A Validation of the Cloud Parameterization in the Regional Model SN-REMO

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Abstract

The cloud parameterization in the atmospheric model SN-REMO (Spectrally Nudged REgional MOdel) was validated using satellite data from ISCCP (International Satellite Cloud Climatology Project). There is an overall good agreement between SN-REMO and ISCCP in temporal and spatial means of cloud amount. However, with further investigation a deficiency was localized regarding the simulation of cloud amount: Too many clouds are simulated. This overestimation occurs especially during the night. It is connected with a poor simulation of the cloud diurnal cycle. Clouds at low-level emissivity heights (1000-475 hPa) are causing this overestimation. The magnitude of the overall overestimation is also affected by the underestimation of simulated cloud amount at high-level emissivity heights (<475 hPa) and its diurnal variation. The overestimation of the simulated cloud amount is caused by sub-grid scale cloudiness. Since the simulation of sub-grid scale clouds in the regional model SN-REMO is described by a relative humidity parameterization these deficiencies are connected with this parameterization.

1. Introduction

International model intercomparisons of global models (e.g. Gates et al. 1999) as well as of regional models (e.g. Jacob et al. 2001) show that a major source of uncertainties in numerical weather forecasts and climate predictions are cloud parameterizations. Therefore great effort is continually being made to validate cloud parameterization schemes. To avoid wrong conclusions regarding the quality of the parameterization it is important to apply a reliable strategy for the validation. In former studies such a validation method has been derived (Meinke 2002 and Meinke, submitted). In this study this strategy is applied to the cloud parameterization in the regional model SN-REMO using satellite data from ISCCP. The validation is carried out for cloud amount, as it is a key variable for many other processes described by cloud and radiation parameterization schemes. The application of this validation method provides reliable insight into the ability of SN-REMO simulating cloud amount.

2. Basis of the validation

a. Validation strategy

There are at least three main requirements for a reliable validation: (1.) Uncertainties of the simulations as well as of the measurements have to be accounted. (2.) The simulated and measured data have to be comparable. (3.) Before changing a parameterization the sources of the localized model deficiencies have to be traced back as accurate as possible. In this study these requirements are fulfilled by the following steps (see also, Meinke 2002 and Meinke submitted):

- Estimation of uncertainties:

  Regarding the simulated cloud amount uncertainties are estimated for the analyses used as initialization and boundary conditions as they are not part of the model and its parameterization but may have impact on the cloud simulation. About the satellite data the cloud detection algorithm applied may cause uncertainties. For the estimation of the uncertainty ranges more than one equivalent realization of model runs and measurements are needed. With these realizations the ranges of uncertainty are estimated using the concept of a confidence band.

- Localization of deficiencies and comparability:

  In consideration of these uncertainty ranges deficiencies in the model are localized by comparing simulated and measured data. Especially comparisons of cloud diurnal cycle and the vertical cloud structure provide an insight into the properties of these deficiencies. In this context it is crucial to make comparable the vertical distribution of simulated and measured clouds. This is achieved by calculating the emissivity heights of the simulated clouds.

- Assigning model deficiencies:

  If deficiencies in the model were localized their sources have to be traced back. This can be achieved by classifying the simulated clouds according to their parameterization. Afterwards they are compared separately with the measurements. This way deficiencies may be assigned to a certain cloud parameterization scheme and its interaction with other parts of the model.

- Approaches for improvements:

  On the basis of these insights approaches for improving the simulation of clouds can be derived. This could either be an additional validation of other model variables interacting with the cloud scheme or the adjustment of empirical parts in the cloud scheme. However, before changing the parameterization it is crucial to be sure that the deficiencies have no other sources than the empirical part of the scheme. Otherwise, the parameterization would be adapted to an unrealistic state.

b. Area and period of interest

The area of interest contains Europe, the northeastern part of the North-Atlantic, the North Sea, the Baltic Sea and the Mediterranean as shown in Figure 1. Located in the mid-latitudes, the area of interest is affected by frontal cyclones and by subtropical high-pressure systems.

The period of interest is from August until October 1995. It is connected with PIDCAP (Pilot Study for Intensive Data Collection and Analyses of Precipitation) a period of intense data collection carried out in the frame of BALTEX (Baltic Sea Experiment). This time span requires the simulation of convective as well as stratiform clouds. Comparisons of the cyclonality in the period of interest and a 30-year mean show that there is a good representation of cyclonality by the chosen period (Meinke 2002).

c. The Spectrally Nudged Regional Model SN-REMO

SN-REMO is a numerical three dimensional, hydrostatical model. It has been developed from the Europa-Modell of the DWD (Deutscher Wetterdienst, 1995 and Majewski, 1991). Prognostic variables of the model are surface pressure, specific humidity, liquid water and horizontal wind components. On the whole lateral boundary of the model area the values of all parameters agree with the forcing used to initialize and to drive the model. In the interior of the model area the prognostic equations are solved. The spherical coordinate system is rotated with the equator in the centre of the model area. Thus, the horizontal grid boxes in the model area are nearly equally spaced with a horizontal resolution of 0.5° (~50 km). The model area consists 81x91 grid boxes. The atmosphere is discretized on 20 vertical model layers in a hybrid coordinate system. The cloud parameterization is divided into grid-scale and sub-grid scale cloudiness. The liquid water content of stratiform cloudiness is calculated by prognostic equations after Sundquist (1978). Cloud fraction is set to 100% if grid scale cloud liquid water has been calculated by the prognostic equations. Otherwise sub-scale cloudiness is calculated if the relative humidity (r) exceeds a pressure dependent critical value

