

New assessments of global climate change

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RESUMEN

Con base en las discusiones en una sesión del Grupo de Trabajo 1 del Comité Intergubernamental sobre Cambios Climáticos, que se llevó a cabo durante el periodo, febrero 26 - marzo 2, 1990 en Gran Bretaña, y en el contexto del informe correspondiente se presenta una revisión del estado del arte de estudios sobre cambio global del clima.

Como una de las más importantes conclusiones, se ha llegado a un consenso, en que las causas del calentamiento climático observado durante el último siglo, permanecen aún poco claras. Esto determina la gran urgencia de llevar a cabo estudios y estimaciones cuantitativos de las variabilidad forzada internamente del sistema climático, sin los cuales la evaluación de los impactos antropogénicos sobre el clima no puede ser confiable.

Factores de formación del clima insuficientemente estudiados, tales como interacciones océano-atmósfera y radiaciones-nubosidad son los aspectos más sustanciales de la variabilidad interna. Se presenta una discusión sobre los correspondientes problemas no resueltos.

ABSTRACT

Based on discussions at a Session of the Intergovernmental Committee on Climate Change Working Group 1 held during the period February 26 - March 2, 1990 in Great Britain, and in the context of the WG-1 Report, a review has been made of the state-of-the-art of studies on global climate change.

A consensus has been reached on one of the most important conclusions that the causes of the climate warming observed during the last century remain still unclear. This determines the top urgency of studies and quantitative assessments of the internally forced variability of the climate system, without which the "filtering-out" of anthropogenic impacts on climate cannot be reliable. Such insufficiently studied factors of climate formation as ocean-atmosphere and cloud-radiation interactions are the most substantial aspects of the internal variability. The related unsolved problems have been discussed.

Introduction

The increasing urgency of the problem of global climate change necessitates regular assessments of the results from studies and developments in this field. This, for example, had been the aim of the International Conference held in 1985 in Villach (Austria). In 1988, the WMO (World Meteorological Organization) and UNEP (United Nations Environmental Programme) decided to form an Intergovernmental Panel on Climate Change (IPCC), which was to prepare a report by the end of 1990 for the consideration by the second World Climate Conference. The purpose of the report is to characterize the present understanding of the observed regularities of climate change and possibilities of climate prediction, its impact on the environment and human activity as well as needed economic measures able to ameliorate undesirable climate changes.

Three Working Groups (WG) have been organized to prepare this report:

1. WG-1: Scientific Assessment of Climate Change (Chairman Dr. J. T. Houghton, Director-General of the U. K. Meteorological Office).
2. WG-2: Climatic Implications (Chairman - Dr. Yu. A. Izrael, Corresponding Member of the USSR Academy of Sciences, Chairman of the USSR Committee on Hydrometeorology).
3. WG-3: Political response to Climate Change (Chairman - Dr. F. Bernthal, USA).

From February 26 to March 2, 1990 a WG-1 Session was held in Edinburgh (Great Britain) to discuss a draft of the report prepared by a large group of experts on scientific assessment of the present state of developments on the problem of climate change. This paper summarizes the results of the WG-1 discussions.

It should be emphasized that the objectives of WG-1 are very difficult to achieve, at least, for two reasons: (i) even an interpretation of the causes of the climate warming trend for the last hundred years is ambiguous, and the existing climate predictions should be considered only as conditional scenarios; (ii) through efforts of a number of scientists and from some mass media information a scientifically unjustified opinion has been rather widely spread that the global climate warming observed in this century has been determined by increasing CO₂ concentrations in the atmosphere, and by the middle of the next century, a catastrophic climate warming will take place, followed by a strong rise of the World Ocean's level.

Note, that both the report of WG-1 (Report..., 1990) and its summary (policymakers Summary..., 1990), first of all, emphasize the reality of the greenhouse effect manifested in that the atmosphere containing greenhouse gases (GG) determines the average Earth's surface temperature 30° higher than in the case of the "non-greenhouse" atmosphere. the most substantial GGs are water vapour, carbon dioxide, methane, chlorofluorocarbons, nitrous oxide, tropospheric ozone (Kondratyev and Moskalenko, 1983, 1984). A similar situation exists on other planets (Kondratyev, 1990). So, for example, on Venus the greenhouse effect reaches 523°C, whereas on Mars it is only 10°C.

