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MICROWAVE SNOW EMISSION MODEL AND ITS CONTRIBUTING PARAMETERS

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Abstract: Satellites with microwave sensors onboard observing land surface from space consist of signal contributions from surface and atmosphere. The up-welling microwave signals are less attenuated by the atmosphere hence, for earthly located features remote sensing satellite microwave sensors have an advantage over visible sensor systems. In order to monitor snow cover with passive microwave data, brightness temperature information of the medium covering the earth surface under different conditions is required. A snow emission model thus, could be used for the estimation of brightness temperature of the medium. The radiative transfer based model has been used to study the emitted radiation from snow surface at the frequencies of the special sensor microwave imager (SSM/I). In the presence of clouds, water vapours and precipitation the radiative transfer calculations simplify as the wavelengths of the radiation approach the Rayleigh scattering regime. The transfer of microwave radiation, in particular is often simpler than the equivalent calculations at shorter wavelengths. This paper presents a simple sensitivity analysis of parameters used in the radiative transfer theory based snow emission model. There are several contribution factors (for example, soil, forest, water, atmosphere and snow) in the model. The effects of these features on brightness temperature values have been analysed in this paper.

Keywords: Microwave sensors, microwave snow emmission model, radiation, Rayleigh scattering, special sensor microwave imager.

INTRODUCTION

With passive microwave data in the land applications, plentiful target features in a single cell create problems in the development of algorithm [Hiltbrunner and Matzler 1997]. Hence, for the development of passive microwave remote sensing techniques brightness temperature information of the medium covering the earth surface under different conditions is required [Loth and Graf 1998]. An emission model may therefore be a useful tool for the estimation of brightness temperature of the medium [Wegmuller and Matzler 1999]. Global and regional brightness temperature retrieval models have been developed and investigated in the past few years using passive microwave radiometric data. Since the launch of the first microwave radiometer in 1972, more advanced instruments containing additional channels and higher spatial resolution have been developed. For example, Special Sensor Microwave Imager (SSM/I) and Scanning Multichannel Microwave Radiometer (SMMR). These radiometers measure signatures that can provide information for the identification of various surface features [Standley and Barrett 1999]. The microwave radiometer used in this study is (SSM/I).

The SSM/I is part of the Defence Meteorological Satellite Program (DMSP). The DMSP is a long term United States Air Force (USAF) mission consisting of two polar orbiting satellites whose data were declassified in 1972 and thus made available to the civil user community [Grody and Basist 1996]. The major aim of the system is to provide global visible, infrared and microwave data for retrieving hydrological meteorological and oceanographic information about the earth. In this series of satellite the first platform with an imaging microwave radiometer onboard, the DMSP Block 5D-2 F8 satellite, was launched on June 19, 1987 whilst, the latest is F14 and was launched on October 4, 1997 [Schiavon *et al*. 1998]. The satellites are in a near-polar, sun-synchronous orbit at a height of around 840 km, completing its orbit in 102 minutes thus resulting in 14 full orbits per day. The SSM/I is a four-frequency seven-channel linearly polarized conically scanning passive microwave radiometer. The SSM/I nominal local incidence angle is 53.1° and its deviation is a function of geographic latitude. The spatial resolution of SSM/I at its highest frequency (85 GHz) range is 14 km by 16 km, and at lowest frequency (19 GHz), the resolution is 45 km by 70 km. The highest frequency penetrates all but the thickest of clouds however, at 37 GHz and 19 GHz the brightness temperatures are relatively unaffected by clouds and atmospheric conditions. The 22 GHz channel is sensitive only to water vapour in atmosphere. It is clear that, as the SSM/I channel frequency decreases, the attenuation effects of the atmosphere on the satellite-measured signal also decrease [Colton and Poe 1999]. SSM/I is a stable and well-calibrated radiometric system which can provide accurate brightness temperature values for microwave images of the earth. The passive microwave sensors have low resolution and this is one of the main problems particularly for small areas less than 20 km x 20 km. Thus, in a single footprint for a passive microwave image, the presence of forested areas, water bodies and many other features may contribute to considerable signal variation [Kumar *et al.* 1999].

