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(Research Article)

Clouds independently appear to have as much or greater effect than man-made CO_2 on radiative forcing

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Abstract

The patterns of behaviour of clouds, both for cloud area and cloud optical thickness, are studied over the period of available data, 1983 to 2017. There was a decrease in cloud cover over the study period, while global surface temperatures increased. The patterns of clouds and temperature indicate that the cloud cover decrease could not have been caused by the increased surface temperature. The clear implication is that the decrease in global cloud area must have been caused by some other unspecified factor, and was not caused directly or indirectly by CO_2. Evaluation of the changes in clouds and CO_2 over the study period indicate that this unspecified factor had as much positive impact as the increase in CO_2, with respect to the amount of radiation reaching the surface (radiative forcing), and possibly a much larger positive impact. The climate models, which have zero or negative cloud impact on radiative forcing independently from CO_2, need to take this into account in order to avoid over-estimating the influence of CO_2.

Keywords: Climate; Clouds; Solar Radiation; Radiative Forcing; Feedback; Global Surface Temperature; Climate Models

1. Introduction

The IPCC (Intergovernmental Panel on Climate Change) repeatedly acknowledge that clouds are a major source of uncertainty in the climate models, including [1]: "*evidence for a systematic indirect solar effect [on global average low-level cloud cover] remains ambiguous*", and "*Large uncertainties remain about how clouds might respond to global climate change.”* As indicated by these statements, the climate models contain little or no provision for cloud cover to change over long time scales other than as a reaction to climate change.

This paper argues that the behaviour of clouds does suggest that other processes are at work, and that the models should make provision for them.

The IPCC also say [2]: "*An albedo decrease of only 1%, bringing the Earth’s albedo from 30% to 29%, would cause an increase in the black-body radiative equilibrium temperature of about 1°C, a highly significant value, roughly equivalent to the direct radiative effect of a doubling of the atmospheric CO_2 concentration.*"

This paper analyses the behaviour of clouds in light of the above statement, in order to see how much effect clouds might have on climate model projections.

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2. Analysis

2.1. Decrease in global cloud cover

Satellite data over the period Jul 1983 to Jun 2017 shows a significant decrease in global cloud cover, while the HadCRUT5 global temperature rose over the same period (see Data and Methods, below).

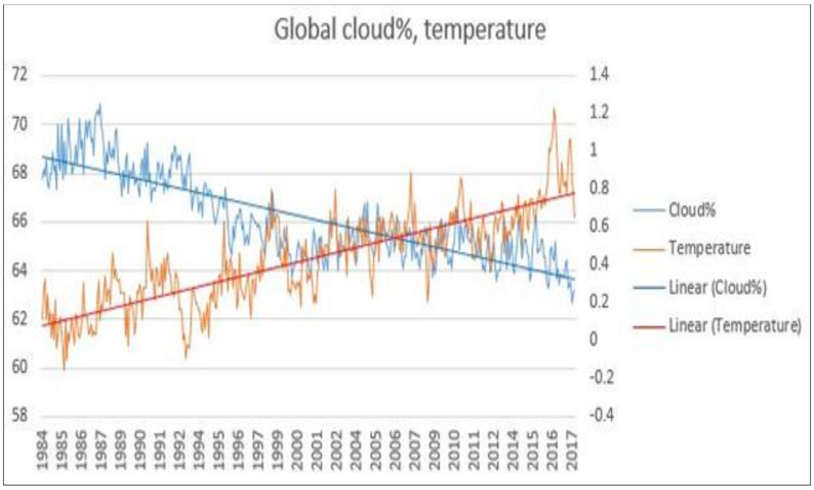

Figure 1 Monthly average global cloud cover (%, left axis) and global surface temperature (anomaly, right axis), with linear trends. Linear 1983-2017 change is -7.3% cloud (NB. percent, not percentage points), 0.7 deg C temperature

In contrast to the trends shown in Figure 1, on time-scales of a few months a rise in temperature causes an increase in cloud cover.

