270.645 Final Report
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Instant Climate Response to Doubled Black Carbon Emission

Abstract

A GCM climate model (GFDL CM2.1) is used to study the climate response to an instantaneous doubling of black carbon in 1800 – 1999. Simulated results from the controlled case and doubled black carbon case were compared. The effects imposed by black carbon on global and regional climatology such as temperature, precipitation and evaporation rate are addressed and discussed. By running the GFDL CM2.1 model, we are able to capture the global transportation path of black carbon from it source. In accordance to some earlier studies, we find that the black carbon increases the atmosphere temperature and cools down the surface temperature by 0.85°K. Precipitation in Equatorial region varies within the range of +170 to -230 mm yearly. Amount of cloud cover is generally increased in all altitude under a double black carbon scenario. The black carbon causes mostly regional effect rather than global effect might due to its short-lived in the atmosphere.

Introduction

Black carbon is a term for those elemental carbon substance formed during partial burning of biomass in condition with low temperature or oxygen level. Other by-products generated from this incomplete combustion include organic carbon and brown carbon which differs with each other from their light absorbing properties. The source of black carbon in industrialized countries is mainly the diesel combustion, while in developing countries, the sources of are residential activities, crop management and diesel combustion. (Baron, et al., 2009)

In the atmosphere, incoming shortwave radiation is reduced by clouds and absorbing aerosols. Absorbing aerosols, also known as black carbon, have a large effect on radiative forcing and contribute to as much as 40% net warming currently. Black carbon can remain in the atmosphere for weeks and be carried from its source to other locations by wind currents. Atmospheric black carbon blocks shortwave radiation reaching the surface by converting it to long wave radiation and causes warming in the atmosphere. Meanwhile, the Earth's surface and lower atmosphere are cooling down due to the dimming effect created by the atmospheric black carbon. However, black carbon only stay in the atmosphere for several weeks to slightly more than a month which may not cause long-term climate change unless keep emitting. (Baron, et al., 2009) Regional and global climate responses to the change of external forcing such as atmospheric black carbon will be the major focus of this paper.

Model Description and Data

The Geophysical Fluid Dynamic Laboratory (GFDL) CM2.1 is a coupled three-dimensional general circulation model (GCM). The model comprises of separated atmosphere, ocean, sea ice, and land component models interacting with a flux coupler module. The atmosphere and land models of CM2.1 are known as AM2.1 and LM2.1 with horizontal resolution 2° × 2.5° and 24 levels in the vertical. (Delworth, et al., 2006). In this study, monthly data was generated by GFDL CM2.1 model with clear sky

Table 1 Output variables simulated by CM2.1. I and J axis represent latitude and longitude, K is the vertical levels and L represents the monthly values from Jan to Dec.

NAME	TITLE	I	J	K	L
HIGH_CLD_AMT	high cloud amount	1:96	1:60	...	1:12
LOW_CLD_AMT	low cloud amount	1:96	1:60	...	1:12
MID_CLD_AMT	mid cloud amount	1:96	1:60	...	1:12
TOT_CLD_AMT	total cloud amount	1:96	1:60	...	1:12
EVAP	evaporation rate	1:96	1:60	...	1:12
U_REF	zonal wind component at 10 m	1:96	1:60	...	1:12
V_REF	meridional wind component at 10	1:96	1:60	...	1:12
TEMP	temperature	1:96	1:60	1:24	1:12
PRECIP	Total precipitation rate	1:96	1:60	...	1:12
SWDN_SFC_CLR	clear skySW flux down at surfac	1:96	1:60	...	1:12

