Application of integral parametrization “SAIL” for climatology incoming shortwave radiation fluxes

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Abstract. Along with field and satellite data, the calculation of fluxes using integral parameterizations can become a source of information about incoming shortwave radiation fluxes on the sea surface. In this work, we used the results of applying the SAIL parametrization created at the IO RAS, based on measurements of incoming shortwave radiation fluxes to the surface of the Atlantic Ocean and the corresponding meteorological parameters. The main task of such parameterizations is to construct climatology of shortwave radiation fluxes according to VOS data. In the course of the work, the new cloud climatology CLAAS ed.2 was used as input to calculate the average daily fields of the incoming shortwave radiation fluxes to the surface of the Atlantic Ocean. As reference data, we used a satellite database of shortwave radiation fluxes for the Atlantic Ocean - SARAH ed. 2. In conclusion, it can be noted that the SAIL parameterization works very well for a total cloud score of up to 4 octa. Further development of the SAIL parameterization is possible by separately taking into account the direct and diffuse flux of incoming shortwave radiation, since as part of the growth of possible cloud regimes, it is very important to know when the flux prevails over the diffuse and when vice versa.

1. Introduction
High-precision calculations of incoming shortwave (SW) radiation fluxes on the sea surface are crucial for obtaining reliable estimates of the thermal balance of the ocean surface. In recent decades (approximately since 1984), several global and regional arrays of satellite dataset if short-wave radiation fluxes [1] and cloud cover [2] have appeared, which make it possible to estimate the interannual dynamics of SW fluxes for this period. However, to estimate the inter-decadal variability of short-wave radiation fluxes, it is necessary to use ship observations of cloud cover and the use of integrated radiation parameterizations, which are based on the dependence of the transmission function of the atmosphere on the total cloud cover at different heights of the Sun. The possibility of such long-term calculations, even regional ones, will make it possible to supplement the reconstruction of turbulent fluxes [3] with estimates of radiation fluxes and to obtain characteristics of long-term changes in the thermal balance of the ocean. In addition, the use of high-resolution satellite data of clouds makes it possible to estimate the applicability of the integral parameterization of SW fluxes for various spatio-temporal scales, which is fundamentally important for estimating SW fluxes with rapid changes in meteorological conditions, in particular at mid latitudes. In this work, for the first time, we test the applicability of one of the most developed integral parametrizations of SW radiation fluxes to
the satellite cloud data [2] and compare the results of calculation with the most accurate high-resolution satellite dataset of SW radiation fluxes today [1].

2. Methods and algorithms
We used the SAIL parametrization [4], created at the Shirshov Institute of Oceanology RAS and based on more than a five-year direct observations of SW radiation fluxes in various regions of the North Atlantic. The SAIL parameterization [4] is the so-called “octa-model” in which the incoming SW radiation fluxes depends on the total cloud cover in octa, and of the transmission function of the atmosphere has a nonlinear dependence on the height of the Sun, which is especially important for the correct description of incoming SW fluxes at low angles of the Sun. To test parameterization SAIL [4], we used the CLAAS ed.2 [2] satellite dataset of cloud cover and SARAH ed.2 [1] satellite dataset of incoming SW radiation fluxes. Both datasets are provided by the EUMETSAT’s Satellite Application Facility on Climate Monitoring (CM SAF).

For calculation of the SW radiation in the framework of the SAIL parameterization, which was originally created for hourly observations, the adaptation of daily average data is necessary. In this work we use the so-called “virtual clockwise rotation” method, when we fix information about cloud cover, and we calculate the height of the Sun with a certain step for the entire diurnal course of local astronomy. In this work, such calculations were carried out every hour based on the location and time of day, and then we made the daily average for the SW radiation fluxes. These values were further compared with values of the SW radiation fluxes from the SARAH ed.2 satellite dataset. This procedure may have a small error in the case of a strong dependence of the daily cloud cover on temperature. This error was estimated and turned out to be very small for the considered regions of the Atlantic.

