POSSIBILITIES OF EXTRACTING INFORMATION ON CLIMATIC PARAMETERS FROM THE AMERICAN OPERATIONAL SATELLITES

K.Ya. Kondrat'ev

Scientific–Research Center for Ecological Safety, St. Petersburg
Received March 20, 1992

Some information about on the climatic parameters which has been already used or can be obtained in the nearest future based on the observational data from the American operational satellites is reviewed.

Already from the first observations with the help of meteorological satellites (note that the first meteorological satellite TIROS–1 was launched on April 1, 1960) it became clear that not only qualitative information in the form of images of the cloud cover and underlying surface within the visible and IR spectra but also some quantitative data on a number of parameters (cloudiness and height of the upper boundary of clouds, the atmospheric moisture content, temperature of the ocean surface, etc.)[1–9] can be obtained.

On the threshold of the fourth decade of the satellite meteorological observations an analysis of a possibility of interpreting the data obtained with the available operational satellites becomes of great interest that is very important because of increasing attention being paid now to the problem of climate change. For example, such an analysis has been done in Ref. 10 taking into account the equipment installed onboard American operational satellites: 1) the advanced very–high–resolution radiometer (AVHRR) used on NOAA satellites, 2) the apparatus of operational remote sensing of the atmosphere (TOVS, NOAA satellites), 3) the radiometer for measuring the backscattered UV radiation (SBUV, NOAA satellites), 4) the radiometer for the visible and IR spectra (VISSR, GOES geostationary satellites), and 5) UHF instruments SSM/I, SSM/T, and SSMR used on meteorological satellites of the Departament of Defence of the USA (DMSP). Sufficiently detailed description of the above–mentioned equipment can be found in Refs. 5–8. Informational possibilities of soviet meteorological satellites were discussed in Ref. 7. Following Ref. 10 let us characterize the potentialities of the American operational satellites depending on the basic groups of observations.

RADIATIVE BALANCE OF THE EARTH (RBE), CLOUDINESS, AND AEROSOL

In obtaining information about climate parameters a possibility of conducting uniform series of observations whose period lasts now more than two decades is of a key importance. It means that there appears a necessity (for a storage of the databases) to ensure the reliability of calibrations, to take into account the variation of instrumental characteristics, parameters of orbits, etc. It is well known, for example,[5,6] that the problem of climate change dictates a need for the data on the global average values of the RBE components with error not more than 1 W/m^2, while in the case of regionally averaged values the error can reach 5 W/m^2 but the errors in revealing long–term trends have to be below 1 W/m^2. This, in turn, imposes very strict limitations on the stability of instrumentation sensitivity and on the reliability of calibration.

An important part of investigations carried out now by the NOAA staff is the development of an algorithm for retrieving the cloudiness and the radiative characteristics of cloud from the data obtained with the help of a 5–channel scanning radiometer AVHRR and the algorithm of retrieving the pressure and temperature at the level of the upper cloud boundary and cloud moisture content from the TOVS data as well. Since 1989 the aerosol optical thickness (AOT) of the atmosphere above the ocean has been regularly retrieved based on the data obtained with the help of a single shortwave channel of the AVHRR, while in future it is planned to use the observational results at 2–3 wavelengths for determining not only the AOT but the aerosol microstructure as well. It is important to perform further development and improvement of the algorithms for reconstructing: 1) the RBE components, including the spectral distribution of outgoing longwave radiation (OLR) and radiant heat flux from the TOVS data, 2) the components of radiative balance of the underlying surface), 3) the characteristics of the cloud cover (cloudiness, pressure and temperature at the level of the upper cloud boundary, and moisture and ice content), and 4) the total content and microstructure of aerosol (not only above the ocean but above dry land, as well). It is especially important to meet the requirements of the Global Energy and Water Cycle Experiment (GEWEX) and of the experiment on studying the Tropical Ocean and the Clobal Atmosphere (TOGA) and the conditions under which the observational data[6–8] were obtained.

STRATOSPHERE

In the part concerning the stratosphere, the determination of the total ozone content (TOC), air temperature and flux of the UV solar radiation is discussed and basic requirements to the observational data reliability are following. The errors in revealing the TOC trends should be less than 1–1.5 % during the whole decade of observations, the errors in vertical concentration profiles of ozone should be less than 3–5 % and those of the stratospheric temperature less than 1–1.5 %. Since the ozone layer dynamics depends on the extraterrestrial variability of the UV solar radiation within the range of wavelengths 170–240 nm (radiation of these wavelengths is responsible for the formation of the atmospheric oxygen in the upper stratosphere), it becomes particularly important to detect the variations of the UV radiation which can amount up to 20 % during 11–years solar cycle. Reliable detection of the variability of the ozone content of natural genesis in the upper stratosphere establishes the base for reliable identification of an anthropogenic effects.