Global climate change assessments

Calculations based on the use of present climate models with an assumed doubled CO₂ concentration have led to the conclusion that a mean global climate warming (a surface air temperature (SAT) increase) within 1.5-4.5°C should happen (apparently, a value of 2.5°C is most likely), with a simultaneous intensification of water cycle, which will manifest itself in growing precipitation (and evaporation) by about 2-13%. With an assumed increase of the GG concentration equivalent to a doubled CO₂ concentration to take place by the year 2030, it can be stated, bearing in mind that delaying effect (thermal inertia) of the World Ocean, that by this time, the mean global SAT can increase by 1-2°C. the global warming should be followed by various regional climate changes. For example, one may expect a faster warming of the land than of the oceans. The calculations have also suggested that the warming in South Europe and North America should exceed the mean global one and will be followed by decreasing summertime precipitation and soil moisture. Probably, the Asiatic monsoon will intensify. It is not possible, so far, to predict the effect of global climate warming on the frequency and intensity of catastrophic events (typhoons,

hurricanes, floods, etc.). Mainly, due to thermal expansion and melting of continental ice, the World Ocean's level may rise up to within 10-30 cm (the catastrophic rise of the ocean's level by several meters due to disintegration and melting of the Western Antarctic ice sheet is not likely).

It has been recognized that climate predictions for the future with the use of the past climates as analogues are incorrect, but the importance of paleoclimatic studies for understanding the causes of climate changes and as a source of information on the past climates, to check the reliability of climate models raises no doubts (Adem, 1988).

During the recent years, climate changes have been calculated based on the use of the latest global models with prescribed not suddenly doubling but continuously increasing (by 1%/year) CO₂ concentrations. The results of these calculations testify to a substantially different response of the climatic system to the stepwise and gradual growth of CO₂ concentration. New results of numerical modeling revealed the possibility of a very long-term internal climatic variability with an amplitude of about $\pm 0.2-0.3^{\circ}\text{C}$ and a strong effect of mixing, in the circumpolar ocean, on climate (this is the reason, for example, why any significant warming of the North Atlantic does not take place).

An analysis of data of meteorological observations for the last hundred years revealed a mean global SAT increase by $0.3-0.6^{\circ}\text{C}$, the most intensive warming taking place in the 1980s. Such a warming agrees, on the whole, with the results of numerical modeling of the impact of CO₂ increase. However, there are no grounds to believe that it is determined by growing concentrations of CO₂. Such a conclusion can be made for several reasons and, in particular, because the spatial distributions of the warming in both hemispheres are quite different and do not correspond to the numerical modeling results, which can be explained by the effect of an inadequately simulated natural (internally forced) climatic variability. Also important is the fact that the estimates of the greenhouse warming are close to natural (internal) climatic variability.

It is interesting that the warming in the current century has been concentrated during two periods (Ellsaesser, 1990; Kondratyev, 1987): 1920-1940 and after 1975. During the time period from the 1940s to the early 1970s in the Northern Hemisphere a climate cooling took place (though at that time an intensive development of industry took place, except for the war period), and the mean SAT in the Southern Hemisphere remained practically constant. The spatial distribution of global warming after 1975 was very inhomogeneous: in some regions (mainly, in the Northern Hemisphere) a cooling took place which lasted till nowadays. An analysis of precipitation data revealed still stronger inhomogeneities. For example, if over the most of the USSR territory an intensification of precipitation was observed during the last century, a strong decrease of summertime precipitation took place south of the Sahara desert, starting from the 1950s.

An important reason of global climate variations was variations in the oceanic general circulation (OGC) during the last 30 years, which could, for example, cause a cooling of the surface waters of the North Atlantic between 1960 and 1985. Much stronger fluctuations of OGC, delaying the post-glaciation warming, had taken place during the time period of the order of several hundred years about 10.5 thousand years ago.

