Box TS.3 | Climate Models and the Hiatus in Global Mean Surface Warming of the Past 15 Years

The observed GMST has shown a much smaller increasing linear trend over the past 15 years than over the past 30 to 60 years (Box TS.3, Figure 1a, c). Depending on the observational data set, the GMST trend over 1998–2012 is estimated to be around one third to one half of the trend over 1951–2012. For example, in HadCRUT4 the trend is 0.04°C per decade over 1998–2012, compared to 0.11°C per decade over 1951–2012. The reduction in observed GMST trend is most marked in NH winter. Even with this 'hiatus' in GMST trend, the decade of the 2000s has been the warmest in the instrumental record of GMST. Nevertheless, the occurrence of the hiatus in GMST trend during the past 15 years raises the two related questions of what has caused it and whether climate models are able to reproduce it. {2.4.3, 9.4.1; Box 9.2; Table 2.7}

Fifteen-year-long hiatus periods are common in both the observed and CMIP5 historical GMST time series. However, an analysis of the full suite of CMIP5 historical simulations (augmented for the period 2006–2012 by RCP4.5 simulations) reveals that 111 out of 114 realizations show a GMST trend over 1998–2012 that is higher than the entire HadCRUT4 trend ensemble (Box TS.3, Figure 1a; CMIP5 ensemble mean trend is 0.21°C per decade). This difference between simulated and observed trends could be caused by some combination of (a) internal climate variability, (b) missing or incorrect RF, and (c) model response error. These potential sources of the difference, which are not mutually exclusive, are assessed below, as is the cause of the observed GMST trend hiatus. {2.4.3, 9.3.2, 9.4.1; Box 9.2}

Internal Climate Variability

Hiatus periods of 10 to 15 years can arise as a manifestation of internal decadal climate variability, which sometimes enhances and sometimes counteracts the long-term externally forced trend. Internal variability thus diminishes the relevance of trends over periods as short as 10 to 15 years for long-term climate change. Furthermore, the timing of internal decadal climate variability is not expected to be matched by the CMIP5 historical simulations, owing to the predictability horizon of at most 10 to 20 years (CMIP5 historical simulations are typically started around nominally 1850 from a control run). However, climate models exhibit individual decades of GMST trend hiatus even during a prolonged phase of energy uptake of the climate system, in which case the energy budget would be balanced by increasing subsurface–ocean heat uptake. {2.4.3, 9.3.2, 11.2.2; Boxes 2.2, 9.2}

Owing to sampling limitations, it is uncertain whether an increase in the rate of subsurface–ocean heat uptake occurred during the past 15 years. However, it is *very likely* that the climate system, including the ocean below 700 m depth, has continued to accumulate energy over the period 1998–2010. Consistent with this energy accumulation, GMSL has continued to rise during 1998–2012, at a rate only slightly and insignificantly lower than during 1993–2012. The consistency between observed heat content and sea level changes yields *high confidence* in the assessment of continued ocean energy accumulation, which is in turn consistent with the positive radiative imbalance of the climate system. By contrast, there is limited evidence that the hiatus in GMST trend has been accompanied by a slower rate of increase in ocean heat content over the depth range 0 to 700 m, when comparing the period 2003–2010 against 1971–2010. There is low agreement on this slowdown, as three of five analyses show a slowdown in the rate of increase while the other two show the increase continuing unabated. {3.2.3, 3.2.4, 3.7, 8.5.1, 13.3; Boxes 3.1, 13.1}

During the 15-year period beginning in 1998, the ensemble of HadCRUT4 GMST trends lies below almost all model-simulated trends (Box TS.3, Figure 1a), whereas during the 15-year period ending in 1998, it lies above 93 out of 114 modelled trends (Box TS.3, Figure 1b; HadCRUT4 ensemble mean trend 0.26°C per decade, CMIP5 ensemble mean trend 0.16°C per decade). Over the 62-year period 1951–2012, observed and CMIP5 ensemble mean trend agree to within 0.02°C per decade (Box TS.3, Figure 1c; CMIP5 ensemble mean trend 0.13°C per decade). There is hence *very high confidence* that the CMIP5 models show long-term GMST trends consistent with observations, despite the disagreement over the most recent 15-year period. Due to internal climate variability, in any given 15-year period the observed GMST trend sometimes lies near one end of a model ensemble, an effect that is pronounced in Box TS.3, Figure 1a, b as GMST was influenced by a very strong El Niño event in 1998. {Box 9.2}

