Global warming and surface heat balance change for CMIP general circulation models

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Abstract

The global warming and the change of surface heat balance in 18 CMIP models are studied. There is strong enough correlation between global warming value and the change of shortwave radiation balance. The connection between global warming value and geographical distribution of short wave radiation in control experiment, and also connection between global warming value and heat flux correction are discussed. These connections are used to estimate global warming value for real climate system.

1. Introduction

The most complete coupled atmosphere-ocean model comparison is carried out under CMIP (Coupled Model Intercomparison Project) (Meehl et al, 2000). More than 30 models take part in this program. All the models execute 2 runs: simulation of observed climate (control run) and simulation of global warming. In control run the concentration of all atmospheric gazes was fixed. The second run (CO_2-run) was the same as control, but concentration of CO_2 was increased by 1% per year. The duration of each run was equals 80 years. Doubling of CO_2 in CO_2-run was achieved near year 70. The response of a model to CO_2 increase is defined as the difference of CO_2 run data averaged over years 61-80 and 1-20. Global warming is defined as near-surface air temperature response averaged over the globe. There is large discrepancy in estimation of global warming in different models. The lowest global warming is 0.75 K, while the largest warming is about 3.7 K. The aim of this study is to find connection between global warming and the response of surface heat balance components. An attempt is done to estimate global warming using short wave (SW) radiation balance in control run, and heat flux correction in control run.

2. The results

Now the results of 18 CMIP-models are available, and their data are used in the comparison. The model descriptions and complete experimental conditions can be seen at CMIP home page: http://www-pcmdi.llnl.gov/cmip/cmiphome.html. Table 1 represents model name, the presence of heat flux correction, global warming value and the response of surface heat flux components: short wave radiation flux (SW), long wave radiation flux (LW), sensible heat flux, latent heat flux, heat flux from the ocean. Fluxes directed to the surface are positive, while fluxes directed from the surface are negative. 10 of 18 models use flux correction procedure, while 8 of them do not use it. Table 1 also presents the data averaged over all the models, model-to-model root mean square (RMS), correlation coefficients and regression coefficients between global warming and heat flux components. Regression coefficients are calculated with the least square method. The models in the table are ordered by reduction of global warming.

Global warming averaged over all the models equals 1.69 K, and RMS equals 0.61 K. Minimum warming occurs in NRL (0.75 K), and maximum warming in NCAR-WM (3.77 K). The second warming is much smaller (2.06 K). Global warming is accompanies with surface heating by LW radiation (2.51 W/m^2) and sensible heating (0.82 W/m^2), while latent heating and heat flux from the ocean tend to compensate the heating. Averaged change of SW radiation is small (-0.14 W/m^2), but its RMS is more than that one for other components (1.37 W/m^2). The regression coefficient between SW radiation and global warming equals 1.62 W/(m^2 K), and correlation coefficient equals 0.72. Correlation coefficient between global warming and latent heat flux equals -0.65, and regression coefficient equals -1.09 W/(m^2 K). For heat flux from the ocean these values equal -0.43 and -0.41 W/(m^2 K). The correlation and regression coefficients for LW radiation and sensible heat flux are small.

Therefore greater global warming is associated with increasing of SW radiation compensated by decreasing of latent heat flux and, to a less extent, heat flux from the ocean. The change of LW radiation and sensible heat flux are weakly correlated with global warming.

Now, try to find how accurately can we estimate global warming in a given model using geographical distribution of SW radiation in control run. All the model data were interpolated to a grid with the resolution of 5^o in longitude and 4^o in latitude. Then, the difference D of composites of SW radiation for the models with global warming above the average and below the average was calculated.

The difference of the composites D is presented in Fig.1 (top). D is maximum in the tropical and subtropical regions near the western coast of Africa, South and North America, while over the most residual tropics and subtropics D is near zero or negative. Maximums of D are located in the regions of relatively cold water. The role of lower stratus clouds in SW radiation balance in these regions is high. Figure 2 shows observed annual mean lower cloud amount in the absence of middle and high clouds according to ISCCP data (Rossow, Schiffer 1991). Lower cloud amount is maximum in the same places, where D is maximum.

Let us define the projection P of SW radiation geographical distribution in the individual model H onto D as scalar product of H and D with cosine of latitude.

