The Oceans in Our Climate System

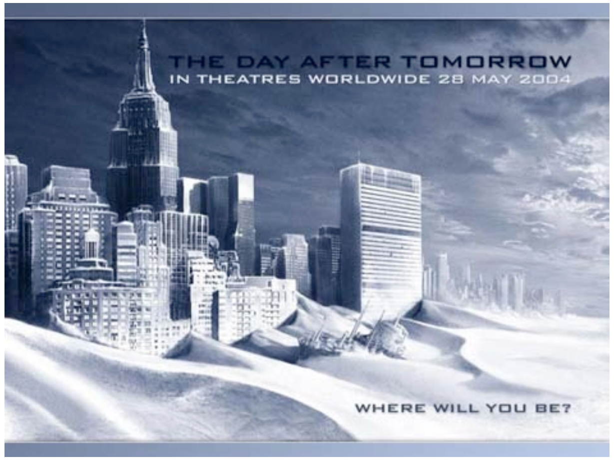
Greg Ayers

Chief

CSIRO Marine & Atmospheric Research

www.csiro.au

Climate change is a 'hot topic'

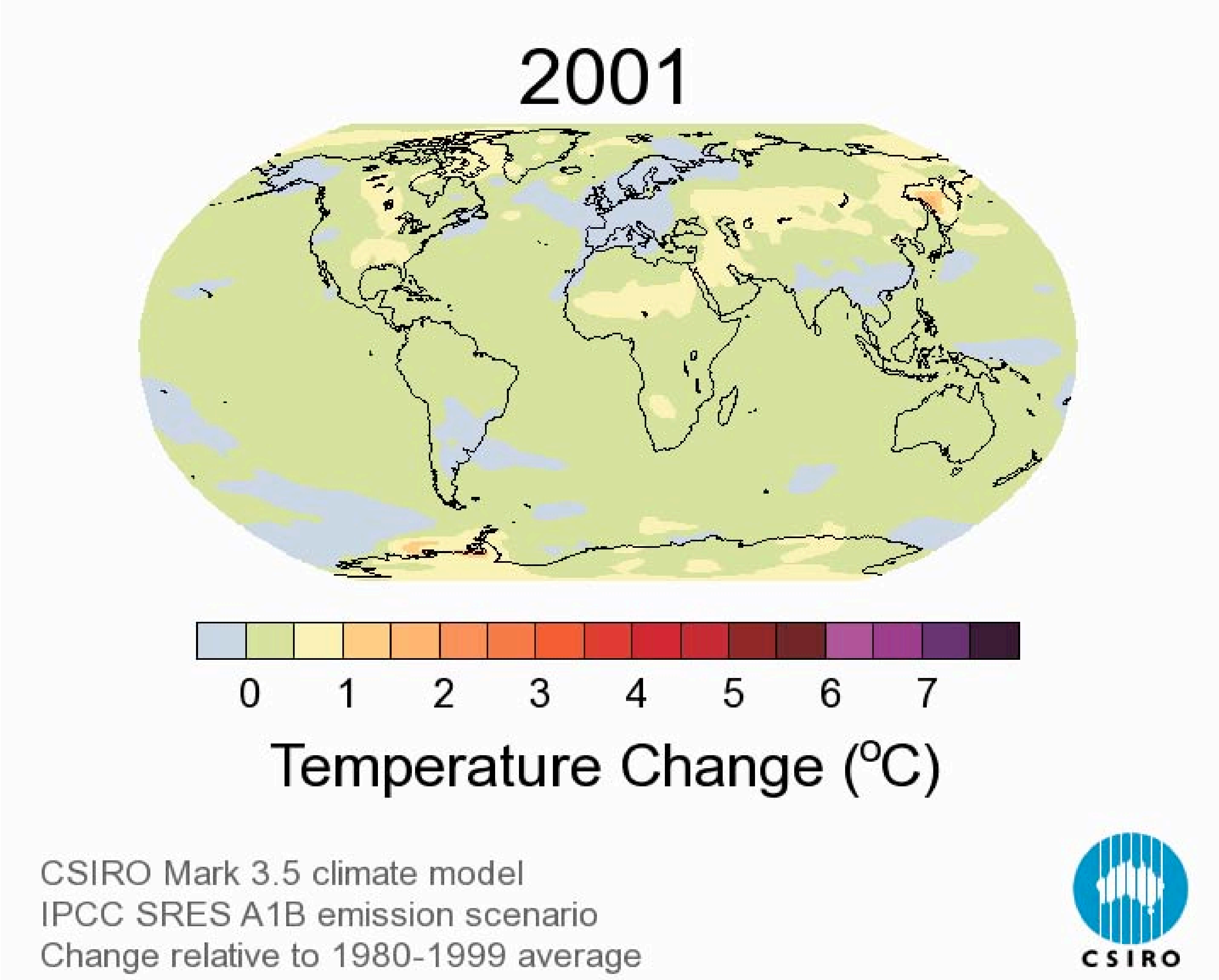


Some of the stimuli include

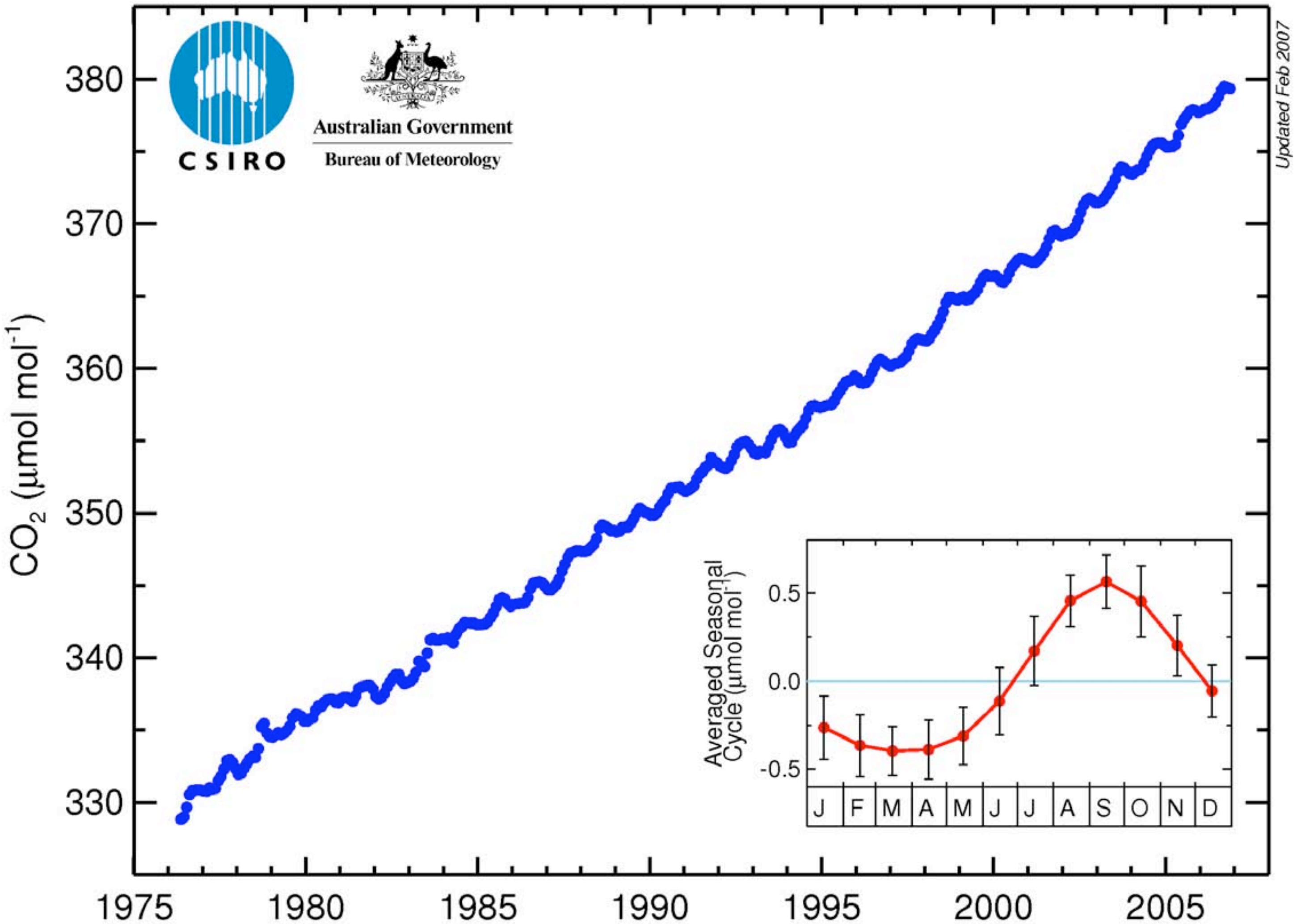
- Hollywood: The Day After Tomorrow
- Al Gore movie
- Stern report on economics of climate change
- Intergovernmental Panel on Climate Change 4th Assessment
- The political cycle
- Australia's long running big (hot) dry period

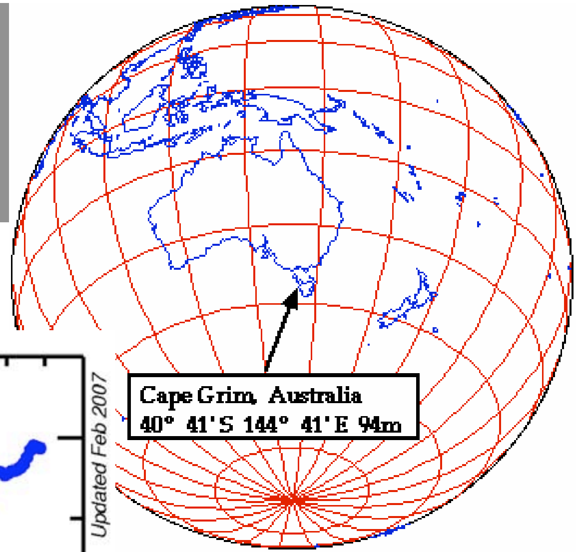
The two big issues on the minds of many people are GHG emissions and temperature rise (and its consequences)

Temperature rise – e.g. as foreshadowed by IPCC

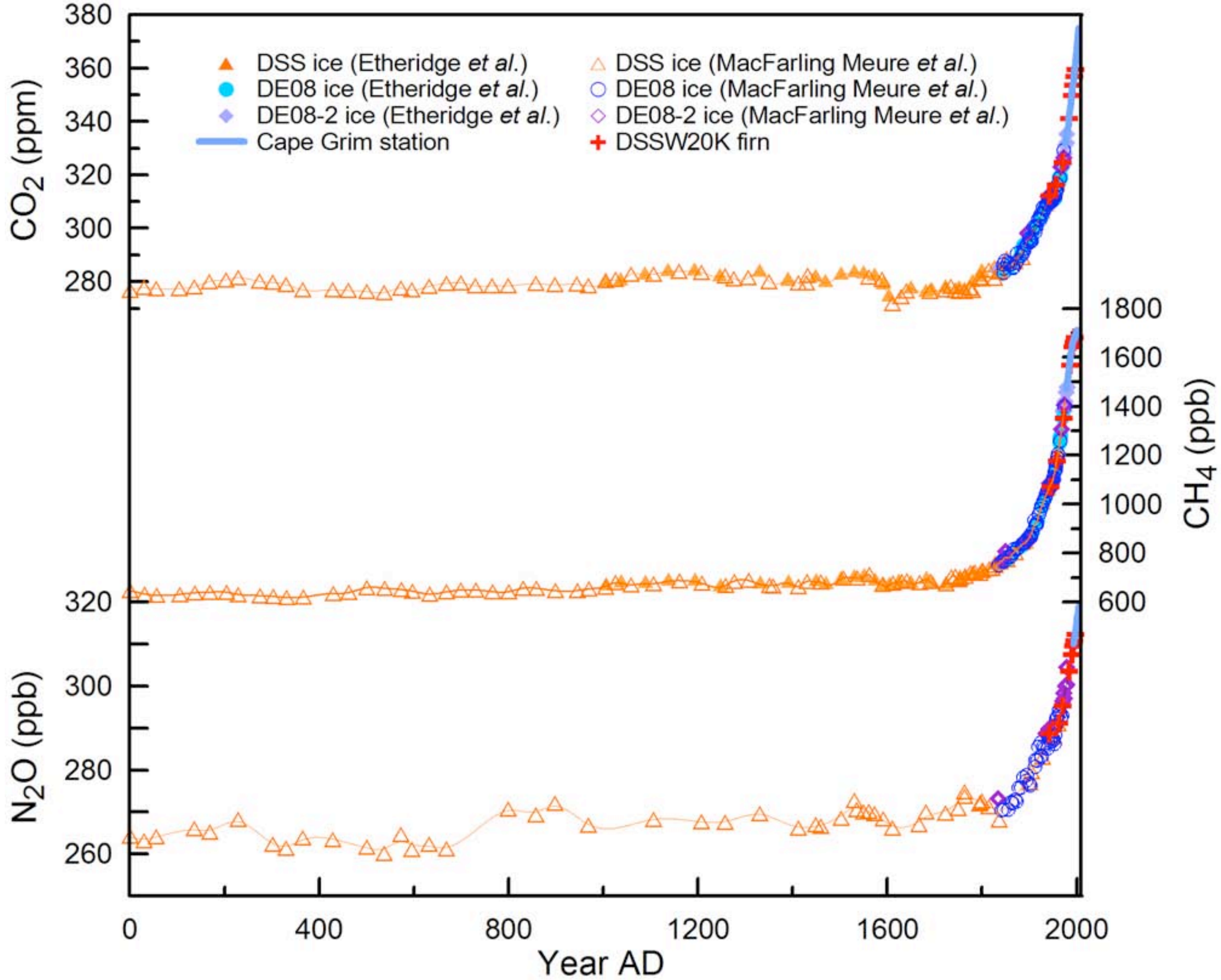


GHG rise – atmospheric CO_2 level





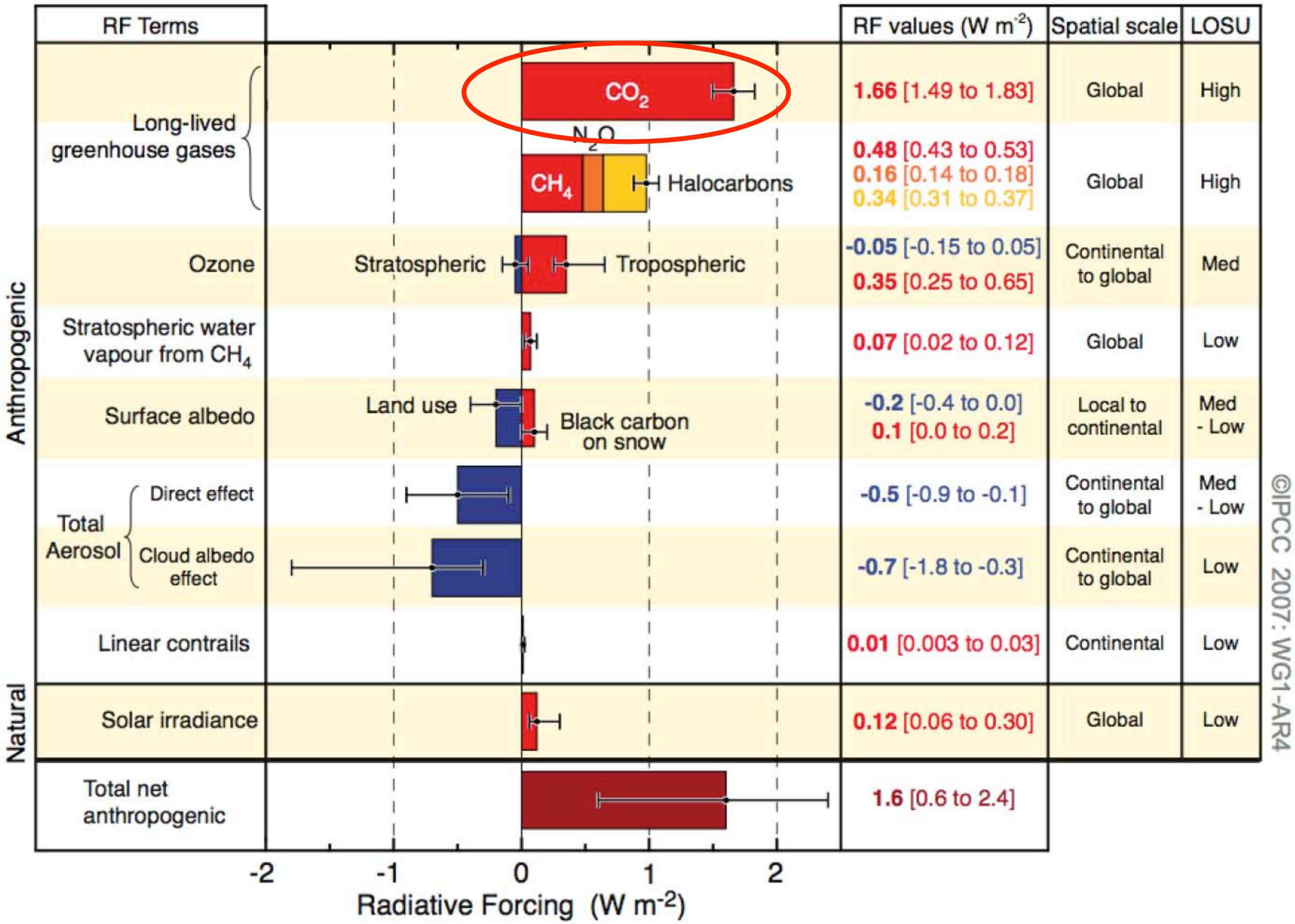
Atmospheric CO_2 over the last 2000 years



MacFarling Meure, C., Etheridge, D., Trudinger, C., Steele, P., Langenfelds, R., van Ommen, T., Smith, A. and Elkins, J. *Geophysical Research Letters*, 2006.
Etheridge, D. M., Steele, L. P., Francey, R. J., and Langenfelds, R. L. *Journal of Geophysical Research,* 1998.
Etheridge, D. M., Steele, L. P., Langenfelds, R. L., Francey, R. J., Barnola, J. M., and Morgan, V. I. *Journal of Geophysical Research*, 1996.

