SATELLITE OBSERVATIONS FOR EDUCATION OF CLIMATE CHANGE

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ABSTRACT. – This paper surveys the key statements of the IPCC (2007) Report based mainly on the satellite-borne observations to support teaching climate change and geography by using the potential of this technology. In the Introduction we briefly specify the potential and the constraints of remote sensing. Next the key climate variables for indicating the changes are surveyed. Snow and sea-ice changes are displayed as examples for these applications. Testing the climate models is a two-sided task involving satellites, as well. Validation of the ability of reconstructing the present climate is the one side of the coin, whereas sensitivity of the climate system is another key task, leading to consequences on the reality of the projected changes. Finally some concluding remarks are compiled, including a few ideas on the ways how these approaches can be applied for education of climate change.

Keywords: climate change, climate models, satellite remote sensing, climate sensitivity

1. INTRODUCTION

The future teacher of geography has to know about everything which is related to his or her profession in the real life. This is especially true for the devices where either the factual knowledge or the interdisciplinary relations can well be emphasized. From both points of view the satellite imagery and processing is such a tool. Since this device reveals figuratively the tiny details of the surface to us. Faculty of Natural Sciences of Eszterházy Károly College uses the satellite images of EUMETSAT during 3 years for educational and scientific purposes starting in autumn of 2010. Running a little bit ahead in time let us be playing about with the thought that this imaginary right is available as physical reality for us already. How we would be able to make use of it merely our basis topic in the interest of the education of the climate change?

The satellites support the climate change in four ways: *Firstly* the modification of the climate, the so called external forcing factors are worth mentioning, especially the atmospheric aerosol particles, exhibiting large spatial variability which demands the use of the satellite technology.

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Secondly, we emphasize the role that helps to justify the changes in such a global covering that would not be possible in any other way especially in the uninhabited regions and the oceans, not allowing the ground-based observations. Testing climate models forms *the third group* of climatic applications, if these models are able to give back the present value of single variables or its past changes. Finally, testing the model sensitivity is *a fourth* application. It asks, if the atmospheric short-, and long wave radiation feedbacks, shaping its balance, are equal to their real intensity.

This question is really important, because the feedbacks influence the climatic sensitivity. In any case, the balance of these feedbacks in the models sensitivity causes as big uncertainty, as the variability of the greenhouse gas emissions scenarios.

2. SPECIFICS OF REMOTE SENSING

Satellite technology is based on electromagnetic radiation observations. The use of remote sensing techniques from space is advantageous, since this is the only way to observe a wide range of geophysical parameters on a global scale to acceptable accuracy in a consistent and repeatable manner (Silvestrin, 2010). The satellite images have fairly high spatial resolution and high (though, costly) temporal resolution already achievable over vast areas. This technology allows us to measure locations of the Earth system impossible or difficult to access, mainly by the all-weather day-and-night capability for microwave sensing. This technology is able to measure several parameters at same time and it can be highly automatic, from acquisition to exploitation. One may even state that on a per-measurement basis, usually far less expensive than any other means of geophysical observations (Silvestrin, 2010).

However, the technology has some caveats too (Silvestrin, 2010). One must always consider that remote sensing data are results of indirect measurements where the observed signal is always affected by more factors than just the one, targeted by the observation. Therefore, further assumptions and models are needed to interpret the measurements, e.g. to calibrate sensor, to remove perturbing effects, etc. The area of the measurement target is often relatively large, raising the representativity issue, considering surface heterogeneities. Due to these problems, validation of remote sensing measurements is often not possible in an optimal way and the estimation of the errors of the data products can be difficult.

Satellite remote sensing is based on primary and combined electromagnetic quantities, e.g. absolute intensities in specific wavelength intervals, intensities relative to the intensity of a reference source at the same wavelength, ratios of intensities at different wavelengths, etc. These quantities are observed in two characteristic groups according to the wavelengths. These are the microwave and the optical (infrared) parts of the parts of the electromagnetic spectrum.

Optical sensing of the surface takes place in visible and near-infrared (ca. 0.3-1.3 μm), middle-infrared (ca. 1.5-1.8, 2.0-2.6, 3.0-3.6, 4.2-5 μm) and thermal infrared (7.0-15 μm) parts of the spectrum, constrained by the atmospheric windows. The microwave sounding can use a rather large window between 10 MHz – ca. 100 GHz.

