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Modeling water and heat balance components of large territory for vegetation season using information from polar-orbital and geostationary meteorological satellites

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To date, physical-mathematical modeling processes of land surface-atmosphere interaction is considered to be the most appropriate tool for obtaining reliable estimates of water and heat balance components of large territories. The model of these processes (Land Surface Model, LSM) developed for vegetation period is destined for simulating soil water content W, evapotranspiration Ev, vertical latent LE and heat fluxes from land surface as well as vertically distributed soil temperature and moisture, soil surface Tg and foliage Tf temperatures, and land surface skin temperature (LST) Ts. The model is suitable for utilizing remote sensing data on land surface and meteorological conditions. In the study these data have been obtained from measurements by scanning radiometers AVHRR/NOAA, MODIS/EOS Terra and Aqua, SEVIRI/geostationary satellites Meteosat-9, -10 (MSG-2, -3). The heterogeneity of the land surface and meteorological conditions has been taken into account in the model by using soil and vegetation characteristics as parameters and meteorological characteristics as input variables. Values of these characteristics have been determined from ground observations and remote sensing information.

So, AVHRR data have been used to build the estimates of effective land surface temperature (LST) $T_{s.eff}$ and emissivity E, vegetation-air temperature (temperature at the vegetation level) T_a, normalized vegetation index NDVI, vegetation cover fraction B, the leaf area index LAI, and precipitation. From MODIS data the values of LST T_{ls}, Å, NDVI, LAI have been derived. From SEVIRI data there have been retrieved T_{ls}, E, T_a, NDVI, LAI and precipitation. All named retrievals covered the vast territory of the part of the agricultural Central Black Earth Region located in the steppe-forest zone of European Russia. This territory with coordinates 49°30'–54°N, 31°-43°E and a total area of 227,300 km^2 has been chosen for investigation. It has been carried out for years 2009-2013 vegetation seasons.

To provide the retrieval of $T_{s.eff}$, E, T_a, NDVI, B, and LAI the previously developed technologies of AVHRR data processing have been refined and adapted to the region of interest. The updated linear regression estimators for $T_{s.eff}$ and T have been built using representative training samples compiled for above vegetation seasons. The updated software package has been applied for AVHRR data processing to generate estimates of named values. To verify the accuracy of these estimates the error statistics of $T_{s.eff}$ and T_a derivation has been investigated for various days of named seasons using comparison with in-situ ground-based measurements. On the base of special technology and Internet resources the remote sensing products T_{ls}, E, NDVI, LAI derived from MODIS data and covering the study area have been extracted from LP DAAC web-site for the same vegetation seasons. The reliability of the MODIS-derived T_{ls} estimates has been confirmed via comparison with analogous and collocated ground-, AVHRR-, and SEVIRI-based ones. The prepared remote sensing dataset has also included the SEVIRI-derived estimates of T_{ls}, E, NDVI, T_a at daylight and night-time and daily estimates of LAI. The T_{ls} estimates has been built utilizing the method and technology developed for the retrieval of T_{ls} and E from 15 minutes time interval SEVIRI data in IR channels 10.8 and 12.0 μm (classified as 100% cloud-free and covering the area of interest) at three successive times without accurate a priori knowledge of E. Comparison of the SEVIRI-based T_{ls} retrievals with independent collocated T_{ls} estimates generated at the Land Surface Analysis Satellite Applications Facility (LSA SAF, Lisbon, Portugal) has given daily- or monthly-averaged values of RMS deviation in the range of 2°C for various dates and months during the mentioned vegetation seasons which is quite acceptable result. The reliability of the SEVIRI-based T_{ls} estimates for the study area has been also confirmed by comparing with AVHRR- and MODIS-derived LST estimates for the same seasons. The SEVIRI-derived values of T_a considered as the temperature of the vegetation cover has been obtained using T_{ls} estimates and a previously found multiple linear regression relationship between T_{ls} and T_a formulated accounting for solar zenith angle and land elevation. A comparison with ground-based collocated T_a observations has given RMS errors of 2.5°C and lower. It can be

treated as a proof of the proposed technique's functionality. SEVIRI-derived LAI estimates have been retrieved at LSA SAF from measurements by this sensor in channels 0.6, 0.8, and 1.6 μm under cloud-free conditions at that when using data in the channel 1.6 μm the accuracy of these estimates has increased.

In the study the AVHRR- and SEVIRI-derived estimates of daily and monthly precipitation sums for the territory under investigation for the years 2009 - 2013 vegetation seasons have been also used. These estimates have been obtained by the improved integrated Multi Threshold Method (MTM) providing detection and identification of cloud types around the clock throughout the year as well as identification of precipitation zones and determination of instantaneous precipitation maximum intensity within the pixel using the measurement data in different channels of named sensors as predictors. Validation of the MTM has been performed by comparing the daily and monthly precipitation sums with appropriate values resulted from ground-based observations at the meteorological stations of the region. The probability of detecting precipitation zones from satellite data corresponding to the actual ones has been amounted to 70-80%. AVHRR- and SEVIRI-derived daily and monthly precipitation sums have been in reasonable agreement with each other and with results of ground-based observations although they are smoother than the last values. Discrepancies have been noted only for local maxima for which satellite-based estimates of precipitation have been much less than ground-based ones. It may be due to the different spatial scales of areal satellite-derived and point ground-based estimates.

To utilize satellite-derived vegetation and meteorological characteristics in the model the special procedures have been developed including:

- replacement of ground-based LAI and B estimates used as model parameters by their satellite-derived estimates from AVHRR, MODIS and SEVIRI data. Correctness of such replacement has been confirmed by comparing the time behavior of LAI over the period of vegetation as well as modeled and measured values of evapotranspiration Ev and soil moisture content W;

- entering AVHRR-, MODIS- and SEVIRI-derived estimates of $T_{s.eff}$ T_{ls}, and T_a into the model as input variables instead of ground-measured values with verification of adequacy of model operation under such a change through comparison of the calculated and measured values of W and Ev;

- inputing satellite-derived estimates of precipitation during vegetation period retrieved from AVHRR and SEVIRI data using the MTM into the model as input variables. When developing given procedure algorithms and programs have been created to transit from assessment of the rainfall intensity to evaluation of its daily values. The implementation of such a transition requires controlling correctness of the estimates built at each time step. This control includes comparison of areal distributions of three-hour, daily and monthly precipitation amounts obtained from satellite data and calculated by interpolation of standard network observation data;

- taking into account spatial heterogeneity of fields of satellite AVHRR-, MODIS- and SEVIRI-derived estimates of LAI, B, LST and precipitation. This has involved the development of algorithms and software for entering the values of all named characteristics into the model in each computational grid node.

Values of evapotranspiration E, soil water content W, vertical latent and sensible heat fluxes and other water and heat balance components as well as land surface temperature and moisture area-distributed over the territory of interest have been resulted from the model calculations for the years 2009-2013 vegetation seasons. These calculations have been carried out utilizing satellite-derived estimates of the vegetation characteristics, LST and precipitation. E and W calculation errors have not exceeded the standard values.