Winter Zvenigorod Cloud-Aerosol-Radiation Experiment (ZCAREZ-99): Preliminary Results

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Introduction

The First Winter Zvenigorod Cloud-Aerosol-Radiation Experiment (ZCAREX-99) was conducted from February 1 through March 5, 1999, in the framework of the Atmospheric Radiation Measurement (ARM) Program at Zvenigorod Scientific Station (55.7°N, 37.8°E) of the Institute of Atmospheric Physics. The aims of the experiment were to measure radiative properties of cloudy and cloudless atmosphere over high-albedo surface at low winter temperatures and small water vapor contents and to compare those measurements with results of measurements at warmer and wetter conditions. Winter measurements of solar radiation at small water vapor contents have an advantage of being to a less extent influenced by strong water vapor absorption (Shukurov 1999). Furthermore, one of the biggest uncertainties in climate modeling relates to the treatment of clouds and their radiative forcing, in particular in wintertime at sites with snow/ice-covered surfaces. Combined experiments, including ground-based measurements, are necessary to test satellite observations, which do not allow distinctive distinguishing between clouds and snow/ice-covered surfaces.

Principal Measurements

The following characteristics were measured during ZCAREX-99 (February 1- March 5, 1999):

- surface radiation
- optical characteristics of cloudless atmosphere

- characteristics of clouds
- aerosol characteristics
- contents of atmospheric gases
- meteorological parameters, including aerological ones.

Surface radiation measurements provided data for total solar and thermal radiation, direct shortwave radiation and total UV-A radiation fluxes. Optical characteristics of the cloudless atmosphere were obtained from spectrograms of relative transmittance of air in the spectral range of 2 μm to 25 μm (400 cm^{-1} to 5000 cm^{-1}). Balloon radiosondes and a ground-based lidar as well as advanced very high-resolution radiometer/National Oceanic and Atmospheric Administration (AVHRR/NOAA14) satellite data were used to determine cloud heights and temperatures. A remote sensing of various types of clouds was made with the use of a spectroscopic technique to estimate liquid water path and liquid water contents. Aureole and extinction, aerosol scattering coefficient, and dried near-surface submicron aerosol contents, as well as the soot contents, were also measured with the help of sunphotometers and spectral nephelometers. Aerosol probes were collected by a cascade impactor to identify chemical composition of the aerosols. Spectroscopic measurements of columnar contents of climatically active gases CH_4, H_2O, and CO were made. Columnar tropospheric NO_2 contents were measured with the visible zenith-viewing spectrometer. Surface NO_x and ozone mixing ratios were also measured.

Results

Surface Radiation

Global downwelling fluxes of the infrared (F) and solar (Q) radiation were measured with an Eppley Precision Infrared Pyrgeometer and Eppley Precision Pyranometer (Golitsyn et al. 2000). The instruments were placed on a tower of 16-m height. The data were sampled every two minutes. Figure 1 shows examples of the temporal course of the shortwave and thermal irradiance.

Water Vapor Continuum Absorption

Air transmittance was measured in spectral microwindows 410, 500, 560, and 610 cm^{-1} on the horizontal near-surface path (of 162-m length) during the experiment and in the summertime with a two-beam spectrometer UR-20 in a wide ranges of air temperature (from -30°C to +34°C) and humidity (atmospheric water vapor partial pressure varied from 0.4 mb to 22 mb). Line-by-line calculations with the use of HITRAN-96 were made to interpret the experimental data. The obtained values of continuum absorption optical thickness exhibit nonlinear dependence on H_2O partial pressure and strong negative temperature dependence about 2% to 3% per 1°K (Shukurov et al. 2000).

