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WORLD CLIMATE RESEARCH PROGRAMME GLOBAL SEA-LEVEL RISE UPDATE

Sea level is higher now and is rising much more rapidly than at any other time in the past 3 000 years. We know that sea level will continue to rise for many centuries, even after global temperatures are stabilized, as it takes that long for the ocean and ice sheets to respond fully to a warmer climate. Unchecked global warming is likely to raise sea level by several metres in coming centuries, leading to the loss of many coastal cities and entire island states. This longer-term threat is already being exacerbated by increased frequency of short-term extreme sea levels due to the superposition of tides and storm surges on rising mean sea level.

The Record

During the last 3 000 years, the mean sea level has been below values observed at present (Figure 1a). Furthermore, variations occurred slowly. For example, the change in sea level over the 1 000 years up to year 1800 was in the range of a few centimetres. The rate of sea-level rise increased between the nineteenth and twentieth centuries (Figure 1b), and now satellite measurements show sea level rising by 3.4 millimetres (mm) per year from 1993 to 2008 (Cazenave and others, 2009; Figure 1c). This is almost twice the average rate for the twentieth century. For the period from 1961 to 2003, thermal expansion of the ocean contributed about 40 per cent to the observed sea-level rise, while melting glaciers and ice sheets contributed about 60 per cent (Domingues and others, 2008). The geographical pattern of change is variable (Figure 1d). For the period from 1993 to 2008, the largest increase took place in the equatorial Western Pacific. Lower values were recorded in other areas of the world ocean.

Factors Contributing to Sea-Level Rise

One of the key scientific achievements since the Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC) is that the estimates of various factors contributing to the global sea-level rise have started to sum up to a total that matches the observed values over recent decades with unprecedented accuracy (Domingues and others, 2008), especially from 2003 to date (Leuliette and Miller, 2009). At the same time, results of the ongoing research and recent observations point to two factors suggesting that the IPCC AR4 conclusions concerning the rate of future change in the global mean sea level may be on the conservative side.

The first factor is widespread evidence of the increased melting of glaciers and ice caps since the mid-1990s. New estimates show that the mass loss of glaciers and ice caps now contributes about 1.2 mm per year to global sea-level rise.

The second factor is the relatively fast dynamic response of the Greenland and Antarctic ice sheets to global warming that has been observed recently. In the case of Greenland, the pattern of ice-sheet change is one of thinning in coastal areas, primarily in the south along fast-moving outlet glaciers. Accelerated flow and discharge from some major outlet glaciers (also called dynamic thinning) are responsible for much of the loss (Rignot and Kanagaratnam, 2006). High-resolution satellite laser altimetry shows that dynamic thinning of fast-flowing coastal glaciers is now widespread at all latitudes of the ice sheet. Glaciers flowing faster than 100 metres (m) per year thinned on average by 0.84 m per year between 2003 and 2007 (Pritchard and others, 2009). In addition, near-coastal surface melt and runoff have increased significantly since 1960 in response to warming temperatures. Total precipitation has also increased (Hanna and others, 2008), but not enough to counter the effect of the ice-sheet thinning and melt. Passive microwave satellite measurements of the Greenland ice-sheet melt area show its expansion since 1979 (Steffen and others, 2008; Figure 2). The net mass loss from the Greenland