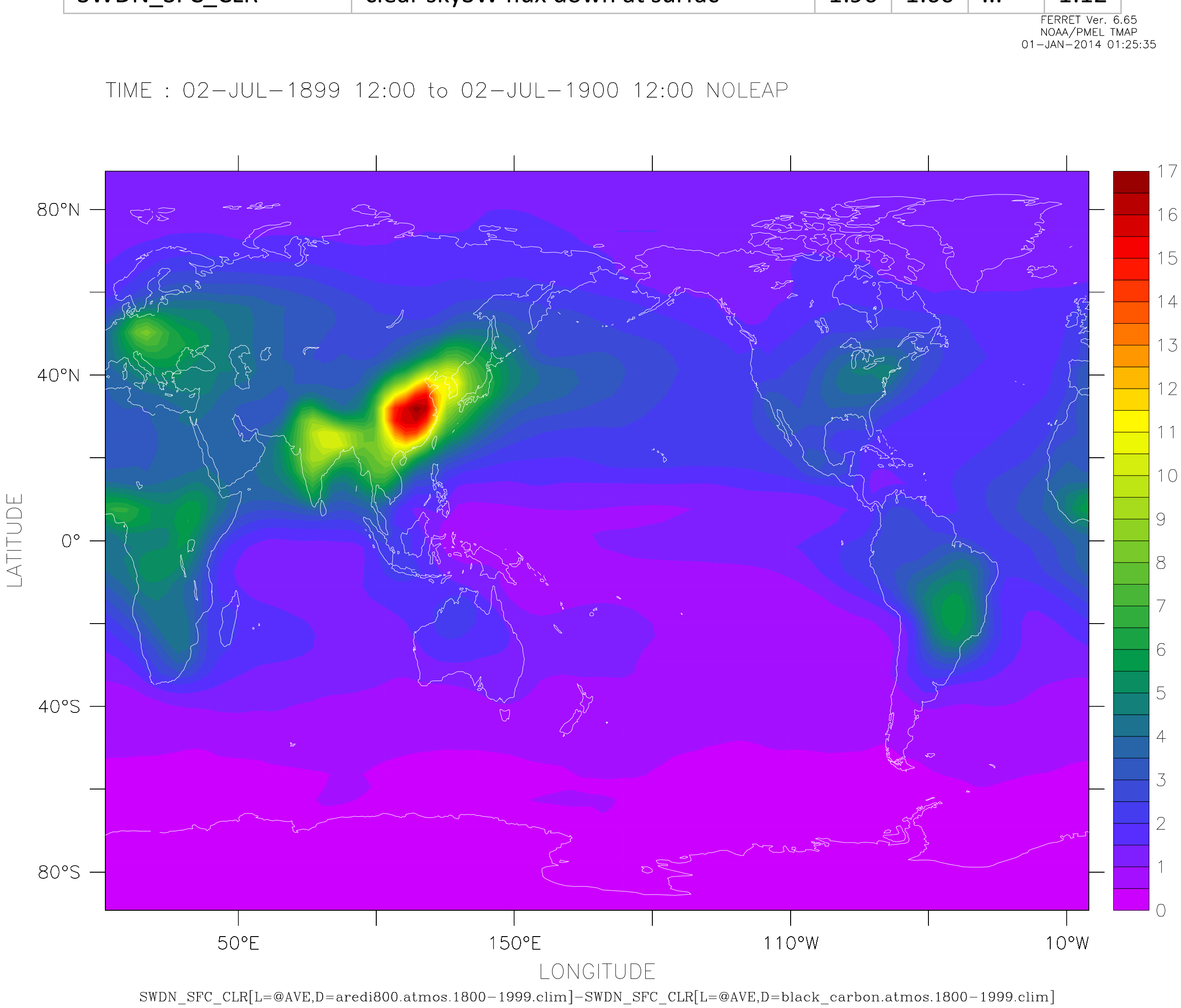

Fig.1 The global pattern of black carbon emission. Difference in the annual mean clear sky shortwave flux (W/m2) down at the surface between a normal case and a doubling black carbon case simulated by general circulation model CM2.1 was shown.

shortwave flux down at surface (SWDN_CLR), temperature (TEMP, T_SURF, T_REF), precipitation (PRECIP) and evaporation rate (EVAP) etc. as the main output variables.

Two datasets used in this study were simulated data adopted lateral diffusion coefficient (A_{redi}) values of 800 m2/s in the format of CDF. For surface data such as SWDN_CLR, T_SURF, T_REF, PRECIP EVAP, and XXX_CLD_AMT (XXX can be low, mid, high and tot) are three-dimensional with monthly values at different latitude and longitude. Table 1 gives all the model output in 4-dimensions: I, J, K and L representing latitude, longitude, height and time respectively.

