Integrated Models of Geophysical Processes Description in Terms of Satellite and Ground-Based Data Interpretation

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Abstract – Two examples are shown of remote sensing data applications for integrated models of separate spheres of the Earth. Innovative techniques of vegetation biomass amount assessment using multispectral satellite imagery is given in the first example. Problems of temporal data series analysis for information products of satellite data processing using a gridded data representation to understand predictability problem of global/regional change are considered in the second example. Both types of the applications serve to demonstrate new opportunities in interpretation of different types of data in the newly defined domain of information & dynamical modeling.

Key words: Remote Sensing, Modeling, Data Interpretation, Integrated Assessment.

INTRODUCTION

Current opportunity to evolve data access and integration techniques of remote sensing data processing implies not only establishing platforms and sensors, development of various applications (terrestrial ecosystems, climate, disasters, etc.), but elaboration of new models of data interpretation and analysis of information products extracted from multispectral satellite images. Mostly empirical techniques (vegetation indices, for instance) are anticipated while using the relevant applications of imagery processing as well as numerical models while approaching to any form of forecasting tools of global/regional change. Meanwhile, new opportunities are appeared of quantitative parameters assessment using satellite and ground-based observations along with information & dynamical models to understand predictability problem of environmental change for sustainability and security (Kozoderov et al., 2000).

Two different directions of practical applications are typical while using updated tools of satellite data processing. The first direction is concerned with a combined utilization of remote sensing and ground-based data interpretation results for Geographical Information System (GIS) development with Integrated Assessment Models as an ultimate goal of data applications (Kozoderov, 2004). The second direction deals with temporal data series analysis of the combined information products for particular areas of the globe to estimate climate variability using Earth radiation budget components (Kondratyev, Kozoderov, Smokty, 1992).

A series of operating satellites together with ground-based observations are producing tremendous volumes of data at a comparatively high level of measurement precision. In order to effectively interpret the data and estimate Earth surface variables, sophisticated and targeted models are under way which would enable to process satellite multispectral images. Models of the imagery interpretation in visual, infrared and microwave spectral bands are initial to solve inverse problems of quantitative parameters assessment (vegetation biomass amount, in particular, for forest and other ecosystems). Each pixel of the images is represented in terms of the listed parameters retrieved from space in accordance with mathematical procedures. These parameters are invariant (not depending on) to angular coordinates of the related targets observation, Sun illumination conditions and the current state of the atmosphere. These are new techniques as compared to standard procedures of pattern recognition and scene analysis (Kozoderov et al., 1994). Their novelty is in proper use of computational mathematics in the retrieval procedures.

Satellite observation systems have given an opportunity to identify the so-called dipole mechanism of convective activity of the atmosphere in tropical latitudes of Pacific ocean due to Sea Surface Temperature (SST) anomalies. This mechanism is characterized by such major condition of the geophysical system (Sadonvichii et al., 2002) that convective cloudiness is prevailing in the central part of the tropical Pacific while this cloudiness is weak at the same latitudes near to Indonesia region. Atmospheric convection is stimulated by the anomalous high SST values at this particular state of geophysical system. However, regularly once each 4-7 year a malfunction of typical western trade winds in the lower layers of the atmosphere is observed in the central part of the tropical region during summer time when maximal levels of the ocean surface are remarkable in the Western Pacific. The emerging changes of circulation of the atmosphere and ocean enable to pileup the anomalous warm waters to the western coast of South America (usually by the end of the relevant year) where deep and cold oceanic waters upwelling is typical during normal conditions. A new branch of the indicated “dipole” gets active after that with convective cloudiness prevailing over the maritime continent and its great attenuation over the oceanic waters of the tropical region. The system is going gradually to its “normal state” where the convective activity over the ocean starts prevailing again.

Let us consider characteristic features of both types of the listed techniques of satellite data processing and interpretation for different spheres of the Earth.

