American Physical Society Climate Change Statement Review

Workshop Framing Document

Climate Change Statement Review Subcommittee[1], December 20, 2013

The detection, attribution, and projection of climate change, especially under anthropogenic influence, are issues of major societal import. The Intergovernmental Panel on Climate Change (IPCC) has issued a series of reports over more than two decades, culminating in that of Working Group 1 of the Fifth Assessment Report (AR5 WG1) released in September, 2013 [http://www.climatechange2013.org/]. Those reports have expressed increasingly confident consensus views of the importance, if not dominance, of anthropogenic influence on the global climate over the past 60 years.

The American Physical Society's (APS) Climate Change Statement Review (CCSR) is a process (mandated by the Society's bylaws) to reconsider its 2007 Statement on Climate Change, available at http://www.aps.org/policy/statements/07_1.cfm . The Subcommittee charged with making a recommendation on that matter has found, as part of its process, the need to better understand the IPCC consensus on climate science through a workshop that will dive deeply into some of the more uncertain aspects. In doing so, it will illuminate for itself, for the APS membership, and the broader public both the certainties and the boundaries of current climate science understanding.

The Subcommittee's scope is the physical basis of climate change[2] and we take the consensus as expressed in the AR5 WG1 Report and its Summary for Policy Makers (SPM). Below, we raise a set of topics and questions (in red) to prime and focus discussion at the workshop. These questions have not been chosen to "pick nits" or "pick cherries", but rather to highlight fundamental issues in current understanding of the physical basis of climate change.[3]

I. General Understanding

I.1 Confidence

The third column of the table on the next page recounts the IPCC's increasing confidence in the anthropogenic GHG attribution of late-20th Century warming.

- What do you consider to be the greatest advances in our understanding of the physical basis of climate change since AR4 in 2007?
- What do you consider to be the most important gaps in current understanding?
- How are the IPCC confidence levels determined?
- What has caused the 5% increase in IPCC confidence from 2007 to 2013?

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[1] Philip Coyle, Scott Kemp, Steven Koonin (chair), Tim Meyer, Robert Rosner, Susan Seestrom

[2] Both climate change impacts and societal responses are beyond the Subcommittee's scope. The former involve a broad range of chemical, biological, and social sciences, while the latter ultimately involve judgments and values about economics, risk tolerance, and intergenerational and geographical equity. None of those are subjects where physicists can claim any particular expertise.

[3] Responses to some of these questions may well be found within the AR5 WG1 material, in which case non-expert understanding will be advanced by their clear exposition during the workshop.

Date	Source	Confidence in Attribution	Equilibrium Climate Sensitivity (C)
1896 & 1938	Arrhenius / Callendar	------	2 – 5.5
1979	Charney Report	------	1.5 – 4.5
1990	IPCC FAR	No quantification of anthropogenic contribution to warming	1.5 – 4.5 (best guess = 2.5)
1996	IPCC SAR	*The balance of evidence suggests a discernible human influence on climate.*	1.5 – 4.5 (best guess = 2.5)
2001	IPCC TAR	*Human-emitted greenhouse gases are likely (67-90% chance) responsible for more than half of Earth's temperature increase since 1951.*	1.5 – 4.5
2007	IPCC AR4	*Human-emitted greenhouse gases are very likely (at least 90% chance) responsible for more than half of Earth's temperature increase since 1951.*	2 – 5.5 (>66% chance correct)
2013	IPCC AR5	*Human-emitted greenhouse gases are extremely likely (at least 95% chance) responsible for more than half of Earth's temperature increase since 1951.*	1.5 – 4.5

The last column of the table above [see Nature Geosciences 1, 735 (2008)] shows successive IPCC estimates of the Equilibrium Climate Sensitivity[4], following first estimates more than a century ago. A factor-of-three uncertainty in the global surface temperature response to increased atmospheric CO_2 as expressed by ECS has persisted through the last three decades of research despite the significant intellectual effort that has been devoted to climate science.

- What gives rise to the large uncertainties in this fundamental parameter of the climate system?
- How is the IPCC's expression of increasing confidence in the detection/ attribution/ projection of anthropogenic influences consistent with this persistent uncertainty? Wouldn't detection of an anthropogenic signal necessarily improve estimates of the response to anthropogenic perturbations?

I.2 The scale of anthropogenic perturbations

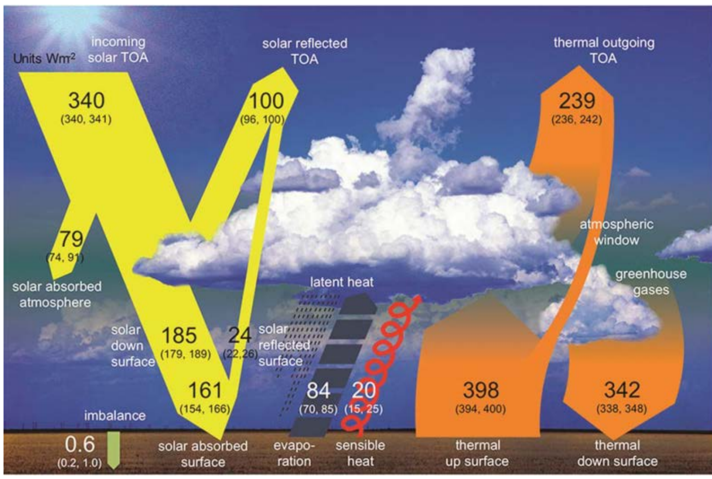
The left-hand figure on the following page [AR5 WG1 Figure 2.11] shows the global radiative balance, with the total downward flux on the Earth's surface estimated as 503 ± 7 W/m^2 (161 W/m^2 solar + 342 W/m^2 thermal). The right-hand figure on the following page [AR5 Figure SPM.4] shows the total anthropogenic direct perturbation of this balance to be some 2.3 ± 1 W/m^2, less than 0.5% of the downward flux.[5]