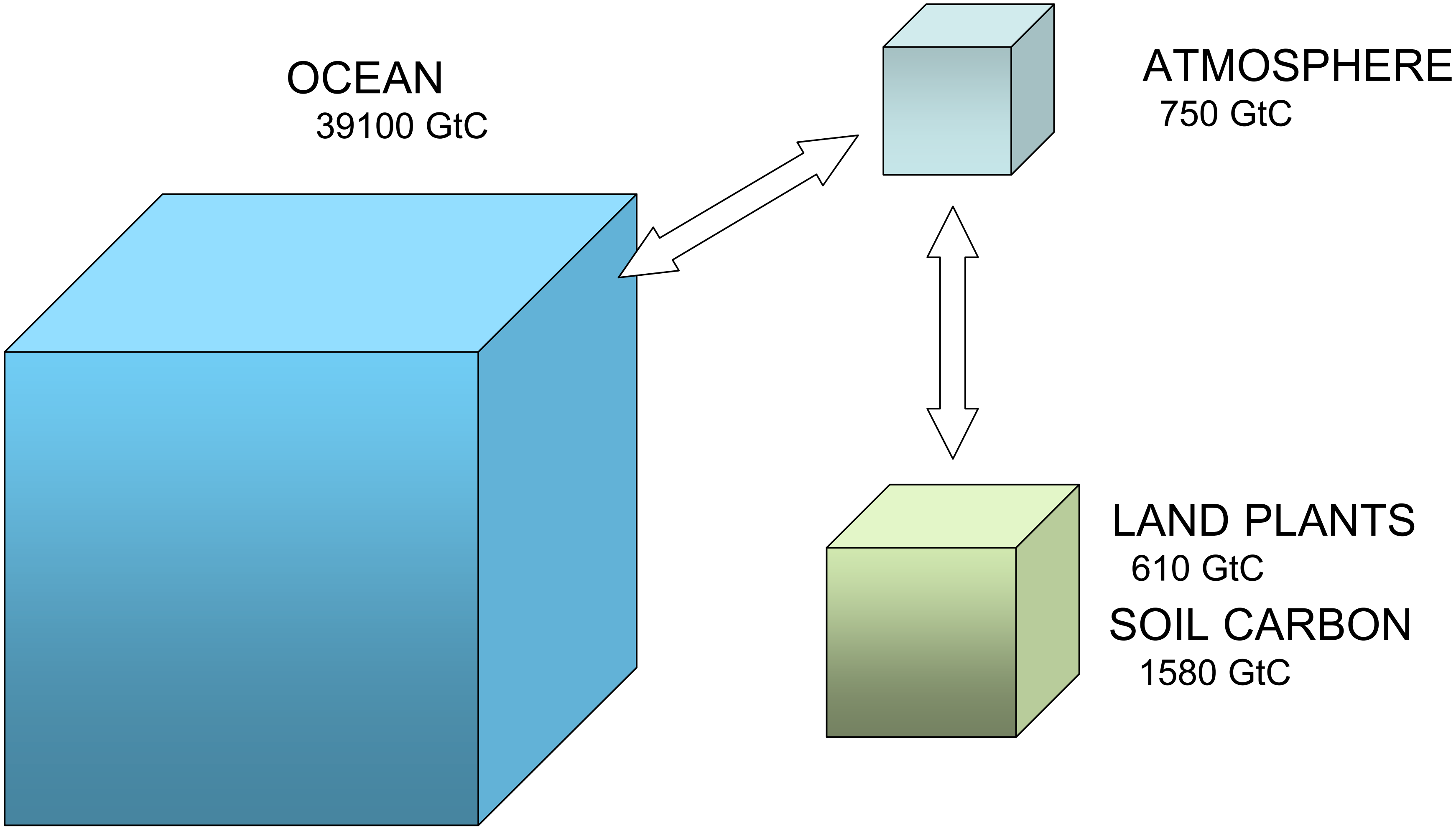
Importance of CO_2 in ‘forcing’ of climate

Radiative Forcing Components

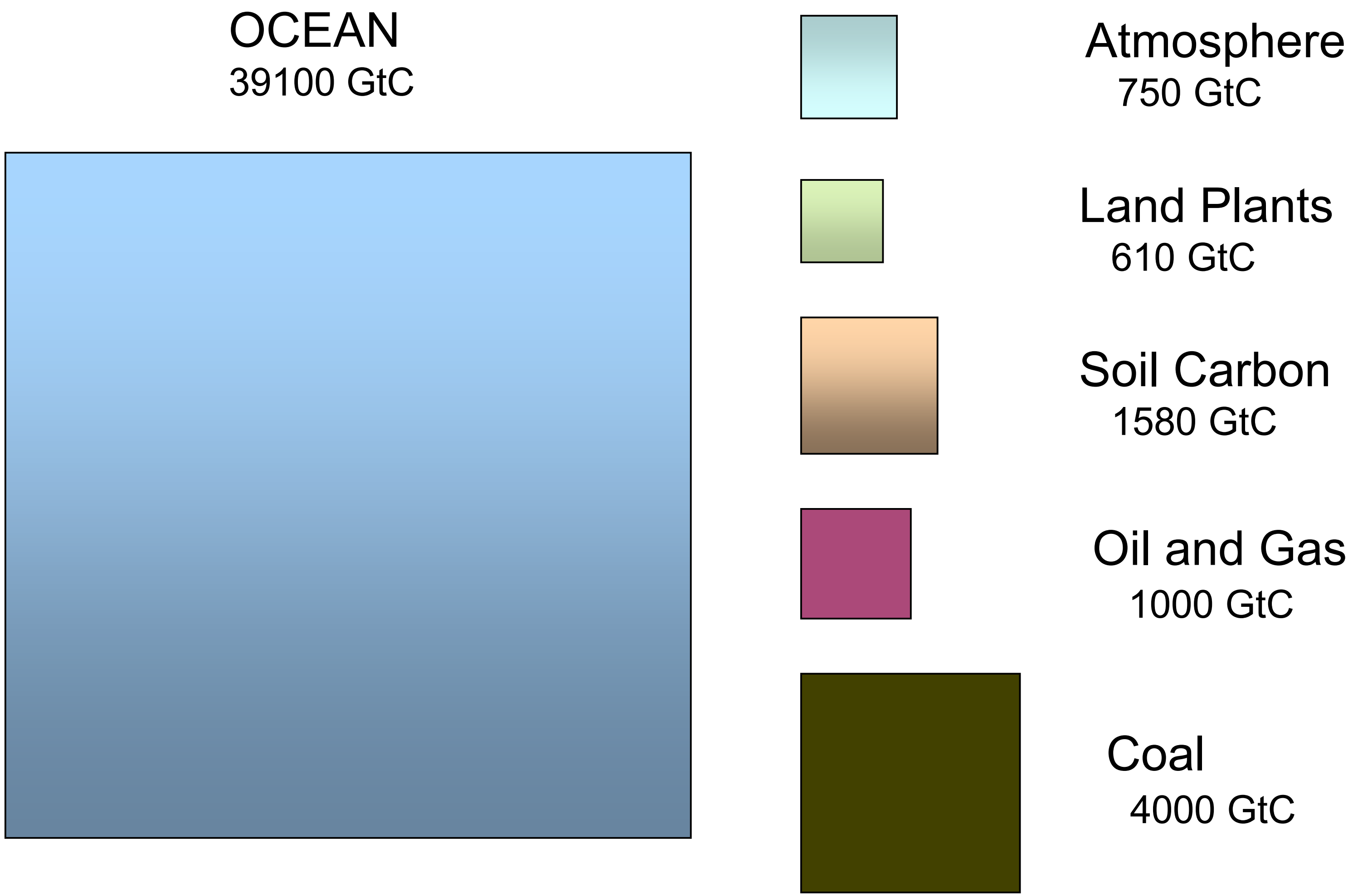


Source: IPCC AR4 (2007)

Given the importance of CO_2, where is all the world's carbon? (1 GtC = one thousand million tonnes)



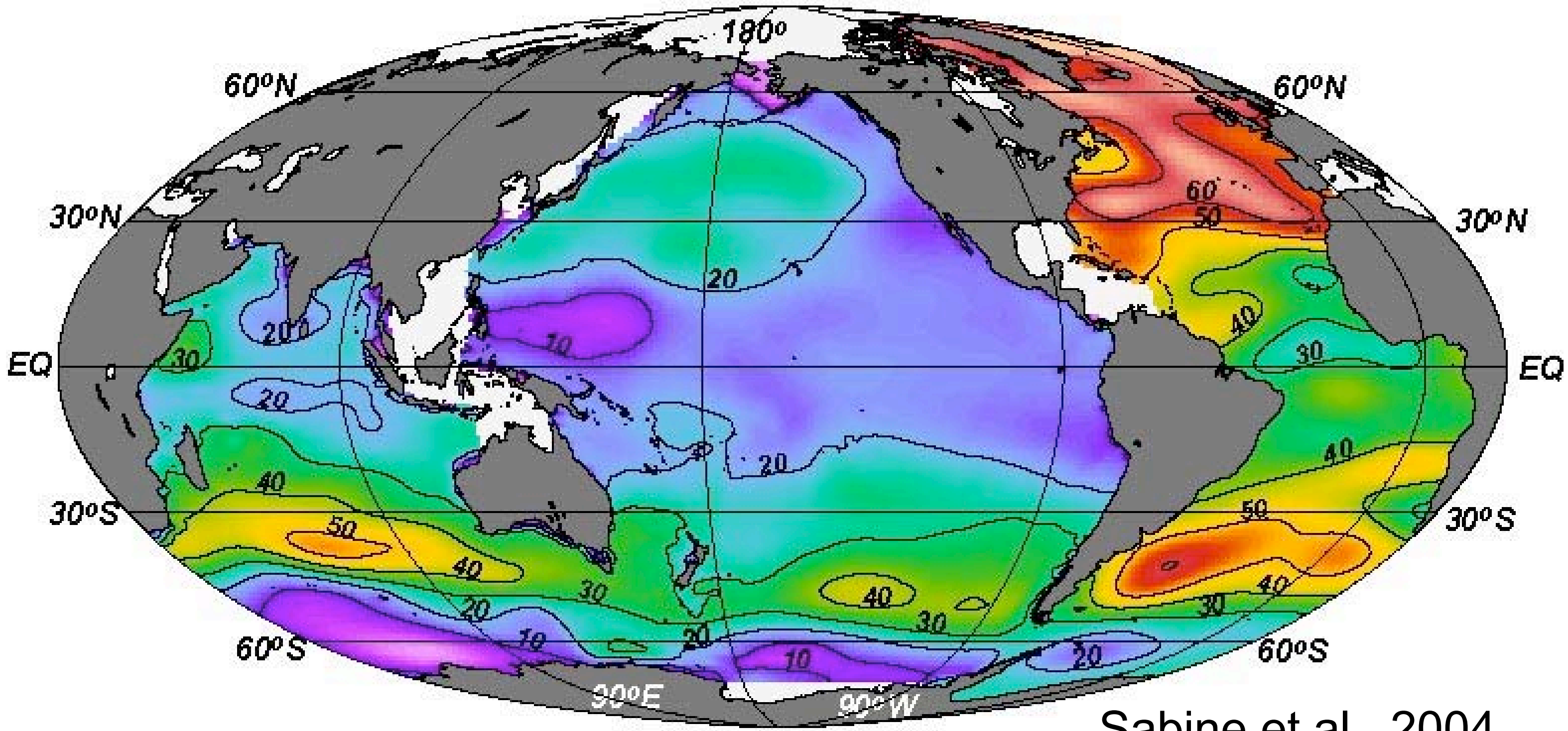
Global carbon reservoirs



It makes some sense to learn that the oceans take up a significant amount of anthropogenic CO_2

In our region, the Southern Ocean absorbs ~ 40% of total oceanic uptake of anthropogenic CO_2

