Estimate of Radiative Forcing from the Surface Albedo Change in the IPCC Models

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http://ccdatacenter.org/documents/EstimateofRadiativeForcingfromAlbedoChangeintheIPCCModels.pdf

Abstract

According to Soden and Held (2006) surface albedo contributes about 6% of the total radiative forcing at the global tropopause in models used by the IPCC. If the same percentage should be used for the estimating the temperature expected at the Earth's surface, then for a 2°C (2.7 W m^{-2}) scenario, this implies that about 0.16 W m^{-2} of radiative forcing would come from changes in the surface albedo (primarily due to changes in the extent of both the Arctic Ocean sea ice and the Northern Hemisphere snow cover). Since the changes in the surface albedo likely already exceed this amount with only 1°C of warming (see box below), most 2°C scenarios likely significantly underestimate the future warming that will come from changes in the surface albedo.

NASA Satellites Measure Increase of Sun’s Energy Absorbed in the Arctic (Dec. 17, 2014)

Since the year 2000, the rate of absorbed solar radiation in the Arctic in June, July and August has increased by five percent… When averaged over the entire Arctic Ocean, the increase in the rate of absorbed solar radiation is about 10 Watts per square meter *(about .27 Watts per square meter globally - the surface area of the Arctic Ocean is about 14 million square kilometers and the surface area of the Earth is about 510 million square kilometers).*

http://www.nasa.gov/press/goddard/2014/december/nasa-satellites-measure-increase-of-sun-s-energy-absorbed-in-the-arctic/#.VOdX7ubF9bI

Analysis

In 2006 Brian J. Soden and Isaac M. Held ("An Assessment of Climate Feedbacks in Coupled Ocean–Atmosphere Models", http://journals.ametsoc.org/doi/full/10.1175/JCLI3799 - see "color coded" extracts below) concluded that surface albedo contributes about 6% of the total radiative forcing in models used by the IPCC: the estimated radiative forcing of the models they reviewed was 4.3 W m^{-2} and, "[o]n average, the strongest positive feedback is due to water vapor (1.8 W m^{-2} K^{-1}), followed by clouds (0.68 W m^{-2} K^{-1}), and surface albedo (0.26 W m^{-2} K^{-1})" . And this also shows that the surface albedo feedback is about 15% that of the water vapor feedback and about 9.5% of all fast feedbacks. (This "foots" with fast feedbacks being responsible for about 60% of forcing (http://www.skepticalscience.com/climate-sensitivity-feedbacks-anyone.html) and surface albedo being responsible for 9.5% of the fast feedbacks: 4.3 * 0.6 * 0.095 = 0.245.)

If these results are "translated" for what would be expected for a 2°C increase since pre-industrial times (2.7 W m^{-2}), then the change in surface albedo that would be projected by the climate models would be about 0.16 W m^{-2} (=2.7 * 0.06). Since the surface albedo change, due to the change in the extent of both the Arctic Ocean sea ice and the Northern Hemisphere snow cover, likely already exceeds this value (and possibly by a wide margin) with a temperature change of only 1°C, the expected temperature increase for the various model runs might need to be increased. The following table shows the additional temperature increase expected for a 2°C scenario for various amounts of the current value of the surface albedo (assuming (1) that the current albedo will double for a 2°C temperature increase, (2) that the "2°C" models expect an RF change of 0.16 W m^{-2}, and (3) that each additional W m^{-2} of radiative forcing increases the temperature by 0.5°C, which is equivalent to about 300 GTC of CO2 emissions):

RF from Current Albedo (W m^{-2})	RF from Future Albedo (W m^{-2})	RF from Additional Albedo (W m^{-2})	Temperature Increase (°C)	Equivalent Emissions (GTC)
0.15	0.30	0.14	0.07	42
0.20	0.40	0.24	0.12	72
0.25	0.50	0.34	0.17	102
0.30	0.60	0.44	0.22	132

Notes:

