/2011



National Snow and Ice Data Center

National Snow and Ice Data Center, Boulder, CO

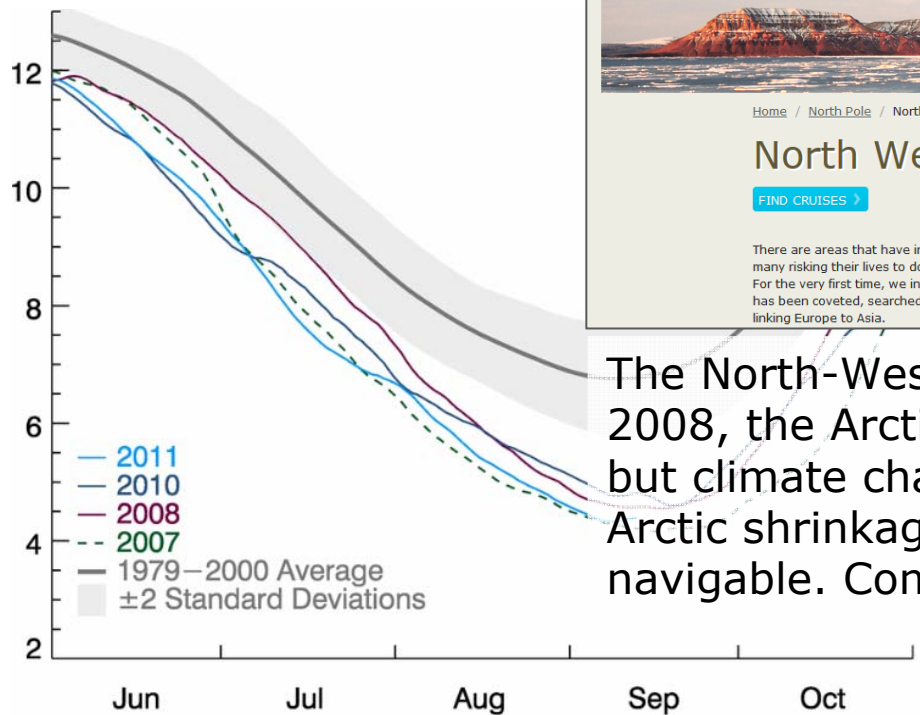




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# Minimum arctic sea ice extent (September)

The last five years have been the five lowest extents. While the record low 2007 had weather conditions that favored ice loss, 2011 had more typical weather conditions that continued warmth over the summer. This supports the idea that sea ice cover is continuing to decrease.



The screenshot shows the website for 'COMPAGNIE DU PONANT YACHT CRUISES'. The page is titled 'North West Passage' and features a large image of a snowy mountain range over a body of water. Navigation buttons include 'NORTH POLE', 'SOUTH POLE', and '5 STAR EXPEDITIONS'. A 'FIND CRUISES' button is visible. The text on the page describes the North West Passage as a legendary maritime route between the Atlantic and the Pacific, linking Europe to Asia.

The North-West Passage is a possible trade route. Until 2008, the Arctic pack ice prevented regular shipping, but climate change has reduced the pack ice, and this Arctic shrinkage made the waterways now more navigable. Commercial cruises start in 2013.