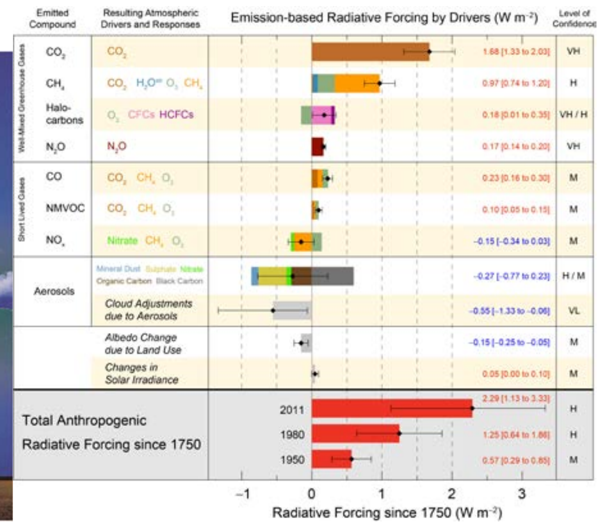
- The earth's climate stems from a multi-component, driven, noisy, non-linear system that shows temporal variability from minutes to millennia. Instrumental observations of key physical climate variables have sufficient coverage and precision only over the past 150 years at best (and usually much less than that). Many different processes and phenomena will be relevant

[4] Equilibrium Climate Sensitivity (ECS) is the change in equilibrium global mean surface temperature induced by a doubling of the atmospheric CO_2 concentration.

[5] If the atmospheric concentration of CO_2 were to rise to 550 ppm with all other anthropogenic effects unchanged, this perturbation would rise to be 3.9 W/m^2. [The radiative forcing associated with atmospheric CO_2 varies logarithmically with the concentration due the shape of the relevant absorption band and the strong saturation of the band center.]

and each needs to be "gotten right" with high precision if the response to anthropogenic perturbations is to be attributed correctly and quantified accurately.[6] Moreover, there are expected feedbacks (water vapor-temperature, ice-albedo, …) that would amplify the perturbative response by factors of several. How can one understand the IPCC's expressed confidence in identifying and projecting the effects of such small anthropogenic perturbations in view of such difficult circumstances?





I.3 The geological context

The figure on the following page [Figure 5.3 from the AR5 WG1 report] places the present climate in the context of the past 800,000 years.

- The present moment is clearly a very special time in the geological context (well into an interglacial). How well do we understand the climate and climate variability expected during such a time, especially at the currently high atmospheric CO_2 concentration? For example, what would be the precursors of an end to the interglacial (beyond the obvious "it will get colder")?

[6] For example, a change in the earth's average shortwave albedo from 0.30 to 0.29 due changing clouds, snow/ice, aerosols, or land character would induce a 3.4 W/m^2 direct perturbation in the downward flux, 50% larger than the present anthropogenic perturbation.

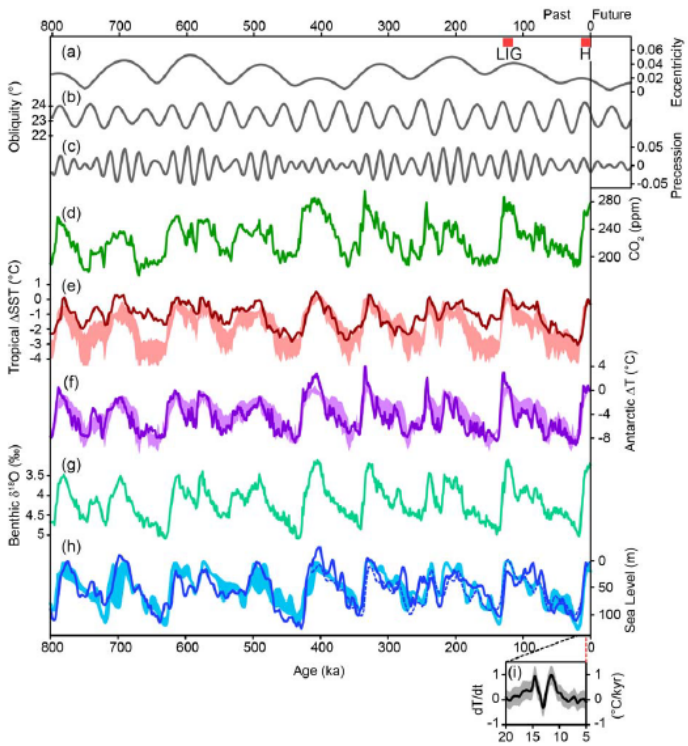
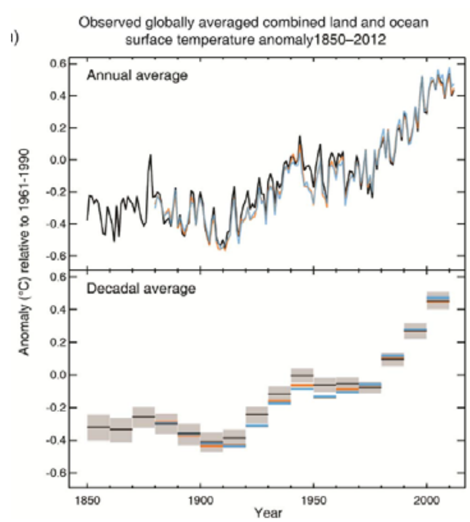


