7A.1 **DO WE NEED TO ACCOUNT FOR LAKES IN CLIMATE AND NWP MODELLING?**

Patrick Samuelsson*
Swedish Meteorological and Hydrological Institute, Norrköping, Sweden

Ekatherina Kuorzeneva
Russian State Hydrometeorological University, Saint-Petersburg, Russia

Dmitrii Mironov
German Weather Service, Offenbach am Main, Germany

1. INTRODUCTION

One of the most important issues in regional climate and numerical weather prediction (NWP) models is the interaction of the atmosphere with the underlying surface. For decades, the interaction with land and sea surface has gotten much attention, but lakes have many times been disregarded or treated in a very simplistic way. The reason for this is of course that land and sea surface dominate the surface of the earth while lakes are only regionally important.

In regions where lakes represent a non-negligible fraction of the surface their large thermal inertia, when compared to the land surface, may cause them to have a substantial impact on the regional climate. This is particularly the case in Fennoscandia, Russia and in Canada. Here we have used a model system to study the influence of lakes on the regional climate.

2. APPLIED MODELS

The models applied are the Rossby Centre regional climate model RCA and the lake model FLake. Here follows an overview of these models and how they are coupled.

2.1 *The regional climate model RCA*

For this study we have used an updated version of the Rossby Centre regional climate model RCA3 (Kjellström et al. 2005, Samuelsson et al. 2006). RCA3 is developed at Rossby Centre, SMHI, and has been extensively used in a number of climate scenario studies. RCA3 is one of the RCMs in the European project http://www.ensembles-eu.org/. Climate scenarios based on RCA3 has also been used as the basis for the governmental Commission on Climate and Vulnerability in Sweden (Persson et al. 2007).

RCA3 includes parameterisations for radiation (Savijärvi 1990, Sass et al. 1994), turbulence (Cuxart et al. 2000), large-scale clouds and microphysics (Rasch and Kristjánsson 1998), convection (Kain and Fritsch 1993, Jones and Sanchez 2002), and land surface (Samuelsson et al. 2006). In the updated version of RCA3 we have replaced the original lake model PROBE (Ljungemyr et al. 1996) by FLake and replaced the land-surface physiographic information by ECOCLIMAP (Masson et al. 2003). These updates also called for some tuning of the atmospheric physics to keep the results close to observed climatology. A new official version of RCA including these updates will be released later during 2008.

2.2 *The lake model FLake*

In RCM and NWP modelling the lower boundary condition for the atmosphere with respect to lakes must be described. The boundary condition is represented by the energy fluxes of radiation, heat and momentum. Thus, the lake interior is really not of importance per se. As long as the surface temperature (including ice) is well simulated the lake model can be made simple. For climate simulations, a computationally cheap model is also of high priority. A lake model that fulfils these criteria is FLake (see http://lakemodel.net and references therein).

FLake is a two-layer model based on a self-similar representation (assumed shape) of the temperature profile in the mixed layer and in the thermocline. The model incorporates (i) a flexible parameterisation of the evolving temperature profile, (ii) an advanced formulation to compute the mixed-layer depth, including the equation of convective entrainment and a relaxation-type equation for the depth of a wind-mixed layer, (iii) an improved module to describe the vertical temperature structure of the thermally active layer of bottom sediments and the interaction of the water column with bottom sediments, and (iv) a snow-ice module. The prognostic variables are: temperature at surface (water, ice, or snow), for mixed layer, at bottom, and in sediment, depth of mixed layer and of sediment max temperature, thickness of snow and ice, and shape factor.

The ability of Flake to predict the temperature structure in lakes of various depths on diurnal and seasonal time scales has been successfully tested against data through single-column numerical experiments. Sensitivity experiments have shown that in summer the mixed layer depth tends to be underestimated. An adjustment of shape factor may be needed. The sensitivity of the model to fetch and optical parameters is not high. Sensitivity for bottom sediments block switched on/off appears only for long periods of simulation. Depth of the lake is the main

* *Corresponding author address:* Patrick Samuelsson, SMHI, Rossby Centre, SE-601 76 Norrköping, Sweden; e-mail: patrick.samuelsson@smhi.se