At SSM/I frequencies, for example, for the snow retrieval model, the global influence and atmospheric effects cannot be considered independently in the distribution of snow cover [McKay and Gray 1981]. The detection in snow variation is also important for applied environmental research and for regional industry [Gray and Male 1981, Pomeroy and Gray 1995]. Considering the snow cover extent as part of the climate system makes it necessary to focus on the snow surface parameters determining the lower atmosphere boundary (albedo, temperature). The change of radiation properties and unstable heat fluxes at the earth's surface has a directly affect on the atmospheric energies and circulation [Aschbacher 1989, Derksen *et al.* 1998]. Since snow cover transforms the high frequency atmospheric turbulence into low frequency variability, it seems a reliable indicator for detecting climate change [Pomeroy and Gray 1995]. Investigation have shown that feedback mechanisms estimated by various atmospheric models cover a wide range of responses to any given snow variance [Yang *et al.* 1997]. The snow pack growth resulted from super-cooled rain droplets, precipitation, and newly fallen snow, reflect parent atmospheric conditions. Consequently the snow pack resulted interact with electromagnetic waves in very different ways, adding errors to the evaluation of snow water equivalent based on both the ground and satellite measurements. Similarly, most snow packs are composed of complex layered characteristics that affect the bulk properties and physical structure and hence, modify the reflected or emitted electromagnetic signals from snow. The dwindling of electromagnetic radiation by different types of layers is very significant in the application of remote sensing. Similarly, the amount of water in a snow pack has significant contribution in the development of models particularly for hydrological purposes [Pulliainen *et al.* 1997]. This is a problem to estimate snow water equivalent even directly from ground measurements. Researcher uses snow depth, snow density, and areal extent of snow to estimate the snow water equivalent [Brown and Goodison 1996]. The precise amount of water in a snow pack is the most useful quantitative parameter for modelling [Pulliainen *et al.* 1999]. Both wet and dry snow has dissimilar electromagnetic response depending on presence of liquid water content and other snow characteristics (for example, snow grain size, snow density and snow depth). The retrieval of snow pack parameters (for example, snow depth and snow water equivalent) depends on temporal and spatial scales of snow extent. The airborne/satellite remote sensing are the potential solutions for the retrieval of data at large scales. It is therefore important to consider the scale of the snow cover inconsistency and the physical change in snow pack characteristics in satellite remote sensing, for the retrieval of snow pack parameters [Matzler 1996].

In a SSM/I footprint dominated with forested area, the forest canopy and the snow covered ground dominate the emissivity behavior. Hence, it is important to analyze the degree to which SSM/I brightness temperature can be affected by the forest parameters in emissivity models [Lakshmi *et al.* 1997]. The boreal forest is the most dominant forest on earth covering the circumpolar regions of Europe, Asia and North America. However, the physical characteristics of conifers (for example, spruce, fir or pine) do not change considerably with time. Thus, the forest can complicate the up-welling radiation during snow monitoring by satellite system. On the other hand, non-forested vegetation can reflect and emit signals and hence modify the scattering behaviour of bulk signal [Kurvonen and Hallikainen 1997]. The empirical methods do not suffer from the presence of water and agricultural areas [Foster *et al.* 1997]. Hence, the empirical models give higher overall accuracies than those from physical model based inversion approach [Jin and Zhang 1999].

From above discussion it is evident that in an empirical model developed for the retrieval of microwave brightness temperature there are several features which have to go under sensitivity test before incorporating them in the model. Hence, a sensitivity test of atmosphere, vegetation, soil, water and snow was performed.

SENSITIVITY ANALYSIS

In order to determine which parameter impacts greatly in the model a sensitivity analysis has to be performed. Hence, the sensitivity analyses of ground, water, vegetation, atmosphere and snow pack parameters are performed using Eq. (1).

$$E_{feature} = \sqrt{E_{f1}^2 + E_{f2}^2 + E_{f3}^2 + \dots\dots} \qquad (1)$$

where E_{f1} = Total error produced by the variation in 1st parameter, E_{f2} = Total error produced by the variations in 2nd parameter, E_{f3} = Total error produced by the variations in 3rd parameter and so on.

