AEROSOL–CLOUD–CLIMATE INTERACTIONS. PART 2. CLOUDS

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The reports devoted to the investigations of the general behavior of spatial distribution and variability of microstructure and radiative characteristics of the clouds are reviewed. The role of the interaction between the clouds and radiation as one of the main factors of climate formation is analyzed in detail. The possibilities of parameterization of the processes of cloud formation for the climatic models are discussed. The results of satellite observations of stratospheric aerosol and Polar stratospheric clouds are considered.

1. CLOUDS IN THE TROPOSPHERE

1.1. Microphysical processes in the clouds. In the review presented by A. Heymsfield (USA), who did not completely covered the whole problems, the following classification of clouds (from the viewpoint of their microstructure peculiarities) was proposed: 1) warm (water clouds at the temperature of the upper boundary of clouds (UBC) $T_C > 0°X$); 2) supercooled (water–ice clouds at $T_C < 0°C$); 3) cold (ice clouds). The first type incorporates, for example, marine stratocumulus and tropical orographic clouds, while the second –– convective and altocumulus clouds. Synoptic and orographic cirrus clouds as well as cirrus clouds surrounded by thunderclouds were typical of the third type. The physical processes determining the formation of clouds of different types were analyzed.

M. Platt (Australia) pointed out that according to the data obtained from aboard the ER–2 aircraft over Wisconsin (USA) on November 2, 1986 cirrus clouds were characterized by a sufficiently high albedo at a wavelength of 3.7 μm in comparison with the clouds located in the other layers of the atmosphere. Retrieval of the effective radius of particles of cirrus clouds (the shape of particles was assumed to be spherical) yielded a value of about 8 mm. Using the data of an SMM/I UHF radiometer placed onboard the DMSP satellite as well as the results of shipborne observations with the help of a one–channel UHF radiometer (the observations were performed over the North sea in 1989), U. Hargens (Germany) intercompared the water content of the clouds retrieved from satellite and shipborne observation. The results of comparison were in a good agreement. The possibility of increasing the spatial resolution of the UHF satellite data by means of their combinaiton with the data of the Meteosat satellite was also pointed out.

P.R.A. Brown et al. (Germany) characterized the microphysical processes in cirrus clouds from the data of the International Cirrus Experiment ICE–1985 carried out over the North sea. An analysis of the occasional airborne data on microstructure revealed the high degree of spatial uniformity of the cloud microstructure, namely, variations in the ice content of clouds were primarily caused by changes of the particle number density. In the other cases the microstructure and shape of particles turned out to be rather changeable. The data obtained were compared with the results of model calculations of nucleation in cirrus clouds.

V. Guillemet and Kh. Isaka (France) investigated the effect of precipitations in the form of ice crystals on the evolution of cloudiness located below them from the data of airborne observations performed as a part of the ICE program by way of comparison of these data with the results of calculation based on the model of microphysical processes in the clouds (both purely water clouds and purely ice clouds were considered). R. Enike et al. (Germany) proposed an interesting holographic technique for measuring the microstructure of small volumes (about 0.5 l) of the clouds (measurements were made at the top of a mountain near Frankfurt).

T. Hayasaka et al. (Japan) briefly characterized the main points of the subprogram of the experimental study of cloud–radiation interactions over the Northwest Pacific ocean which has been performed since 1987 as a part of the Global Program of Climate Research (GPCR). A large amount of experimental data about microphysical and radiative characteristics of marine stratocumulus clouds were obtained from aboard of two Cessna–4 aircrafts with the help of an actinometric apparatus intended for measuring the SW (short–wave) and LW (long–wave) radiation fluxes, a spectrometer (500–1100 nm), instruments for microphysical measurements, a UHF radiometer, and a photographic equipment in January, 1990 and January, 1991.

Based on the data of direct measurements, D. Mitchell and S. Chai (USA) proposed the following analytical approximation for the particle number density distribution N over the diameter D for stratus clouds: $N(D) = N_0D^{\nu}\exp(-\lambda D)$, which can be used for numerical modeling of clouds as a factor of climate formation. The empirical dependencies of the parameters N_0, ν, and λ on the water content of the clouds were justified. I. Ensen (Australia) summarized the results of airborne observations of the microstructure and thermodynamic parameters of the clouds of different types. He devoted a particular attention to an analysis of the microstructure transformations in the process of the cloud evolution from the rainless to the rainy and as a result of an entrainment process.

