USE OF A HIGH-RESOLUTION CLOUD CLIMATE DATA SET FOR VALIDATION OF ROSSBY CENTRE CLIMATE SIMULATIONS

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ABSTRACT

Simulated cloud climate results from the SMHI Rossby Centre regional climate model (RCA2) and the ECMWF 40-year reanalysis data set (ERA-40) for the period 1991-2000 and over the northern European region were compared to a corresponding NOAA AVHRR cloud climate data set - the SCANDIA cloud climatology. Results indicated a reasonable agreement concerning the horizontal distribution of cloudiness in the region, especially for the ERA-40 data set, but a substantial overestimation of cloud amounts was generally seen for both models. This was particularly evident over land surfaces during the winter season where both models showed cloud amounts exceeding the SCANDIA values with as much as 15-20% in fractional cloud cover units.

It became obvious that the studied RCA2 model data set included a significant contribution to the cloud amounts from optically very thin clouds. A large effort, based on radiative transfer simulations of cloudy radiances, was therefore undertaken to define the lower detection limit for clouds analysed by the SCANDIA methodology. The purpose was to prepare for future attempts to filter the model data sets from the contribution from the optically thinnest clouds for which the satellite data set would have an incomplete coverage. Results indicated that a reasonable lower boundary for the optical thickness of detectable clouds for SCANDIA could be approximated to a value close to 1.

Apart from completing the filtering attempt of model results for the further clarification and confirmation of the deviations between model simulations and satellite observations, future work will also consider the possibility to define appropriate model data simulation tools to support and facilitate the use of satellite-derived cloud climate data sets (e.g. those derived by the Climate Monitoring SAF) in model validation activities.

1 INTRODUCTION

The differences in results from various climate simulation centres are partly explained by differences in cloud parameterisations and in the used methods for describing the crucial cloud-radiation interaction processes. Consequently, the task of validating simulated cloud results is important for the basic evaluation and further development of climate simulations. This paper presents a validation method based on the use of cloud information derived from high-resolution satellite imagery from the NOAA AVHRR sensor.

In order to give an appropriate background to the conditions for the satellite-to-model comparisons, a short description of the satellite-derived data set – the SCANDIA cloud climatology - is given in section 2 and a corresponding description of the Rossby Centre Atmospheric model (RCA) cloud data set is given in section 3. For enlarging the scope of the project somewhat, also an additional model data set (the ECMWF 40 year reanalysis data set – ERA40) has been included in some of the comparisons. The ERA-40 data set is briefly introduced in section 4. Section 5 presents the results from direct comparisons between the mentioned data sets.
Although the results of the direct comparisons were basically found quite useful and encouraging, it was also understood that there were also some fundamental and difficult problems associated with the applied method of comparing the satellite and model data sets. This is explained more in detail in section 6 which also includes a description of an alternative method for carrying out the comparison based on the concept of filtering of the satellite and the model data sets. For this, the use of a radiative transfer model (RTM) capable of simulating cloudy radiances for the NOAA AVHRR channels was found necessary. The chosen RTM model is described in this section together with some results from some preparatory simulations providing guidance for the suggested filtering approach to be carried on in the near future. Finally, section 8 summarises the main conclusions and outlines the future plans of additional satellite-to-model comparisons.

2 THE 1991-2000 SCANDIA CLOUD CLIMATOLOGY

The used approach for the compilation of satellite-derived cloud climatologies has been to use results from the SCANDIA (SMHI Cloud ANalysis model using DIGital AVHRR data) cloud classification model (described in detail by Karlsson, 1996a and Karlsson, 1997) covering the period 1991-2000. SCANDIA uses the full five-channel NOAA AVHRR data set at maximum horizontal resolution. However, the cloud climatology results presented here have been based on a data set with a reduced resolution of 4 km. The covered region is the Nordic region (Sweden, Norway, Denmark and Finland) including the entire Baltic Sea and nearby coastal areas and parts of the Norwegian Sea.

SCANDIA results from four daily overpasses over the area (observing approximately at night, in the morning, in the afternoon and in the evening) have been used to define a daily mean of cloud cover over the area. Results have then been accumulated to define monthly, seasonal and yearly climatologies for the studied time period. Since SCANDIA makes a separation of many different cloud types, the data set permitted also studies of different cloud groups in addition to the central parameter total fractional cloud cover.