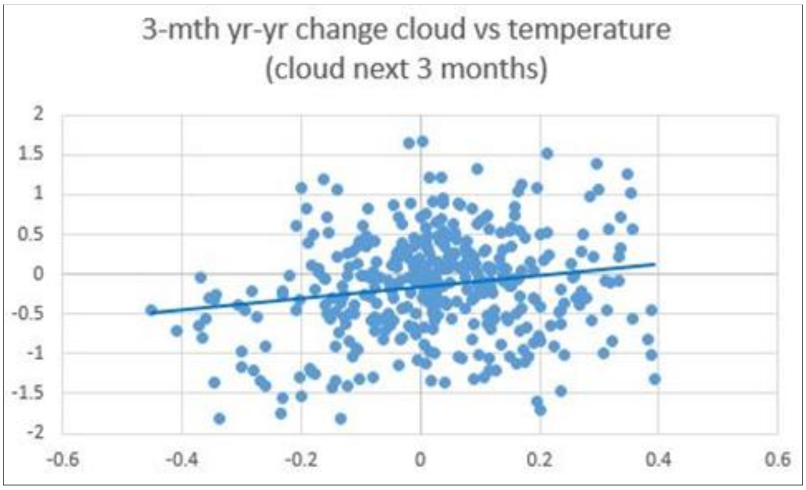

Figure 2 $(C_{n+3} - C_{n-9})$ y-axis charted against $(T_n - T_{n-12})$ x-axis, where C_n, T_n are global cloud cover (percent), global temperature anomaly respectively over three months to month n, with linear trend. The one-year differences are used in order to avoid seasonal effects. The linear trend gradient is 0.71 percentage points of cloud cover per deg C of temperature

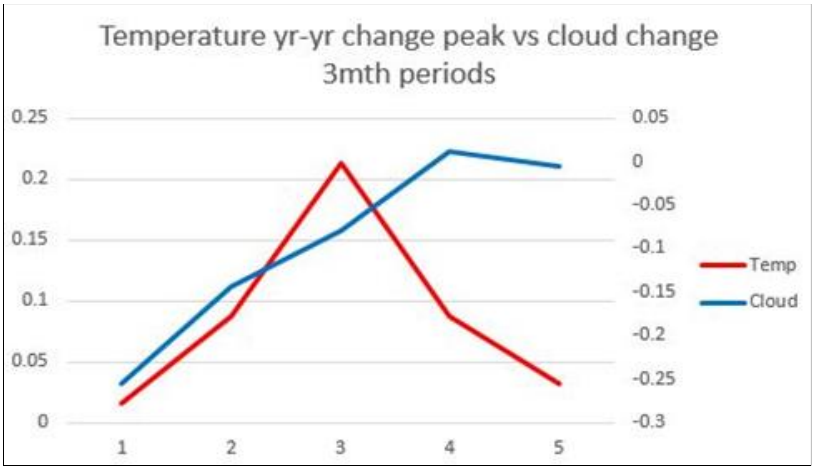

Figure 3 One-year temperature (left axis) and cloud cover (right axis) changes averaged over each of the five 3-month periods within every 15-month period in the study period in which temperature change was highest in the middle 3-month period. One-year differences are used in order to avoid seasonal effects. The chart clearly shows that a cloud increase follows a temperature increase