The wavelengths in the two regions differ by around 5 orders of magnitude: features observed are very different and usually highly complementary. The two groups exhibit very different spatial resolutions: only tens of km for the microwave, whereas 1 km is easily achieved for the optical measurements. On the other hand, microwave sensing is little affected by atmosphere and clouds (but rainfall may be a problem), and they can even penetrate vegetation, dry soil and snow. For the visible wavelengths clouds are obstacles, and daylight is also a condition. In the optical part of the spectrum various atmospheric corrections are needed to clear the targeted signal from other effects. In this respect, wide and partly unknown radiation parameters of the aerosol components are the problem.

For microwaves the surfaces appear smoother than in the optical region, hence larger occurrence of mirror-like reflections is available. This can be utilized in case of both passive and active remote sensing. Active sensing offers more control on incident energy, enabling new sensing capacities. However, legal and technological constraints also occur with the microwave spectrum allocation (interference with other sources), lidar (laser-radar) safety issues, etc. (Silvestrin, 2010).

3. CHANGES OF CLIMATE

Detection of changes in the climate system is a rather difficult and long-term task of the satellite based remote sensing. The key problems are the limited *accuracy* of the observations, i.e. the non-random, systematic error, or bias, that defines the offset between the measured value and the true one. There is also the limited *precision* of each observation, i.e. its random errors. Suitable averaging of the random errors can improve the precision of the measurement, so this problem is not a strict obstacle of the long-term observations. But, the limited *stability*, i.e. the time varying accuracy, when no absolute standard is available can lead to systematic error as a function of time. Finally, the *representativity* might also be a constraint though a good sampling strategy can mitigate this problem (Doherty, 2010).

There is a very large number of variables in the climate system. The most straightforward, and also realistic ones to observe by remote sensing, are listed in *Table 6.4*, according the present and future activity of the "ESA Climate Change Initiative" (Liebig, 2010). It is not possible to overemphasize how important it is to have multi-variable objective data on recent climate changes. Any national or larger scale policy decision on the mitigation of the changes or on the adaptation to them should be based on the detection of the changes. (Attribution of them is another task, with substantial synergies with the detection, as well.).

Common sense, physical considerations and also the technical possibilities and constraints lead the decision on the priorities among these variables. The first two drivers are needed to have the maximum set of fairly independent physical state variables, as soon as possible. The first 11 variables of the ESA mission are bold set in *Table 1*.

Table 1. ***Essential climate variables, as considered by the ESA Climate Change Initiative. Observation of the 11 bold-set variables is already in process (Liebig, 2010).***

Atmosphere	Surface	Air temperature, precipitation, air pressure, water vapour, surface radiation budget, wind speed & direction.
	Upper air	*Cloud properties,* wind speed & direction, Earth radiation budget, upper air temperature, water vapor
	Composition	*Carbon dioxide, methane & other GHGs, ozone, aerosol properties*
Ocean	Surface	*Sea-surface temperature. Sea-level, sea-ice, ocean color,* sea state, sea-surface salinity, carbon dioxide partial pressure
	Sub-surface	Temperature, salinity, current, nutrients, carbon, ocean tracers, phytoplankton
Terrestrial	*Glaciers & ice caps, land cover, fire disturbance,* fraction of absorbed photo-synthetically active radiation, leaf-area index (LAI), albedo, biomass, lake levels, snow cover, soil moisture, water use, ground water, river discharge, permafrost and seasonally frozen ground	

Among the variables in Table 1, the most frequently used one is the near surface air temperature, which increased 0.8°C in the last 100 years (Copenhagen Diagnosis, 2009). The temperature of the second part of 20th century on average was very likely above all 50 years in last 500 year's, and likely even in the last 1300 years.

An example of satellite remote sensing for climate change detection is the microwave remote sensing. By this methodology it was possible to detect same warming in the lower and middle layers of the troposphere together with the surface changes during the newer examination. (See IPCC 2007: Fig. 3.16 for the methodology and Fig. 3.17 for the long-term changes, not showing here for the lack of space.)

The warming (caused by anything) could be proven beside the air temperature with the change of other geophysical characters. Such variables are the area of snow cover and sea ice which could be detected well only in the era of satellites. Fig. 1 shows the changes of these components of the cryosphere in the last decades. As it is shown in Fig. 1 both the snow cover and the sea ice area have decreased in the last decade parallel to the global warming over the Northern Hemisphere. Both changes are apparent and statistically significant.