The quality of the SCANDIA climatology has previously been examined (Karlsson, 2001, 2003) through comparisons with corresponding climatologies derived from surface cloud observations (SYNOP). In general, cloud amount deviations from surface observations were smaller than 10% except for some individual winter months when the separability between clouds and snow-covered cold land surfaces often is poor introducing a considerable (10-15%) overestimation of SCANDIA cloud amounts.

The SCANDIA cloud climatology is described in detail by Karlsson (2003) and by Karlsson et al. (2002) where also results from comparisons to corresponding ISCCP (International Satellite Cloud Climatology Project – described by Rossow and Schiffer, 1999) and ERA-40 (introduced in section 4) data sets have been added.

3 THE ROSSBY CENTER CLOUD CLIMATE SIMULATION DATA SET

In this study the second version of the SMHI Rossby Centre Regional Climate Model (RCA2) has been used (described by Jones, 2001, 2002). In RCA2, some changes in the cloud parameterisation and radiation schemes were introduced as compared to previous versions of the model (Rummukainen et al., 2001).

In RCA cloud processes are basically separated into the treatment of two groups of clouds: resolved clouds (large- and/or mesoscale) and sub-grid scale (convective) clouds. For the studied RCA2 version, large-scale clouds (or large-scale condensation processes) are described using the scheme of Rasch and Kristjansson (1998). Convective clouds (or subgrid-scale condensation processes) are described using the approach of Kain and Fritsch (1990). This latter scheme assumes that meso-scale circulations are basically resolved in the model and that only cloud scale fluxes have to be parameterised. A consequence here is that Cirrus anvils in deep convective systems can in some sense now be seen as resolved clouds and that only the inner cores of the clouds with areas of active vertical ascent are parameterised. The diagnosis of the cloud fraction in a grid square follows the ideas of Slingo (1987) but various modifications of the calculations of resolved and sub-grid scale clouds have been introduced.

In this particular study, results from a 17-year RCA2 climate simulation have been utilised. The total simulation period was 1985-2001 but only the period 1991-2000 (coinciding with the SCANDIA climatology period) was studied in this context. The RCA2 model was run using ECMWF analysed fields (ERA-15 1985-1993 and operational ECMWF analyses 1994-2001) as the lower and lateral boundary conditions. Figure 1 illustrates the full geographical model domain and the model land-sea mask. When extracting the cloud
information for this comparison study, the concept of maximum-random cloud overlap has been used since this is considered as the most physically realistic assumption. This means that for clouds in adjacent vertical layers maximum cloud overlap is applied while for clouds separated by several cloud-free vertical layers random overlap is used.

4 THE ERA-40 CLOUD DATA SET

The main objective of the ECMWF Re-Analysis project (ERA) was to promote the use of global analyses of the state of the atmosphere, land and surface conditions over long periods. In particular, ERA offers such data sets defined by the most up to date data assimilation system applied invariantly (i.e., remaining unchanged) during the analysed period. A first 15-year data set (denoted ERA-15) covering the period 1979-1993 has previously been produced and a second version (ERA-40) has now been completed (Uppala, 2001). More details on the ERA project can be found under http://www.ecmwf.int/research/era/.

The ECMWF ERA-40 data set includes a cloud component generated as a mixed assimilation-forecast product. Through the assimilation of observations (both radiosonde and satellite derived), the basic thermodynamic variables (e.g. vertical temperature and humidity profiles) will be well constrained to follow observed conditions over the region of study. From this high quality analysed model state, a short range 6-hour forecast is made. The cloud field resulting from this short range forecast is the cloud field subsequently averaged into a monthly mean dataset. Cloud amounts from the first 6-hour forecast are used in the next assimilation cycle, along with newly introduced thermodynamic observations and a new 6-hour forecast is made. In this manner, the basic state of the ERA-40 model is constrained to follow observations and the spin up in the forecast cloud field is minimised over the entire ERA-40 period (see Jakob, 2000, for more details).