First, for the sensitivity analyses of soil parameters the results of Butt [2002a] show that ground temperature and ground volumetric moisture are insensitive parameters whilst surface roughness as shown in Fig. 1 is sensitive parameter. However, the combined errors of the surface parameters in the brightness temperature contribution are given as:

E_{ground} = 0.27 K

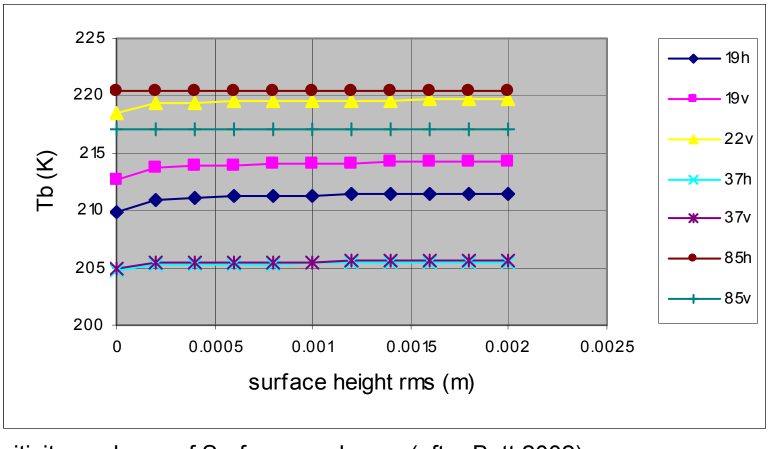

Fig. 1: Sensitivity analyses of Surface roughness (after Butt 2002).

Second, for the sensitivity analyses of water parameters the results of Butt [2002b] show that water temperature, water salinity, and wind speed are insensitive parameters, whilst area fraction covered by water bodies has a significant effect, as shown in Fig. 2, and is sensitive parameter. Using Eq. 1 the combine errors of the water parameters in brightness temperature estimation are:

E_{water} = 9.22 K

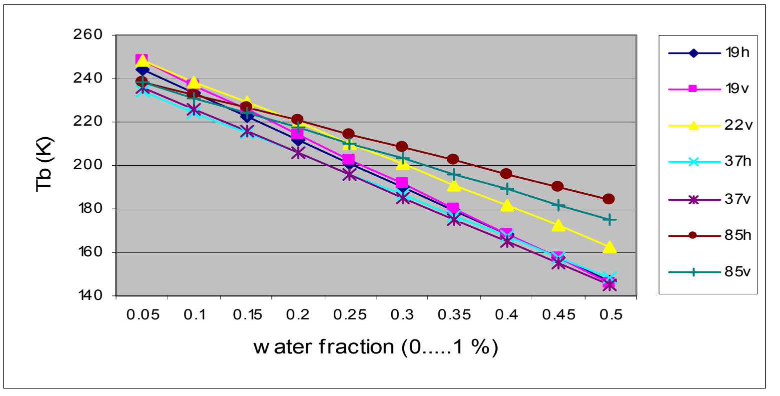

Fig. 2: Sensitivity analyses of Water fraction (after Butt 2002).

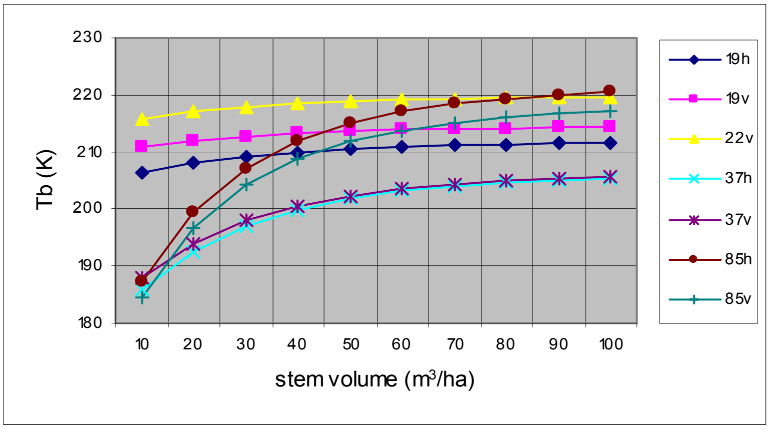

Fig. 3: Sensitivity analyses of Stem volume (after Butt and Kelly2003).