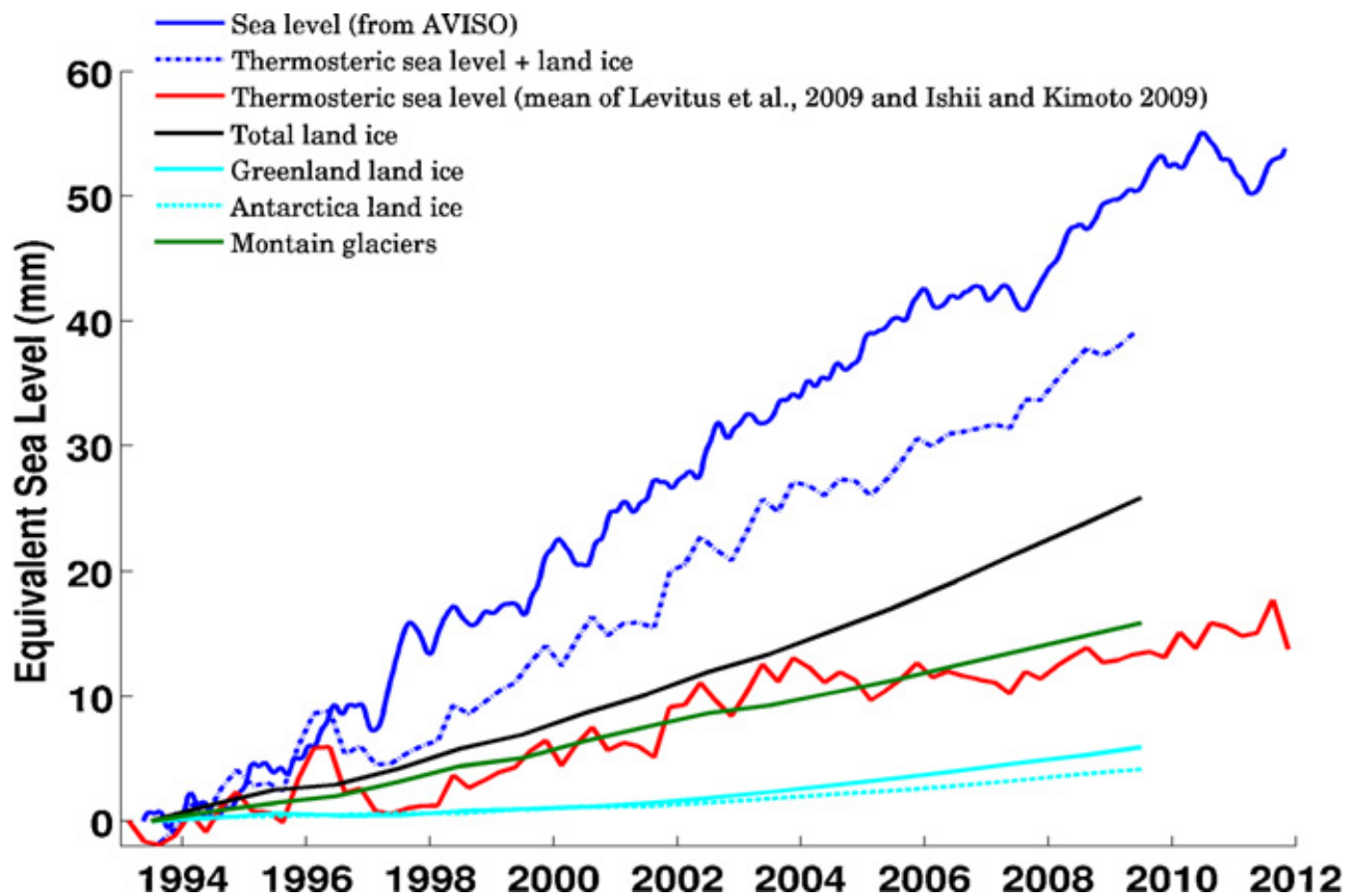






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# Observed global sea level



Journal of Geodynamics 58 (2012) 96–109

Contents lists available at ScienceDirect

Journal of Geodynamics

journal homepage: <http://www.elsevier.com/locate/jgg>

Review

Sea level: A review of present-day and recent-past changes and variability

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LEOS-UMR, Toulouse, France

ARTICLE INFO

ABSTRACT

In this review article, we summarize observations of sea level variations, globally and regionally, during the 20th century and the last 2 decades. Over these periods, the global mean sea level rose at rates of 1.7 mm/yr and 3.2 mm/yr respectively, as a result of both increase of ocean thermal expansion and land ice loss. The regional sea level variations, however, have been dominated by the thermal expansion factor over the last decades even though other factors like ocean salinity or the land ice response to the last deglaciation can have played a role. We also present examples of local sea level variations that include the global mean, for the regional variability and empirical records, focusing on the tropical Pacific islands. Finally we address the future evolution of the global mean sea level under ongoing warming climate and the associated regional variability. Expected impacts of future sea level rise are briefly presented.

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Keywords:  
Sea level  
Altimetry  
Climate change  
Global mean sea level  
Regional sea level  
Ice sheet reconstruction  
Climate change

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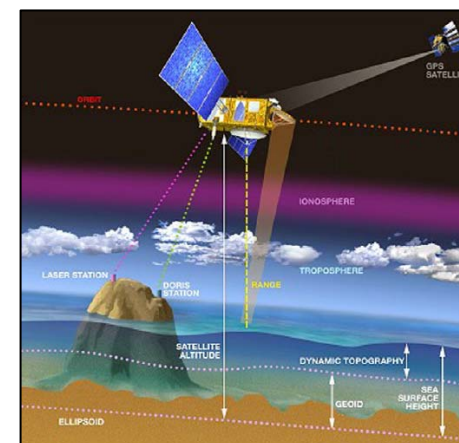
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1. Introduction

Sea level variations spread over a very broad spectrum. The largest global scale sea level change (100–200 m in amplitude) occurred on geological time scales (on the order of ~100 million years) and depended primarily on tectonic processes (e.g. large-scale change in the shape of ocean basins associated with seafloor spreading and mid-ocean ridges expansion) (e.g. Haug and Schuster, 2006; Mörner et al., 2008; Miller et al., 2011). With the formation of the Antarctic ice sheet about 34 million years ago, global mean sea level dropped by about 50 m. More recently, cooling of the Earth starting about 3 million years ago led to glacial/interglacial cycles driven by incoming insolation changes in response to variations of the Earth's orbit and obliquity (Berger, 1988). Corresponding growth and decay of northern hemisphere ice caps on time scales of tens of thousands years produced large

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E-mail address: [benoit.meysignac@ird.fr](mailto:benoit.meysignac@ird.fr) (B. Meysignac).

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doi:10.1016/j.jgg.2012.03.005



