# Radiation Fluxes During ZCAREX-99: Measurements and Calculations

*G. S. Golitsyn, P. P. Anikin, E. M. Feigelson, I. A. Gorchakova, I. I. Mokhov,*
*E. V. Romashova, M. A. Sviridenkov, and T. A. Tarasova*
*Oboukhov Institute of Atmospheric Physics*
*Russian Academy of Sciences*
*Moscow, Russia*

## Introduction

During the preliminary winter Cloud-Aerosol-Radiation Experiment at Zvenigorod (ZCAREX-99), global shortwave and thermal fluxes were measured in parallel with characteristics of aerosol and clouds and meteorological parameters of atmosphere. For clear-sky and overcast cloudiness conditions, the measured fluxes were compared with those calculated by different techniques. The cloud radiative forcing for ice and mixed clouds was estimated on the basis of the experimental data.

## Description of Measurements

The global fluxes of the infrared (F) and solar (Q ) radiation were measured with an Eppley Precision Infrared Pyrgeometer and Eppley Precision Pyranometer. The instruments were placed at the tower with a height of 16 meters. The downwelling infrared and solar irradiances were observed from February 1 to March 5, 1999. The data were sampled every two minutes. Cloud base heights were measured by means of a lidar range finder. Optical thickness of the aerosol and semi-transparent clouds was continuously measured with Multiple Field of View (MFOV) sunphotometer at a wavelength of $\lambda \sim 0.53$ μm. The fields of view were 1.9°, 3.2°, 5.3°, 6.7°, and 8.3°. Spectral aerosol optical thickness and aureole sky brightness in the wavelength region from 0.41 μm to 0.79 μm were observed episodically using an aureole photometer based on the acoustic-optical spectrometer (Golitsyn et al. 1997). Both instruments were mounted at the active solar tracking systems.

## Retrieval of the Aerosol Microphysical and Optical Parameters and Optical Thickness of Clouds

Optical characteristics of the aerosol needed for the calculations of the downwelling radiative fluxes were obtained using the approach described earlier (Sviridenkov and Anikin 1998). This approach may be named as “microphysical extrapolation.” Spectral dependencies of the optical thickness, single scattering albedo, and mean cosine are recalculated for the size distributions retrieved from the spectral aureole and extinction measurements.

Estimates of the cloud optical thickness for overcast cloudiness were made by different methods from the pyranometer and spectral zenith measurements (Anikin et al. 1998) and using the sonde data for the temperature and water vapor profiles.

## Calculations of the Shortwave and Thermal Radiation Fluxes

Integral solar fluxes were calculated according to Gorchakova and Leont'eva (1991), Gorchakova (2000), and Sviridenkov and Anikin (1998), taking into account molecular scattering, cloud and aerosol particles extinction, absorption of atmospheric gases ($H_2O$, $CO_2$, $O_2$, $O_3$), and multiple reflection from clouds and surface. Absorption of atmospheric gases was calculated using both the integral and spectral transmission functions. Calculations of the integral thermal fluxes take into account the absorption of $H_2O$ (including continuum absorption in the optical window 8 mcm to 12 mcm), $CO_2$, $O_3$, aerosol and clouds with the use of integral and spectral transmission function. For high ice clouds, the parameterization of Liou (1992) was used. The calculated global solar and thermal irradiances were compared with Zvenigorod observational data. For comparison, we chose the period close to the sonde launching. The surface albedo was estimated from satellite data by Rublev (private communication). Its value was approximately 0.4. Aerosol parameters were taken from the nearest aureole measurement and corrected for the variations of aerosol optical thickness. Measured and calculated by different methods fluxes are compared in Table 1 for the clear-sky case (08.02) and low cloudiness.

**Table 1.** Comparison between measured and calculated irradiances.

| Date, 1999 | 05.02 | 08.02 |
|---|---|---|
| Time, UTC | 12.00 | 12.00 |
| Air mass | 4.39 | 4.12 |
| $\tau$ (aerosol) | 0.12 | 0.11 |
| $Q^{meas}$, W/m$^2$ | 95 | 234 |
| $Q(1)^{calc}$, W/m$^2$ | 98 | 225 |
| $Q(2)^{calc}$, W/m$^2$ | 96 | 234 |
| $F^{meas}$, W/m$^2$ | 288 | 174 |
| $F(1)^{calc}$, W/m$^2$ | 294 | 169 |
| $F(2)^{calc}$, W/m$^2$ | 293 | 168 |

(1) refers to fluxes calculated according to Gorchakova (2000) and (2) – to Sviridenkov and Anikin (1998). Indices $^{meas}$ and $^{calc}$ refer to measured and calculated values respectively.

## Estimates of the Cloud Radiative Forcing

A satisfactory agreement of calculated and measured radiative fluxes at the surface allows the influence of clouds on the radiative balance in atmosphere to be estimated in winter cases with high surface albedo.

For the solar radiation, cloud radiative forcing (CRF) can be characterized by $R=C_S(0)/C_S(\infty)$, where $C_S(0)$ and $C_S(\infty)$ are the differences between the clear-sky and cloudy shortwave radiative balances at the surface and at the top of the atmosphere.

The estimates of the parameter R and values of $C_S$ and $C_L$ for two cases with high and low clouds are presented in Table 2 in W/m$^2$ ($C_L$ is the same as $C_S$ but for the thermal radiation). The sensitivity of the solar absorption in the cloudy atmosphere to surface albedo, cloud microstructure, cloud height and size of cloud particles was estimated. In particular, the increase of surface albedo leads to an increase of the R range. The changes of radiative influxes due to clouds relative to clear sky are given in Table 3.

