Contrail Frequency over Europe from NOAA-Satellite Images

S.Bakan$_2$, M.Betancor$_1$, V.Gayler$_1$, H.Graßl$_{1,2}$
1 Institut für Meteorologie. Universität Hamburg. 20146 Hamburg. Germany
2 Max-Planck-Institut für Meteorologie, 20146 Hamburg. Germany

Abstract Contrail cloudiness over Europe and the eastern part of the North Atlantic Ocean was analyzed for the periods Sept. 1979-Dec. 1981 and Sept. 1989-Aug. 1992 by visual inspection of quicklook photographic prints of NOAA/AVHRR infrared images. The yearly averaged value, seasonal and daily cycle of contrail cloud cover are presented, as well as significant differences between both time periods. Lifetime and displacement of contrail regions were studied using a smaller data set of only a few months. Causes, possible errors and consequences are discussed.

1. Introduction

Air traffic is the dominant source of pollution in the high troposphere. Visible manifestation of high flying jets are the contrails. They appear, when the ambient temperature sinks below $-45oC$ (*Appleman, 1953*), triggered by the condensation of water vapor, that is produced, when the kerosen of the flying jet burns out. Their residence time depends on the ambient relative humidity and the degree of mixing with the environment *(Schumann, 1993)*. A growing demand of air transportation linked to high fliht levels could increase the appearance and persistence of contrails. It is therefore a matter of interest to determine, wether the radiative properties of contrails, as man-made ice clouds, differ from that of cirrus clouds, causing an additional but differing climatic effect. To determine the impact of contrails on climate their optical properties, as well as, their areal coverage must be known. This paper tries to solve part of this problem, giving insight in the regional and time-dependent variability of contrail cloud cover over Europe and the eastern part of the Atlantic Ocean. There are many studies *(Chagnon, 1981; Carleton and Lamb, 1988; Liou et al., 1990; Wendling and Schumann, 1990; Roll, 1990)* analyzing the additional cloud cover due to high clouds or contrails, but non of them documents jet contrail occurrence on a large spatial scale, for periods spanning a decade, as it would be necessary for the rigorous evaluation of the contrail-cirrus climate relationship. *(Carleton and Lamb, 1988)*

2. Data Sources and Processing

There are still many difficulties to automatically detect contrail areas through image processing and to distinguish them from structured cloud areas like cirrus clouds. Therefore, to study cloud occurrence in the European/East Atlantic area photographic image prints of NOAA/AVHRR data, as available in the satellite image archive at the University of Dundee, were taken for visual inspection. The high quality of these photographic prints with a spatial resolution of 20km/mm still permits a good identification of aged contrails. From the scenes available only photographic prints of the channel 4 around $10 \mu m$ were analysed. In this spectral range, contrails and cirrus-level features can be easily discriminated from lower tropospheric clouds and surface phenomena. In the channels of the short wave spectrum varying solar height influences cloud brightness and contrast, and similar looking features like ship trails can be confused with contrails. In the infrared channel such features are excluded through the brightness of high and cold clouds.

The quicklooks used enclose the region between $50^oW - 40^oE; 35^oN - 75^oN$, that includes Europe and the eastern part of the Atlantic Ocean,and thus of the transatlantic flight route. Only the quicklooks of the early afternoon pass (between 12:00 and 14:00 UTC) were processed for a time period of 5 years. Due to the daily shift of the satellite orbital path only a core region around 0 -longitude is displayed daily. Only those regions, which were covered by the satellite field of view on more than 30% of the days processed, were analyzed.

On the quicklooks contrails are detected due to their linear structure and distinguished from cirrus clouds by their alignment: not paralell to the wind direction, but intersecting one another, showing the directions of different flight paths. Contrails appear mostly in groups and spread out over areas of hundreds of km. This procedure does not cover young and thin contrails due to the limited spatial resoluion of the images. Also very old contrails were excluded from the contrail classification when their appearance made it difficult to separate the from natural cirrus clouds.

