Ground-Based Microwave Study of LWP Spatial Anisotropy in Winter Clouds

A. V. Koldaev, E. A. Miller, V. E. Kadygrov, and A. I. Gusev
Central Aerological Observatory
Moscow, Russia

A. V. Troitsky
Radio Physics Institute of Nigny
Novgorod, Russia

W. Strapp
Meteorological Service of Canada
Cloud Physics Research Division
Ottawa, Canada

Introduction

The role of horizontal anisotropy of the cloud field in the radiation transfer is under investigation of Atmospheric Radiation Measurement (ARM) science team since the beginning of the program. It was recognized within last few years that the inhomogeneity of clouds could lead to large errors in heat fluxes calculations. It was calculated and experimentally proved (Gorchakova, Golitsyn et al. 2001) that the effect of horizontal inhomogeneity of winter clouds may led to many percent in estimation of radiative fluxes. Three-dimensional (3D) numerical models (Gu and Liou 2001) demonstrates very interesting effect that clouds with maximum overlapping produce less heating than those with random overlapping. Nevertheless, the experimental works that can provide numerical characteristics of that anisotropy are still rare.

At the recent stage of technology it looks like strange that the experimental data about cloud inhomogeniety are not available in the world common database although the satellite and radar networks provide us with the cloud pictures 24 hours a day within last 20 years. But all the recent satellite data are not able to distinguish space scale that is reasonable for single-column model (SCM) application. The radar network data may be useful only in case of heavy clouds because of the network radar is operating at respectively high wavelength. But the main role into the radiation transfer processes is playing the clouds with sufficient liquid water content.

There are only two possibilities to investigate liquid water into the clouds: in situ aircraft measurements and remote microwave sounding. Despite the aircraft measurements are much more accurate than the microwave ones, only microwave ground based measurements are able to provide long term statistics with the acceptable cost and space resolution.

The article is intended to present long-term measurements of winter cloud parameters and results of analysis of their anisotropy as it was measured during the Alliance Icing Research Study (AIRS) project, which took place in Ottawa - Montreal area during the winter 1999-2000.

Instrumentation

The measurements were made by two independent microwave systems. First of them was created as a common one (Hogg et al. 1983). It was a trailer housing with thermo-stabilizing system, in which two microwave radiometers with 85 GHz and 37 GHz working frequencies were installed. Atmospheric radiation was received through the radio-transparent window. The calibration was performed by using a "black body" and "clear-sky" technique.

The second system is composed with the same microwave radiometers operating at 37 and 85GHz, but was made especially for unmanned operation during the harsh winter weather conditions. The common view of the system is presented on the Figure 1. The schematic and functional diagrams are demonstrated in Figures 2 and 3.

Figure 1. View of microwave system made for unmanned operation during the harsh winter weather conditions.

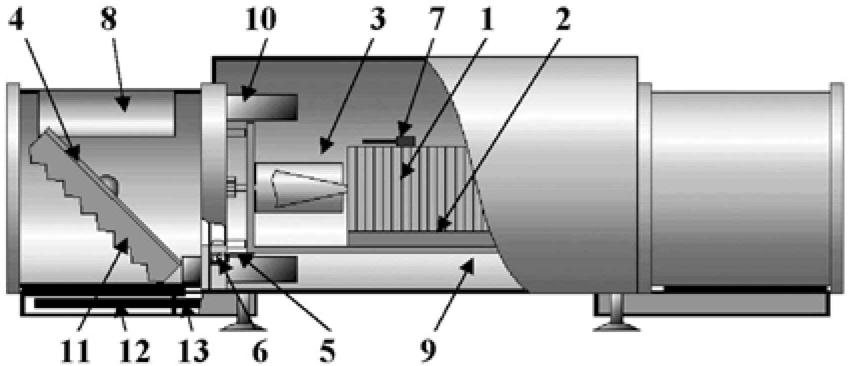


Figure 2. Schematic diagram.