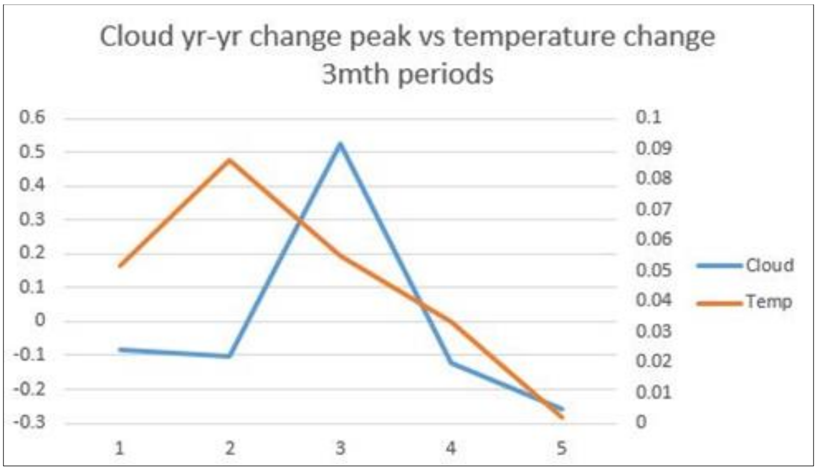

Figure 4 One-year cloud (left axis) and temperature (right axis) changes averaged over each of the five 3-month periods within every 15-month period in the study period in which cloud cover change was highest in the middle 3-month period. One-year differences are used in order to avoid seasonal effects. The chart clearly confirms that a cloud increase follows a temperature increase

It is reasonable to expect that a rise in temperature would cause an increase in cloud cover, as shown in Figures 2, 3 and 4, because a warmer ocean would evaporate more moisture, which would then rise in the atmosphere and condense into clouds. In other words, Figures 2, 3 and 4 are consistent with a known mechanism. This has been confirmed by [3], who also state "*This [hydrological cycle] rate is double the response projected by current-generation climate models*".

The data strongly suggests that the longer term decline in cloud cover shown in Figure 1 is caused by some unspecified factor ("Factor X") and not by the increasing temperature. Consider the two alternative propositions:

2.1.1. Proposition (a)

The decline in cloud cover is caused by increasing temperature: Increasing temperature causes cloud cover to increase over the next few months, as in Figures 2, 3 and 4. This causes a negative feedback, because increased cloud cover has a cooling effect. The negative feedback must be in excess of 100%, because at some later date the cloud cover becomes lower than when it started. (Note that the proposition is that the decline in cloud cover is caused by increasing temperature, and therefore the line of logic must flow from the original rise in temperature.)

Logically, there is a remote second possibility, that the rise in temperature causes an increase in cloud cover, but it also changes something else which at some later date causes the cloud cover to decrease. No indication has been found in the IPCC reports or anywhere else of the existence of this "something else". The latest IPCC report [4] discusses the roles of aerosols and cosmic rays, for example, but neither of these are caused by a rise in surface temperature.

2.1.2. Proposition (b)

The decline in cloud cover is caused by an unspecified factor: The unspecified factor causes cloud cover to decrease. The decrease in cloud cover has a net warming effect which causes cloud cover to increase, ie. there is a negative feedback, but because the negative feedback is less than 100% there is still an overall decrease in cloud cover. Consequently, over time, cloud cover decreases and temperatures increase.

Proposition (b) appears to be much more probable, especially as the negative feedback of over 100% required for proposition (a) would appear to be extremely unlikely. Proposition (b) should therefore be included in the climate models. Because the mechanism is not known, (1) the process would have to be parameterised, and (2) model projections would have to be based on assumptions about how clouds might behave in future and would therefore be unreliable. Neither of these is an insurmountable problem - clouds are already parameterised in the models, and there are other features (such as ENSO (El Niño Southern Oscillation) [1]) whose future behaviour is already acknowledged to be unpredictable. Parameterisations are already used to represent a number of unresolved physical processes [1], and it is acknowledged that some parameterisations may be operating outside the range for which they were designed [5]. Consequently, there are already many ways in which the models' projections are already highly unreliable. NB. The direct cloud cover decrease to be parameterised is actually greater than the observed decrease, because of the negative feedback (Figures 2, 3 and 4).

2.2. Cloud Albedo

The IPCC explain that much of climate modelling is non-linear, eg. [6] "*... Parametrization changes can interact nonlinearly with each other so that the sum of change A and change B does not produce the same as the change in A plus B*". However, the primary effect of cloud albedo is on how much solar radiation reaches the surface, and the primary effect of CO_2 is also on how much radiation reaches the surface, so these aspects of clouds and CO_2 can reasonably be combined linearly. ie, for clouds and CO_2, with respect to radiation reaching the surface (radiative forcing), the comparison is of like with like (as indicated in the IPCC quote [2] in **Introduction** above, relating the effects of albedo and CO_2 concentration). In particular, feedbacks from radiative forcing are the same regardless of the causes of the radiative forcing.