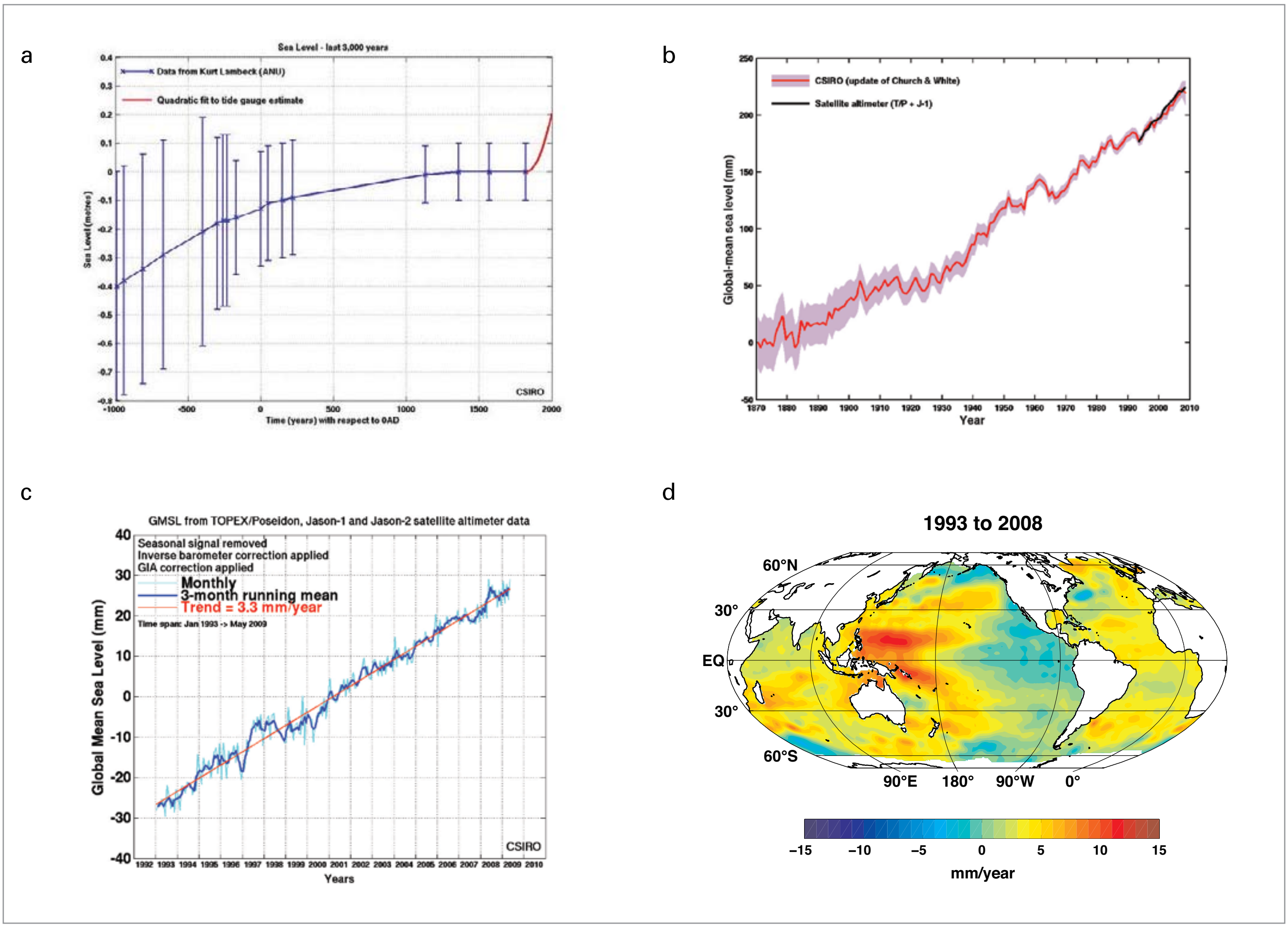

Figure 1: (a) Sea-level changes from 1000 B.C. to A.D. 2000 inferred from a range of sources (CSIRO, http://www.cmar.csiro.au/sealevel); (b) global mean sea level from 1870 to 2008, based on in situ measurements with one standard deviation error estimates, is in red (Church and White, 2006) and the Topex/Poseidon/Jason-1 and Jason-2 satellite altimeter global mean sea level, based on the same standard processing from 1993 to 2008, is in black. Both series have been set to a common value at the start of the altimeter record in 1993; (c) altimetric estimates of sea-level rise from 1993 to the present with the seasonal signal removed from this time series (CSIRO); (d) geographical pattern of 1993–2008 sea-level trends.

ice sheet has accelerated since the mid-1990s and is now contributing up to 0.7 mm per year to sea-level rise (Velicogna, 2009).

Antarctica is also losing ice mass at an accelerating rate, mostly from the West Antarctic ice sheet due to increased ice flow, and this contributes to sea-level rise at a rate nearly equal to that of Greenland (Velicogna, 2009). Narrow fast-moving ice streams in East Antarctica are now also contributing to the mass loss of the ice continent (Pritchard and others, 2009).

The Projections

For the complete range of scenarios outlined in the Special Report on Emissions Scenarios in IPCC AR4, the expected sea-level rise for 2090-2099 relative to 1980-1999 values was estimated to be between 18 and 59 centimetres (cm) (Figure 3a). An additional allowance of 0 to 20 cm was given to account for a dynamic response of the ice sheets. It is worth noting that IPCC warned that there could be a larger ice-sheet contribution. The data from coastal tide gauges corroborate the recent satellite estimates of sea-level change and show that the current rate of sea-level rise corresponds to the upper limit of model projections given in the IPCC Assessments in 2001 and 2007 (Figure 3b).

The new scientific evidence discussed above suggests that the future ice-sheet contribution to sea-level rise may exceed the allowance of 20 cm given in IPCC AR4. For example, simple statistical models, such as those

