Heat fluxes during the spring thermal bar in Lake Dolgoe, Belarus

Bair Tsydenov[1*], *Nikita* Trunov[1], *Dmitriy* Degi[1], and *Andrey* Bart[1]

[1]Tomsk State University, 36, Lenin Avenue, Tomsk, 634050, Russian Federation

Abstract. The values for short- and longwave radiation, latent and sensible heat fluxes were calculated for the spring thermal bar in Lake Dolgoe. A thermal bar phenomenon is a narrow zone of waters sinking in the area of temperature of maximum density. The calculations are based on meteorological data from stations in Sharkawshchyna, Polotsk and Lepel (44 km NW, 46 km NE, and 48 km SE of the lake, respectively). A comparative analysis was conducted for heat fluxes in April 2023. Maximum, minimum, and mean values of fluxes of short- and longwave radiation and latent and sensible heat were obtained.

1 Introduction

Livestock farm activity on the coast of Lake Dolgoe, Belarus, in the end of 1970s led to a considerable decline in the lake environmental state. Untreated wastewater discharge with high levels of nutrients increased water turbidity in the lake and massive microalgae bloom. The environmental condition of the lake in present is characterized by intensive inorganic nutrients input from agricultural lands in the lake drainage basin. Anthropogenic impact on the ecosystem of Lake Dolgoe may result in the reorganisation of the trophic structure of biocoenosis, extinction of rare flora and fauna (whitefish-smelt ichthyofauna, as well as Ice Age relics), and drastic deterioration of sanitary-hygiene water quality.

One of the natural phenomena influencing environmental conditions of a body of water is the thermal bar [1-2]. It appears in lakes of moderate latitudes in spring and autumn and is a narrow zone of waters sinking in the area of temperature of maximum density [3-4]. The thermal bar is formed in the littoral part of a lake and it is destroyed in its central part. The development of spring (autumn) thermal bar is driven by heating (cooling) of lake waters. In spring and autumn the environmental state of lakes in moderate latitudes directly depends of the thermal bar activity. It creates a barrier for horizontal heat exchange, thus forming temperature differences in isolated areas – thermoactive in the littoral zone and thermoinert in the pelagic zone [5].

The aim of this work is to compare and analyze heat fluxes calculated on the basis of meteorological data from stations in Sharkawshchyna, Polotsk, and Lepel during the thermal bar presence in Lake Dolgoe.

[*] Corresponding author: tsydenov@math.tsu.ru

2 Materials and methods

For the calculations of short- ($H_{Ssol,0}$) and (H_{lw}) longwave radiation, latent (H_L) and sensible (H_S) heat the following formulas were used [6-7]:

$$H_{Ssol,0} = \begin{cases} S_0 \cdot \left(a_g - a_w\right) \cdot \cos\zeta \left[a(C) + b(C) \ln(\cos\zeta)\right], & \cos\zeta > 0; \\ 0, & \cos\zeta \le 0, \end{cases} \tag{1}$$

Where S_0 is solar constant (≈*1367* W/m^2); ζ – solar zenith angle; $a(C)$, $b(C)$, a_g, a_w – empirical coefficients and function depending on the atmospheric parameters [8-9];

$$H_{lw} = \varepsilon_w \varepsilon_a \sigma \left(1 + 0.17C^2\right) T_A^4 - \varepsilon_w \sigma T^4 \tag{2}$$

Where T and T_A are water and air temperatures, respectively; ε_w and ε_a are radiation coefficients of water and atmosphere, respectively; C is cloudiness; σ is the Stefan-Boltzmann coefficient (=5.669×10^{-8} W/m^2/K^4);

$$H_L = f_u \left(e_A - e_w\right) \tag{3}$$

Where f_u is the mass transfer coefficient; e_A and e_w are water vapour pressure in the atmosphere and saturated water vapour pressure, respectively;

$$H_S = \beta \cdot f_u \left(T_A - T\right) \tag{4}$$

Where β is the Bowen ratio (=*0.62* hPa/K).

Atmospheric parameters (air temperature, relative humidity, atmospheric pressure, cloudiness, wind speed and direction) in the calculations were taken according to the meteorological data recorded at stations in Sharkawshchyna, Polotsk, and Lepel with a 3-hour time-step (Figure 1) in April 2023 [10].

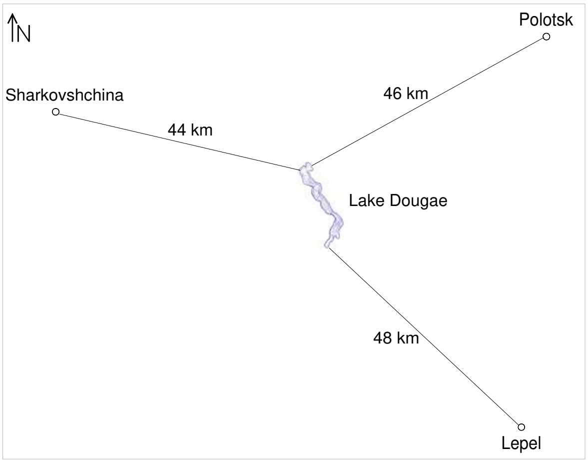

Fig. 1. Location of meteorological stations relative to Lake Dolgoe.