TECHNIQUES

Inverse problems of satellite data processing are written symbolically as

$$\boldsymbol{J}_{ij}\,\{F^{(n)}\,[(\theta,\varphi);\,\theta_0;\,A;\,\boldsymbol{M}\,(\Pi_k)]\}\Rightarrow \boldsymbol{M}_{ij},$$

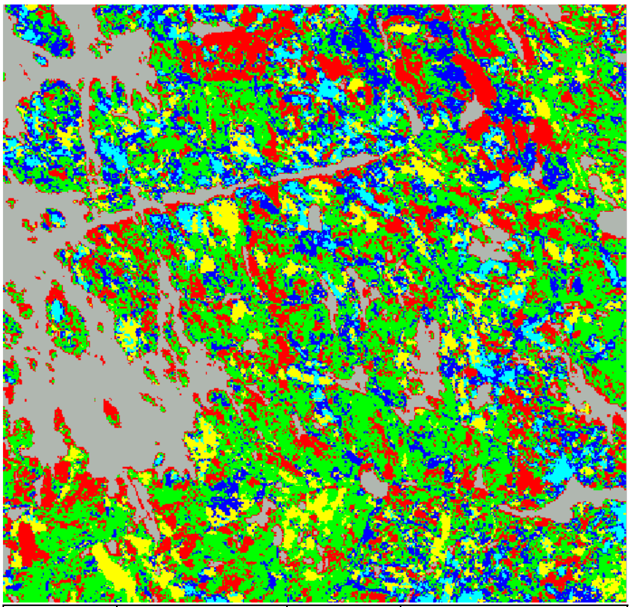
where $\boldsymbol{J}$ is the initial functional of spectral radiances for each line and column (i, j) of a multispectral image (n spectral bands) under given zenith angle of view and azimuth (θ, φ), solar zenith angle θ_0 and the current condition of the atmosphere A (is typically determined by transparency and path radiance of the atmosphere) having the sensitivity function F of satellite instruments into consideration. The functional $\boldsymbol{J}_{ij}$ is dependent on the above ground biomass amount $\boldsymbol{M}$ that in turn is dependent on parameters Π_k (k is total number of such parametric characterization) of density of

Fig.1. Initial ETM+ Landsat-7 image synthesized by a standard way using spectral bands of red, green and blue colors. Dark are water bodies, other plots belong to forest vegetation, bushes, swamps, open places, etc. Road infrastructure is seen as light lines delineating separate plots.

vegetation canopy, "tracery" of crowns of trees for forest ecosystems, etc. Technological realization of the described techniques results in obtaining final information products in terms of $\boldsymbol{M}_{ij}$. Statistical significance research of cross-correlations of anomalies of the related processes for temporal data series $\boldsymbol{M}_{ij}$ (t) opens up a possibility to solve predictability problem as a mathematical discipline of finding signal/noise ratios of currently observed changes in the biosphere (Kozoderov et al., 1998).

Tropical atmosphere is functioning as a giant heat engine that influences on global atmosphere by a specified configuration of atmospheric pressure waves. Analysis of SST anomalies in tropical Pacific is associated with well-known El-Nino/Southern Oscillation (ENSO) phenomena and gives a tool for studying the atmospheric pressure response in higher latitudes. This oscillation is maintained to be responsible for a large-scale atmospheric circulation in the tropical latitudes and El-Nino is to play a key role in the anomalies transformation from the ocean to the atmosphere. Since interactions between the ocean and atmosphere are accompanied by atmospheric convection, precipitation and similar other observable effects, it is worth to think about the ENSO predictability value on the scales of interannual variability of satellite data sets.

