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Clouds-Radiation-Hydrologic interactions in a limited-area model

A.C.A.P. van Lammeren, A.J. Feijt, R. van Dorland, E. van Meijgaard, P. Stammes, A.P. van Ulden

Royal Netherlands Meteorological Institute (KNMI)
P.O. Box 201, 3730 AE De Bilt

Abstract

In this project work has been directed towards the improvement of the knowledge on clouds and the way they influence our climate. The activities include measurement of cloud properties on a regional scale (120x120 km^2), analysis of global satellite datasets and the development of a model environment to enhance the regional data analysis and the improvement of parametrizations of clouds and radiation.

1. Introduction

Clouds play an important role in our climate. They produce precipitation which is an essential ingredient of the hydrological cycle. Clouds modify the earth-radiation budget. Thin cirrus clouds have a warming effect while low clouds have a distinct cooling effect [1]. Clouds dominate the vertical transport of energy, momentum and trace gasses in the free troposphere. Despite their importance, clouds are represented only rudimentary in climate as well as weather forecast models. It appears that the model representation of clouds in climate models has a major impact on model predictions for climate change. Cess et al. [2] showed that cloud feed-back is a major source of uncertainty in model responses to climate forcing.

There are two main reasons why the uncertainties with respect to clouds are so large. The first reason is that cloud processes are extremely complicated. A proper represenation of clouds requires the parameterization of subgrid processe both on the macro-scale (cm - km) and on the microscale (<<cm).

The second reason is the lack of good quantitative observations of cloud characteristics (cloud cover, cloud structure, optical depth, droplet spectra). This lack of good data hampers the development and validation of models. Satellites begin to provide usefull data on global cloud statistics and corresponding radiation budgets (ISCCP, ERBE). However, these data sets still have to be validated.

To validate these global data sets on a regional scale, detailed measurements of the cloud cover and structure are necessary. It is important to measure the variabillity of the cloud characteristics within one datapoint of the global dataset.

High resolution measurements are also crucial for the development and improvement of parameterization schemes for clouds and cloud-radiation interactions.

The aim of the project "Clouds-Radiation-Hydrologic interactions in a limited-area model" is threefold:

- Provide a detailed regional dataset on cloud cover and cloud characteristics.
- Analyse the ISCCP and ERBE datasets with respect to validity and possible applications for climate model verification.
- Create a model environment for the enhancement of regional data analysis and for the improvement of parameterizations of clouds and radiation.

These items will be described below.

2. Hybrid cloud detection system

A proper description of clouds and cloud-radiation interactions in climate models requires the parametrization of the subgrid processes which determine cloud cover and cloud structure. To develop and improve these parametrizations a set of measurements is required, so results of the model can be validated. At the KNMI a project is ongoing which yields accurate and high resolution cloud measurements over the Netherlands. A hybrid cloud detection system in which both groundbased and satellite remote sensing instruments data are combined has been built. This cloud detection system is described in full detail by Stammes et al. [3]. An outline is given below.

The cloud detection system is used to retrieve the following cloud characteristics: cloud cover fraction, cloud top temperature, cloud base height, cloud base temperature, reflectivity and optical thickness; it provides information on the 3-dimensional structure of cloud ensembles. The cloud detection system consists of a network of stations for groundbased remote sensing and a processing environment for AVHRR and METEOSAT measurements. In the

120x120 km^2 target area a network of stations for groundbased remote sensing has been built. Each station consists of a LIDAR ceilometer, narrowband IR radiometer and a pyranometer. On two stations more extensive radiation measurements are done. This provides data for the analysis of cloud-radiation interactions. In order to obtain a complete description of the geometry and height of the clouds the signals from the various instruments are correlated.

Other available tools for interpretation of the measurements are data on the actual atmospheric conditions from model analysis and radiosonde. Radiative transfer calculations are performed using Lowtran-7 [4] for longwave and DAK (KNMI Doubling Adding radiative transfer model [5]) for shortwave radiation. AVHRR data will be analysed using the Apollo retrieval scheme [6], which has been implemented at the KNMI. The use of state-of-the-art retrieval techniques is garanteed by the international cooperation with other institutes with a tradition in satellite remote sensing, among others: D.L.R. (Oberpfaffenhofen), L.M.D. (Paris), Universität Berlin.

The following data is archived:

a) Satellite instruments:	NOAA/AVHRR, Meteosat
b) 13 Groundstations:	LIDAR, IR-radiometer and solar radiation
c) Radiation stations:	Direct, diffuse and total downward SW flux, downward and upward LW flux
d) Other datasources:	3-hourly analysis data of the operational HIRLAM (High Resolution Local Area Model) weather forecast model, 6-hourly rawinsonde data in De Bilt

The aim is to obtain continuous data on clouds and radiation for two years.

3. Global datasets

The Earth Radiation Budget Experiment (ERBE) dataset contains invaluable information about the radiation budget at the top of the atmosphere. The International Satellite Cloud Climatology Project (ISCCP) dataset contains information on clouds, their height, temperature, optical thickness, etc.. Both global datasets are derived from satellite measurements and cover many years.

