Comparison of cirrus cloud coverage calculated from reanalysis meteorological data with satellite data

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ABSTRACT: An offline cirrus cloud coverage calculation was conducted using a parameterisation similar to that adopted in ECHAM (Chen et al., 1997), as part of a preliminary analysis from ongoing work on estimating the uncertainties from contrail radiative forcing. The resulting cirrus cloud coverage, calculated from ECMWF ERA-40 reanalysis specific humidity and temperature data, was compared with ISCCP cirrus cloud data. Monthly mean results showed that computed coverage statistics between 45° South and 45° North were comparable with those from satellite observations. Similar spatial coverage structures, i.e. the high and low coverage values, were captured by both the parameterised calculation and the ISCCP dataset. A sensitivity analysis on the critical value of relative humidity over ice (U_{ci}) necessary for clouds to form highlights the importance of selecting an appropriate value of U_{ci}, optimized for the meteorological dataset used.

1 INTRODUCTION

The IPCC 'Aviation and the Global Atmosphere' report (1999) identified contrails and cirrus clouds as being, potentially, the largest effects from aviation on radiative forcing. This work forms part of a wider investigation to identify the sources of uncertainties in estimating radiative forcing from contrails. Cirrus coverage is required to determine which fraction of a grid cell is available for potential contrail formation. Therefore, it is important to compare calculated cirrus cloud coverage with observations.

2 METHODOLOGY

2.1 *Cirrus cloud parameterisation*

A method to calculate contrail coverage has previously been published by Sausen et al., 1998. The first stage of this work uses this method to produce an offline model that calculates the cirrus cloud coverage from different sources of meteorological data. In order to produce a suitable coverage map, it is necessary to have access to sufficiently resolved meteorological data in time and space. The European Centre for Medium-Range Weather Forecasts (ECMWF) Re-Analysis (ERA-40) datasets fulfil these criteria. From these datasets, fractional cirrus cloud coverage is calculated from specific humidity and temperature data using a parameterisation similar to that adopted for the general circulation model, ECHAM (Chen et al., 1997).

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Fractional cirrus cloud coverage (cirrus cloud by levels), b_{ci}, is calculated from Equation (1), where U_i is the relative humidity over ice and U_{ci} the critical value of relative humidity over ice. Total cirrus cloud coverage (over different levels) was then calculated from b_{ci} using random and maximum overlap assumptions (Sausen et al., 1998).

$$b_{ci} = 1 - \sqrt{\frac{1 - \max(U_i, U_{ci})}{1 - U_{ci}}} \tag{1}$$

The parameter U_{ci} determines whether cirrus cloud will form in a particular grid box, i.e. U_{ci} has to be exceeded for cirrus cloud to form (Sundqvist, 1978). Generally, U_{ci} is optimized for a given General Circulation Model (GCM) in order to yield a cloud distribution that leads to an optimal closure of the global annual radiation balance at the top of the atmosphere. If a modification is made to the resolution of a GCM or the cloud-radiative interaction, then the radiation balance at the top of the atmosphere may be disturbed. It is therefore necessary to restore the radiative balance either by modifying parameters affecting the cloud optical properties or by modifying the U_{ci} value. Various U_{ci} values have been used for previous ECHAM runs, e.g. ECHAM3 (U_{ci} = 0.85), ECHAM4 (U_{ci} = 0.6), ECHAM4.L39 (U_{ci} = 0.7).

In this preliminary work, total cirrus cloud calculated using U_{ci} = 0.6 (as adopted by Sausen et al., 1998) is compared with satellite data. U_{ci} values ranging from 0.5 to 0.85 are then applied to the parameterisation to determine the sensitivity of U_{ci} in predicting cirrus cloud coverage using ERA-40 data.

2.2 *Satellite data*

The International Satellite Cloud Climatology Project (ISCCP) was established in 1982 to produce global, reduced resolution datasets of basic properties of the atmosphere from which cloud parameters could be derived (Rossow et al., 1996). Five geostationary and two polar orbiting satellites have been used to infer the global distribution of cloud properties and their diurnal, seasonal and inter-annual variations. ISCCP analysis correlates radiances measured by satellites with temperature, humidity, ice and snow from TOVS (TIROS Operational Vertical Sounder) in order to determine information about clouds and the surface. Satellites (apart from TOVS) which cover January 1999 are NOAA-12, NOAA-14, GOES-8, METEOSAT-5 and GMS-5.