3 Results and Discussion

The meteorological data from stations in Sharkawshchyna, Polotsk, and Lepel, recorded in April 2023, regarding air temperature (Figure 2, a) mostly match or differ insignificantly, with a few exceptions related to sharp air temperature variations throughout a day. The air temperature varies from -2°C to 19°C.

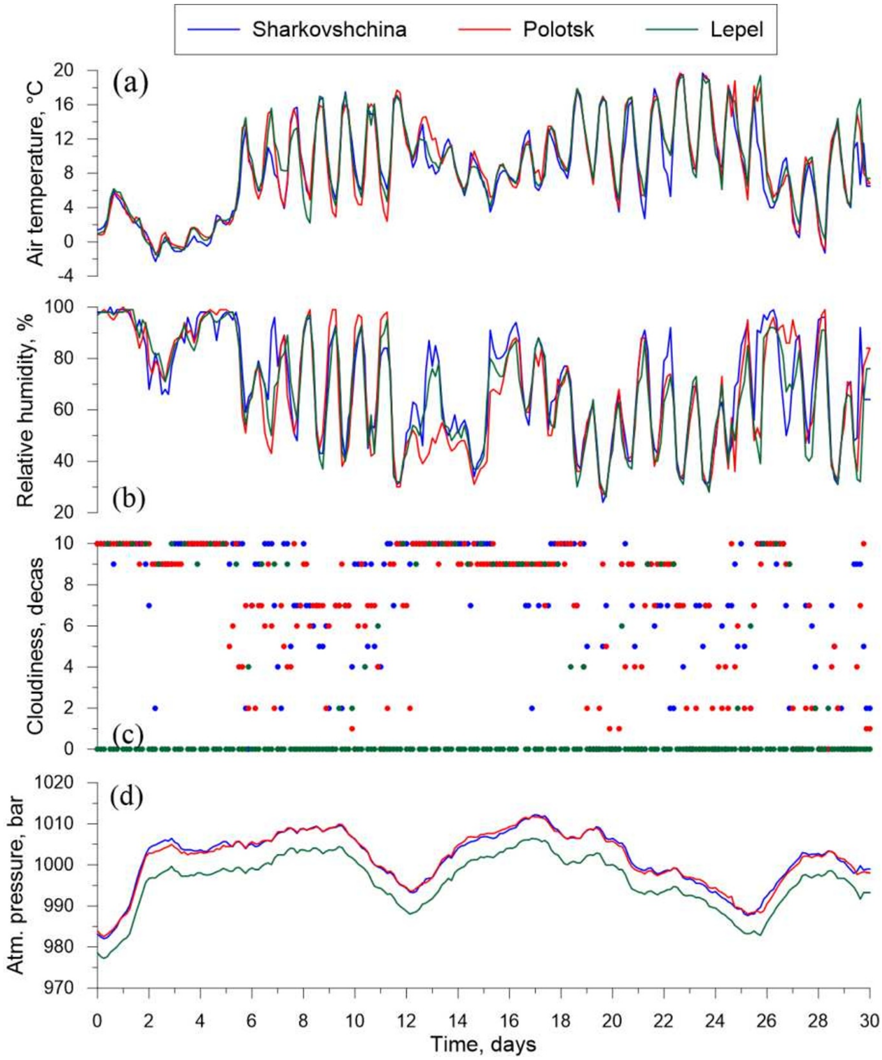

Fig. 2. Air temperature (a), relative humidity (b), cloudiness (c), and atmospheric pressure (d) in April 2023.

The relative air humidity data (Figure 2, b) are also similar, although some peaks were not registered in Polotsk stations. On days 13-14, the difference in peak values of relative air humidity between Polotsk and Sharkawshchyna was 30%, on day 15 - 25%, while minimum values of relative air humidity differed by 35% on day 27. According to the data from all stations, relative air humidity in this period varied from 25% to 100%. Cloudiness data (Figure 2, c) from stations in Sharkawshchyna and Polotsk are mostly similar, while there are not enough data from the stations in Lepel regarding this parameter (the data is absent for 0, 3, 6, 12, 15, and 18 h). However, it is clear that the Lepel station recorded lower values of cloudiness in general. All stations registered high cloudiness (9-10 points) on days 1-5, 13-18 and 10 points on day 27. In the last 10 days of April 2023 cloudiness went down. Air pressure data (Figure 2, d) are very similar for stations in Sharkawshchyna and Polotsk, and the data values from the Lepel station are 5-10 hPa lower. Atmospheric pressure varies from 982 hPa to 1012 hPa in Sharkawshchyna and Polotsk and from 977 to 1004 hPa in Lepel.