The accuracy of the SAIL integral parameterization was estimated by us on the analysis of the absolute differences between the calculated SW radiation fluxes and satellite data of SW radiation fluxes at coinciding time instants for each point in the data array. The fields of standard deviation (RMS) between calculated values of SW radiation fluxes form SAIL parametrization and satellite dataset were also evaluated, which characterize the cumulative calculation error [5]. The calculations were performed over a 12-year period from January 2004 to December 2015.

Figure 1 shows the average climate distribution of the total cloud cover for the satellite coverage area for the period 2004 - 2015. The spatial distribution, analyzed in more detail in [6], agrees quite well with climatology over the surface of the ocean [7]. The total cloud cover over the Ocean varies from 4 octa in tropical regions to 7-8 octa (overcast) in subpolar regions which are characterized by intense cyclonic activity, especially in winter [8]. It should be noted that estimates from the data of passing observations [7] give somewhat lower values, which is explained by the scaling effect of both the individual observations themselves and the subsequent grid averaging. Thus, visual observations usually refer to the visible horizon (approximately 15–25 km), while satellite observations of CLAAS ed.2 [2] have an initial resolution of about 5 km. In addition, the spatial averaging of data in [7] is 5°, and in the CLAAS ed.2 array [2] - 0.05°.

The obtained total cloud cover in octa according to CLAAS ed.2 [2] (figure 1) was used to calculate the incoming SW radiation fluxes using the SAIL parameterization. Figure 2 shows the absolute differences in the values of SW radiation fluxes calculated from the SAIL parameterization and satellite dataset SARAH ed.2 [1].

3. Shortwave radiation fluxes comparison
Over the ocean, the fields of SW radiation flux calculated by SAIL parameterization are in good agreement with satellite data SARAH ed.2 [1] for the North Atlantic; the systematic error lies within ± 5 W/m² (figure 2). The standard deviation correlates well with the value of the total cloud cover in this part of the Atlantic. In areas with an average total cloud cover of 4-5 octa, the standard deviation is 20-30 W/m² (figure 3). With such cloud cover, mainly in tropical regions, the direct SW radiation fluxes regime prevails over the diffuse SW radiation fluxes. At the same time, with a cloud cover of 6-7 octa
in the mid-latitude and subpolar regions (figure 1), the standard deviation can reach 50 W/m², which is associated with a greater variability of cloud regimes and conditions, which are characterized by both direct and diffuse SW radiation fluxes. In the southern part of the Atlantic, a zonal distribution of clouds is observed, and there is also a zonal distribution of RMS. With an increase total cloud cover to 8 octa (overcast), the RMS values decrease to about 30-35 W/m², which seems reasonable, since the absolute values of SW radiation fluxes and its short-period variability decrease in case of overcast.

Figure 1. Distribution of the total cloud cover in OCTA for the period 2004-2015.

In general, the SAIL parameterization shows better results for the North Atlantic compared to the South Atlantic. This is explained by the fact that when creating the parameterization, we used a much larger data obtained in the North Atlantic [5]. Note that in the eastern part of the South Atlantic, a
subtropical region is distinguished, where the SAIL parameterization seriously overestimates the values of the SW radiation fluxes by up to 30 W/m². The reason for this is apparently the significant influence of the lower layer clouds in this area. Clouds of the lower layer in case of moderate cloud cover (4-6 octa) are the least optically transparent for SW incoming radiation fluxes. In this context, should be noted that the SAIL parametrization in a complicated form [4] allows us to take into account the types and height of the lower edge of the clouds, which significantly reduces the errors for different cloud modes, however, the identification of cloud modes associated with different types is impossible according to SARAH ed. 2 [1].

Figure 2. Systematic error between the incoming shortwave fluxes from SAIL Parameterization and the Surface incoming shortwave radiation from SARAH ed.2 database in W/m².
Figure 3. The standard deviation between the incoming shortwave fluxes from SAIL Parameterization and the Surface incoming shortwave radiation from SARAH ed.2 database in W/m².