2.3 *Comparison study*

In this work we select a way of evaluating cirrus coverage that is directed towards identifying the sources of uncertainties in the intended contrail coverage analysis. Factors taken into consideration include the availability of satellite data, temporal resolution and high air traffic movement regions (Europe, North America, North Atlantic corridor and the Far East). Table 1 provides a summary of the data used to produce cirrus cloud coverages for this initial comparison work.

Table 1: Data used in the comparison study (U_{ci} = 0.6)

	Meteorology	Satellite
Dataset	ECMWF ERA-40	ISCCP climatological summary product (D2)
Parameters	Specific humidity and temperature	Daytime cloud (cirrus) amount (%)
Year	January 1999	January 1999
Horizontal resolution	2.5° x 2.5° globally	Equal area grid, latitudinally 2.5°
Vertical range	500 to 50 hPa	440 to 50 hPa
Temporal resolution	Monthly mean calculated from 00, 06, 12, 18 UTC	Monthly mean calculated from 00, 03, 06, 09, 12, 15, 18 and 21 UTC

3 RESULTS AND DISCUSSION

3.1 *Comparison between cloud parameterisation and observations*

The resulting cirrus cloud coverage for the case where U_{ci} = 0.6 (Figure 1) is compared with observed global cloud data from the ISCCP dataset (Figure 2) for one calendar month (January 1999).

In this study, only data for latitudes between 45° South and 45° North were used to evaluate cirrus coverage from the cirrus parameterisation and ISCCP.

This initial attempt indicates that a longer time period, such as one year or more, is necessary because there are not enough data from ISCCP at important contrail-affected regions such as North America and Northern Europe (mainly due to January being a winter month). A comparison of the calculated cirrus cloud coverages with the ISCCP dataset shows that ISCCP has a higher maximum coverage (99%) and mean value (30%) than the calculated maximum coverage (92%) and mean value (24%) from the ERA-40 dataset.

Relative maxima of cirrus coverage were calculated over Polynesia in the Pacific Ocean, Amazon basin, central Africa and along the Inter Tropical Convergence Zone (ITCZ). These are similar to the ISCCP data, even though the ISCCP cirrus coverage in these areas was higher than that calculated from ERA-40 data. Relative minima were calculated over the East Pacific Rise, Central America, North Africa and India. Similar structures were observed in ISCCP data but again with higher values. Spatial patterns from both sources were comparable but computed coverages lacked the finer details that were observed in ISCCP data.

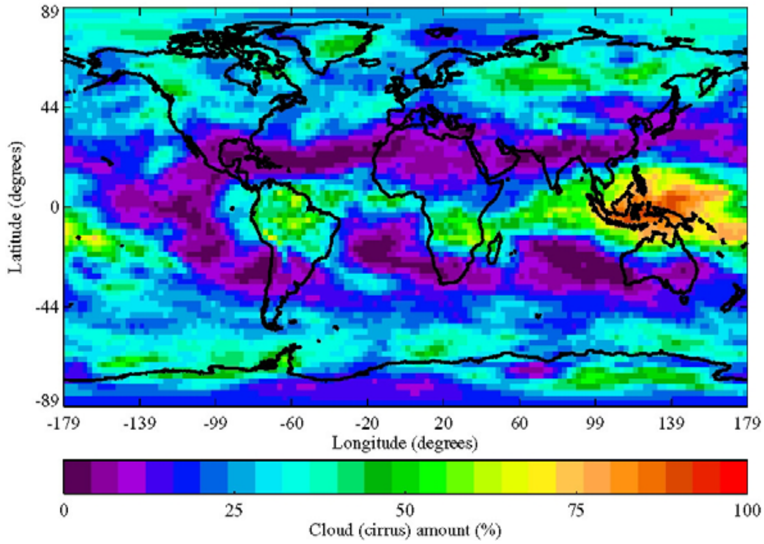

Figure 1. Cirrus cloud coverage calculated from ERA-40 data using ECHAM parameterisation for reference case (U_{ci} = 0.6)