3.Results

The following pictures show the additional cloud cover due to contrails over Europe and the eastern part of the Atlantic Ocean, depending on different time scales, for the entire analysis period (Sept.79 - Dec. 81; Sept.89 - Aug.92). Fig. 1 shows the regional distribution of the yearly averaged contrail cloudiness. Contrails are primarily observed over western Europe and the Eastern Atlantic.

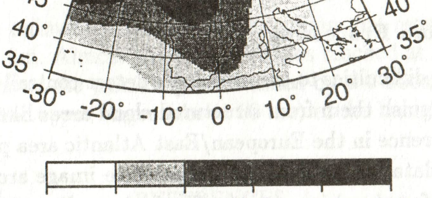


Figure 1: Yearly averaged contrail cloudiness (in percent) over Europe and the eastern part of the Atlantic Ocean for the total analysis period Sept. 1979-Dec. 1981; Sept. 1989-Aug. 1992.

Maximum values of 2% are reached over the Ocean. For the whole scene contrail cloud cover has an averaged value of 0.5%. The pattern of the contrail cloudiness distribution along the scene fits well with the path of the transatlantic flight route.

Contrail cloudiness exhibits a strong seasonal cycle. The highest maximum values are found in spring and summer (s. Fig. 2a. and 2b.), around 2%, over the Atlantic Ocean. Above all, the summer season shows the highest values sorrounding a region between the Atlantic Ocean and Western Europe. These maximum values for the two seasons dissappear over the Atlantic Ocean for autumn and winter (s. Fig. 2c. and 2d.) and displace to Southwestern Europe with lower values around 1%. The regional distribution of contrail cloudiness displays a westward component from spring to autumn, that may correspond, as already stated, to the transatlantic flight corridor. There is also a southward component lasting from autumn to spring. It is linked to a displacement southwards of the northern limit of contrail appearance towards the winter. It may be an expression of the seasonal motion of the jet stream, that moves also to the south in the winter.

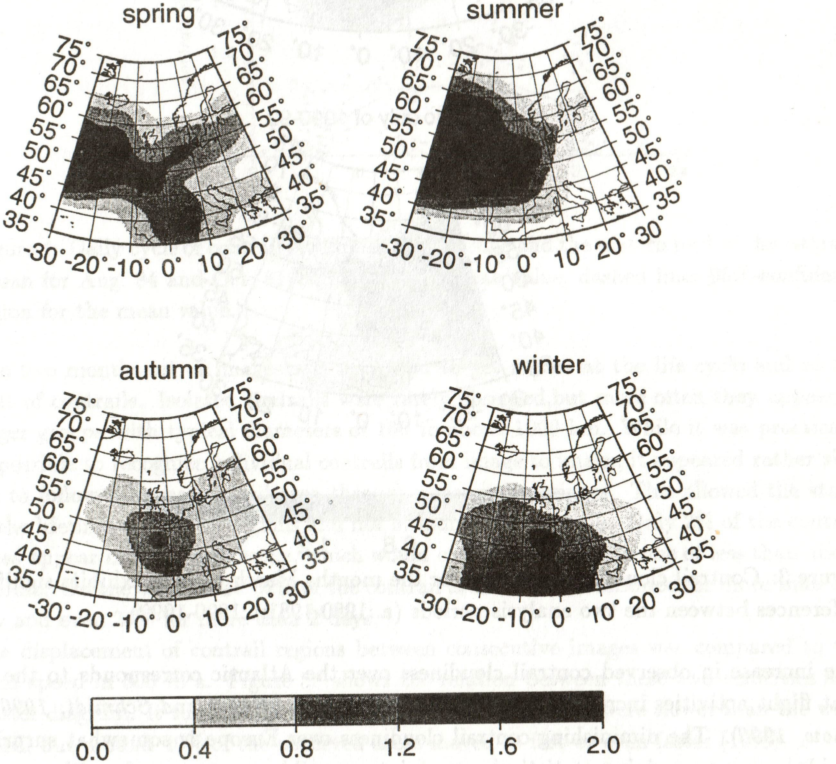
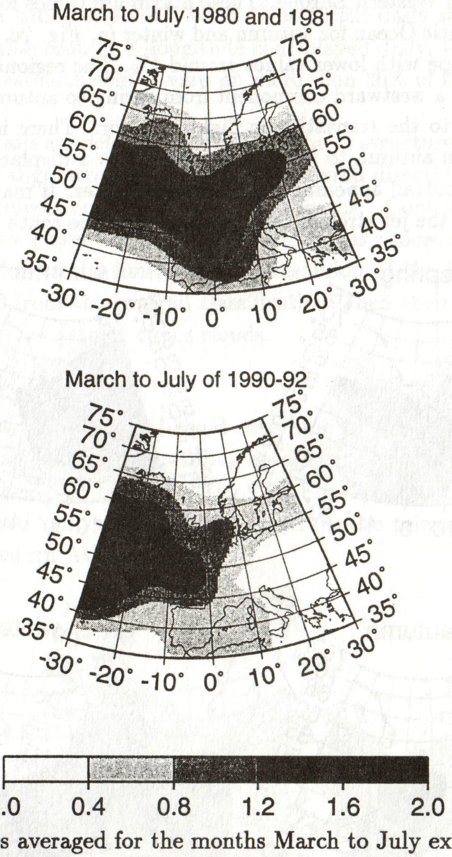