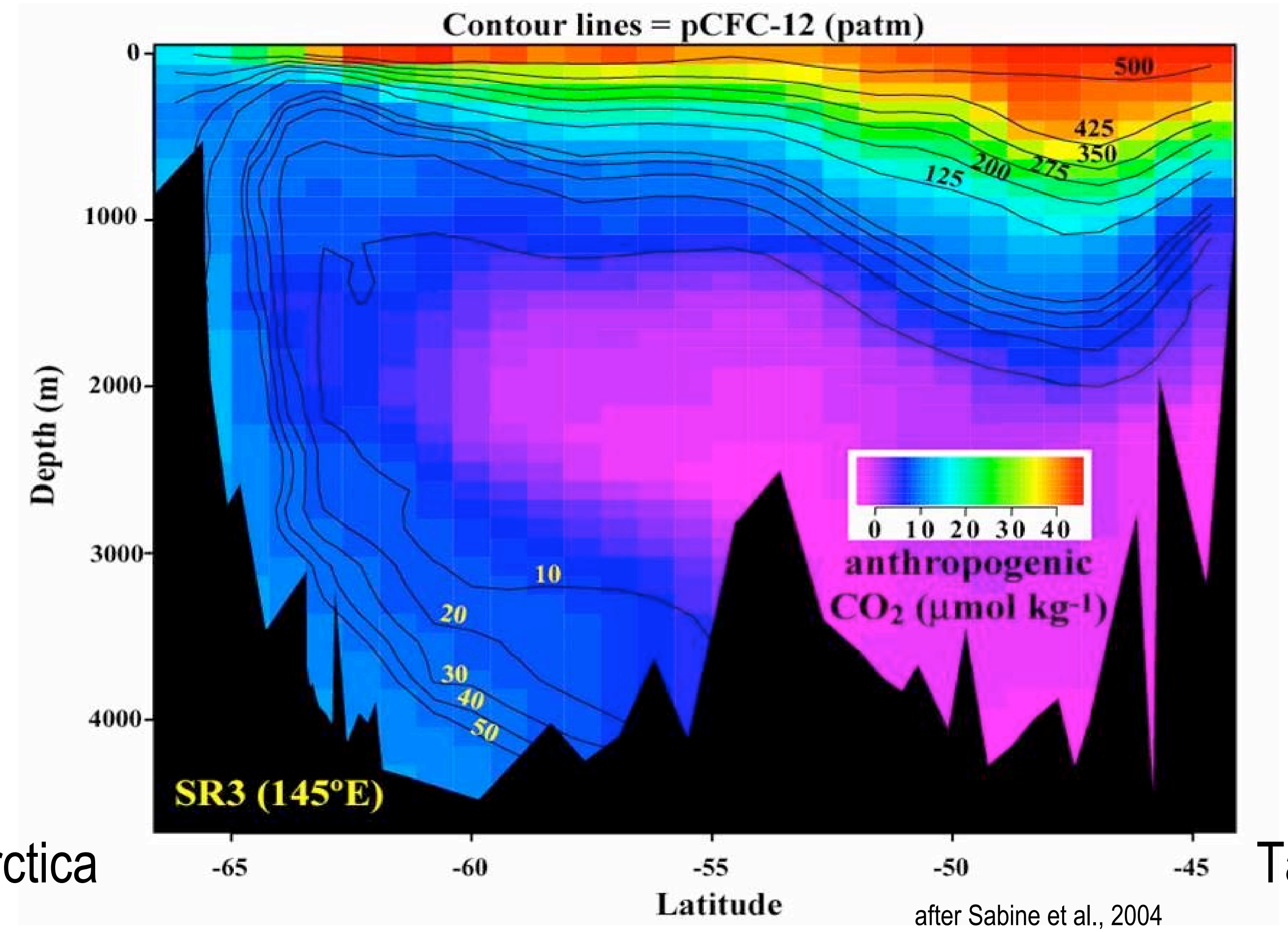
Anthropogenic CO_2 Column Inventory (mol m^{-2})



Sabine et al., 2004

Anthropogenic CO_2 is carried into the ocean interior by water masses formed in the Southern Ocean, so any changes in this circulation will affect future uptake

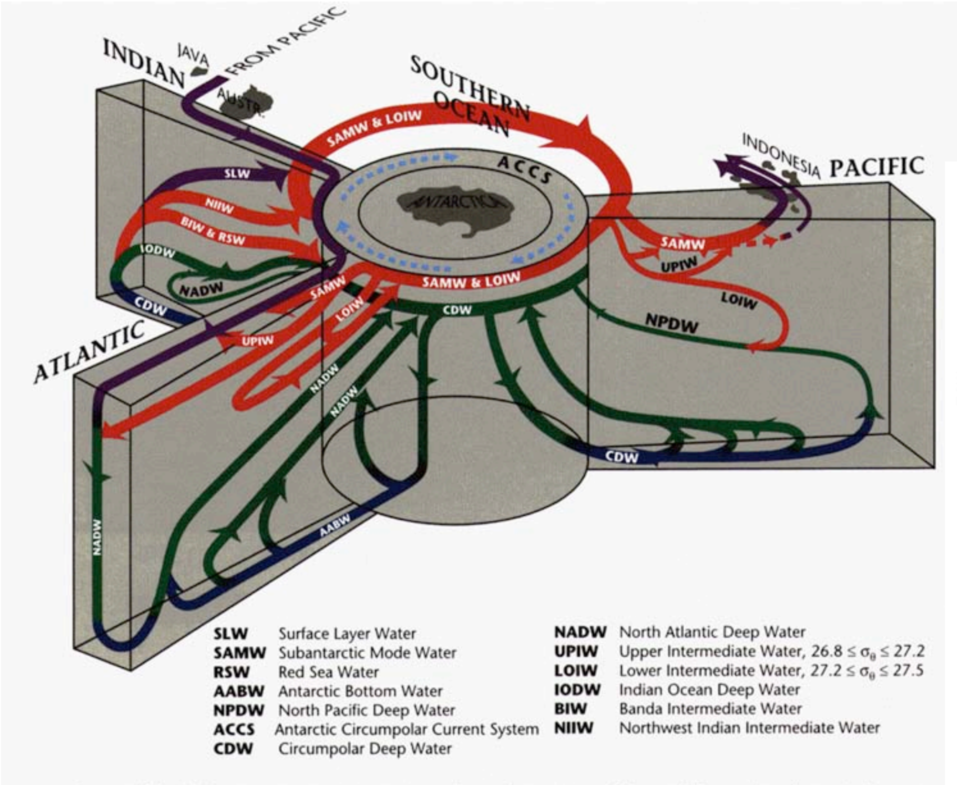
Antarctica

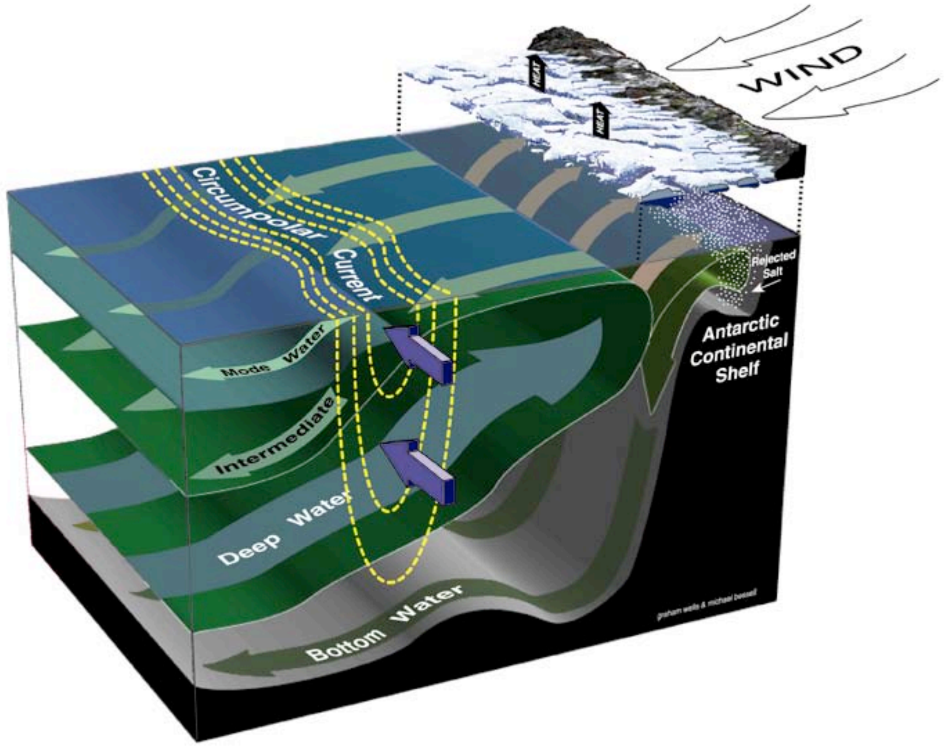


Tasmania

after Sabine et al., 2004

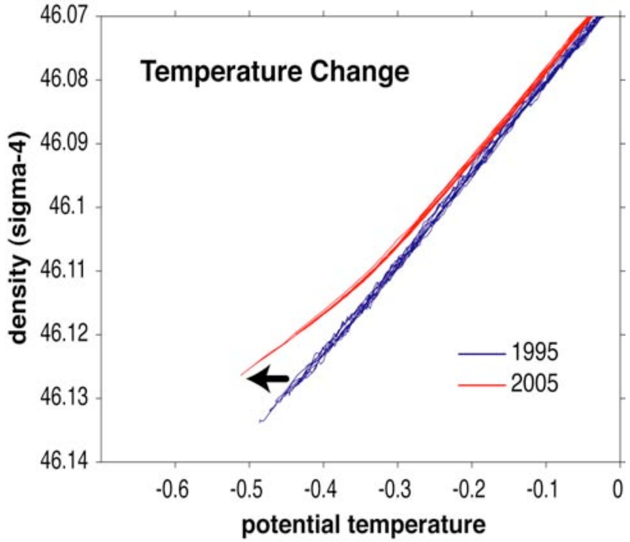
Southern Ocean overturning

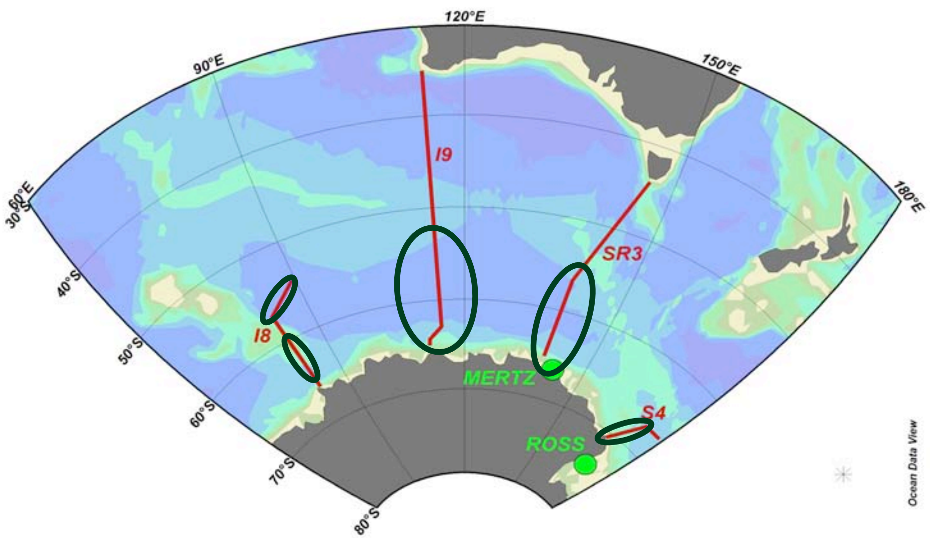


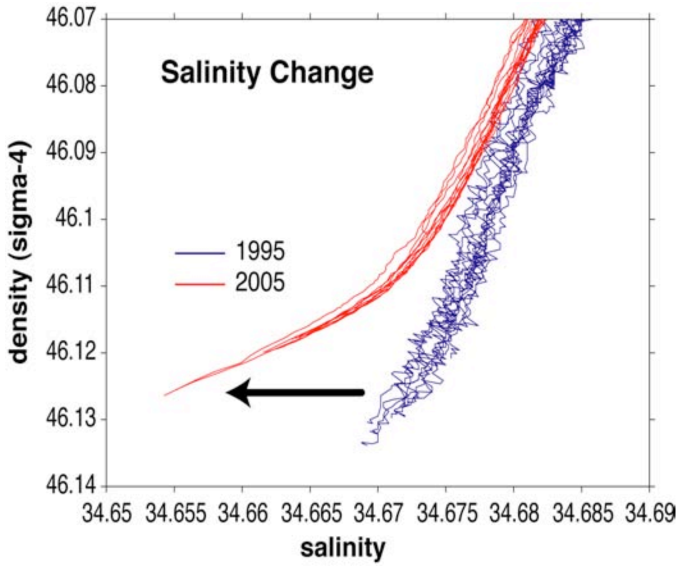


We have seen rapid changes in the deep SO

In 10 years, the deep layers of the entire basin have become fresher and less dense.







1. Implications for 'forcing' of climate change

Most of the world's carbon is in the ocean

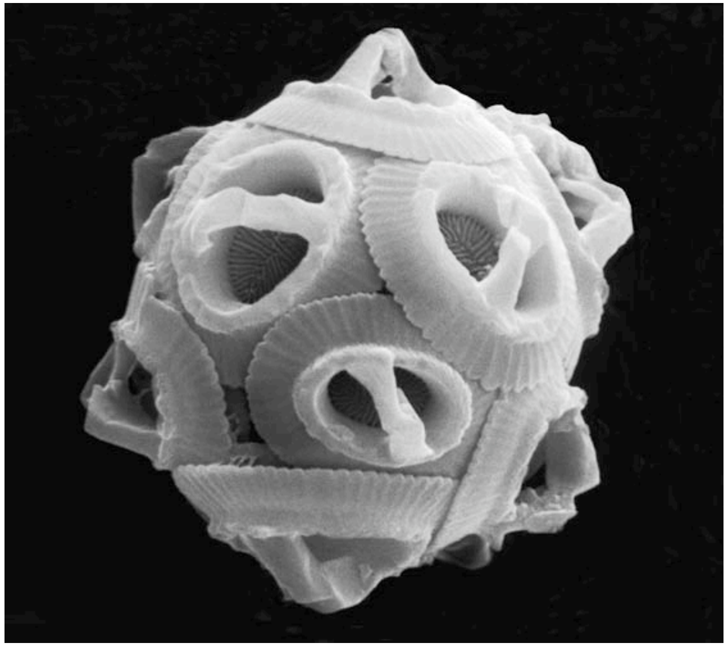
- Human activities now emit about **7.2 Gt** of carbon per year
- About **2.2 Gt** of this anthropogenically generated carbon is taken up by the ocean, thereby reducing the amount that builds up in the atmosphere
- **Any reduction in net ocean uptake** caused by shifts in ocean circulation (or the 'biological pump') could lead to an **acceleration in the rate** of atmospheric CO_2 increase and global warming
- Ergo, improving our knowledge of physical, chemical and biological oceanographic processes is a high priority, among others . . . .

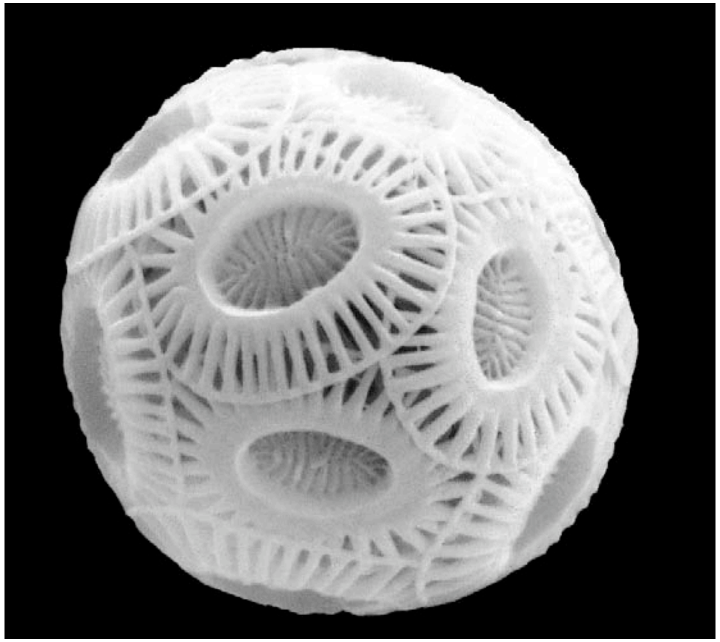
Carbon in the ocean is also chemically important

Ocean carbonate chemistry – carbonate ions are needed to enable skeleton/shell-forming creatures to form their calcium carbonate structures

- $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$

e.g. coccolithophore exoskeletons, pteropod shells, coral reef structures . . .





Does adding to the oceans 2.2 GtC of anthropogenic carbon in the form of CO_2 assist shell formation?

No: the opposite is the case.