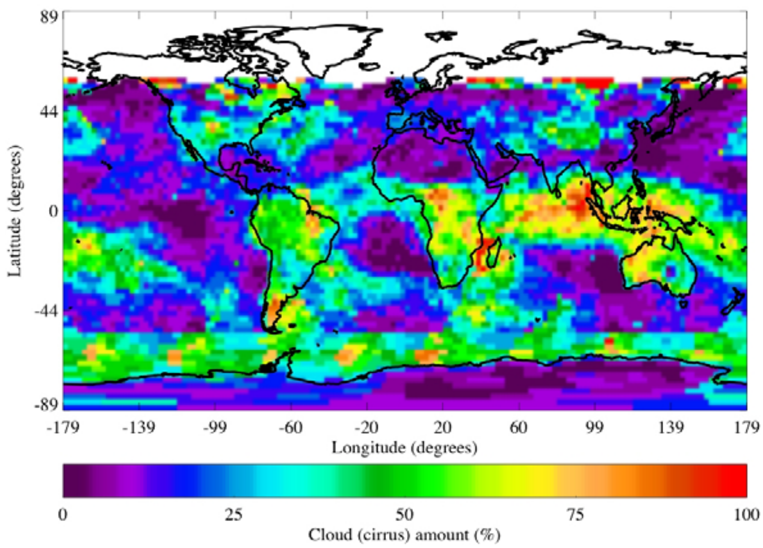

Figure 2. Cirrus cloud coverage from ISCCP

3.2 *Sensitivity of U_{ci}*

Results of the sensitivity analysis on U_{ci} in predicting cirrus cloud coverage using ERA-40 data are presented in Table 2. As expected, there is a variation of global mean coverage values for different U_{ci} values. The lowest U_{ci} value tested (0.5) produced the highest maximum coverage (92.9%) and the highest global mean coverage (30.3%). There was a gradual decrease of maximum and global mean coverage with increasing U_{ci}. For U_{ci} = 0.5 and U_{ci} = 0.85, there was a difference of 6% for the maximum coverage and 14% for the global mean coverage. In this preliminary study, even though the global mean coverage decreases approximately linearly with increasing U_{ci}, this is not reflected on a cell-by-cell basis.

Table 2: Comparison of global coverage statistics

Statistic	Parameterisation (%)							
U_{ci}	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85
Maximum	92.9	92.5	92.1	91.5	90.8	89.9	88.8	87.2
Mean	30.3	28.5	26.6	24.7	22.8	20.9	18.9	16.8

Spatial plots for U_{ci} = 0.5 and U_{ci} = 0.85 are presented in Figures 3 and 4, respectively. These show that they have the same basic patterns but the structural details are different. For instance, low cirrus cloud coverage (< 12%) was observed in both figures over the Pacific Ocean, west of Mexico. However, the low coverages from the U_{ci} = 0.85 test case extend further northwards onto the west coast of the United States when compared with the coverage produced using U_{ci} = 0.5.

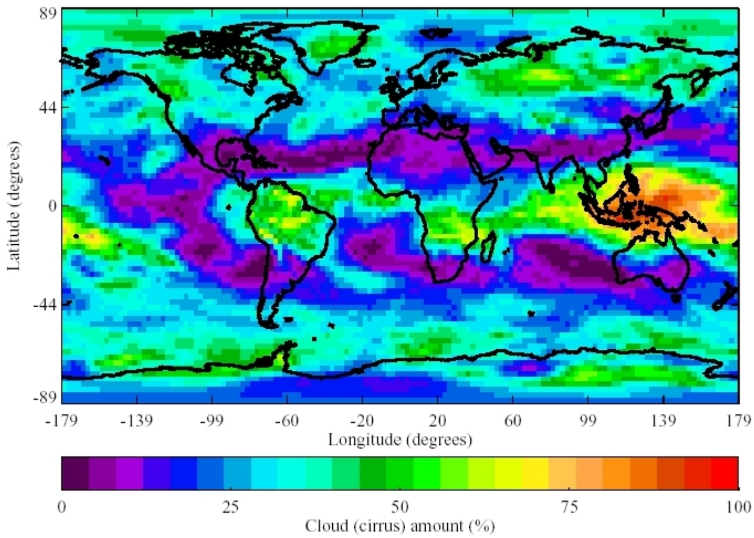

Figure 3. Cirrus cloud coverage calculated from ERA-40 data using ECHAM parameterisation for test case U_{ci} = 0.5