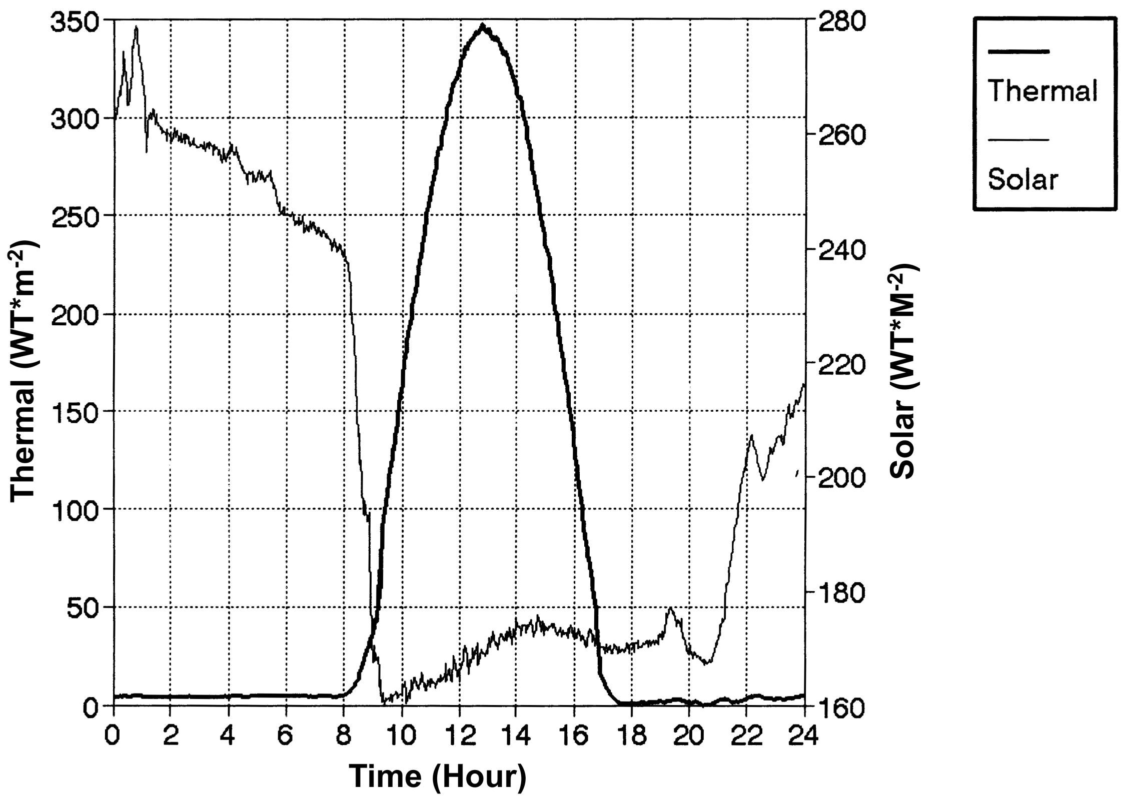

Figure 1. Global shortwave and thermal irradiance.

Clouds

Remote sensing of clouds in spectral intervals within 2.07 µm to 2.32 µm was made with the help of a fast scanning infrared (IR) spectrometer and the sun as a radiation source. The effective photon path length is determined with the use of absorption by O_2 and CO_2. Processes of cloud absorption and scattering are formally separated via a formal consideration of sun photon trajectories in a cloud. Then the spectroscopic analysis of measured absorption spectra of solar radiation scattered by a cloud allows estimating liquid water path, optical thickness, and mass scattering coefficient. Simulated synthetic spectrum, being compared with the measured one, allows retrieving the ratio of mass concentrations of water and ice.

The preliminary results show that all sounded clouds included water and ice. The ratio of volume absorption by water and ice varied from 0.4 to 3 when the surface air temperature changed from -20°C to 0°C. The liquid water path was in the 50 g/m^2 to 200 g/m^2 range, while liquid water contents along an effective way of radiation in a cloud did not exceed 400 g/m^2 (Dvorjashin et al. 2000).

Cloud base height was measured with a lidar range finder. The detection range is 50 m to 8 km, with an accuracy of 10 m. The frequency histogram of measured cloud base heights H obtained during ZCAREX-99 and compared with the data of the previous summer experiments is shown in Figure 2.