Specification

1. Radiometer
2. Microprocessor card
3. Stepping motor
4. Mirror
5. Sensor of antenna position
6. Magnet
7. Termistor
8. Teflon
9. Fans
10. Mirror control units
11. "Black body"
12. Cleaning unit
13. Precipitation sensor with heater
14. Cleaning heater

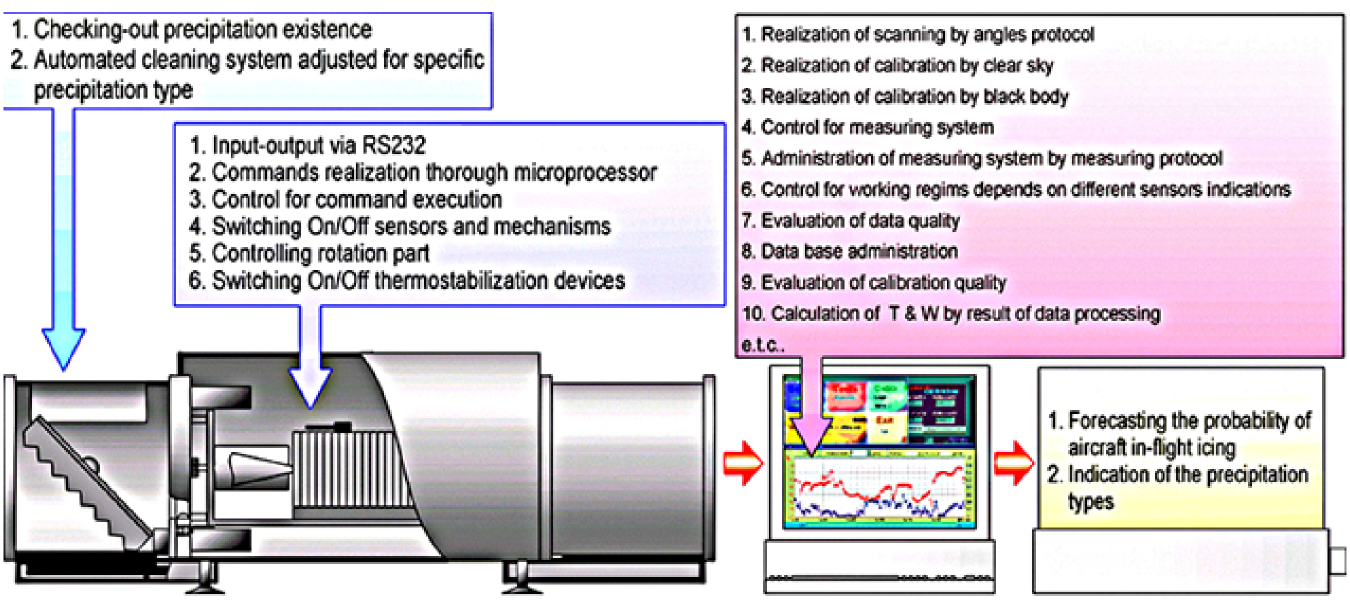


Figure 3. Functional diagram.

The main features of the system are as follows:

1. Weather protection: both radiometers are installed in a waterproof housing. The housing has the shape of a dome with two radio transparent tube heads in opposite direction. Each head is 14” in diameter and 16” long. The tube heads can rotate around horizontal axes. The dome includes two microwave radiometers with appropriate antennas, a thermo-stabilizing system, four stepping motors (two for permanent rotating of the tube and two for scanning of the flat reflectors), two microprocessor control boards, and a set of sensors. The rotating heads includes flat metal reflectors, which are rotated by individual stepping motors. The connections between the rotating and stationary parts are waterproof.

2. All-weather operation: the shape of the weather protection housing prevents snow and water accumulation. To protect the radio-transparent window from water drops or snow, the rotating part is turned permanently (two r.p.m.) and the windshield cleaners, which are solid with the stationary part of the housing, clean it. Two thermo-stabilizing systems are used to provide a +40°C/-40°C range of operation. The first one is inside the radiometer. It maintains +50°C+/-0.5°C temperature inside each radiometer box. The second one is in the stationary part of the housing. It does not provide such an accurate thermo-stabilization, but makes it possible to control the inner temperature by using a heating/cooling system.