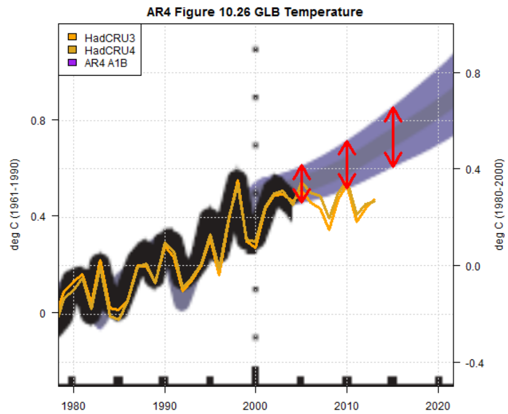
Figure 5.3: Orbital parameters and proxy records over the past 800 kyr. (a) Eccentricity, (b) obliquity, (c) precessional parameter, (d) atmospheric concentration of CO2 from Antarctic ice cores, (e) tropical SST stack, (f) Antarctic temperature stack based on up to seven different ice cores, (g) stack of benthic δ18O, a proxy for global ice volume and deep-ocean temperature, (h) reconstructed sea level. Lines represent orbital forcing and proxy records, shaded areas represent the range of simulations with climate, climate-ice sheet models of intermediate complexity and an icesheet model forced by variations of the orbital parameters and the atmospheric concentrations of the major greenhouse gases. (i) Rate of changes of global mean temperature during Termination I. [See WG1 report for full caption with references.]

II. The temperature stasis

While the Global Mean Surface Termperature (GMST) rose strongly from 1980 – 1998, it has shown no significant rise for the past 15 years, as shown in the upper panel of Figure SPM.1 below.



That behavior does not track the CMIP3 model projections of AR4, as shown in the figure below, where the observations are overplotted on the AR4 projections (http://climateaudit.org/2013/09/30/ipcc-disappears-the-discrepancy/):



Nor is the stasis reproduced by the CMIP5 ensemble projections of AR5 WG1 under any of the emissions scenarios considered, as shown in the upper panel of that report's Figure 11.25 below. [See AR5 WG1 report page 11-120 for complete figure and caption.]

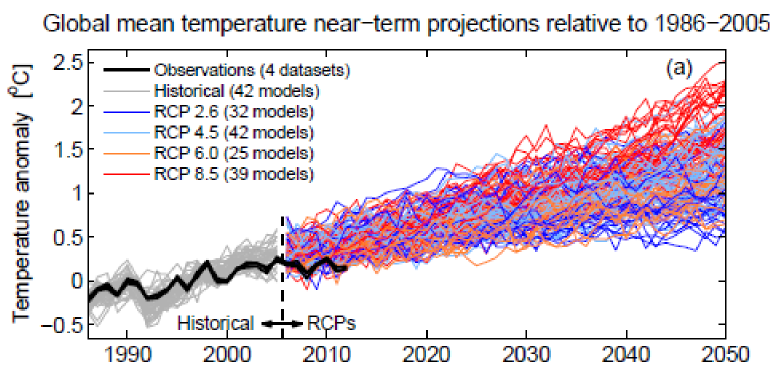


Figure 11.25: Synthesis of near-term projections of global mean surface air temperature (GMST). a) Projections of annual mean GMST 1986–2050 (anomalies relative to 1986–2005) under all RCPs from CMIP5 models (grey and coloured lines, one ensemble member per model), with four observational estimates (HadCRUT4:(Morice et al., 2012); ERA-Interim: (Simmons et al., 2010); GISTEMP: (Hansen et al., 2010); NOAA: (Smith et al., 2008)) for the period 1986–2012 (black lines).

Section D.1 of the AR5 WG1 SPM discusses this shortfall (greater detail can be found in the citations to the WG1 report):

> The observed reduction in surface warming trend over the period 1998–2012 as compared to the period 1951–2012, is due in roughly equal measure to a reduced trend in radiative forcing and a cooling contribution from internal variability, which includes a possible redistribution of heat within the ocean (*medium confidence*). The reduced trend in radiative forcing is primarily due to volcanic eruptions and the timing of the downward phase of the 11-year solar cycle. However, there is *low confidence* in quantifying the role of changes in radiative forcing in causing the reduced warming trend. There is *medium confidence* that internal decadal variability causes to a substantial degree the difference between observations and the simulations; the latter are not expected to reproduce the timing of internal variability. There may also be a contribution from forcing inadequacies and, in some models, an overestimate of the response to increasing

greenhouse gas and other anthropogenic forcing (dominated by the effects of aerosols). {9.4, Box 9.2, 10.3, Box 10.2, 11.3}

- This IPCC text lists internal variability, forcing inadequacies, and model over-responsiveness as all possibly contributing to the stasis, but without a quantitative resolution. To what would you attribute the stasis?
- If non-anthropogenic influences are strong enough to counteract the expected effects of increased CO_2, why wouldn't they be strong enough to sometimes enhance warming trends, and in so doing lead to an over-estimate of CO_2 influence?
- What are the implications of this stasis for confidence in the models and their projections?
- Some analyses attempt to fit the GMST over almost a century by a linear combination of aerosol, ENSO, CO_2, and TSI[7]. As the natural aerosol and ENSO forcings are coherent only over a few years, only anthropogenic aerosols, CO_2, and perhaps TSI are responsible for interdecadal climate change. As the anthropogenic aerosols and CO_2 were present only after about 1850, this picture implies that only variations in TSI are responsible for centennial-scale climate change prior to the 20th Century. [See AR5 WG1 Figure 5.7 below.]