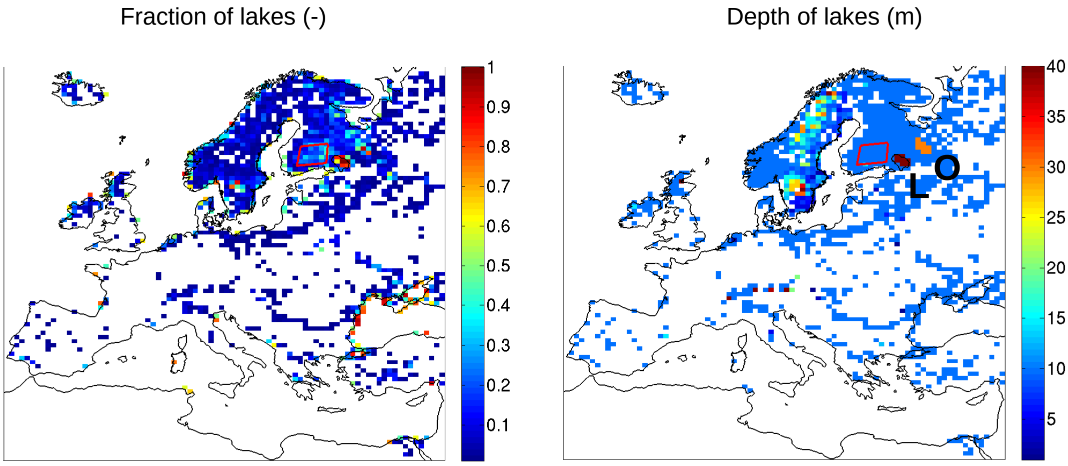

Figure 1. Total fraction of lakes and depth of lakes in the model domain. Note the relatively large fraction in southern Finland (denoted by the red rhombus) represented by many small and moderately deep lakes (10 m in the simulation). Note also the large and deep lakes Ladoga (L, 40m) and Onega (O, 30m) in western Russia.

parameter for which the model is sensitive to. Tests have shown that a maximum lake depth of 40m is recommended.

Today FLake is implemented into the NWP model COSMO-LM (DWD) and into the regional climate models RCA (SMHI) and CLM (GKSS). It is also on its way into the NWP model HIRLAM and into the externalised surface module SURFEX as used for ALADIN, AROME and HARMONIE NWP systems.

2.3 *The coupling RCA-FLake*

RCA uses a tiled surface scheme which means that any water in a grid square is treated independently of other sub-grid surfaces. The energy fluxes from each individual tile are area averaged to form grid-averaged fluxes. In RCA all inland water (lakes and rivers, but from hereon only referred to as lakes) is modelled by FLake. There is a possibility to distinguish between three different lake categories in each grid square; shallow (3.5 m), medium (7.4 m) and deep lakes (≥10 m). The fractional area of lakes in each grid square is given by ECOCLIMAP. Due to the lack of detailed lake information all lakes are in general specified as category deep with a depth of 10 m. However, for Sweden additional lake information is available which allow us to use all three categories. Some large and deep lakes outside Sweden are also given a specified known mean depth (i.e. Ladoga 40 m, Onega 30 m). RCA and FLake are flux coupled which means that the system is energy consistent. In the tiled surface scheme we can also distinguish between i.e. different 2m air temperatures over the individual tiles. Thus, we have separate 2m air temperatures computed over lakes, open-land, and in forest areas. A grid averaged 2m air temperature is simply an area averaged value of these individual 2m air temperatures.

3. METHODOLOGY

To answer the question in the title we have performed two 30-year integration experiments with RCA (1961-1990). In the first experiment (EX_lake) lakes are present, RCA is coupled to FLake, while in the second experiment (EX_land) all lakes in RCA are replaced by land (grass and forest). In comparing the results of the two experiments we can identify for which geographical regions the lakes play an important role for the climate and also we can quantify their effect on the meteorological conditions. For these experiments snow was not explicitly stored on lake ice (but the albedo was adjusted for the presence snow) and the bottom sediment of lakes was switched off.

The RCA model domain is shown in Figure 1 along with the fractional coverage of lakes and their depth. From this figure it is obvious that the largest influence of lakes should be expected in Northern Europe. The domain is resolved by 102x111 grid points (0.4deg~50km) and we use 24 levels in the vertical. The model uses Semi-Lagrangian dynamics and is hydrostatic. The time step is 30 minutes. ECMWF 40 year reanalysis data (ERA40) has been used for lateral and sea-surface temperature boundary conditions.