Result

Clear sky shortwave flux down at surface reflects the amount of black carbon suspended at the atmosphere as it ignores the effect of cloud and leaves only the absorbing aerosols. Fig 1 indicates that the single most important source for black carbon is in Eastern China, causing up to 17 W/m2 reduction in downward SW flux. Other potential important sources include India, Unite State, Brazil and some countries in the Eastern Europe and Central Africa. These countries will be the contributors for the doubling of black carbon scenario in this study.

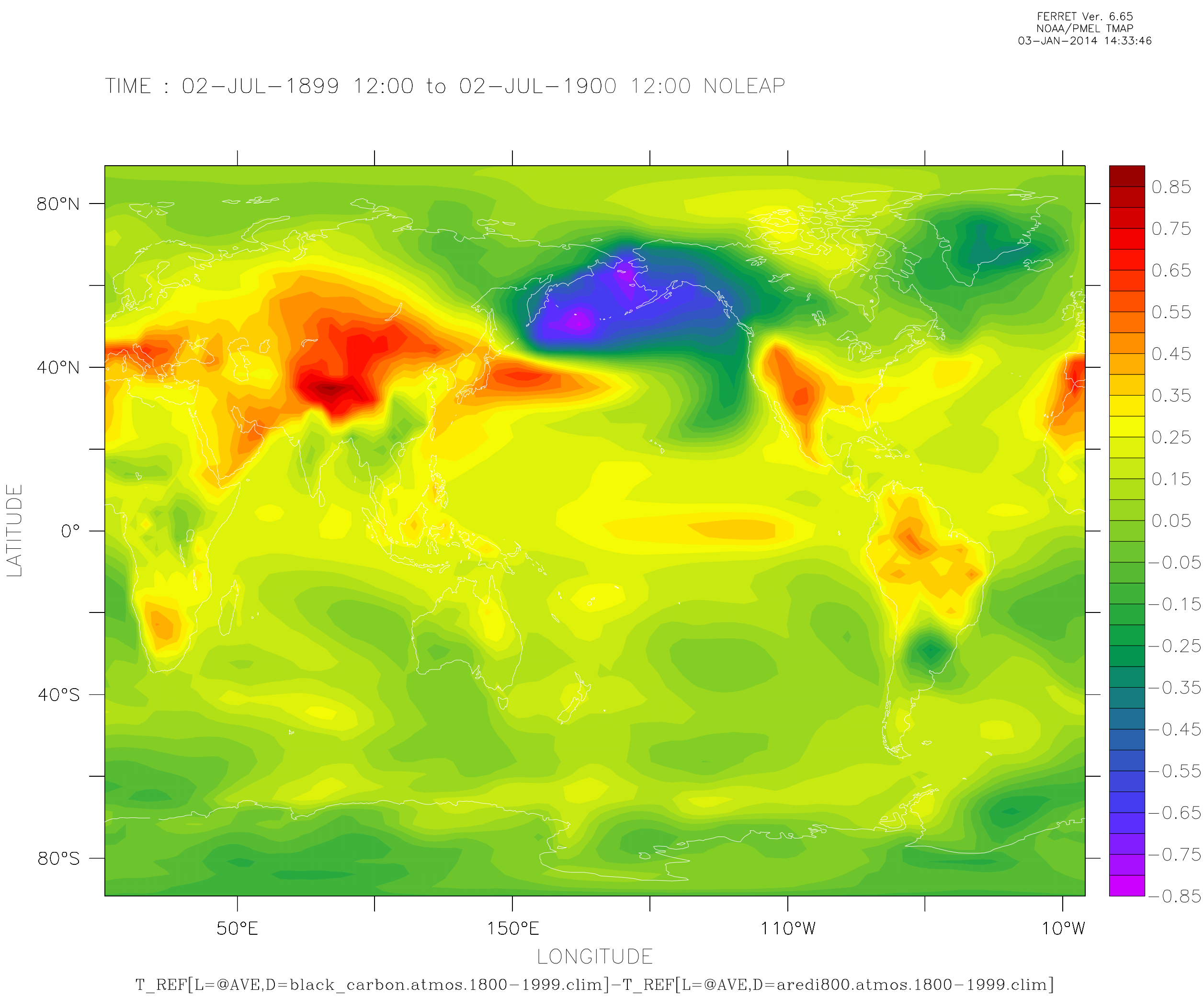

Fig 2 Geographical distribution of the change of annual mean surface temperature (°K) under a doubled black carbon scenario