Wind direction data in April 2023 from the three stations (Figure 3) are very different under light wind (0-2 m/sec), but under moderate wind (4-6 m/sec) the difference does not exceed 22.5 degrees. All stations recorded prevailing N and NNW winds of different intensity (4-6 m/sec) on days 2-5, ENE or similarly directed winds (below 6 m/sec) on days 6-15, NE wind (below 4 m/sec) on days 18-20, S wind (below 5 m/sec) on days 23-24, and WNW wind (below 4 m/sec) on days 27-28.

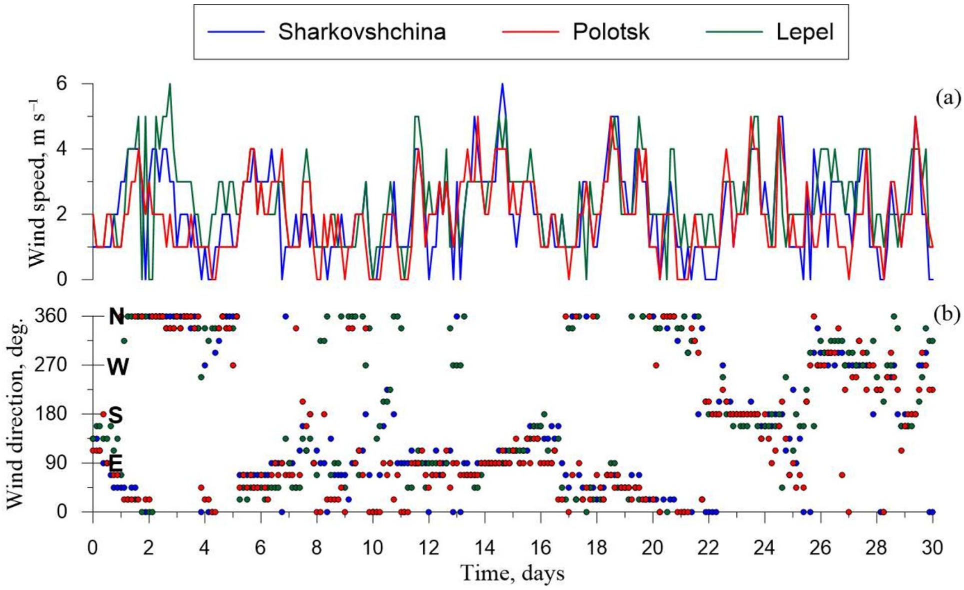

Fig. 3. Wind speed (a) and direction (b) in April 2023.

The calculated values of latent and sensible heat fluxes in April 2023, according to the meteorological data from the stations in Sharkawshchyna, Polotsk, and Lepel, are very close (Figure 4, a, b). The greatest difference is observed on day 13-14 due to the variations in air temperature and relative humidity in Polotsk (latent and sensible heat flux difference was 50 and 15 W/m^2, respectively). Longwave radiation values in the considered stations (Figure 4, c) vary much more, and the mean value from the Lepel station is much lower than in the other two stations throughout the entire April 2023 (Table 1).

Shortwave radiation values (Figure 4, d), calculated from the Lepel station data, also vary considerably: diurnal peaks grow during April very gradually, unlike diurnal peaks in other stations. It is related to the absence of cloudiness measurements for 0, 3, 6, 12, 15, and 18 h on the Lepel station (cloudiness values for these points were taken as zero during calculations).