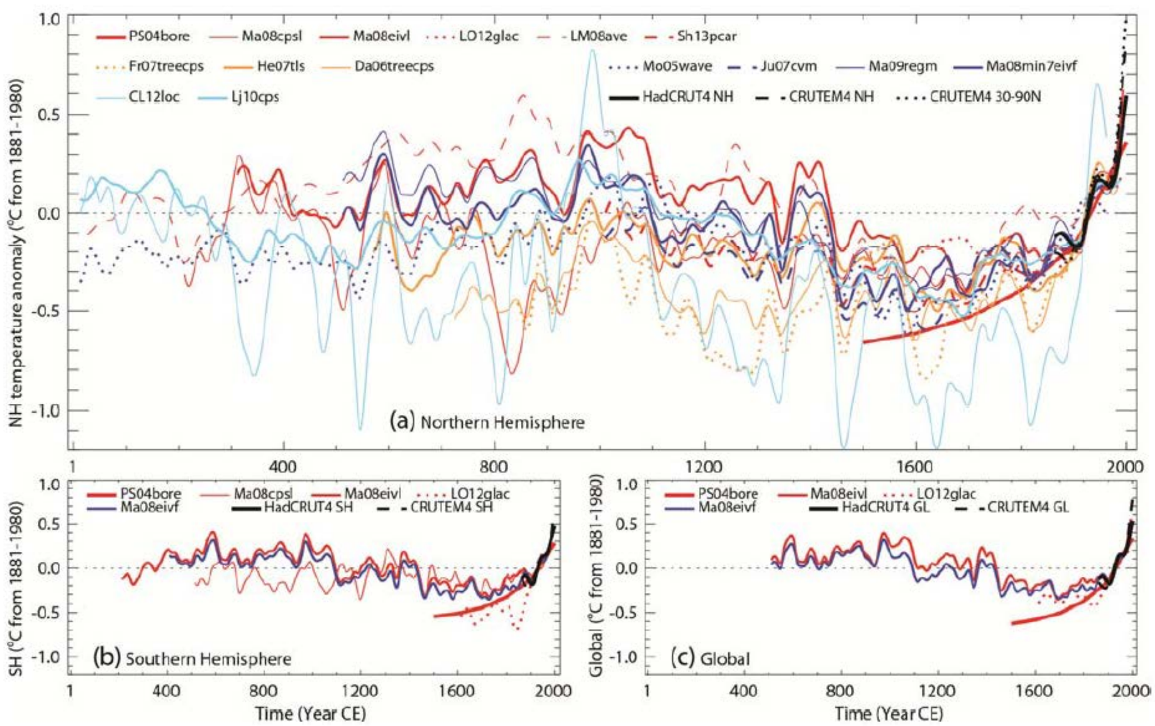


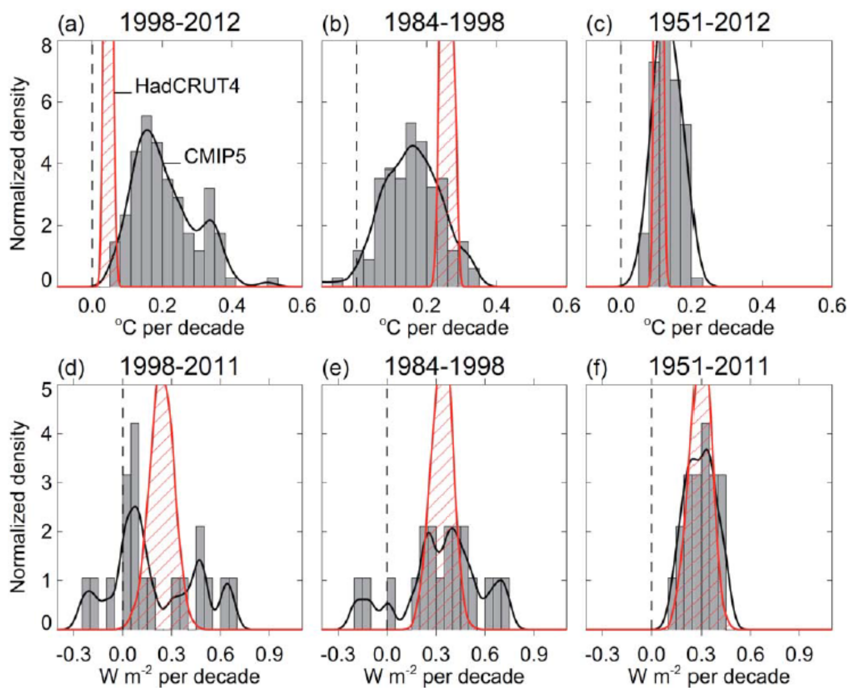
Figure 5.7: Reconstructed (a) Northern Hemisphere and (b) Southern Hemisphere, and (c) global annual temperatures during the last 2000 years. Individual reconstructions (see Appendix 5.A.1 for further information about each one) are shown as indicated in the legends, grouped by colour according to their spatial representation (red: land-only all latitudes; orange: land-only extra-tropical latitudes; light blue: land and sea extra-tropical latitudes; dark blue: land and sea all latitudes) and instrumental temperatures shown in black (HadCRUT4 land and sea, and CRUTEM4 land-only; Morice et al., 2012). All series represent anomalies (°C) from the 1881–1980 mean (horizontal dashed line) and have been smoothed with a filter that reduces variations on timescales less than ~50 years.