Satellite images enable to reproduce the related ocean-atmosphere processes manifestation from the point of view of typical configuration of atmospheric pressure waves resulting in heavy floods in some parts of the Earth and severe droughts in its other parts. Mechanisms of typical trade winds malfunction in equatorial Pacific are shown in (Kozoderov et al., 2004) in conjunction with a partly melted media oscillation under Nazca lithosphere plate (approximate coordinates 0 – 40 S; 75 – 110 W). This part of the lithosphere is usually called as astenosphere and the plate oscillation is assumed to give rise to the onset of ENSO events with subsequent weather & climate disturbances for the entire globe. Thus, processes in the lithosphere system can be imbedded into the atmosphere-hydrosphere fluctuations.



(red)	grass/open places, less than 6 t/ha	(yellow)	solid cover, coniferous species (spruce, fir), less than 18 t/ha
(green)	solid cover, deciduous species (aspen), less than 12 t/ha	(cyan)	coniferous species, but more green than class 4, more than 18 t/ha
(blue)	mixed forest, (12-18) t/ha	(grey)	open water

Fig.2. Cluster-analysis results for the selected test area with the green phytomass amount in tons per hectare (t/ha).

Coefficients α_{xy} (τ) of a shifted correlation with any time interval τ are usually selected as a measure of signal/noise ratio in temporal data series analysis x (t) relative to y (t). These might be the series for the $\boldsymbol{M}_{ij}$ (t) or any other information products taken with their monthly shifts τ to be considered as two different series of the products. Earth radiation budget components (in fact, reflected radiation flux and temperature of the observed system) would play the role of $\boldsymbol{M}_{ij}$ (t) for global constrains. Scientific problem in both cases is in finding the ratios

$$\alpha_{xy}(\tau) = \boldsymbol{M}_{xy}(\tau) / \mathrm{SD}\,[\boldsymbol{M}_{xy}(\tau)],$$

where SD is standard deviation of the values considered as the interannual variability of the relevant results of satellite data processing. Mathematical formulation of the predictability problem P_{xy} (τ) of any x (t) process via y (t) is derived from statistical significance of the ratios $P_{xy}(\tau) = \alpha_{xy}(\tau) / \alpha_{xy}(0)$ as a measure of observed variability of the products in time.

RESULTS AND DISCUSSION

Particular results of the innovative techniques realization for vegetation cover are given at Fig.1 and Fig.2.

Fig.1 is an initial ETM+ (Enhanced Thematic Mapper) Landsat-7 image represented in a true color form for a selected test area of observations. The entire land area is 40 km x 40 km for the date of 20 June 2000. Dark natural objects (water bodies) are alternated with lighter objects characterized by forest vegetation. There are

