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Methane emissions from wildfires in Siberia caused by the atmospheric blocking in the summertime

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ABSTRACT

It is shown that in the Siberian region the most intense fires are associated with atmospheric blocking (blocks), as well as the processes of Rossby waves breaking (RWB). Blocks and RWB in Siberia and Russian Far East in summertime both cause high temperatures, low humidity, and the decrease of clouds. Methane emissions from wildfires in Western Siberia during periods of atmospheric blocking are studied based on the Global Fire Assimilation System (GFAS) and the Global Fire Emissions Database (GFED). Both datasets have shown a sharp increase in methane emissions during or a few days after blocks. Methane emissions associated with blocks are higher according to GFAS data, compared to GFED. Even though for both datasets, there are problems with the correction of cloudiness, for GFAS, the problem of identification and correction of hot spot associated with gas flaring is probably more significant.

Keywords: natural fires, wildfires, atmospheric blocking, methane emissions, GFAS, GFED

1. INTRODUCTION

Wildfires have a significant impact on ecosystems, as well as on the composition of the atmosphere [1-5]. Forest fires emit large amounts of gaseous and particulate pollutants into the atmosphere, including carbon dioxide (CO_2) carbon monoxide (CO), methane (CH4), nitrogen oxides (NOx), ammonia (NH_3), particulate matter (PM), nonmethane hydrocarbon (NMHC), and other chemical species [3]. Thus, wildfires, directly affecting the quality of atmospheric air, also have a significant impact on the feedback between the climate and the biosphere, by increasing greenhouse gases and aerosols [2]. Large wildfires reduce atmospheric carbon sinks due to reduced biomass. At the same time, due to fires, forests are transformed into carbon sources due to direct emissions from biomass combustion (from 40.0 to 130.0 Mt per year) and indirect effects of fires on thermal and water regimes, as well as on the structure and functioning of ecosystems [1].

The forests of Siberia, which are part of the boreal zone of the Northern Hemisphere, have been increasingly exposed to strong fires in recent decades [6]. According to estimates [6], forest fires in Eastern Siberia dominate in Russia, and in total, fires in Western and Eastern Siberia account for more than half (55%) of forest fires throughout the boreal zone. According to estimation for Siberia [7] the total direct carbon emissions range from the traditional scenario estimate of 116 Tg C in 1999 (6.9 M ha burned) to the extreme scenario estimate of 520 Tg C in 2002 (11.2 M ha burned), which are equivalent to 5 and 20%, respectively, of total global carbon emissions from forest and grassland burning.

Fires in Siberia and the Far East occur every summer season, but in some periods they become catastrophic. The strongest fires occurred in 1998 [7,8], 2002 [7,9,10], 2003 [1,10], 2012 [1,9,11-14], 2014 [15], 2016 [16-18]. Despite numerous studies of the effects of fires on ecosystems and atmospheric composition, at present there are not a lot of works that explore the reason of the fires in Siberia [13,17-18], mainly the authors draw attention to two cases of 2012 and 2016. However, already based on existing works, it can be concluded that the most extreme events are accompanied by atmospheric blocking [13,17-18].

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The frequency of forest fires in Siberia is most closely related to incoming solar radiation (SR) (correlation coefficient of 0.9) [19]. The SR in mid-latitudes strongly depend on the type of atmospheric circulation, and the highest SR values occur during periods of the predominance of large anticyclones. The predominance of anticyclone for blocking processes of temperate latitudes is most typical. Barotropic anticyclones are most characteristic of blocking formations. Due to the stable stratification in the anticyclone, cloudiness decreases. Over Asia, these processes have a maximum in the summer period. Therefore, we have assumed that blocking is a good candidate for one of the main reasons for the increase in the number of extreme fires.

Our work aims to study the effect of atmospheric blocking on the occurrence of forest fires in Siberia; the focus will be on the western regions. In addition to the fact of blocking, we are investigating the conditions for Rossby waves breaking (RWB) preceding blocking. Given the increased risk of large fires [20], such studies are relevant.

2. METHOD AND DATA

2.1 Atmospheric blocking and Rossby wave

Atmospheric data used in this study are from the European Centre for Medium-Range Weather Forecasts ECMWF Era-Interim [21]. The spatial and temporal resolution is 2.5×2.5 and 12 UTC.

