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The Clouds Climate Change Initiative: Assessment of state-of-the-art cloud property retrieval schemes applied to AVHRR heritage measurements

M. Stengel [a,*], S. Mieruch [a,b], M. Jerg [a], K.-G. Karlsson [c], R. Scheirer [c], B. Maddux [d], J.F. Meirink [d], C. Poulsen [e], R. Siddans [e], A. Walther [f], R. Hollmann [a]

[a] Deutscher Wetterdienst, Frankfurter Str. 135, 63067 Offenbach, Germany
[b] Institute for Meteorology and Climate Research, Karlsruher Institut für Technologie, Karlsruhe, Germany
[c] Swedish Meteorological and Hydrological Institute (SMHI), Norrköping, Sweden
[d] Royal Netherlands Meteorological Institute (KNMI), De Bilt, The Netherlands
[e] Rutherford Appleton Laboratory, Didcot, Oxfordshire, UK
[f] Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, Madison, WI, USA

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ABSTRACT

Cloud property retrievals from 3 decades of the Advanced Very High Resolution Radiometer (AVHRR) measurements provide a unique opportunity for a long-term analysis of clouds. In this study, the accuracy of AVHRR-derived cloud properties cloud mask, cloud-top height, cloud phase and cloud liquid water path is assessed using three state-of-the-art retrieval schemes. In addition, the same retrieval schemes are applied to the AVHRR heritage channels of the Moderate Resolution Imaging Spectroradiometer (MODIS) to create AVHRR-like retrievals with higher spatial resolution and based on presumably more accurate spectral calibration. The cloud property retrievals were collocated and inter-compared with observations from CloudSat, CALIPSO and AMSR-E The resulting comparison exhibited good agreement in general. The schemes provide correct cloud detection in 82 to 90% of all cloudy cases. With correct identification of clear-sky in 61 to 85% of all clear areas, the schemes are slightly biased towards cloudy conditions. The evaluation of the cloud phase classification shows correct identification of liquid clouds in 61 to 97% and a correct identification of ice clouds in 68 to 95%, demonstrating a large variability among the schemes. Cloud-top height (CTH) retrievals were of relatively similar quality with standard deviations ranging from 2.1 km to 2.7 km. Significant negative biases in these retrievals are found in particular for cirrus clouds. The biases decrease if optical depth thresholds are applied to determine the reference CTH measure. Cloud liquid water path (LWP) is also retrieved well with relative low standard deviations (20 to 28 g/m^2), negative bias and high correlations. Cloud ice water path (IWP) retrievals of AVHRR and MODIS exhibit a relative high uncertainty with standard deviations between 800 and 1400 g/m^2, which in relative terms exceed 100% when normalized with the mean IWP. However, the global histogram distributions of IWP were similar to the reference dataset.

MODIS retrievals are for most comparisons of slightly better quality than AVHRR-based retrievals. Additionally, the choice of different near-infrared channels, 3.7 μm as opposed to 1.6 μm, can have a significant impact on the retrieval quality, most pronounced for IWP, with better accuracy for the 1.6 μm channel setup. This study presents a novel assessment of the quality of cloud properties derived from AVHRR channels, which quantifies the accuracy of the considered retrievals based on common approaches and validation data. Furthermore, it assesses the capabilities of AVHRR-like spectral information for retrieving cloud properties in the light of generating climate data records of cloud properties from three decades of AVHRR measurements.

1. Introduction

Growing long-term observational data records from meteorological satellite instruments provide a unique source of measurements for deriving geophysical parameters in the Earth–atmosphere system on climate time scales of several decades. One particular application is the long-term analysis of clouds and their variability in space and time, as for example provided by the International Satellite Cloud

* Corresponding author.
E-mail addresses: martin.stengel@dwd.de (M. Stengel), sebastian.mieruch@kit.edu (S. Mieruch), matthias.jerg@dwd.de (M. Jerg), karl-goran.karlsson@smhi.se (K.-G. Karlsson), ronald.scheirer@smhi.se (R. Scheirer), bcmaddux@wisc.edu (B. Maddux), meirink@knmi.nl (J.F. Meirink), caroline.poulsen@stfc.ac.uk (C. Poulsen), richard.siddans@stfc.ac.uk (R. Siddans), andi.walther@ssec.wisc.edu (A. Walther), rainer.hollmann@dwd.de (R. Hollmann).

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Climatology Project (ISCCP; Rossow & Schiffer, 1999), the Pathfinder Atmospheres Extended (PATMOS-x; Heidinger & Pavolonis, 2009; Heidinger et al. 2012) datasets and the EUMETSAT Satellite Application Facility on Climate Monitoring (CM SAF; Schulz et al., 2009) cLoud, Albedo and RAdiation (CLARA-A1; Karlsson et al., 2013) datasets. These long-term, (partly) AVHRR-based cloud property datasets, as well as datasets inferred from the Moderate Resolution Imaging Spectroradiometer (MODIS; King et al., 1992), the High resolution Infrared Radiation Sounder (HIRS; e.g. Wylie et al., 2005) and the Television and InfraRed Observation Satellite (TIROS) operational vertical sounder (TOVS) heritage instruments (e.g. Stubenrauch et al., 1999, 2006) have supported a global, space-based analysis of cloud spatial patterns and temporal variability. This is important because clouds are one of the most important components of the Earth's climate system, acting as significant feedback mechanism in a changing climate (e.g. Kiehl & Trenberth, 1997). Furthermore, reanalyses and climate models can be evaluated with these space-based observational datasets, leading to clear indications where potential model improvements can be made. However, the existing cloud climatologies often differ to a significant extent. This can be due to different algorithmic approaches, as well as spectral capabilities, spatiotemporal sampling, orbit characteristics, etc., of the instruments.