Having implemented a two–dimensional model of the ABL, P. Bechtold et al. (France) studied the evolution processes in the clouds in the marine ABL atendant to change in the temperature of the ocean surface (TOS). He paid a considerable attention to an analysis of the mesoscale interaction of the clouds with radiation and turbulent mixing

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in the process of motion of the cold air mass from the continent over the coast of California toward a warmer surface of the Pacific ocean. J.—Ph. Duvel et al. (France) described dynamics of cloud accumulations over Tropical Africa and the Atlantic ocean from the IR data (10.5—12.5 μm channel) of the Meteosat satellite. IR imaging showed that after averaging over relatively large areas, the number of accumulations can be approximated by the function proportional to r^{-2} (r is the radius of accumulations). A clear—cut diurnal variation over the ocean was typical only of very large accumulations, while over the dry land the complicated diurnal variation occured depending on the size of accumulations. Diurnal variability of cloud accumulations was of great importance.

1.2. Spatial distribution of the clouds. V. Wieliski (USA) summarized the results of the International Satellite Cloud Climatology Program (ISCCP). The corresponding data archives incorporated the global arrays of cloud amount, altitude of the upper cloud boundary and optical thickness of clouds averaged over a period of 3 hours. A comparison of the observed global fields of the cloud amount with the results of numerical modeling of the climate showed considerable disagreements which substantially exceeded the variability of the fields retrieved from the data obtained with the use of different climatic arrays (during the ISCCP and ERBE). Undoubtedly, this indicated the necessity for substantial modification of the scheme of parameterization of cloud dynamics for the climatic models.

I. Mazin (USSR) discussed the results of intercomparison of the 15 years—long ground—based and airborne visual estimates of the cirrus cloud amounts (airborne observations were carried out during 1958—1973 over 8 regions of the USSR) which showed a quite satisfactory agreement (within the limits of the error being not greater than 10%). K. Wu (USA) proposed the technique for assimilation of the data of satellite observations of outgoing longwave radiation (OLR) within the scope of the model of numerical weather forecast in order to estimate the cloud amount more correctly. The employed technique of nonlinear programming was based on the refinement of the data on cloudiness by minimizing the difference between observed and calculated values of the OLR. The estimate of the cloud amount optimized against the radiative can be used (according to the data of the numerical experiment) to decrease the standard deviation of the calculated values of the OLR from the measured ones by 50% thereby reducing it down to the noise level. The above—discussed optimization is of great importance for the prediction of the surface temperature but is of no importance in other cases.

A. Arking (USA) tabulated the characteristics of the cloud cover (cloud amount, altitude of the upper boundary, optical thickness, albedo, emissivity, and microphysical index) from the data of two—years—long observations (April, 1986 — March, 1988) with the help of the MRVHR in the region extended from 30 to 50° n.l. and from 60 to 140° e.l. where the first international radiative experiment of the ISCCP (FIRE) was carried out. This data array can be used to analyze the peculiarity of the cloud characteristics over both the ocean and dry land, their annual behavior, and year—to—year changeability. A. Brisson et al. (France) developed an automated technique for a cloud classification in real time based on the Meteosat satellites data, while T. Inoue (Japan) proposed a technique for a cloud classification based on the NUOA satellites data recorded in the "splitted" channel (at the wavelengths of 11 and 12 μm) in the atmospheric transparency window. It was shown, in particular, that the brightness temperature difference $\mathrm{BTD} = T_{11}–T_{22}$ is the reliable indicator for identifying the optically dense (cumulus and cumulo—nimbus) and cirrus clouds, while the classification, as a whole, can be performed with the use of the TD and T_{11}. Data processing showed that, for example, cirrus clouds predominated in the Tropical Pacific ocean.

S. Yang et al. (USA) estimated the information content of the remote sensing data with the help of the TOVS apparatus used aboard the NUOA satellites from the viewpoint of retrieval the average monthly values of the cloud amount and the altitude of the upper boundary (AUB) of clouds. Comparison with the analogous data revealed considerable disagreements. G. Campbell et al. (USA) gave an example of processing of the Indian geostationary INSAT satellite data with the purpose of retrieving the cloud amount, OLWR, and index of precipitations. Y. Hou et al. (USA) described the CLAVR system for processing of the data obtained with the help of a modified radiometer with a very high spectral resolution (MRVHSR) aiming at retrieving the characteristics of the cloud cover in real time and illustrated its application to the measurements performed on February 8, 1990. D. Reinke et al. (USA) compared the data of the ISCCP archives for the clouds with the GOES satellite data providing a higher spectral resolution.