$$r_0(p) = r_{0,top} + (r_{0,surf} - r_{0,top})e^{\left[1-(p_s/p)^4\right]}$$

where p is the pressure, p_s is surface pressure, $r_{0,top}$ = 0.8 and $r_{0,surf}$ = 0.99, (Semmler 2002, Roeckner 1996). Sub-grid scale cloud cover (b) is parameterized by a non-linear function of grid mean relative humidity r:

$$b = 1 - \sqrt{1 - b_0},$$

where

$$b_0 = \frac{r - r_0}{r_{sat} - r_0},$$

with r_{sat} as saturation humidity (Sundquist et al. 1989). The parameterization of convection is described by the mass flux concept after Tiedtke (1989). The radiation parameterization is mainly taken from the ECMWF model (Fouquart et al. 1980 and Mocrette et al. 1980) with slight changes by Roeckner et al. 1996.

The time period between August and October 1995 is simulated twice, by forcing SN-REMO with two different analyses (Feser et al. 2001). One of these are the NCEP re-analyses. The other analyses are taken from the assimilation cycle of the EM (Europa Modell) of the DWD. The model runs were carried out in climate mode: The 6-hourly input were linearly interpolated in time and fed into the regional model via the lateral boundaries at every 5 minutes time step. In addition, for both model runs the spectral nudging technique is applied (von Storch et al. 2000). This method keeps the regional model solution close to the global forcing data at large scales (>750km) for which the highest quality in the forcing can be expected, while regional features may evolve independently from the forcing. This is achieved by adding nudging terms in the spectral domain with maximum strength for small wave numbers and high model levels, which are less influenced by regional structures.

d. The ISCCP-DX Data

The data used for the validation of cloud parameterization in the SN-REMO is taken from the International Satellite Cloud Climatology Program (ISCCP). ISCCP provides a cloud detection algorithm for surface scanning radiometers. It can be applied to polar orbiting as well as to geostationary satellites. The data processing has been carried out operational since 1983 (e.g. Rossow et al. 1996). The ISCCP-DX data used for validation has the highest resolution of all ISCCP products. Depending on the field of view of the infrared radiometer on various satellites the spatial resolution is between four and seven kilometers. The satellites, which were available over the area of interest during August to October 1995, were NOAA-12, NOAA-14 and METEOSAT-5. The data of their overpasses are accumulated in three hourly time slots. In order to reduce the data volume one pixel with a resolution of the standardized field of view of the infrared radiometers is extracted once every 25 to 30 kilometers. On the basis of this reduced data set cloud parameters are derived. The cloud detection of ISCCP is based on two main steps: First dynamical background values for cloud free situations are derived. On the basis of these background values threshold tests for cloud detection may be carried out in the infrared and visible spectra.

For calculating the cloud top pressure, the cloud top temperature is simulated in a radiation transport model (Rossow et al. 1989). Using temperature profiles from TOVS (TIROS Operational Vertical Sounder) the corresponding cloud top pressure is determined.

3. Uncertainties within the model validation

The presence of differences between simulated and measured data are not necessarily an indication for a model deficiency. These differences might also be caused by uncertainties which are not part of the model but influence the simulation. Also the data used for model validation might have uncertainties. The random character originates from the process of generating the data. In case of the simulated cloudiness, the randomness has its origin in the use of different analyses as forcing conditions for the same regional model: Figure 2 shows the simulated cloud amount of the two SN-REMO runs forced by two different types of analyses. Although both model runs where carried out by exactly the same SN-REMO version there is a statistical significant difference between these two curves with a mean value of 4.83% and a standard deviation of 3.52%. The sole reason for this difference is the differing forcing (see also 2. c).

In case of the satellite derived cloudiness the randomness has its origin in the cloud detection algorithm used for deriving cloud properties from the radiances. This is shown in figure 3. NOAA-14 AVHRR data has been processed by two different cloud detection algorithms. One is from ISCCP and the other is from APOLLO (AVHRR Processing Scheme over cLouds Land and Oceans). Although the data basis of both cloud detections is exactly identical there is a statistical significant difference in the result of the two different cloud detection algorithms. The mean value of this difference is 11.75% with a standard deviation of 5.69%. This indicates that the cloud detection algorithm applied to the satellite data is causing uncertainties. These differences and their standard deviations are varying with the surface type: Over land surfaces the mean difference between ISCCP and APOLLO cloud amount is 23.51% with a standard deviation of 6.62%. Whereas over water surfaces the mean difference between ISCCP and APOLLO cloud amount is much smaller with a mean value of 0.92% and a standard deviation of 2.7%.