Figure 2: Monthly averaged contrail cloudiness (in percent) in spring (a.), summer (b.), fall (c.) and winter (d.) for the same time period as in Fig. 3.

For this study 5 years of data were chosen, divided into two periods with 10 years separation, in order to study a possible longterm trend in contrail cloudiness. In the following results only the summer months from March to July were included. Figure 3. shows a considerably smaller cloudiness over Central Europe during the latter time period as compared to the former, while over the Atlantic flight corridor the average contrail cloudiness increased. These changes are significant (95%), as an applied student-t-test showed. For the winter time no significant changes were found.


March to July 1980 and 1981

March to July of 1990-92

Figure 3: Contrail cloudiness averaged for the months March to July exhibits significant differences between the two analysis periods (a.:1980-1981;b:1990-1992).

The increase in observed contrail cloudiness over the Atlantic corresponds to the fact, that flight activities increased continuously in the past (*Nüßer and Schmidt, 1990; Reichow, 1990*). The diminishing contrail cloudiness over Europe is somewhat surprising. Besides some reamaining statistical uncertainty, possible causes may be either systematically changed flight level or/and pattern in inner european air traffic, or the effect of changing environmental conditions due to secular changes in the atmospheric circulation pattern.

As stated before, only one image per day could be analysed for the whole period. In order to understand how representative these results are for the daily average, two months (Aug.84 and Sept.85) were analysed in addition, including 4 quicklooks per day (4:00,8:00,14:00,18:00). Figure 4. contains contrail cloudiness values for 53 days. First of all, the large scatter gives an idea of the day by day fluctuation in the evaluated data. Nevertheless, a rather well expressed daily cycle is observed. The solid line displays the averaged value over these two months with a reduction of cloudiness during the night by a factor of two. The dashed lines represents the variance of the averaged value.

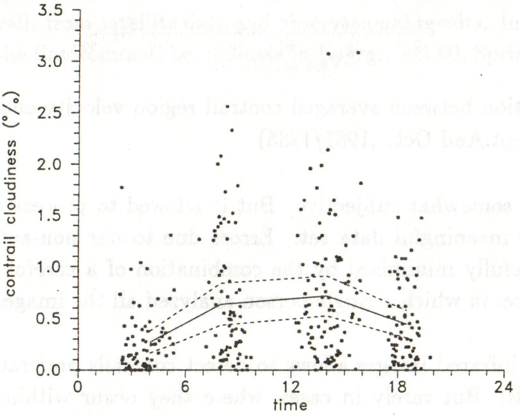


Figure 4: Daily cycle of contrail cloudiness over Europe and the eastern part of the Atlantic Ocean for Aug. 84 and Oct. 81/85. Solid line: mean value, dashed line: 95%-confidence region for the mean value.