1.3. Radiative characteristics and effect of the clouds on the climate. A rather superficial review of the radiative characteristics of the clouds presented by M. King (USA) was extremely incomplete because of ignoring numerous and various results of investigations performed in the USSR (perhaps, it particulary concerns the airborne observations and theoretical investigations). In spite of the fact that the above—mentioned results were comparatively copious, the report turned out to be fragmentary without a conceptual tie—in with the climatic problem (generally speaking, this would have to made up the main content of the report).

Having 12 minutes in my disposal, I briefly discussed two tendencies in developments: 1) a three—dimensional mesoscale model created by V.I. Khvorost'yanov, who took into account all major processes determining the formation and evolution of clouds (in my opinion, it is the best model now), and its application and 2) the procedure which took an account of the global aerosol and its radiative effects and was the product of efforts of many years and co—operation with N.I. Moskalenko and his colleagues. This procedure can be, in particular, used for numerical modeling of the climate (now this procedure is unique and this fact shows the necessity for energetic efforts for its substantiation as an object for the international collaboration).

E. Shettle (USA) described the data of observations and the results of calculations of the cloud brightness in the spectral intervals 3—5 μm and 8—12 μm. K. Liou (USA) discussed the problem of parameterization of microphysics of the ice particles in the radiative transfer theory (within the scope of a delta—four—flux approximation). The results were illustrated by a calculated dependence of albedo and emissivity of clouds on their ice content. R. Davis et al. (USA) drew attention to the importance of taking account of the effect of horizontal nonuniformity (topography) of the upper boundary of clouds on the fluxes and influxes of the long—wave radiation. The results indicated that the radiative cooling depended on the curvature of the surface of the UBC, namely, the convex surface is cooled with greater efficiency than the concave surface. As a whole, the nonuniformities of the topography of the UBC weakened radiative cooling and delayed convective subversion (the calculations of convection were performed for a one—dimensional model).

I. Joseph and I. Kaufman (Israel and USA) studied (using the LANDSAT images recorded with high spatial resolution) the dependence of the reflectivity of individual convective clouds on their effective radius, fractile length of the perimeter of clouds, and spatial distribution of nearby clouds in order to justify the estimates of the contribution of clouds of different size to the cloud amount and albedo determined for one cycle as a function of the cloud amount. The obtained results were used for taking account of the effect of "subgrid" clouds in retrieving the albedo of the underlying surface and vegetative index. P. Flatau et al. (USA) reported on new data of investigations of light scattering on the nonspherical ice particles of hexagonal and cubic shapes based on the discrete dipole approximation. The obtained data were comparable with the results of calculations for equivalent spherical particles. The anomalous diffraction and geometric optics approximations were also considered.

I. Takano et al. (USA) analyzed an effect of cavities near the ends of the crystals forming cirrus clouds and having the shapes of small columns. The results of calculations of light scattering and absorption due to the particles by the Monte Carlo method and of the radiation fluxes (by the method of summing over the layers) were used to study an effect of nonsphericity of the particles on the angular distribution of the reflectivity of cirrus clouds and on the parameterization of the scattering phase function. The purpose of the report presented by R. Boers and R. Mitchell (Australia) was the theoretical investigation of the relation of the variations of the albedo with the optical thickness, microstructure, and water content of the clouds under the effect of the antropogeneous aerosol and of mixing in the clouds. S. Twohy et al. (USA) evaluated an effect of the CN of the clouds on the microstructure and radiative characteristics of marine stratocumulus clouds from the data of airborne observations near the coast of North California.

The preliminary results of the field experiment performed over the Northern Sea as a part of the ICE from September 15 to October 21, 1989 (not only the cirrus clouds but also the convective clouds and contrails of aircrafts were studied) were characterized in detail in the review presented by E. Rashke (Germany). A considerable attention in the report was paid to an analysis of the data obtained on September 28, 1989 in the process of observation of the jets of multilayer cirrus clouds at altitudes of from 7 to 9.5 km (these clouds were characterized by the high degree of horizontal uniformity). G. Stephens (USA) tried to answer the question about an effect of the bright cirrus clouds on the climate from the data of the Earth's Radiation Balance Experiment (ERBE) simultaneously with the results of observations performed as a part of the FIRE program. An important result of this study was a determination of the considerable underestimation of the calculated values of the albedo of the clouds in comparison with the observed ones (thus, an anomaly, which manifested itself as the bright cirrus clouds, was considered).