Third, for the sensitivity analyses of vegetated area the results of Butt and Kelly [2003] show that vegetation temperature is insensitive parameter, whilst stem volume, as shown in Fig. 3 is sensitive parameter. The combine error in the brightness temperature estimation of the vegetated parameters is given as:

$E_{vegetation} = 1.86$ K

Fourth, for the sensitivity analyses of the atmospheric contribution the results of Butt [2003] show that all of the atmospheric parameters (atmospheric temperature, ground level pressure and ground level water vapour), are insensitive parameters. Their combine error is given as:

$E_{atmosphere} = 0.53$ K

Finally, for the sensitivity analyses of snow surface the results of Butt [2002c] show that the snow salinity, snow temperature and snow density are regarded as the insensitive parameter whilst, snow layer thickness (Fig. 4), snow moisture (Fig. 5) and snow grain size (Fig. 6) are regarded as the sensitive parameters.

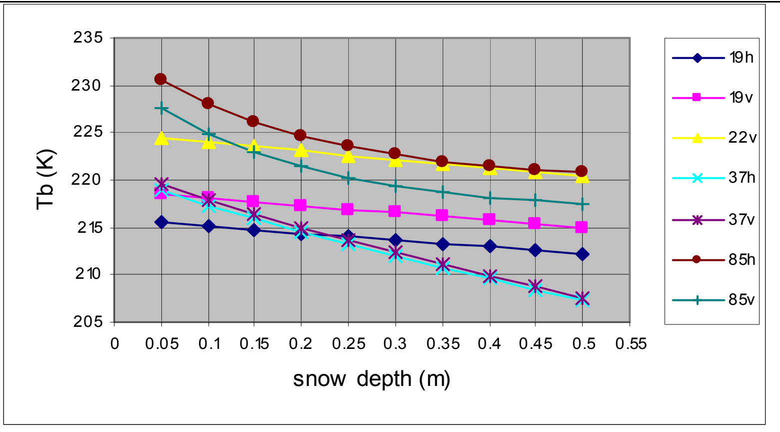

Fig. 4: Sensitivity analyses of Snow layer thickness (after Butt 2002).

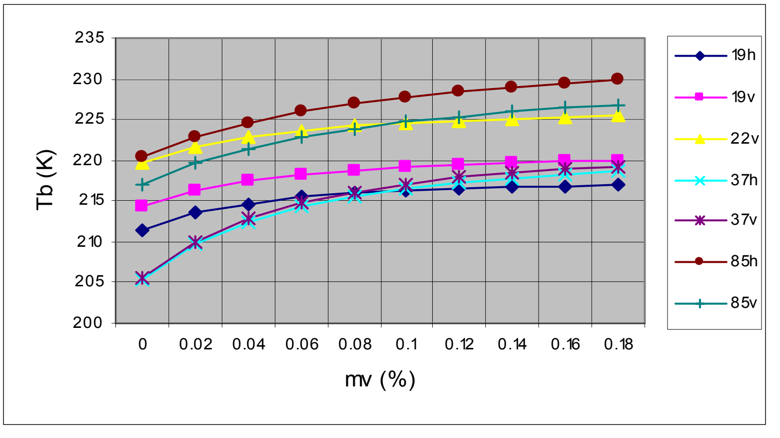

Fig. 5: Sensitivity analyses of Snow moisture (after Butt 2002).

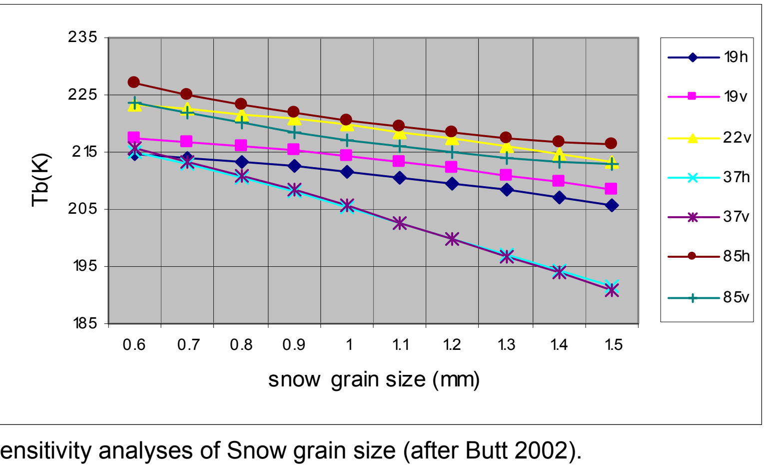

Fig. 6: Sensitivity analyses of Snow grain size (after Butt 2002).