  - Are there any other possible multidecadal modes of variability? If so, how is that variability accounted for?

[7] Lean and Rind, GRL 35, L18701, 2008. ENSO is a measure of El Nino state; TSI is Total Solar Irradiance incident upon the Earth.

- What do you see as the likelihood of solar influences beyond TSI? Is it coincidence that the stasis has occurred during the weakest solar cycle in about a century?

- Some have suggested (e.g., Meehl et *al*., Nature Climate Change 1, 360 (2011)] that the “missing heat”[8] is going into the deep ocean, causing mK temperature rises. [IPCC quoted above notes “…a possible redistribution of heat within the ocean.”]
  - Are deep ocean observations sufficient in coverage and precision to bear on this hypothesis quantitatively?
  - Why would the heat sequestration have “turned on” at the turn of this century?
  - What could make it “turn off” and when might that occur?
  - Is there any mechanism that would allow the added heat in the deep ocean to reappear in the atmosphere?
- IPCC suggests that the stasis can be attributed in part to “internal variability.” Yet climate models imply that a 15-year stasis is very rare (von Storch et al., 2013, available at http://www.academia.edu/4210419/Can_climate_models_explain_the_recent_stagnation_in_global_warming) and models cannot reproduce the observed GMST even with the observed radiative forcing [See figure immediately below from the AR5 WG1 report].



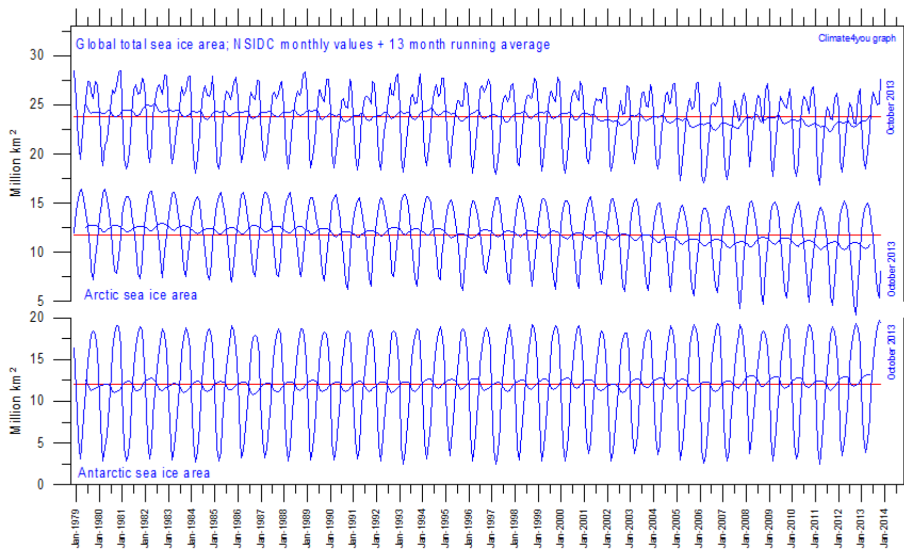
Box 9.2, Figure 1: Top: Observed and simulated GMST trends in °C per decade, over the periods 1998–2012 (a), 1984–1998 (b), and 1951–2012 (c). For the observations, 100 realisations of the HadCRUT4 ensemble are shown (red, hatched; (Morice et al., 2012)). The uncertainty displayed by the ensemble width 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 characterised through the width of the model ensemble. For the models, all 114 available CMIP5 historical realisations are shown, extended after 2005 with the RCP4.5 scenario and through 2012 (grey, shaded; after (Fyfe, Gillett, & Thompson, 2010)). 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; Section 8.5.2, Figure 8.18) and CMIP5 ERF (grey, shaded; from (Forster et al., 2013)). Black lines are smoothed versions of the histograms. Each histogram is normalised so that its area sums up to one.

[8] Failure of the atmosphere to warm in response to the expected radiative forcing.

- What is the definition of "internal variability"? Is it poorly defined initial conditions in the models or an intrinsically chaotic nature of the climate system? If the latter, what features of the climate system are predictable?
- How would the models' underestimate of internal variability impact detection and attribution?
- How long must the stasis persist before there would be a firm declaration of a problem with the models? If that occurs, would the fix entail: A retuning of model parameters? A modification of ocean conditions? A re-examination of fundamental assumptions?

II. Sea ice

The observational record of sea ice during the satellite era (from 1979) is shown in the figure below depicting data from the National Snow and Ice Data Center (NSIDIC). The long-term decline of the 13-month running average in the Arctic and the slight secular increase in the Antarctic are evident.



- To what extent do you believe the recent Arctic decline to be unusual, given that Section 5.5.2 of the AR5 WG1 report states: "There is medium confidence that the current ice loss and increasing SSTs in the Arctic are anomalous at least in the context of the last two millennia."?

The ability of the models to reproduce these trends is shown in AR5 WG1 Figure 10.16 on the following page.