Some studies reported that the effect of black carbon on temperature is insignificant. (Jones et al., 2007; Pendergrass & Hartmann, 2012) But, we do find observable variability in surface and near-surface temperature after an instantaneous doubling of black carbon. The variability of temperature for surface and 2m above the surface is ±1°K and ±0.85°K respectively. The major heating areas are located in Eurasian Plate and North America around 40°N while the cooling area is the Pacific Ocean at around 50°N to 60°N. Other heating areas include the Pacific Ocean at around ITCZ, Latin America at 20°S to 0° and South Africa at around 20°S.

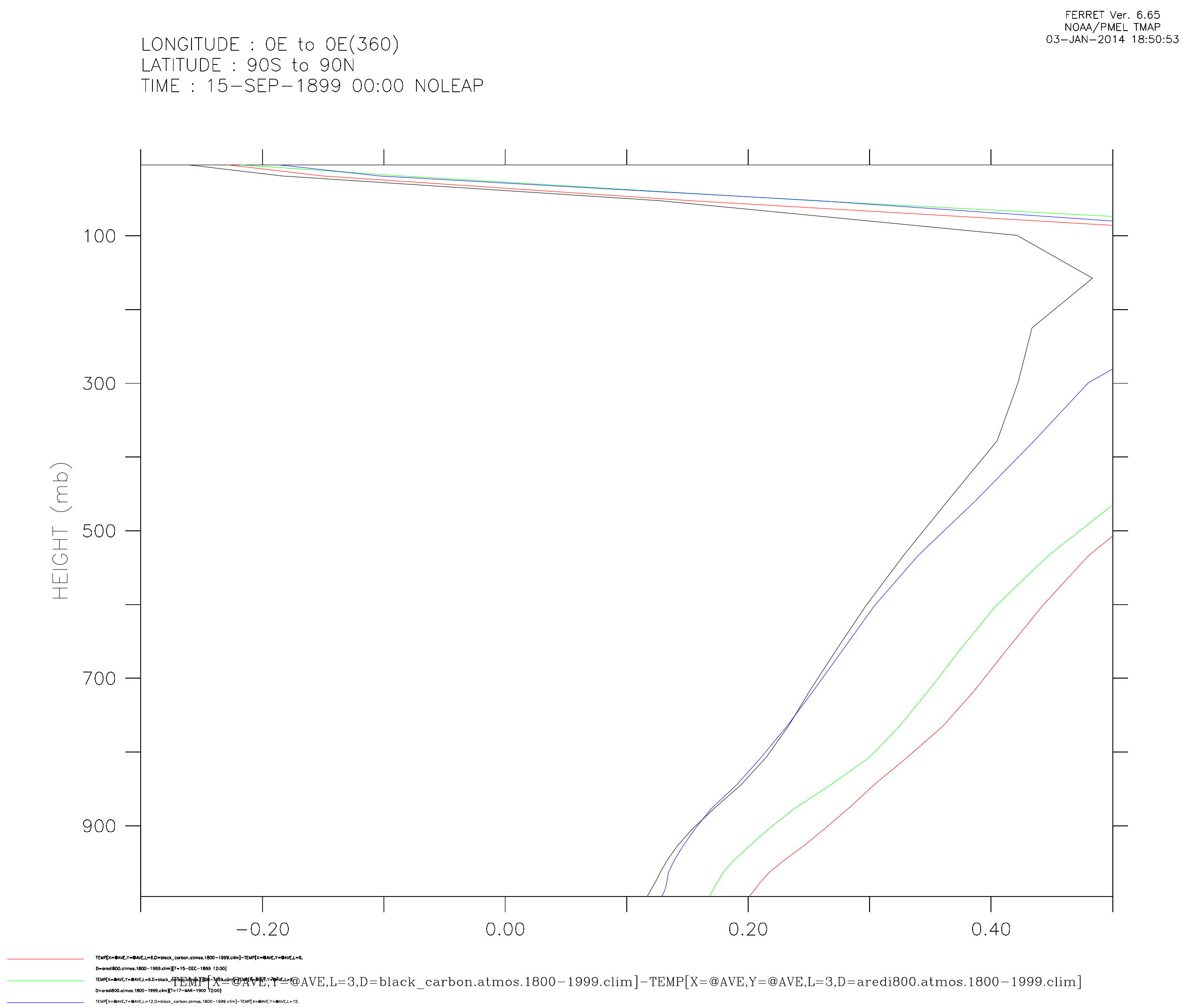

Fig 3 Monthly mean of vertical temperature (°K) variation with latitude and longitude averaged under a doubled black carbon scenario. Black, red, green and blue lines represents the temperature profile in March, June, September and December respectively.