Figure 1 (bottom) represents the projection P against global warming for all the CMIP models. Correlation coefficient between P and global warming equals 0.73. Also the line drawing by the least squares method is shown. All the model data are not far from this line. The only exception is data of NCAR-WM, which global warming is the strongest. High correlation coefficient means that there is strong enough connection between global warming in CO_2 run and the value of P in control run. Global warming in the real climate system can be estimated using the observed SW radiation in assumption that real data lies at the line shown in Fig.1 (bottom). This estimation for SW radiation observational data of Darnell et. al (1992) is shown in the figure. The value of P for real climate system equals -3.68 W/m^2, and therefore the estimation of global warming is approximately 1.3 K. It is smaller than global warming averaged over all the models (1.69 K).

We have not direct observations of SW radiation over all the globe, the data of Darnell et. al (1992) is only the estimation using the observed ISCCP clouds. So, it is useful to produce another estimation of the observed global warming using another model parameter.

Figure 3 (top) represents the difference of composites D of heat flux correction (HFC) for the models that include this procedure. Such models are signed by + in Table 1. The HFC data for NRL and ECHAM3 are not available, so only 8 model data sets take part in the calculation. The calculation of P was made in the same manner as for SW radiation, but for tropics and subtropics only (36S - 36N). The difference D is negative in the regions with lower clouds mentioned above, and it is near zero or positive over most of all residual tropics and subtropics. The projection of HFC onto D for individual models P against global warming is shown in Fig.3 (bottom). The correlation coefficient between P and global warming value equals 0.91. HFC for real climate system is zero, and assuming that real climate system data lies at the line represented in fig.3, one can see that the estimation of global warming in the real climate system equals 1.48 K. It is slightly greater than the estimation from SW radiation (1.3 K). But the estimation of global warming for real climate system again is smaller than the global warming averaged over all the models.

3. Conclusion and discussion

The study shows that model global warming can be estimated using SW radiation balance or heat flux correction geographical distribution in control run. In the same manner global warming expected in real climate system can be estimated. The estimated real value is smaller than global warming averaged over the models. The possible reason of overestimation of global warming by the models is underestimation of lower cloud amount. For adequate reproduction of lower cloudness it is necessary to include the dependence of cloud amount on vertical temperature stratification (Gordon et. al, 2000). Such a parameterization is used in few models only. Taking into account the dependence of cloud amount on temperature stratification is important for global warming modelling because under increased CO_2 conditions tropospheric warming is stronger than surface warming (Covey et. al, 2000). This leads to increase of near-surface inversion conditions and therefore the increase of inversion lower cloudness. It is the reason of decreasing of SW radiation and reduction of global warming. This means that probably correct reproduction of lower cloudness is crucial for reproduction of correct global warming.

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Table 1. Global warming and the response of surface heat flux balance components to increasing of CO_2 for different models.

T - global warming (K), H_L - the response of latent heat flux, H_O - heat flux from the ocean, H_S - sensible heat flux, H_{LW} - LW radiation, H_{SW} - SW radiation (W/m^2). AV - value averaged over all the models, D - model-to-model RMS, C - correlation coefficient between heat flux component and T, k - regression coefficient between heat flux component and T, $(W/(m^2K))$. Positive heat flux means flux to the surface. The models are ordered by the reduction of global warming. FC - using of heat flux correction (+ yes, - no).