- Please comment on the ability of the models to reproduce the Arctic trend, but not the Antarctic trend.
- The figure caption reads: "Only CMIP5 models which simulated seasonal mean and magnitude of seasonal cycle in reasonable agreement with observations are included in the plot." Only 6 (Antarctic) or 11 (Arctic) CMIP5 models were used, while there are some 40 models in the ensemble. One may therefore conclude that the bulk of the CMIP5 models do not reproduce reasonable seasonal mean and magnitude of the ice cycle. Is that the case? And if so, what are the implications for the confidence with which the ensemble can be used for other purposes?

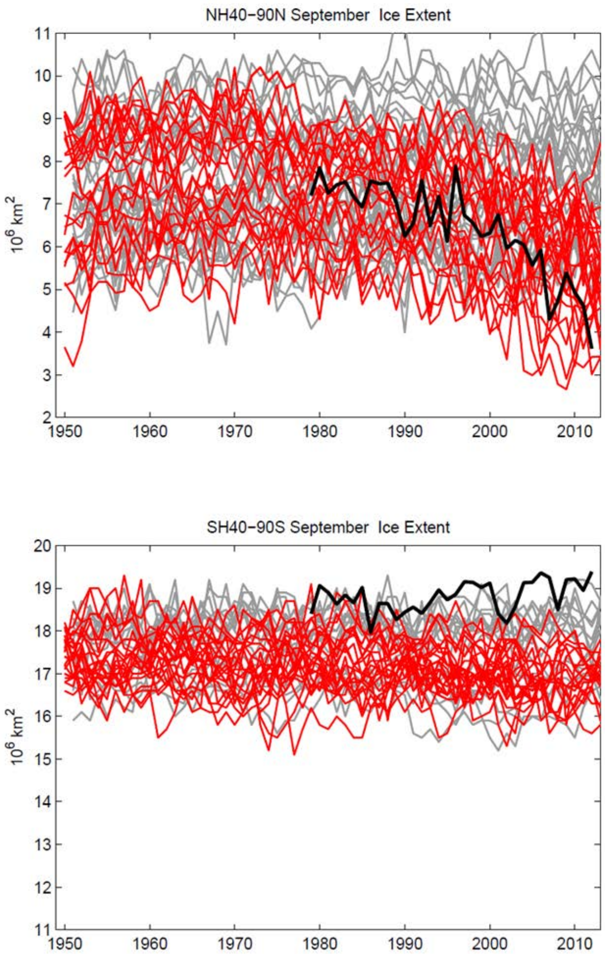


Figure 10.16: September sea ice extent for Arctic (top panel) and Antarctic (bottom panel) adapted from (Wang and Overland, 2012). Only CMIP5 models which simulated seasonal mean and magnitude of seasonal cycle in reasonable agreement with observations are included in the plot. The grey lines are the runs from the pre-industrial control runs, and the red lines are from Historical simulations runs patched with RCP8.5 runs for the period of 2005–2012. The black line is based on data from NSIDC. There are 24 ensemble members from 11 models for the Arctic and 21 members from 6 models for the Antarctic plot. See Supplementary information for the precise models used in the top and bottom panel.

III. Oceans

The rate of global mean sea level (GMSL) rise is portrayed in AR5 WG1 Figure 3.14 below and discussed in detail in Section 3.7.4 of the AR5 WG1 report.

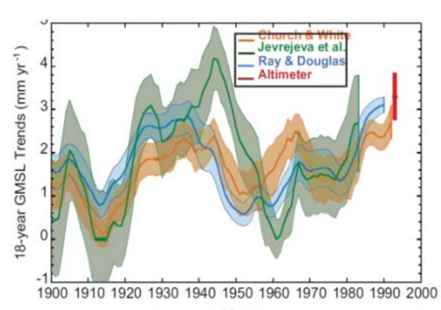


Figure 3.14: 18-year trends of GMSL rise estimated at 1-year intervals. The time is the start date of the 18-year period, and the shading represents the 90% confidence. The estimate from satellite altimetry is also given, with the 90% confidence given as an error bar. Uncertainty is estimated by the variance of the residuals about the fit, and accounts for serial correlation in the residuals as quantified by the lag-1 autocorrelation.

- The rate of rise during 1930-1950 was comparable to, if not larger than, the value in recent years. Please explain that circumstance in light of the presumed monotonic increase from anthropogenic effects.
- The IPCC-projected rise of up to 1 m by the end of this century (depending upon the emissions scenario) would require an average rate of up to 12 mm/yr for the rest of this century, some four times the current rate, and an order of magnitude larger than implied by the 20th century acceleration of 0.01 mm/yr^2 found in some studies [AR5 WG1 Report Section 3.7.4]. What drives the projected sea level rise? To what extent is it dependent upon a continued rise in GMST?

The oceans are the slowly varying components of the climate system. They exhibit seasonal, interannual, interdecadal, and centennial scale variability. The rapidly varying atmosphere (timescale of a week) responds to (and influences) ocean surface conditions. Reliable climate hindcasts and projections therefore require that the state of the oceans (current, temperature, salinity …) be known well on long timescales. Yet, as illustrated in WG1 AR5 Figure 3.A.2 below, good observational coverage has been available for less than a decade[9].