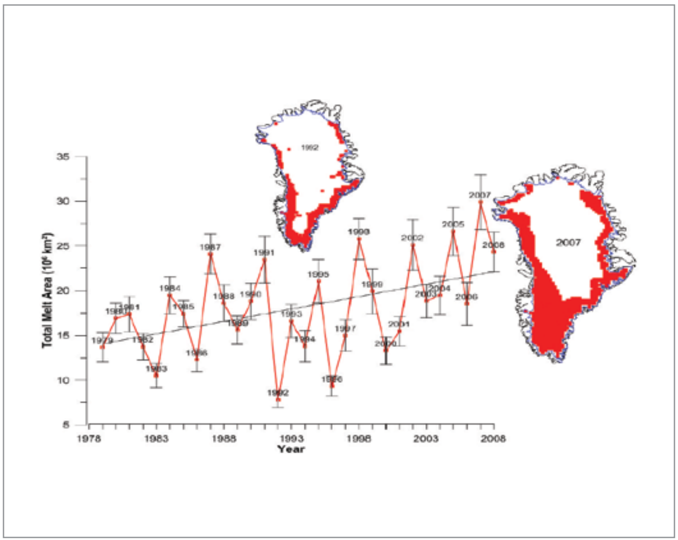

Figure 2: The total melt area of the Greenland ice sheet increased by 30 per cent between 1979 and 2008, based on passive microwave satellite data, with the most extreme melt in 2007. In general, 33–55 per cent of the total mass loss from the Greenland ice sheet is caused by surface melt and runoff. For 2007, the area experiencing melt was around 50 per cent of the total ice-sheet area. The low melt year in 1992 was caused by volcanic aerosols from Mount Pinatubo, which resulted in a short-lived global cooling (Steffen and others, 2008).

described in Horton and others (2008) and Rahmstorf (2007), based on relations between observed sea levels and temperatures, predict sea-level rise for 2100 of up to 1.4 m above the 1990 value.

Main remaining scientific challenges

Significant progress has been achieved by science in quantifying and explaining the observed sea-level change in recent decades. The main challenge for climate science now is to address the uncertainties in the projection of future sea-level changes due to recently discovered processes in the Greenland and Antarctic ice sheets. A joint Task Group on Sea-Level Variability and Change was established by the World Climate Research Programme and Intergovernmental Oceanographic Commission of UNESCO to further improve our ability to monitor, explain and predict global and regional sea level and all environmental factors related to it, and to use this information for informed decision-making.

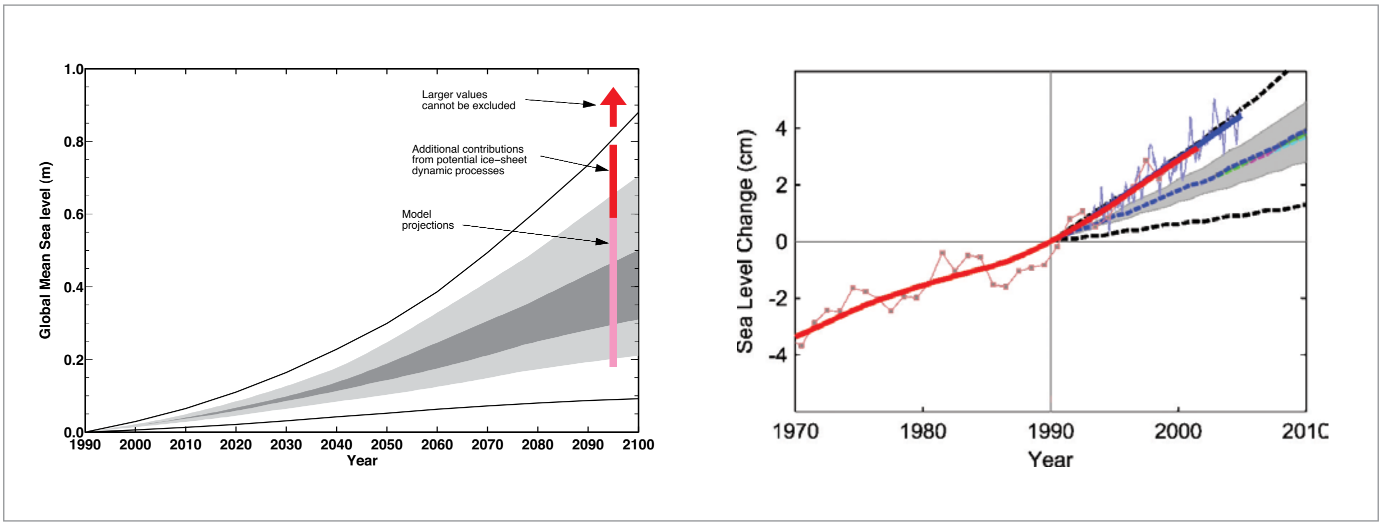

Figure 3: (a) Sea-level projections in the IPCC Third Assessment Report (TAR) shown in shading and lines and AR4 shown at the bar plotted at 2095, with their range of uncertainties shown as a pink bar depicting the possible range of contributions from thermal expansion of the ocean waters and melting of glaciers; the red bar corresponds to additional rise due to instabilities of ice sheets (Church and others, 2010); (b) observed and projected (starting for the year 1990) sea level: red line – coastal stations; blue line – altimetric data; dashed black lines and the grey area and various dashed lines within it – range of model-based sea-level rise projections from Rahmstorf and others (2007).

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