0235-6880/92/07 468-05 $02.00

Determination of the stratospheric temperature is one of the most difficult problem in sounding the stratosphere, since the ceiling of radiosondes is limited, as a rule, by the altitudes less than 30 km, rocket sounders are launched very seldom, and techniques of remote (in particular, lidar) sensing are now developed insufficiently. Meanwhile, the information about the trends of the stratospheric temperature is of great importance: as numerical simulations of the climate changes caused by the intensification of the atmospheric green–house effect showed that the stratosphere[6] has the most reactive sensitivity which must result in cooling. In this case an account of interactive character of the temperature and ozone variations is very important.

For the first time the SBUV/2 instrumentation was launched onboard the NOAA–9 satellite in March 1985 to obtain the data on the TOC. An improved version of this instrumentation was then installed onboard the NOAA–11 satellite in January 1989. Although these observations were assumed to be operational (following the preceding observations with the SBUV instrument used onboard the Nimbus–7 satellite) some difficulties in data interpretation do not allow one to consider these observations as climatic. A new stage of ozonometric observations started with launching the UARS satellite and the TOMS instrumentation onboard a Meteor–3 satellite in 1991.

Beginning in 1978 the TOVS remote sensing instrumentation is an ordinary component of a scientific instrumentation complex of all NOAA satellites. A by–product of the operation of the TOVS instrument were data on the TOC that were obtained using a linear regression technique from the ground–based Dobson observations, later on replaced by a physically more correct reconstruction technique.

The first data of remote thermal sensing of the atmosphere were obtained in 1969 with the help of a SIRS spectrometer which was developed for the satellites of the Nimbus series. Since then different instruments were used for this purpose but an operational thermal sensing of the atmosphere started only in 1978 from satellites of the TIROS–N (NOAA) series. The TOVS instrument, which is used now, consists of three blocks: a block of IR high resolution sensing (HIRS–2), blocks of UHF sensing (MSU), and stratospheric sensing (SSU). Each of these instruments makes scanning observations in the plane perpendicular to the orbit with the spatial resolution not less than 200 km. It ensures a retrieval of the vertical profile of temperature within the atmospheric thickness from 1000 to 0.4 hPa (0–54 km) with the vertical resolution of the order of 10 km. It is obvious, that the central problem here is the problem on errors of reconstruction and on reliable detection of trends. A comparison with the rocket sensing data showed that mean deviation of the temperature (relative to the rocket data) at the levels 5, 2, 1, and 0.4 hPa were 6, –3, –7, and 6°C, respectively, with the presence, at the same time, of a considerable temporal variability of deviations (for example, at the level of 2 hPa the deviations varied from 0 to 6°C).

An important mean for eliminating the sensitivity drift of the satellite instruments (both for ozone and temperature observations) are the reference ground–based observations. For this purpose a plan of the stratospheric monitoring in 1988–1997 was developed in the USA. The main goal of this shedule is to provide uniform series of satellite observations, in combination with data of the ground–based observations at different points on the globe (by 1993/94 5 stations will have to operate in tropics, at mid–latitudes of both hemispheres, in the Arctic, and in the Antarctic) obtained with a reliably calibrated instrumentation. The basic source of reference information about the stratospheric temperature has to be lidar sensing but the remote sensing is proposed to be carried out simultaneously in the UV, visible, IR, and UHF regions.

Since the data of the SBUV/TOMS make it possible to reconstruct the sulphur gas content in the stratosphere (at least, after the volcanic eruptions when SO_2 content is essentially enhanced), the problem of developing a new reconstruction algorithm which makes it possible to obtain information not only about the ozone but also about the sulphur gas was formulated.

TROPOSPHERE

From the point of view of monitoring of the climate dynamics the satellite observations of the general circulation of the atmosphere including water vapor and cloud cover are of key importance. In this connection provision is made for obtaining data of three levels: 1) direct observational data of the intensity of outgoing radiation (both shortwave and longwave) provided that uniformity of the observational series is guaranteed (first of all, elimination of the discrepancies between the data that could be caused by specific features of different instrumentation), 2) reconstructed values of the geophysical parameters, and 3) four–dimensionally adopted data. Data division of such a kind makes (in case of appearance of more reliable reconstruction algorithms) the reprocessing of earlier compiled data to be possible.

Data on the remote sensing of the atmosphere accumulated from 1969 include the results of the observations obtained with the following instrumentation: SIRS–A (Nimbus–3 satellite, spectral range of operation is 11–15 μm, the spatial resolution along nadir is 250 km, the observational period is 1969–1972); the VTPR (NOAA–2 ... 5, 12–19 μm, 7–14 km, 1972–1978); the TOVS (TIROS–N, NOAA–6 ... 11, from October 1978 till now); the HIRS–2 (NOAA, 4–15 μm, 145 km); and, the MSU (NOAA, 50–60 GHz, 109 km).