An approximate estimate of the change in cloud albedo from the 1983-2017 decrease in cloud cover can be obtained by weighting cloud cover by solar angle of incidence and by taking cloud opacity into account (see **Data and Methods**, below).

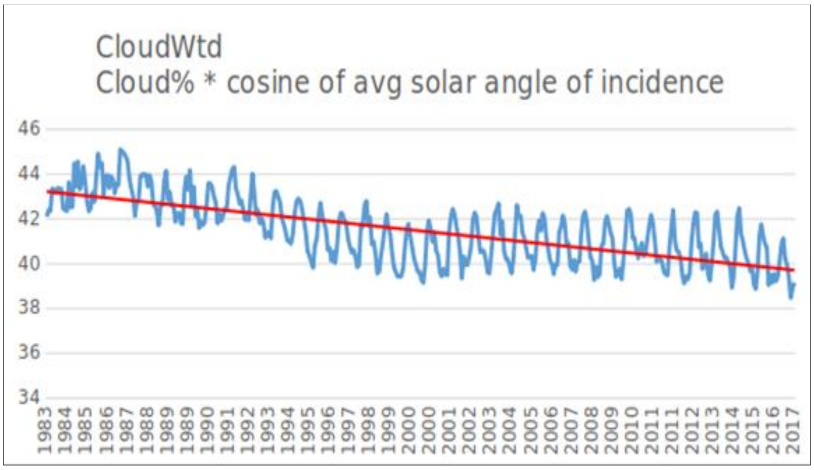

Figure 5 Monthly average global cloud cover weighted by solar angle of incidence, with linear trend. The formula for solar angle of incidence is given in Data and Methods, below. Linear 1983-2017 change is -7.0% (NB. percent, not percentage points)

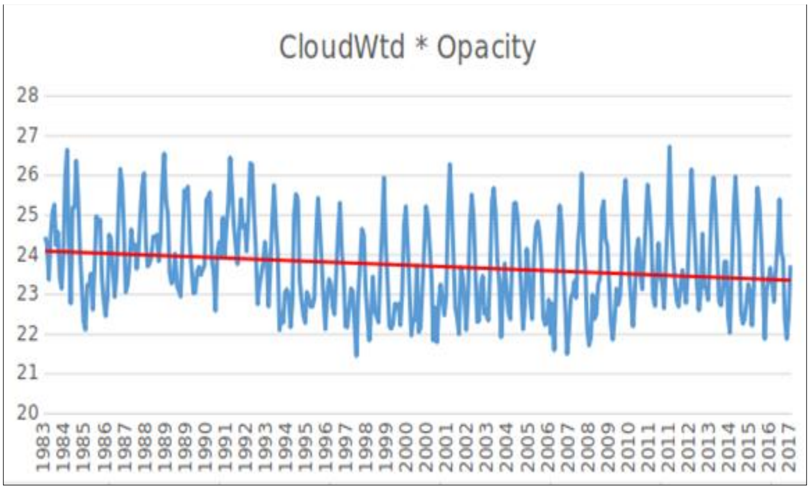

Figure 6 Weighted monthly average global cloud cover as shown in Figure 5 multiplied by opacity, with linear trend. Linear 1983-2017 change is -2.9% (NB. percent, not percentage points)

Opacity is the term used here for the proportion of incoming sunlight that is blocked by clouds. Some of this is reflected, some is absorbed and re-emitted upwards and lost to space, and some is re-emitted downwards and reaches the surface. The change in cloud albedo is therefore likely to be somewhere between the change in cloud of 7.0% (cloud wtd, Figure 5) and the change in cloud*opacity of 2.9% (cloud wtd * opacity, Figure 6).

The total cloud albedo net effect is approximately 16 Wm−2 [7], therefore the increase in radiative forcing caused by the observed decrease in cloud cover over the study period is likely to be between 7.0% and 2.9% of 16 Wm−2, ie. Between 1.1 and 0.5 Wm−2.