There are no convincing evidence, so far, to believe that the climate has become more variable during the last several decades. No doubt, however, the episodes of heightened temperature will become more frequent in the future, because total rise of temperature is to take place.

The increasing trends of GG concentrations

From the view-point of assessing possible anthropogenic impacts on climate the starting factor to be taken into account (and forecast) is the trends of GG concentration growth. From data of direct and proxy indicators one can reliably judge about not only present but also paleovariations of GG concentrations in the atmosphere. Analysis of ice cores has led to the conclusion, for example, that concentrations of carbon dioxide, methane and nitrous oxide during the glaciations had been much lower than in the interglacial periods. Thousands of years before the industrial revolution, comparatively stable GG concentrations had been observed. However, as population and industrialization had grown, the GG amount in the atmosphere increased. The data of Table 1 illustrate variations in GG concentrations (volume mixing ratios are given) compared to the pre-industrial period, as well as the present values of the rate of the concentration growth.

Table 1. Observed trends of concentrations of principal greenhouse gases in the atmosphere

Parameter	Gas	CO ₂	CH ₄	CFC-11	CFC-12	N ₂ O
Pre-industrial concentration		280 ppm	0.79 ppm	0	0	288 ppb
Present concentration		354ppm	1.717 ppm	280 ppt	484 ppt	310 ppb
Observed annual increase of concentration		1.6 ppm (0.5%)	0.15 ppm (0.9%)	10 ppt (4%)	17 ppt (4%)	8 ppb (0.25%)
Life-time, years		50-200	10	65	130	150

At present, the causes of the growth of concentrations of carbon dioxide, methane, chlorofluorocarbons (CFC) and tropospheric ozone are, in general, known, but in the case of nitrous oxide they are not that definite.

Of interest is the long live-time in the atmosphere of such components as carbon dioxide (here the uncertainty in the estimates is determined by difficulty of an account of processes in the ocean, responsible for the formation of global carbon cycle), CFCs (especially CFC-12), and nitrous oxide. This testifies to long-term consequences of emissions of such GG to the atmosphere: an equilibrium level of concentration (even after the cessation of emissions) can be reached only during many centuries. So, for example, if in 1990 the emission of CFC-12 totally stops, the level of the concentration of this freon in the atmosphere by the year 2100 will, still reach one third with respect to the present level. Another situation exists for some substituors for CFCs and methane, for which the time to reach an equilibrium concentration constitutes only several decades. The estimates have shown that to provide stable concentrations for different GGs in the future, now the following relative reductions of emissions are necessary (respective values are given in brackets): carbon dioxide (60-80%), methane (15-20%), nitrous oxide (70-80%), CFC-11 (70-75%), CFC-12 (75-85%), CFC-113 (85-95%), HCFC-22 (40-50%). The data of Table 1 shown a more rapid increase (compared to CO₂) of concentrations of methane, nitrous oxide and CFCs, which reflects their increasing contribution to the formation of the greenhouse effect.

The GG dynamics and the formation of the atmospheric greenhouse effect

An important aspect of assessing the "greenhouse" climate warming is calculations of contributions of various GGs into the formation of the atmospheric greenhouse effect, with different prescribed scenarios of the GG dynamics (concentration growth). This problem has been discussed in detail by Kondratyev and Moskalenko (1983, 1984) as applied to the atmospheres of the Earth and other planets.

The principal difficulty is assessing the contribution of various GGs to the formation of the Greenhouse effect and related climate change is determined by the existence of numerous feedbacks (both positive and negative), which determine an exclusive complexity of the account of respective interrelated processes (Kondratyev, 1987). Naturally, with the feedbacks ignored, a global climate warming should be expected, determined by the greenhouse effect intensification. In estimations of the contribution of various GGs to the formation of the greenhouse effect, of great importance is the fact that the contribution per one GG molecule strongly differs. So, for example, the calculated impact of one molecule of methane on the greenhouse effect is 25 times more intensive, compared to CO₂, and that of CFC-11 molecule is 11 thousand times stronger. This is particularly important in connection with the rapid growth of CH₄ and CFC-11 concentrations. Therefore an increase of an equivalent CO₂ concentrations (calculated with an account of the contribution by other GGs) is now about twice as high than the real CO₂ concentration increase.