4. RESULTS – EVALUATION

The lake surface temperatures from experiment EX_lake have been evaluated against observations. In Figure 2 we show two examples; the deep lake Ladoga in western Russia and the shallow lake Võrtsjärv in Estonia. Ladoga has an observed mean depth of 51 m and a maximum depth of 230 m. The mean depth used for FLake is 40 m. Võrtsjärv has an observed mean depth of 2.8 and a maximum depth of

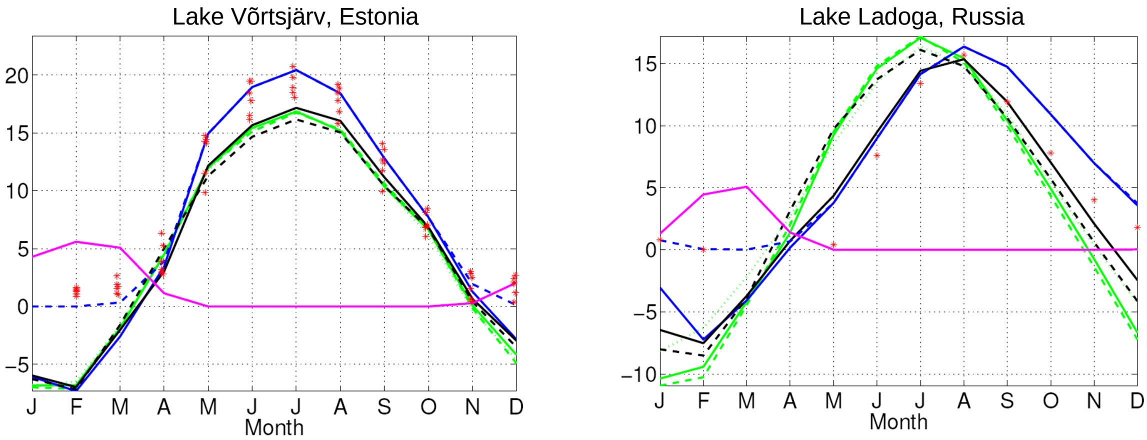

Figure 2. All lines show annual cycle of temperatures (℃) except for the magenta coloured line which shows annual cycle of ice thickness (m times 10, i.e. 5 corresponds to 50 cm of ice). The red symbols denote observed lake surface temperature. The green lines denote observed T2m air temperature (ERA40, CRU, Willmott). The lines with simulated temperatures are: surface (solid blue), mixed layer (dashed blue), T2m air over lake (solid black), and T2m air over open land (dashed black).

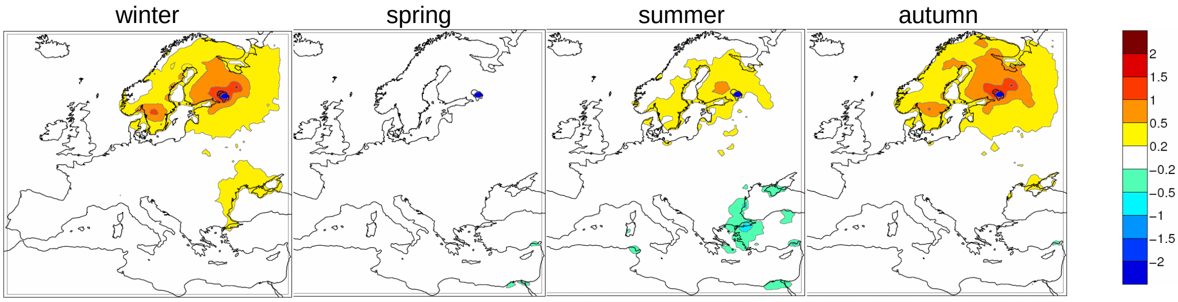

Figure 3. Difference in 2m open-land temperature (°C) between the two experiments (EX_lake – EX_land) for four different seasons.

6 m. The mean depth used for Flake is 3 m. The lake information is provided by the International Lake Environment Committee (ILEC) (http://www.ilec.or.jp).

Both lakes are ice covered during winter with a maximum simulated ice thickness reaching 50 cm. The ice covered period extends over 4-6 months which is comparable to observed periods (ILEC). The simulated mixed layer temperature for Võrtsjärv corresponds quite well with observations (http://clime.tkk.fi/), although there is a small tendency of a warm bias. Note that for a shallow lake like in this case the annual cycles of lake and surrounding temperatures, respectively, almost coincide.