There are several ways to define blocking. They are reviewed in detail in [22]. We use the blocking index algorithm as in [22]:

$$GHGS = \frac{Z(\varphi_0) - Z(\varphi_s)}{\varphi_0 - \varphi_s}, \tag{1}$$

$$GHGN = \frac{Z(\varphi_n) - Z(\varphi_0)}{\varphi_n - \varphi_0}, \tag{2}$$

where Z is the 500 hPa geopotential height, φ_n = 80°N±Δ, φ_0 = 60°N±Δ, φs = 40°N±Δ , Δ = −5°, −2.5°, 0°, 2.5° or 5°. The 500 hPa geopotential height gradients (GHG) north and south (GHGN and GHGS, respectively) of (φ_0) latitude are computed.

This algorithm is based on the GHGS criterion proposed in [23]. The criterion was further supplemented by [24,22]. Authors [24] have imposed the GHGN gradient to exclude cutoff lows, whereas [22] used the five values of the Δ as given above, instead of only −4°, 0°, and 4° as suggested by [24].

The situation when GHGS>0, GHGN<10 m/deg lat is referred to as blocking. A longitude is considered blocked when both GHGN and GHGS satisfy these conditions for at least one of the five Δ values.

In fig. 1 are shown the time-longitude cross-section of blocking frequency (BF) according to the criteria GHGS/GHGN. The blocking frequency for the more specific area was calculated as follows. Siberia was divided into two longitudinal intervals 50°-80°E (the Urals - Western Siberia, U-WS), 80°-110°E (Eastern Siberia -, ES), 110°-130°E (Russian Far East, RFE). Let us note that according to [25] in 80°-120°E longitudinal interval, there is the climatic minimum of blocking frequency in summer-time, and the authors of [25] did not represent blocking index for it. So, we calculated the blocking frequency in this longitudinal interval, too, and included in our study. Accordingly, despite its low frequency, ES-blocking may play an important role in forest fire formation. Then, for each of three intervals at each longitude within it, we calculated GHGS and GHGN indices (formulas 1 and 2) and checked whether the blocking conditions were met for each day in each July from 1979 to 2016. Finally, in each longitudinal interval, we summed up the number of points (longitude×time), where the blocking conditions were fulfilled, and obtained blocking frequency for each summer month (June, July, August) of each year.

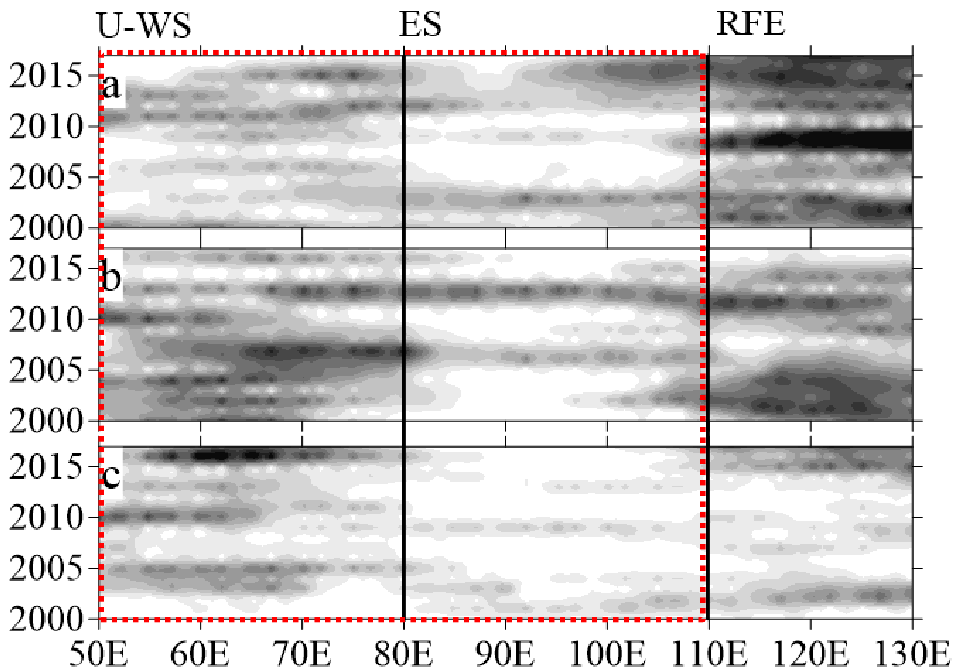


Figure 1. The time-longitude diagram of BF.

For analysis blocking events in this work, we used the blocking periods obtained in [13] for 2005-2013. To clarify the period and position of blocking events, we use a GHGS (geopotential height – gradient south). We use GHGS with the fix blocking latitude (φ_{fix}) and flexible blocking latitude (φ_{flex}) according to [26]. The flexible latitude was used only for some of the periods. The GHGS criterion was used to determining blocking dates in 2016. For clarifying the blocking dates, we also used the potential temperature on the dynamic tropopause (PV–θ). According to [27,28] PV–θ is a very good candidate to study the development of blocking as it is materially conserved in time, providing an excellent tracer for the air masses contributing to blocking formation, and can be inverted to give the balanced composition of the flow. Also, the reversal of the meridional gradient PV–θ is associated with Rossby wave-breaking [28]. The determined blocking dates are shown in table 1.