Mauna Loa data [8] shows that atmospheric CO_2 increased from 345ppm to 408ppm between 1983 and 2017 (the period of this study). This increase is generally understood to be man-made. The increase can be calculated to generate 24% of the direct radiative effect of a doubling of CO_2 (see Data and Methods, below). The effective radiative forcing (ERF) for a doubling of CO_2 is about 3.9 Wm−2 [4], so the CO_2 increase over the study period generates about 24% of 3.9 Wm-2, ie. About 0.9 Wm-2.

Cloud albedo decrease due to Factor X is greater than observed cloud albedo decrease by a factor of $1/(1 + f)$, where f (< 0) is negative cloud feedback (see Data and Methods, below). f is not known, but if f is small then the ratio of cloud effect from Factor X to CO_2 effect is likely to be between 1.1/0.9 = 1.2, and 0.5/0.9 = 0.6, depending on the actual placing of cloud albedo between cloud area and cloud*opacity. These numbers would be higher with larger values of f. Figures 2, 3 and 4 suggest that f is not small, and therefore that the cloud effect from Factor X is indeed higher.

In any case, a substantial proportion of the radiative forcing generated in the period 1983-2017 would appear to be due to Factor X, and comparable to that due to CO_2. This estimate is refined further in Negative Cloud Feedback, below.

2.3. Negative Cloud Feedback

If the change in cloud area and in cloud opacity are viewed separately for clouds over land and sea, there is an interesting pattern:

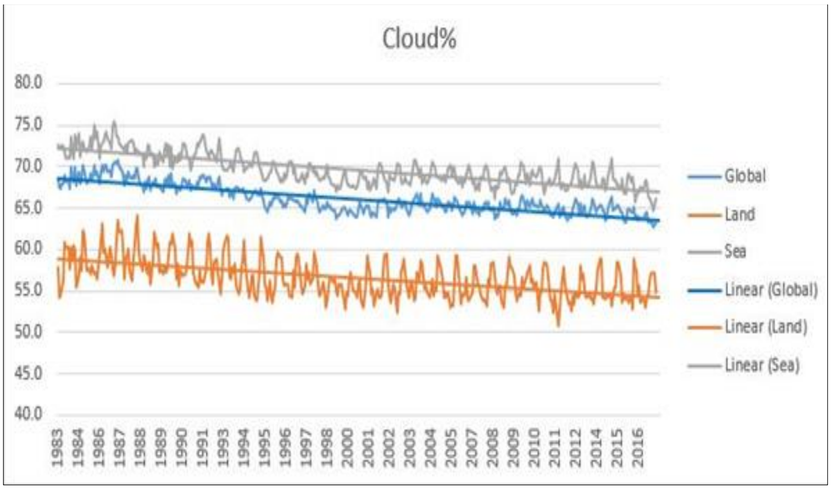

Figure 7 Cloud area 1983-2017 - global, over land, and over sea. Linear 1983-2017 change is -7.3% globally, -7.5% over land, -7.3% over sea (NB. percent, not percentage points)

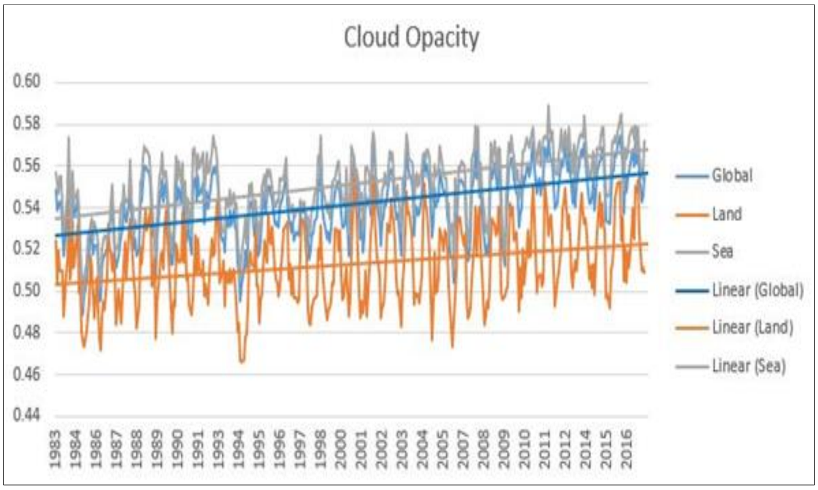

Figure 8 Cloud opacity 1983-2017 - global, over land, and over sea. Linear 1983-2017 change is 5.5% globally, 3.9% over land, 6.1% over sea (NB. percent, not percentage points)