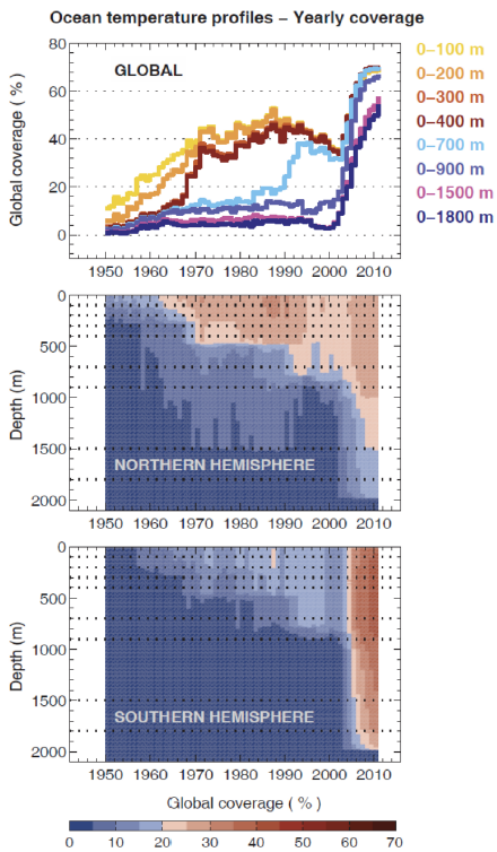


Figure 3.A.2: (top) Percentage of global coverage of ocean temperature profiles as a function of depth in one degree latitude by one degree longitude by one-year bins (top panel) shown versus time. Different colors indicate profiles to different depths (middle panel). Percentage of global coverage as a function of depth and time, for the northern hemisphere. (bottom panel) As above, but for the southern hemisphere.

[9] Indeed, guidance for the CMIP5 decadal prediction experiments initialized at dates from 1960 through 2005 states that "Ocean initial conditions should be in some way representative of the observed anomalies or full fields for the start date" [K. E. Taylor et *al*., *A Summary of the CMIP5 Experimental Design*, 2011, Section 3.c, p. 13]

- Section 3.6.6 of the AR5 WG1 report states:

> Given the short duration of direct measurements of ocean circulation, we have *very low confidence* [less than 10% confidence] that multi-decadal trends can be separated from decadal variability.

Please comment on this circumstance, particularly its impacts on the ability to validate coupled Atmosphere Ocean General Circulation Models (AOGCMs) and on the uncertainties in their projections.

Oceans have approximately 1000 times the thermal capacity of the atmosphere and are well coupled to the atmosphere through sensible and latent heat transfer.

- Is it correct that ocean surface temperature changes have the potential to drive significant changes in GMST?

If yes, then we note that Section 3.4.2.1 of the AR5 WG1 report states:

> The overall uncertainty of the annually averaged global ocean mean [heat flux] for each term is expected to be in the range 10–20%. In the case of the latent heat flux term, this corresponds to an uncertainty of up to 20 W m^{-2}. In comparison, changes in global mean values of individual heat flux components expected as a result of anthropogenic climate change since 1900 are at the level of <2 W m^{-2}.

- With uncertainty in ocean data being ten times larger than the total magnitude of the warming attributed to anthropogenic sources, and combined with the IPCC's conclusion than it has less than 10% confidence that it can separate long-term trends from regular variability, why is it reasonable to conclude that increases in GMST are attributable to radiative forcing rather than to ocean variability?

IV. Models and projections

VI.1 Multimodel ensembles

The use of multimodel ensembles to detect/attribute/project anthropogenic climate influences may be the best strategy currently available, but it is not without its problems. In particular, it is not sufficient to demonstrate that some member of the ensemble gets it right at any given time. Rather, as in other fields of science, it is important to know how well the "best" single model does at all times.

- How were the models and runs in the CMIP3 and CMIP5 ensembles chosen? Excessive restriction (whether explicit through selection or implicit through model interdependence) could understate uncertainties, while too liberal a selection could overstate uncertainty, so improving agreement with observations.
- Were inclusion/exclusion decisions made prior to examining the results? How do those choices impact the uncertainties?

The AR5 WG1 report expresses progress in modeling since AR4. For example, Section D.1 of the SPM:

> Climate models have improved since the AR4. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-20th century and the cooling

immediately following large volcanic eruptions (*very high confidence*). {9.4, 9.6, 9.8}

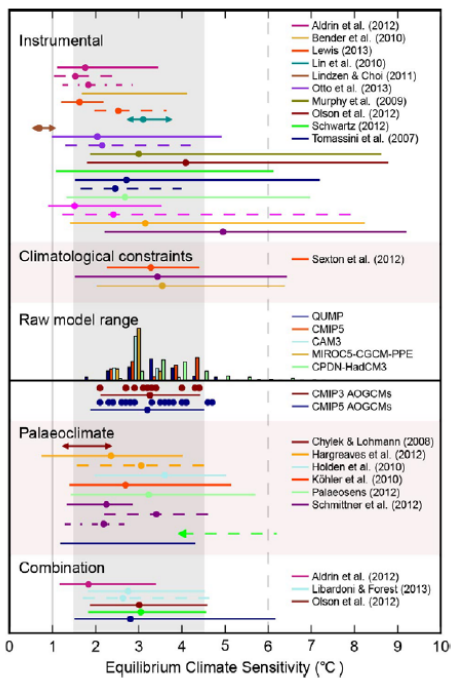
- Which metrics were used to assess the improvements in simulations between AR4 and AR5 as noted in the WG1 report?
- How well do the individual models do under those metrics? How good are the best models in individually reproducing the relevant climate observations to a precision commensurate with the anthropogenic perturbations?