The data set obtained with the above–mentioned instrumentation includes the following information (at a nominal horizontal resolution about 60 km): the vertical profiles of the temperature and humidity, the TOC, the pressure at the level of the upper cloud boundary and effective cloudiness amount, the temperature of the ocean surface and dry land, the OLR due to cloudiness, longwave radiation force effect, the precipitation intensity, UHF–emittance of the snow and ice cover, and wind velocity field (estimated from the drift of clouds or of the water vapor content inhomogeneities).

A central problem of interpreting the observational data on the tropospheric parameters is to investigate the interactions between cloudiness and radiation within the scope of the problem on the global energy balance[6,8] that requires, in particular, reliable information about water vapor content and characteristics of the cloud cover. Satellite data available involve information about the total moisture content in the atmosphere above the oceans (SSM/I, SSMR), relative humidity of the upper troposphere (6.7 μm channel of the GOES satellites), and corresponding data obtained with the TOVS. The use of data of the channel No. 2 of the MSU instrument is of great importance for intercalibrations. Since in the past there could occur variations of the instruments sensitivity with time, the corresponding data should be reprocessed in order to provide the observational series uniformity.

CHARACTERISTICS OF THE LAND SURFACE

Characteristics of plant canopy, snow and ice covers are the integrated indicators of weather and climate on the environment. In addition, they can be used as indirect indicators of thermal and hydrologic regimes. To reach a success in numerical simulations of the climate it is very important to solve the problem on parametrization of the processes occuring on the land surface. As in the above–considered cases of remote sensing, high quality of data obtained from satellite measurements of the intensity of outgoing radiation at different wavelengths is of key importance. The most important components of the data set being discussed is information about the vegetation index, as well as on the extension, thickness, and water content equivalent of the snow cover.

Information about the vegetation index was used for solving a wide range of problems involving the studies of biogeochemical cycles and ecosystems. As an example the following problems can be mentioned: monitoring of pastures, arid zones, and tropical forests, classification of lands, estimations of photosynthetic activity and primary crops, and also gaseous emission when burning a biomass, etc. To accumulate the data for determining the land parameters the storage of the AVHRR data of two kinds is performed: 1) data with spatial resolution 1.1×1.1 km^2 ensuring a solution of the local problems (local arrays LAC) and 2) data with spatial resolution 4.4×4.4 km^2 (global arrays GAC). Beginning in February 1982 the GAC data were regularly used for calculating the vegetation indices (as a rule, the normalized vegetation index NDVI) and their mapping at the subsequent stage.

In addition, from the AVHRR data the maps of distribution of the snow cover were plotted weekly. Although there was a possibility of mapping global picture of the snow cover based on the UHF data, in this field only methodological developments were carried so far. The same situation is observed in the case of using the UHF data for obtaining data on the thickness and water content equivalent of the snow cover.

Developments of techniques for determining the amount of radiation active in photosynthesis are also of certain interest.[3]

WORLD OCEAN

The needs for information about the world Ocean that could be critically important in climate studies, can be classified into two categories: monitoring and estimates of different inducing actions and reliability of the numerical simulation results of the climatic processes (of course, both these categories are closely interconnected). Among the parameters from the first category there are: temperature of the ocean surface (TOS), the height of the ocean–surface level, dimensions of the ice cover (DIC), and albedo; while the second category includes, in particular, the TOS and the DIC, the wind velocity field near the ocean surface, components of the heat balance of the surface, and difference between evaporation and precipitation.

At present information about different categories on the TOS is routinely compiled in the archives at NOAA. Based on the GAC AVHRR data possessing 4–km spatial resolution the global arrays are composed for the day– and nighttime averaged over pixels 8×8 km^2. In the daytime the source of information for determining the TOS is the data from channels Nos. 4 and 5 (wavelengths 11 and 12 μm), while the measurements carried out from channel No. 2 (0.9 μm) are used for filtering out the cloudiness. For processing the nighttime observations both these problems are solved using the data obtained from channels Nos. 3 (3.723 μm), 4, and 5. The standard deviations of thusly determined TOS values from those obtained from the buoy observations vary within the limits 0.3–0.7°C. Daily results of the global objective analysis are generated in the form of a map with the grid of 1° of latitude by 1° of longitude belts within the range 70°N–70°S and, in addition, twice a week regional maps are prepared (mainly, for the coastal waters of the USA) with the resolution of 0.5° and 0.125° and test global maps with the resolution 0.5° are also prepared sometimes. All available data on the TOS are generalized in the form of monthly mean global fields on the grid $2.5° \times 2.5°$. Other forms of the data representation are used as well, for example, weekly fields of the TOS on the grid $1° \times 1°$, which are calculated using the technique of optimal interpolation. To decrease the reconstruction errors down to 0.5°–0.3° it is necessary to increase the accuracy of measurements and their verification based on the buoy data, to improve the calibration and determination of geographical coordinates, to increase reliability of the atmospheric correction with an account of aerosol, to introduce the corrections for difference between the temperatures of the surface and the upper ocean layer, to unify the techniques of processing of the daytime and nighttime data, and to perform the construction of the monthly mean daytime and nighttime fields of the TOS separately.