The two months-set of images was also used to get a hint at the life cycle and at the shift of contrails. Isolated contrails were rarely observed,but more often they appear in larger groups with typical diameters of 100 to about 1000 km. While it was practically impossible to recognize individual contrails from image to image, it appeared rather simple to follow a larger contrail area through consecutive images. This allowed the study of the lifetime of contrail regions and not of individual contrails. Only 2% of the contrail areas appear in one single scene, which would correspond to a lifetime of less than about 6 hours. On the other hand 62% of the contrail areas could be followed for more than one day and even 24% for more than 2 days.

The displacement of contrail regions between consecutive images was compared to the wind speed in 300 hPa. Figure 5. shows the relation between these two velocities as a scatter diagram. It turned out, that most of the contrail areas were slower than the wind speed, but around 40% of the observed areas moved as fast or even faster (10%).

4. Conclusions

The chosen method to analyze contrail occurrence in satellite images from quicklook

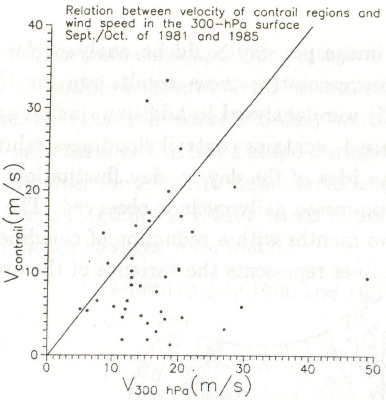


Figure 5: Relation between averaged contrail region velocity and wind speed in the 300 hPa-surface (Sept.And Oct. ,1981/1985)

photographs is somewhat subjective. But it allowed to process a rather large and thus climatologicaly meaningful data set. Errors due to our non-automated image analysis have been hopefully minimized by the combination of a careful training phase with an evaluation phase, in which a single person analyzed all the images without any change of the procedure.

Using only infrared images allows to detect contrails preferably over clear areas and low level clouds. But rarely in cases, where they occur within or near natural cirrus. Therefore the most probable error of the applied procedure is a systematic underestimation of contrail cloudiness. Relative variations in space and time should be more reliably reproduced.

The interpretation of the observed spatial and temporal variation of contrail cloud cover needs the consideration of air traffic statistics as well as tropopause height, temperature and moisture statistics. Non of them is available at the moment with required detail and accuracy. Therefore, no quantitative interpretation of our results is possible at the moment.

REFERENCES

Applemann, H., The formation of exhaust condensation trails by jet aircraft. Bull. Amer. Metorol. Soc., 34, 14-20, 1953

Carleton and A., P. Lamb, Jet contrails and cirrus clouds: A feasibility study employing high-resolution satellite imagery. Bull. Amer. Meteorol. Soc., 67, 301 -309, 1988

Chagnon, S.A, Midwestern cloud, sunshine and temperature trends since 190 1: Possible evidence of jet contrail effects. J. Appl. Meteor., 20, 496-508, 1981

Liou, K-N., S-C. Ou and G. Koenig, An investigation of the climatic effect of contrail cirrus. In: U. Schumann (ed.): Air traffic and the environment. Lect. Notes in Engrg., Vol 60, Springer-V., Berlin, p.154-169, 1990

Nüßer, H-G and A. Schmitt, The global distribution of air traffic at high altitudes, related fuel consumption and trends. In: U. Schumann (ed.): Air Traffic and the Environment. Lect. Notes in Engrg., Vol 60, Springer-V., Berlin, p.1-11, 1990

Reichow, H-P., Fuel consumptions and emissions of air traffic. In: U. Schumann (ed.): Air Traffic aand the Environment. Lect. Notes in Engrg., Vol 60, Springer-V., Berlin, p.12-22, 1990

Roll, O., Kondensstreifen im Satellitenbild. Master Thesis, Univ. Cologne. Germany, 1990

Schumann, U., On the effect of emissions from aircraft engines on the state of the atmosphere. DLR .Report No.1. ISSN 0943-4771, 1993 Wendling, P. and U. Schumann, Determination of contrails from satellite data and observational results. In: U. Schumann (ed.): Air Traffic and the Environment Lect. Notes in Engrg., Vol 60, Springer-V., Berlin, p.138-153, 1990