Adding CO_2 to the atmosphere acidifies the ocean because CO_2 is a weak acid

- $CO_2 + H_2O \Leftrightarrow H^+ + HCO_3^-$

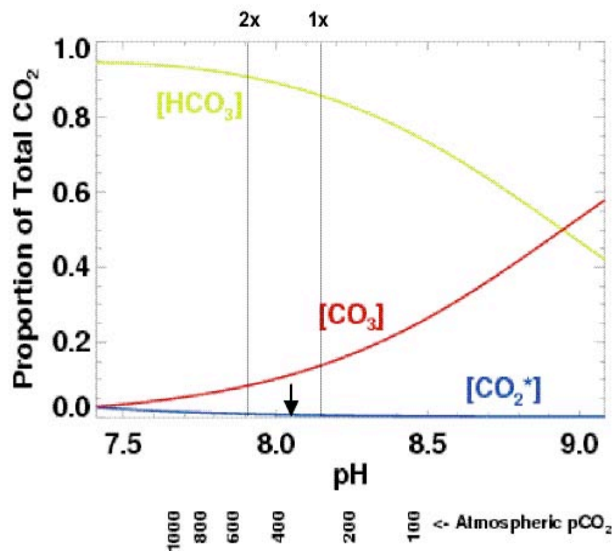
The increased ocean acidity reduces ocean carbonate levels, by converting carbonate to bicarbonate

- $H^+ + CO_3^{2-} \rightarrow HCO_3^-$

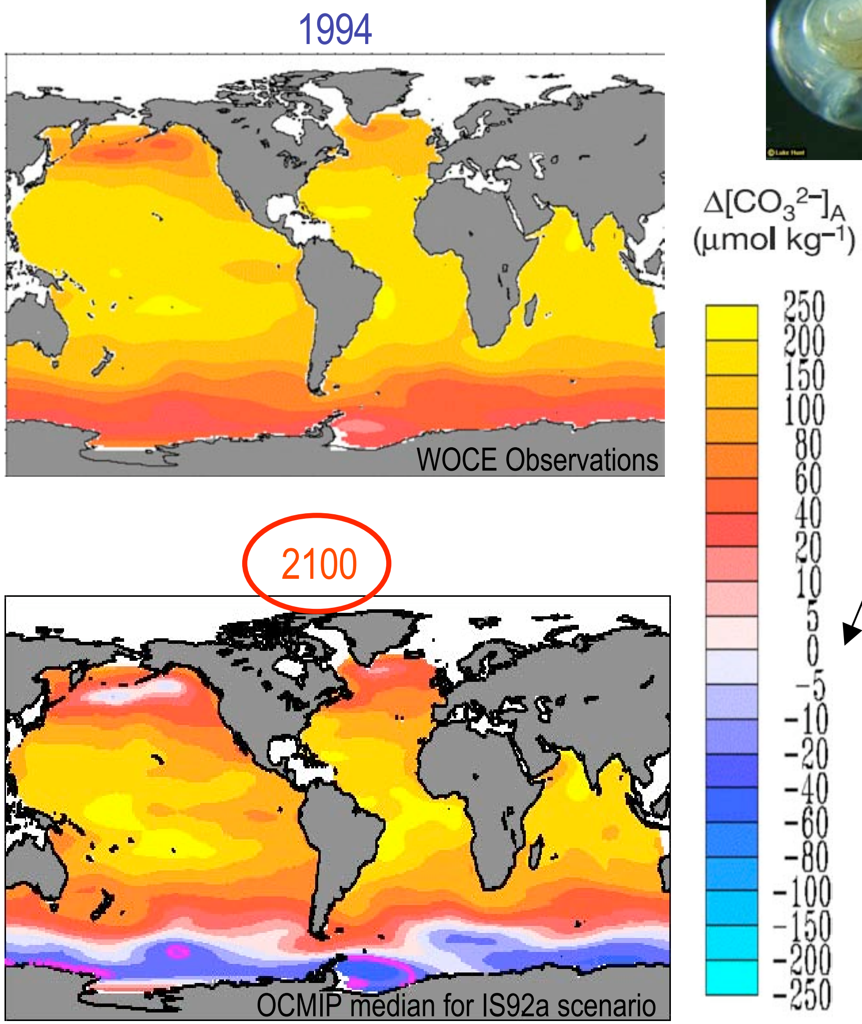
Lowering CO_3^{2-} levels will make it more difficult for shell-forming creatures to form their calcium carbonate shells

- $Ca^{2+} + CO_3^{2-} \rightarrow CaCO_3$

Acidity is represented by hydrogen ions

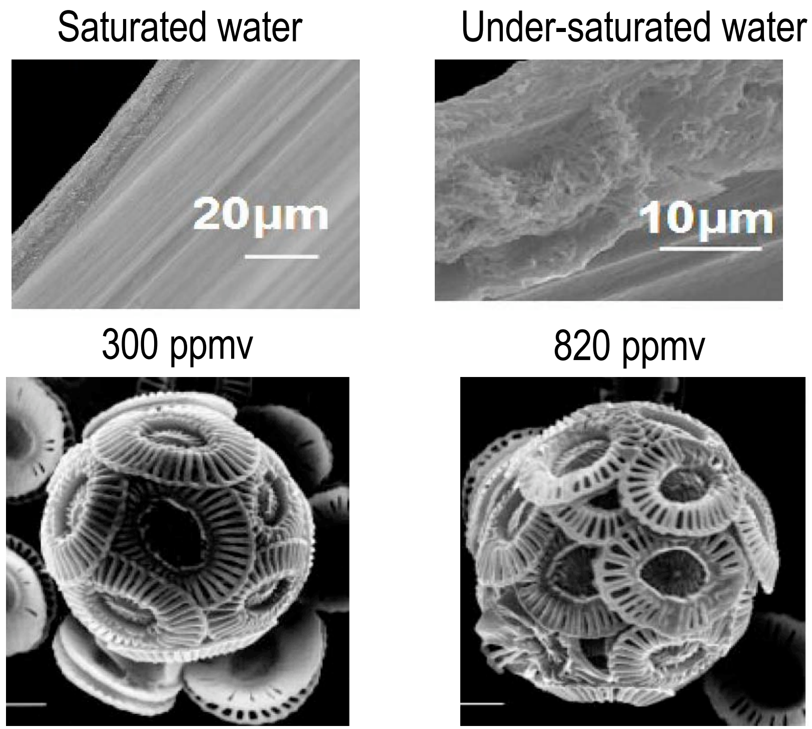


Ocean acidification & plankton – at base of the food chain



Orr et al. (2005)

‘Aragonite’ is a major form of calcium carbonate in question: the future of Aragonite ‘saturation’ is the issue, as aragonite dissolves in under-saturated conditions



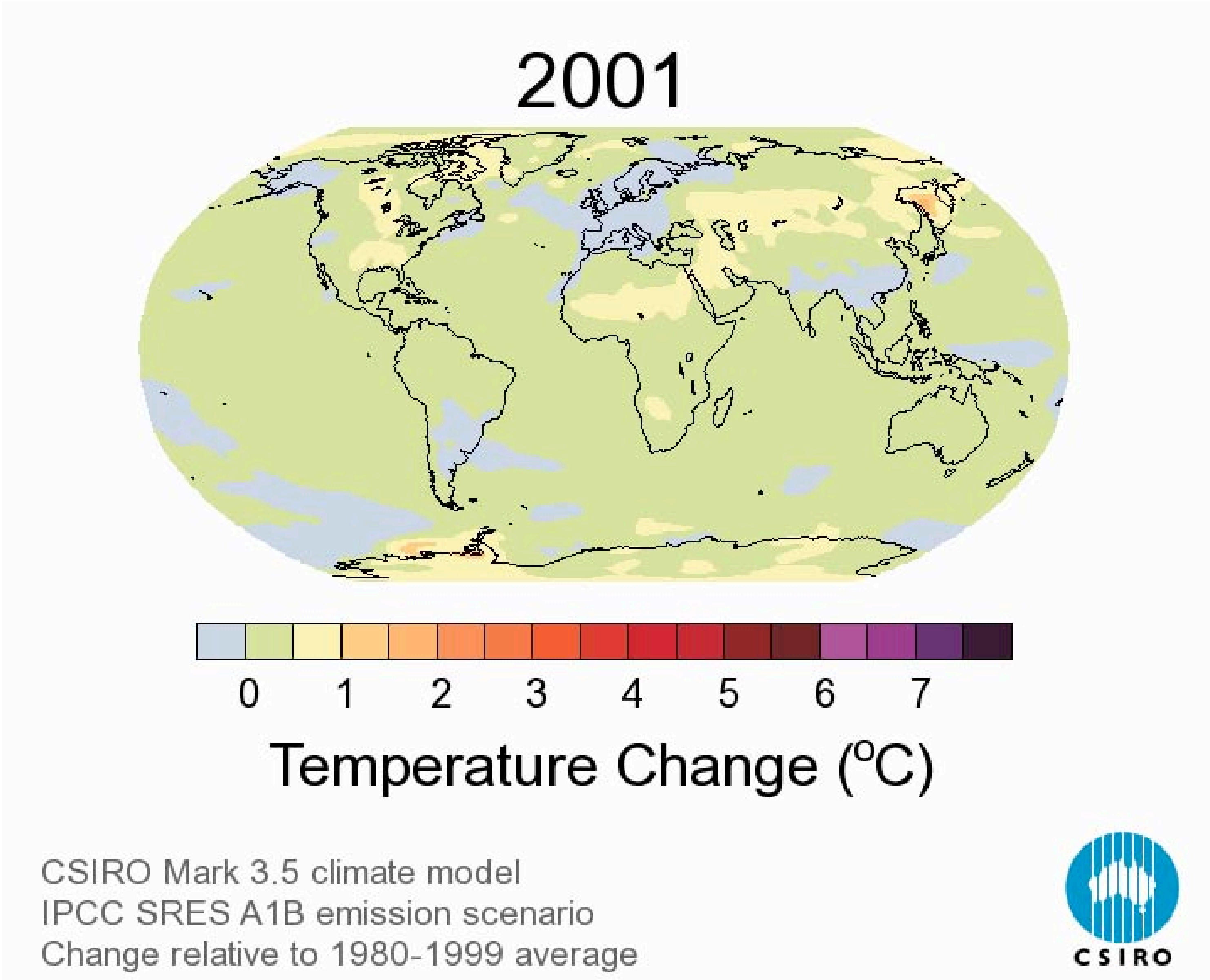
Riebesell et al. (2000)

2. Implications of ocean acidification

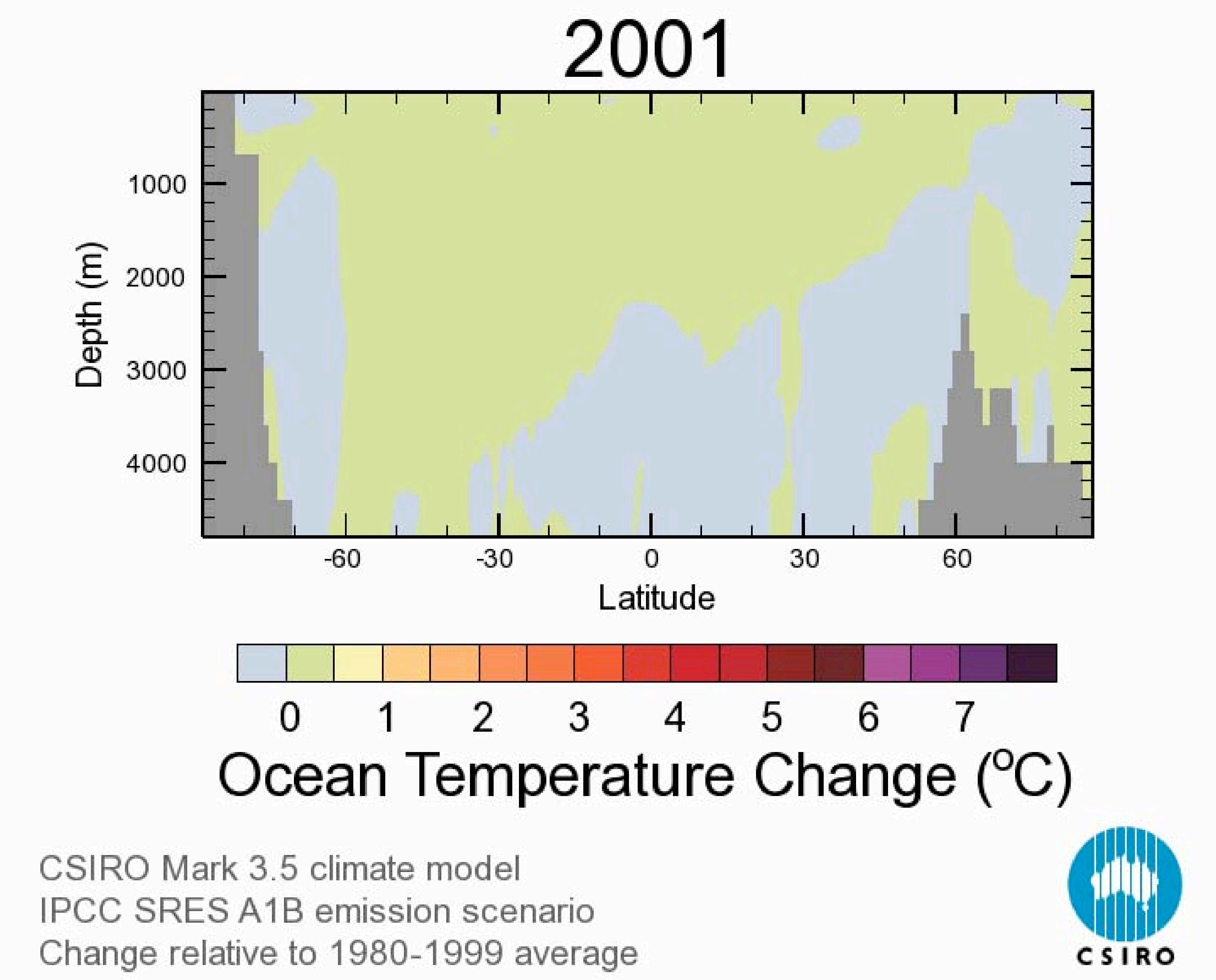
Summary

- Rising CO_2 levels in the atmosphere reduce the ocean's $[CO_3^{2-}]$, decrease the ability of biological organisms to calcify and decrease the stability of calcium carbonate
- At present, calcium carbonate (both aragonite and calcite) is stable in the surface ocean
- By 2100, with the IS92a CO_2 emissions scenario, aragonite becomes unstable in the entire Southern Ocean south of 60°S

What about temperature?