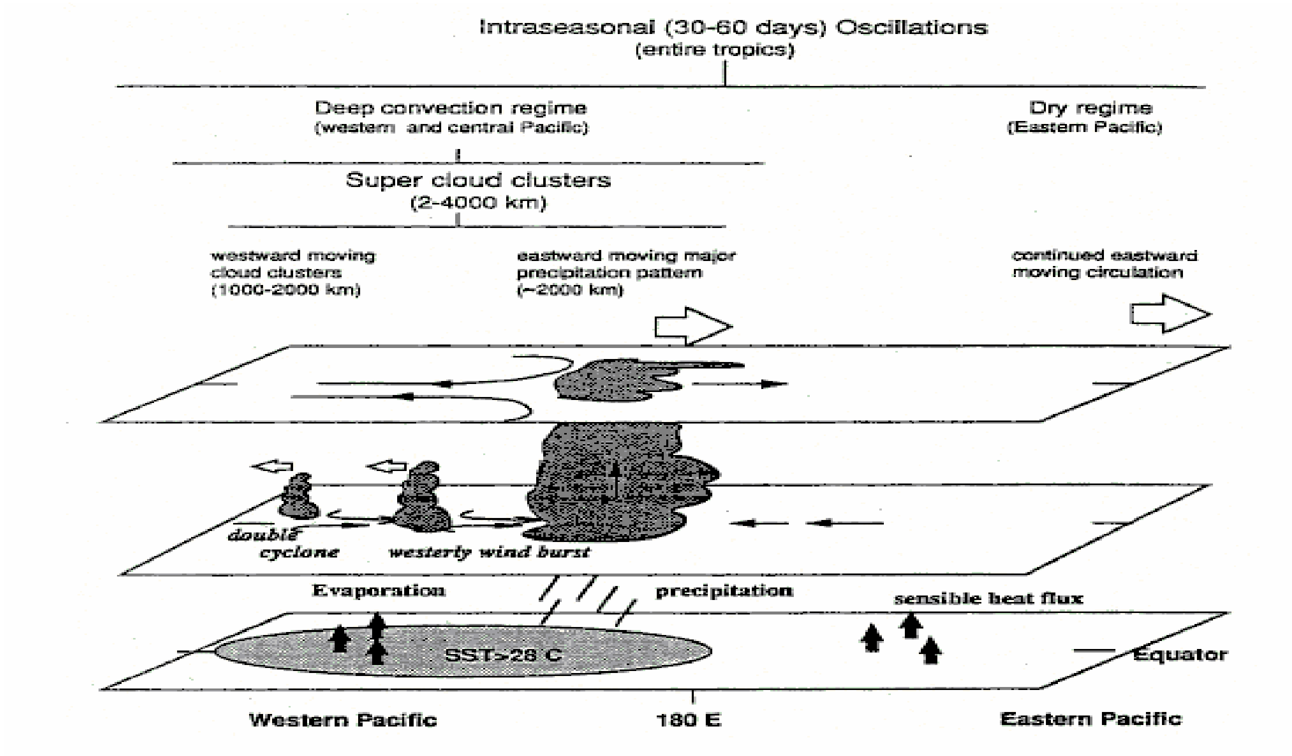


Fig.3. Characteristic scheme of intraseasonal (30-60 days) atmospheric oscillations for the entire tropics as a prerequisite of ENSO events. Dark arrows represent typical processes of evaporation and sensible heat exchange between the atmosphere and ocean. Different types of other arrows reproduce the relevant processes of horizontal exchange between the indicated longitudinal effects and lower latitudes.

mainly coniferous stands (pine) reflected by lighter colors along with spruce species of red-brown colors with background of bushes and deciduous species (prescribed by green colors). Other light color plots belong to logging places and young forest.

Multispectral processing of the synthesized image of Fig.1 was conducted in accordance with the described techniques of the inverse problem solution. The amount of green phytomass of leaves/needles is retrieved at Fig.2 for each pixel of the Fig.1 image. At least five classes of the vegetation condition in terms of the major quantitative parameter is selected for the area under consideration. The classified species and their phytomass amounts are represented at Fig.2. This parameter can be empirically estimated by foresters at a particular site of their ground observations or measurements of specified indicators (diameters of trees on the breast level, etc.). The parameter is known to give useful information about carbon content of the forested area as the main indicator of sequestering and other processes of vegetation growth. These are innovative classification techniques and soil-vegetation condition assessment as compared with the previously discussed by (Curran et al., 1990) which were based on radiation transfer theory.

Returning to major problems of global change, it is necessary to note that an appearance of characteristic configuration of the atmospheric pressure waves on global scale is a consequence of the indicated above SST anomalies. These anomalies are fixed by satellite observations. It is not yet clear in the process of the anomaly emergence what is the source of the trade wind malfunction and how the onset of the oceanic warm water pileup mechanism is turning on. If a concurrent mechanism of the malfunction is connected with the oceanic level changes due to Nazca plate oscillation, than combined models of geophysical processes could be constructed in the lithosphere, hydrosphere and atmosphere (Kozoderov et al., 2004).

