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Utilization of remote sensing data on meteorological and vegetation characteristics for modeling water and heat regimes of large agricultural region

Eugene Muzylev (1), Zoya Startseva (1), Alexander Uspensky (2), and Elena Volkova (2)

(1) Water Problem Institute of Russian Academy of Sciences, Moscow, Russian Federation (muzylev@iwp.ru), (2) State Research Center of Space Hydrometeorology Planeta. Moscow, Russian Federation (uspensky@planet.iitp.ru)

Presently, physical-mathematical models such as SVAT (Soil-Vegetation-Atmosphere-Transfer) developed with varying degrees of detail are one of the most effective tools to evaluate the characteristics of the water and heat regimes of vegetation covered territories. The produced SVAT model is designed to calculate the soil water content, evapotranspiration (evaporation from bare soil and transpiration), infiltration of water into the soil, vertical latent and sensible heat fluxes and other water and heat regime characteristics as well as vegetation and soil surface temperatures and the temperature and soil moisture distributions in depth. The model is adapted to satellite-derived estimates of precipitation, land surface temperatures and vegetation cover characteristics. The case study has been carried out for the located in the forest-steppe zone territory of part of the agricultural Central Black Earth Region of Russia with coordinates 49º 30'-54º N and 31º -43º E and area of 227 300 km2 for years 2011-2014 vegetation seasons.

The soil and vegetation characteristics are used as the model parameters and the meteorological characteristics are considered to be input variables. These values have been obtained from ground-based observations and satellite-based measurements by radiometers AVHRR/NOAA, MODIS/EOS Terra and Aqua, SEVIRI/MSG-2,-3 (Meteosat-9, -10). To provide the retrieval of meteorological and vegetation cover characteristics the new and pre-existing methods and technologies of above radiometer thematic processing data have been developed or refined. From AVHRR data there have been derived estimates of precipitation P, efficient land surface temperature (LST) Ts.eff and emissivity E, surface-air temperature at a level of vegetation cover Ta, normalized difference vegetation index NDVI, leaf area index LAI and vegetation cover fraction B. The remote sensing products LST Tls, E, NDVI, LAI derived from MODIS data and covering the study area have been downloaded from LP DAAC web-site for the same vegetation seasons. The SEVIRI data have been used to retrieve P (every three hours and daily), Tls, E, Ta (at daylight and nighttime), LAI, and B (daily). All named technologies have been adapted to the territory of interest. To verify exactness of assessing AVHRR- and MODIS-based LST (Ts.eff, Ta and Tls) the error statistics of their derivation has been investigated for various samples using comparison with in-situ measurements during the all considered vegetation seasons. When developing the method to derive LST from the SEVIRI data its validation has been carried out through comparison of given Tls retrievals with independent collocated Tls estimates generated at LSA SAF (Lisbon, Portugal).The later check of SEVIRI-derived Tls and Ta estimates has been performed by their comparing with ground-based observation data. Correctness of LAI and B estimates has been confirmed when comparing time behavior of satellite- and ground-based LAI and B during each vegetation season.

The all-important part of the study is to improve the developed Multi Threshold Method (MTM) intended for assessing daily and monthly rainfall from AVHRR and SEVIRI data, to check the correctness of carried out calculations for the considered territory and to develop procedures of utilizing obtained satellite-derived estimates of precipitation in the SVAT model. The MTM allows automatic pixel-by-pixel classifying AVHRR- and SEVIRI-measured data for the cloud detection, identification of its types, allocation of precipitation zones, and determination of instantaneous maximum intensities of precipitation in the pixel range around the clock throughout the year independently of land surface type. Measurement data from 5 AVHRR and 11 SEVIRI channels as well as their differences are used in the MTM as predictors. Calibration and verification of the MTM have been carried out using observation data on daily precipitation at agricultural meteorological stations of the region. In the frame of this approach the transition from the rainfall intensity estimation to the calculation of their daily sums has been fulfilled at that two variants of this calculation have been realized which focusing on climate researches and operational monitoring. Such transition has required verifying the accuracy of the estimates obtained in both variants at each time step. This verification has included comparison of area distributions of satellite-derived precipitation estimates and analogous estimates obtained by the interpolation of ground-based observation data.

The probability of correct precipitation zone detection from satellite data when comparing with ground-based meteorological observations has amounted 75-85 %. In both variants of calculating precipitation for the region of interest in addition to the fields of daily rainfall the fields of their monthly and annual sums have been built. All three sums are consistent with each other and with a ground-based observation data although the satellite-derived estimates are more "smooth" in comparison with ground-based ones. Their discrepancies are in the range of the rainfall estimation errors using the MTM and they are peculiar to the local maxima for which satellite-derived rainfall is less than ground-measured values. This may be due to different scales of space-averaged satellite and point-wise ground-based estimates.

To utilize satellite-derived estimates of meteorological and vegetation characteristics in the SVAT model the procedures of replacing the ground-based values of precipitation, LST, LAI and B by corresponding satellite-derived values have been developed taking into account spatial heterogeneity of their fields. The correctness of such replacement has been confirmed by the results of comparing the values of soil water content W and evapotranspiration Ev modeled and measured at agricultural meteorological stations. In particular, when the difference of precipitation sums for the vegetation season resulted from the model calculation in both above variants having been 20% the discrepancy between corresponding modeled values of W for the same period has not exceeded 8% and the discrepancy between values of E has been within 15%. Such discrepancies are within the limits of the standard W and Ev estimation errors.

The final results of the SVAT model calculation utilizing satellite data are the fields of soil water content W, evapotranspiration Ev, vertical water and heat fluxes, land surface temperatures and other water and heat regime characteristics area-distributed over the territory of interest in their dynamics for the year 2011-2014 vegetation seasons. Discrepancies between Ev and W calculation results and observation data ($\sim$ 20-25 and 10-15%) have not exceeded the standard error of their estimation which corresponds to the adopted accuracy criteria of such estimates.