**Table 2**. The changes of radiative balance due to clouds relative to clear sky. The values of parameter $R = C_S(0)/C_S(\infty)$.

| **February 5, 1999, Sc Mixed Cloud** | | | | **February 18, 1999, Ci Ice Cloud** | | | |
|---|---|---|---|---|---|---|---|
| Z, km | $C_L$ | $C_S$ | $C^*=C_L+C_S$ | Z, km | $C_L$ | $C_S$ | $C^*=C_L+C_S$ |
| 0.0 | 75.5 | -53.7 | 21.8 | 0.0 | 13.4 | -25.1 | -11.7 |
| 0.6 | 85.7 | -59.7 | 26.0 | 5.8 | 26.9 | -44.3 | -17.4 |
| 1.0 | 12.6 | -47.4 | -34.8 | 7.8 | 21.8 | -35.8 | -14.6 |
| ∞ | 8.3 | -44.2 | -35.9 | ∞ | 20.1 | -35.5 | -15.4 |
| R | | 1.21 | | R | | 0.71 | |

**Table 3.** The changes of radiative influxes due to clouds relative to clear sky.

| **February 5, 1999, Sc Mixed Cloud** | | | | **February 18, 1999, Ci Ice Cloud** | | | |
|---|---|---|---|---|---|---|---|
| $\Delta z$ km | $\Delta C_L$ | $\Delta C_S$ | $\Delta C^*=\Delta C_L+\Delta C_S$ | $\Delta z$, km | $\Delta C_L$ | $\Delta C_S$ | $\Delta C^*=\Delta C_L+\Delta C_S$ |
| (0.,0.6) | 10.2 | -6.0 | 4.2 | (0.,5.8) | 13.5 | -19.2 | -5.7 |
| (0.6,1.) | -73.1 | 12.3 | -60.8 | (5.8,7.8) | -5.1 | 8.5 | 3.4 |
| (1.0,∞) | -4.3 | 3.2 | -1.1 | (7.8,∞) | -1.7 | 0.3 | -1.4 |
| (0,∞) | -67.2 | 9.5 | -57.7 | (0,∞) | 6.7 | -10.4 | -3.7 |

## Conclusions

Several conclusions can be made from the results of radiative flux calculations illustrated in Tables 2 and 3. The cooling of the atmospheric column was found in February to be related basically to the cooling inside clouds in the case of low clouds. In the case of cirrus clouds, the atmospheric cooling is connected mainly with the atmospheric layer under the clouds, while the cloud layer was heated. In the presence of low clouds (February 5, 1999) the change of the total radiation balance at the surface $C^*(0)$ relative to the clear sky is determined by the appropriate change of longwave balance at the surface $C_L(0)$. The change of total radiative balance of the surface-atmosphere system $C^*(\infty)$ relative to the clear sky is determined by the appropriate decrease of solar radiation balance with the cooling of the system. In case of cirrus clouds (February 18, 1999), the changes of radiation balance at the surface $C^*(0)$, at any atmospheric level z $C^*(z)$, as well as for the whole surface-atmosphere system $C^*(\infty)$ relative to the clear sky, are determined according to the changes of solar balance $C_S(0)$, $C_S(z)$, $C_S(\infty)$ due to increasing solar fluxes reflected backward.

In the presence of clouds, in winter the whole atmosphere is cooled. In the case of low clouds, this cooling and the cooling of the cloud layer are of similar magnitude (Table 3). 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 shortwave region. The influence of clouds is substantially larger on solar radiation than on thermal radiation.

## Acknowledgment

This work was supported by the U.S. Department of Energy's Atmospheric Radiation Measurement (ARM) Program (Contract No 354476-A-Q1).

## References

Anikin, P. P., E. V. Romashova, and D. P. Anikin, 1998: About determination of the cloud optical depth from the data of the cloud-radiation-aerosol experiments (1994, 1996) at IAPh, Russia. In *Proceedings of the Eighth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, DOE/ER-0738, pp. 27-30. U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9803/anikine(2)-98.pdf

Golitsyn, G. S., P. P. Anikin, and M. A. Sviridenkov, 1997: Solar aureole measurements and coarse dispersed aerosol size distributions in ARM Enhanced Shortwave Experiment intensive observation period. In *Proceedings of the Sixth Atmospheric Radiation Measurement (ARM) Science Team Meeting*, CONF-9603149, pp. 109-111. U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9603/gol3_96.pdf

Gorchakova, I. A., and E. N. Leont'eva, 1991: Approximate calculations of the thermal radiation fluxes. *Izvestiya*, *Atmos. Oceanic Phys.*, **27**, 165-171.

Gorchakova, I. A., 2000: Parameterization of the integral solar fluxes. *Izvestiya, Atmos. Oceanic Phys.*, **37**, in press.

Liou, K. N., 1992: *Radiation and cloud processes in the atmosphere*. Oxford University Press.

Sviridenkov, M. A. and P. P. Anikin, 1998: Aerosol optical and microphysical characteristics retrieved from observations during ARESE. In *Proceedings of the Seventh Atmospheric Radiation Measurement (ARM) Science Team Meeting*, CONF-970365, pp. 43-46. U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_9703/svir-97.pdf