The effect of doubled black carbon on atmospheric temperature profile is shown in Figure 3. In accordance with most studies, black carbon is found warming the atmosphere and as the height increases, the degree of warming increases. The temperature goes down at stratosphere where the black carbon loses its buoyancy. The difference in temperature is greater in summer (June) than in the winter (December).

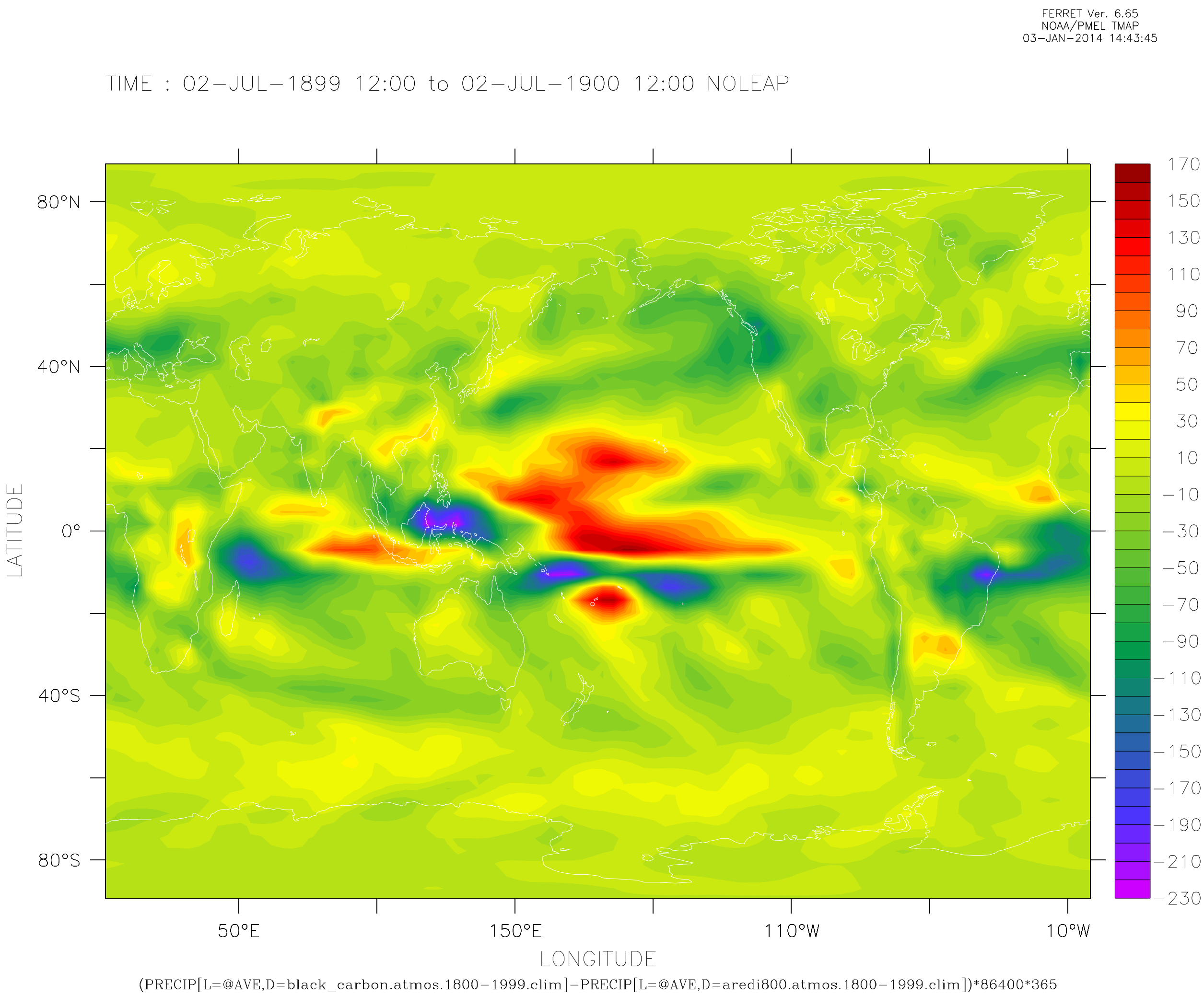

Fig 4 Geographical distribution of the change of annual mean precipitation rate (mm/year) under a double black carbon scenario

Precipitation is more sensitive to the increase in black carbon level. Pendergrass & Hartmann (2012) temporally matched the precipitation time series with the time series of the clear-sky atmospheric shortwave absorption. In our simulation, the variability in precipitation rate was limited to the Equatorial Region. The major area subjected to the increase in annual mean precipitation is Pacific Ocean with up to 170 mm/yr. A band of decreasing precipitation rate is located at around 10°S in the ocean. Besides, some island countries including Malaysia were found dramatically decrease in precipitation to as high as 210 mm/yr.