E. Jensen et al. (USA) proposed a one–dimensional model of the formation and evolution of cirrus clouds taking into account simultaneously the microphysical and radiative processes having compared the results of calculations of the vertical profiles of the SW and LW radiation fluxes (based on a two–flux approximation) with the FIRE data obtained in 1986. The comparison revealed a quite satisfactory agreement. The main purpose of the elaboration of the model was an analysis of the dependence of sensitivity of radiative characteristics of cirrus clouds to the changes in such input parameters as the concentration of the CN, specific humidity, and vertical speed. The calculations showed a large increase in the concentration of crystals and in the optical thickness of clouds as the vertical speed increased. The increase of the CN concentration was accompanied by the decrease of the mean size of the cloud particles from 100 to 70 μm. An attempt of reproducing the formation of cirrus clouds observed on November 1, 1986 was undertaken. R. Saunders (Great Britain) used the results of airborne measurements of the vertical profiles of the LW radiation flux, particle number density, and microstructure of dense and thin cirrus clouds (measured over the Northern Sea, in September–October, 1989) to justify the parameterization of the LW radiation transfer in cirrus clouds. S. Kinne et al. (USA) summarized the airborne observations of cirrus clouds (during the FIRE–86) in order to give grounds for the empirical model of the optical characteristics of clouds (albedo of single scattering, asymmetry factor of the scattering phase function, vertical profile of the extinction coefficient). Mean values of the optical thickness (at a wavelength of 0.5 μm) and of the extinction coefficient were about 3 km and 0.8 km^{-1}, respectively.

G. Brogniez et al. (France) presented the data of lidar sensing performed as a part of the ICE–89 in Nordholz (Germany) and of ground–based observations of cirrus clouds with the help of the IR radiometer and the solar and aureole photometers and used them for retrieving the parameters of the cloud microstructure. Daren Lu et al. (China) analyzed the structure and characteristics of clouds from the data of simultaneous ground–based and satellite (with the help of the MRVHSR) observations performed in Pekin as a part of the international experiment ECLIPS. In addition, they estimated the possibility of retrieving the optical thickness of the atmosphere based on the MRVHSR data obtained over the dry land. The report presented by M. Platt et al. (Australia) was devoted to the development of the techniques for retrieving the altitudes of the lower and upper boundaries of clouds as well as the vertical profile of the extinction coefficient from the data of lidar sensing obtained as a part of the Experimental Cloud Lidar Pilot Study (ECLIPS) program. Determination of the altitude of the lower boundary of clouds (ALBC) called for careful filtering out (if necessary) of the contributions of underlying haze and weak precipitations. Systematic disagreements between the effective radius of cloud drops from the *in situ* and remote sensing data forced T. Nakajima et al. (Japan and USA) to seek for the reasons of this disagreement (by way of comparison of the data). Apparently, ignorance of the continuum absorption was one of the main reasons.

K. McGuffie and A. Henderson–Sellers (Australia) estimated the information content of the photographs of the sky and of the data obtained at the meteorological network stations of Canada (158 stations operated in 1985, and 5 stations operated during 1970–1979) and Australia (14 stations operated during 1979–1988) as the source of the data on the spatial structure and radiative characteristics of the clouds. Thus, the characteristic length of the clouds, undergoing strong annual dependence, varies, on the average, within the limits 0.4–3.4 km. Various information about horizontal spatial structure of the cloud cover yielded an analysis of 400 photographs of the sky. F. Berger (Germany) used the MRVHSR data (the channels Nos. 1, 2, and 4) to classify the clouds on the basis of the two–dimensional histograms and the maximum likelihood method. The results of calculation of the optical characteristics of the clouds based on the MRVHSR data (albedo, transmittance, and absorption/emissivity) were used for subsequent calculations of the cloud–radiation forcing (CRF) for the "underlying surface–atmosphere" system and the underlying surface. In the first case strong LW heating and SW cooling of the system took place. The resultant values of the CRF reflected a well–known effect of cooling caused by the low and middle clouds, while the thin cirrus clouds were responsible for warming. The main points of the ECLIPS program were given in the review presented by M. Platt (Australia).