Table 1. The blocking dates for summer period with the maxima blocking frequency in Western Siberia.

Y,m	longitude, latitude	Block, data	Y,m	longitude, latitude	Block, data
2005/7	75E, 70-50N* 75E, 60-40N**	22-28 July 22-28 July	2011/06	75E, 70-50N 75E, 60-40N	1-5 July 3 July
2006/7	70E, 70-50N 70E, 60-40N	10-16 July 10-17 July	2012/6-7	75E, 60-40N	9-16, 21-26 June, 1-5, 18-22 July
2007/7	75E, 70-50N 75E, 60-40N	28 June-7 July, 12-16 July 2-7 July, 12-16 July	2013/7-8	75E, 70-50N 75E, 60-40N	16-25 July 16-28 July
2010/7-8	65E, 60-40N	26 July- 6 Aug	2016/7	75E, 70-50N 75E, 60-40N	14-22 July 17-22 July

* flex lat, ** fix lat

2.2 Fire intensity data sets

The choice of methane (CH_4) as an indicator of fire intensity was made for two reasons. First, methane is the main product resulting from combustion along with CO and CO_2. CH_4 is a long-lived gas, which is well traced even in transformed smoke plumes [29]. Secondly, the need for assessments of the contribution of methane, including from fires, increases [30-33].

Several global fire emission databases have been developed in recent years: FLAMBE (Fire Locating and Modeling of Burning Emissions), GFED (Global Fire Emissions Database), FINN (Fire INventory from NCAR), QFED (Quick Fire Emission Dataset), IS4FIRES and GFAS (Global Fire Assimilation System). All of these products rely on satellite observations of fire radiative power (FRP), hot spots, or burnt areas because they alone provide sufficient spatial coverage and temporal sampling frequency [34]. We used daily data of methane emission are from GFED (Global Fire Emissions Database) [35, available at https://www.globalfiredata.org/] and CAMS GFAS (Global Fire Assimilation System) [36, available at https://apps.ecmwf.int/datasets/data/cams-gfas/]. The Global Fire Assimilation System (GFASv1.0) calculates biomass burning emissions (BBE) by assimilating Fire Radiative Power (FRP) observations from the MODIS instruments onboard the Terra and Aqua satellites (resolution 0.1×0.1). The Global Fire Emissions Database (GFED4) calculated emission by burned area from the MODIS.

2.3 Other methods

The Pearson correlation analysis (PCC) is used for data interpretation. The PCC is usually used to measure the degree of the linear relationship between two variables. The correlation will be noted when the statistical significance is equal to or exceeds the 95% confidence level. We correlated the BF for WS-U, ES, RFE and surface solar radiation downwards (SSRD) for 2000-2018. As noted [19], the SSRD is most closely related to wildfires.

3. RESULTS

3.1 The linkage between the BF and SSRD

Fig. 2 shows the coefficients for the U-WS, ES, and SSRD (for RFE the correlation is not shown). All blocking occurring in the region of 50-130°E has a significant impact on the SSRD so they can influence the occurrence of fires. It can be seen that the closest relationship between incoming solar radiation is observed with blocks occurring in the sector of 80-110° E. It can be noted that the region of maximum correlations is located in the region of the maximum distribution of pine forests [19]. It can be assumed that the most important for fires in Siberia are blocking, formed by breaking the ridge from Western to Eastern Siberia. In confirmation of the assumption about the connection of the configuration of blocking and the occurrence of fires on fig. 3 shows an example of the dynamics of the ridge in Siberia. Well, it can be seen that the maximum methane emissions from fires are starting to observe at the time of the eastward moving the Western Siberia's ridge.

3.2 The linkage between the blocking events and forest fire in Western Siberia

Figure 3 shows the variability of methane emissions from two databases for summer periods, during which the blocking of more than five days was observed over western Siberia (table 1). The emissions were summarized over the territory, taking into account the cell areas. It can be seen that in summer periods with blockings, methane emissions from fires increase significantly relative to background summer values. GFAS data shows higher values than GFED data. Thus, it can be concluded that the results of applying the algorithm based on the radiating power of fires as compared with the algorithm for burnt areas show higher emissions of gases and aerosols. For assimilating with GFAS, there is, however, the problem of eliminating the hot spots associated with gas flaring. Fig. 5 shows the methane emission from fuel exploitation based on the EDGAR database and photo of gas flares. The radiating power of the gas flares in conditions of a cloudless sky accompanied to the blocking anticyclone is sufficient to be interpreted as a fire, besides the area of oil fields in the western Siberia is very extensive (fig. 5).