The problem in both cases of data generating processes is that we have only very few samples of the random variables, which makes all estimation rather cumbersome and inaccurate. Nevertheless, the little information we have should be used to derive some admittedly crude estimates of uncertainty ranges. As commonly done, we use the concept of a confidence band. When we have n samples W_i of the random variable $\mathbf{W}$, we estimate the mean value by

$\mu = \frac{1}{n}\sum_{i=1}^{n} W_i$ and the variance by $\sigma_w^2 = \frac{1}{n}\sum_{i=1}^{n}(W_i - \mu)^2$. Then the α confidence interval, which on average contains α of all realizations W_i of **W,** is given by

$$P(W \in [\mu - k\sigma_w ; \mu + k\sigma_w]) = \alpha$$

with $k = S^{-1}(\frac{\alpha+1}{2})$; *S* is denoting the distribution function of the normal distribution and *P* the probability of the event given in parentheses. Thus $\pm S^{-1}(\frac{\alpha+1}{2})\sigma_w$ is the uncertainty at a level of α. Thus, if α *=90%,* then $k = S^{-1}(0.95)$ and the uncertainty is $\pm 1.64485\sigma_w$. This is the standard approach (e.g., von Storch and Zwiers, 1999). The problem is to estimate the unknown parameters μ and σ_w when only very few data are available.

Regarding the uncertainty of the model SN-REMO we have two equivalent realizations. The two realizations (SN-REMO forced by NCEP analyses and SN-REMO forced by DWD analyses) are denoted as W_1 and W_2. Then $\mu = [W_1 + W_2]/2$ and $\sigma_w^2 = [W_1 - W_2]^2/2$. Hence, the uncertainty range of simulating cloud amount with SN-REMO ($k\sigma_{w(SN\text{-}REMO)}$) caused by changing the forcing is about ±5.6% (tab. 1). Over land surfaces the derived uncertainty range is about ±6.1%. Over water surfaces the range of uncertainty is slightly lower with a value of about ±5% (tab. 1).

Regarding the uncertainty of the satellite derived cloudiness we have one regular realization for the three months (August to October 1995), the cloudiness derived with the ISCCP cloud detection algorithm (W_1), plus cloudiness derived with the cloud detection algorithm APOLLO for August 1995 (W_2). Since cloudiness has a distinct annual cycle, we cannot use the time limited APOLLO data to estimate the seasonal mean (August to October), and we have to set $\mu = W_1$. However we propose to use the APOLLO data to estimate the variance, and we find $\sigma_w^2 = [W_1 - W_2]^2/2$ as before. Thus, the range of uncertainty caused by the cloud detection algorithms ($k\sigma_{w(SAT)}$) derived as described above is about ±13.7% over all surface types (tab. 1). The ranges of this uncertainty are varying with the surface type (tab. 1): Over land surfaces the range of uncertainty is about ±27.3%. Over water surfaces the range of uncertainty is much smaller with a value of about ±1.1% (tab. 1). This shows that the cloud detection is most reliable over homogeneous surfaces like water (tab. 1). The combined range of the uncertainties (U) caused by the model ($k\sigma_{w(SN\text{-}REMO)}$) and the satellite data ($k\sigma_{w(SAT)}$) is given by $U = \sqrt{(k\sigma_{w(REMO)}{}^2 + k\sigma_{w(SAT)}{}^2)}$ (tab. 1). Hence, for cloud amount the combined range of uncertainty is about ±14.8% in mean over all surface types, about ±28% in mean over land surfaces and about ±5.1% over water surfaces (tab. 1).

As already mentioned, this is a very crude estimate of the uncertainty ranges. Even an increase by just one additional sample would be very helpful in achieving more reliable estimates. However, if only 2 samples are available even this limited information is useful for estimating the inherent uncertainty in order to obtain more reliable localizations of deficiencies in the model.

4. Localization of deficiencies in the regional model SN-REMO

To identify deficiencies of the model by comparing the model output with satellite derived data, the magnitudes of the differences between both model runs and the data have to exceed the combined estimated ranges of uncertainty as shown in table 1. Otherwise uncertainties such as described above might have caused these differences. Or the differences between model and data might be random. Only by fulfilling this criteria the differences between the simulated and measured data can be identified as model deficiency (Meinke, 2002 and Meinke, submitted).

a. *Representation of cloud amount*

For comparison of simulated and satellite derived cloud amounts the simulated values are only taken into account if data in the ISCCP-DX data set are available at the same time in the same grid box. To avoid inconsistencies caused by the model boundaries the values of the eight outer model grid boxes (sponge zone) are not taken into account (Fig. 4). The differences between cloud amount of both SN-REMO runs and the ISCCP data are statistically significant. The mean difference between SN-REMO, forced by DWD analyses and ISCCP is 6.34% with a standard deviation of 8.6%. Between SN-REMO, forced by NCEP analyses and ISCCP the mean difference is much smaller with a value of 1.51% with a standard deviation of 8.4%. Thus, the differences of both model runs and ISCCP are not exceeding the combined uncertainty ranges of ±14.8% (tab. 1).

However, over water surfaces where cloud detection from satellite data is most accurately the magnitudes of the mean differences between both SN-REMO runs and the ISCCP-DX data are exceeding the combined uncertainty range of ±5.1%: Over water surfaces the mean difference between SN-REMO, forced by DWD analyses minus ISCCP is 10.32%. Between SN-REMO, forced by NCEP analyses minus ISCCP the mean difference is slightly smaller with a mean value of 6.03%. This indicates that SN-REMO has a deficiency regarding the simulation of cloud amount. This deficiency is expressed by an overestimation of simulated cloud amount.