1. *Hudson, et all ("Estimating the Global Radiative Impact of the Sea-Ice-Albedo Feedback in the Arctic", JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 116, D16102, DOI:10.1029/2011JD015804, 2011) estimated a .3 W m^{-2} change in forcing if the Arctic Ocean is ice-free for a month. This is about double the 6% of the total radiative forcing that the climate models might be using for a 2°C increase and does not include changes due to reduced snow cover extent.*
2. *See http://ccdatacenter.org/documents/FeedbackFromNHSnowCover.pdf for a "back of the envelope" calculation of the albedo change from reduced snow cover extent (based on a linear extrapolation of the current decline in snow cover) that estimates the forcing in 2015 to be 0.14* W m^{-2}
3. *See http://ccdatacenter.org/documents/FeedbackFromArcticSeaIceMelt.pdf for a "back of the envelope" calculation of the albedo change from reduced sea ice extent (based on a linear extrapolation of the current decline in sea ice extent) that estimates the forcing in 2015 to be 0.10* W m^{-2}
4. *Obtaining a value for the current surface albedo should be a high priority as the above two estimates total about 0.24 W m^{-2} for 2015 (which is close to a NASA measurement of 0.27 W m^{-2} for changes from 2000-2012 - see box above), which is 50% greater than the 0.16 W m^{-2} expected for a 2°C increase*

This could have a significant impact on the remaining portion (220 GTC) of the IPCC carbon budget if the budget was based on the surface albedo feedback described in the first paragraph above.

Extracts from "An Assessment of Climate Feedbacks in Coupled Ocean–Atmosphere Models"

The feedback strengths from various mixed-layer GCMs forced with increasing CO_2 have been computed in prior studies. A review of these calculations by Colman (2003) revealed, surprisingly, that intermodel differences in the reported feedbacks for clouds, water vapor, lapse rate, and surface albedo were roughly equal in magnitude (Fig. 1 [see below]).

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Feedback calculations are performed for climate change simulations from 14 different coupled ocean–atmosphere models integrated with projected increases in well-mixed greenhouse gases and aerosols as prescribed by the IPCC Special Report on Emissions Scenarios (SRES) A1B scenario (Table 1). This scenario corresponds roughly to a doubling in equivalent CO_2 between 2000 and 2100, after which time the radiative forcings are held constant. The estimated radiative forcing (i.e., the change in the global mean net radiative flux at the tropopause holding all other inputs to the radiative transfer fixed) under this scenario is 4.3 W m^{-2}

…

3. Results

Figure 1 [see below] shows our estimates of the climate feedback parameters for lapse rate, water vapor, cloud, and surface albedo for each of the IPCC Assessment Report 4 (AR4) models for which the necessary data was available. The results are also listed in Table 1 [see below]. The sign convention is such that positive values indicate an amplification of the climate change (i.e., a positive feedback). The strength of Λ_0(Table 1) ranges from roughly −3.1 to −3.2 W m^{-2} K^{-1}. Intermodel differences in Λ_0 arise from different spatial patterns of warming; models with greater high-latitude warming, where the temperature is colder, have smaller values of Λ_0. On average, the strongest positive feedback is due to water vapor (1.8 W m^{-2} K^{-1}), followed by clouds (0.68 W m^{-2} K^{-1}), and surface albedo (0.26 W m^{-2} K^{-1}). The troposphere warms faster than the surface in all models resulting in a negative lapse rate feedback (−0.84 W m^{-2} K^{-1}). The intermodel variability in these feedbacks is addressed below.

As compared to the survey by Colman, the range of feedback strengths computed here is smaller for all feedbacks except clouds. The smaller range noted here could indicate an actual reduction in feedback differences in the current generation of models. However, it is more likely to result in large part from the lack of a consistent methodology in previous studies. In particular, the lapse rate feedbacks are significantly larger here than in previous results, which may reflect the inappropriate inclusion of stratospheric temperature responses in the calculations performed by some modeling groups (Colman 2003; Held and Soden 2000). The surface albedo feedbacks are somewhat smaller in magnitude compared to those reported by Colman. Both the magnitude and intermodel range of surface albedo feedback are consistent to within ~10% of those estimated by Winton (2006) for the IPCC AR4 models.