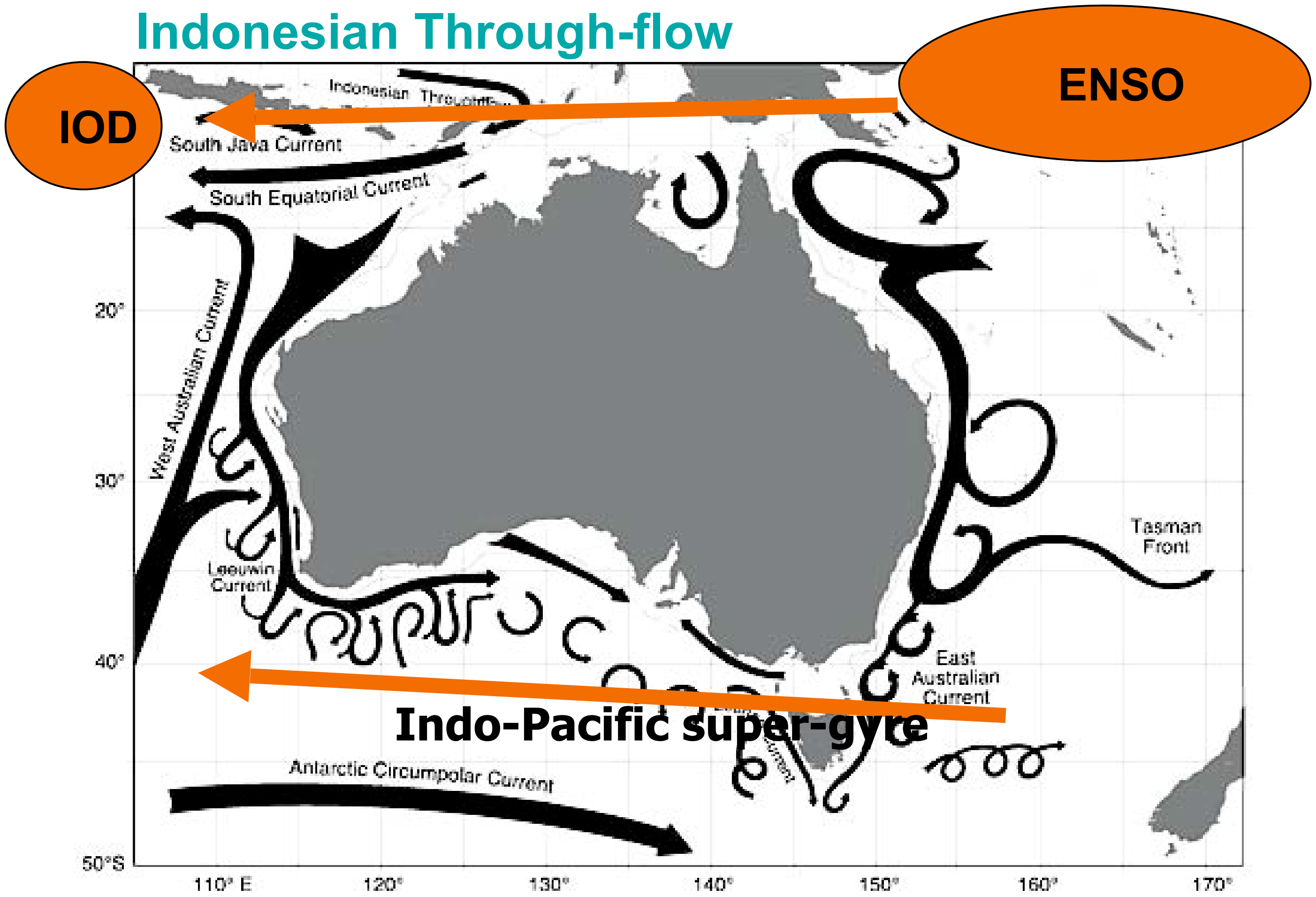


3. Implication: the oceans have absorbed vast amounts of added heat (>80% since 1950s), **but the ocean response will continue to lag**

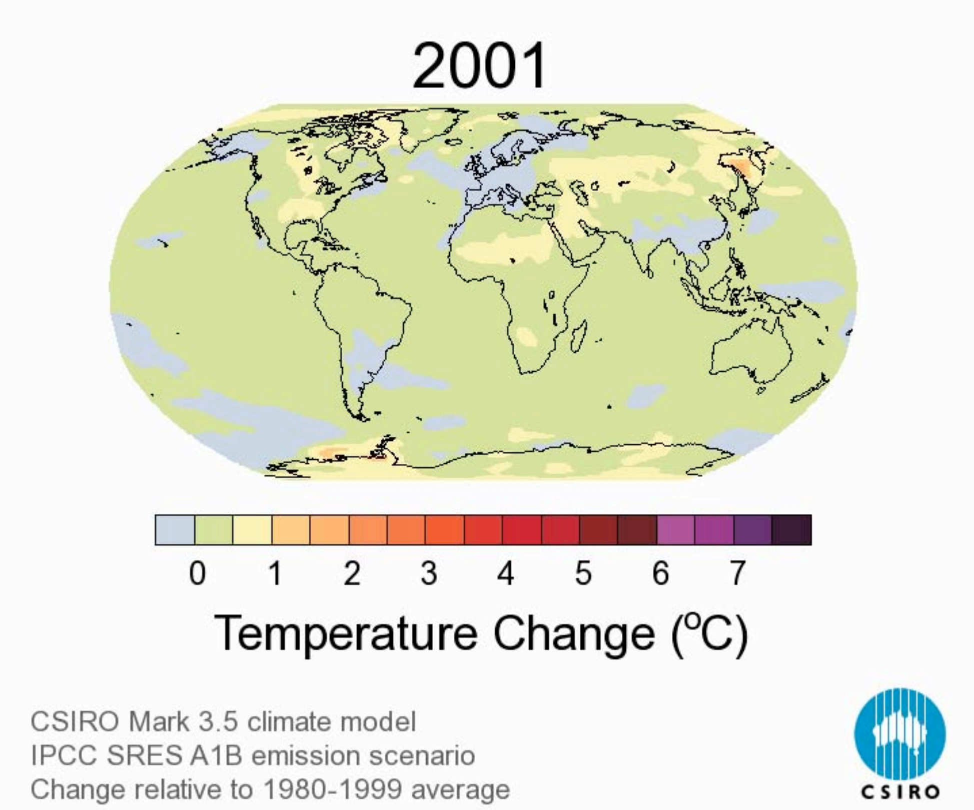


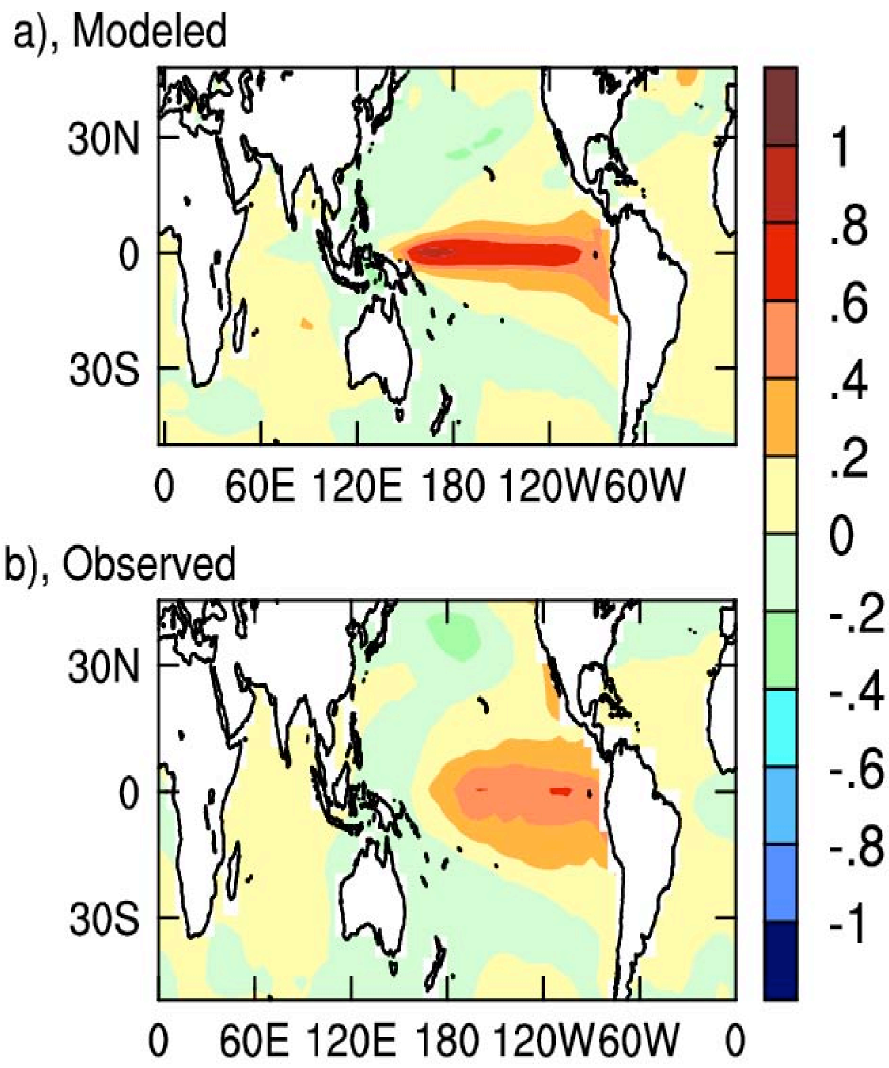
Importance of ocean warming: to weather & rain

Sea Surface Temp (SST), ocean currents, rainfall trends and marine impacts are inter-related: ENSO; IOD



El Nino Southern Oscillation (ENSO) is well known via its signature in SSTs – quite a modelling challenge!

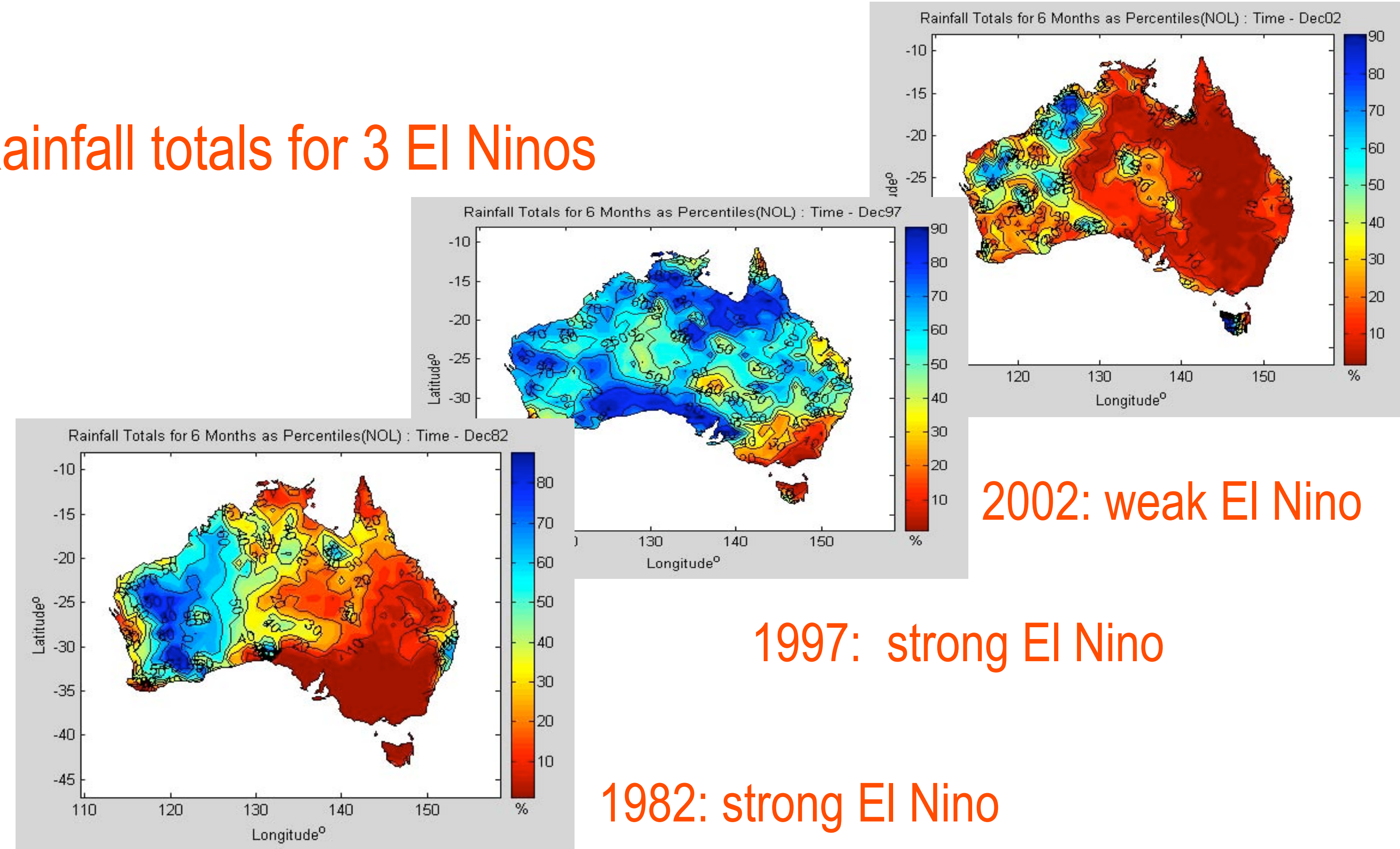




ENSO is reasonably simulated in Mk3 climate model, but the Indian Ocean Dipole (IOD) is simulated unrealistically

But impact of El Nino varies – challenge for scientists is to determine how it will change as global warming continues