3. Self-calibration: there is the “black body” with thermo sensors inside each of rotating heads that are installed beneath the flat reflectors. Once per hour the flat mirrors are turned backward to receive radiation from the “black body”. The rotating part is not thermally insulated from the environment but has good thermal insulation from the stationary part and the absorber being at ambient temperature. As the ambient temperature changes at least by 5°C every 24 hours, one needs to get information about the recent temperature value and the output code of the radiometer to continuously update the calibration data set.

4. Unattended operation: the in-built microprocessor board performs unattended mode of operation as well as «real-time» data processing and transmission. A 12 V DC is used as power supply. Automobile battery along with radio-modem system can be easy used for completely autonomous operation.

The given system includes 4 functional blocks or units: the rotating and stationary parts of the weather protection housing, a commercial computer and a user’s terminal (Figure 3).

The rotating and stationary parts of the housing are connected only mechanically (without any wires or rotating contacts). The computer and weather protection housing are connected with a special cable enabling operation at ambient temperatures up to -60°C. The user’s terminal and computer are connected via radio modem line with RS232 exchange protocol. Each part of the system fulfils specific operational functions as it is pointed on separate posters of Figure 3.

Investigation of the anisotropy was made due to geometry of sounding: the unmanned system received radiation from zenith direction at time the trailer mounted system received radiation from the direction 20 degree above horizon, as it is shown in Figure 4. Both directions of soundings compose plane of sounding that is perpendicular to the ground. It is easy to see that with the cloud base height about 1 km, the sampling area into the clouds will be separated at about 3 km in horizontal plane and for cloud base height 4 km, the separation will be 12 km.

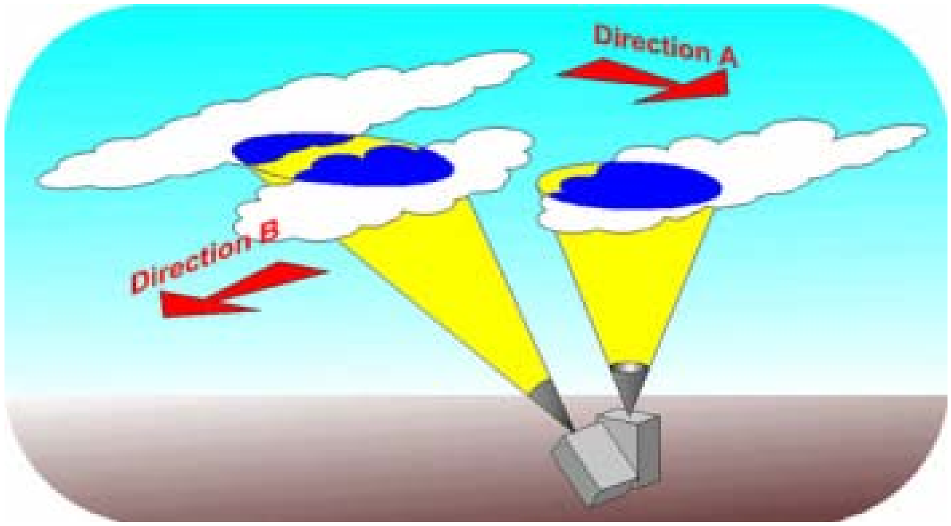


Figure 4.

Both systems were installed at the same location in Ottawa International Airport and the data were written on the same PC, so the records were automatically synchronized in time.

Data Processing

The time series of liquid water path (LWP) records within about 1000 hours were available for the statistical processing. Two types of data processing were used for the analysis of cloud anisotropy in application to the SCM and to the cloud-resolving models (CRMs).

First type of processing we call 3D seasonal distributions. All the data were confluence in one big file. After that the pair of column of the appropriate data were created which are namely the pair: LWP - ground temperature; cloud average temperature - ground temperature; duration of zone- ground temperature. Each pair of columns was processed by the sorting software, that creates the matrix with first column and first row corresponded to specified parameter and ground temperature, respectively. Each element of the matrix is the probability of occurrence of event that defined as simultaneous appearance of ground temperature and value of parameters that are corresponded to the intersection of column and row of this element. The matrix is constructed with the optional steps for temperature and chosen parameter. So if the step for temperature will be specified as 1°C, the value 12.1°C and 12.9°C will be classified as corresponded to the same sell 12°C-13°C. The same for the other specified parameter.