The following comparisons are carried out for cloud amount over water surfaces. All comparisons between SN-REMO and ISCCP over land surfaces show the same tendencies as over water surfaces. The only distinction is the higher range of uncertainty over land surfaces especially because of the higher uncertainty of cloud detection from satellite data over surfaces with inhomogeneous radiative properties. Figure 5 shows the temporal distribution of the differences (area means) between simulated and satellite derived cloud amount over water surfaces. The mean temporal distribution of SN-REMO simulated cloud amount shows a clear overestimation. This is indicated by both difference curves (SN-REMO_NCEP minus ISCCP and SN-REMO_DWD minus ISCCP). There are only few exceptions with negative differences. Independent from the analyses used as forcing the differences have a high temporal variability. To find reasons for this high temporal variation of the differences the diurnal cycle was examined (Fig. 6). Compared to the diurnal cycle of cloud amount derived from the ISCCP-DX data the diurnal cycle of the simulated cloud amount has a different progression. ISCCP cloud amount has its maximum at noon whereas the simulated cloud amount of both model runs has a maximum at 6:00 UTC (Fig. 6). Especially during nighttime both model runs show large overestimations of the cloud amount. The smallest differences appear in the afternoon between 12:00 and 18:00 UTC.

Summarizing this part of the validation there are two main results: (1.) A model deficiency has been identified regarding the simulation of cloud amount. This deficiency is expressed by an overestimation of the simulated cloud amount. (2.) Appearing mainly during nighttime it is connected with a poor simulation of the diurnal cycle of cloudiness.

b. Representation of clouds on emissivity levels

The importance of the vertical distribution of clouds for the simulation of the radiation budget has been indicated by several studies (e. g. Chevallier and Mocrette 2000). Ryan et al. 2000 show that large scale as well as limited area models have severe deficiencies regarding the simulation of cloud vertical distribution. By comparing the vertical distribution of simulated and satellite derived cloud amount it has to be taken into account that the cloud top pressure derived from data of surface scanning radiometer are representing rather the emissivity height of a vertical cloud column than the exact physical cloud top height. Hence, to fulfill the requirements for comparability with the ISCCP data the emissivity heights of the simulated cloud columns have to be calculated (Meinke 2002). The emissivity height is the pressure level whose corresponding temperature is the same as the brightness temperature of the vertical cloud column. The brightness temperature of the simulated vertical cloud column is calculated after the delta-eddington-approximation (Wiscombe 1977, Slingo 1988, Slingo and Schrecker 1982). As the calculation of cloud properties in SN-REMO is based on the center of each model layer twenty emissivity levels can be distinguished at maximum. The thickness of these emissivity levels is varying between 5 hPa and 100 hPa according to the hybrid coordinate system. In Figure 7 the differences between simulated and satellite derived cloud amount at the various emissivity levels are shown. According to the signs of the differences between simulated and satellite derived cloud amount two different classes of differences can be distinguished: (1.) Differences at low-level emissivity heights from 1000 hPa to 475 hPa and (2.) differences at high-level emissivity heights above 475 hPa. There is a clear overestimation of simulated cloud amount at low-level emissivity heights. Whereas at high-level emissivity heights simulated cloud amount is under predicted by SN-REMO. Thus, the overall overestimation of simulated cloud amount is caused by the overestimation of simulated cloud amount at low-level emissivity heights. Vertically integrated it is weakened by the underestimation of simulated clouds in the high-level emissivity heights.

Figure 8 shows that the pronounced overestimation of overall cloud amount during nighttime caused by simulated clouds at low-level emissivity heights (1000-475 hPa). This overestimation with an integrated mean value of 30.2% is statistically significant. During daytime the overestimation is only slightly smaller with a mean value of 28.5%. This shows that the diurnal variation of magnitude of the overall overestimation is mainly impacted by the vertical integration of positive and negative differences at low-level and high-level emissivity heights: During daytime the large underestimation of simulated clouds at high-level emissivity heights with a mean value of 23.7% is nearly equalizing the overestimation at low-level emissivity heights. During the night the underestimation at high-level emissivity heights is smaller than during daytime by about 10%. Its mean integrated value is 13.5%. Thus, the overall overestimation of simulated cloud amount is much larger during nighttime although at low-level emissivity heights the overestimation is not much larger (Fig. 8).

Comprising, three main results can be derived from the comparison between the distributions of simulated and measured cloud amount on emissivity heights: (1) The simulated cloud amount at low-level emissivity heights (1000-475 hPa) mainly causes the overestimation of all simulated cloud amounts. (2) The underestimation of simulated clouds at high-level emissivity heights (<475 hPa) is mainly affecting the diurnal variation of the magnitude of the overall overestimation. (3) The overall smaller differences between simulated and satellite derived cloud amount during daytime are mainly caused by the large underestimation of simulated cloud amount at high-level emissivity heights. Vertically integrated this underestimation is equalizing the overestimation of simulated cloud amount at low-level emissivity heights nearly completely.

5. Assignment of model deficiencies to a certain cloud parameterization scheme

After localizing a deficiency in the simulation of cloud amount within the regional model SN-REMO, we still do not know which cloud parameterization scheme is causing deficiencies. Thus, the next step of the validation is the assignment of the found deficiencies to a certain cloud parameterization scheme. This is achieved by classifying the simulated clouds according to their parameterization. The emissivity levels of simulated clouds are representing a mixed signal of grid-scale and sub-scale clouds and their radiative properties in a vertical cloud column. In SN-