## IPCC 2007:

For 1961–2003: 1.8 mm/yr; Models: 1.2 mm/yr

## This study:

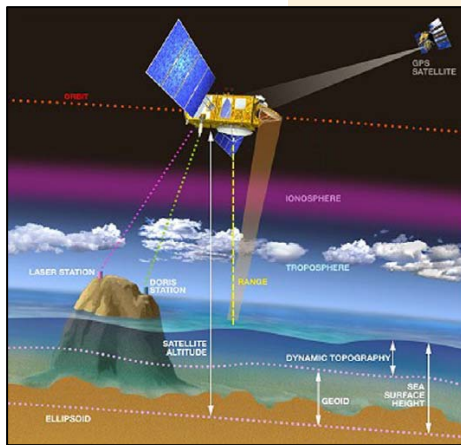
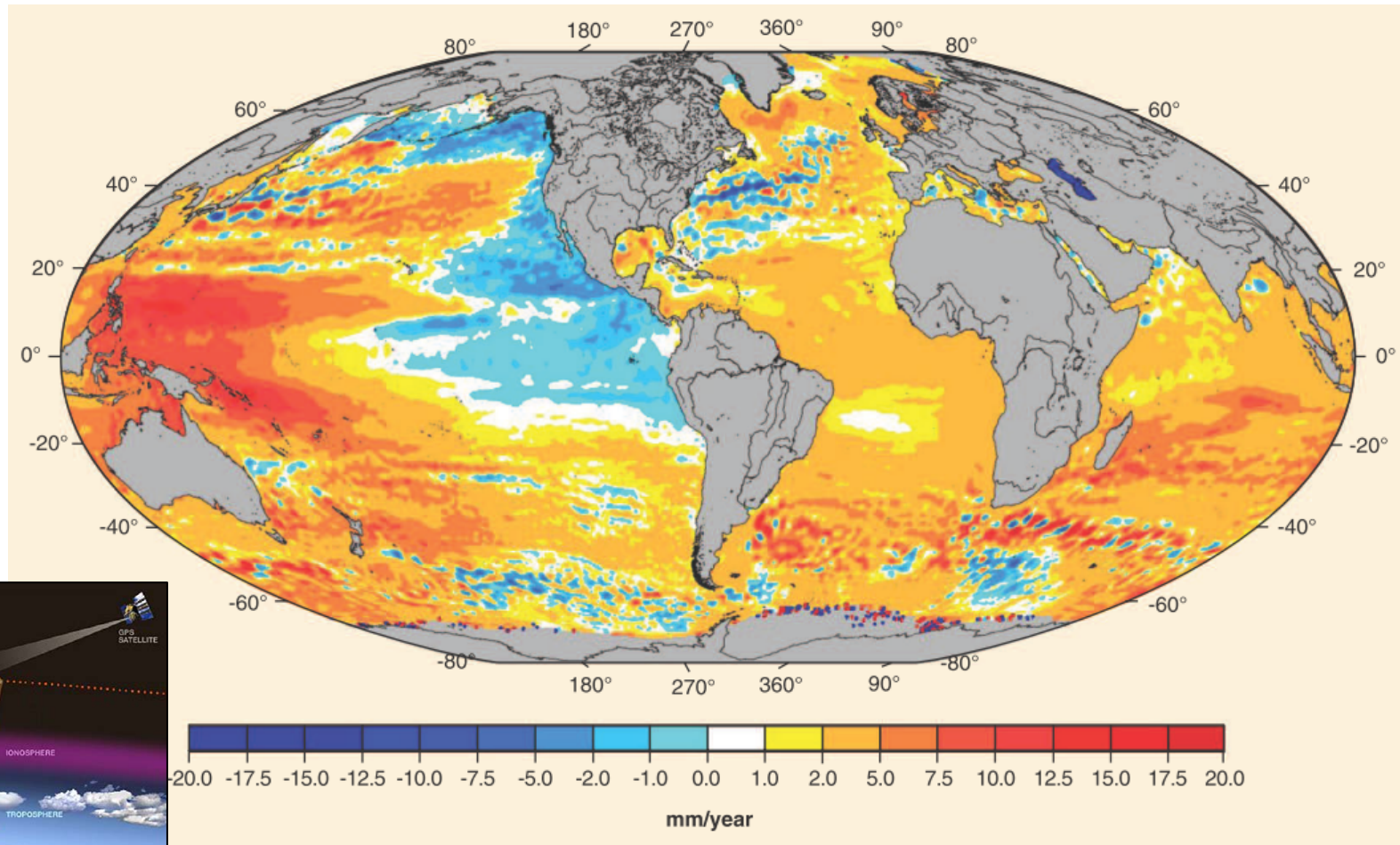
Last century: 1.7 mm/yr; 1990–2010: 3.2 mm/yr

Meysignac, B. and A. Cazenave (2012). Sea level: A review of present-day and recent-past changes and variability. *Journal of Geodynamics* 58: 96–109.



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# Spatial variations of sea level



Local sea-level trends up to 10 times higher than the global mean rise (but very likely **transient phenomena**). Regional sea level trends largest in the Pacific.

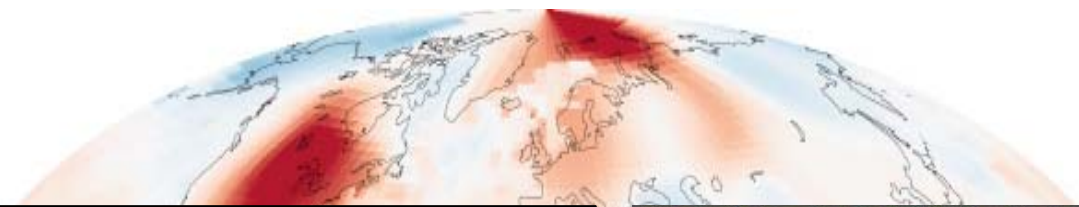
Nicholls, R. J. and A. Cazenave. 2010. Sea-Level Rise and Its Impact on Coastal Zones. *Science* 328:1517-1520.



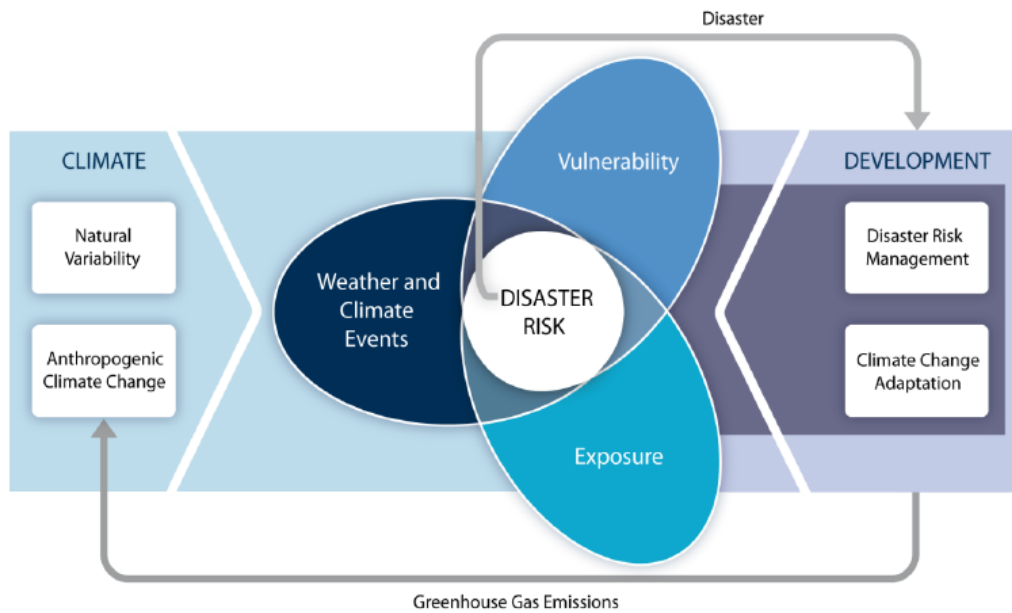


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# Climate extremes (e.g. March temperatures)



Increasing vulnerability, exposure, or severity and frequency of climate events increases **disaster risk**

