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Evaluation of radiation forcing from snow pollution by black carbon emissions from forest fires using the SNICAR radiation model and data from the INMCM5 climate model

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Motivation

Over the past decades, issues related to global warming have become relevant. We consider the effect on climate of one of the atmospheric aerosols - black carbon, emiited from forest fires. When falling on snow, BC changes the reflectivity of the snowy surface of the Earth - the albedo, which creates additional radiation forcing, causing faster snowmelt and an increase in surface temperature in the spring season.

Description of the technology for calculating radiation forcing (RF), associated with account for black carbon (BC) emissions

Estimates of additional RF are derived from changes in surface albedo. For this, we used the data of a historical experiment with the climate model INMCM5 [1], as well as the one-dimensional model of radiation transfer in the snow layer SNICAR (SNow-ICe-AErosole) [2].

In a historical experiment with INMCM, conducted as part of the CMIP6 project [3], the climate of the Earth system was modeled from 1850 to 2014. In this case, the external influence on the Earth's system was established as close as possible to the observable. Based on the monthly average data of the model on the height of the snow cover H_{sn}, as well as on the flow of black carbon from the atmosphere I_{bc}, provided that the precipitation of BC is evenly mixed in the snow, the BC concentration in each cell of the model grid was calculated using the following formula:

$$C_{bc} = \frac{M_{bc}}{M_{sn}} = \frac{I_{bc}dt}{H_{sn}\rho},$$ here dt is time interval (1 month), ρ is density

To clarify the results when calculating the mass of BC, its stocks from the previous month were taken into account. Let, there is a time series of values $\{h_i, m_i\}$ of the average monthly thickness of snow and the mass of precipitation BC in the cell covered with snow, respectively. Then for the specified mass of BC in the cell M_i we have:

$$M_i = \begin{cases} 0, & if\ h_i = 0; \\ m_i, & if\ \ h_i > 0, \quad h_{i-1} = 0; \\ m_i + M_{i-1} min\left(\frac{h_i}{h_{i-1}}, 1\right), & if\ \ h_i > 0, \quad h_{i-1} > 0; \end{cases}$$

Then, using the obtained BC concentrations and the SNICAR model, we calculated the changes in surface albedo and radiation forcing caused by BC emissions from forest fires. It was assumed that the cosine of the solar zenith angle for the northern hemisphere depends on the declination angle of the Sun and latitude as follows: let δ is the declination angle of the Sun, φ is latitude, θ is the solar zenith angle.
Then: $\cos\theta = \cos(\varphi - \delta)$, wherein: $\sin\delta = \sin\varepsilon \sin\left(\frac{2\pi(d - d_e)}{365}\right)$
Here $\varepsilon = 23{,}45^0$ is the inclination of the Earth to the plane of the ecliptic, d is the time (in days), $d_e = 80{,}5$. For each month, this value was calculated at noon on the 15th.

From the SNICAR model, we obtain albedo values corresponding to different wavelength ranges of incident radiation (alb_{vis} is the visible range, alb_{nir} is the near infrared range) corresponding to clean and dirty snow (α_{bc} and α_0). Based on these results, radiation forcing was calculated using the following formula:

$$R_{bc} = \sigma\left[\left(\alpha_0^{vis} - \alpha_{bc}^{vis}\right)F_{vis}^{down} + \left(\alpha_0^{nir} - \alpha_{bc}^{nir}\right)F_{nir}^{down}\right]$$

Moreover, we can assume that: $F_{vis}^{down} \approx F_{nir}^{down} \approx 0.5F_{sw}^{down}$, here F_{sw}^{down} is the incoming short-wave radiation flux in this mesh cell from the INMCM model.

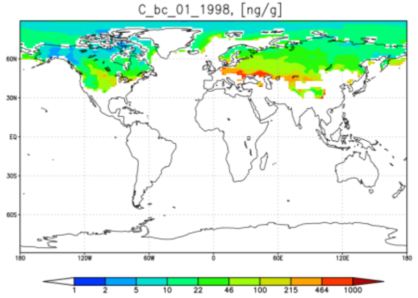

Fig. 1 *The monthly average concentration of BC in January 1998*

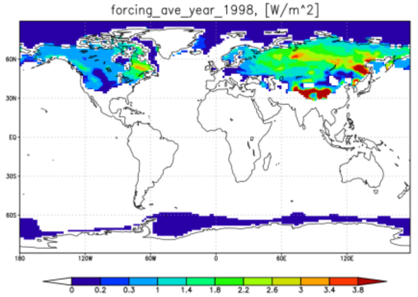

Fig. 2 *Average annual radiation forcing for 1998*

Assessment of additional RF due to forest fires

Since anthropogenic emissions of black carbon significantly exceed emissions resulting from biomass burning, two seasons that differ in the intensity of forest fires were chosen to study the role of forest fires in the radiation balance. Based on GFED [4], 1998 and 2001 were chosen as such seasons (which corresponds to large and small emissions of BC at mid-latitudes into the atmosphere as a result of biomass burning, respectively). Moreover, it is known that the anthropogenic source for the specified period has changed slightly.

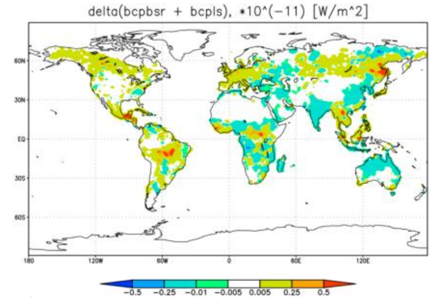

Fig. 3 *Difference between BC emissions from biomass burning in 1998 and 2001, according to the INMCM5 model*

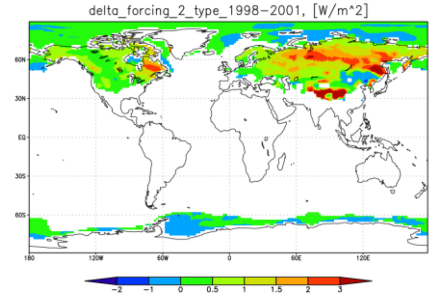

Fig. 4 *The difference between the average annual radiation forcing for 1998 and 2001*

Summary

Based on the obtained technology for calculating radiation forcing, an estimate of additional forcing from forest fires is obtained. It is locally 2-3 W/m^2 with a relative estimation error of the order of 10-15%, which is comparable to radiation forcing in general. Moreover, it is worth noting that the results of calculations of the average annual radiation forcing are in good agreement with [2], [5].

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