Unlike the CMIP5 historical simulations referred to above, some CMIP5 predictions were initialized from the observed climate state during the late 1990s and the early 21st century. There is medium evidence that these initialized predictions show a GMST lower by about 0.05°C to 0.1°C compared to the historical (uninitialized) simulations and maintain this lower GMST during the first few years of the simulation. In some initialized models this lower GMST occurs in part because they correctly simulate a shift, around 2000, from a positive to a negative phase of the Inter-decadal Pacific Oscillation (IPO). However, the improvement of this phasing of the IPO through initialization is not universal across the CMIP5 predictions. Moreover, although part of the GMST reduction through initialization indeed results from initializing at the correct phase of internal variability, another part may result from correcting a model bias that was caused by incorrect past forcing or incorrect model response to past forcing, especially in the ocean. The relative magnitudes of these effects are at present unknown; moreover, the quality of a forecasting system cannot be evaluated from a single prediction (here, a 10-year prediction within

(continued on next page)

Box TS.3 (continued)

the period 1998–2012). Overall, there is *medium confidence* that initialization leads to simulations of GMST during 1998–2012 that are more consistent with the observed trend hiatus than are the uninitialized CMIP5 historical simulations, and that the hiatus is in part a consequence of internal variability that is predictable on the multi-year time scale. {11.1, 11.2.3; Boxes 2.5, 9.2, 11.1, 11.2}

Radiative Forcing

On decadal to interdecadal time scales and under continually increasing ERF, the forced component of the GMST trend responds to the ERF trend relatively rapidly and almost linearly (*medium confidence*). The expected forced-response GMST trend is related to the ERF trend by a factor that has been estimated for the 1% per year CO_2 increases in the CMIP5 ensemble as 2.0 [1.3 to 2.7] W m^{-2} °C^{-1} (90% uncertainty range). Hence, an ERF trend can be approximately converted to a forced-response GMST trend, permitting an assessment of how much of the change in the GMST trends shown in Box TS.3, Figure 1 is due to a change in ERF trend. {Box 9.2}

The AR5 best-estimate ERF trend over 1998–2011 is 0.22 [0.10 to 0.34] W m^{-2} per decade (90% uncertainty range), which is substantially lower than the trend over 1984–1998 (0.32 [0.22 to 0.42] W m^{-2} per decade; note that there was a strong volcanic eruption in 1982) and the trend over 1951–2011 (0.31 [0.19 to 0.40] W m^{-2} per decade; Box TS.3, Figure 1d–f; the end year 2011 is chosen because data availability is more limited than for GMST). The resulting forced-response GMST trend would approximately be 0.12 [0.05 to 0.29] °C per decade, 0.19 [0.09 to 0.39] °C per decade, and 0.18 [0.08 to 0.37] °C per decade for the periods 1998–2011, 1984–1998, and 1951–2011, respectively (the uncertainty ranges assume that the range of the conversion factor to GMST trend and the range of ERF trend itself are independent). The AR5 best-estimate ERF forcing trend difference between 1998–2011 and 1951–2011 thus might explain about one-half (0.05 °C per decade) of the observed GMST trend difference between these periods (0.06 to 0.08 °C per decade, depending on observational data set). {8.5.2}

The reduction in AR5 best-estimate ERF trend over 1998–2011 compared to both 1984–1998 and 1951–2011 is mostly due to decreasing trends in the natural forcings, –0.16 [–0.27 to –0.06] W m^{-2} per decade over 1998–2011 compared to 0.01 [–0.00 to +0.01] W m^{-2} per decade over 1951–2011. Solar forcing went from a relative maximum in 2000 to a relative minimum in 2009, with a peak-to-peak difference of around 0.15 W m^{-2} and a linear trend over 1998–2011 of around –0.10 W m^{-2} per decade. Furthermore, a series of small volcanic eruptions has increased the observed stratospheric aerosol loading after 2000, leading to an additional negative ERF linear-trend contribution of around –0.06 W m^{-2} per decade over 1998–2011 (Box TS.3, Figure 1d, f). By contrast, satellite-derived estimates of tropospheric aerosol optical depth suggests little overall trend in global mean aerosol optical depth over the last 10 years, implying little change in ERF due to aerosol–radiative interaction (*low confidence* because of *low confidence* in aerosol optical depth trend itself). Moreover, because there is only *low confidence* in estimates of ERF due to aerosol–cloud interaction, there is likewise *low confidence* in its trend over the last 15 years. {2.2.3, 8.4.2, 8.5.1, 8.5.2, 10.3.1; Box 10.2; Table 8.5}