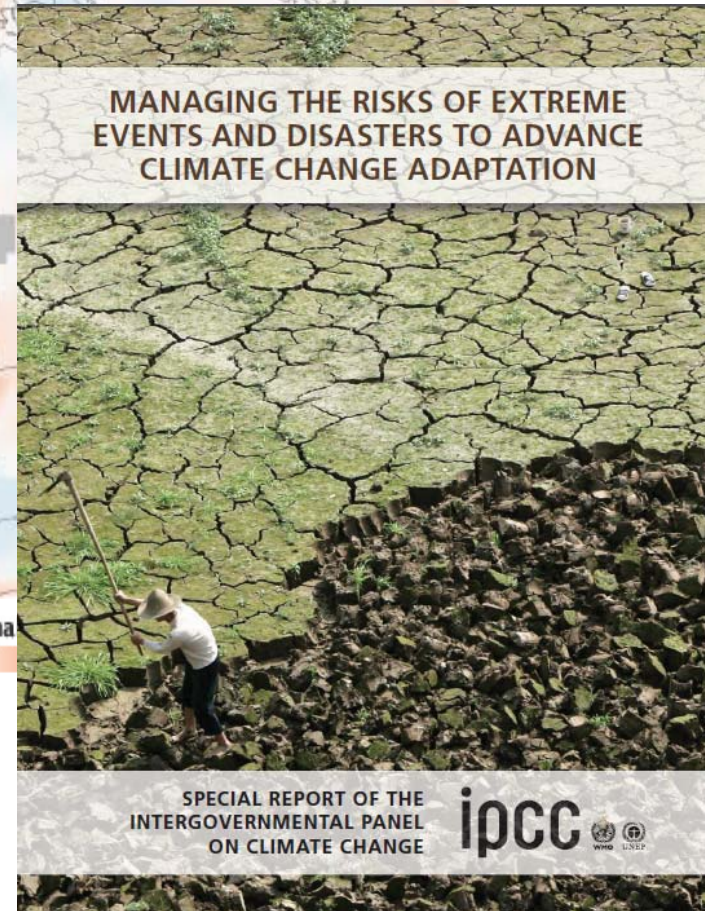


*Disaster risk management and climate change adaptation can influence the degree to which **extreme events translate into impacts and disasters***

7



INTERGOVERNMENTAL PANEL ON climate change





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# Carbon Budget 2010

opinion & comment

**CORRESPONDENCE:**  
Rapid growth in CO<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> 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<sub>2</sub> emissions in developing countries (non-Annex B countries) increased 4.6% 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

**Figure 1** | Global CO<sub>2</sub> emissions and carbon intensity. a, Emissions of CO<sub>2</sub> from fossil-fuel combustion and cement production for the world (Pg C yr<sup>-1</sup>; 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<sub>2</sub> 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 (1992), where EU is the 15 member states of the European Union as of 1992; c, The collapse of the Former Soviet Union (FSU); 1989; d, The Asian financial crisis (1997); e, The recent global financial crisis (2008–2009).

(0.025 Pg C) and the 27 member states of the European Union 2.2% (0.022 Pg C). US dollar of economic output, that is CO<sub>2</sub> per unit of gross domestic product (GDP)).

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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

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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>

1 Pg = 1 Petagram = 1x10<sup>15</sup>g = 1 Billion metric tons = 1 Gigaton  
1 Tg = 1 Teragram = 1x10<sup>12</sup>g = 1 Million metric tons  
1 Kg Carbon (C) = 3.67 Kg Carbon Dioxide (CO<sub>2</sub>)

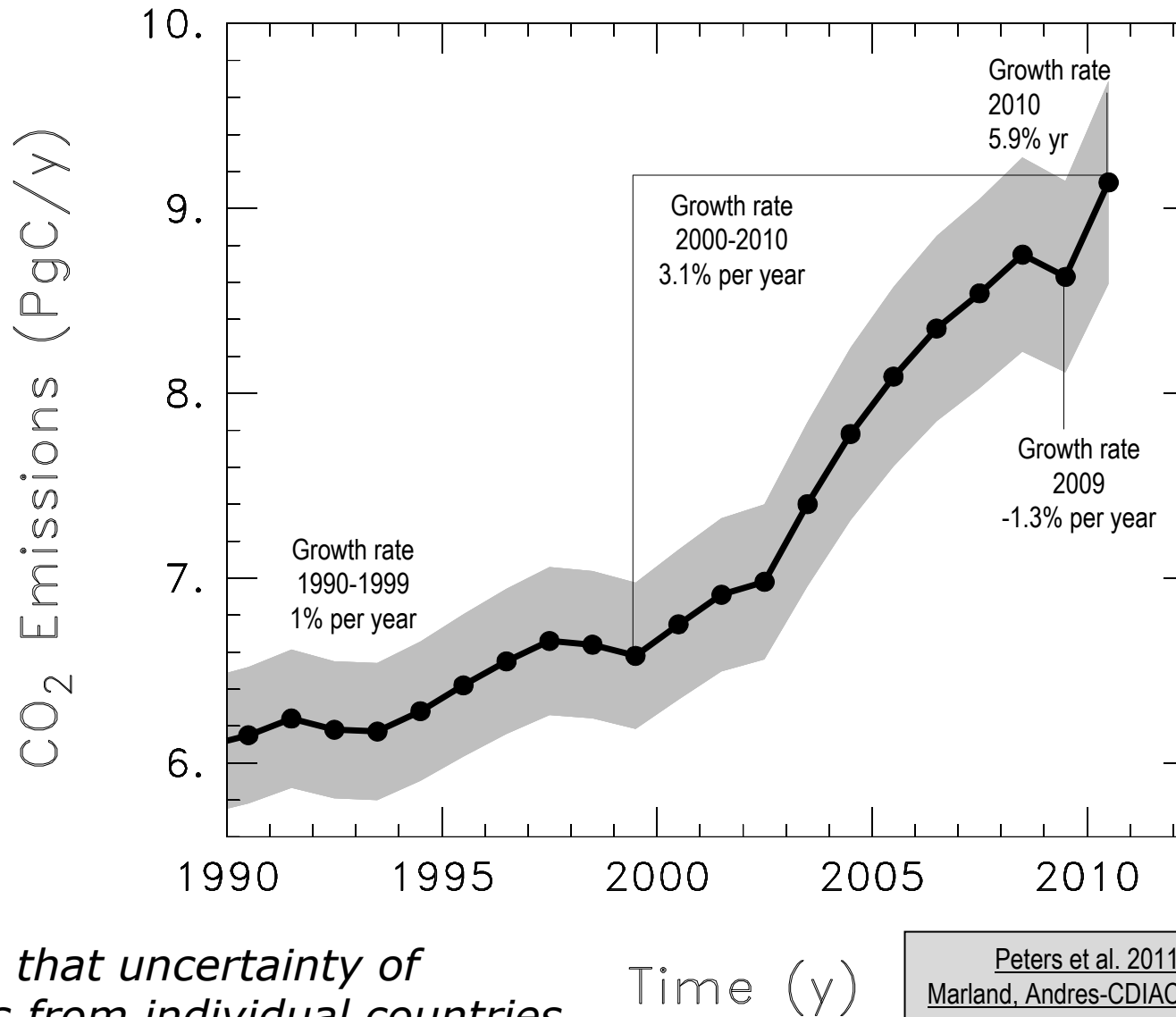
Peters GP, Marland G, Le Quéré C, Boden T, Canadell JG, Raupach MR (2011) Rapid growth in CO<sub>2</sub> emissions after the 2008–2009 global financial crisis. *Nature Climate Change*, doi: 10.1038/nclimate1332.