For a deep lake like Ladoga the lake T2m air temperature is clearly lagged compared to the surrounding open-land temperature. The simulated surface temperature shows a warm bias compared to the observed temperature (ILEC). This warm bias reflects a general picture around this area of the model domain in this version of RCA. As a consequence the ice break up is almost one month earlier than observed.

5. RESULTS – COMPARING EXPERIMENTS

5.1 *2m air temperature*

Figure 3 shows the difference in 2m open land air temperature between the two experiments (EX_lake – EX_land). Note that the effect of lakes on the open-land temperature must act via the lowest model level (at ~90 m in these simulations). In general the presence of lakes has a warming effect on the climate for all seasons except spring. In autumn this is certainly expected since the lakes are still relatively warm while a land surface cool more quickly. In cold winter climates the warming effect during winter is explained by the fact that the ice covered period usually extends from mid winter until mid spring. Thus, during the first half of the winter the lakes are still warmer than a corresponding land area would be. During summer the warming effect of lakes is due to a relatively warm lake surface temperature during night time. This is seen in Figure 5 which shows the diurnal 2m air temperature cycle for a grid point in southern Finland. The night time 2m air temperature over the lake is considerable warmer compared to land

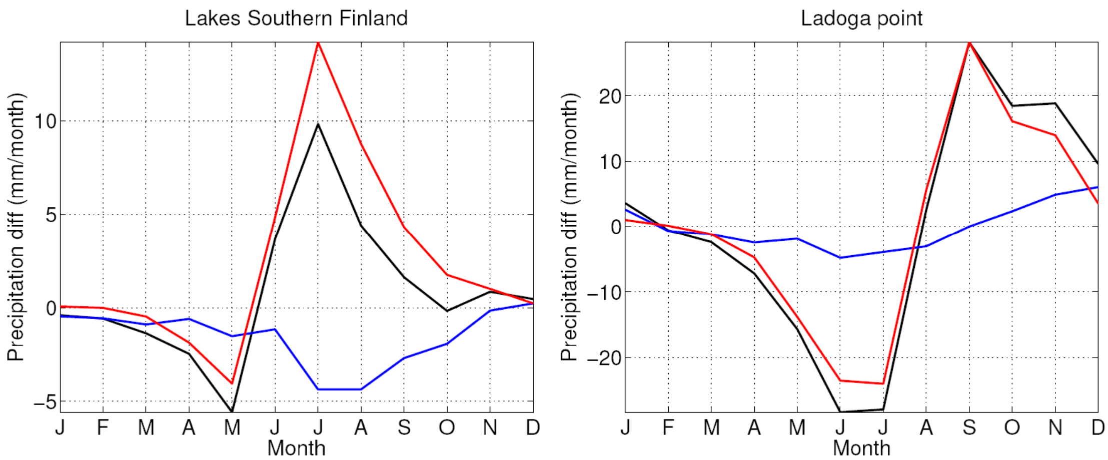

Figure 4. Annual cycle of difference in precipitation (EX_lake – EX_land) for the area in southern Finland (as marked in Figure 1) and for a point over Lake Ladoga. The lines represent total precipitation (black), large scale precipitation (blue), and convective precipitation (red).

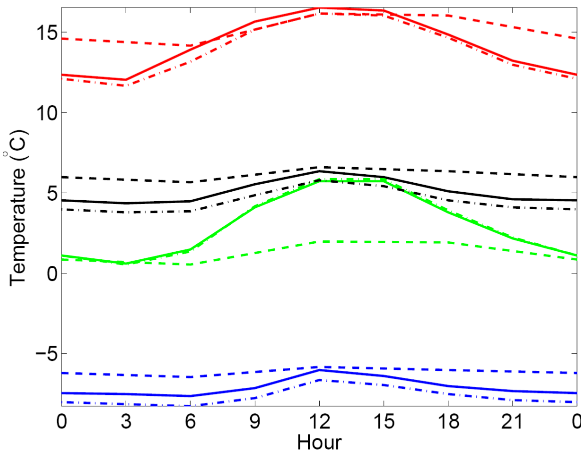

Figure 5. Diurnal cycle of 2m air temperature for a grid square close to lake Pääjärvi in southern Finland. The lines represent temperature over lake (dashed) and open land (full) in EXP_lake and over open land (dash-dotted) in EXP_land. The colours represent the four seasons; summer (red), autumn (black), winter (blue), and spring (green).