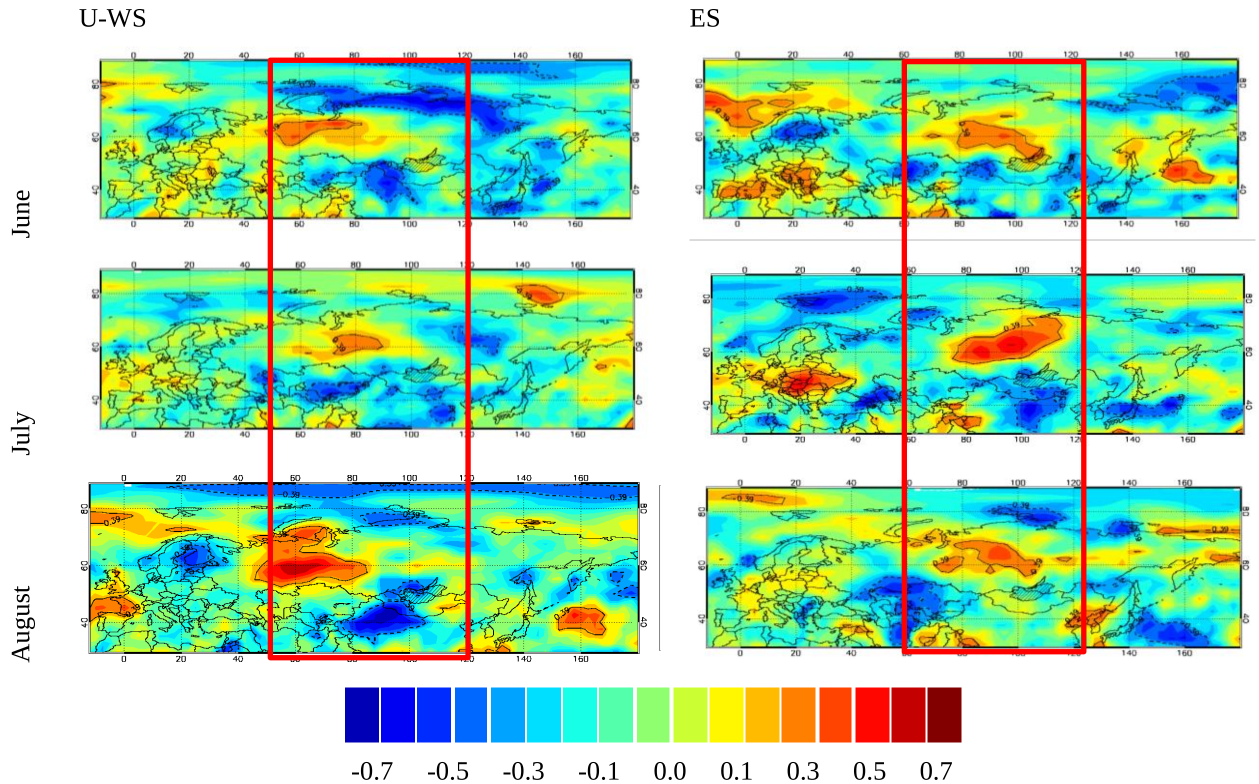


Figure. 2. The coefficient of correlation of BI for U-WS and ES and surface solar radiation downwards (SSRD) for 2000-2018 (JJA). The red boxes show the Siberia region, 95% significant level (solid line for positive correlation, dotted-for negative).