Rainfall totals for 3 El Ninos



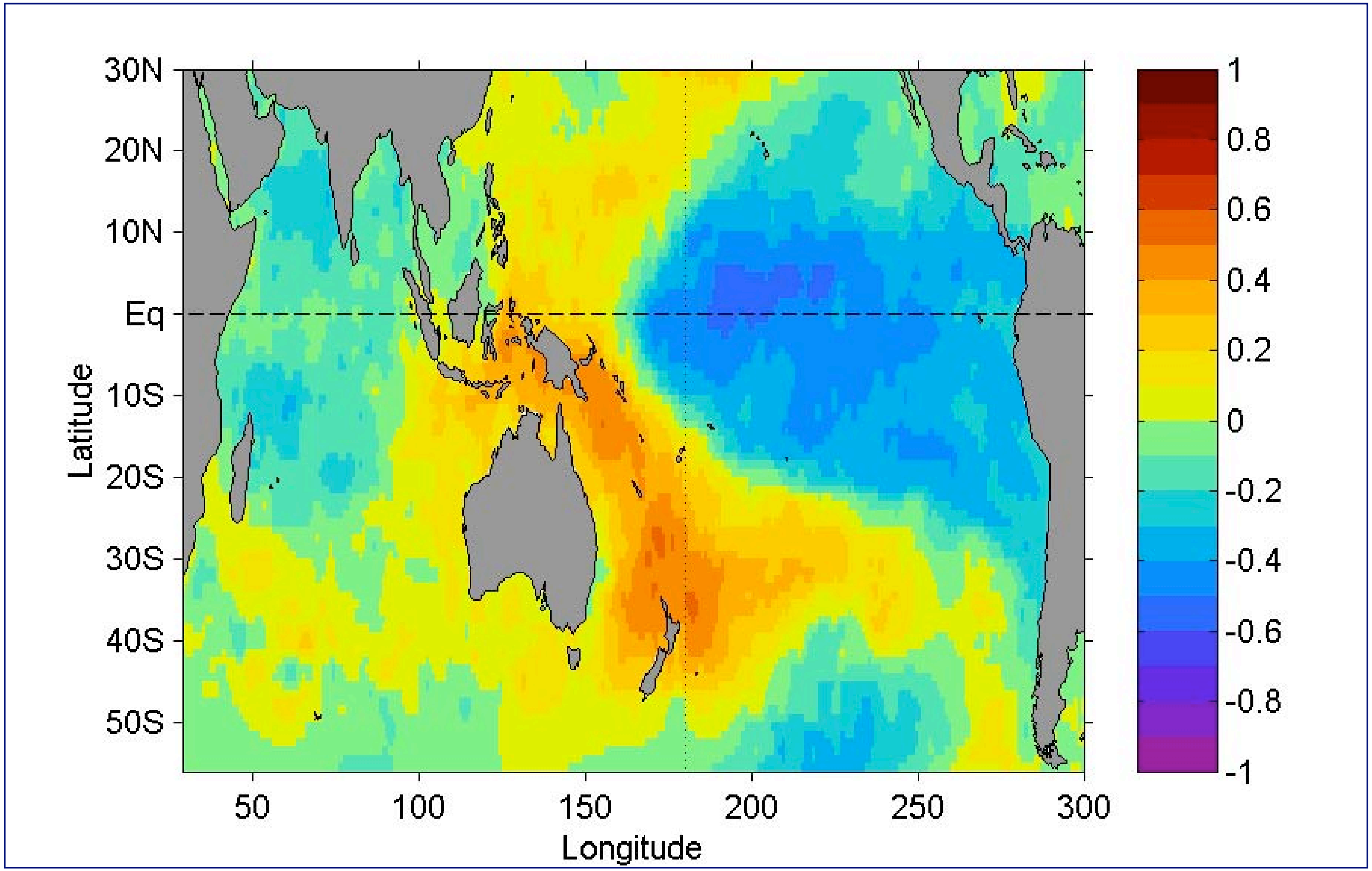
2002: weak El Nino

1997: strong El Nino

1982: strong El Nino

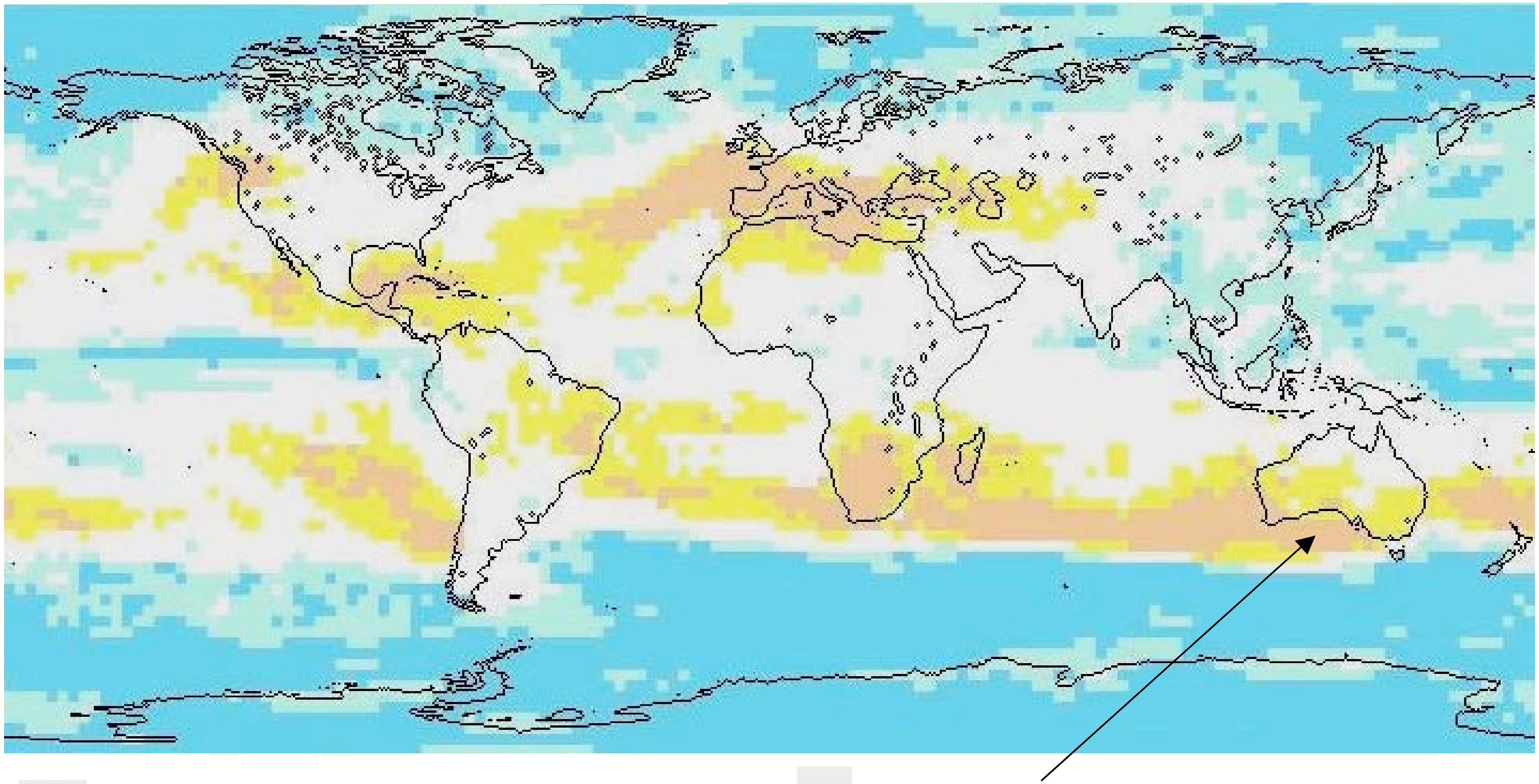
Importance of ocean warming: to weather & rain

Correlation patterns between SST (sea surface temperature) in June and pasture growth days in the subsequent Jul-March period in NE Qld



What will happen to rainfall as land and ocean warm? [IPCC AR4 climate model consistency plot for 2100]

June-July-August (JJA)



Precipitation increase in ≥90% of simulations

Precipitation increase in ≥75% of simulations

Precipitation decrease in ≥75% of simulations

Precipitation decrease in ≥90% of simulations

4. Implications for weather patterns and rainfall

While climate models still face challenges in simulating the detail of observed SST patterns and their regional responses to global warming, at global scale the modelled trends are consistent with observations.

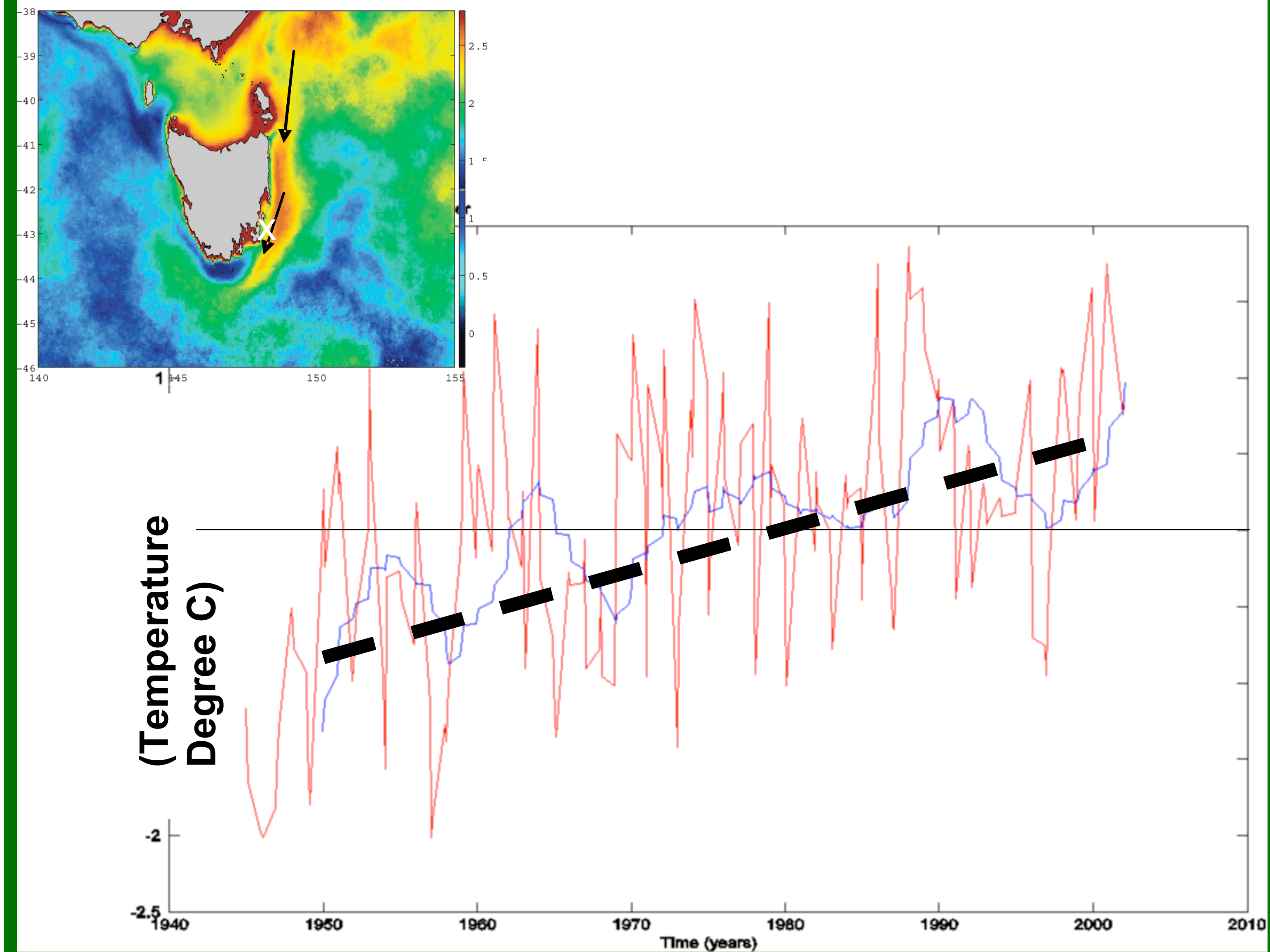
For example the southward shift in mid-latitude storm tracks and the instabilities that generate rainfall over southern Australia are consistent with a majority of climate model simulations.

A move to more ‘El Nino-like’ conditions in the future would pose a significant challenge to Australia.

Importance of ocean warming: biological effects

e.g. Tasman Sea warming/poleward increase in SST affects species range

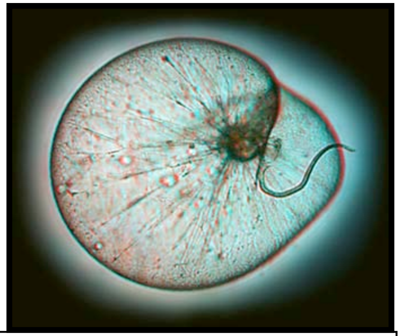
Maria island long-term ocean temperature observations show warming in the region of some 1.6 ºC in 50 years, three times as large as the global average



Importance of ocean warming: biological effects

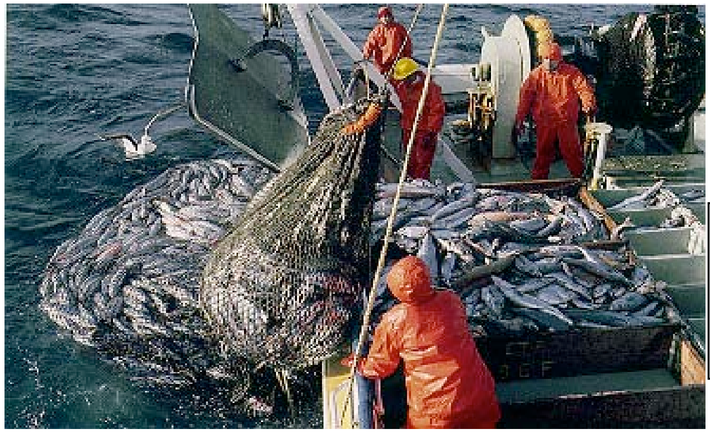
e.g. Tasman Sea warming/poleward increase in SST affects species range

Invasion of sea urchins native to NSW coast causing barrens (loss of kelp) off eastern Tasmania *(S. Ling)*



Changing composition of phytoplankton blooms off Tasmania– increased tropical species *(S. Blackburn)*

Rock lobster catch and distribution correlated with regional SST changes around Tasman Sea *(Harris et al 1988)*



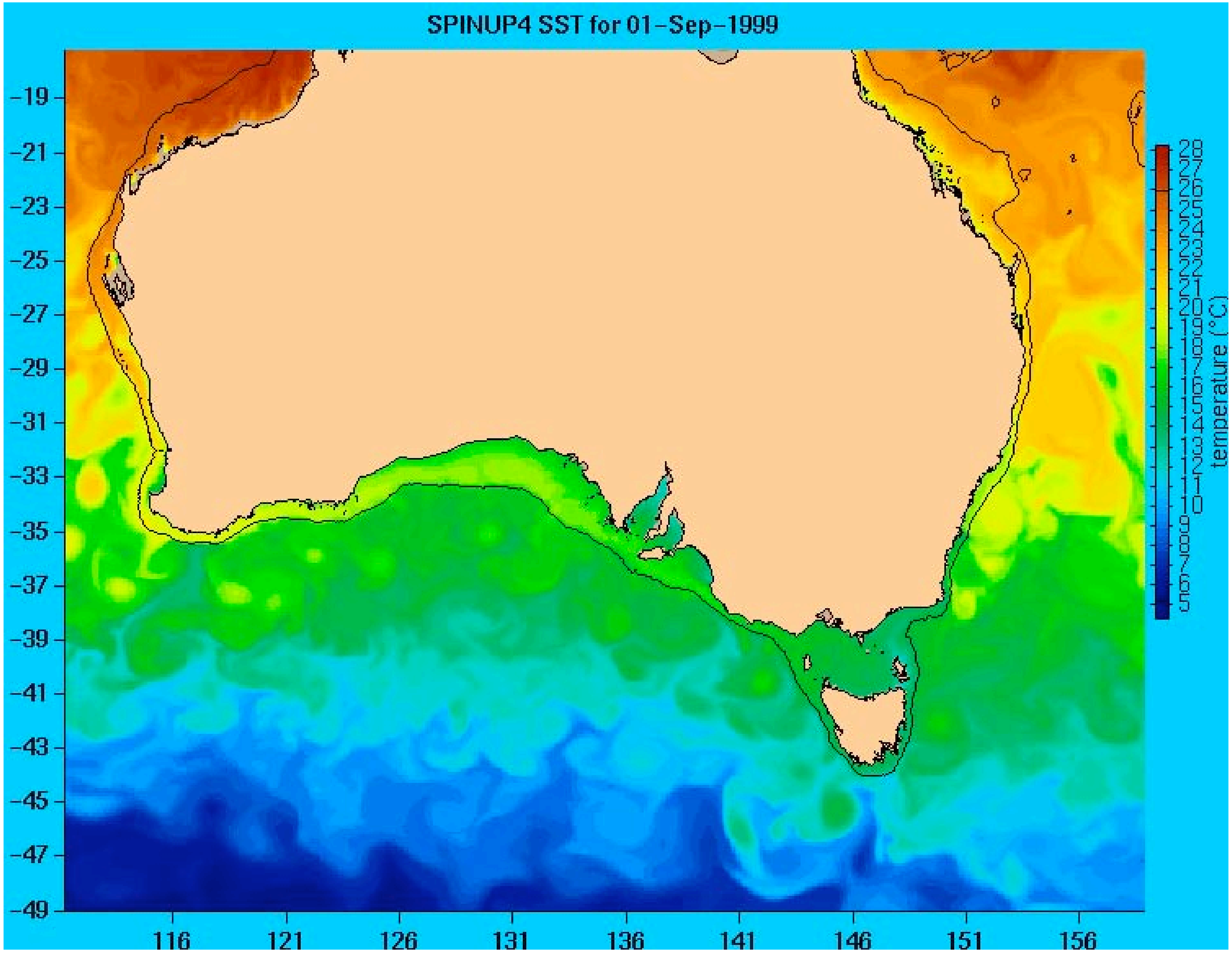
In last decade 34 fish species have exhibited major distributional changes: either newly established south of Bass strait, or show significant range extensions. *(P. Last)*

Hill, 2005

5. Implications for biological systems

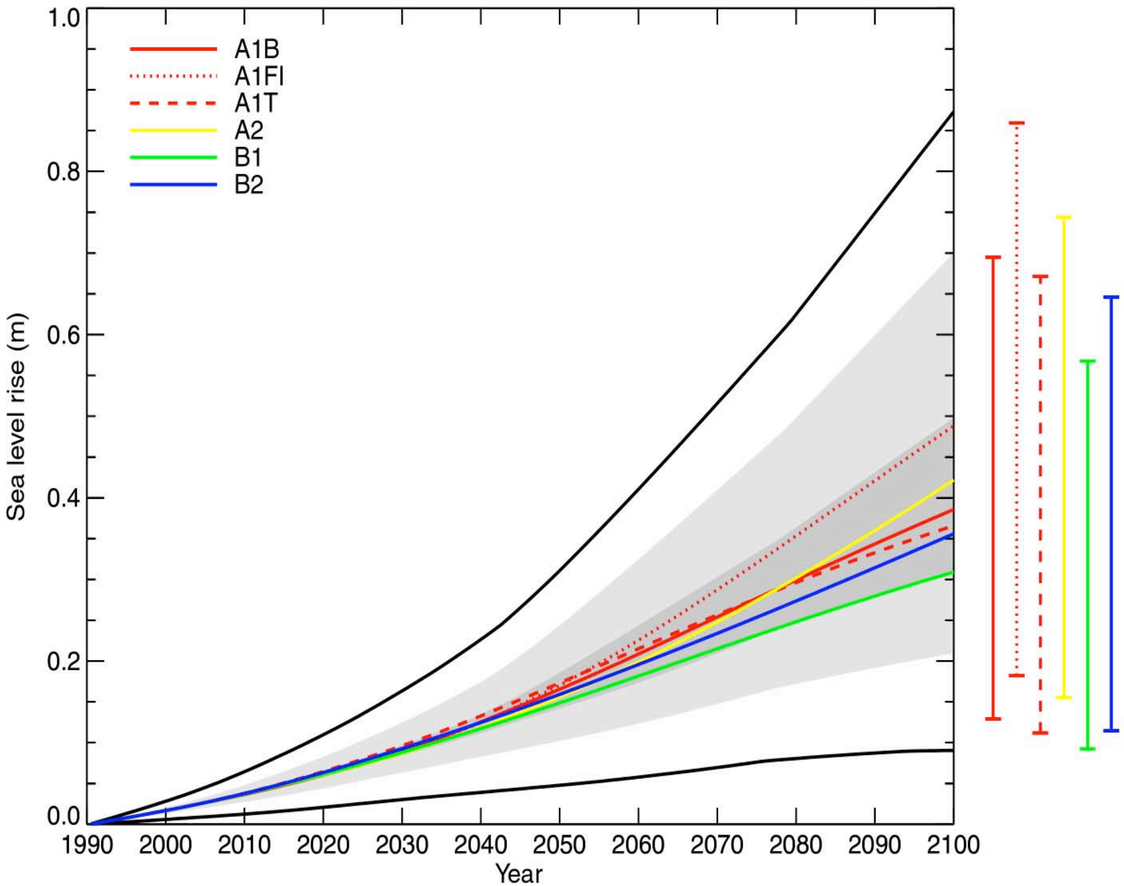
Changes in habitat range due to changed physical and chemical environment as ocean currents vary in response to altered ocean heat content and warming