After the matrix is constructed, the 3D distribution could be charted by the use of a standard Microsoft Excel tools in a form a field. Three dimensions of such chart means that one dimension is ground temperature, second dimension is specified parameter from the list mentioned above and 3D is the probability of the event which is given by different colours. The norm for this 3D distribution is that the double integral for ground temperature and specified parameter will give 100%, so in mathematics sense this 3D distribution is simply production of the single distribution for ground temperature and specified parameter.

The convenience of such presentation is that any other partial or integral distribution can be easy obtained just as an integral along respective axes within the specified interval. For example, if you are interested with distribution only for frozen temperatures, you can integrate the 3D distribution along the ground temperature axes from 0°C to the minimum one which is presented at the respective chart. The same procedure for the temperatures above 0°C, just the upper limit for integral will be the highest temperature for the chart. If to calculate a full integral along any specified parameter axes any time you will get the same distribution of the ground temperature for all period of the time.

Second type of processing is a common correlation analysis. It was calculated self-correlation functions for each direction of sounding as well as cross correlation functions between two directions. The calculations were made for the time series of the data within the intervals 1-6 hours during the cloudy periods.

Taking into account the difference in two described above procedures we can identify the first type of processing as a “seasonal correlation” and the second type as “immediate correlation.”

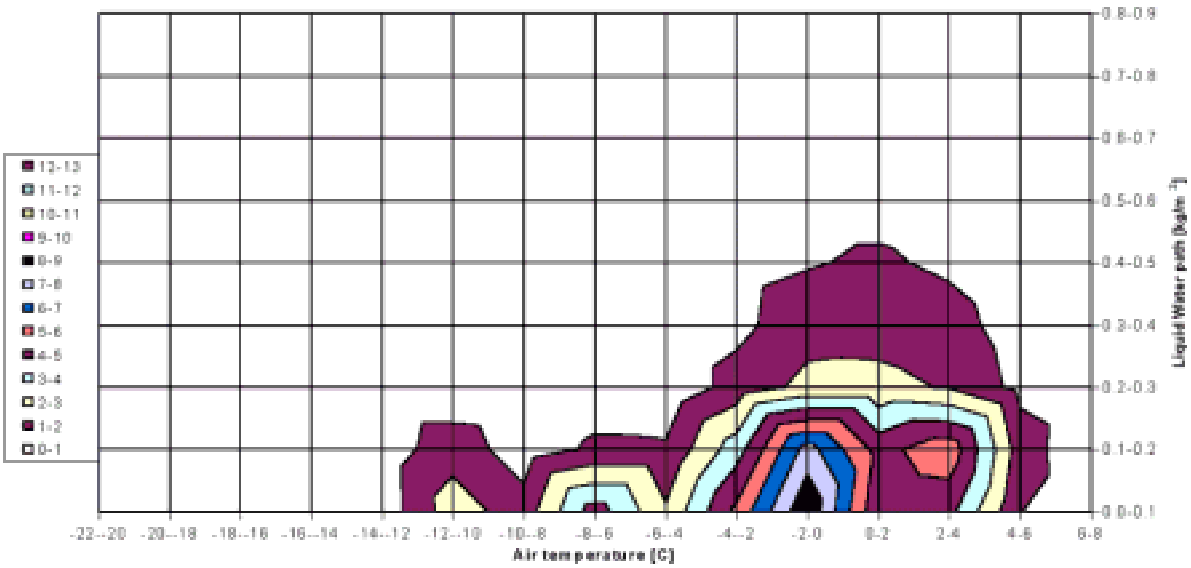
Results and Conclusions

The 3D distributions of LWP for both inclined and vertical sounding beams are presented on the Figure 5. To make the charts in the compatible values the data retrieved from the inclined beam were normalized on the 1/cos(20 degree). It is easy to see that the “seasonal correlation” is so obvious that no needs in any comments. Both pictures corresponds one to other including the small features.