To assess the contribution of various GGs to the greenhouse effect formation, it is worthwhile to introduce the concept of the global warming potential (GWP) for GG, determined as the contribution of GG to the greenhouse effect per 1 kg of an instant release of the given GG with respect to related CO₂ contribution for conditions of the present atmosphere. Table 2 contains the results of calculations of relative cumulative contributions for three time intervals. The last but one column of the Table shows present absolute values of GG emissions to the atmosphere, and the last column - relative cumulative contributions of GG to the greenhouse effect for a time period of one hundred years, calculated with the prescribed present level of emissions. Table 2 shows, for example, that during the decades to come, a substantial contribution to the formation of the greenhouse effect will be made by methane, whereas the effect of longer-lived nitrous oxide will be substantial for a longer time interval. Still more it refers to chlorofluorocarbons.

Table 2. Global warming potentials calculated per 1 kg of an instant GG emission with respect to carbon dioxide

Gas	Time interval, years			Emission levels in 1990, Tg	Relative cumulative contribution during 100 years, %
	20	100	500		
CO ₂	1	1	1	26000	61
CH ₄	67	23	10	300	16
N ₂ O	290	310	210	6	4
CFC-11	4900	3800	1600	0.3	3
CFC-12	7700	7900	4900	0.4	7
CFC-22	4400	1600	550	0.1	0.4

Though it follows from Table 2 that CO₂ is the least effective GG, abundant CO₂ emissions determine its prevailing contribution to the formation of the greenhouse effect. Data like those given in the Table, are important in planning a reduction of GG emissions in order to prevent from undesirable climate changes. In this connection, the first priority of the problem of the growth of CO₂, CH₄ and CFC concentrations raises no doubts.

When discussing the problem of impacts on the greenhouse effect and climate formation, such an optically active component as aerosol must be taken into account (Kondratyev *et al.*, 1983), the more so that the intensifying pollution of the atmosphere by gas components (e.g., sulphur dioxide) is connected with the intensification of gas-to-particle conversions of the anthropogenic aerosol formation. It should be stated that, so far, the fact that the atmosphere is a dynamic colloidal medium has been adequately treated. The development of numerical modeling of future global climate should foresee an interactive account of biogeochemical cycles, including gas-to-particle reactions of the aerosol formation.

With respect to the problem of feedbacks, one should emphasize its exclusive complexity determined by a great number of feedbacks and (in some cases) poor knowledge of these feedbacks (Marchuk *et al.*, 1986, 1988, 1989). No doubt, of key importance in this connection are the following two problems: (i) the atmosphere-ocean interaction; (ii) the dynamics of cloud cover, the cloud-radiation interaction.

The atmosphere-ocean interaction

From the viewpoint of assessing the anthropogenic impacts on climate, of key importance is the numerical modeling of the ocean-atmosphere interactive system to analyze the processes that influence the delayed reaction of the climatic system to external forcings. Even with an account of only the interaction between the atmosphere and the oceanic mixed layer 100 m thick, the process of warming takes about ten years. A consideration of circulation in deep layers of the ocean (in this connection, of primary importance is the heat input to great depths in high latitudes of the North Atlantic and Antarctica) has led to a characteristic time for reaching an equilibrium warming of about thousands of years.

The most powerful mechanisms for transformation and redistribution of energy function in the ocean. Having a low albedo and, respectively, absorbing the most part of solar radiation reaching the Earth's surface, the ocean redistributes this energy through the currents, and then the energy gets to the atmosphere, where it is realized, largely, as the latent heat of condensation. The oceanic currents are determined by exchange of momentum, heat and water between the atmosphere and the ocean. The currents have a complicated spatial structure which is governed by the spatial distribution of the continents, and by the bottom relief.