The changes of cloud area over land and sea are similar, which suggests that the decrease in cloud area caused by Factor X is relatively unaffected by whether the clouds are over sea or land. However, the increase in opacity being predominantly over sea suggests that this is influenced by the warmer ocean. If these interpretations are correct, then the cloud area decrease would be due to Factor X, but the increase in cloud opacity would be a feedback and/or independent of Factor X. Consequently, the proportion of the radiative forcing generated in the period 1983-2017 directly by Factor X would be at the upper end of the range given in Cloud Albedo above. ie, it would be around the figure for 'cloud wtd' only, regardless of the actual relationship between cloud area, opacity and albedo, because the opacity change is caused by something other than Factor X or is a feedback. If the slight difference between changes in cloud area over land and sea are real (eg, not from inaccurate measurement) then the slightly smaller cloud decrease over sea might also be due to the warmer ocean, in which case the proportion of the increased radiative forcing generated in the period 1983-2017 directly by Factor X would be above the upper end of the range given in Cloud Albedo, with less than a half being due to CO_2.

Note that the increase in radiative forcing in the period 1983-2017 does not necessarily relate directly to the increase in global temperature over the period. The IPCC's concept of 'equilibrium climate sensitivity' being reached only over a period of time is relevant here, and also there may be other factors affecting surface temperature. Because clouds and CO_2 can reasonably be combined linearly (see Cloud Albedo, above) the same considerations do apply to both.

3. Discussion

It could be tempting to look at factors, other than clouds and CO_2, which could have been active during the 1983-2017 period - ocean oscillations for example - and to use them to increase or reduce the proportions of global warming from clouds and CO_2. If, for example, the AMO (Atlantic Multidecadal Oscillation) index increased during the 1983-2017 period, then the observed global temperature increase over this period might have been caused at least partly by the AMO, thus arguably reducing the amount that could be attributed to clouds and CO_2.

There are two principal reasons why such an argument needs to be treated extremely carefully:

- Whereas clouds and CO_2 operate primarily on how much radiation reaches the surface, the mechanism for ocean oscillations is quite different, therefore they cannot safely be compared to clouds or CO_2 in any linear manner.
- Observed global temperature change cannot safely be used for comparing the effects of factors such as ocean oscillations with the effects of clouds and CO_2, because clouds and CO_2 relate more to 'equilibrium climate sensitivity' over time than they do to observed global temperature changes at or about the same time.

In this paper, comparisons between clouds and CO_2 are restricted to their effect on radiation reaching the surface (radiative forcing) and are not related to the observed global surface temperature. These comparisons are therefore not affected by other factors such as ocean oscillations.

It should be noted also that if the changes in cloud opacity over the study period were in fact caused by other factors such as ocean oscillations, then they were not caused directly or indirectly by the decrease in cloud area, and the findings in Negative Cloud Feedback above still apply.

There is no provision in the latest IPCC report [4] for any independent factor having caused a decrease in cloud cover and hence an increase in radiative forcing.

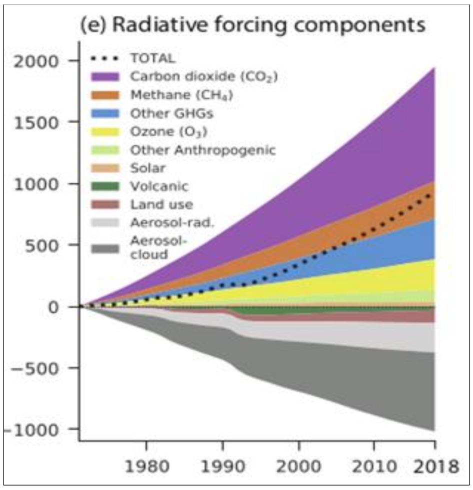

Figure 9 This is Figure TS.13(e) in the 6th IPCC report [4], captioned "Panels (d) [not shown here] and (e) show the breakdown of components, as indicated in the legend, for the global energy inventory and integrated radiative forcing, respectively.". ie, their Figure TS.13(e) shows the breakdown of components for integrated radiative forcing. The period covered is similar to the study period of this paper