D. Hartmann (USA) presented a review devoted to the contribution of clouds in the climate formation. This review incorporated an information well known from the scientific literature (note once again that the results of investigations of the Soviet scientists were not even mentioned). The results of calculations of the spatio–temporal variability of the CRF from the data of the ERBE were presented in this report; in addition, an attempt to determine the dependence of the CRF on the cloud type was made. Discussing the relation between the variability of the CRF and the temperature of the ocean surface (TOS), the author questioned the validity of the recent paper (published in 1991) of Ramanathan and Collins who stated that the variability of albedo of the clouds controls the TOS variations, since the comparison of the global charts of the TOS anomalies recorded in spring (during 1985–1987) and the CRF charts revealed correlation. As a whole, the author supposed that the CRF values calculated from the satellite data were quite reliable.

The subsequent reports were devoted mainly to the analysis of the satellite data on the Earth's radiation obtained as a part of the ERBE. G. Gibson et al. (USA) have summarized the results of the ERBE from the viewpoint of contribution of the clouds to the climate formation (mainly concerning the data of 3–years–long observations of the CRF). Dynamics of the global and regional fields of the CRF (for the LW and SW radiation components as well as for the ERB) clearly showed the key role of the clouds in climate formation. The CRF anomalies were recorded in several regions of the globe. D. Curry and E. Ebert (USA) discussed the trends in the calculated annual behavior of the optical characteristics of the clouds over the Arctic Ocean which agreed with the satellite data on the OLR (obtained during the ERBE) and with the data obtained at the network of the actinometric stations of the USSR in the Arctic (it seems to be the only case in which foreign specialists used the data obtained in the USSR). Particular attention was paid to the analysis of the sensitivity of the radiation fluxes to the changes in the radiative cloud characteristics and in this connection, of their dependence on different factors (including the cases of the pollutants entering into the Arctic, which were manifested through the haze formation).

Sh. Gupta et al. (USA) performed the calculations of the global distribution of the SW and LW radiation components of the CRF on the grid with the steps 2.5° in latitude and 2.5° in longitude for different months with the use of the meteorological data from the ISCCP archives and of the albedo of the clear sky retrieved from the data on the ERB. The obtained results were compared with the estimates based on the climatic models. An analogous development was realized by S. Ackerman et al. (USA) on the basis of observations performed with the help of apparatus used aboard the NOAA–9 satellite consisting of a sensor of the ERB, the MRVHSR, and a remote sensing system. Remote sensing data were used to study the spectral distribution of the CRF. E. Harrison et al. (USA) using the data of 3–years–long observations of the ERB studied the peculiarities of the radiative anomalies in the equatorial belt of the Pacific ocean during the ENSV (El Nin'o/Southern Variation) recorded in 1987 and accompanied by a very large negative index of the Southern variation. The period of a maximum evolution of El Nin'o (during March–May, 1987) was characterized by the strong negative anomaly of the OLR comparable with the anomaly recorded during El Nin'o in 1983. Strong positive anomalies of the OLR took place on both sides (to the north and to the south) of the equatorial zone of the "waveguide" regime. The analysis of the ERB data was supplemented by the meteorological information from the ISCCR archives.

Using the same archives of data obtained during 1983–1986, D. Key et al. (USA) carried out the calculations of the radiation fluxes and of the CRF near the underlying surface in the Arctic having specified the microphysical and optical characteristics of the low, middle, and upper clouds. The purpose of these calculations was, first of all, an analysis of the sensitivity of the radiation fluxes to the variability of the input parameters. Although the input parameters, used in calculations of the radiation fluxes, were burdened with large errors, the data of climatologic calculation were of great interest from the viewpoint of the results of the numerical modeling of the climate. K. Poetzsch–Heffter and E. Ruprecht (Germany) calculated the OLR based on the two–flux approximation with the use of the meteorological data obtained as a part of the ISCCP in order to determine the contribution of cloudiness to the formation of the greenhouse effect in the atmosphere.

Based on the data of the MRVHSR (used onboard the NOAA–7 satellite in 1984), D. Coakley and D. Judge (USA) discussed the differences between the reflectivity of clouds of small horizontal size and practically infinitely extended clouds as well as the dependence of the reflectivity of the clouds on their microstructure and water content. Unfortunately, the report of O. Kyarner (Estonia) incorporating the analysis of the NIMBUS–7 data of 6–years–long observations of the ERB devoted to the determination of the interaction of the clouds with radiation was not presented (because the author was absent). D. Mol'nar (USA) used the archives of the ISCCP to estimate the dependence of the dynamics of the cloud cover over the ocean in the Tropics on the changes in the TOS using a two–dimensional radiative–dynamic model of the climate. Possible warming of the climate caused by the increase in the concentration of greenhouse gases was demonstrated to be strongly dependent on the peculiarities of the cloud–radiation inverse relationship which seriously complicated the forecast of the global climate changes.