![Figure 1. The RCA2 model domain used in the present study. Shown is the Land-Sea mask.](image)

In this study, the ERA-40 cloud component covering the period 1991-2000 (the SCANDIA cloud climatology period) has been used as an additional complementary model data set to the cloud information produced by the RCA2 model. The data set has essentially been treated as a model data set (being generated by the prognostic ECMWF cloud scheme) even if it is evident that a strong indirect influence from the assimilated observations have constrained the results.
5 RESULTS FROM DIRECT COMPARISONS OF SATELLITE-DERIVED AND
MODEL-GENERATED CLOUD CLIMATOLOGIES

Figure 2 shows the mean monthly cloud cover over the studied period 1991-2000 over the SCANDIA geographical domain for all corresponding model grid points. All data sets show a considerable seasonal and yearly variation over the area. Most of the time they agree reasonably well on the occurrences of individual maxima and minima in cloudiness but differences exist in terms of the seasonal amplitude and also in some cases concerning actual cloud amounts. For the model data sets (in particular for RCA2), cloud amounts are generally higher than SCANDIA, especially for the winter seasons (e.g., large deviations are found for winters 1994/1995 and 1997/1998). ERA-40 is seen to give a better similarity with SCANDIA results and especially the low cloud amounts in the summer season are reproduced much better than by RCA2.

Figure 2. Time series 1991-2000 of mean monthly total cloud amount (%) for SCANDIA, RCA2 and ERA-40.

Figure 3 illustrates results further showing the mean two-dimensional distribution of cloud amounts over the SCANDIA domain for all seasons. From this we may also conclude that the large deviation between SCANDIA and the model data sets in the winter seasons appears to be a typical problem mainly over land areas in the region.

6 IMPROVING INTERPRETATION OF RESULTS – INTRODUCTION OF A
FILTERING APPROACH

The fact that results showed a general model overestimation of cloudiness did cause quite some concern in this study and it actually lead to some reconsideration of the initial study goals. The overestimation of cloud amounts was not initially expected. The finite vertical resolution in models was expected to create ambiguities in the interpretation of 2-D cloud data sets and, especially, modelled cloud amounts were actually expected to be underestimated. The reason for this is that modelled horizontal cloud data sets are normally computed from the volume fraction in a grid volume. Since the vertical resolution of model layers is often much larger than the vertical dimension of real cloud layers (especially for thin high-level clouds), this leads inevitably to a model-underestimation of the interpreted horizontal cloud fraction. However, it must be understood that this is not a model error but only an effect of the finite vertical resolution. The achieved results of this study so far would then strongly indicate that there is currently a significant overestimation of cloud amounts in the models.
However, it became obvious in the more detailed evaluation of results that the model data set included non-negligible contributions from optically very thin clouds. Two questions then arose:

1. Are these clouds observed in reality?
2. Is the SCANDIA data set capable of describing the contribution from these clouds?

A possible answer to the first question is provided by recent experience of analysing data from high-sensitivity ground-based cloud radar and lidar instruments. For example, the measurements performed during the Arctic SHEBA experiment (reported by Intrieri et al., 2002) shows clearly a frequent existence of optically very thin clouds. Corresponding data sets from satellite-retrievals and manual surface observations (SYNOP) were not capable of detecting these clouds. Thus, we conclude concerning question 1 above that a substantial contribution from optically very thin clouds is possible and cannot therefore be excluded. Then, we are now forced to try to answer question number 2 and, furthermore, provide a tool for determining the SCANDIA lower detection limit in order to carry out a filtering of the model results. Without the filtering of the contribution from the thinnest clouds, a fair comparison between the SCANDIA and the model data sets will never be achieved.

The proposed solution was then to try to simulate the cloudy radiances by use of available RTM tools. The choice fell upon the SSCR (Signal Simulator for Cloud Retrieval) radiative transfer code described by
Nakajima and King (1992) and Nakajima (1995). SSCR is based on the previous work of Nakajima and Tanaka (1986) and is basically a discrete-ordinate method (DISORT – Stamnes and Swansson, 1981) solving the transfer equation for diffuse solar radiation in a plane-parallel scattering atmosphere. The method allows for simulation of clouds by inserting them as homogeneous sub-layers with certain specified characteristics (water phase, volume size distribution and particle optical thickness). SSCR has been extended to include thermal radiative transfer as proposed by Stamnes et al. (1988).

The SSCR model was used to simulate radiances in AVHRR channels for thin water and ice clouds (however with ice cloud simulations restricted to using only spherical particles) over a Lambertian land surface and an ocean surface. A large set of different viewing angles, solar zenith angles and different combinations of satellite and solar azimuth angles was used in the simulations. Figures 4 and 5 below give typical results from these simulations showing AVHRR channel 1 (at 0.6 µm) reflectivities for various optical thicknesses of low level water and high ice clouds displayed together with some of the SCANDIA thresholds for the thinnest (i.e., least reflective) cloud categories. The latter included Altocumus and Stratus/Fog cloud types for water clouds and also small Cumulus cloud categories where contributions from sub-pixel scale cloud elements also could be foreseen. For ice clouds the thinnest Cirrus cloud categories were selected. Notice here that reflectivities are not normalised with the solar zenith angle and that they are also scaled with the factor 2.55 (8-bit representation). The majority of the simulations indicated that a detection limit for SCANDIA should exist for clouds having an optical thickness of approximately 1.0. Also for the threshold tests used in other AVHRR channels (applied simultaneously in SCANDIA) this limit appeared to be the most appropriate. Consequently, we conclude that a filtering of clouds with an average optical thickness less than 1.0 should be applied to the RCA model data set to improve the understanding of the validation results. The method for doing this was still under development at the time of the conference.