3.1 ERBE

During the NRP project the literature on ERBE dataprocessing scheme was studied [7]. The main questions were: Can ERBE data be used for climate model validation and how can the data be used most reliably? Special attention has been given to assumptions about atmospheric and surface conditions, field-of-view homogeneity, spectral variability, time and space variability of cloud cover. It is concluded that the errors in radiative fluxes show much variation related to geographical and atmospheric conditions and the viewing geometry, the positions of the sun and the satellite relative to the area. Nevertheless, monthly mean values data are useful for climate model validation if used properly. Individual values should be used with caution, because the accuracy is highly dependent on the viewing geometry and surface/cloud type observed.

It is advisable to users of the ERBE dataset to spend some time on the merits of the data. Likewise it would be good practise if global datasets which are to be used over a wide range of research areas were accompanied by an indication of the errors involved, written down in a way readable by the non-specialist investigator.

3.2 ISCCP

In the course of 1993 parts of the ISCCP-cloud detection algorithm were implemented at the KNMI. Numerous case-studies have been performed on the merits of these modules for North-west Europe. This yielded a feel for the sensitivity of the algorithm for atmospheric conditions and possible related error-sources. Furthermore, the literature on the algorithm was studied in order to obtain insight into the coherent set of thresholds making up the detection algorithm.

Recently, Rossow [8] published a validation study on the cloud detection algorithm. In general his findings agree well with our own investigations (to appear in KNMI technical report in 1994). The algorithm performance decreases with: increasing variability of the surface albedo and temperature, decreasing contrast between clouds and surface and decreasing temporal variability of the cloud fields. As the ISCCP algorithm is based on spatial and temporal coherence tests this is not surprising. In terms of geographic areas: the algorithm performs well over ocean, somewhat worse over landsurfaces and worst over polar regions. Moreover the algorithm is hampered by areas of persistent cloud fields and storm tracks. Two cloud types are missed frequently: low broken cloud fields and high semi-transparent cirrus clouds. Both cause little contrast in albedo and brightness temperature and are hard to identify especially over cold bright surfaces (polar regions) or highly variable land surfaces.

The cloud climatology over the period 1982-1988 shows a global mean annual cloud cover of 63%, which is on the higher end of the range of values which are reported in literature. Rossow [8] states that this value is still an underestimation, because the derived cloud fraction is too low about 10% over land and 10-15% in polar regions. The derived cloud fractions are approximately correct over ocean.

The hybrid cloud detection system (paragraph 2.1) will provide a dataset which will be intercompared with the results of the ISCCP algorithm. This comparison will yield information on the merits of the basic assumptions and the used thresholds, and hopefully give directions for improvement of the ISCCP cloud detection algorithm.

4. The model environment

A Regional Atmospheric Climate MOdel (RACMO) has been implemented at KNMI [9]. This is a descendant of the High Resolution Limited Area Model (HIRLAM) and the Global Climate Model developed at the Max Planck Institute in Hamburg (ECHAM). HIRLAM is the operational weather forecast model at the KNMI which employes a 50 km grid and 16 layers. RACMO inherited the dynamics and initialization environment from HIRLAM. All physics modules, including the liquid water and radiation modules, stem from the ECHAM model. There is close cooperation with the research groups involved in the development of HIRLAM and ECHAM. The research environment supports flexible module management, so new versions of cloud and radiation modules can be activated and compared.

The Morcrette radiation scheme is included in RACMO [10]. This scheme has been extended to include trace gases and aerosols.

In addition to the Morcrette scheme a radiative transfer code for the shortwave spectrum was developed. This KNMI Doubling-Adding radiative transfer model [5] is a line-by-line model which yields so called exact results provided exact information on the atmospheric conditions and constituents is given. DAK was adapted to calculate the radiative properties of a plan-parallel cloud of which the user can define the cloud droplet size distribution and optical thickness.

References

1 Ramanathan V. et al.: Cloud radiative forcing and climate: Results from the earth radiation experiment, Science, 243, 57-63, 1989.

2 Cess R.D. et al.: Interpretation of cloud-climate feedback as produced by 14 atmospheric General Circulation Models, Science, 245, 513-516, 1989

3 Stammes P. et al.: TEBEX observations of clouds and radiation - potential and limitations, KNMI TR-162, 1994.

4 Kneizys, F.X. et al., Users' guide to Lowtran-7, Air Force Geophysics

Laboratory, Hanscom AFB(MA), AFGL-TR-88-0177, 1988.

5 Stammes P.: Influence of clouds on radiative flux profiles and polarization, in "IRS '92: Current problems in atmospheric radiation", Eds. S. Keevallik and O. Kärner, 129-132, A. Deepak, Hampton, VA 1993.

6 Saunders R.W. and K.T. Kriebel: An improved method for detecting clear sky and cloudy radiances from AVHRR data, Int. J. Remote Sensing, 9, 123-150, 1988.

7 Feijt, A.J.: The earth radiation budget experiment: overview of data-processing and error sources, KNMI TR-146, 1992.

8 Rossow, W.B. and L.C. Garder: Validation of ISCCP cloud detections, J. Climate, 6, 2370-2393, 1993.

9 Christensen, J.H. and E. van Meijgaard: On the construction of a regional atmospheric climate model, KNMI TR-147, 1992.

10 Morcrette, J.-J.: Radiation and cloud radiative properties in the European Centre for Medium Range Weather Forcasting system, J. Geophys. Res., 96, 9121-9132, 1991.