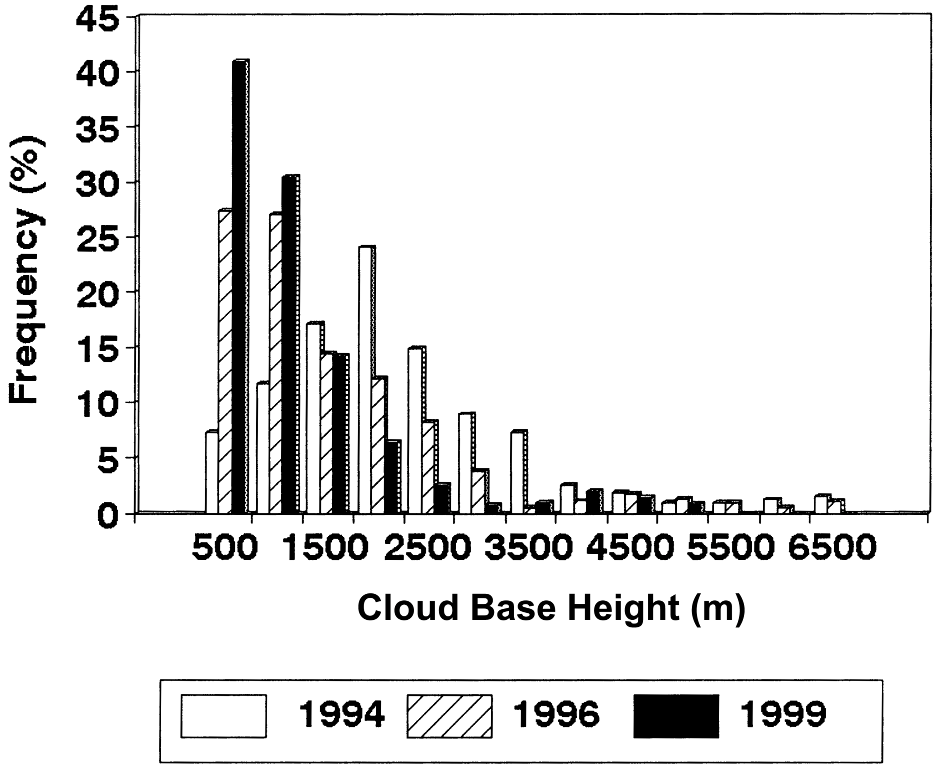

Figure 2. Histograms of cloud base heights for three experiments.

Aerosols

Only a few days were available for clear-sky measurements during the experiment. They were characterized by small-to-moderate aerosol loading in the atmospheric column. The minimal aerosol optical thickness in the visible region reached 0.04. Examples of aerosol size distributions retrieved from the spectral aureole and extinction measurements are presented in Figure 3. The contents of the near-surface aerosols are typical for this period at Zvenigorod. The spectral dependence of the directed scattering coefficients is well described by Angstrom's formula with the exponent varying from 0.5 to 2.5. The correlation exists between a scattering coefficient and the Angstrom's exponent (Isakov et al. 2000).

Greenhouse Gases

Columnar contents of CH_4, CO, and water vapor were obtained from spectroscopic measurements with the help of infrared grating spectrometer and a sun as a light source (Grechko et al. 2000; Yurganov et al. 1997). During the experiment, the CO column contents varied within 0.09 atm.cm to 0.16 atm.cm, CH_4 column contents within 1.18 atm.cm to 1.31 atm.cm, and water vapor column contents within 0.1 g/cm^2 to 0.58 g/cm^2 (Figure 4).

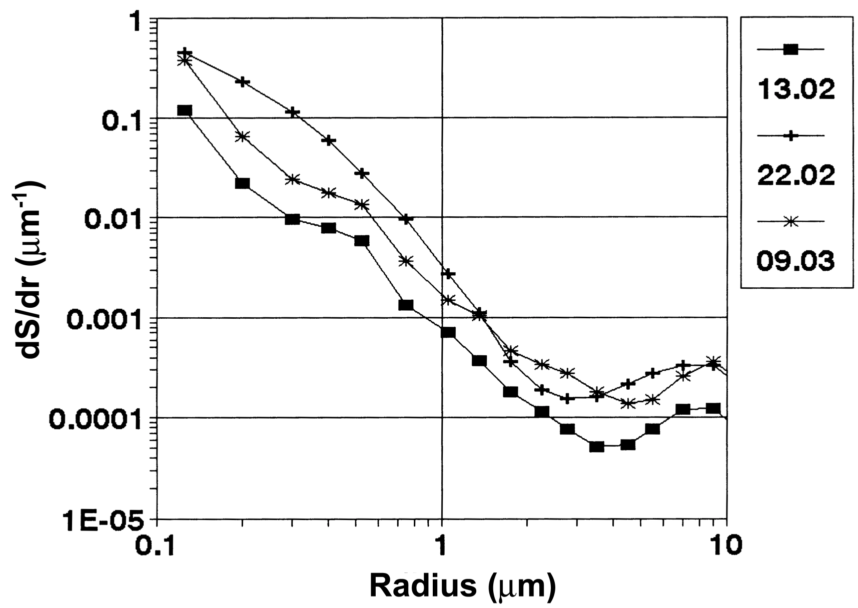

Figure 3. Cross-section aerosol size distributions retrieved from spectral aureole and extinction measurements.