REMO grid-scale clouds and the sub-scale stratiform clouds are described by different parameterizations. In order to assign the deficiencies to a certain parameterization scheme the clouds are classified according to their parameterization. Afterwards their emissivity levels are calculated separately and the frequency distribution of these clouds on emissivity heights is compared with the ISCCP-DX data. Figure 9 shows the distributions of simulated grid-scale and sub-grid scale cloud amount as well as the cloud amount from the ISCCP-DX data on emissivity heights. The overestimation of cloud amount at low-level emissivity heights can be clearly assigned to the sub-grid scale cloudiness. Below 750 hPa even the single frequency of these clouds is higher than the cloud amount from the ISCCP-DX data set. This can be found in both model runs. The amount of grid-scale clouds might as well be overestimated. However, this cannot be derived by the comparison. The underestimation of the simulated cloud amount at high-level emissivity heights cannot be assigned to a certain cloud parameterization scheme. Comparison of the diurnal cycle indicates, that sub-scale clouds mainly cause the overestimation of cloud amounts at low-level emissivity heights during nighttime as well as during the day (Fig. 10)

6. Approaches for improvements

By separating the simulated clouds into grid scale and sub-grid scale clouds it has been indicated that the overestimation of clouds in the low-level emissivity heights is caused by sub-grid scale cloudiness. As sub-grid scale cloudiness is parameterized by a relative humidity parameterization these deficiencies of SN-REMO are related to this relative humidity parameterization. Therefore two sources might be the reason for these model deficiencies: (1.) They can either be connected with the empirical part of the relative humidity parameterization (see chapter 2. c) or (2.) the deficiencies can be associated with the relative humidity being the basis of calculations in that parameterization. Providing boundary information every six hours keep the prognosis of water vapor, pressure, temperature and cloud water close to the measured state. Therefore, it is more likely that the deficiencies of the SN-REMO are connected with the empirical part of the relative humidity parameterization. Nevertheless, to avoid wrong adaptations of the parameterization, validation of the water vapor- and temperature profile is required. As this validation implies similar uncertainties it should be conducted following the same strategy as used in this study. In case that the simulation of these prognostic variables has no deficiency the empirical part of the relative humidity parameterization has to be adjusted.

7. Discussion

The presented validation takes into account the uncertainties both, of the model as well as of the satellite derived data. The uncertainty ranges are estimated using the concept of confidence bands. For this purpose as many as possible equivalent data generation processes (simulation and measurement) are needed to make the estimation of the uncertainty range accurate. In the presented case only two realizations of the simulated and the satellite derived cloud amount were available. Thus, the estimated range of uncertainty is not as precise as it could be with more equivalent realizations available. This affects as well the comparison criterion regarding the combined uncertainty range. Nevertheless even this crude estimate is useful to assess the inherent uncertainty for model validation. The smallest combined simulated and satellite derived uncertainty range appears over water surfaces. This is mainly caused by the cloud detection from satellite data, which is most accurate over homogeneous surfaces.

A statistically significant difference between the simulated and satellite derived cloud amount was found. The magnitude of this difference exceeded the estimated combined range of uncertainties over water. Thus, in the regional atmospheric model SN-REMO cloud amount is over predicted. This overestimation occurs especially during the night, which in turn is indicating that SN-REMO has a deficiency regarding the simulation of a proper diurnal cycle of cloudiness.

To compare the simulated and satellite derived vertical cloud structures emissivity heights of the simulated clouds were calculated. Comparisons show that the overestimation of all simulated clouds is caused by an overestimation at low-level emissivity heights. In the daytime there is also a considerable underestimation at high-level emissivity heights (<475 hPa) equalizing the overestimation at low-level emissivity heights. By separation of the simulated clouds according to their parameterization the overestimation at low-level emissivity heights was assigned to the relative humidity parameterization for sub-grid scale cloudiness. Therefore, at first validation of the water vapor and temperature profiles is required. This validation should be conducted following the same strategy as applied in this study. In case that the simulation of the water vapor and temperature profiles have no deficiencies the empirical part of the function defining the critical value for creation of sub-grid scale cloudiness has to be adjusted.

The underestimation at high-level emissivity heights could not be assigned to a certain parameterization scheme as both, grid scale and sub-grid scale clouds are almost absent.

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Tables

	Simulated (SN-REMO)	**Satellite derived (ISCCP)**	**Combined range**
All surface types	5.6%	13.7%	14.8%
Land surfaces	6.1%	27.3%	28.0%
Water surfaces	5.0%	1.1%	5.1%

Tab. 1: Uncertainty ranges at a level of 90% of the processes generating the data (cloud amount)

Figure captions

Fig. 1: Area of interest

Fig. 2: Area means of cloud amount simulated by the SN-REMO run with NCEP analyses and with DWD analyses and their differences (August – October 1995)

Fig. 3: Cloud amount of NOAA-14 AVHRR data derived by the cloud detection algorithm of ISCCP and APOLLO and their differences

Fig. 4: Mean differences in cloud amount; August to October 1995 (left: SN-REMO, forced by NCEP analyses minus ISCCP; right: SN-REMO, forced by DWD analyses minus ISCCP)

Fig. 5: Temporal variations of differences between simulated (SN-REMO) and satellite derived (ISCCP) cloud amounts (area means over water surfaces from August-October 1995)

Fig. 6: Diurnal cycle of cloud amount and differences between SN-REMO and ISCCP (temporal averages of area means over water surfaces from August to October 1995)

Fig. 7: Differences between simulated (SN-REMO) and satellite derived (ISCCP) cloud amounts on emissivity levels (mean over water surfaces from August to October 1995)

Fig. 8: Diurnal variation of differences between simulated and satellite derived cloud amounts on emissivity levels (mean over water surfaces from August to October 1995)