On other hand, around Antarctica the sea ice has been increasing, despite the near-surface warming over the majority of the continent (Steig et al., 2009). This pattern has been attributed to intensification of circumpolar westerlies, in response to changes in stratospheric ozone, letting less warm air masses into the centre of the island. This, in turn, leads to colder centre of Antarctica and southward shift of the Polar front. In *Fig. 1*, the linear trend of ice cover decreasing is 33±7 thousand km^2 per decade. Its magnitude is -2.7 %, and it is significant. Simultaneously, the ice-cover expansion, as much as 6±9 thousand km^2 per decade, is not significant in the Southern Hemisphere.

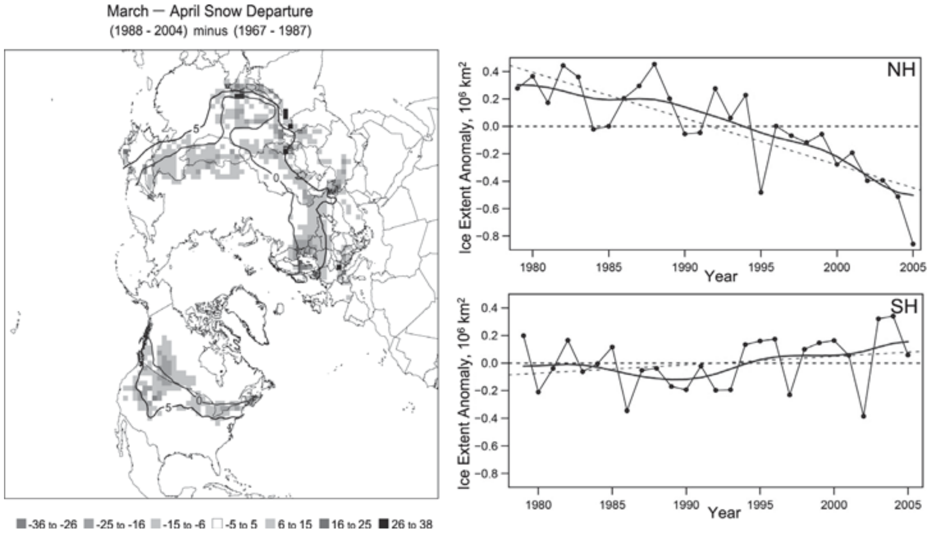

Fig. 1. ***The extension of snow cover on the continents of Northern Hemisphere in two following satellite observation interval during the thawing period, between 1967 and 1987, and 1988 and 2004 respectively (a). The modification of snow cover represented by color squares showing almost on every place 5-15 or 15-25% shortening in time. The continuous lines are 0 and 5 °C mean isotherms of air temperature for total 1967-2004 periods in March-April. The biggest area decreasing is nearly parallel with the isotherms. The next two figures show the extension of oceanic ice cover on the Northern (b) and Southern Hemispheres (c) between 1979 and 2005. The dots show the yearly mean ice extension, with decadal smoothing. (IPCC 2007: Fig. 4.3, 4.8 and 4.9).***

4. TESTING OF CLIMATE REPRODUCED BY MODELS

The climate system, the atmosphere, the lands, the oceans, the biosphere and solid water (the cryosphere) is one of the most complicated non-linear systems. The spatial scales of the system start from the millimeter magnitude of cloud-physical processes until the length of the Equator.

The temporal scales of the system changes between the few minute long micro turbulence to the many hundred year long ocean circulation. No model is able to take everything into consideration. Besides the lack of computer capacity, we have to consider the lack of knowledge derived form the limitations of the observation network.

For this reason, testing climate models is very important. The simpler part of testing is to check whether the fields in the models, simulated with present external circumstances, fit reality. A positive example of this validation is shown in Fig. 2. It demonstrates that the water content of atmosphere and its changes was estimated relatively well by the model and was fitted to the reality via sea surface temperature as lower boundary condition. We can state that the dynamical processes of the atmosphere can handle the atmospheric water content.

It is also worth mentioning, that the increasing trend of water content during this two decades, with global warming behind, points at the positive inter-relatedness of temperature and water content at global scales: Warming climate initiates increased water vapor content, leading to further warming, as is also mentioned in the next Section.