A few attempts have been made to quantify the deviations among these datasets. The most comprehensive one is the Global Energy and Water Cycle Experiment (GEWEX) cloud assessment (Stubenrauch et al., 2013). While the GEWEX assessment focuses on averaged quantities and frequencies (e.g. monthly means and histograms), pixel-based products can be used for direct (inter-)comparison, for which the results are not affected by disparate averaging procedures. Such investigations are performed within the Cloud Retrieval Evaluation Workshop series (Roebeling et al., 2013), in which a variety of retrieval schemes are applied to the same instrument and qualitatively assessed. Other studies are for example given in Nauss et al. (2005), who present qualitative investigation of retrievals of effective radius, cloud optical thickness and liquid water in selected MODIS scenes. A comprehensive investigation of cloud ice water path (IWP) retrievals is reported in Eliasson et al. (2013). They considered IWP retrievals based on different retrieval approaches and different instruments including MODIS and AVHRR as visible-near-infrared (VIS/NIR) imagers, as well as microwave-based and radar-based sensors (e.g. CloudSat). Most of these studies show that different retrieval schemes can produce dramatically different results, even among different schemes applied to the same sensor.

Addressing this topic, this article presents an assessment of three state-of-the-art retrieval schemes applied to polar-orbiting VIS/IR passive imager data. This study is part of Cloud CCI, a project funded by the European Space Agency (ESA) within its Climate Change Initiative (CCI) programme. An overview of the scientific aspects of this programme is given in Hollmann et al. (2013). Cloud CCI focuses on the generation of long-term cloud property datasets incorporating European and non-European satellite sensors. A key feature here is the utilization of a common channel subset, limited to AVHRR channels (AVHRR heritage channels, hereafter). This limitation furthers the overall project goal, which is to achieve cloud property datasets composed of retrievals from the following satellite sensors: AVHRR (on several NOAA satellites and EUMETSAT satellites), MODIS (on Aqua and Terra), and AATSR (on ENVISAT). The inhomogeneities among the produced individual datasets will be reduced due to the AVHRR heritage channel approach. The data will be spectrally consistent due to the simultaneous retrieval of cloud properties, and temporally highly resolved within the time periods in which the measurement records overlap. A reprocessing of the AVHRR data record spanning more than 30 years with a state-of-the-art retrieval scheme, which also supplies consistent uncertainty measures, provides an additional motivation.

As a preparatory step in this project, well-established cloud retrieval schemes have been applied to the same radiance record of AVHRR and MODIS (limited to the AVHRR heritage channels), and their retrieval results were validated against A-Train observations and inter-compared. The cloud property retrieval schemes considered are: CLAVR-x (being the basis for PATMOS-x, Heidinger & Pavolonis, 2009; Heidinger et al., 2012), CM SAF schemes (being the basis for CLARA-A1, Karlsson et al., 2013), and ORAC (being the basis for the Global retrieval of ATSR cloud parameters and evaluation (GRAPE); Poulsen et al., 2012). The developer teams of these three schemes met the requirements of being able to provide AVHRR and MODIS based retrievals within a short period of time and using the same MODIS and AVHRR radiance data. Much experience has been gained that has aided to the development of these schemes in the last years. Their usage for generating cloud climate records and other applications has proven their maturity. While validation studies for the mentioned schemes were done individually, see Section 2.1 for references, the assessment presented in this article is the first attempt to validate and inter-compare their retrievals based on common framework and validation datasets, which are inferred from A-Train sensor observations. The results give an objective indication not only of the quality of each scheme, but also of the bounds of the quality of currently existing state-of-the-art AVHRR-cloud property retrievals. This is important in light of AVHRR being one of the very few sensors providing decades of measurements back to the early eighties, and thus allowing cloud climate studies. As an additional feature of this study, the retrieval schemes are applied to MODIS measurements (limited to AVHRR heritage channels), which allows the investigation of the impact of higher calibration accuracy, narrower channel definition, finer spatial resolution and the choice of the near-infrared channel in the retrieval. Here, MODIS onboard the Aqua satellite is considered, which is part of the A-Train, thus providing near-ideal overlap with respect to the reference sensors.

In Section 2 we give an overview of the methodology of our study including the general approach and a detailed description of the retrieval schemes and the validation data used. Section 3 presents the validation results and the analysis and interpretation. A summary and some concluding remarks are given in Section 4.

2. Methodology

To provide an objective and significant evaluation of the retrieval schemes, a common set of measurements from AVHRR (onboard the NOAA-18 satellite) and MODIS (onboard the Aqua satellite) was prescribed. The choice of NOAA-18 is motivated by the similarities of its orbital characteristics compared to the A-Train satellites (Stephens et al., 2002), because A-Train sensors are used as reference datasets in this study. The cloud retrievals were carried out for all available orbits on five days in 2008. These days are characterized by exceptionally large swath overlap between NOAA-18 AVHRR and the A-Train sensors. The days considered are: 20 March, 13 June, 20 June, 21 September, and 20 December, in 2008. The same days are considered for MODIS-Aqua, which provides very close temporal collocations to the reference observations, because it is part of the A-Train. Details on the satellite measurements used in this study are given in Section 2.2.

Using the spectral information of the AVHRR heritage channels, a number of cloud properties can be derived. However, in this assessment we focus on a particular subset of parameters, which were chosen with respect to their relevance for climate analysis and with respect to available references measurements, namely:

- Cloud mask (CMa): a binary decision if cloud contamination exists in a pixel. This parameter is normally used to create cloud fractional coverage representing a certain spatial and temporal window. The cloud mask is very important for the retrieval of other cloud parameters, which are usually only retrieved in pixels identified as cloudy.
- Cloud phase (CPH): a binary decision about the thermodynamic state of the cloud condensate at the cloud top. The thermodynamic phase