Fig. 9: Distribution of simulated clouds classified according to their parameterization and ISCCP clouds on emissivity levels; SN-REMO, forced by NCEP analyses (left), SN-REMO, forced by DWD analyses (right), (mean over water surfaces from August to October 1995)

Fig. 10: Distribution of simulated (SN-REMO run with DWD analyses) clouds classified according to their parameterization and ISCCP clouds on emissivity levels at 00:00 UTC (left) and 12:00 UTC (right), (mean over water surfaces from August to October 1995)

Figures

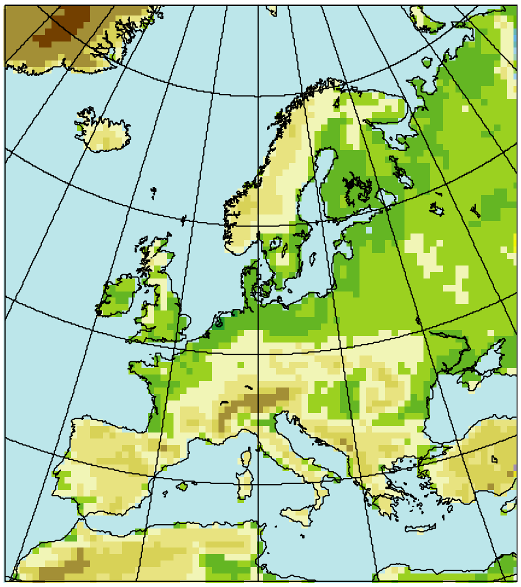


Fig. 1: Area of interest

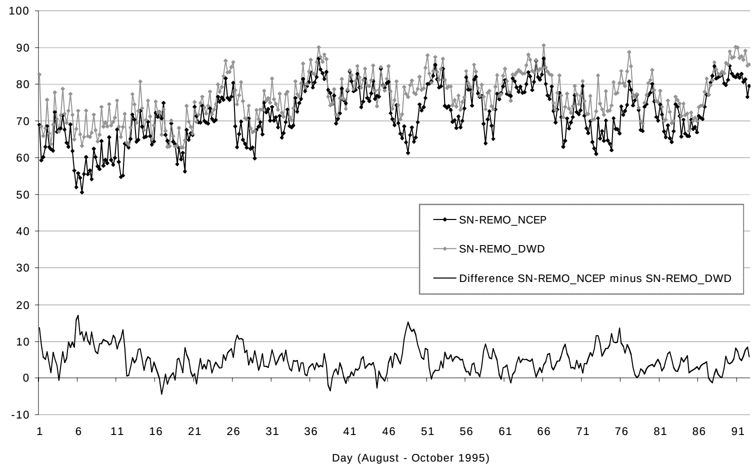


Fig. 2: Area means of cloud amount simulated by the SN-REMO run with NCEP analyses and with DWD analyses and their differences (August – October 1995)

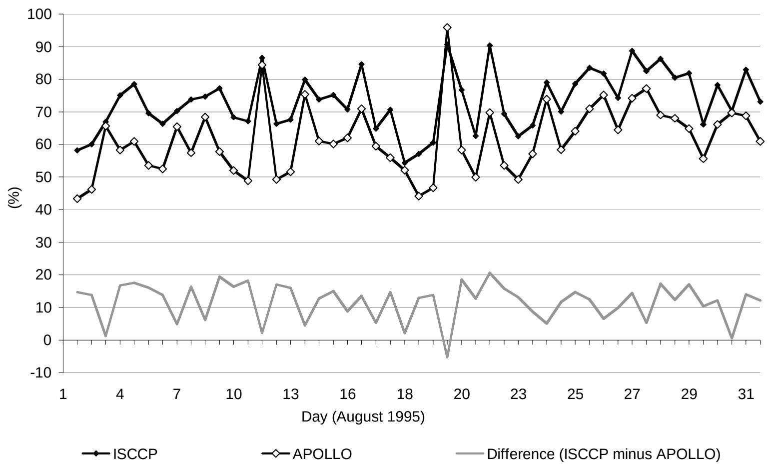


Fig. 3: Cloud amount of NOAA-14 AVHRR data derived by the cloud detection algorithm of ISCCP and APOLLO and their differences