1.4. Parameterization of aerosol and clouds in numerical models for weather forecast and in climatic models. The discussion of these most urgent problems started with the review presented by H. Sundquist (Sweden) devoted to the parameterization of dynamics of cloudiness for large–scale models of climate. The author restricted himself only to the consideration of the parameterization of the microphysical processes in the water and ice clouds, which control their microstructure as well as (separately) of the mesoscale processes of cumulus and stratus (including stratocumulus) cloud formation. But there is no doubts that (1) both processes must be described as interrelated and (2) the problem of inserted meso–scale grid requires special analysis. H. Sundquist correctly stressed an importance of the problem–oriented experiments. J.J.. Morcrette (Great Britain) characterized the peculiarities of an account of the interaction between the clouds and radiation for the spectral model of general atmospheric circulation developed in the European Center of Medium–Range Weather Forecast. By way of example, he analyzed the model referring to July, 1987 in which the results were obtained with different horizontal resolution (varying from T–21 to T–106). The use of different schemes of parameterization of cloudiness with varying resolution showed that the average global estimates of the total cloud amount varied slightly (within the limits 0.49–0.60). An effect of the CRF on the sensitivity of the results of numerical modeling to the horizontal resolution and parameterization of moist convection was also discussed.

Having employed the method of the adjoint equations, proposed by G. Marchuk in the 1960's, T. Prager (Hungary) analyzed the sensitivity of the climate to the cloud–radiation inverse relation as well as to the interrelation between the temperature and humidity based on the thermodynamic box model of the climate. She paid a particular attention to the physical sense of the adjoint functionals as the factors determining the transmission of natural signals in the climatic system. L. Donner (USA) considered the peculiarities of parameterization of the ice clouds and their radiative effects for the CCM climatic model, envisaging the differentiated account of two types of ice clouds: (1) the clouds being formed on the synoptic scale in the presence of ascending air motions and (2) the clouds associated with convection in the cumulus clouds. In both cases ice particles were formed from the water vapor in the process of air ascent and were removed due to sedimentation. In addition, in the second case an additional condensate enters into the ice clouds from the cells of the cumulus clouds. The analysis of the preliminary results showed that the clouds of the second type had a high emissivity (E). They were formed at altitudes where the intense longwave CRF was possible. Large scale (extended) ice clouds had moderate emissivity at the altitude corresponding to 35 GPa but near the altitude corresponding to 15 GPa the emissivity was much less (probably, the last estimate was not reliable and was a consequence of inadequacy of the model).

The report presented by K. Taylor and P. Norris (USA) was devoted to an analysis of mutually compensating climatic effects of the cloud–radiation inverse relationship (CRIR) and of changes of the snow cover based on the CCM–1 model. The authors drew attention to the contribution of the CRIR restraining the manifestation of other inverse relationships. The matter was that the albedo inverse relationship engendered the secondary inverse relationship manifesting through the variability of the cloud cover which practically completely compensated for the albedo inverse relationship resulting from the variations of the extent of the snow cover and of the surface albedo. This conclusion showed the necessity for the correct account of synergism of the climate formation.

K. Bower and T. Choularton (Great Britain) tabulated the microphysical characteristics of the clouds of different types (primarily, the water content and the vertical profile of the effective radius of the drops) and analyzed an effect of entrainment on the microstructure of cumulus clouds. The simple parameterization of the effective radius suitable for the climatic models was proposed. An analysis of the use of the global spectral model of the climate for description of the cloud cover was given by L. Rikus (Australia). He compared this model with the results of satellite observations and found that it was impossible to reproduce within the scope of this model the vast zones of stratocumulus clouds over the oceans of the Southern Hemisphere due to the rough scheme of parameterization of the clouds against the criterion of the threshold relative humidity. More successful results were obtained with an additional account of the dependence of the low cloud formation on robustness. D. Westphal et al. (USA) proposed a technique for choosing the most adequate schemes of parameterization of the cloud formation using the input parameters optimized on the basis of the observed data verified by the results of numerical weather forecast. I. Foyo–Moreno et al. (Spain) examined different techniques for calculating the total radiation from the data of 5–years observations performed at 6 stations of Spain.