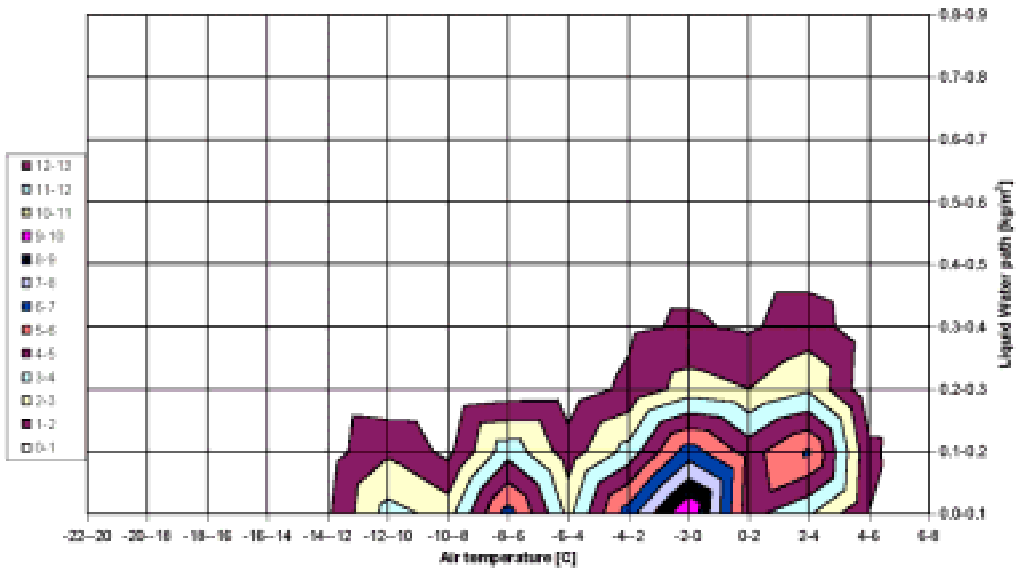
Completely different situation is observed with “immediate correlation.” These functions have a definite differences depending on the direction of cloud field transfer with respect to the sounding plane. Two typical examples of self-correlation and cross correlation functions are presented on the Figure 6 and Figure 7. On the Figure 6 can be seen high level of cross correlation , but without any delay with respect of self-correlation functions. Synoptic analysis indicates that such a situation corresponds to the cloud transfer perpendicular to the plane of sounding. On the Figure 7 the opposite situation can be seen: the maximum of cross correlation function is close to 0.6, but it is shifted with respect to the self-correlation functions. Due to available radiosonde data this case corresponds to the cloud transfer direction close to the plain of sounding.

The main results that can be formulated after analysis of the «immediate correlation» and «seasonal correlation» are:

- Seasonal distributions of LWP in inclined and vertical directions demonstrates exactly the same behaviour and can be referred one to other by simple calculation with the use of “cosecant” dependence like in case of flat-layered isotropic atmosphere assumption.



Differential 3D distribution of probability to find determined LWC at the presence of determined air temperature near the ground. Statistics for cloudy sky and for trailer mounted data.



Differential 3D distribution of probability to find determined LWC at the presence of determined air temperature near the ground. Statistics for cloudy sky and for unmanned system data.

Figure 5. 3D distributions of LWP for both inclined and vertical sounding beams.