(BLUElink simulation)



Importance of ocean warming: sea level rise

IPCC TAR Global Sea-level rise projections (2001)



The science challenge is to substantially reduce the uncertainties in projections – FAR controversy

Stabilisation Costs
Tens to hundreds of billions of dollars

People to respond to coastal flooding
-Tens to hundreds of millions potentially affected (effective adaptation reduces this dramatically)

Impacts on ecosystems – biodiversity

We are already committed to longer-term changes due to climate system lags

Church *et al., IPCC TAR,* 2001

Coastal effects are of concern: *Herald Tribune Jan 2007*

/ 20 / SUNDAY JANUARY 21 2007

The future must float

e about climate change continues, **William Little** talks to people whose communities have already been affected and who are adapting to the challenges

iean sea-
ks of the
coasts of
of India,
ique in
ving few
e planet
are six-
lling into
a result
n, while
ns, such
Honduras,
to bigger

mong the
Kolkata,
urg, that
nt Stern
g risks of
the earth
s. It also
ising sea
n people.
n predic-
story is
sidential
from the
r sea lev-
d risk of
prohibi-
against.
re being
resulting
rs claim
national
Cosgrove,
d Water
d think
od disas-
n relent-
he 1950s;
1970s; 18
0s.
0 people
ear was a
pattern,
titute of
and very
ral India

Dilemma: efforts to save one area of coastline can have detrimental effects elsewhere — Corbis

becomes imminent – but was based on its 'riskless' market value, which preserved the interest of relocated families," he says.

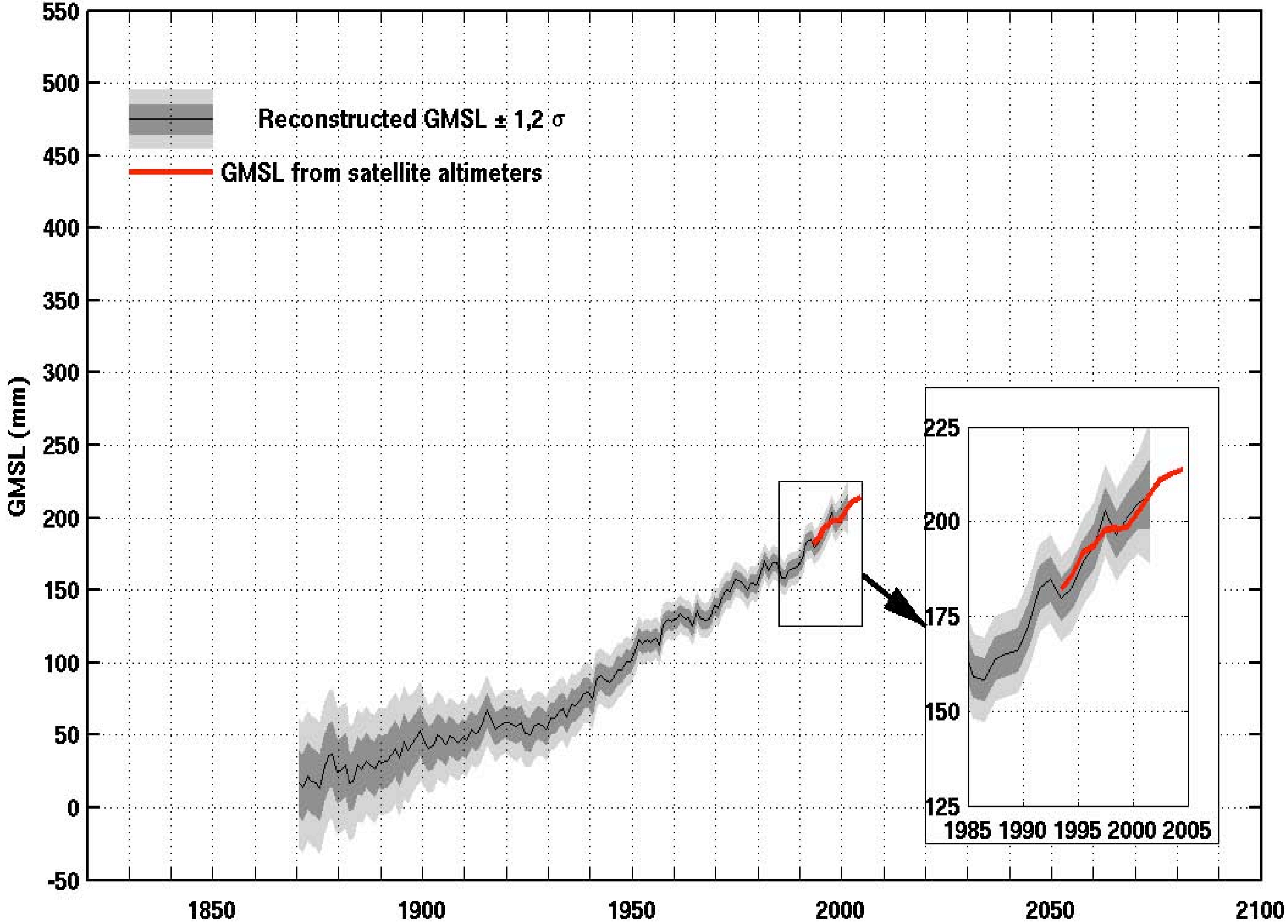
Decisions are made at the commune level in France and the mayor was able to access the fund to provide compensation to the residents so they could move further inland. The cliffs will continue to retreat and provide valuable sediment to protect the valleys behind, which are a higher priority as they contain the much larger settlements of Dieppe, Saint-Valery, Fécamp and Le Tréport – which lie below the high water level during spring tides. This risk has become higher still since the establishment of two nuclear power stations – Paluel and Penly – along the shoreline.

Many other communities around Europe are also providing creative solutions to climate change. For centuries the Dutch have been building dykes to protect themselves from the sea and rivers, which are more likely to flood as sea levels rise. But now they are designing homes to live with water rather than against it. The villagers of Maasbommel, near Arhmen, still pray each day that waters won't topple their 12ft dyke, as they did in the 1953 flood, bursting 50 such defences and killing more than 1,800 people. But 36 homeowners are now worry-free, living in houses on the wrong side of the dyke but designed to float.

Each house is made of lightweight wood and the concrete base is hollow, giving it ship-like buoyancy. With no foundations anchored in the earth, the structure rests on the ground and is fastened to 15ft-long mooring posts with sliding rings, allowing it to float upward should the river flood. All the electrical cables, water and sewage flow through flexible pipes inside the mooring piles.

Chris Zevenbergen of Dura Vermeer, the company behind the project, says floating houses could help make up the

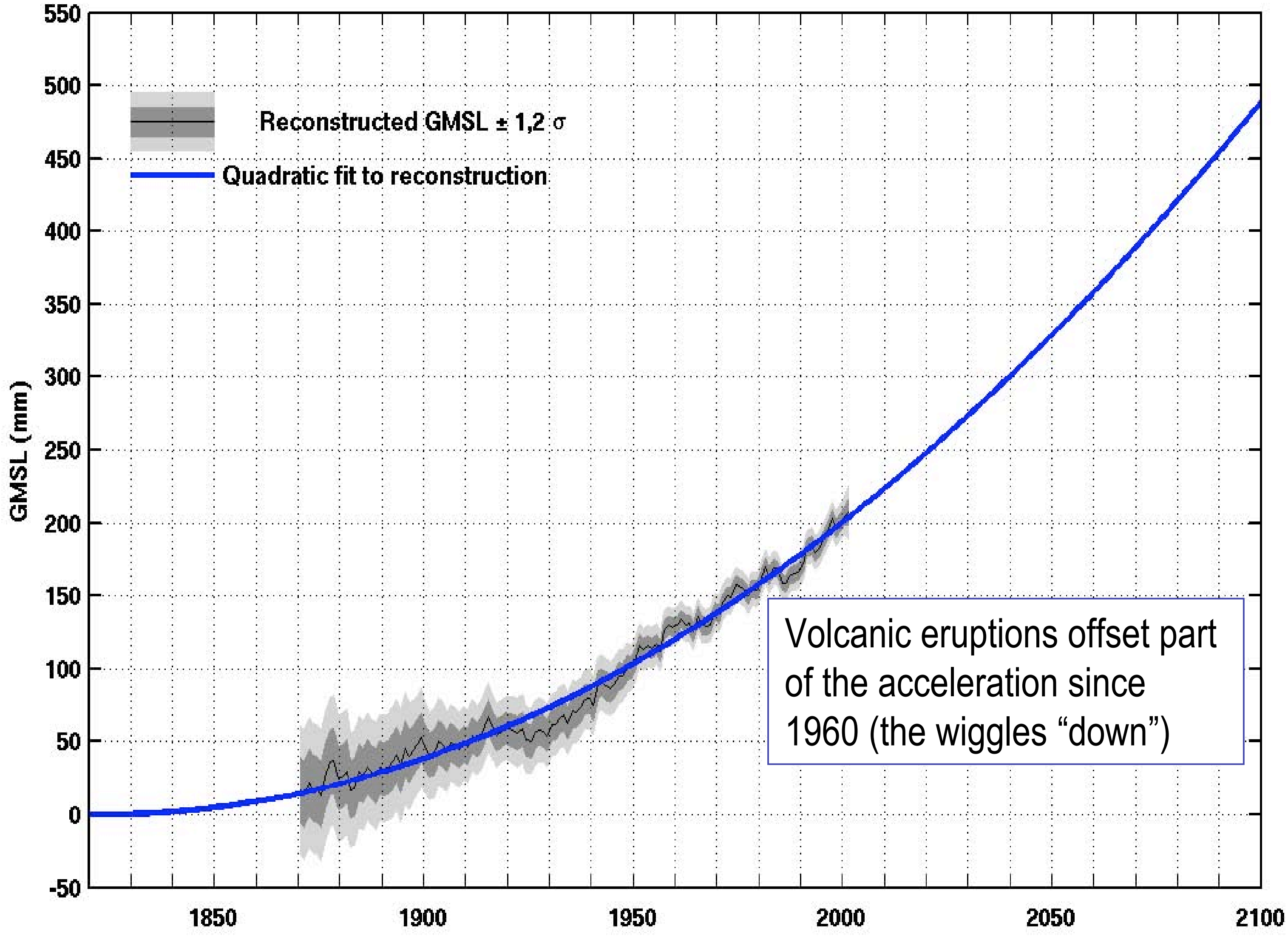
IPCC 4th Assessment (2007): Measurement uncertainty in observed sea level rise has been reduced



Church and White, GRL, 2006;

Church et al., Nature, 2005

Observations show an increasing rate of rise



Church and White, GRL, 2006;

Church et al., Nature, 2005

IPCC 4th Assessment (2007)

Table SPM-1. Observed rate of sea level rise and estimated contributions from different sources. {5.5, Table 5.3}

Source of sea level rise	Rate of sea level rise (mm per year) 1961 – 2003	1993 – 2003
Thermal expansion	0.42 ± 0.12	1.6 ± 0.5
Glaciers and ice caps	0.50 ± 0.18	0.77 ± 0.22
Greenland ice sheet	0.05 ± 0.12	0.21 ± 0.07
Antarctic ice sheet	0.14 ± 0.41	0.21 ± 0.35
Sum of individual climate contributions to sea level rise	1.1 ± 0.5	2.8 ± 0.7
Observed total sea level rise	1.8 ± 0.5[a]	3.1 ± 0.7[a]
Difference (Observed minus sum of estimated climate contributions)	0.7 ± 0.7	0.3 ± 1.0

Table note:

[a] Data prior to 1993 are from tide gauges and after 1993 are from satellite altimetry.

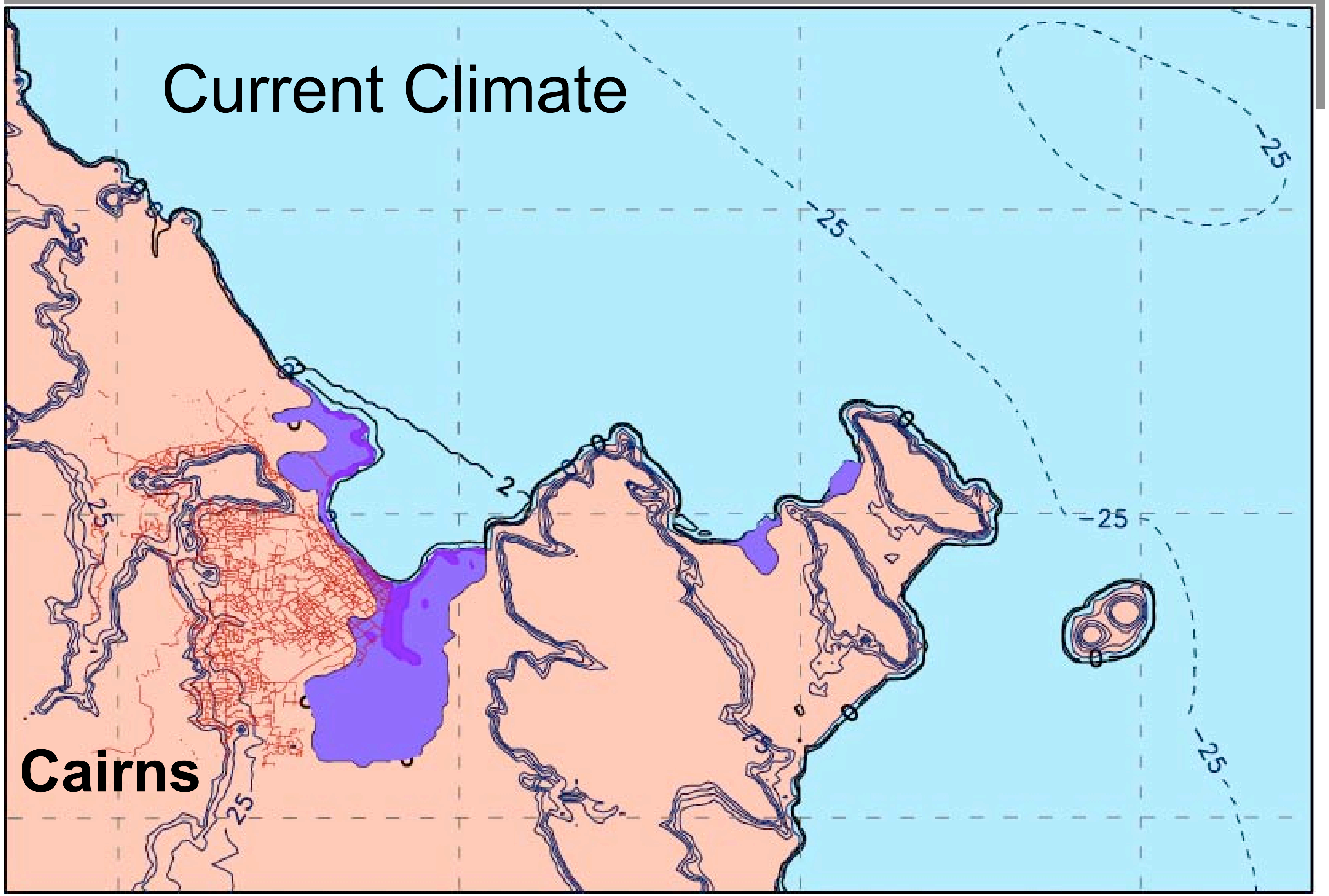
6. Implications: sea level rise

Thermal expansion of the ocean has contributed the major component of observed seal level rise to date