R. Somerville and S. Iacobelis (USA) discussed different approaches to the account of the cloud optical dynamic effect (CODE), manifesting through the changes in the optical thickness of the clouds, for the climatic models. Variety of the CODE and its sensitivity to the variability of the cloud characteristics necessitated further investigations of this inverse relationship. In Hong Yin (China) used a one–dimensional radiative–convective climatic model to estimate the contribution of different radiative perturbating effects. L. Lemus et al. (Australia) justified the parameterization of the optical thickness of the clouds as a function of their water content and microstructure. V. Ingram (Great Britain) characterized the parameterization of cloudiness for a new model of numerical weather forecast and general circulation of the atmosphere developed by the scientists of the British Meteorological Service. V. Michele et al. (Great Britain) compared the global fields of cloudiness and radiation based on the model of the European Center on Medim–Range Weather Forecast with the ERB data and revealed a good agreement between the average monthly SW and LW radiation components of the CRF. However, the calculated amplitudes of variability agreed badly with the observed ones.

Zh. Seze et al. (France) used the data of 4–years–long observations from the archives of the ISCCP (C1 data) array to determine the trends in the spatio–temporal variability of the global distribution of the cloud cover including the vertical profile and optical characteristics of the clouds as well as to analyze the usefulness of the data being considered from the viewpoint of verifying the climatic model developed in the Laboratory of Dynamic Meteorology of the Polytechnical Institute. Ch. Senior (Great Britain) employed this climatic model for estimating the changes of the clouds and radiation fields caused by doubling of the CO_2 concentration having compared the calculated results for the present–day atmosphere with the data of the ERBE. An important peculiarity of the above–mentioned climatic model was the parameterization of the clouds whose water content was inner (precalculated) variable. Numerical modeling showed the strong dependence of the results on the choice of the parameterization scheme of the cloud cover, which determined the reliability of the estimates of the climatic changes when the CO_2 concentration was doubled.

2. STRATOSPHERIC AEROSOL AND CLOUDS

Unfortunately, a little attention was devoted to the consideration of this important problem (half a day from six days), but the discussion drew attention of the well–known specialists and was full of interest. This statement refers first of all to the review presented by P. McCormic (USA) who summarized the results of satellite observations of stratospheric aerosol content retrieved from the global data of 6.5–years–long observations obtained with the help of an apparatus used aboard the SAGE–II satellite as well as from the SAM–II data of 12.5–years–long observations over the Polar regions. Observations carried out with the help of the apparatus aboard the SAM–II were used to obtain a plentiful information about aerosol content in the upper troposphere. The peculiarities of the annual behavior of aerosol and the effect of the volcanic eruptions on the stratosphere were analyzed in detail. Aerosol mass in the global stratosphere varies from $(1–2)\cdot 10^5$ ton to $(300–400)\cdot 10^5$ ton. The data on the Polar stratospheric clouds (PSC) observed at the temperature below 200 K and playing the critically important role in the distruction of stratospheric aerosol drew a particular attention. Balloon sensing performed by the scientists of the Wyoming University over Laramie (41° n.l.) with the use of photoelectric counters made a large contribution to the investigations of both stratospheric and tropospheric aerosol. Discussing the results of 20–years–long observations (which referred to the particles with radii larger than 0.15 μm and 0.25 μm, while the data on the CN were collected during 15 years), D. Hofmann (USA) stressed that these results characterized the trends of natural continental background sulphate aerosol, disturbed by the strong effects of volcanic eruptions (it referred, in particular, to the eruption of the Pinatubo volcano). An analysis of the data showed the pronounced annual behavior of the aerosol content in the troposphere and the lower stratosphere reaching maxima in spring at the altitudes less than 10 km and in winter above these altitudes (obviously, the last fact was associated with the stratospheric transfer process which predominated at this time and was directed toward the north). The wide maximum in the troposphere was typical of the CN at the end of summer, which probably was indicative of the existence of the photochemical source of the CN. As to the vertical profile of the mixing ratio for the CN it was characterized by the maximum appearing, as a rule, under the tropopause (most probably it was connected with the higher rate of nucleation in this region). K. Brogniez and J. Lenoble (France) retrieved the vertical profiles of the effective radius of particles and calculated their average monthly values in the 10° latitude belts from the SAGE–II data obtained for the period from October 1984 up to date referring to four wavelengths (0.385, 0.453, 0.525, and 1.02 μm). Both the directly measured aerosol extinction coefficient and the effective radius underwent only weak seasonal trends in separate latitude belts and at fixed altitudes with the superimposed trend of their decay engendered by an eruption of the El Chichon volcano.