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# Fossil Fuel & Cement CO<sub>2</sub> Emissions



*Be aware that uncertainty of emissions from individual countries can be several-fold bigger*

Peters et al. 2011, Nature CC; Data: Boden, Marland, Andres-CDIAC 2011; Marland et al. 2009

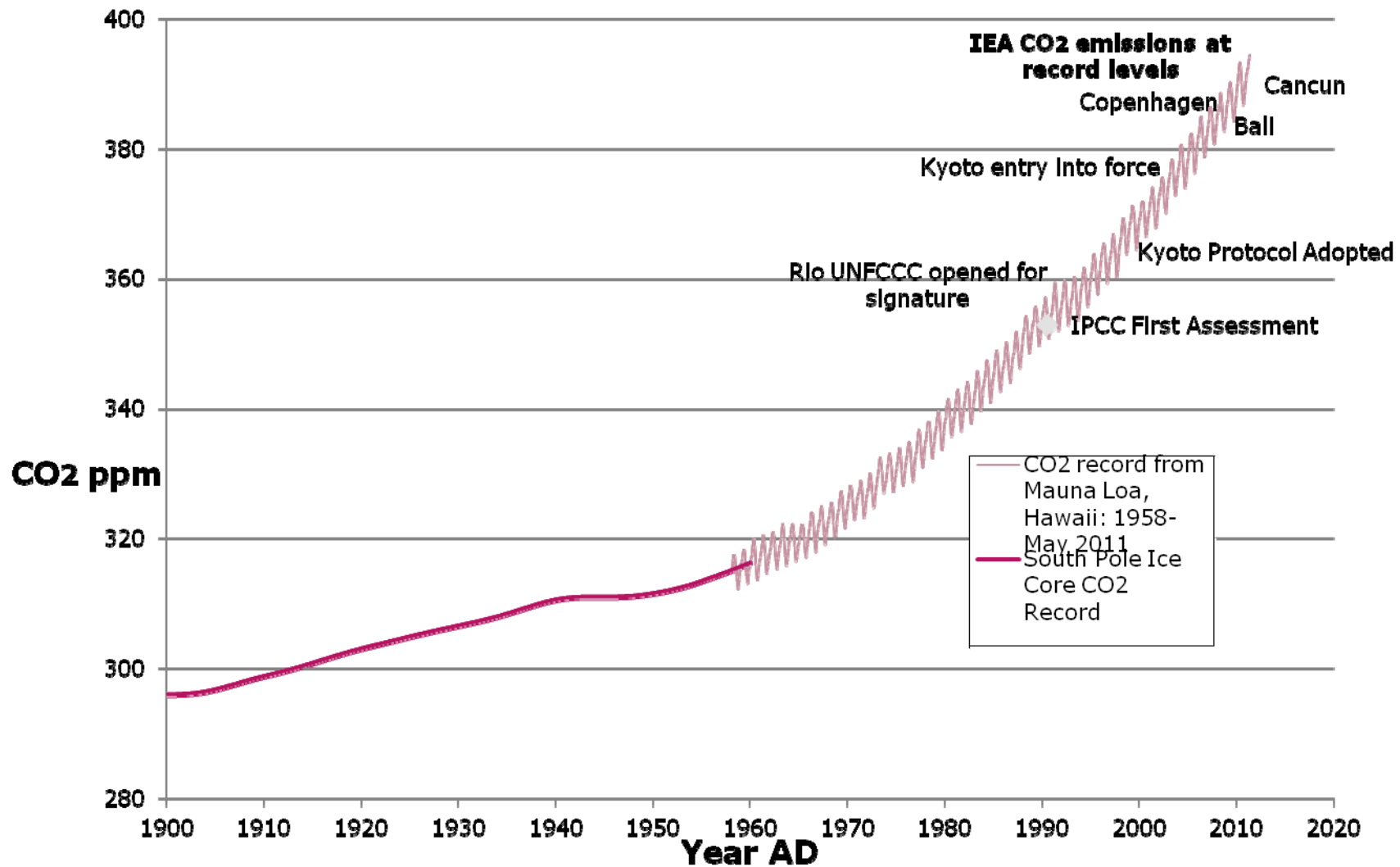
Time (y)