As the Ocean continues to warm expansion will continue

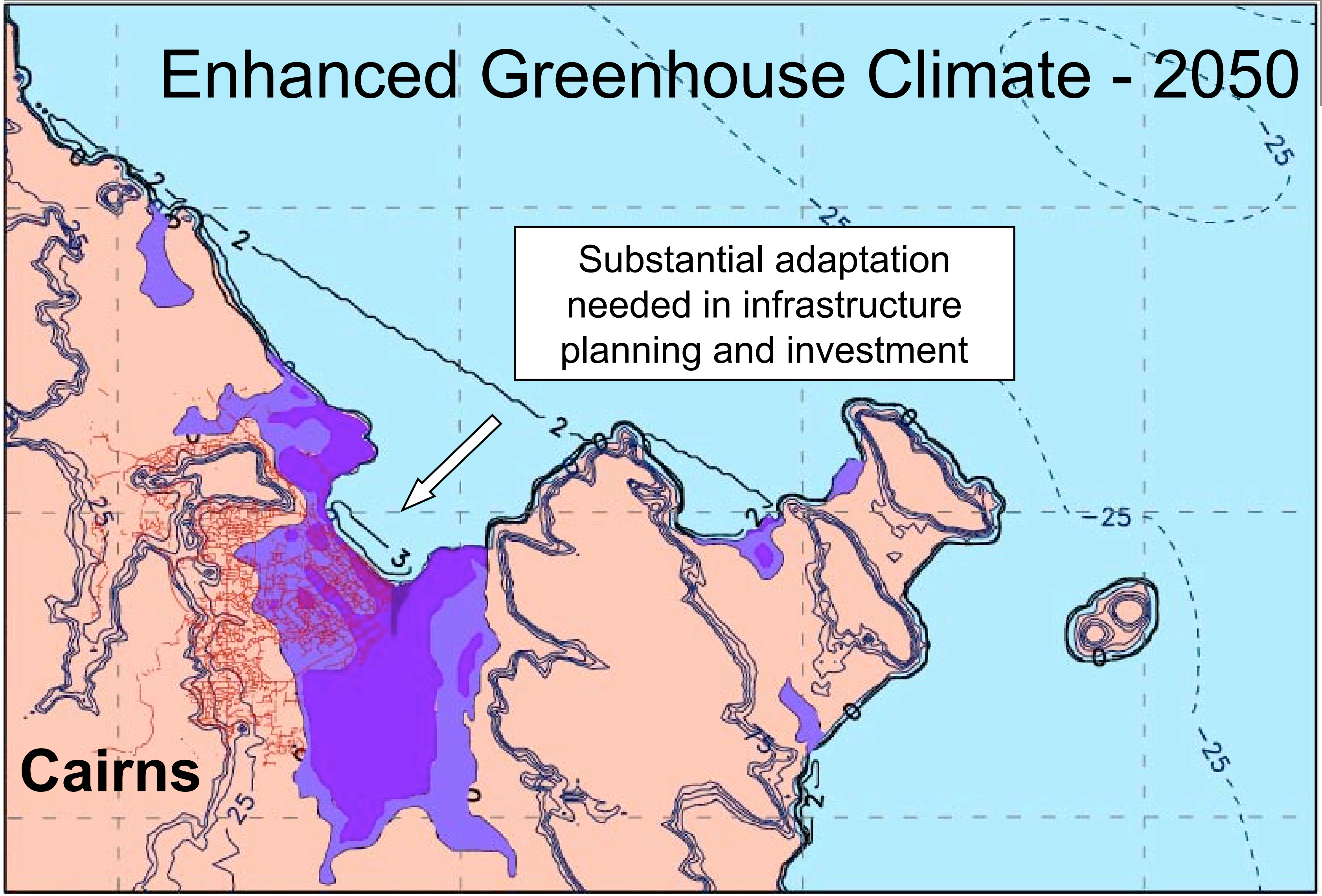
Due to the ‘thermal lag’ inherent in ocean warming, this expansion will continue, slowly, for a very long time after GHGs are stabilised

Adverse coastal implications of SL rise may be added to by changes in the intensity of weather systems (storms): i.e. any tendency to increases in storm surge inensity plus will reinforce effects of sea level rise



Average flooding by top 5% of storm surges from 1000 simulations

Enhanced Greenhouse Climate - 2050



Average flooding by top 5% of storm surges from 1000 simulations

Synthesis (1)

We have considered six ways in which the ocean plays a role in the climate system (we could have done more!)

Two concerned the carbon cycle:

- Ocean uptake of anthropogenic CO_2, which moderates build-up of CO_2 in the atmosphere
- CO_2 acidification of the surface oceans has potential in the long-term for some organisms to be unable to calcify and produce skeleton/shell (aragonite under-saturation)

Synthesis (2)

We have considered six ways in which the ocean plays a role in the climate system

Four concerned ocean warming:

- The huge heat capacity of the ocean results in ocean warming lagging warming of the atmosphere and land masses – ocean warming and thus some degree of global warming will continue for many decades after stabilisation of GHG levels
- Ocean circulation and weather patterns are affected by changes in SSTs – El Nino provides one example of this, and the challenge we have is to understand future shifts in such phenomena
- Changes in marine ecosystems with changes SSTs and ocean circulation are already apparent, and can be expected to accelerate
- Sea level rise has been observed, at the upper end of the expected range

CSIRO

Others are more succinct . . .

WBGU

GERMAN ADVISORY COUNCIL ON GLOBAL CHANGE

Mission | Members | Publications | Press | Global Change Portal | Download | Secretariat

SEARCH

MISSION AND CONCEPTS

MISSION

deutsch

The German federal government set up WBGU as an independent, scientific advisory body in 1992 in the run-up to the Rio Earth Summit. The Council's principal tasks are to:

- analyse global environment and development problems and report on these,
- review and evaluate national and international research in the field of global change,
- provide early warning of new issue areas,
- identify gaps in research and to initiate new research,
- monitor and assess national and international policies for the achievement of sustainable development,
- elaborate recommendations for action and research and
- raise public awareness and heighten the media profile of global change issues.

WBGU publishes flagship reports every two years, making its own choice of focal theme. In addition, the German government can commission the Council to prepare special reports and policy papers.

Mission

Mission Leaflet

Global Change

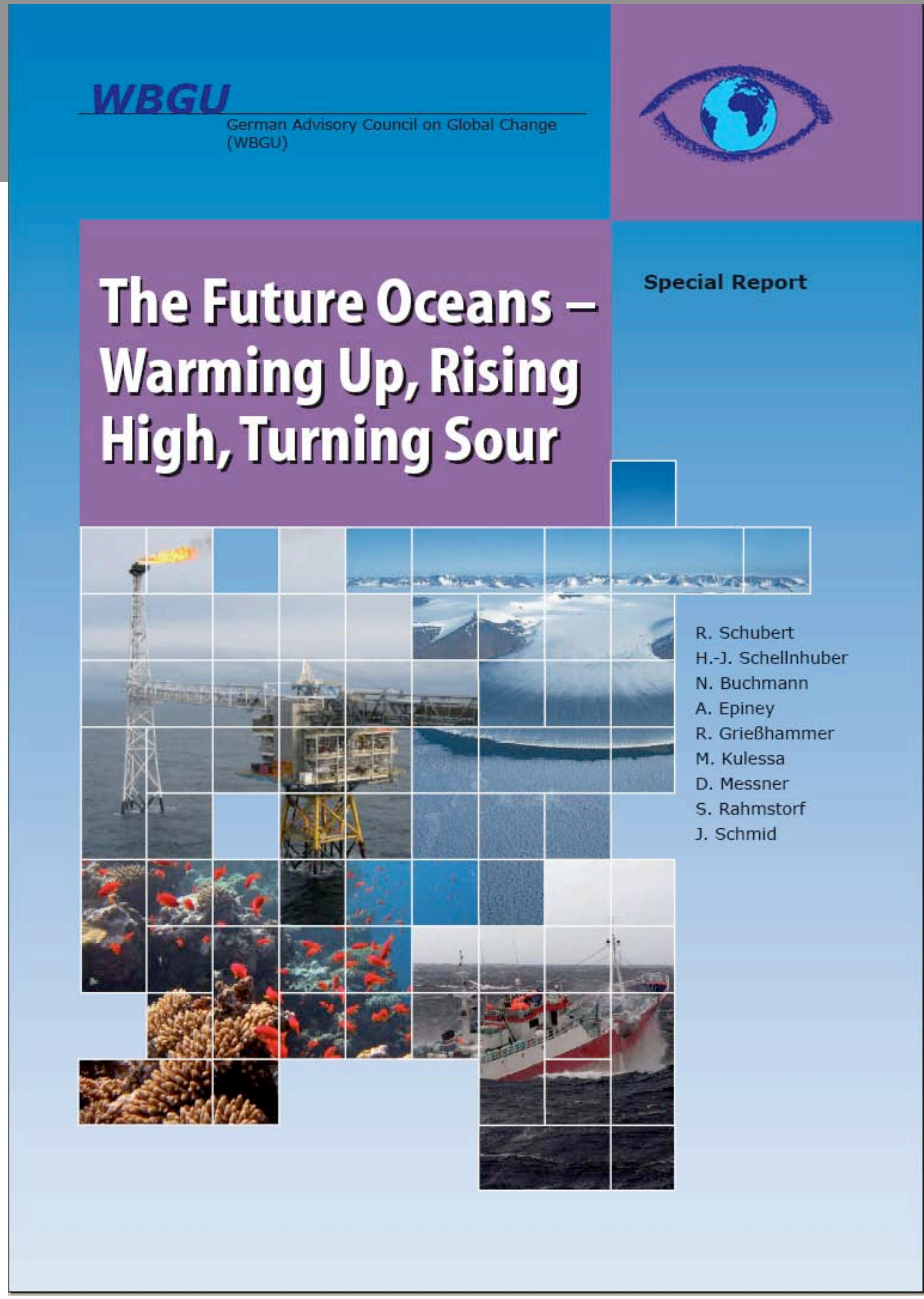
Decree (25.10.2000)

Decree of Establishment (8.4.1992)

Syndrome Concept

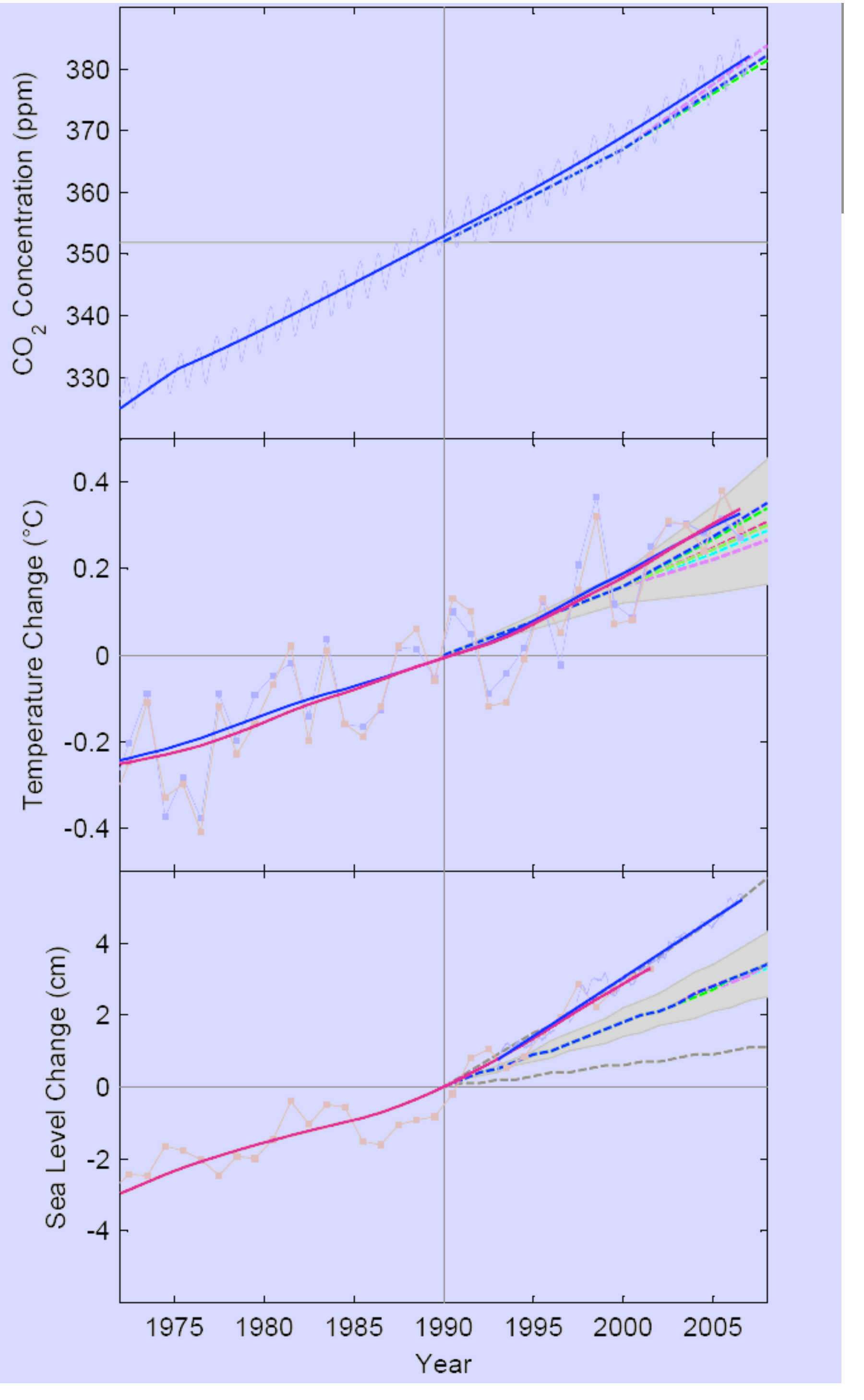
© WBGU

Webmaster



Addendum (1)

Recent climate observations compared to projections. Rahmstorf S, Cazenave A, Church J, Hansen J, Keeling R, Parker D and Somerville R. Recent climate observations compared to projections. *Science.* (25/01/07)



Addendum (2)

In some quarters the challenge posed by climate change has been cast largely as an 'atmospheric' phenomenon – rising GHGs; resultant atmospheric temperature and precipitation changes

I hope that you will agree with me that the climate change challenge is just as much an 'oceanic' phenomenon, indeed a different speaker might have made compelling statements about the response of terrestrial physical, chemical and biological systems to greenhouse forcing

We are moving well beyond 'climate models' = 'meteorological models', to *Earth System Simulation*, where the Earth's physics, chemistry and biology are all coupled

When you see that term in the future – you will now know why it has arisen

Acknowledgements

Numerous CSIRO ‘stars’ – in Divisions and in Flagships

Colleagues in our partner agencies – Bureau of Meteorology, Australian Greenhouse Office, Antarctic Divisions, Commonwealth Departments and other Agencies . . .

State Departments and Agencies . . . .

Universities: ACE CRC/UTas, Macquarie, Monash, UNSW, Melbourne . . . .

International colleagues . . . .

Supporters in Commerce and Industry . . . .

mecu

Conveyor.avi Australia_Flyby.avi