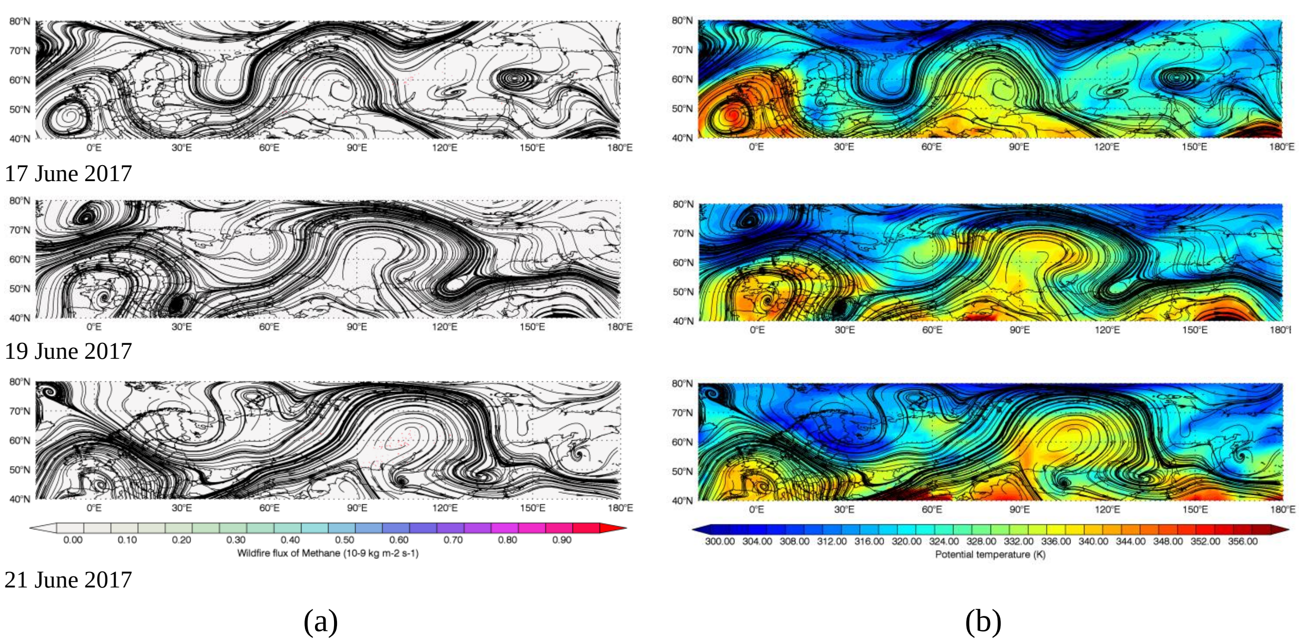


Figure. 3. Methane emission and streamflow at 500 hPa (a) and PV-Θ and streamflow at 500 hPa (b) for 17, 19, 21 June 2017.