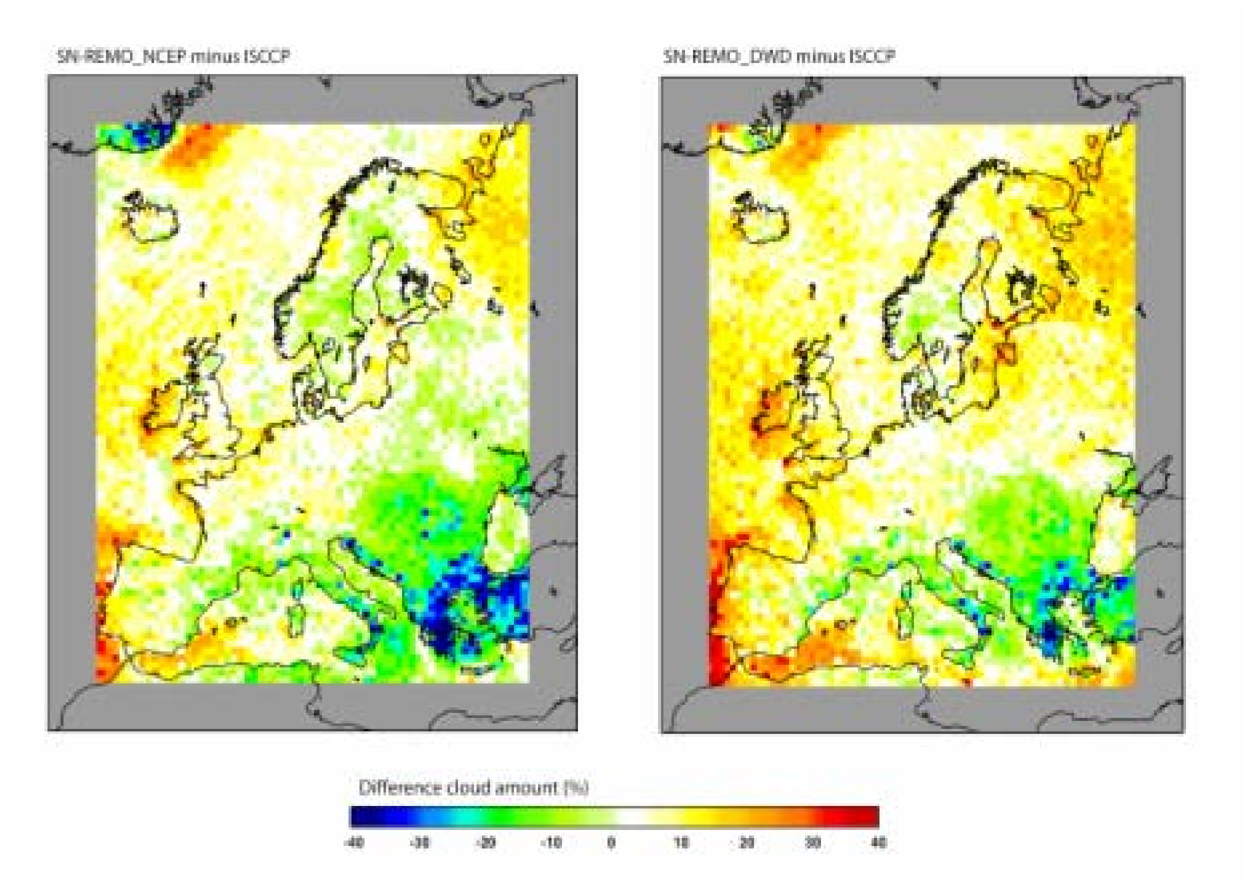


Fig. 4: Mean differences in cloud amount; August to October 1995 (left: SN-REMO, forced by NCEP analyses minus ISCCP; right: SN-REMO, forced by DWD analyses minus ISCCP)

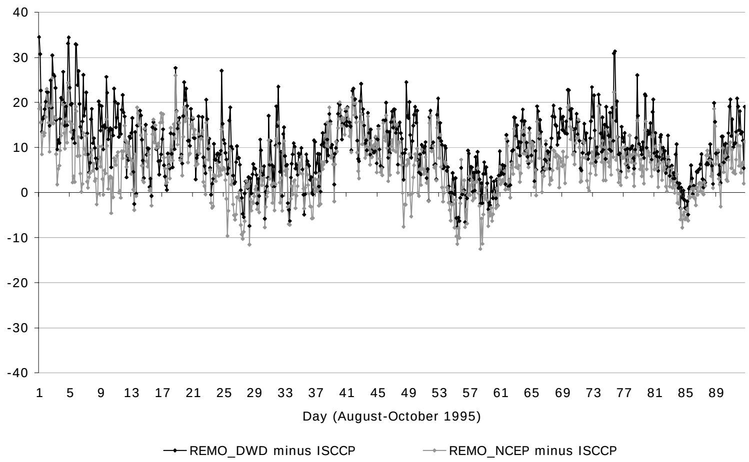


Fig. 5: Temporal variations of differences between simulated (SN-REMO) and satellite derived (ISCCP) cloud amounts (area means over water surfaces from August-October 1995)

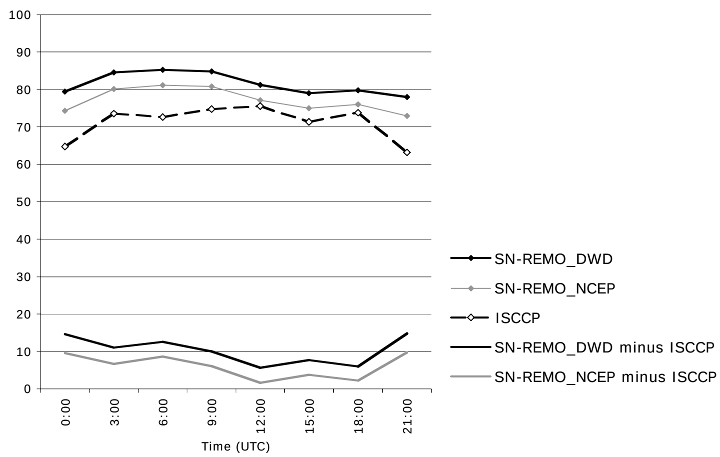


Fig. 6: Diurnal cycle of cloud amount and differences between SN-REMO and ISCCP (temporal averages of area means over water surfaces from August to October 1995)