The sensitivity analysis of ground surface, water areas, vegetation, atmosphere and snow surface was performed. The result of sensitivity analysis shows that, water fraction, forest stem volume, snow depth, snow grain size and snow moisture have significant effects in the radiative transfer theory based emission model.

CONCLUSIONS

From the above analyses it is evident that the brightness temperature sensed by a microwave satellite sensor depends on the receiving system parameters (frequency, angle and polarisation) and on the surface space and time-dependent physical properties. All earth objects either reflect and/or emit electromagnetic radiation whose strength and spectral distribution received by the satellite sensor system are modified to some extent through scattering by atmospheric parameters. The effect of various atmospheric features on the emission model using Special Sensor Microwave Imager (SSM/I) frequencies were performed. Sensitivity analyses of four different parameters of atmosphere (atmospheric temperature, atmospheric sky type, water vapour quantity, and pressure) indicate that only the water vapour quantity is sensitive parameter.

The sensitivity analysis of forest fraction shows that the forest temperature (an average decrease of 0.27 K is observed for all SSM/I channel frequencies) has a very little effect on SSM/I predicted brightness temperature values. On the other hand, the forest stem volume has an average increase of 1.84 K, which is considered to be more sensitive than forest temperature.

Sensitivity analyses of soil temperature, soil volumetric moisture content and surface roughness were performed. These analyses show that except the surface roughness the soil temperature and soil volumetric moisture content has very little effect and hence are regarded as insensitive parameters.

The sensitivity analyses of snow parameters show that the snow salinity and snow temperature are insensitive parameters. The snow density has very little effect particularly at 19 and 37 GHz frequencies. The other snow parameters, snow layer thickness, snow moisture and snow grain size are regarded as the sensitive parameters.

From the sensitivity analyses of wind speed, water temperature and water salinity it is clear that they have very little effect and hence are regarded as insensitive parameters. On the other hand, the percentage of water fraction has comparatively large effect on brightness temperatures predictions and hence on snow retrieval parameters. Butt [2001] showed that the percentage of water fraction has a major influence on brightness temperature retrieval. In this study the sensitivity analysis of water fraction shows that an average decrease of 9.22 K is observed for all SSM/I channel frequencies. Although, in case of emission from earth surface the contribution could be divided into the number of various elements present in the area under consideration however, the total contribution (the sum of all the features emission) remain unity.

Reference

Aschbacher, J., (**1989**) "Land Surface Studies and Atmospheric Effects by Satellite Microwave Radiometry", PhD Dissertation, University of Innsbruck, Austria.

Brown, R.D. and Goodison, B.E. (**1996**) "Interannual Variability in Reconstructed Canadian Snow Cover 1915-1992", *Journal of Climatology*, 9(6), 1299-1318.

Butt, M.J. and Kelly, R.E.J. (**2003**) "Snow Emission Model and Forest Effects", *Science International*, 15(1), 13-16.

Butt, M.J. (**2003**) "The Role of Atmosphere on Upwelling Microwave Radiations", *Journal of Pure and Applied Sciences*, 22(1), (In Press).

Butt, M.J. (**2002a**) "Investigation of the Effects of Rough Bare Soil Reflectivity Model", *J. Pure and Applied Sciences*, 21(2), 13-25.

Butt, M.J. (**2002b**) "Sensitivity Analysis of Brightness Temperature Retrieval Algorithm", *Science International*, 14(4), 279-289.

Butt, M.J. (**2002c**) "Contribution of Snow parameters in a Semi-Empirical Model", *Journal of Research (Science)*, 13(2), 177-187.

Butt, M.J. (**2001**) "Snow Monitoring in the UK Using a Microwave Emission Model", PhD Dissertation, University of London, UK.

Colton, M.C. and Poe, G.A. (**1999**) "Intersensor calibration of DMSP SSM/I=s: F-8 to F14, 1987-1997", *IEEE Transactions on Geoscience and Remote Sensing*, 37(1), 418-439.

Derksen, C., Wulder, M., LeDrew, E. and Goodison, B. (**1998**) "Association Between Spatially Autocorrelated Patterns of SSM/I-Derived Prairie Snow Cover and Atmospheric Circulation", *Hydrological Processes*, 12, 2307-2316.