4. Discussion and conclusions
Our work shows that the integral parameterization SAIL is generally applicable for the use of satellite cloud data. If we study the Validation Report for SARAH ed.2 [10] regarding the comparison of satellite data with Baseline Surface Radiation Network stations, the accuracy of calculation of short-wave fluxes is declared at 20 W/m² for daily average values. For a large part of the Atlantic Ocean, with a low cloud cover, less than 4 octa, we are close to this value. It is important that in this case the systematic error in these areas is close to 0 W/m². In areas of the Atlantic Ocean with a cloud regime close overcast standard deviation, does not exceed 25 W/m² in other areas, this value does not exceed 50 W/m².
Figure 4. The ratio between the standard deviation to the average value for incoming shortwave fluxes from SAIL Parameterization in %.

However, operating with the standard deviation without considering the average value of the shortwave fluxes is somewhat incorrect. Figure 4 shows the ratio of the values of standard deviation for the shortwave fluxes from SAIL parameterization and the average shortwave flux calculated by the SAIL integral parameterization for the period January 2004 - December 2015. It is significant that, taking into account the relative values, the SAIL parameterization reproduces fluxes well for cloud cover less than 5 octa. At the same time, in middle and high latitudes, where the average cloud cover increases and the variability of cloud modes increases too, the quality of calculations decreases. The largest errors are noted in the South Atlantic, where the standard deviations are at the level of 25 W/m² against the background of average shortwave radiation fluxes of ~ 150 W/m². Further improvement of
the SAIL parameterization should be aimed at separately accounting for the direct and diffuse flux of incoming shortwave radiation, since with increasing variability of possible cloud conditions, it is necessary to reliably identify the periods when the direct flux of solar radiation prevails over diffuse, and vice versa.

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References.
[1] Pfeifroth U, Kothe S, Müller R, et al. 2017 Surface Radiation Data Set - Heliosat (SARAH) - Edition 2 Satellite Application Facility on Climate Monitoring DOI:10.5676/EUM_SAF_CM/SARAH/V002
[2] Finkensieper S, Meirink J-F, van Zadelhoff G-J, et al. 2016 CLAAS ed.2: CM SAF CLoud property dataset using SEVIRI - Edition 2 Satellite Application Facility on Climate Monitoring (CM SAF) DOI:10.5676/EUM_SAF_CM/CLAAS/V002
[3] Gulev S K, Latif M, Keenlyside N, Koltermann K P 2013 North Atlantic Ocean Control on Surface Heat Flux on Multidecadal Timescales Nature 499 464–7
[4] Aleksandrova M P, Gulev S K, Sinitsyn A V 2007 An improvement of parametrization of short-wave radiation at the sea surface on the basis of direct measurements in the Atlantic Russian Meteorology and Hydrology 32(4) 245-51
[5] Sinitsyn A V, Gulev S K 2017 Comparison of In-Situ and Satellite Data of Surface Incoming Short-Wavelength Radiation for the Atlantic Ocean during 2004–2014 Okeanologiya 57(2) 268–74
[6] Finkensieper S, Hanschmann T, Stengel M, et al. 2016 CM SAF Validation Report SEVIRI cloud products CLAAS Edition 2 EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) 88 p
[7] Aleksandrova M, Gulev S K, Belyaev K P 2018 Probability distribution for the visually observed fractional cloud cover over the ocean J. Climate 31 3207-32:
[8] Tilinina N, Gulev S K, Bromwich D 2014 New view of Arctic cyclone activity from the Arctic System Reanalysis Geophys. Res. Lett. 43
[9] Bedacht E, Gulev S K and Mackea A 2007 Intercomparison of global cloud cover fields over oceans from the VOS observations and NCEP/NCAR reanalysis Int. J. Climatol. 27 1707-19
[10] Pfeifroth U, Kothe S, Müller R, 2016 CM SAF Validation Report Meteosat Solar Surface Radiation and Effective Cloud Albedo Climate Data Record SARAH 2 EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF) 196