For the periods 1984–1998 and 1951–2011, the CMIP5 ensemble mean ERF trend deviates from the AR5 best-estimate ERF trend by only 0.01 W m^{-2} per decade (Box TS.3, Figure 1e, f). After 1998, however, some contributions to a decreasing ERF trend are missing in the CMIP5 models, such as the increasing stratospheric aerosol loading after 2000 and the unusually low solar minimum in 2009. Nonetheless, over 1998–2011 the CMIP5 ensemble mean ERF trend is lower than the AR5 best-estimate ERF trend by 0.03 W m^{-2} per decade (Box TS.3, Figure 1d). Furthermore, global mean aerosol optical depth in the CMIP5 models shows little trend over 1998–2012, similar to the observations. Although the forcing uncertainties are substantial, there are no apparent incorrect or missing global mean forcings in the CMIP5 models over the last 15 years that could explain the model–observations difference during the warming hiatus. {9.4.6}

Model Response Error

The discrepancy between simulated and observed GMST trends during 1998–2012 could be explained in part by a tendency for some CMIP5 models to simulate stronger warming in response to increases in greenhouse-gas concentration than is consistent with observations. Averaged over the ensembles of models assessed in Section 10.3.1, the best-estimate GHG and other anthropogenic scaling factors are less than one (though not significantly so, Figure 10.4), indicating that the model-mean GHG and other anthropogenic responses should be scaled down to best match observations. This finding provides evidence that some CMIP5 models show a larger response to GHGs and other anthropogenic factors (dominated by the effects of aerosols) than the real world (*medium confidence*). As a consequence, it is argued in Chapter 11 that near-term model projections of GMST increase should be scaled down by about 10%. This downward scaling is, however, not sufficient to explain the model mean overestimate of GMST trend over the hiatus period. {10.3.1, 11.3.6}

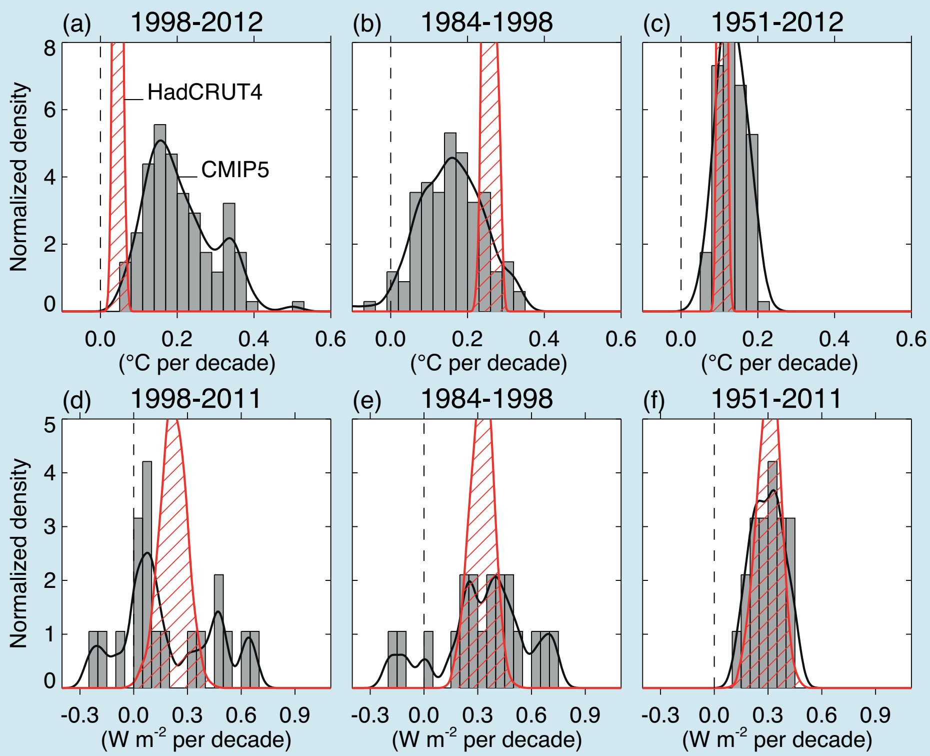
Another possible source of model error is the poor representation of water vapour in the upper atmosphere. It has been suggested that a reduction in stratospheric water vapour after 2000 caused a reduction in downward longwave radiation and hence a surface-cooling contribution, possibly missed by the models. However, this effect is assessed here to be small, because there was a recovery in stratospheric water vapour after 2005. {2.2.2, 9.4.1; Box 9.2} *(continued on next page)*