S. Bekkii (Great Britain) developed a new two–dimensional model of a layer of the stratospheric aerosol with detailed account of the microphysical processes (nucleation, condensation, evaporation of water and sulphuric acid, coagulation, washing out by precipitations, and sedimentation) and chemical reactions. The calculations of the variability of the vertical profiles of the number density and microstructure of the stratospheric aerosol under the effects of volcanic eruptions and emissions of the nitrogen oxides due to the supersonic jets of aircrafts were performed. It was noted that the aircrafts appeared to be strong sources of sulphur in the stratosphere.

V. Ramaswami (USA) used the data of lidar and satellite observations during 1978–1987 to estimate the radiative effect of the stratospheric aerosol in tropical, mid–, and polar latitudes for different seasons and compared this effect with the greenhouse one for the same or more prolonged time (during 1958–1987 and 1950–1987). The calculations based on the radiative–convective model led to a conclusion that the aerosol effect on the climate during separate years and for the entire period during 1978–1987 was comparable with the contribution of the greenhouse intensification effect or even exceeded it. In this case aerosol strongly affected the field of the long–wave radiation.

The estimates of aerosol contribution to the radiative heat influx into the troposphere and stratosphere obtained by S. Ackerman (USA) on the basis of the two–flux approximation for calculation of the radiation fluxes were used to analyze the aerosol contribution to the radiative heat influx over deserts and ocean. M. Pitts et al. (USA) studied an interrelation between the stratospheric temperature and the temperature of the surface layer over the ocean (SLO) from the SAM–II data of 10–years–long observations and from the meteorological observations. In addition, they analyzed the ways of entering and removing the gaseous forerunner of the SLO. A. McKenzie (Great Britain) performed numerical modeling of the SLO of the first type consisting of the crystals of trihydrate of nitric acid formed in the process of the binary molecular condensation. The rate of binary condensation is inversely proportional to the sum of the three processes counteracting the condensation: (1) diffusion of water vapor molecules toward the surface of the particles , (2) latent heat release on the surface of the particles, and (3) surface processes associated with the formation of the crystal lattice. The estimates showed that the contribution of the last process was of particular importance, and sometimes it predominated.

L. Stefanutti et al. (Italy) analyzed the results of lidar sensing of the stratosphere over the Antarctic. E. Chio et al. (USA) studied the trends in the global distribution of thin layers of cloudiness over the upper troposphere in summer and winter from the SAM–II data obtained during 1987–1989 in order to determine their relationships with zones of the intense convection. The obtained results were compared with the available data on the global distribution of the cirrus clouds.

3. CONCLUSION

3.1. Undoubtedly, this Symposium devoted to the discussion of the problems of the clouds and aerosol as the climate–formation factors drew attention of many well–known specialists and was, on the whole, useful. However, it should be noted that the leading specialists in the field of numerical modeling of the climate did not take part in the Symposium but preferred to take part in other Sections of the Assembly.

The great difference between the number of reports presented by Soviet specialists (two) and American specialists (about 70 without the poster papers) in the field which always was (and now remains to a considerable extent) one of those branches of science in which the contribution of scientists from the USSR was (and now remains) very significant attract much attention. Of course, this situation is the result of unsatisfactory work on organization of the Assembly (first of all, the Section of Meteorology and Atmospheric Physics of the Interdepartmental Geophysical Committee and its Comission on climate, Cloud Physics and Radiation as well as of the Scientific Council on Global Changes and Climate of the State Commitee on Science and Engineering. It is hardly understandable why the specialists of such prominent scientific research institutes as the Institute of Atmospheric Optics, Scientific–Production Union "Taifun", and others did not take part in this Symposium. It should be mentioned that Organizing Committee of this Symposium did not include the Soviet specialists in the list of invited speakers (from 7 invited reports 4 were presented from USA, two – from Germany, and one – from Sweden). Unfortunately, it looks like discrimination.

3.2. Participation experience in the Symposium discussed being and my observations referring to the Assembly as a whole, stimulate me to declare that scientific meetings of many thousands of scientists, splitting into many independent groups, should be considered as an obsolete stereotype. It is surprising that the scientific leadership of the International Union of Geodesy and Geophysics failed to do all their best to focus the attention of participants on the key problems. I can refer, for example, to the International Geosphere–Biosphere Program and Global Program of Climate Research.

I must acknowledge that I am seriously disappointed with my participation in the Assembly of the International Union of Geodesy and Geophysics after a long interruption.