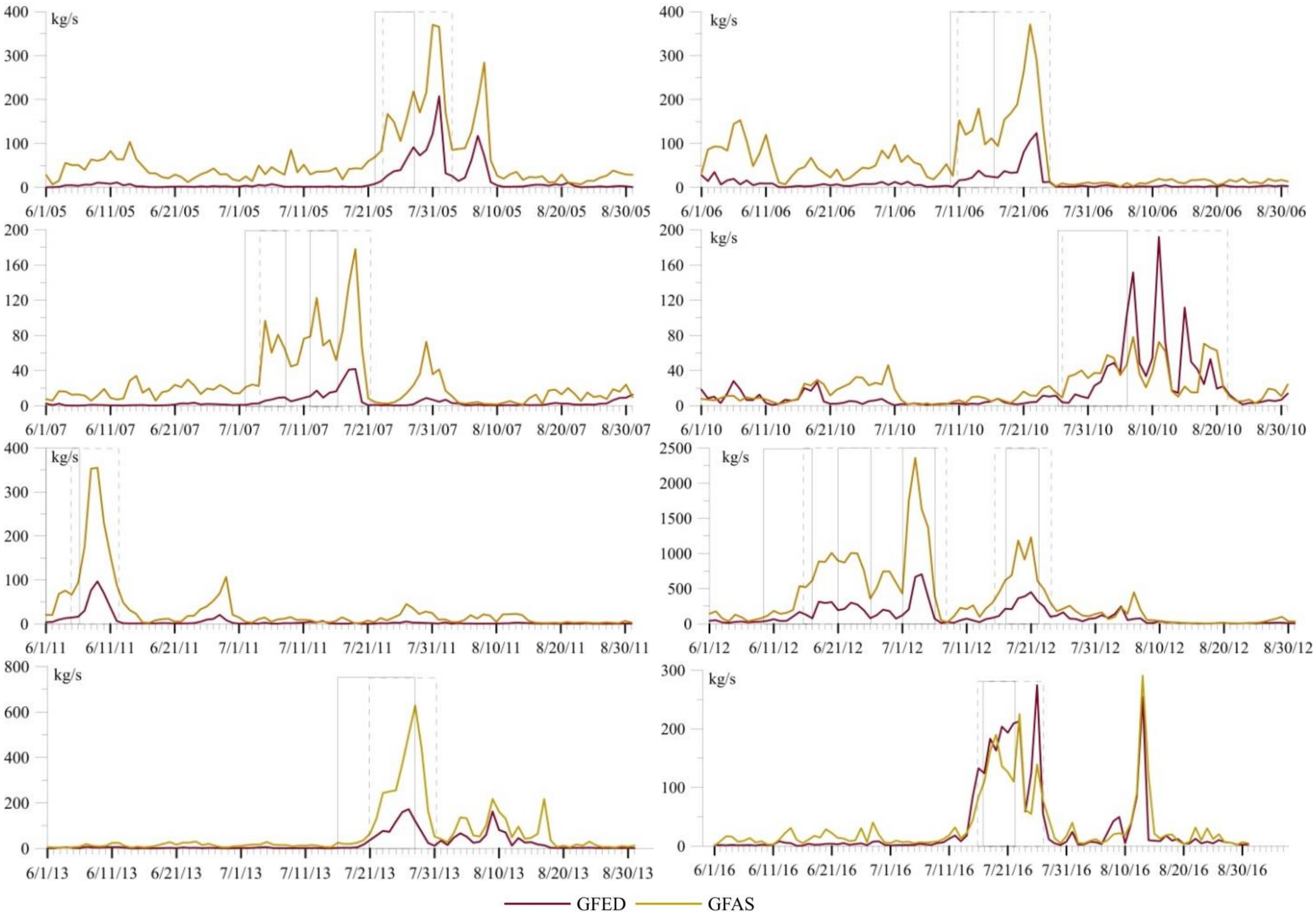
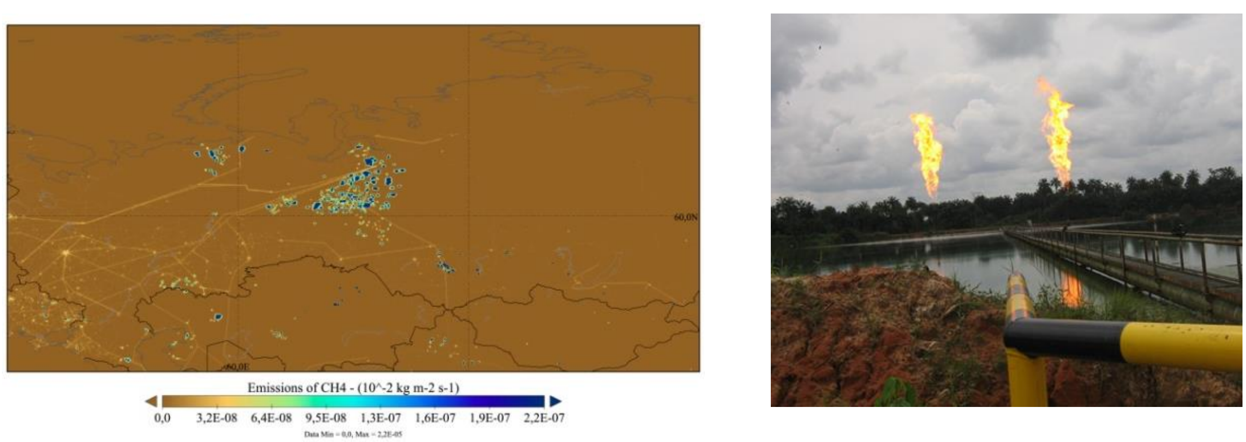


Figure. 4. Total biomass burning emission during different summer seasons according to GFED and GFAS for 50-70N, 60-90E.



a

b

Figure. 5. Methane emission from Fuel exploitation. The Emissions Database for Global Atmospheric Research (EDGAR) [http://edgar.jrc.ec.europa.eu/htap.php] (a) and photo of gas flares (https://en.wikipedia.org/wiki/Gas_flare)

4. CONCLUSION AND DISCUSSIONS

The linkage between the atmospheric blocking phenomenon and forest fire and Siberia was discovered. For blocking identification, the criteria proposed [22-24] was used. PV-Ɵ was applied for RWB analysis accompanied the blocking formation. For analysis, a forest fire, we used two data sets of the methane emission from biomass burning.

It is shown that in the Siberian region, the most intense fires are associated with atmospheric blocking (blocks), as well as the processes of Rossby waves breaking (RWB). Blocks and RWB both cause high temperatures, low perceptible water, and the decrease of clouds. Methane emissions from wildfires in Western Siberia during periods of atmospheric blocking are studied based on the Global Fire Assimilation System (GFAS) and the Global Fire Emissions Database (GFED). Both data sets have shown a sharp increase in methane emissions during or a few days after blocks. Methane emissions associated with blocks are higher according to GFAS data, compared to GFED. Even though for both data sets, there are problems with the correction of cloudiness, for GFAS, the problem of identification and correction of oil field plumes is probably more significant.

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REFERENCES

[1] Bondur, V. G., “Satellite monitoring of trace gas and aerosol emissions during wildfires in Russia,” Izvestiya, Atmospheric and Oceanic Physics 52(9), 1078–1091 (2016).