In spring the lakes are cold enough to create a stable boundary layer which more or less isolates the lakes from the rest of the atmosphere with respect to turbulent fluxes.

5.2 *Cloudiness and precipitation*

The difference in cloudiness is not very big between the two experiments (not shown). Nevertheless, there is somewhat less cloudiness during summer in EX_lake which leads to a bit more incoming short-wave radiation. The local lake effect is in reality of course bigger but the model can only represent changes on the scale of the whole grid square.

The difference in precipitation between the two experiments is illustrated in Figure 4. The presence of lake Ladoga reduces the summer precipitation but increases the autumn precipitation. Over an area with many moderately deep lakes as in southern Finland we see the reduction in spring and the increase in summer. Although the division into large-scale and convective precipitation is very dependent on the parameterisation of clouds and microphysics the difference between the two experiments indicate that the convective component is influenced the most.

5.3 *Energy fluxes*

Figure 6 shows the differences between the different energy flux components. The net input of energy to lakes peaks in May and June respectively. The main contributions are from SWnet and evaporation. The change in ΔSWnet from April to May over Southern Finland is due to a change in albedo; the albedo decreases in both experiments but the decrease in EX_lake is more dramatic as snow covered ice is replaced by water. The albedo of water is lower than for land. Therefore, we get at positive ΔSWnet for the ice free period. The difference in evaporation, ΔLE, is explained by the fact that the stable boundary layer over the lake in early summer suppresses the evaporation as compared to the evapotranspiration from a land surface. During autumn on the other hand the evaporation loss from the warm lake surface is much larger than for a land surface.

The net loss of energy from lakes peaks in November and December respectively. The main contributing components are LWnet, evaporation and sensible heat.

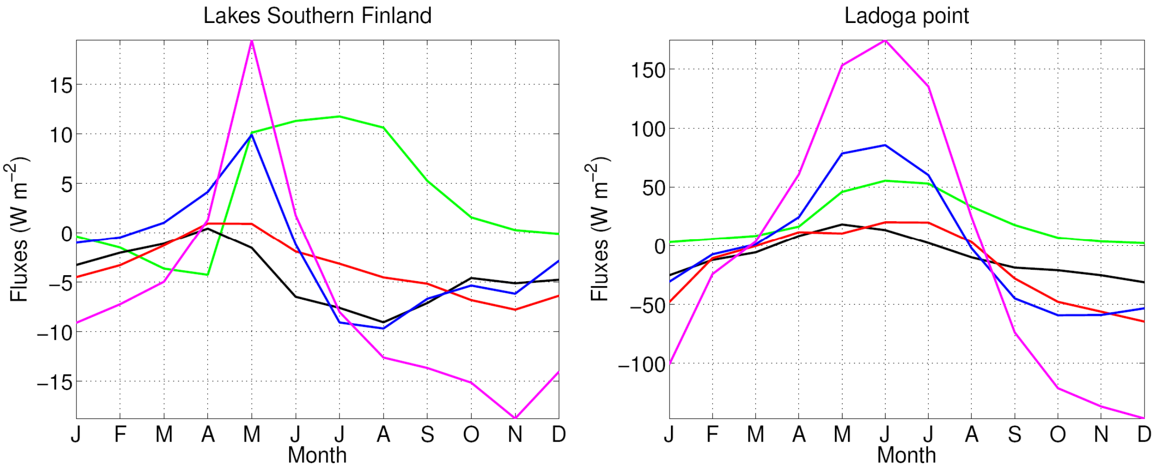

Figure 6. Annual cycle of difference in fluxes (EX_lake – EX_land) for the area in southern Finland (as marked in Figure 1) and for a point over Lake Ladoga. The lines represent SWnet radiation (green), LWnet radiation (black), sensible heat flux, H, (red), latent heat flux, LE, (blue), and net flux, SWnet+LWnet+H+LE, (magenta). Note that positive LE difference means less evaporation in EX_lake.

For the lake area in southern Finland we see that the energy loss due to LWnet and evaporation peaks around August when the lakes are characterised by relatively warm night-time temperature.