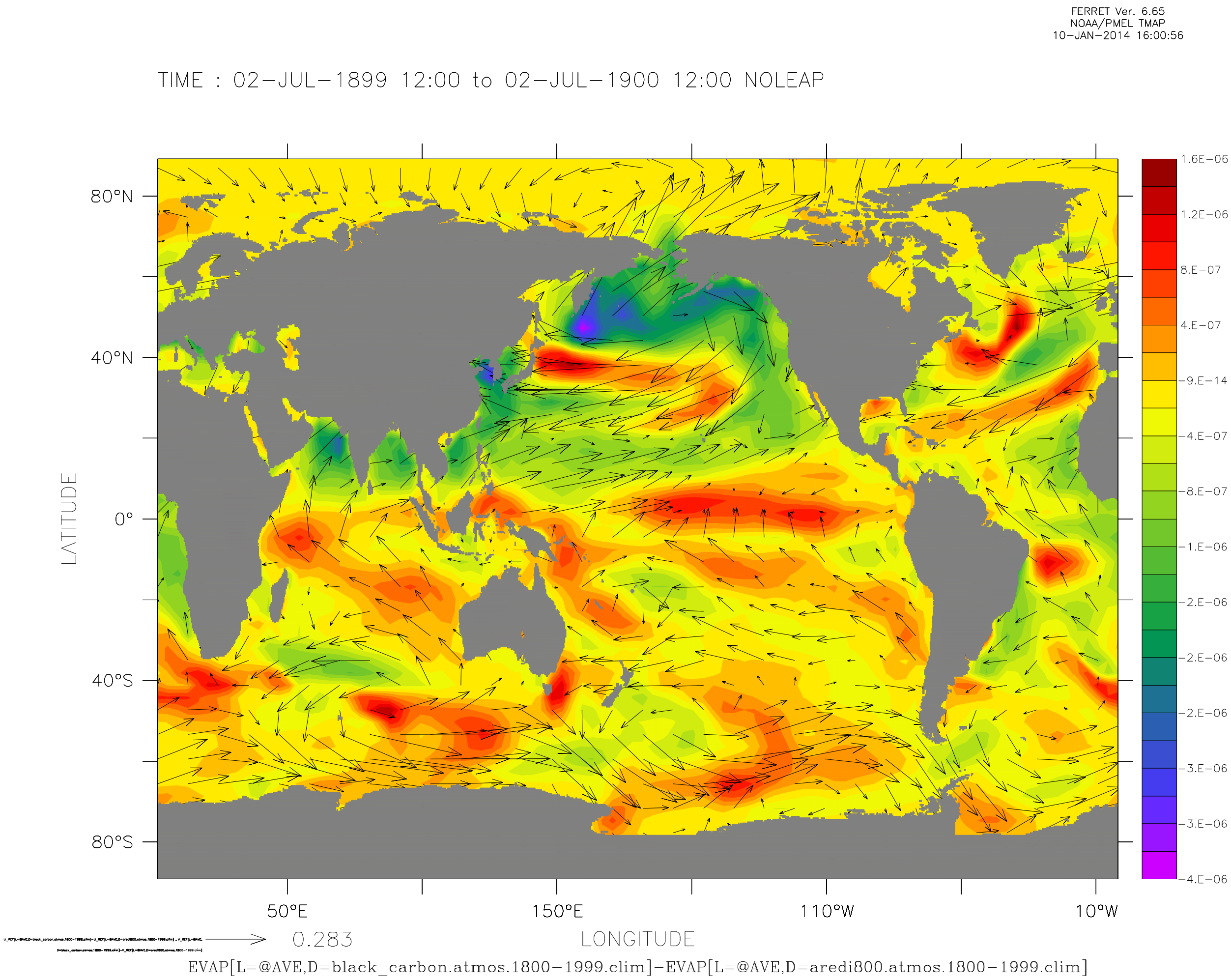

Fig 5 Geographical distribution of the change in evaporation and surface wind speed (m/s) under a double black carbon scenario. The arrows indicate the difference of surface wind speed and direction.

Atmospheric circulation is enhanced evident by the increase of evaporation rate knowing the fact that the change of temperature is minor under double black carbon scenario. As shown in Figure 5, increasing evaporation rate can be found at Equatorial region and at places with major ocean currents. The wind speed is generally intensified by the doubling of black carbon.