A typical scheme of the ENSO onset formation is given by Fig.3. SST anomalies of near surface water temperature exceeding 28^o C in the western and central Pacific (to the left from the 180^o longitude at Fig.3) give rise to enhanced precipitation that results in heavy convective cloudiness formation and westerly wind burst with further cyclone activity in the western direction from these longitudes. A dry regime is typical for the Eastern equatorial Pacific for this scheme. Thus, mainly sensitive heat flux is prevailing at these longitudes at the lower levels of the atmosphere.

This scheme was taken from Lau et al., 1997 to reveal the active period of the so-called intraseasonal atmospheric oscillation that forces westward propagation of tropical cloud clusters with a zonal extension. ENSO events are typically derived from the wind-induced moisture convergence situations leading to a vertical distribution of moist static energy of the basic state of the atmosphere that is closely related to the SST. This common-used explanation is designated to indicate tropical oscillation impacts on tropical and extra-tropical climatology by atmospheric General Circulation Models, but true sources of the El-Nino onset in fact can not be caught by this simplified approach. The Fig.3 scheme is shown here to link the atmosphere, hydrosphere and solid Earth sciences addressing to the lithosphere plate oscillation as a possible source of this phenomena onset.

The convective super cloud clusters with a wide range of horizontal scales from 2 km up to 2400 km due to the outlined deep convection regime are extended upward reaching the tropopause as “a wall”, i.e. a boundary between the higher level of the atmosphere where temperature gradient gets positive with height and its lower level with typical negative values of the gradient. The precipitation pattern moves eastward and the cloud clusters typically westward. Characteristic are westerly winds at the base level of the cloud clusters altitude of the atmospheric boundary layer. Each ENSO episode emerges when the oceanic level to the right side from 180^o is sunk additionally to its enhancement to the left side from this longitude in accordance with the described scheme of the intraseasonal oscillation within one month or two for the entire tropics (Fig.3).

Having its thickness less than ten kilometers, Nazca plate might be considered as rigid with its transverse characteristic dimensions much lower than longitudinal dimensions. The conducted studies of eigen values of the plate oscillation as a rigid shell due to bending waves typical for thin plates have shown (Troukhin, Kozoderov, Kuzmin, 2004) that the elasticity theory can not elucidate the long-wave oscillations of Nazca plate with the above period of 4-7 years. But a magnetic & hydrodynamic approach for the astenosphere under Nazca plate has allowed to establish a physical mechanism of transverse waves appearance which is connected with line of force tightening for magnetic field of the Earth in the nested region. The obtained estimates of the wave processes manifestation in the astenosphere have appeared to be consistent with the relevant periods of the ENSO events (50-80 months). When during summer months in tropical Pacific near to the region of dates change (180^o) the oceanic level gets prevailing under the level at the same latitudes but to the east from the region, favorable conditions appear for the warm waters pileup in the direction to Peru coast. Triggering mechanism inevitably emerges in one from these 50-80 months when a critical difference takes place between the oceanic level for the expense of its enhancement during summer near-surface water heating in the first case and Nazca plate sinking in the second case.

The magnetic & hydrodynamic models for the Nazca plate oscillations encompass the related conditions for the so-called self-supporting geo-dynamo originating from processes in solid and liquid core of the Earth and resulting in magnetic induction field formation in turbulent media of the liquid core and a typical structure of field transfer through the silicate mantle up to the astenosphere. The latter is treated in terms of plasma physics. Specific conditions of transverse wave propagation in the astenosphere layer under Nazca plate can identify the above-mentioned mechanism of interaction between geophysical processes in lithosphere, hydrosphere and atmosphere. So, models of weather & climate anomalies description, models of lithosphere plates oscillation and models of self-supporting magnetic field of the Earth are united within the proposed approach.

CONCLUSION

New applications have been shown of vegetation biomass assessment using improved techniques of solution of inverse problems additionally to common-used object-oriented classification techniques of remote sensing and ground-based data processing. New models are also accounted for a gridded representation of information products given by the innovative techniques. As a result, data of integrated multi-sensor observations can be linked for wider applications of climate, biosphere and lithosphere research.

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