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Accelerated Global Warming after 1998 Is Caused by Decrease in Terrestrial Evapotranspiration (ET)

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INTRODUCTION

Global warming, as one aspect of global climate change, is becoming more significant in recently years. The global observed rising temperature rate is 0.180K per decade over the last 50 years (Muller et al., 2012), however, it increased to 0.334K per decade after 1998 (calculation based on the data of Muller et al., 2012). Up to now, there are no satisfactory explanations for this accelerated global warming after 1998. The basic hypothesis of this study is that the accelerated global warming after 1998 is mainly caused by a decrease in global terrestrial evapotranspiration (ET). To verify this hypothesis, we estimated the scale of terrestrial ET energy consumption (latent heat), the effects of change ET on global warming, and the alleviation of global warming by increasing ET.

ENERGY CONSUMPTION OF GLOBAL TERRESTRIAL ET

As shown in Table 1, global terrestrial ET consumes 1.480×10^{20} KJ/y of energy every year (Qiu, et al., 2012). This is about 3.0×10^{5} times of annual human energy use (4.935×10^{14} KJ/y, data from World Bank database). Because of the huge amount of energy consumption associated with ET, the solar energy used by increasing global terrestrial ET can easily offset the energy emitted in the lower atmosphere due to human activities. Therefore, increasing global terrestrial ET could be a potential solution to the challenge of global warming.

Table 1 Global land ET and the corresponding latent heat (LH). ET data were cited from Oki and Kanae (2006). Solar energy absorbed at the terrestrial surface was 145.1 W/m^2 (Trenberth et al., 2009), while annual human energy consumption was 4.935×10^{14} KJ/y (data from World Bank database).

Land type	Forest	Grassland	Cropland	Lake	Wetland	Other	Total
ET (10^3 km^3/y)	29.0	21.0	7.6	1.3	0.2	6.4	65.5
Area (10^6 km^2)	40.1	48.9	15.6	2.7	0.2	26.4	133.9
ET (mm/y)	723.19	429.45	487.18	481.48	1000.00	242.42	489.17
LH (10^{19} KJ/y)	6.554	4.746	1.718	0.294	0.045	1.446	14.803
LH (W/m^2)	51.8	30.8	34.9	34.5	71.7	17.4	35.1

GLOBAL TERRESTRIAL ET CHANGE IN RECENT YEARS

Because it was difficult to accurately estimate global terrestrial ET, the actual variations of global terrestrial ET were not well estimated until the recent publication of an article in Nature by Jung and 32 other scientists (Jung et al. 2010), entitled, "Recent decline in the global land evapotranspiration trend due to limited moisture supply." Their findings came from every corner of the globe and have been widely accepted by the academic world (Mu et al., 2011; World climate report, Jan. 20th, 2012). This article indicates that, accompanied by global warming, global annual terrestrial ET increased on average by 7.1 mm per year per decade between 1982 and 1997. Coinciding with the last major El Nino event, global land ET has decreased on average by 7.9 mm per year per decade since 1998. They further suggested that persistent reduction of global land ET has occurred since 1998, driven primarily by moisture limitation in the Southern Hemisphere, particularly Africa and Australia (Jung et al. 2010).

ACCELERATED GLOBAL WARMING AFTER 1998 IS CAUSED BY DECREASE IN TERRESTRIAL ET

Our hypothesis is that accelerated global warming after 1998 is mainly caused by a reduction of global terrestrial ET. To verify this hypothesis, we first summary three recent findings: (1) Global observed temperature increased at a rate of 0.180K per decade for the last 50 years (Muller et al., 2012); however, it increased at the faster rate of 0.334K per decade after 1998 (Our calculation based on Muller`s result); (2) Global terrestrial ET increased by a rate of 7.9 mm per year per decade during 1982 to 1997; however, it decreased by 8.9 mm per year per decade after 1998 (Jung et al., 2010); and (3) Globally adding a uniform 1 W/m^2 source of latent heat flux along with a uniform 1 W m^{-2} sink of sensible heat could lead to a decrease in global mean surface air temperature of 0.54 ± 0.04 K (simulation result for a 70 years period with $\pm$95% confidence interval, Ban-Weiss et al. 2011).