Model	FC	T	H_L	H_O	H_S	H_{LW}	H_{SW}
NCAR-WM	-	3.77	-4.07	-1.98	0.76	1.76	3.77
GFDL	+	2.06	-3.39	-1.52	1.40	2.00	1.43
LMD	-	1.97	-2.81	-0.52	0.98	3.21	-0.86
CCC	+	1.93	-1.17	-1.31	1.34	2.88	-1.76
UKMO3	-	1.86	-1.44	-0.98	-0.19	2.76	-0.24
CERF	-	1.83	-3.70	-0.75	1.26	3.39	-0.21
CCSR	+	1.75	-1.37	-0.92	0.53	2.75	-0.99
CSIRO	+	1.73	-2.56	-1.29	0.77	2.01	1.19
GISS	-	1.70	-2.26	-1.59	1.24	1.85	0.76
UKMO	+	1.59	-2.46	-0.79	0.78	2.89	-0.43
BMRC	+	1.54	-1.61	-0.94	0.51	2.53	-0.45
ECHAM3	+	1.54	-2.33	-0.78	0.68	2.75	-0.48
MRI	+	1.50	-3.46	-0.91	1.37	1.30	1.61
IAP	+	1.48	-0.67	-2.93	0.80	3.93	-1.82
NCAR-CSM	-	1.26	-1.63	-0.77	0.78	2.22	-0.59
PCM	-	1.14	-1.57	-0.70	0.77	2.28	-0.78
INM	-	0.99	-0.93	-0.77	0.48	2.37	-1.15
NRL	+	0.75	-0.75	-0.45	0.48	2.22	-1.50
AV		1.69	-2.12	-1.11	0.82	2.51	-0.14
D		0.61	1.02	0.59	0.39	0.62	1.37
C			-0.65	-0.43	0.16	-0.12	0.72
K			-1.09	-0.41	0.11	-0.12	1.62