Box TS.3 (continued)

In summary, the observed recent warming hiatus, defined as the reduction in GMST trend during 1998–2012 as compared to the trend during 1951–2012, is attributable in roughly equal measure to a cooling contribution from internal variability and a reduced trend in external forcing (expert judgement, *medium confidence*). The forcing trend reduction is due primarily to a negative forcing trend from both volcanic eruptions and the downward phase of the solar cycle. However, there is *low confidence* in quantifying the role of forcing trend in causing the hiatus, because of uncertainty in the magnitude of the volcanic forcing trend and *low confidence* in the aerosol forcing trend. {Box 9.2}

Almost all CMIP5 historical simulations do not reproduce the observed recent warming hiatus. There is *medium confidence* that the GMST trend difference between models and observations during 1998–2012 is to a substantial degree caused by internal variability, with possible contributions from forcing error and some CMIP5 models overestimating the response to increasing GHG forcing. The CMIP5 model trend in ERF shows no apparent bias against the AR5 best estimate over 1998–2012. However, *confidence* in this assessment of CMIP5 ERF trend is *low*, primarily because of the uncertainties in model aerosol forcing and processes, which through spatial heterogeneity might well cause an undetected global mean ERF trend error even in the absence of a trend in the global mean aerosol loading. {Box 9.2}

The causes of both the observed GMST trend hiatus and of the model–observation GMST trend difference during 1998–2012 imply that, barring a major volcanic eruption, most 15-year GMST trends in the near-term future will be larger than during 1998–2012 (*high confidence*; see Section 11.3.6 for a full assessment of near-term projections of GMST). The reasons for this implication are fourfold: first, anthropogenic GHG concentrations are expected to rise further in all RCP scenarios; second, anthropogenic aerosol concentration is expected to decline in all RCP scenarios, and so is the resulting cooling effect; third, the trend in solar forcing is expected to be larger over most near-term 15-year periods than over 1998–2012 (*medium confidence*), because 1998–2012 contained the full downward phase of the solar cycle; and fourth, it is *more likely than not* that internal climate variability in the near term will enhance and not counteract the surface warming expected to arise from the increasing anthropogenic forcing. {Box 9.2}



Box TS.3, Figure 1 | (Top) Observed and simulated GMST trends in °C per decade, over the periods 1998–2012 (a), 1984–1998 (b), and 1951–2012 (c). For the observations, 100 realizations of the Hadley Centre/Climatic Research Unit gridded surface temperature data set 4 (HadCRUT4) ensemble are shown (red, hatched). The uncertainty displayed by the ensemble width is that of the statistical construction of the global average only, in contrast to the trend uncertainties quoted in Section 2.4.3, which include an estimate of internal climate variability. Here, by contrast, internal variability is characterized through the width of the model ensemble. For the models, all 114 available CMIP5 historical realizations are shown, extended after 2005 with the RCP4.5 scenario and through 2012 (grey, shaded). (Bottom) Trends in effective radiative forcing (ERF, in W m^{-2} per decade) over the periods 1998–2011 (d), 1984–1998 (e), and 1951–2011 (f). The figure shows AR5 best-estimate ERF trends (red, hatched) and CMIP5 ERF (grey, shaded). Black lines are smoothed versions of the histograms. Each histogram is normalized so that its area sums up to one. {2.4.3, 8.5.2; Box 9.2; Figure 8.18; Box 9.2, Figure 1}