Based on these three findings, we further analyze the effects of ET decrease on global temperature. Terrestrial ET decrease can reduce its evaporative cooling effect and thus increase sensible heat flux. Changes in sensible heat fluxes alter lower atmosphere direct heating, but water vapor condensation in the atmosphere balances the change in surface evaporative flux, and thus evaporative cooling itself is not expected to cause global climate change on a planetary energy balance basis (Ban-Weiss et al. 2011). However, climate changes from the repartitioning of latent and sensible heat can occur from changes in clouds, which can alter shortwave and/or longwave radiative fluxes, changes in the vertical temperature profile, and changes in atmospheric water vapor. Recent research discovered that adding a uniform 1 W/m^2 source of latent heat flux globally along with a uniform 1 W/m^2 sink of sensible heat leads to a decrease of global mean surface air temperature by an amount of 0.54 ± 0.04 K (Ban-Weiss et al. 2011). This occurs largely as a consequence of planetary albedo increases associated with an increase in low elevation cloudiness caused by increased evaporation (Ban-Weiss et al., 2011)

We then quantitatively analyzed the effect of ET change on global temperature change. As reported by Jung et al. (2010), global land ET increased on average by 7.1 mm per year before 1998, which is equivalent to an increase in energy consumption of 0.509 W/m2 and could lead to a decrease of global air temperature by 0.080K per decade. The calculation processes are shown in detail in Table 2 line 1.

It is noted that the global terrestrial surface temperature increased by about 0.90K in the past 50 years (Muller, 2012), which was equivalent to 0.180K per decade. If there was no buffering from the increasing in land ET, the global temperature would rise at a rate of 0.180K + 0.080K = 0.260K per decade before 1998. It was clear that ET increase before 1998 helped to mitigate global warming.

As discussed before, ET increase stopped abruptly in 1998, and afterwards terrestrial ET began to decrease at a rate of 7.9 mm per year per decade. This terrestrial ET decrease raised sensible heat flux and lowered cloudiness, which contributed to global warming. According to our calculation, decreasing ET by 7.9 mm per year was equivalent to an energy emission increase of 0.566 W/m^2, which led to global air temperature rising at a rate of 0.089K per decade (Table 2, line 2). Therefore, the overall global temperature increase after 1998 would be 0.180 (based on actual increase trend) + 0.080 (buffered by ET increasing) + 0.089 (accelerated by ET decreasing) = 0.349K per decade.

The observed global temperature increase rate was 0.334K per decade after 1998 (estimated from Muller`s figure, 2012), which was very close to our estimation of 0.349K per decade.

Table 2 Procedures to estimate the effects of ET change on global temperature. Lines 1 and 2 represents the situation before and after 1998, respectively. Note: 1 mm ET = 1 kg/m^2 ET.

Line	Latent heat of water (10^6J/kg)	Change in ET per year per decade (kg/m^2)	Energy used by ET change (10^6 J/m^2)	Time in second per year (10^7 s)	Energy for ET per second (W/m^2)	Temperature change to 1 W/m^2 global ET change (K)	Ratio of land to total global surface	Change in global air temperature per decade (K)
	A	B	C=A×B	D	E=C/D	F	G	H=E×F×G
1	2.260	7.1	16.046	3.1536	0.509	0.54	0.292	0.080
2	2.260	7.9	17.854	3.1536	0.566	0.54	0.292	0.089

CONCLUSIONS

Since 1998, global terrestrial ET has decreased by 8.9 mm per decade. This ET reduction would result in the rising of global temperature at a rate of 0.349K per decade, which is very close to the observed global temperature increase during the same period, or 0.334K per decade. Therefore, the accelerated global temperature since 1998 was mainly a result of terrestrial ET reduction.

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