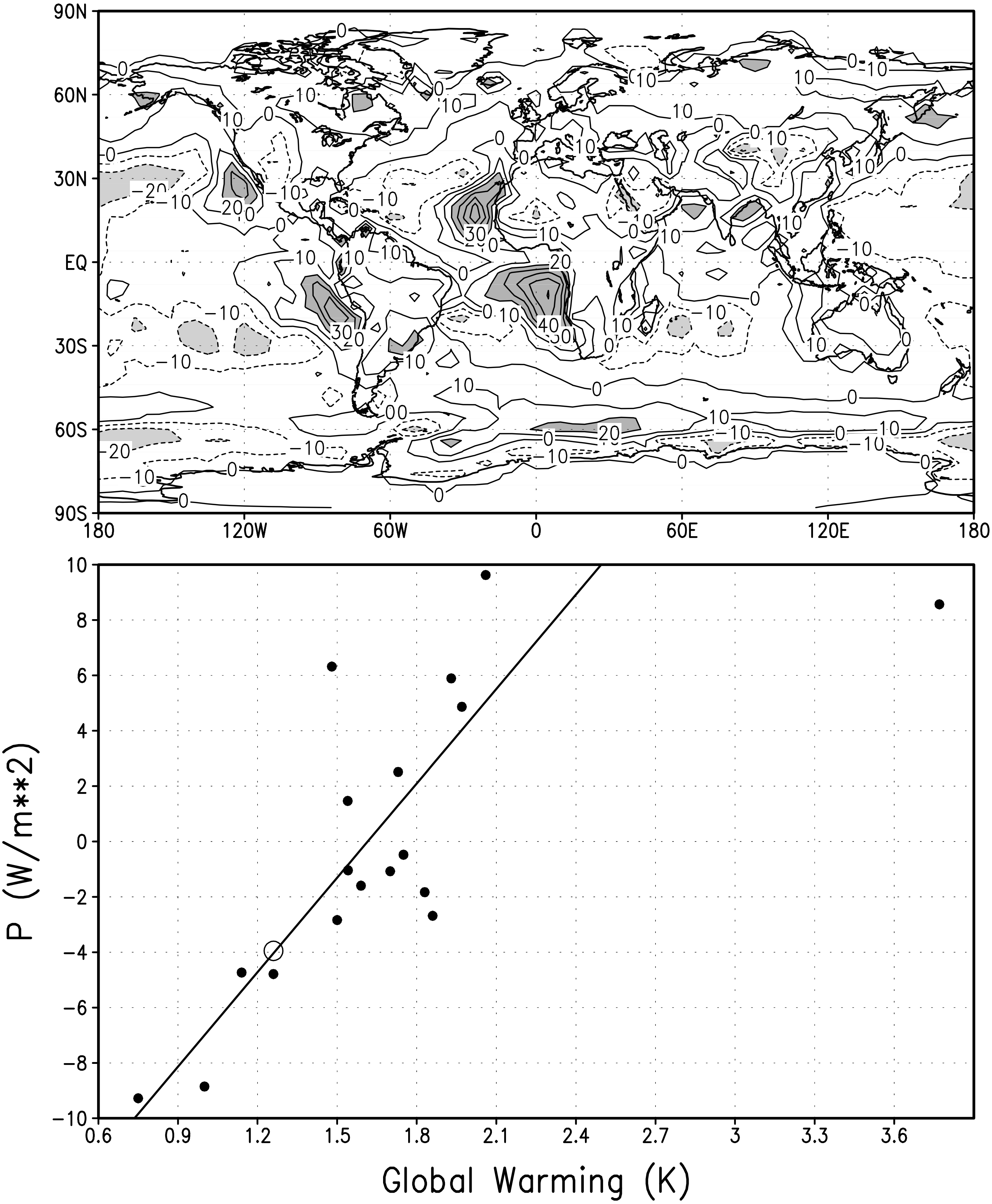

Fig.1. Top: the difference *D* of the composites of SW radiation for the models with global warming above the average and below the average (W/m^2). The values above 20 W/m^2 are shaded. Bottom: the projection *P* of SW radiation onto *D* (W/m^2) against global warming value for the models (K). Open circle means the estimation for the observations.

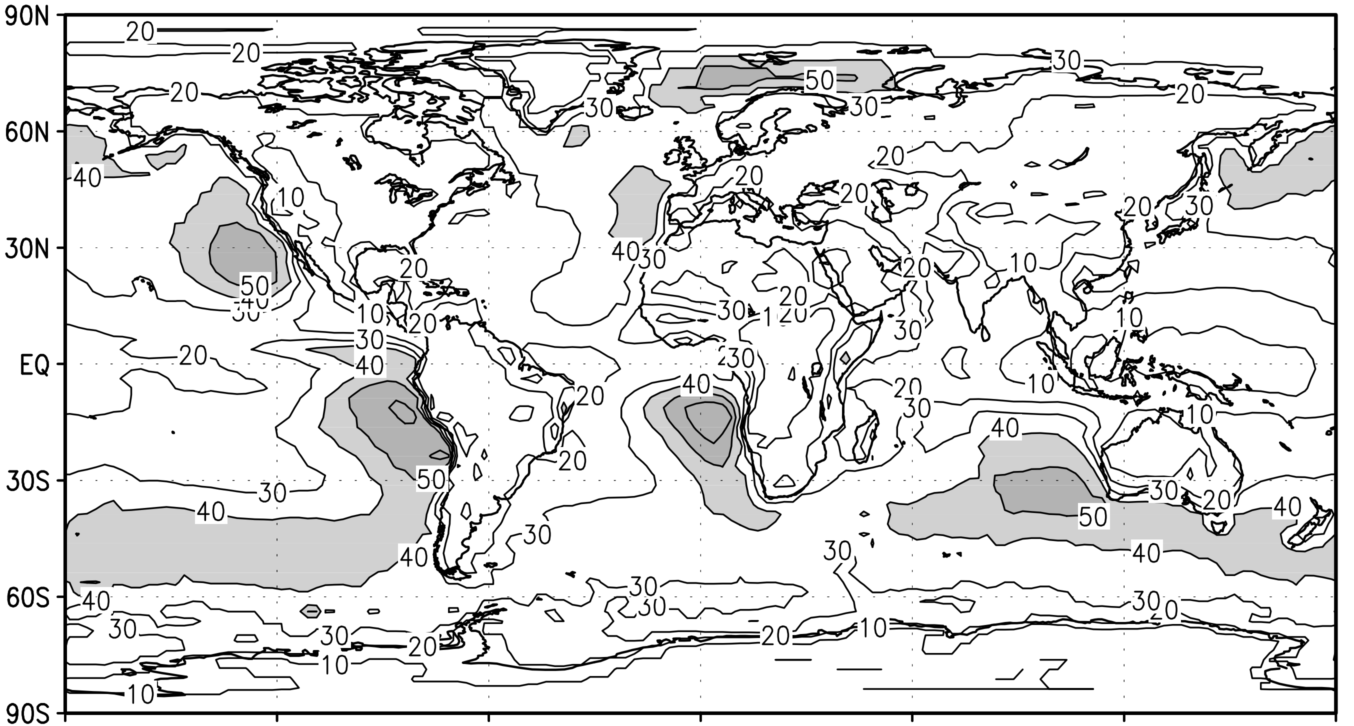

Fig.2. Annual mean observed ISCCP lower cloudness in the absence of middle and high cloudness (percent).