[2] Bowman, D. M. J. S., Balch, J. K., Artaxo, P., Bond, W. J., Carlson, J. M., Cochrane, M. A., D'antonio, C. M., Defries, R. S., Doyle, J. C., et al., “Fire in the Earth System,” Science 324(5926), 481–484 (2009).

[3] Crutzen, P. J., Andreae, M. O., “Biomass Burning in the Tropics: Impact on Atmospheric Chemistry and Biogeochemical Cycles,” Science 250(4988), 1669–1678 (1990).

[4] Flannigan, M., Stocks, B., Turetsky, M., Wotton, M., “Impacts of climate change on fire activity and fire management in the circumboreal forest,” Global Change Biology 15(3), 549–560 (2009).

[5] Shvidenko, A. Z., Shchepashchenko, D. G., Vaganov, E. A., Sukhinin, A. I., Maksyutov, S. S., Mccallum, I., Lakyda, I. P., “Impact of wildfire in Russia between 1998–2010 on ecosystems and the global carbon budget,” Doklady Earth Sciences 441(2), 1678–1682 (2011).

[6] Sitnov, S.A., Mokhov, I.I. “Comparative analysis of the characteristics of fires in boreal forests of Eurasia and North America using satellite data,” Earth exploration from space 2, 21-37 (2018). (In Russian with English abstract).

[7] Soja, A. J., “Estimating fire emissions and disparities in boreal Siberia (1998–2002),” Journal of Geophysical Research 109(D14) (2004).

[8] Kasischke, E. S., Bruhwiler, L. P., “Emissions of carbon dioxide, carbon monoxide, and methane from boreal forest fires in 1998,” Journal of Geophysical Research 108(D1) (2002).

[9] Tomshin, O. A., Solovyev, V. S., “Study of variations in parameters of atmospheric aerosol due to large-scale forest fires in Central Yakutia (2002),” Atmospheric and Oceanic Optics 28(1), 95–99 (2015).

[10] Vasileva, A., Moiseenko, K., “Methane emissions from 2000 to 2011 wildfires in Northeast Eurasia estimated with MODIS burned area data,” Atmospheric Environment 71, 115–121 (2013).

[11] Vinogradova, A. A., Smirnov, N. S., Korotkov, V. N., “Anomalous wildfires in 2010 and 2012 on the territory of Russia and supply of black carbon to the Arctic,” Atmospheric and Oceanic Optics 29(6), 545–550 (2016).

[12] Zhuravleva, T. B., Kabanov, D. M., Nasrtdinov, I. M., Russkova, T. V., Sakerin, S. M., Smirnov, A., Holben, B. N., “Radiative characteristics of aerosol during extreme fire event over Siberia in summer 2012,” Atmospheric Measurement Techniques 10(1), 179–198 (2017).

[13] Antokhin P.N., Antokhina O.Yu., Arshinov M.Yu., Belan B.D., Davydov D.K., Sklyadneva T.K., Fofonov A.V., Sasakawa M., Machida T Impact of atmospheric blocking in Western Siberia on the change in methane concentration in the summer period 2017 Optics of the Atmosphere and Ocean 30(5) 393-403

[14] Antokhin, P. N., Arshinova, V. G., Arshinov, M. Y., Belan, B. D., Belan, S. B., Davydov, D. K., Ivlev, G. A., Fofonov, A. V., Kozlov, A. V., et al., “Distribution of Trace Gases and Aerosols in the Troposphere Over Siberia During Wildfires of Summer 2012,” J. Geophysical Research: Atmospheres 123(4), 2285–2297 (2018).