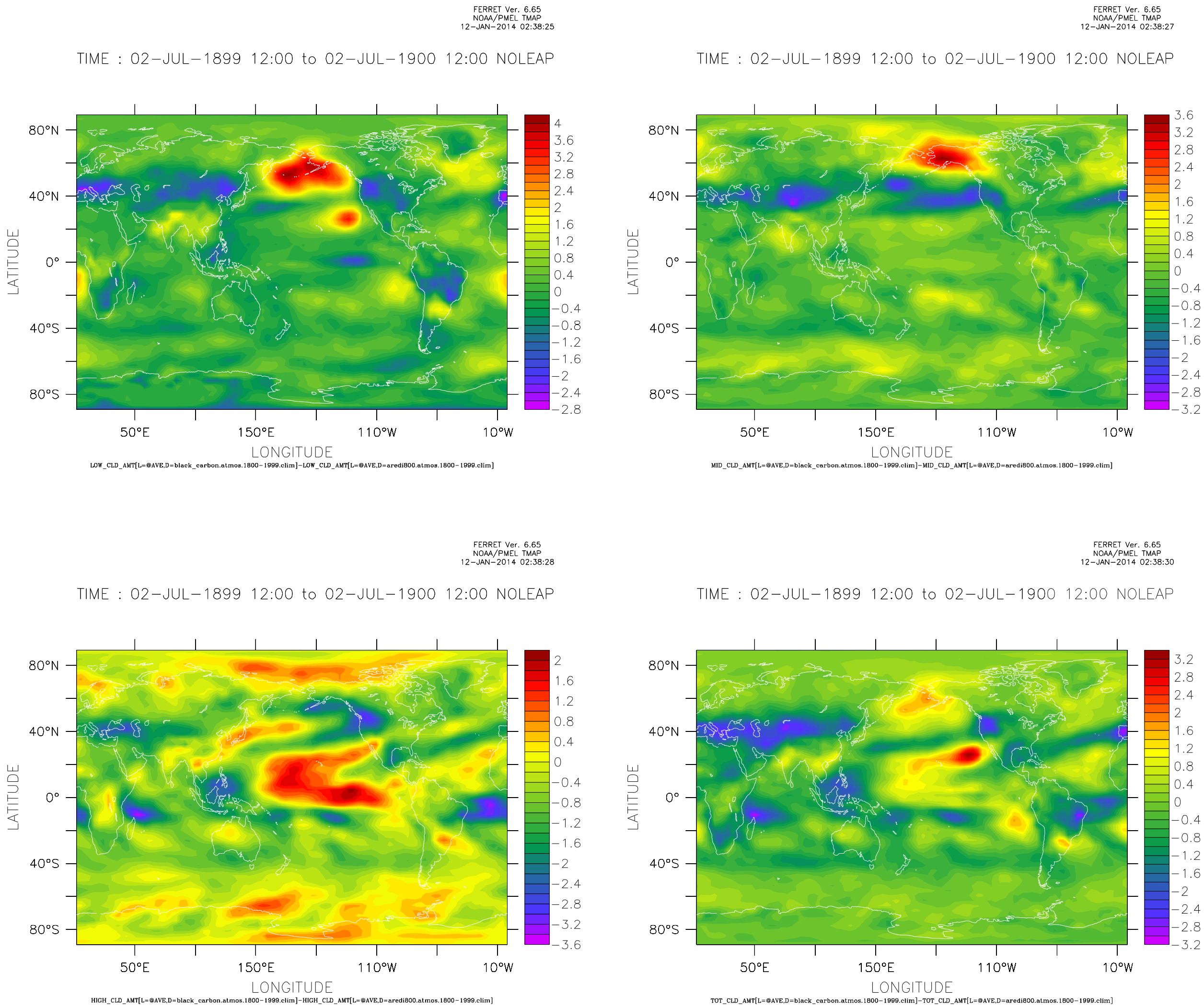

Fig 6 Geographical distribution of the change in cloud amount and at low, middle, and high altitude under a double black carbon scenario.

Doubling of black carbon has a regional effect on the amount of low- and mid-altitude cloud and has a global effect on high altitude cloud. For low- and mid-altitude cloud, the amount is increased exclusively above the Northern Pacific Ocean and decreased in the nearby Asia and North America. High-altitude cloud is increased globally, particularly at the Pacific in Tropical region. Overall, most increase in cloud cover occurs at Pacific Ocean while decrease in Atlantic Ocean and Continents.

Discussion and Conclusion

The doubling of black carbon is obviously changing the Earth's climate by altering the global patterns of temperature, precipitation and evaporation rate. The clear sky shortwave flux down at surface clearly indicates the major sources of black carbon in the world as the incoming solar radiation is mainly shortwave ultraviolet radiation which can only be absorbed by aerosols and cloud. When the effect of cloud is neglect, the difference of the shortwave flux down at surface before and after the doubling of black carbon become its good indicator. The model output on sources of black carbon is in accordance to the fact that China is the major source of black carbon in the world. According to IIASA (2005), East Asia (China) was the dominant source for black carbon on Earth and approximately 70% of the emission come from domestic sources such as heating and cooking using biomass fuel. Another important source contributing to the black carbon is the practice of crop burning in China.

In general, the warming effect imposed by black carbon in near surface is regional rather than global. The warming in Eurasia and cooling in the Northern Pacific might indicate the travel of black carbon from Eastern China eastward to the Northern Pacific by the mid-latitude Westerlies. The cooling of Northern Pacific is due to the increase in low cloud above that region. In the vertical