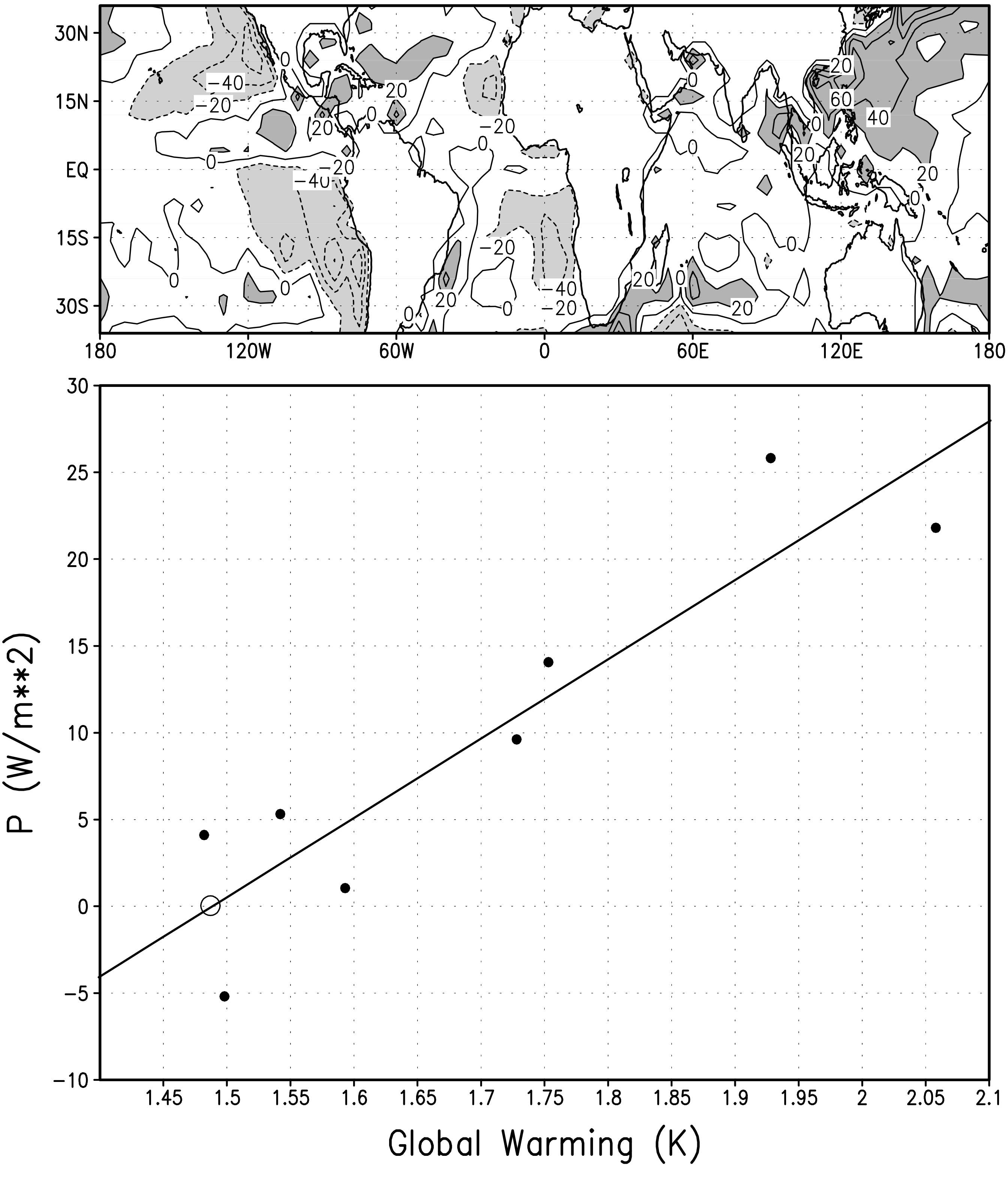

Fig.3. Top: the difference D of the composites of heat flux correction at 36S-36N for the models with global warming above the average and below the average (W/m^2). The values above 20 W/m^2 are shaded. Bottom: the projection P of heat flux correction onto D (W/m^2) against global warming value for the models (K). Open circle means the observations (zero flux correction). P was calculated at 36S-36N.