Foster, J.L., Chang, A.T.C. and Hall, D.K. (**1997**) "Comparison of Snow Mass Estimates from a Prototype Passive Microwave Snow Algorithm, a Revised Algorithm and a Snow Depth Climatology", *Remote Sensing of Environment*, 62, 132-142.

Gray, D.M. and Male, D.H. (**1981**) "Handbook of Snow: Principles, Processes, Management and Use", Pergamon Press, Toronto, p.776.

Grody, N.C. and Basist, A. (**1996**) "Global identification of snowcover using SSM/I measurements", *IEEE Transactions on Geoscience and Remote Sensing*, 34(1), 237-249.

Hiltbrunner, D. and Matzler, C. (**1997**) "Land surface temperature retrieval and snow discrimination using SSM/I data", *Proceedings of the EARSeL Workshop Remote Sensing of Land Ice and Snow*, University of Freiburg Germany, pp. 87-94.

Jin, Ya-Qiu and Zhang, N. (**1999**) "Correlation of the ERS and SSM/I Observations Over Snow Pack and Numerical Simulation", *International Journal of Remote Sensing*, 20(15 & 16), 3009-3018.

Kumar, S., Sahoo, P.K. and Singh, R.P. (**1999**) "Monitoring of Brightness temperature Over Indian and Adjoining Regions Using SSM/I Data", *International Journal of Remote Sensing*, 20(12), 2305-2307.

Kurvonen, L. and Hallikainen, M. (**1997**) "Influence of land cover category on brightness temperature of snow", *IEEE Transactions on Geoscience and Remote Sensing*, 35(2), 367-377.

Lakshmi, V., Wood, E.F. and Choudhury, B.J. (**1997**) "Investigation of Effect of Hetrogeneities in Vegetation and Rainfall on Simulated SSM/I Brightness Temperatures", *International Journal of Remote Sensing*, 18(13), 2763-2784.

Loth, B. and Graf, H.F. (**1998**) "Modeling the Snow Cover in Climate Studies 1. Long-Term Integration Under Different Climate Conditions Using a Multilayered Snow Cover Model", *Journal of Geophysical Research*, 103(D10), 11313-11327.

Matzler, C. (**1996**) "Microwave permittivity of dry snow", *IEEE Transaction on Geoscience and Remote Sensing*, 34(2), 573-581.

McKay, G.A. and Gray, D.M. (**1981**) "The distribution of snow cover", In: D.M. Gray and D.H. Male (Eds.), *Handbook of Snow: Principles, Processes, Management and Use*, Pergamon Press, Toronto, pp. 153-190.

Pomeroy, J.W. and Gray, D.M. (**1995**) "Snowcover: Accumulation, Reloction and Management", National Hydrology Research Institute (NHRI) SCI., Rep. 7, Saskatoon, Saskatchewan, p. 144.

Pulliainen, J.T., Grandell, J. and Hallikainen, M.T. (**1997**) "Retrieval of surface temperature in boreal forest zone from SSM/I data", *IEEE Transactions on Geoscience and Remote Sensing*, 35(5), 1188-1200.

Pulliainen, J.T., Grandell, J. and Hallikainen, M.T. (**1999**) "HUT Snow Emission Model and its Applicability to Snow Water Equivalent Retrieval", *IEEE Transactions on Geoscience and Remote Sensing*, 37(3), 1378-1390.

Schiavon, G., Ferrazzoli, P., Solimini, D., de Maagt, P. and Baptista, J.P. V.P. (**1998**) "A Global High-Resolution Microwave Emission Model for the Earth", *Radio Science*, 33(3), 753-766.

Standley, A.P. and Barrett, E.C. (**1999**) "The Use of Coincident DMSP SSM/I and OLS Satellites Data to Improve Snow Cover Detection and Discrimination", *International Journal of Remote Sensing*, 20(2), 285-305.

Wegmuller, U. and Matzler, C. (**1999**) "Rough bare soil reflectivity model", *IEEE Transactions on Geoscience and Remote Sensing,* 37(3), 1391-1395.

Yang, Z.L., Dickinson, R.E., Robock, A. and Vinnikov, K.Y. (**1997**) "On Validation of the Snow Sub Model of the Biosphere-Atmosphere Transfer Scheme with Russian Snow Cover and Meteorological Observations Data", *Journal of Climatology*, (In press).