Sources of information about the wind velocity near the ocean surface are the data of passive UHF–observations (SSM/1), while for obtaining the wind shears the results of active radio sensing are necessary. The use of the active UHF sensing data obtained with the help of scatterometers and radars with a synthesized aperture is still at the stage of tests (a considerable progress should be expected from the processing of data obtained with RS–1 and Almaz–1 satellites launched in 1991, while the Oceanographic Center of the USA Air Force has already made first attempts to construct the global wind fields. The attempts to reconstruct the ocean surface height from radio altimeter measurements are also only the experimental ones.

Determination of components of the heat balance of the ocean surface[5,6,8] is also a difficult problem. A noticeable progress was achieved in using the AVHRR data for reconstructing the total radiation and albedo, but only the first steps were done in solving the problem on reconstruction of the latent and explicit heat fluxes.

CONCLUSION

A general characteristic of the possibilities of determining the climate parameters from the results of observations being carried out with the instrumentation installed onboard the American operational satellites is given below in the table.

TABLE I.

Climate parameters	Apparatus							
	AVHRR	TOVS	SBUV	PRE–TOVS	COES	SSM/I	SSM/T	SSMR
Improved available parameters								
Vertical profile of temperature	+	+		+	+		+	
Vertical profile and total ozone content		+	+					
Solar radiation flux		+		+				
Outgoing longwave radiation (OLR)	+	+						
Earth's albedo	+							
Parameters of the cloud cover	+	+			+	+		
Total aerosol content	+	+				+		
Vegetation index	+					+		
Extension of snow cover	+				+		+	
Temperature of the ocean surface								
New parameters								
Database on the intensity of outgoing radiation	+	+		+	+			
Temperature of the dry land surface	+				+			
Depth of snow cover						+		+
Water equivalent of snow cover						+		
Forest fires	+							
Fluxes of outgoing radiation for clear sky	+	+						
Water content of clouds	+					+		
Moisture content of separate layers of the atmosphere		+		+				
Climatology of water vapor					+	+		
Wind for drift of the water vapor					+			
Wind near the ocean surface						+		
Extension and ice–cover packing	+					+		
Fluxes of the heat between the atmosphere and ocean	+					+		
Aerosol parameters	+							
Histograms of intensity of outgoing radiation	+	+						
Multispectral outgoing longwave radiation		+						
Radiative heat influx in the atmosphere		+						
Counter radiation of the atmosphere		+						
Albedo of underlying surface	+							
Index of radiation gradient	+							

REFERENCES

1. K.Ya. Kondrat'ev, *Satellite Climatology* (Gidrometeoizdat, Leningrad, 1983), 264 pp.
2. K.Ya. Kondrat'ev, Itogi Nauki Tekh. Ser. Meteorol. Klimatol. **14**, 204 (1985).
3. K.Ya. Kondrat'ev, *Earth's Radiative Balance* (Gidrometeoizdat, Leningrad, 1988), 350 pp.
4. K.Ya. Kondrat'ev, Itogi Nauki Tekh., Ser. Geomagnetizm Vysok. Sloi Atm. **11**, 212 (1985).
5. K.Ya. Kondrat'ev, Itogi Nauki Tekh., Ser. Teor. Obshch. Vopr. Geograph. **9**, 454 (1990).
6. K.Ya. Kondrat'ev, *Global Climate* (Nauka, Leningrad, 1992), 361 pp.
7. K.Ya. Kondrat'ev, A.A. Buznikov, and O.M. Pokrovskii, Itogi Nauki Tekh. Ser. Meteorol. Klimatolog. **12**, 471 (1992).
8. G.I. Marchuk and K.Ya. Kondrat'ev, *Urgent Problems of Global Ecology* (Nauka, Moscow, 1992), 317 pp.
9. G.I. Marchuk, K.Ya. Kondrat'ev, V.V. Kozoderov, and V.I. Khvorost'yanov, *Clouds and Climate* (Gidrometeoizdat, Leningrad, 1986), 512 pp.
10. *Product Development Plans for Operational Satellite Products. NOAA Climate and Global Change Program*, Special Reports No. 5, UCAR, Boulder (1991), 78 pp.