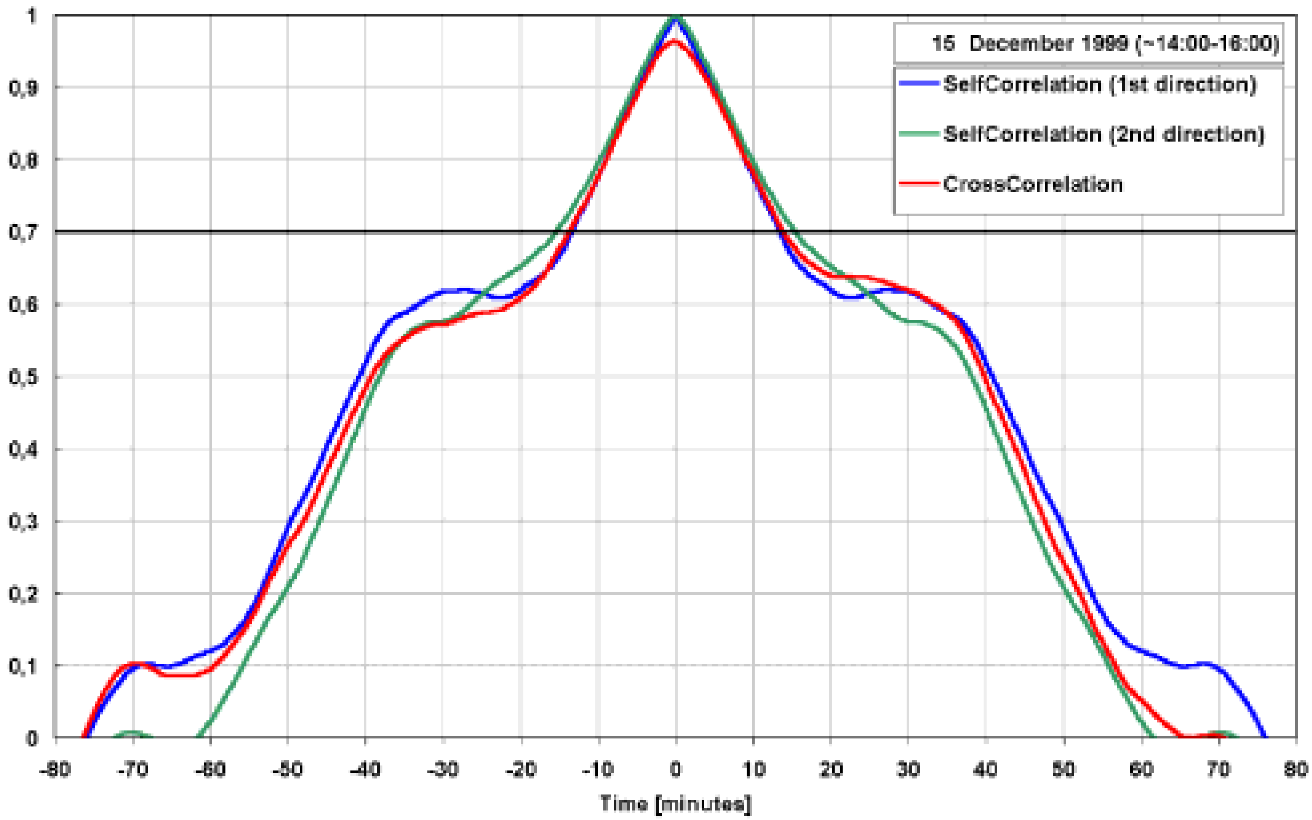


Figure 6. High level of cross correlation without any delay with respect of self-correlation functions.

- "Immediate correlation" demonstrates very significant differences for inclined and vertical directions, that difference is minimized during the period when the direction of cloud transfer is perpendicular to the plane of sounding.

One can be concluded on the base of the above: SCM may employ the assumption about isotropy of clouds in its application to seasonal statistics of radiation transfer. The numerical data useful for CRMs derived from "immediate correlation" use to be proven on the base of consequent measurements of the same type.