Figure 4. Example of simulations of AVHRR channel 1 reflectivities of low level water clouds for various optical thicknesses as a function of solar zenith angles. This particular figure shows simulations for a satellite zenith angle of 25 degrees and azimuth angle difference of 0 degrees (backscattering mode).
Figure 5. Example of simulations of AVHRR channel 1 reflectivities of high level ice clouds for various optical thicknesses as a function of solar zenith angles. This particular figure shows simulations for a satellite zenith angle of 25 degrees and azimuth angle difference of 180 degrees (forwardscattering mode).

7 SUMMARY AND FUTURE PLANS

This study has illustrated and highlighted some of the challenges and problems that are encountered when trying to use satellite-retrieved cloud parameters for validating climate model simulations. A direct comparison of satellite-derived and model-generated parameters is seldom possible. Substantial post-processing efforts are often necessary in order to adapt the data sets for permitting a fair comparison.

In this particular study, two model data sets (RCA2 and ERA-40) were compared to a ten-year cloud climatology derived from NOAA AVHRR describing the cloud type occurrence and the fractional cloud cover over the Nordic region. The satellite data-set was resampled from a high-resolution to a low-resolution mode to fit the corresponding horizontal resolution of the models. Results indicated a reasonable agreement concerning the horizontal distribution of cloudiness in the region (especially for the ERA-40 data set) but a substantial overestimation of cloud amounts was generally seen for both models. This was particularly evident over land surfaces during the winter season where both models showed cloud amounts exceeding the SCANDIA values with as much as 15-20 % in fractional cloud cover units.

However, it became obvious that the studied RCA2 model data set included a significant contribution to the cloud amounts from optically very thin clouds. In order to investigate if this contribution could by itself explain the excessive cloud amounts, a large effort based on radiative transfer simulations of cloudy radiances was undertaken to define the lower detection limit for clouds analysed by the SCANDIA model. Extensive simulations for various viewing and illumination conditions and for various cloud types (ice and water clouds) and surface conditions showed that a reasonable lower boundary for the optical thickness of detectable clouds could be approximated to a value close to 1. The work with filtering the model data set based on this estimated value was not finished at the time of the conference and results have thus to be reported later.

An interesting observation is that the current simulation results for the RCA2 scheme for the studied period did not give significant positive biases in the surface temperatures over land surfaces in winter. This would have been expected if wintertime cloud amounts were greatly overestimated. However, this could possibly
be explained by the existence of other compensating model errors. The RCA2 radiation scheme is based on
the formulation originally described by Savijärvi (1990) which later was slightly modified by Räisänen et al.
(2000). In this context, it should be noted that clouds are actually treated with a Maximum cloud overlap
instead of the Maximum-Random overlap that has been used in this particular study when diagnosing the
total cloud amounts. This means that the radiation code systematically sees less cloud amounts, in the
context of cloud interaction with radiation, than those retrieved diagnostically from the model. Consequently,
there could be a complex model inconsistency between various parts of the model physics that cannot easily
be removed.

Several additional aspects of model validation that were initially planned (e.g., studies of the diurnal variation
of cloudiness and the water and ice cloud contributions) have not yet been completed due to the
complications encountered related to the large and basically unforeseen contribution from optically very thin
clouds. These aspects have to be studied in the future as well as the more intriguing one to try to filter out
also clouds that should be vertically resolved by the climate model (if being perfect). The latter would then
give a chance of estimating the performance of the parameterisation of sub-grid scale cloud processes and
their contribution relative to that from the resolved group of clouds. Finally, it should be mentioned that the
current experiences in this study might lead to attempts of defining a Climate Monitoring SAF (CM- SAF) data
simulation tool that could assist in adapting model data sets to allow a more efficient and appropriate
comparison with satellite-derived cloud climate data sets.

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