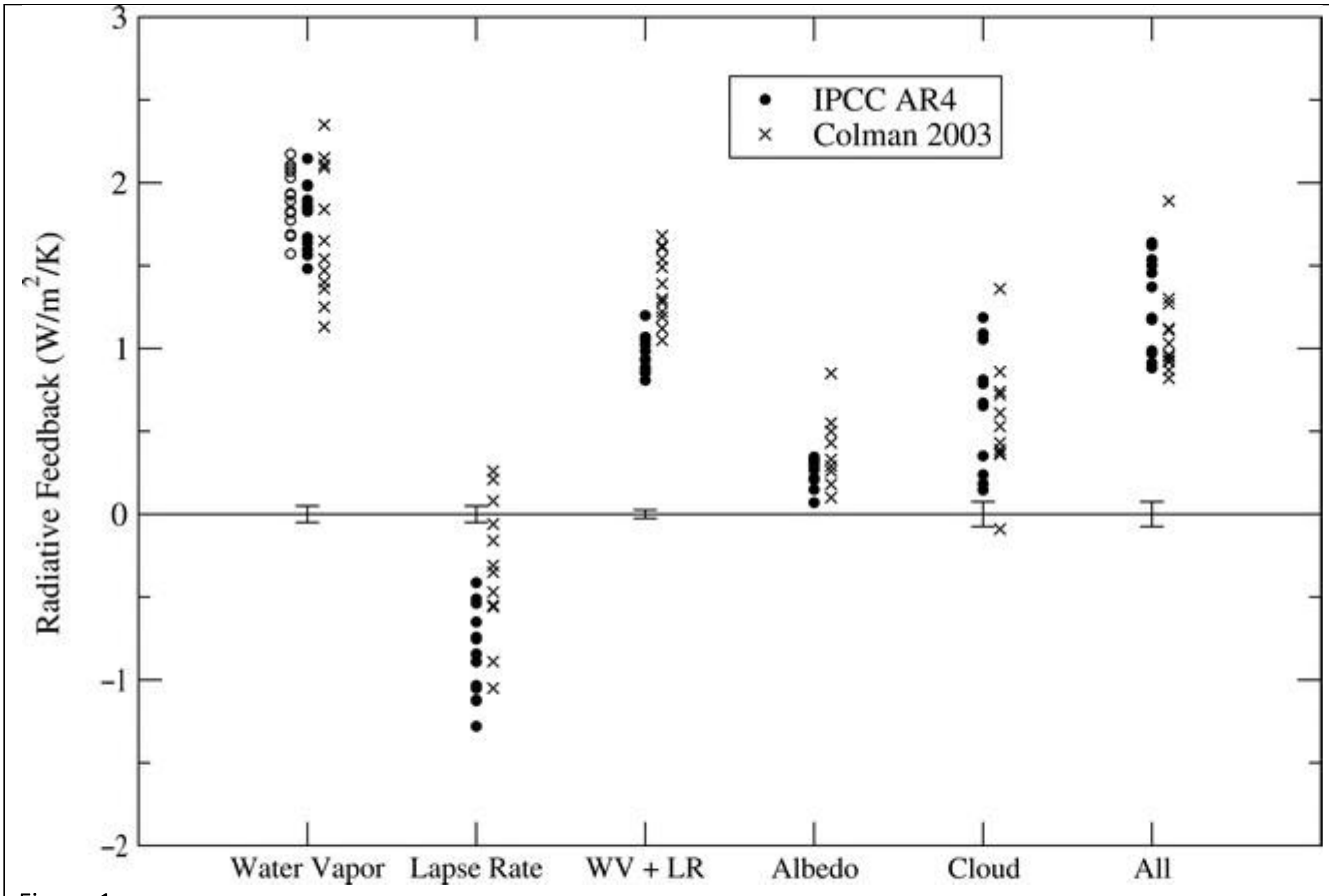

Figure 1

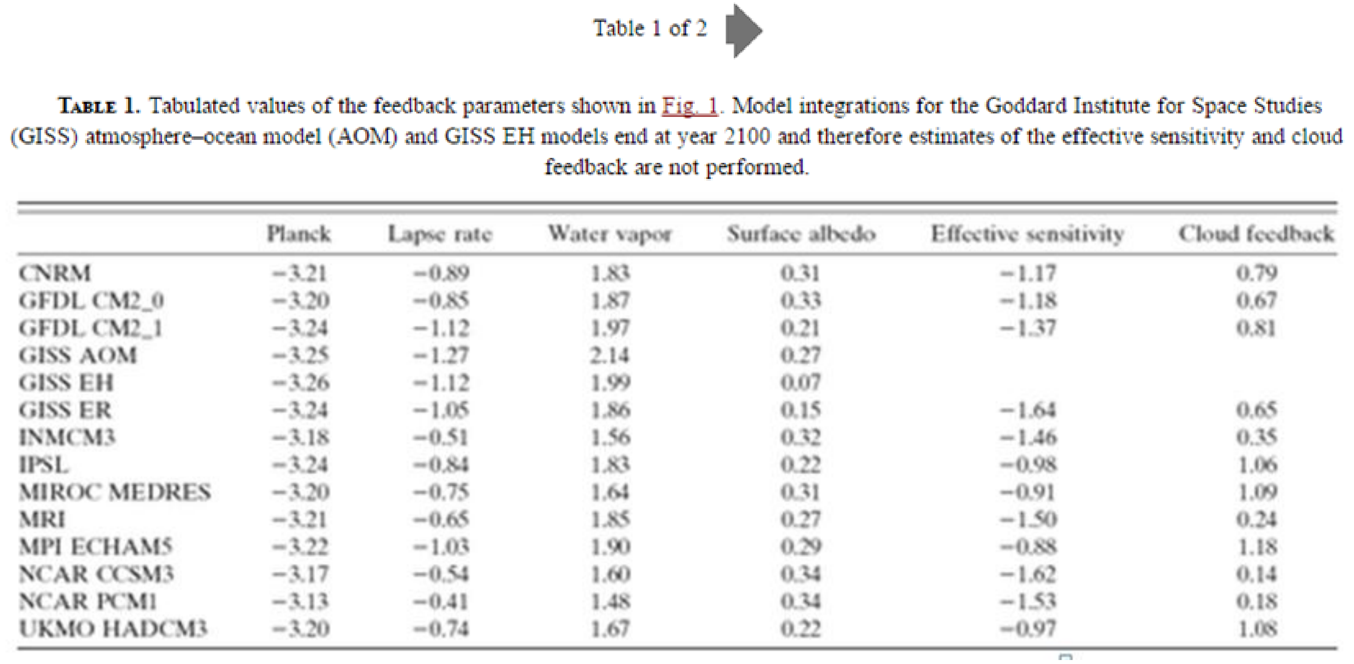

Table 1 of 2

TABLE 1. Tabulated values of the feedback parameters shown in Fig. 1. Model integrations for the Goddard Institute for Space Studies (GISS) atmosphere–ocean model (AOM) and GISS EH models end at year 2100 and therefore estimates of the effective sensitivity and cloud feedback are not performed.

	Planck	Lapse rate	Water vapor	Surface albedo	Effective sensitivity	Cloud feedback
CNRM	−3.21	−0.89	1.83	0.31	−1.17	0.79
GFDL CM2_0	−3.20	−0.85	1.87	0.33	−1.18	0.67
GFDL CM2_1	−3.24	−1.12	1.97	0.21	−1.37	0.81
GISS AOM	−3.25	−1.27	2.14	0.27		
GISS EH	−3.26	−1.12	1.99	0.07		
GISS ER	−3.24	−1.05	1.86	0.15	−1.64	0.65
INMCM3	−3.18	−0.51	1.56	0.32	−1.46	0.35
IPSL	−3.24	−0.84	1.83	0.22	−0.98	1.06
MIROC MEDRES	−3.20	−0.75	1.64	0.31	−0.91	1.09
MRI	−3.21	−0.65	1.85	0.27	−1.50	0.24
MPI ECHAM5	−3.22	−1.03	1.90	0.29	−0.88	1.18
NCAR CCSM3	−3.17	−0.54	1.60	0.34	−1.62	0.14
NCAR PCM1	−3.13	−0.41	1.48	0.34	−1.53	0.18
UKMO HADCM3	−3.20	−0.74	1.67	0.22	−0.97	1.08

Table 1