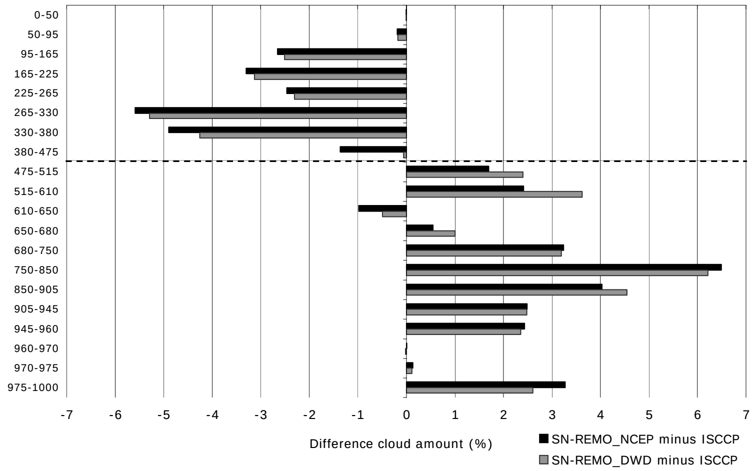


Fig. 7: Differences between simulated (SN-REMO) and satellite derived (ISCCP) cloud amounts on emissivity levels (mean over water surfaces from August to October 1995)

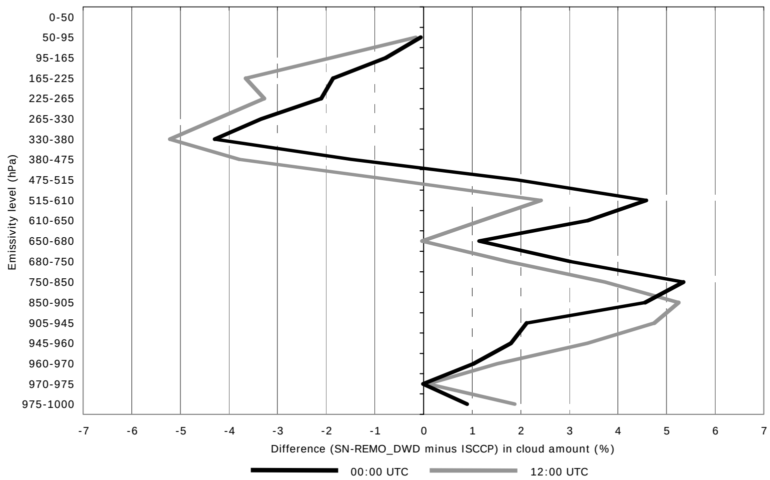


Fig. 8: Diurnal variation of differences between simulated and satellite derived cloud amounts on emissivity levels (mean over water surfaces from August to October 1995)

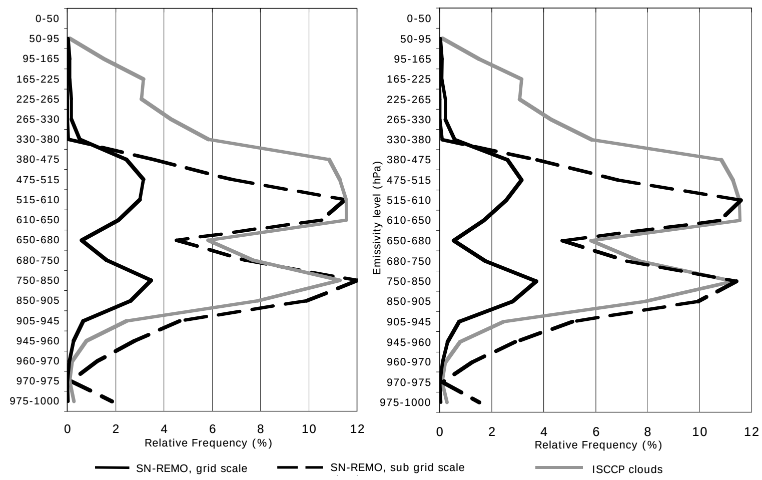
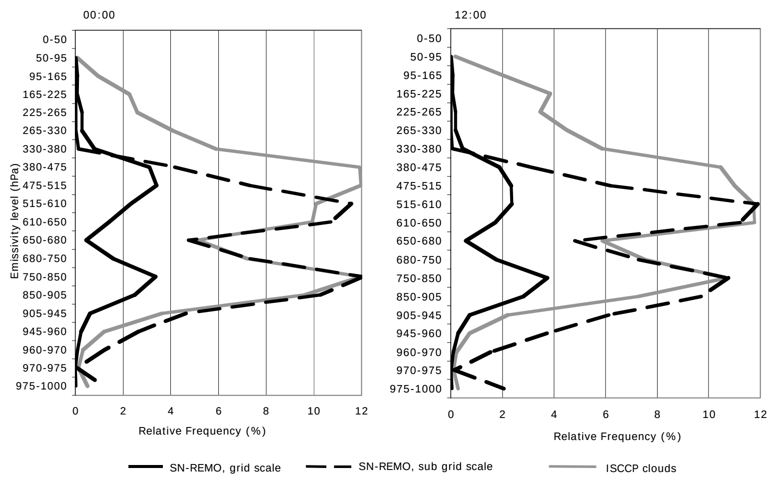


Fig. 9: Distribution of simulated clouds classified according to their parameterization and ISCCP clouds on emissivity levels; SN-REMO, forced by NCEP analyses (left), SN-REMO, forced by DWD analyses (right), (mean over water surfaces from August to October 1995)



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