[15] Jung, J., Lyu, Y., Lee, M., Hwang, T., Lee, S., Oh, S., "Impact of Siberian forest fires on the atmosphere over the Korean Peninsula during summer 2014," Atmospheric Chemistry and Physics 16(11), 6757–6770 (2016).
[16] Sitnov, S. A., Mokhov, I. I., "Anomalies in the Atmospheric Methane Content over Northern Eurasia in the Summer of 2016," Doklady Earth Sciences 480(1), 637–641 (2018).
[17] Sitnov, S. A., Mokhov, I. I., Gorchakov, G. I., "The link between smoke blanketing of European Russia in summer 2016, Siberian wildfires and anomalies of large-scale atmospheric circulation," Doklady Earth Sciences 472(2), 190–195 (2017).
[18] Semoutnikova, E. G., Gorchakov, G. I., Sitnov, S. A., Kopeikin, V. M., Karpov, A. V., Gorchakova, I. A., Ponomareva, T. Y., Isakov, A. A., Gushchin, R. A., et al., "Siberian Smoke Haze over European Territory of Russia in July 2016: Atmospheric Pollution and Radiative Effects," Atmospheric and Oceanic Optics 31(2), 171–180 (2018).
[19] Ponomarev, E., Kharuk, V., Ranson, K., "Wildfires Dynamics in Siberian Larch Forests," Forests 7(12), 125 (2016).
[20] Mokhov, I. I., Chernokulsky, A. V., Shkolnik, I. M., "Regional model assessments of fire risks under global climate changes," Doklady Earth Sciences 411(2), 1485–1488 (2006).
[21] Dee, D. P., Uppala, S. M., Simmons, A. J., Berrisford, P., Poli, P., Kobayashi, S., Andrae, U., Balmaseda, M. A., Balsamo, G., et al., "The ERA-Interim reanalysis: configuration and performance of the data assimilation system," Quarterly Journal of the Royal Meteorological Society 137(656), 553–597 (2011).
[22] Barriopedro, D., García-Herrera, R., Lupo, A. R., Hernández, E., "A Climatology of Northern Hemisphere Blocking," Journal of Climate 19(6), 1042–1063 (2006).
[23] Lejenäs, H., Økland, H., "Characteristics of northern hemisphere blocking as determined from a long time series of observational data," Tellus A 35A(5), 350–362 (1983).
[24] Tibaldi, S., Molteni, F., "On the operational predictability of blocking," Tellus A 42(3), 343–365 (1990).
[25] Park, Y.-J., Ahn, J.-B., "Characteristics of atmospheric circulation over East Asia associated with summer blocking," Journal of Geophysical Research: Atmospheres 119(2), 726–738 (2014).
[26] Pelly, J. L., Hoskins, B. J., "A New Perspective on Blocking," Journal of the Atmospheric Sciences 60(5), 743–755 (2003).
[27] Hoskins, B. J., "Towards a PV-θ view of the general circulation," Tellus B: Chemical and Physical Meteorology 43(4), 27–35 (1991).
[28] Masato, G., Hoskins, B. J., Woollings, T. J., "Wave-breaking characteristics of midlatitudes blocking," Quarterly Journal of the Royal Meteorological Society 138(666), 1285–1296 (2011).
[29] Urbanski, S. P., Hao, W. M., Baker, S., "Chapter 4 Chemical Composition of Wildland Fire Emissions," Wildland Fires and Air Pollution Developments in Environmental Science, 79–107 (2008).
[30] Bousquet, P., Ciais, P., Miller, J. B., Dlugokencky, E. J., Hauglustaine, D. A., Prigent, C., Werf, G. R. V. D., Peylin, P., Brunke, E.-G., et al., "Contribution of anthropogenic and natural sources to atmospheric methane variability," Nature 443(7110), 439–443 (2006).
[31] Sasakawa, M., Ito, A., Machida, T., Tsuda, N., Niwa, Y., Davydov, D., Fofonov, A., Arshinov, M., "Annual variation of CH4 emissions from the middle taiga in West Siberian Lowland (2005–2009): a case of high CH4 flux and precipitation rate in the summer of 2007," Tellus B: Chemical and Physical Meteorology 64(1), 17514 (2012).
[32] Dlugokencky, E. J., Bruhwiler, L., White, J. W. C., Emmons, L. K., Novelli, P. C., Montzka, S. A., Masarie, K. A., Lang, P. M., Crotwell, A. M., et al., "Observational constraints on recent increases in the atmospheric CH4burden," Geophysical Research Letters 36(18) (2009).
[33] Nisbet, E. G., Dlugokencky, E. J., Bousquet, P., "Methane on the Rise--Again," Science 343(6170), 493–495 (2014).
[34] Rémy, S., Veira, A., Paugam, R., Sofiev, M., Kaiser, J. W., Marenco, F., Burton, S. P., Benedetti, A., Engelen, R. J., et al., "Two global data sets of daily fire emission injection heights since 2003," Atmospheric Chemistry and Physics 17(4), 2921–2942 (2017).
[35] Giglio, L., Randerson, J. T., Werf, G. R. V. D., "Analysis of daily, monthly, and annual burned area using the fourth-generation global fire emissions database (GFED4)," Journal of Geophysical Research: Biogeosciences 118(1), 317–328 (2013).
[36] Kaiser, J. W., Heil, A., Andreae, M. O., Benedetti, A., Chubarova, N., Jones, L., Morcrette, J.-J., Razinger, M., Schultz, M. G., et al., "Biomass burning emissions estimated with a global fire assimilation system based on observed fire radiative power," Biogeosciences Discussions 8(4), 7339–7398 (2011).