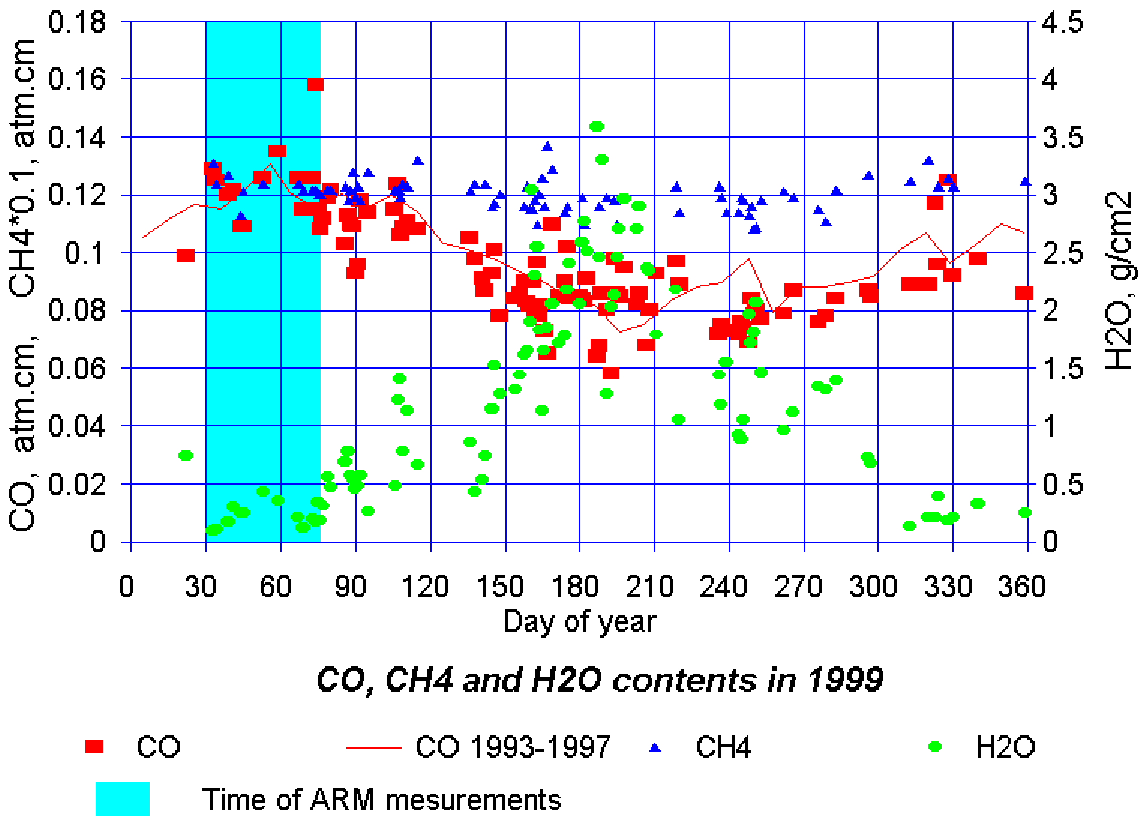

Figure 4. Columnar contents of CO, CH_4, and water vapor.

Nitrogen Compounds in Atmospheric Air and Aerosols

Submicron atmospheric aerosols from the near-surface layer (3 m height above the earth surface) were deposited by a cascade impactor on germanium plates transparent in the infrared region. Transmittance spectra of the collected aerosol samples were obtained with a spectral resolution of 8 cm^{-1} with the use of a two-beam spectrophotometer UR-20 to identify molecular composition of aerosols analyzing absorption bands in the 1300 cm^{-1} to 1400 cm^{-1} wavelength range.

Volume mixing ratios of NO and NO_2 at a 10-m height were measured with an analyzer AC-30M, added by measurements of column tropospheric NO_2 contents in daytime with the help of a zenith-viewing grating spectrometer MDR-23 scanning in the 435-mm to 450-nm wavelength range (Elokhov and Gruzdev 1998).

All the aerosol transmittance spectra exhibit absorption bands characteristic of ammonium sulfate. Six spectra exhibit an absorption band probably related to HO-NO_2, which has been only found in aerosol samples collected during periods including episodes of enhanced column tropospheric NO_2 contents (Figure 5). This implies a possible relation of aerosol nitric acid compounds to pollution of the atmosphere by nitrogen compounds, more definitely, to large contents of nitrogen dioxide (Shukurova et al. 2000).