Corresponding Author

A. V. Koldaev, src_attex@mtu-net.ru, +7 095 4087758

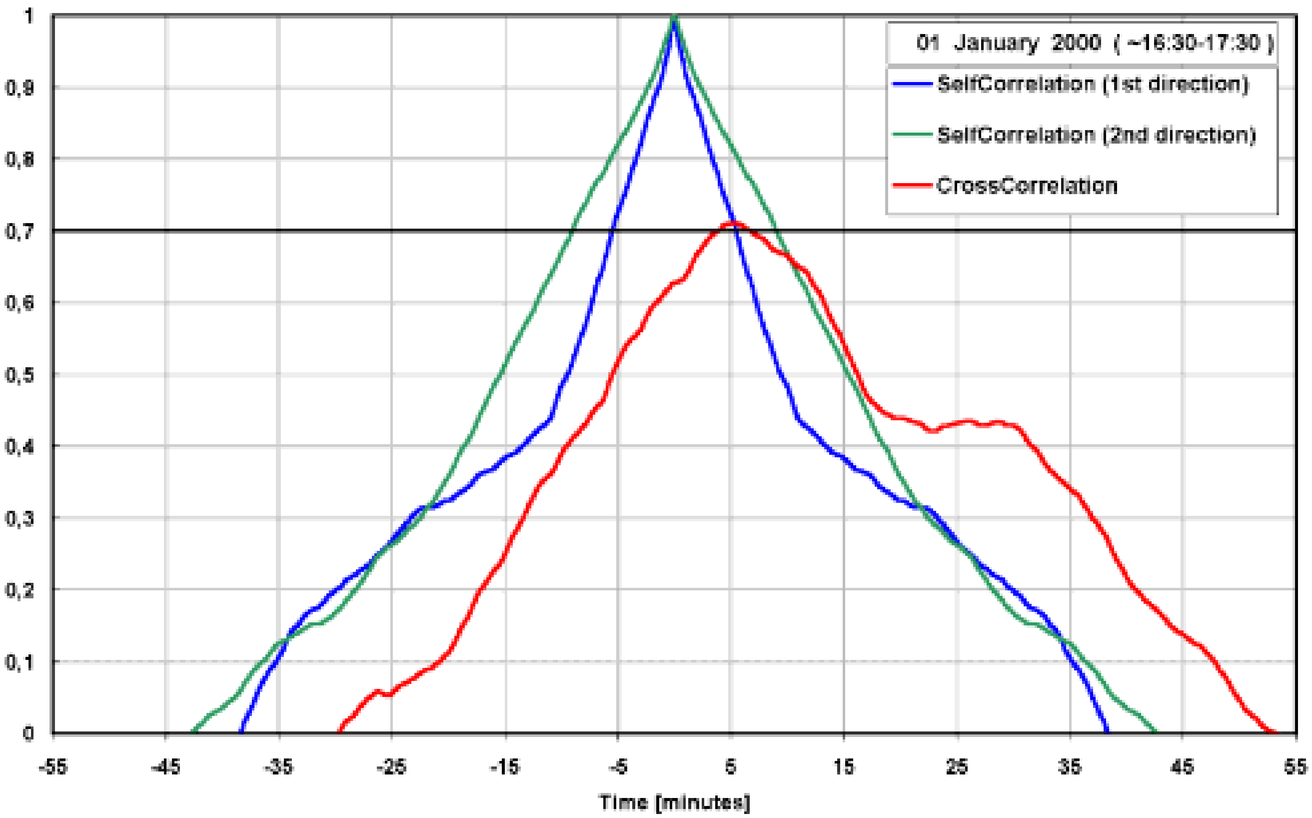


Figure 7. Maximum of cross correlation function is close to 0.6, but shifted with respect to the self-correlation functions.

References

Gorchakova, I. A., G. S. Golitsyn, I. I. Mokhov, and T. B. Zhuravleva. 2001. Estimate of the cloud horizontal inhomogeneity influence on the solar fluxes for the winter Zvenigorod experiment. In *Proceedings of the Eleventh Atmospheric Radiation Measurement (ARM) Science Team Meeting*, ARM-CONF-2001. U.S. Department of Energy, Washington, D.C. Available URL: http://www.arm.gov/docs/documents/technical/conf_0103/gorchakova-ia.pdf

Gu, Y., and Liou, K. N. 2001. Radiation parameterisation for three-dimensional inhomogeneous cirrus clouds: Application to Climate Models. In *Proceedings of the Eleventh Atmospheric Radiation Measurement (ARM) Science Team Meeting*, ARM-CONF-2001. U.S. Department of Energy, Washington, D.C.

Hogg, D. C., F. O. Guiraud, J. B. Snider, M. T. Decker, and E. R. Westwater. 1983. A steerable dual-channel microwave radiometer for measurement of water vapour and liquid in the troposphere. *J. Climate Appl. Meteor*., **22**.