The principal feature of the vertical structure of the ocean is the presence of three layers: (i) the seasonal boundary layer of the ocean (BLO) whose thickness varies during most of the year from less than 100 m in the tropics to several hundred meters in the sub-polar seas (except for the Northern Pacific); (ii) a sphere of warm waters ventilated by the seasonal BLO, which propagates down to many hundreds of meters in the form of gyres under the influence of the Eckman convergence of wind-driven near-surface currents; (iii) a sphere of cold waters covering an enormous volume of bottom waters (about 80% of the oceanic waters) and ventilated by the seasonal BLO in the polar seas. The fields of temperature, salinity and concentration of

chemical components in these three layers had been established under the influence of heating due to solar radiation absorption and interaction with the atmosphere during thousands of years. In conditions of the equilibrium state, the oceanic currents (like the wind in the atmosphere) affect these fields, determining, thereby, global circulations of the heat, fresh water and chemical compounds dissolved in sea waters.

Deviations from the equilibrium cause a time-dependent reaction of the atmosphere-ocean interactive system to external disturbances, with the characteristic time for such a reaction being determined by the processes in the ocean which are much more slower than in the atmosphere due to high density and specific heat capacity of sea waters. The sphere of cold waters exhibits the slowest reaction, which is explained by its enormous volume and by spatially restricted regions of ventilation in the polar seas. In this case the time for establishing a new equilibrium reaches many hundreds of years, whereas in the case of the sphere of warm waters it is reduced to about one hundred years (due to intensive ventilation), though the effect of the deep oceanic layers on this sphere must be taken into account. The characteristic time for the reaction of the seasonal BLO (which is annually renewed) is determined by variations in the sphere of warm waters in time scales of an order of decades. Thus the World Ocean governs the dynamics of global changes in time scales for tens to hundreds of years. The reliability of the climate change forecasts depends much on an adequate account of the processes in the ocean and their interaction with the atmosphere.

In the course of further development of the interactive model of the atmosphere-ocean system, the emphasis should be placed on the following processes:

1. Small-scale (about 50 km) time-dependent gyres in the ocean which control the structure of permanent gyres and fluxes as well as the interaction of these gyres with the sub-water relief. Such gyres determine also the horizontal distribution of chemical compounds, like CO_2 , dissolved in sea water.
2. Small-scale (tens of km) patchy structures of the deep-water winter-time convection in the polar seas and in the northern part of the North Atlantic, which determine the transport of the heat and dissolved CO_2 to the depths more than 1 km (to the cold-water reservoir) as well as slow currents responsible for circulation of new waters coming to the World Ocean.
3. An intensive mechanism for ventilation of thermocline, through which part of the surface mixed layer waters goes from the seasonal BLO to the warm-water sphere.
4. The biological "pump" in the seasonal BLO determining an assimilation of CO_2 dissolved in sea waters by phytoplankton with the subsequent input of processed CO_2 to deep layers of the ocean and sedimentation.
5. An impact of global circulations of the heat, fresh water and dissolved chemical compounds on the formation of global fields of temperature, salinity, ice cover and chemical compounds near the ocean surface in equilibrium with climate change in the past.

These and other studies constitute an important part of the program of World Ocean Circulation Experiment (WOCE) and Joint Global Ocean Flux Study (JGOFS).

Cloud cover dynamics. Cloud-radiation interaction

Clouds are the most dynamic component of the climatic system playing the key role in its energetics (Marchuk *et al.*, 1986, 1988, 1989; Kondratyev and Binenko, 1988). This manifests itself, for example, in the important role of the latent heat released in the formation of clouds, and in the prevailing role of the cloud cover dynamics as a factor of the spatial and temporal variability of the Earth's radiation budget (ERB). In this connection, critically important is an adequate parameterization of the processes of cloud formation in climate models, whose evolution can be illustrated by the UKMO climate model developed by the U, K. Meteorological Office (Saunders and Mitchell, 1989). The UKMO 11-layer (with a non-uniform vertical distribution of the levels) model has the horizontal resolution $5^\circ \times 5^\circ$ lat-long and takes into account the possibility of the formation of a 3-layer cloudiness of lower (three lower layers of the model), middle (three middle layers), and upper (three upper layers) levels, as well as convective clouds.