direction, the difference of temperature between doubled black carbon and the original is increasing with height, indicating the black carbon was lifted to around tropopause (10mb) where the largest degree of warming occurs. Precipitation are very much depending on evaporation rate which is influenced by temperature at the surface. The black carbon affects mainly the precipitation in the tropical and subtropical region but the effect is not uniform. The precipitation might be impacted by altering vertical temperature profile that results in the formation of cloud and increasing the evaporation rate underneath. It is possible that black carbon promotes the formation of cloud cover, especially the low and mid-altitude clouds, by serving as nuclei essential for its formation.

The increasing amount of high altitude cloud basically follows the increase of evaporation rate. The change of evaporation rate under doubled black carbon emission is more global compared to temperature, precipitation and cloud cover we previously discussed. Besides the enhanced hydrological cycle due to increased precipitation or change in surface temperature, the more credulous explanation for the change of evaporation rate seems to be the increase of ocean currents or near-surface wind due to doubled black carbon. However, the evidence is lacking as not proved by previous studies. Simulation result from more models is required to take a further step.

Since black carbon is short lived in the atmosphere, in the real world, it is hard to judge whether it would continue to increase throughout the century or decrease. As the advancing of technology, developing countries like China and India might reduce their emissions of black carbon from household or agricultural practice. In this study, we consider only the short-term effect on climate and thus most of the changes in climatology are regional. For future studies, model inter-comparison could be applied to investigate more on its forcing to precipitation and circulations.

Main Reference

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