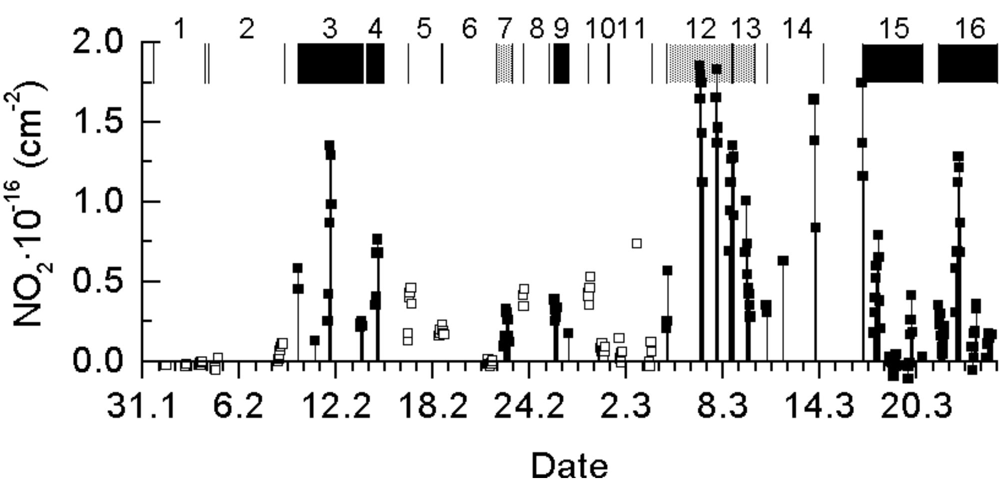

Figure 5. 15-minute column tropospheric NO_2 contents superimposed by information about collected submicron aerosol samples (numbered). Full squares with drop lines and open squares mark out NO_2 values corresponding to aerosol samples with and without HNO_3, respectively. Aerosol samples containing HNO_3 are marked by black, containing only signs of HNO_3 by gray, while samples not containing any sign of HNO_3 are not marked by any color.

Calculation of Radiation Fluxes

Calculation of shortwave fluxes requires knowledge of aerosol optical characteristics, which were obtained from aureole and extinction measurements for aerosol radii 0.1 μm to 11 μm. Integral solar fluxes were computed according to Gorchakova (2000), Tarasova (1997), and Sviridenkov and Anikin

(1998) taking into account molecular scattering, cloud and aerosol extinction, absorption of atmospheric gases (H_2O, CO_2, O_2, O_3), and multiple reflection from clouds and the surface. Absorption of atmospheric gases was calculated using both the integral and spectral transmission functions. Calculations of the integral thermal fluxes took into account absorption by water vapor (including continuum absorption in the 8-µm to 12-µm window), CO_2, O_3, aerosols and clouds with the use of integral and spectral transmission functions. The calculated global solar and thermal irradiances were compared with Zvenigorod observational data close to the time of radiosonde launching. Fluxes measured and calculated by different methods are in good agreement with each other within 5% (Golitsyn et al. 2000).

Conclusions and Deductions

The preliminary results of the first winter cloud-aerosol-radiation experiment provide the following conclusions.

- The change of the total radiation balance at the earth surface relative to the balance at clear-sky conditions is mainly determined by the appropriate change of the longwave balance at the surface.

- The change of total radiation balance of the surface-atmosphere system relative to the balance at clear-sky conditions is mainly determined by the appropriate change in the solar radiation balance decreasing with the cooling of the system.

- In the presence of cirrus clouds, the changes of radiation balance at the surface, at any atmospheric level as well as for the whole surface-atmosphere system relative to clear-sky conditions, are determined basically by the changes of the solar balance due to increasing solar fluxes reflected backward.

- The whole atmosphere is cooled in winter in the presence of clouds. In the case of low clouds, this cooling and the cooling of the cloud layer are of similar magnitudes. The subcloud layer is heated.

- In the case of high clouds, the cloud and overcloud layers are heated, the subcloud layer is cooled strongly in the solar range of spectrum. The influence of a cloud is substantially larger on solar radiation than on thermal radiation.

- The probability of low clouds (up to 500 m) is higher in winter than in summertime, while the probability of middle-level clouds in wintertime is less.

- Water vapor continuum absorption has a negative temperature dependence of 2% to 3% per 1°K, and the nonlinearly depends on water vapor content.

- The ratio of volume absorption by water and ice in clouds varied from 0.4 to 3 when the surface air temperature changed from -20°C to 0°C. The liquid water path was in the range of 50 g/m^2 to 200 g/m^2, while the liquid water content along the effective way of radiation in a cloud did not exceed 400 g/m^2.

- Large NO_x contents peculiar to pollution episodes can be important factors influencing composition of atmospheric aerosols, which can result in the change of microphysical and radiative properties of aerosols. Taking into account that lower tropospheric NO_2 in pollution can also essentially contribute to absorbing solar radiation (Solomon et al. 1999), one could expect additional radiation forcing related to NO_2, at least at the regional scale. We can deduce therefore that aerosol, radiation, and climate models should take account of these NO_2 effects.

Continued measurements in winter conditions will give important new results in addition to the results obtained during warm seasons.

Acknowledgments

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