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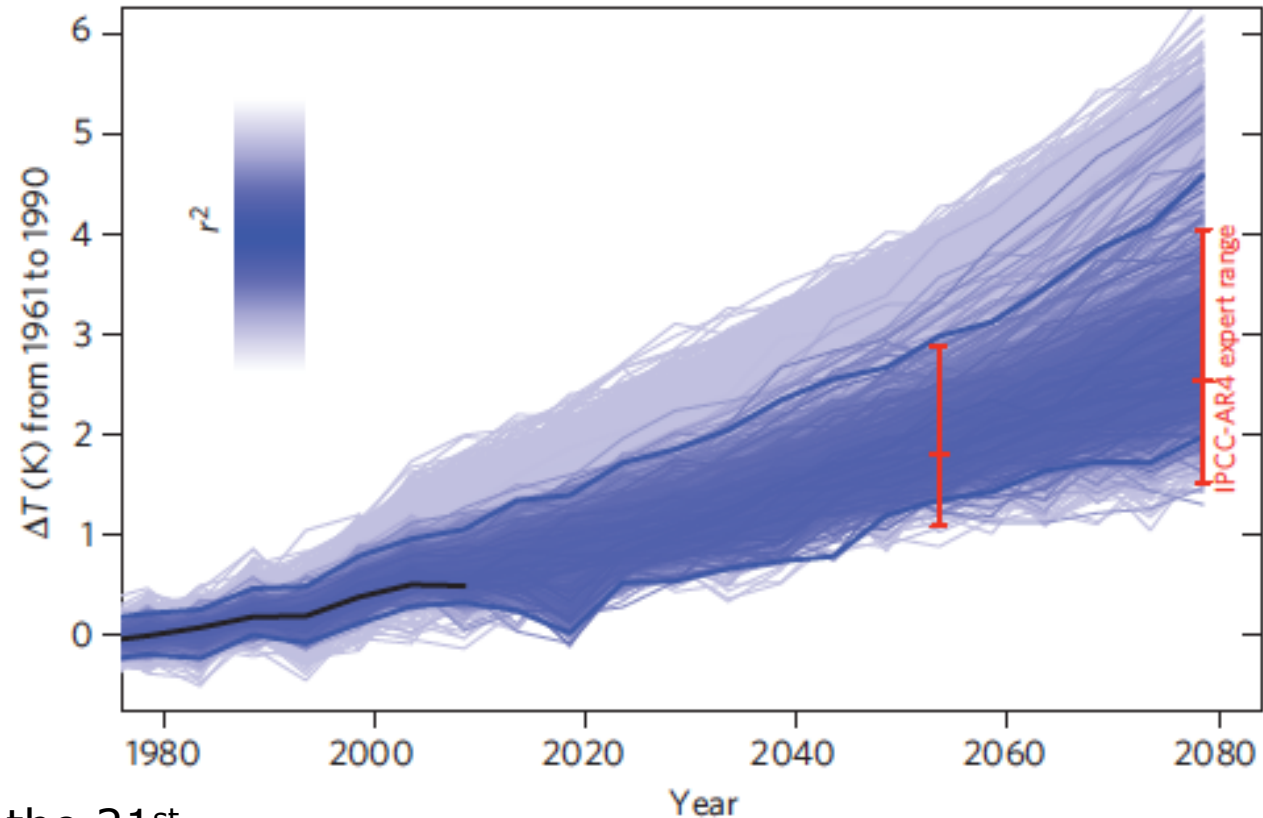
# CO<sub>2</sub> concentration rising





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# Consequent warming may be higher than earlier estimates



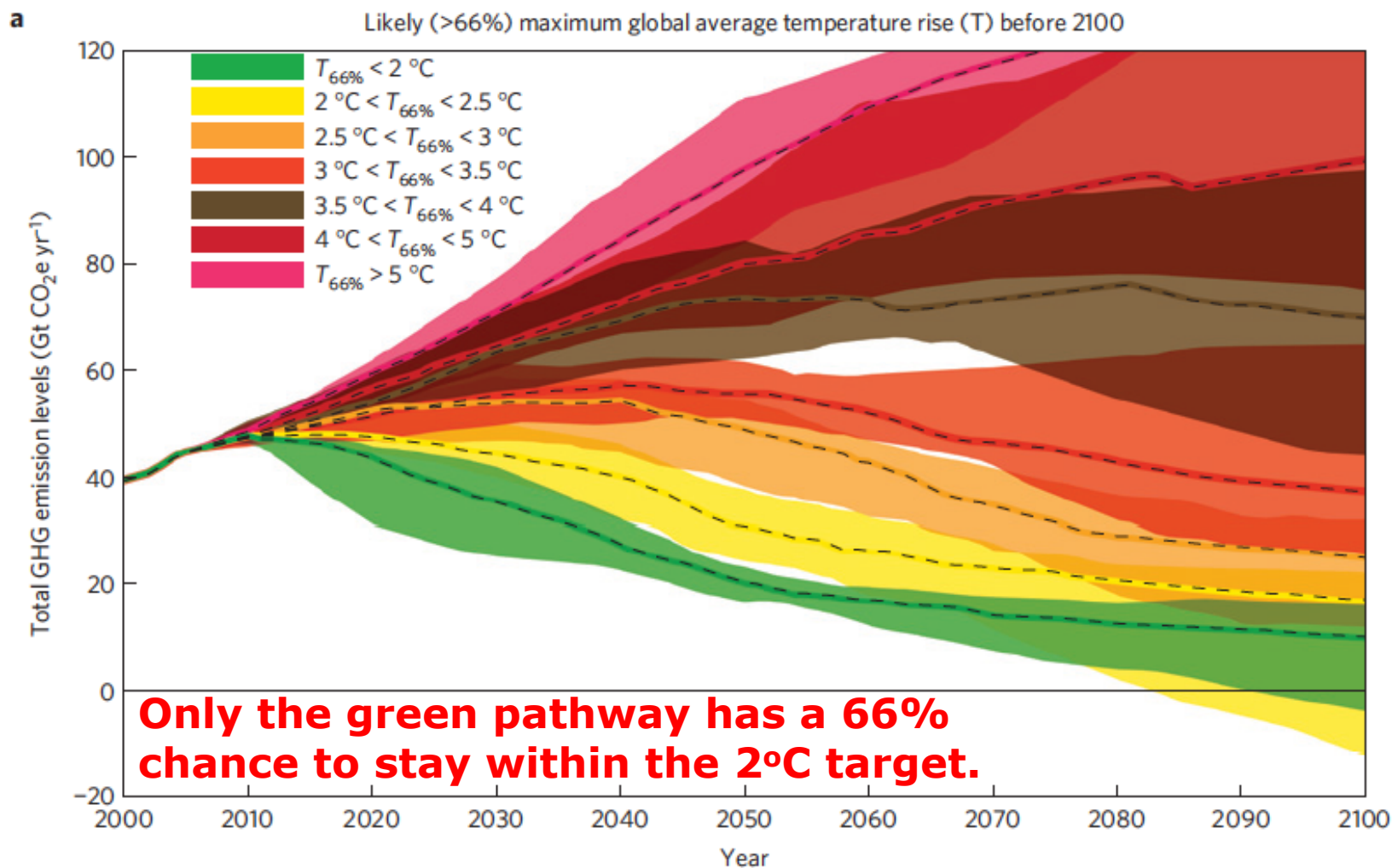
Warming by the middle of the 21<sup>st</sup> century that is stronger than earlier estimates is consistent with recent observed temperature changes and a mid-range 'no mitigation' scenario for greenhouse-gas emissions