VI.2 Climate sensitivities

Box 12.2 of AR5 WG1 contains a key discussion of model calculations of the Equilibrium Climate Sensitivity (ECS) and Transient Climate Response (TCR)[10]. Figure 1 of Box 12.2 below summarizes observational and model values for the ECS. Box 12.2 notes

> "AOGCMs show very good agreement with observed climatology with ECS values in the upper part of the 1.5°C–4.5°C range (Section 9.7.3.3), but the simulation of key feedbacks like clouds remains challenging in those models."

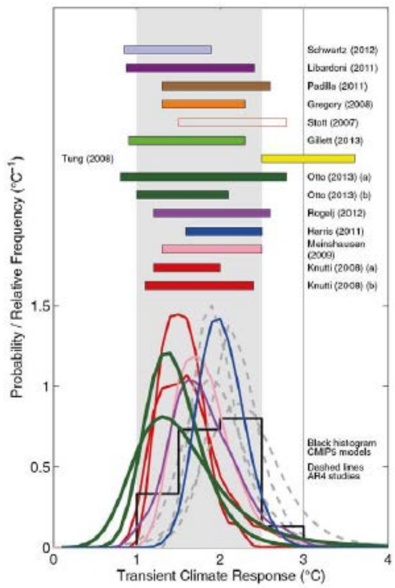
- Please comment on the cause and significance of these model overestimates of ECS, particularly for projections of future anthropogenic impacts



Box 12.2, Figure 1: Probability density functions, distributions and ranges for equilibrium climate sensitivity, based on Figure 10.20b plus climatological constraints shown in IPCC AR4 (Meehl et *al*., 2007, Box 10.2 Figure 1), and results from CMIP5 (Table 9.5). The grey shaded range marks the likely 1.5°C–4.5°C range, grey solid line the extremely unlikely less than 1°C, the grey dashed line the very unlikely greater than 6°C. See Figure 10.20b and Chapter 10 Supplementary Material for full caption and details. Labels refer to studies since AR4.

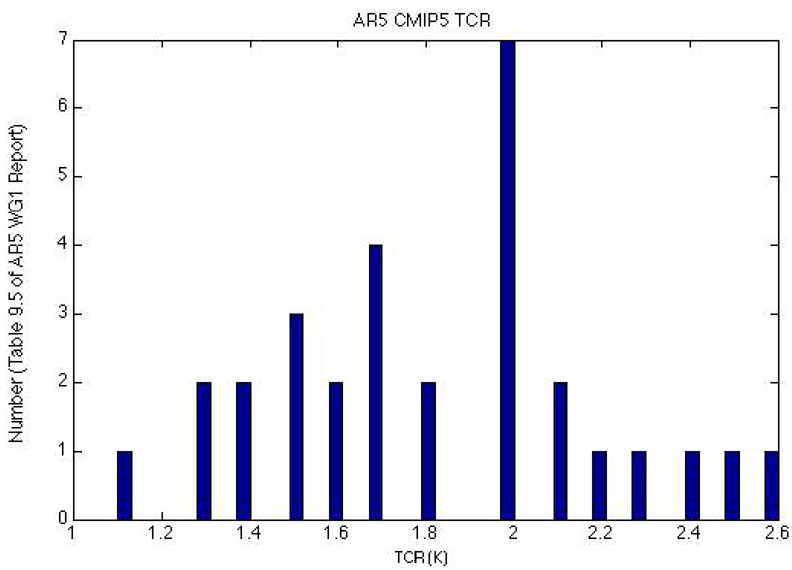
Figure 2 of Box 12.2 below summarizes the transient climate responses of the CMIP models as listed in Table 9.5 of the AR5 WG1 report.

[10] ECS is the equilibrium GMST increase induced by a doubling of atmospheric CO_2. TCR is the GMST increase induced by a doubling through 70 years of 1% annual increases. The difference between ECS and TCR is due to the thermal inertia of the oceans, among other components of the climate system.



Box 12.2, Figure 2: Probability density functions, distributions and ranges (5–95%) for the transient climate response from different studies, based on Figure 10.20a, and results from CMIP5 (black histogram, Table 9.5). The grey shaded range marks the likely 1°C–2.5°C range, the grey solid line marks the extremely unlikely greater than 3°C. See Figure 10.20a and Chapter 10 Supplementary Material for full caption and details.

The behavior of the CMIP5 models portrayed in the black histogram above is more evident in the histogram below



Transient climate response distribution for CMIP5 models in AR5 Table 9.5. The bar heights show how many models in Table 9.5 exhibit each level of TCR. The mean of all models is slightly over 1.8 C.

As the observational value of TCR is simply estimated to be approximately 1.3 C[11], it appears that the models overestimate this crucial climate parameter by almost 50%.

- Please comment on the above assessment
- Box 12.2 of AR5 WG1 states:

  > "Unlike ECS, the ranges of TCR estimated from the observed warming and from AOGCMs agree well, increasing our confidence in the assessment of uncertainties in projections over the 21st century."

  Please comment on that statement in light of the discussion above.

[11] From 1950 to 2011, GMST rose by 0.6C, while Figure SPM.4 shows that total anthropogenic forcing rose by 1.7 W/m^2 over this same period. Since the forcing corresponding to doubling CO_2 is 3.7 W/m^2, the TCR is easily estimated to be 0.6C X (3.7/1.7) = 1.3 C. This value is in accord with the more sophisticated observational values shown in Box 12.2, Figure 2.