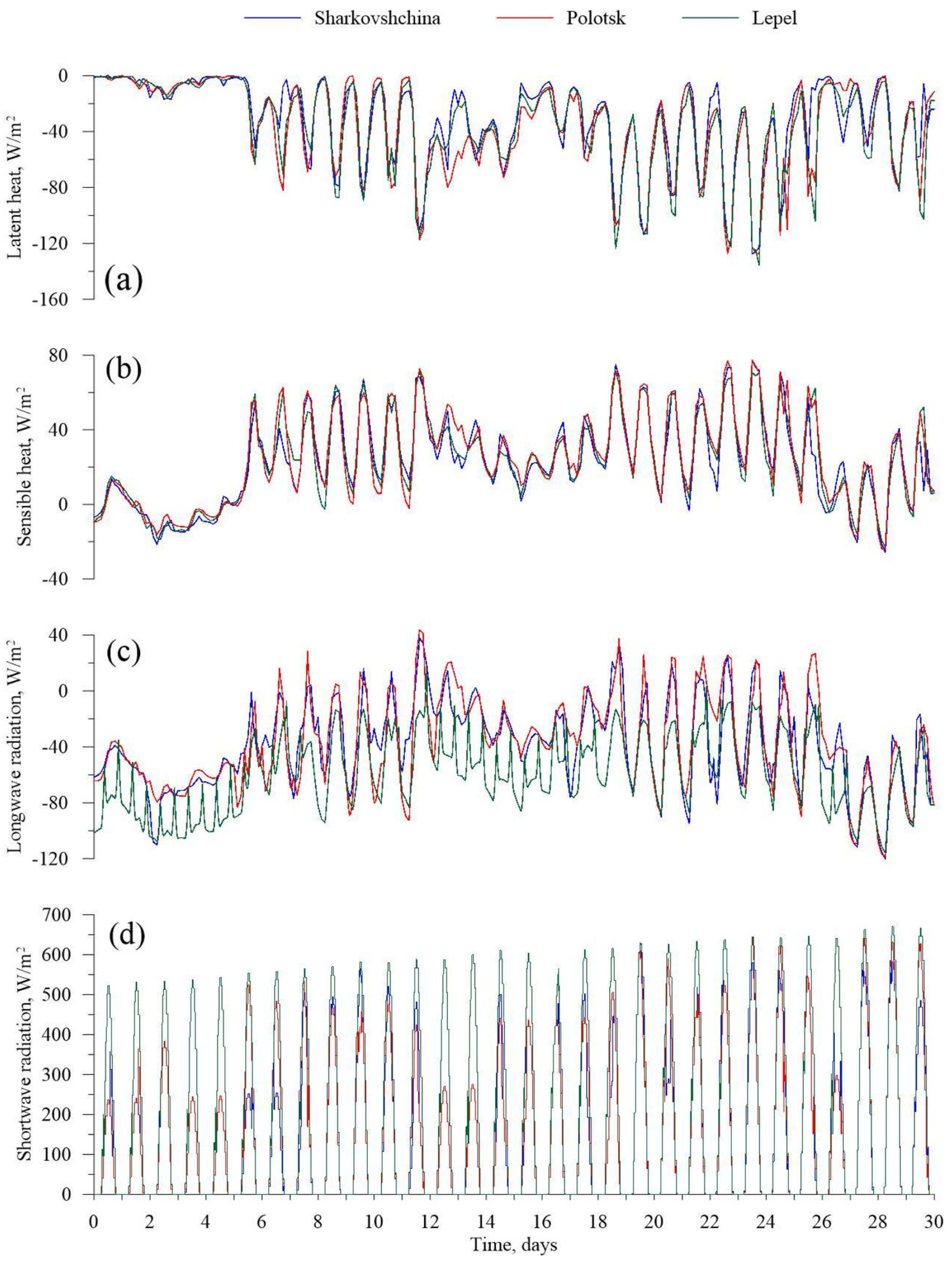

Fig. 4. Calculated vales for latent (a) and sensible (b) heat fluxes, long-(c) and shortwave (d) radiation in April 2023 according to the meteorological data from the stations in Sharkawshchyna, Polotsk, and Lepel.

The obtained maximum, minimum, and mean values of heat fluxes are presented in Table 1.

Table 1. Maximum, minimum, and mean values of heat fluxes in April 2023 according the meteorological data from Sharkawshchyna, Polotsk, and Lepel stations.

	Weather station	Heat fluxes, W/m^2			
		Shortwave radiation	Longwave radiation	Sensible heat	Laten t heat
Minimum	Sharkovshchina	0	-120.1	-25.6	-127.3
	Polotsk	0	-118.4	-24.1	-127.5
	Lepel	0	-115.8	-22.7	-135.5
Maximum	Sharkovshchina	628.4	37.7	77.3	0
	Polotsk	644.3	43.6	77.2	0
	Lepel	670.2	15.8	71.6	-0.6
Average	Sharkovshchina	137.3	-38.6	23.0	-31.7
	Polotsk	143.3	-37.4	25.0	-36.3
	Lepel	191.7	-59.8	23.4	-36.2

Monthly mean value of sensible heat flux in Sharkawshchyna and Lepel was 23 W/m^2, despite the considerable difference in maximums (5.7 W/m^2) and minimums (2.9 W/m^2). Similar mean values of latent heat flux were also registered in Polotsk and Lepel (36 W/m^2).

4 Conclusion

The comparative analysis of atmospheric characteristics in April 2023, according to the data from the stations in Sharkawshchyna, Polotsk, and Lepel and calculated on their basis heat flux values, allows us to make the following conclusions:

- The lower the wind speed, the greater the difference in wind direction in the considered meteorological stations.
- According to the calculations, latent and sensible heat fluxes have very similar values in all three stations.
- The lowest value of monthly mean longwave radiation flux was registered in Lepel.
- The obtained diurnal peaks of shortwave radiation for Lepel have the greatest values due to the absence of cloudiness data at certain time intervals.

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