As shown in Figure 9, the only positive contributions to radiative forcing allowed for in the IPCC report are greenhouse gases, ozone, and other anthropogenic factors. The solar contribution is shown as being about zero, and the aerosol-cloud contribution is shown as strongly negative. Therefore, where this study finds that cloud changes caused by Factor X had a positive effect with respect to the increase in radiative forcing, the IPCC report either ignores those cloud changes or evaluates them as strongly negative (depending on their exact meaning of 'aerosol-cloud').

The implication is that the climate models and the IPCC over-estimate the effect of the atmospheric CO_2 change over the study period on radiative forcing by a factor of about two or maybe much more, and their future projections of global warming caused by man-made CO_2 are therefore likely to be much too high. There is an indication of this in recent acknowledgements that the climate models have been running too 'hot' [9], possibly because of problems rendering clouds [10].

4. Conclusion

The patterns of behaviour of clouds, both for cloud area and cloud opacity, indicate that the decrease in global cloud area over the study period 1983-2017 was caused by an unspecified factor and was not caused directly or indirectly by the global surface temperature increase over the same period. This also implies that the decrease in global cloud area was not caused by a man-made increase in CO_2.

Evaluation of changes in both clouds and CO_2 in the study period 1983-2017 indicate that cloud changes caused by this unspecified factor had a similar impact to that of the increase in CO_2, with respect to the increase in radiation reaching the surface (radiative forcing), and possibly a much larger impact. NB. The comparison is with respect to radiative forcing only, and specifically not to global surface temperature.

The climate models, which have zero or negative cloud impact independently from CO_2, need to take this into account in order to avoid over-estimating the influence of CO_2.

Data and Methods

Cloud data: Equal-area monthly cloud data (cloud cover % and optical depth) was downloaded from the International Satellite Cloud Climatology Project (ISCCP) [11].

Global surface temperature data: HadCRUT5 global monthly mean data was downloaded from the Climatic Research Unit, University of East Anglia [12].

Solar angle of incidence: The formula used [13] is

*Cos (A) = Sin (Lat)*Sin (d) + Cos (Lat)*Cos (d)*Cos (h)*

Where *A* is solar angle of incidence, *Lat* is latitude, *d* is solar declination, *h* is hour angle.

Cloud opacity: Opacity is the term used here for the proportion of incoming sunlight that is blocked by clouds. Optical depth in the cloud data is converted to opacity as follows:

- Optical depth *d* is defined [11] as *d = ln (Fr/Ft)* where *Fr* is flux received, *Ft* is Flux transmitted.
- Opacity *q* is *(Fr - Ft)/Fr* and hence *q = 1 – e^ (-d)*.

Increase in atmospheric CO_2: The effect on radiative forcing by atmospheric CO_2 is logarithmic, so the observed increase in atmospheric CO_2 from 345ppm to 408ppm between 1983 and 2017 (the period of this study), relative to a doubling of CO2, is Log2(408/345) = 0.24. ie, 24%.

Negative feedback: If an effect has a feedback f ($-1 < f < 1$), and if the observed change is x, then the original change y would have been such that ($y + fy$) = x. ie, $y = x/(1 + f)$. Thus for negative feedback ($f < 0$), the original change y is greater than the observed change x by a factor of 1/ ($1 + f$). Note that for any feedback, f may vary over time.

Changes over the study period: Unless stated otherwise, changes over the study period as given in this paper use a least-squares linear fit on monthly data from 1983/7 to 2017/6, extended half a month at each end. ie, from start 1983/7 to end 2017/6. The change in atmospheric CO_2 from 345ppm to 408ppm (Cloud Albedo, above) is the change from 1983/6-7 average to 2017/6-7 average. Using the same linear method as for the other changes would give the same result (24%).

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

There is no conflict of interest.

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