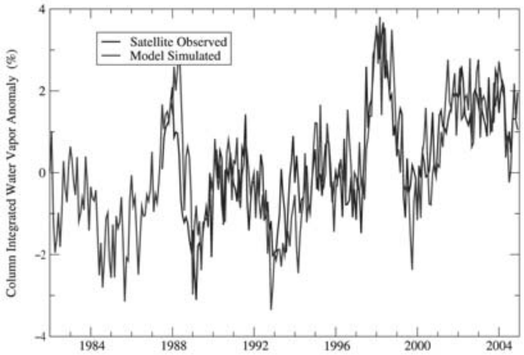

Fig. 2. ***The anomaly of vertically integrated water vapor content above the ocean, expressed in percent of 1987-2000 period average. The values are simulated by the general circulation model of Geophysical Fluid Laboratory, Princeton and observed by the SSM/I satellite. The model was driven by observed sea-surface temperature, as lower boundary condition, otherwise by external climate forcing. The model well reproduces the slow increase of water vapor content in connection with warming, and the inter-annual fluctuation in relation to the El Nino/La Nina oscillation (IPCC 2007: Fig. 9.17).***

5. TESTING CLIMATE MODEL SENSITIVITY

The final aim of climate modeling is to project the future climate in response to reasonable changes in the external forcing factors. These external factors and their uncertainty are influenced by many circumstances. Among others, they are the world population, the structure of energy industry, development difference between the regions, etc. The other uncertainty factor is how correctly we simulate the sensitivity of climate system, namely the expected temperature in response to given changes of the external factors. We are not really able to estimate the first uncertainty source, due to its complexity, but we can validate the climate sensitivity simulations through testing certain particular processes. These particular processes are the climate feedback mechanisms, including variables and processes, that change due to climate changes, but which re-direct the measure of climate change, as well.

The expected changes in the global average could be determined from Fig. 3. The expected changes are shown using the three scenarios of the IPCC Report (IPCC 2007) assuming constant atmospheric composition as it was in 2000. The right side of Fig. 3 shows the absolute uncertainty of three basic scenarios in addition to three more popular alternatives given in the Report 2001.

If we compare the uncertainty originated from different emission scenarios from sensitivity differences of the models, we have to assess both uncertainty sources to be similar. Hence, decreasing the difference of climate models, reflecting better knowledge of the real sensitivity, would be equally useful from the point of view of the prediction as reduction of the uncertainty of future emissions.

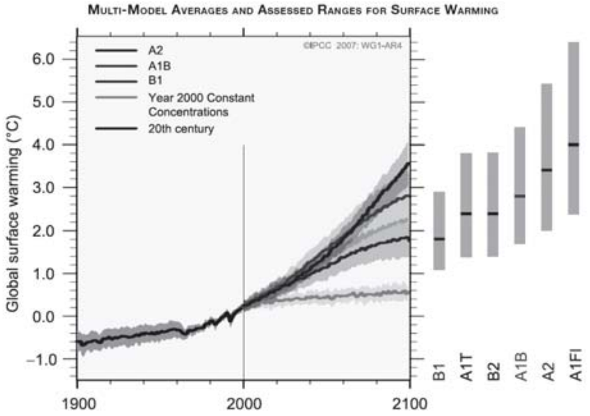

Fig. 3. ***Global mean temperature scenarios. The solid lines show the changes of global mean temperature. The lines before 2000 show the observed values and their ±1 standard deviation. Later they are the results of all available model simulations as deviation from the 1980-1999 average, according to the A2, A1B, and B1 scenarios. The lower, almost constant line is for the experiment with constant concentrations after 2000. The right hand columns show the uncertainty, characterized by 60% higher and 40% lower values (IPCC 2007: Fig. 10.29).***

Above it was shown that the sensitivity of climate models differs form each other. It is important to test simulated feedbacks in the models, in which the satellite observation will have important role. The most frequently referred to figure of the IPCC (2007) Report shows how the mean Earth's temperature can change according to the possible scenarios and climate sensitivity values.

In *Fig. 4* two tests of such feedback are shown. The long-wave radiation emitted from the surface is influenced only by water vapor content of atmosphere under clear sky. The more water vapor is in the atmosphere, the bigger part of the surface long-wave radiation can be absorbed. It means that a smaller part of the energy could leave into the space. The water vapor is a greenhouse gas itself causing more than the a half of the natural greenhouse effect. But, since water vapor content of the atmosphere is changing mainly due to internal processes of the climate system, from environmental point of view we do not consider it as a greenhouse gas.