Rowlands, D. J., D. J. Frame, et al. (2012). "Broad range of 2050 warming from an observationally constrained large climate model ensemble." *Nature Geoscience* 5(4): 256-260.



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# Emission pathways and warming limits



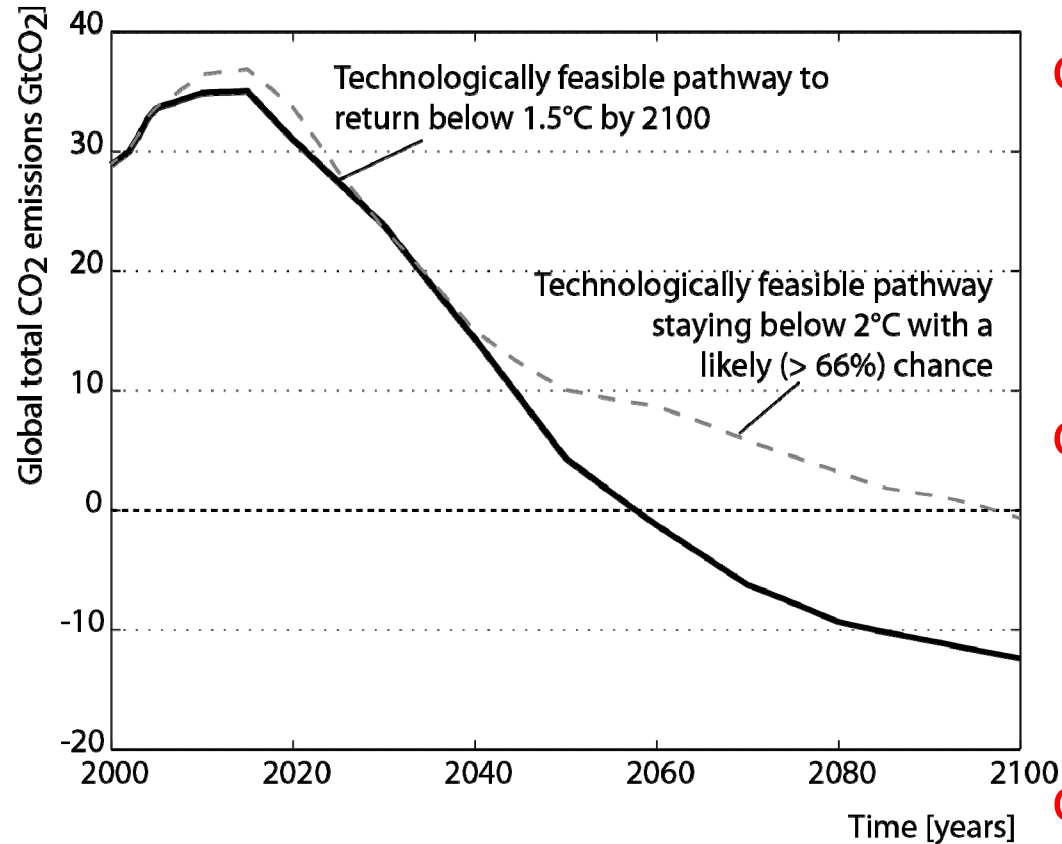
Rogelj, J., W. Hare, J. Lowe, D. P. van Vuuren, K. Riahi, B. Matthews, I. Hanaoka, K. Jiang & M. Meinshausen. 2011. Emission pathways consistent with a 2°C global temperature limit. *Nature Climate Change* 1:413-418.





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# Implications for staying below 2°C (or 1.5°C)



The two scenarios shown are from  
ADAM project ([www.adamproject.eu](http://www.adamproject.eu))