6. CONCLUSIONS

The two-layer lake model FLake has been successfully implemented in RCA and gives satisfactory results for simulated lake temperatures. FLake is a good candidate to be the next official lake model in RCA and in HIRLAM/HARMONIE NWP systems.

The answer to the title question is: Yes we should account for lakes in climate and NWP modelling, at least in Northern Europe, where they make the surrounding mean temperature climate warmer for most seasons.

The results are based on two model experiments where the lakes are replaced by land in one of them. A comparison of the two experiments shows that the presence of lakes has a warming effect on the climate for all seasons except spring. In cold winter climates the warming effect during winter is explained by the fact that the ice covered period usually extends from mid winter until mid spring. During summer the warming effect of lakes is due to a relatively warm lake surface temperature during night time. The results also show that many small lakes (as in Southern Finland) act differently on the summer climate than a few big lakes. Many small, and relatively warm, lakes enhance the summer precipitation due to more evaporation while big, and relatively cool, lakes suppress evaporation and consequently also the precipitation.

In near future we should look into snow on ice. Snow is not yet allowed on lake ice which may cause an unrealistic heat transfer through the ice. Soon we will also implement a lake data base for Europe (depth and area).

Acknowledgements

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REFERENCES

Cuxart, J., Bougeault, Ph. and Redelsperger, J-L., 2000. A turbulences scheme allowing for mesoscale and large eddy simulations. Q. J. R. Meteorol. Soc., 126, 1-30.

Jones C.G. and Sanchez, E., 2002. The representation of shallow cumulus convection and associated cloud fields in the Rossby Centre Atmospheric Model. HIRLAM Newsletter 41, Available on request from SMHI, S-60176 Norrköping, Sweden.

Kain, J.S. and J.M. Fritsch, 1993. Convective parameterizations for Mesoscale Models: The Kain-Fritsch scheme. In: The representation of cumulus convection in numerical models, Eds: K.A. Emanuel and D.J. Raymond. AMS Monograph, 46, 246 pp.

Kjellström, E., Bärring, L., Gollvik, S., Hansson, U., Jones, C., Samuelsson, P., Rummukainen, M., Ullerstig, A., Willén U. and Wyser, K., 2005. A 140-year simulation of European climate with the new version of the Rossby Centre regional atmospheric climate model (RCA3). Reports Meteorology and Climatology 108, SMHI, SE-60176 Norrköping, Sweden, 54 pp.

(http://www.smhi.se/sgn0106/if/biblioteket/rapporter_pdf/RMK108.pdf)

Ljungemyr P., Gustafsson N. and Omstedt A., 1996. Parameterization of lake thermodynamics in a high resolution weather forecasting model. Tellus, 48A, 608–621.

Masson, V., J.L. Champeaux, F. Chauvin, C. Mériguet and R. Lacaze, 2003, A global database of land surface parameters at 1km resolution for use in meteorological and climate models. J. Climate, 16, pp 1261-1282.

Persson, G., Bärring, L., Kjellström, E., Strandberg, G. and Rummukainen, M. 2007. Climate indices for vulnerability assessments. SMHI Reports Meteorology and Climatology RMK No 111. Swedish Meteorological and Hydrological Institute, SE-601 76 Norrköping, Sweden, 64 pp. (http://www.smhi.se/sgn0106/if/biblioteket/rapporter_pdf/RMK111.pdf)

Rasch, P.J. and Kristjansson, J.E., 1998. A comparison of the CCM3 model climate using diagnosed and predicted condensate parameterisations, J. Climate, 11, 1587-1614.

Samuelsson, P., Gollvik, S. and Ullerstig, A. 2006. The land-surface scheme of the Rossby Centre regional atmospheric climate model (RCA3). SMHI Meteorologi No 122 . 25 pp. (http://www.smhi.se/sgn0106/if/biblioteket/rapporter_pdf/meteorologi_122.pdf)

Sass B.H., Rontu L., Savijärvi H., Räisänen P., 1994. HIRLAM-2 Radiation scheme: Documentation and tests. Hirlam technical report No 16., SMHI. SE-601 76 Norrköping, Sweden, 43 pp.

Savijärvi H., 1990. A fast radiation scheme for mesoscale model and short-range forecast models. J. Appl. Met., 29, 437-447.