The formation of clouds of a certain category can take place only in one of the layers, which is defined as a layer in which the amount of clouds of this category prevails. Three schemes of parameterization of stratus clouds have been developed:

1. According to the "relative humidity" (*RH*) scheme, the cloud amount *C* is determined from the relationship:

$$C = \left[\frac{RH - R_c}{100 - R_c} \right]^2, \quad (1)$$

where $RH > R_c$ and $R_c = 90\%$, or $C = 0$, where $RH < R_c$. *C* denotes the conventional cloud amount.

The threshold value $R_c = 90\%$ is assumed in all cases, except for upper-level clouds and clouds in the lowest layer of models for which $R_c = 100\%$. Table 3 characterizes *a priori* radiative properties of clouds.

Table 3. Radiative properties of clouds (RH scheme)

Level of Clouds	Albedo	Transmission	Emissivity
Lower	0.56	0.3	0.9
Middle	0.52	0.3	0.94
Upper	0.18	0.75	0.42

2. For the scheme of "cloud water" (CW) the water content of clouds whose dynamics is determined by relationship between water vapour condensation and precipitation, was assumed as a predictor. It is assumed that at a temperature above zero the water is liquid, and at a temperature below -15°C it freezes, and the rate of snowfall is constant and equals to 1 m/s, which means that the resultant rate of conversion to precipitation for the frozen particles is an order of magnitude higher than for liquid droplets. In the range $0^\circ + -15^\circ\text{C}$ the relationship between the shares of liquid and frozen particles is a monotonous function of temperature.

In the scheme considered, the radiative properties of clouds have been prescribed, too (Table 4), but the respective values have been found by calculations based on the use of a model with interactive radiative properties.

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3. The third scheme "cloud water radiative properties" (CWRP) is based on an interactive parameterization of the variability of the radiative properties of clouds, depending on their water content via analytical approximation of available data of observations and calculations. In particular, the emissivity

$$E = 1 - \exp(-kq) \quad (2)$$

where q is the water content of clouds (g/m^2), and $k = 0.13 \text{ m}^2/\text{g}$ (water clouds) or $0.0065 \text{ m}^2/\text{g}$ (ice clouds).

An application of the enumerated schemes of parameterization to the UKMO model has shown that in the case of the RH scheme a strong positive cloud feedback appears. Such a feedback is relatively neutral for the CW scheme and negative for the CWRP scheme. Such results testify to the principal importance of an adequate parameterization of clouds in climate models. An analysis of numerical modeling results revealed also the importance of correct understanding and parameterization of processes in ice clouds.

An inadequacy of the present-day cloud parameterization schemes necessitates the testing of the reliability of the existing schemes and their further improvement, bearing in mind, first of all: (i) an extensive programme of numerical experiments to analyze the climatic sensitivity to cloud cover characteristics; (ii) various observational programmes.

Below are given some considerations with respect to observations.

The International Satellite Cloud Cover Climatology Project (Kondratyev, 1983) has made it possible to accumulate a large global data base on various cloud cover characteristics. Extremely important are regular observations of the ERB (Marchuk *et al.*, 1988) which will be continued in the nearest future within the Soviet-French Programme SCaRaB. In this connection, Saunders and Mitchell (1988) substantiated the requirements for the data on ERB and cloudiness (Table 5).

Table 5. Requirements for the observational data on clouds and ERB characteristics (AVHRR-advanced very high resolution radiometer; AMSU-advanced microwave sounding unit).