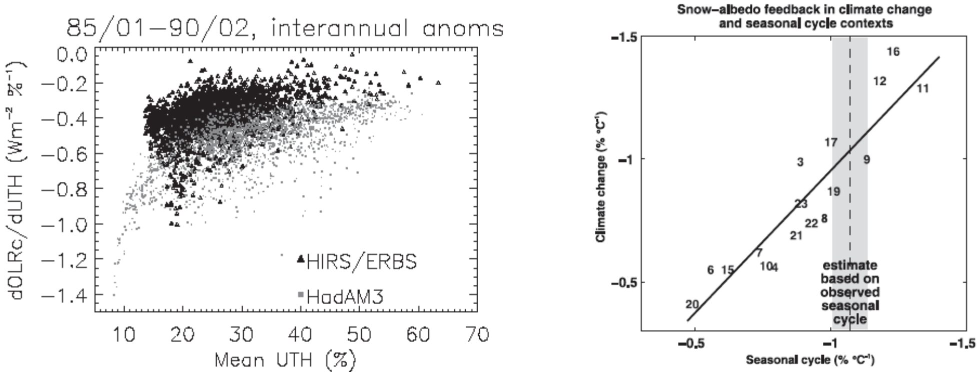

Fig. 4. ***Model estimation of most important elements of (cloudless) long wave (a) (Allan et al., 2004: Fig. 2) and shortwave balance (b) (IPCC, 2007: Fig. 8.16). In first figure the HadAM3 climate model of British Hadley Centre, calculated for tropical area, under clear sky, shows that the long-wave component decreases too fast with increasing water vapor content of upper stratosphere. It means that the model simulates a bigger value for the irradiance than it was measured by ERBS and HIRS satellites. This error means too strong negative feedback in the model. We can also see how the short-wave balance depends on surface albedo in case of 17 different models in the lower part of the figure. The vertical axis shows the albedo decrease depending on unit global warming as one difference between 20th and 22nd Century simulated climates. The horizontal axis shows the ratio of satellite observed April-May albedo and temperature values for the Northern Hemisphere. The seasonal albedo sensitivity is estimated using data fields of ISCCP cloud climatology and ERA-40 atmosphere analysis projects. The models produce large deviations from this value, and in majority they exhibit weaker feedback than the empirical estimation. Both errors lead to smaller climate sensitivity than in reality.***

The upper part of *Fig. 4* demonstrates that the mentioned model overestimates the influence of water vapor on the irradiance. It means that the model simulates the most important stabilizing negative feedback of the climate system to be weaker than in the reality. Contrary to this, the positive feedback has got the biggest influence on short wave balance connected with the changes of snow and ice cover. The stronger the warming is, the larger area of the elements of cryosphere will thaw, and the albedo of a large area will be darker instead of snow and ice with high reflectivity. Since the snow-free surface is able to absorb more energy and use it for warming of the atmosphere, it will amplify the warming as well.

6. CONCLUSION

The use of remote sensing from space is advantageous, since it allows us to observe a wide range of climate parameters on a global scale in a consistent and repeatable manner. There are several parameters that can practically be observed only this way.

Though there are some constraints in accuracy and in precision, as well, the moderate space and time resolution, which is enough for climate science applications, mean that they are not especially limiting. Detection of climate change is important since ground-based detection has many local influences and other practical constraints, especially concerning the cryosphere and the strongly related sea-level.

The third group, the validation of the present climate model simulations could have been more detailed, but the results of the comparison are rather model-dependent with some uncertainties in the indirect observations. More attention was paid to the validation of the feedback mechanisms, determining the radiation balance of the atmosphere largely influencing the sensitivity of our climate to the external forcing factors. Undoubtedly, this is the most policy-related aspect of climate science.

For teaching climate change in any school subject, satellite images always bear the advantage of undoubted fidelity. Both the primary products and composites are straightforward tools to understand weather. Though the above illustrated possibilities required far more elaborations than that in case if a single image or a moving series of them, the satellite images are of high confidence among the public (students or pupils). Hence, the above indicators of climate change and its research by climate modelling can effectively be applied to illustrate the statements of contemporary climate science.

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