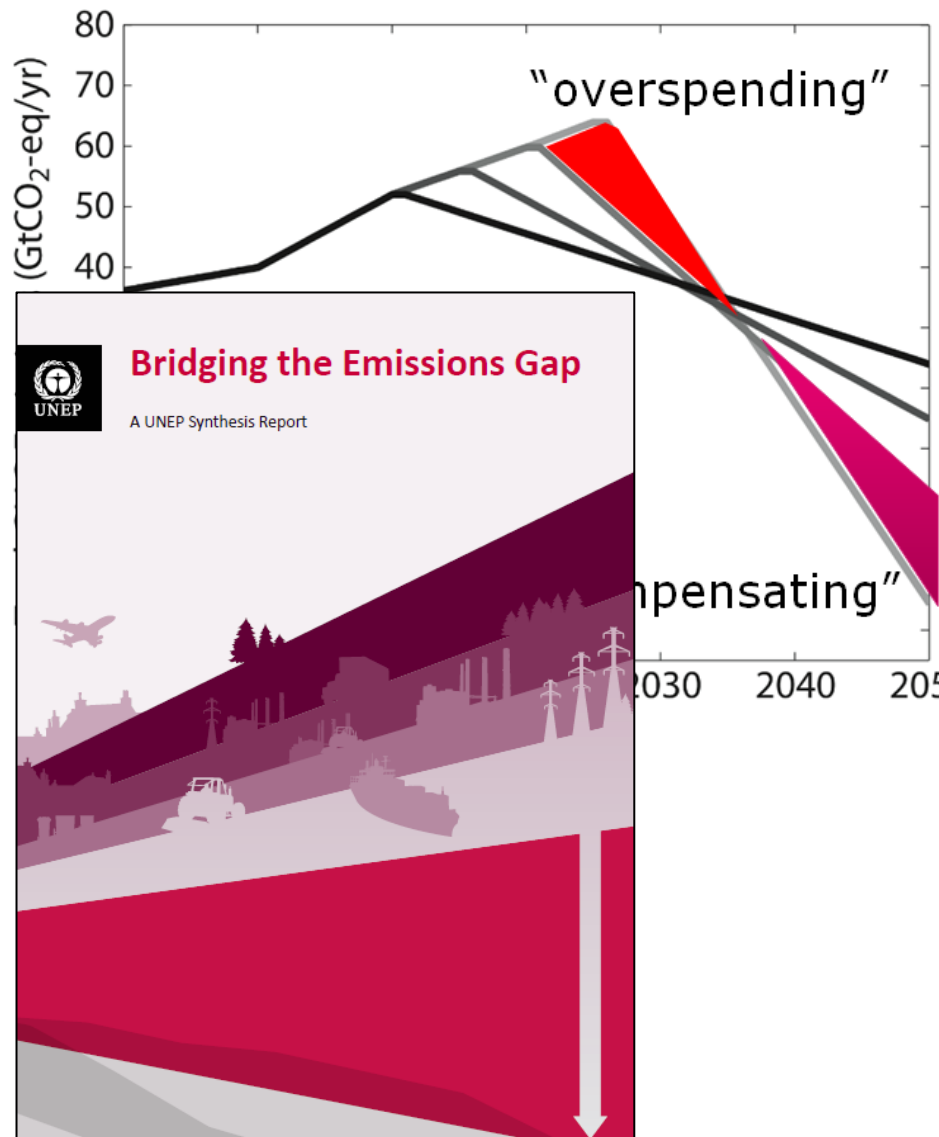
- Emission should peak before 2020 and then rapidly reduced by 70% in 2050 and going to zero in 2100.
- Until 2050 the 1.5°C pathway is similar to a likely 2°C pathway, but with deep reductions afterwards.
- Emissions are constrained by the terrestrial and oceanic sources and sinks!

Hulme, M., H. Neufeldt, and H. Colyer. 2009. Adaptation and mitigation strategies: Supporting European Climate Policies. Final Report from the ADAM Project, Tyndell Centre for Climate Change Research, Norwich, UK.

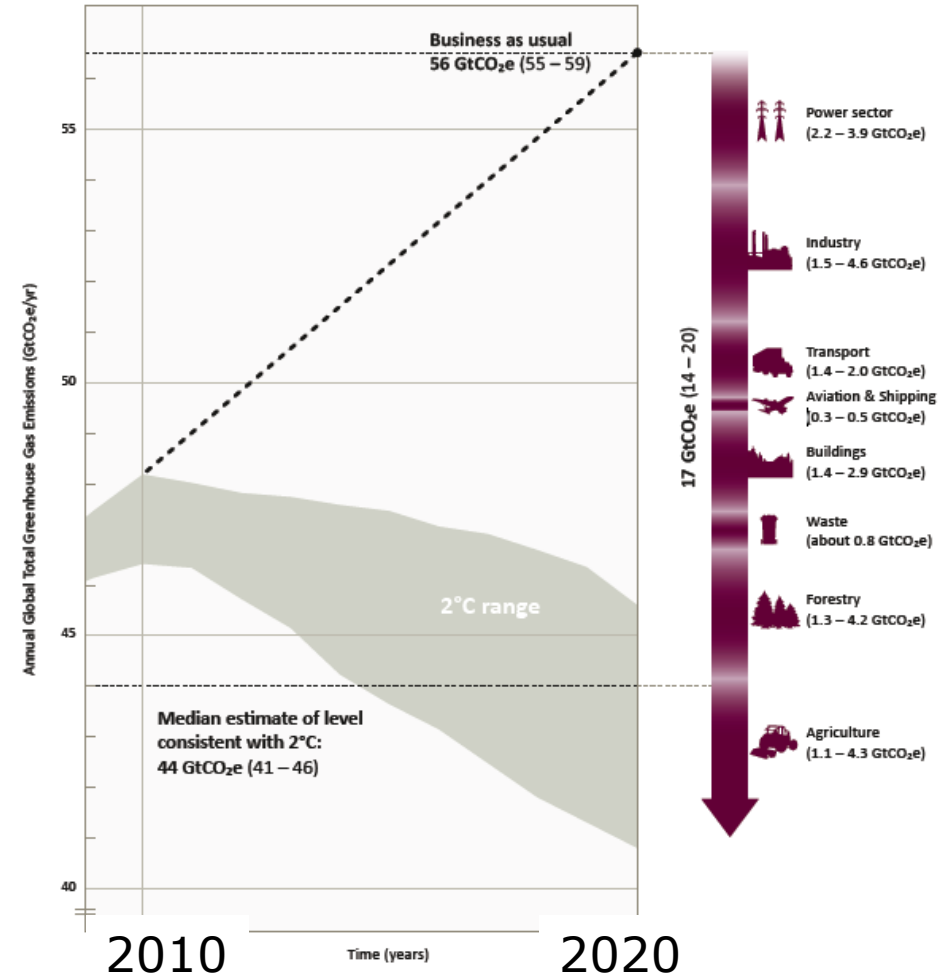


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# Major lesson on delays: Later reductions require faster AND deeper reductions



How the bridge the gap: What the sectoral studies say





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## Main final conclusions

- To keep within your 2°C climate-change target, global greenhouse gas emissions have to be more than halved by 2050 and should peak no later than 2020.
- **The next years are thus a crucial to change course towards a sustainable future for all nations.**
- If this is not achieved risks will increase rapidly and food, water and energy security cannot be guaranteed
- The long term solutions involve rethinking fundamental aspects of international and national economic, technical, institutional and social developments. This requires major innovations, capacity building and political will.

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