Parameter	Available or potential data of observations	Required accuracy	Reached accuracy
ERB components	Global data bases on ERB (ERB satellites, Nimbus-6, 7 satellites)	$\pm 288 \text{ W/m}^2$	$\pm 1.3 \text{ W/m}^2$ $\pm 5\text{-}10 \text{ W/m}^2$
Clear-sky ERB components	ERB satellites	$\pm 2 \text{ W/m}^2$	$\pm 1.3 \text{ W/m}^2$
Water (ice) Content of clouds	No operational data	$\pm 10\%$	$\pm 40\%$
	Use of AVHRR data is possible and AMSU data for certain		$\pm 20\%$
Cloud-top height	ISCCP global data base	$\pm 0.5 \text{ km}$	$\pm 1 \text{ km}$
Cloud amount	Global data base	$\pm 5\%$	$\pm 3\%$
Equivalent size of cloud droplets	No developed techniques	$\pm 1 \mu\text{m}$	
Narrow-band data on the outgoing longwave radiation	AVHRR global data base	$\pm 1\%$	$\pm 1\%$

The available ERB global data has been successfully used to analyze the spatial and temporal variability of the global ERB fields, bearing in mind the analysis of real dynamics of energy-active zones (Marchuck *et al.*, 1988, 1989) and testing the reliability of climate models by comparing observed and calculated ERB fields. In this connection, a comparison of satellite and ground data on the ERB (to determine the radiative heat flux divergence for the whole atmosphere) as well as an accomplishment of dedicated programmes of sub-satellite, ground, aircraft, and balloon observations are very urgent. The results of such observational experiments will be important for verification both of climate models and their individual units, especially from the viewpoint of parameterization of cloud-radiation interaction. The effect of cirrus clouds and the effect of pollutions on cloud properties remain the least studied (Kondratyev and Binenko, 1988). The "aerosol-climate" observation experiments are also important (Kondratyev, 1987).

A special feature of the process of cloud formation is their multi-scale nature, which seriously complicates the solution of the problem of cloud parameterization. In this connection, an important direction of research is use of nested grid for large-scale climate models to apply (for certain regions) 3-dimensional mesoscale models which realistically simulate the processes of cloud for-

mation in the interaction with radiative and other processes (Marchuk *et al.*, 1989). Of course, meso-scale models should also be verified, and this necessitates the planning and accomplishing of respective field experiments, especially in conditions of broken cloudiness.

In the context of cloud parameterization, special emphasis should be placed on the hypothesis of the important role of dimethylsulfide produced by marine phytoplankton. Dimethylsulfide suffers in the atmosphere the gas-to-particle transformation into submicrone aerosol (condensation nuclei), affecting the micro-physical and optical properties of clouds and, hence, the ERB and climate. To check the reliability of this hypothesis, dedicated numerical and observational experiments are needed. It is of interest that an analysis of data of satellite observations of the Earth's albedo in the region of the U. S. eastern coastline and adjacent parts of the Atlantic Ocean, performed recently by R. Cess, revealed a marked increase of the albedo of clouds over the ocean, which can be explained by the effect of industrial emissions of sulphur dioxide to the atmosphere.

Conclusion

Results of the present-day numerical assessments of possible climate change in the future are very uncertain due to first of all, inadequate account of cloud feedbacks, which can either intensify or limit the response of the atmosphere to increasing concentrations of GG, as well as of the atmosphere-ocean interaction, which delays the impact of the intensified greenhouse effect on climate. The biospheric dynamics (global land vegetation cover and oceanic phytoplankton) plays the key role as a factor of the formation of global carbon cycle. This determines the importance of the biosphere as a component of the climatic system "atmosphere-hydrosphere-lithosphere-cryosphere-biosphere".

A deeper understanding of the causes of observed climate change requires further development of global observational systems (with special role of satellite observational means) and numerical modeling of climate. The nearest perspectives of the development of climate models are connected with a more reliable parameterization of cloudiness (especially, cloud-radiation interaction) and ocean-atmosphere interaction, with a parameterization of relevant interactive physical, chemical and biological processes with gradually increasing spatial resolution. A substantial contribution to the solution of the problem of climate change will be achieved through an accomplishment of the World climate Research Programme (WCRP) and International Geosphere-Biosphere Programme (IGBP). The difficulty of the solution of respective problems necessitates much effort.

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