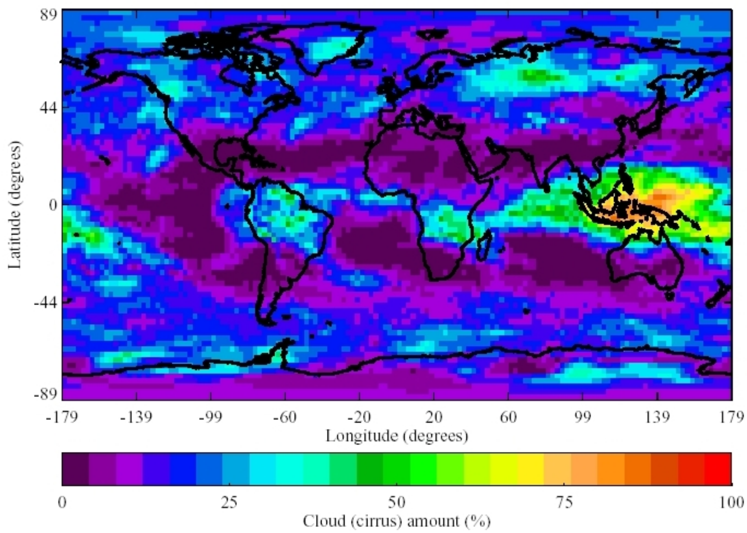

Figure 4. Cirrus cloud coverage calculated from ERA-40 data using ECHAM parameterisation for test case U_{ci} = 0.85

The results of this sensitivity analysis demonstrate the importance of selecting an appropriate U_{ci} value for the meteorological dataset used. This value may influence the spatial distribution of cirrus coverage calculations and, therefore, the global mean coverage. A possible approach is to optimize the U_{ci} value to the high cloud field inherent in the ERA-40 dataset. Theoretically, the U_{ci} values can be below 0.5 (the lower limit tested) and higher than 0.85 (the upper limit tested) (Walcek, 1994). Therefore, it is possible to further adjust U_{ci} for ERA-40 data to produce an optimized cloud distribution for regions with high aircraft movements.

4 CONCLUSIONS AND FURTHER WORK

Cirrus cloud coverage is an important parameter in estimating the uncertainties for contrail coverage as it is required to determine which fraction of a grid cell is available for potential contrail formation. There was good agreement between the cirrus cloud coverage calculated using the ECHAM cirrus cloud parameterisation and the dataset obtained from ISCCP. Spatial patterns from both sources were comparable with each other. However, computed coverages lacked the finer details that were observed in ISCCP data.

January 1999 ISCCP data did not have enough data capture (due to January being a winter month) for important contrail coverage regions such as high air traffic regions in North America and Northern Europe. Hence, a longer time period is necessary to yield an evaluation that serves the purpose of this study. There are also other data sources for cirrus climatology that can be used for such a comparison, such as SAGE and HIRS data (well established) and the University of Oxford's MIPAS and GRAPE datasets (under development). However, ISCCP is still the most widely used and commonly accepted dataset.

A sensitivity analysis on U_{ci} showed the importance of this parameter in determining cirrus coverages resulting from the parameterisation. The first step in the next stage of work is to optimize U_{ci} for the ERA-40 dataset to match its global high cloud dataset. Then, U_{ci} can be optimized for latitudes with high air traffic and then tested in other regions. Other planned further work includes comparison of calculated coverage using this new U_{ci} value; comparisons of different temporal statistics (diurnal, seasonal and inter-annual variations) and detailed comparisons over specific regions.

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