Contrail Coverage over Western Europe derived from NOAA-AVHRR-Data

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INTRODUCTION

High and optically thin ice clouds reduce the outgoing longwave flux at top of atmosphere mostly stronger than they decrease the downward solar radiative flux [14, 8]. Thus an increase of thin ice clouds may lead to warmer surface temperatures [6].

Under certain atmospheric conditions aircraft form condensation trails [12] that can persist for hours and spread out to cover large parts of the sky. In regions where these conditions for formation of persistent contrails are frequent and air traffic is dense the regional climate is affected. Due to the rapid growth of air traffic - fuel consumption is increasing 3% per year [11] - its possible effects need further study.

To model the regional and global climatic effect of contrails we need to know their temporal and spatial distribution as well as their optical properties. Optical properties can be derived from in-situ measurements [4] and by remote sensing techniques [2, 5, 10]. The frequency of contrail occurrance can be obtained from synoptic observations of contrails as it was shown by Minnis et al. [9] for the US, but to acquire their mean coverage of the sky areal measurements have to be taken. For this task we need remote sensing data with a high repetition rate and reasonable spatial resolution. Up to now only a few studies on regional contrail coverage have been performed. Mostly AVHRR data was used due to the availability of long time-series which is needed for proper means. Schumann and Wendling [13] estimate an average contrail coverage of 1.5% from AVHRR-data for Southern Germany and the Alps by visual inspection of digital AVHRR data. Bakan et al. [1] analyzed the biggest data set so far. Through visual inspection of daily AVHRR hard-copies from 52 months an average contrail coverage of 1% over Central Europe and 2% over the eastern part of the North Atlantic was obtained.

All these observations suffered from the subjectivity introduced by visual interpretation. Therefore there was a strong need for a fully automated scheme that detects contrails in satellite data. Engelstad et al. [3] created the first algorithm which was able to find contrails in AVHRR data, but had the tendency to misinterpret linear streaks of natural cirrus as contrails. The algorithm used here [7] was designed to have a low false alarm rate at a constant detection rate. This for the first time enables to analyze a large number of AVHRR-scenes operationally.

DETECTION OF CONTRAILS

With passive remote sensing methods ice clouds can recognized by their low brightness temperatures in the thermal infrared if they are thick enough and by their influence on the spectral transmissivity, if they are thin. Due to originally smaller crystal sizes contrails tend to show higher transmissivity in the AVHRR-channel 4 (10.3 to 11.3 μm) than in channel 5 (11.5 to 12.5 μm) at the edge of the atmospheric window [4]. This causes contrails to appear bright in images of the temperature difference between these split-window channels.

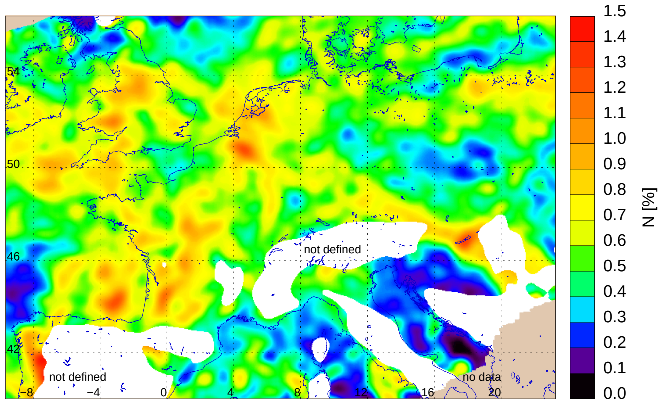

Figure 1: *AVHRR-derived heterogeneity-corrected contrail coverage N at noon for the period March 1995 to February 1997.*

The algorithm used here is described en detail by Mannstein et al. [7]. It makes use of both informations, the mostly bright ridges contrails show in the temperature-difference images and in the inverted temperature image.

Unfortunately contrails often appear as very fuzzy structures hard to distinguish from background. Other objects like cloud edges, coast lines, mountain ridges etc. also form linear ridge structures of comparable scale and amplitude.

Therefore we use a scheme that combines different tests to avoid misdetections. Those tests are mainly based on spatial patterns - the way a human observer recognizes contrails in satellite images. Important for the derivation of climatological values is a constant detection efficiency for all scenes and viewing angles. To make the data independent from the individual scenery both images get normalized with their local standard deviation SD in a 5 x 5 pixel surrounding. Within these normalized images the contrast is evenly distributed and independent from size and content of the actual scene. Therefore we can use global thresholds without loosing sensitivity.

To derive linear elements the sum of the normalized im-

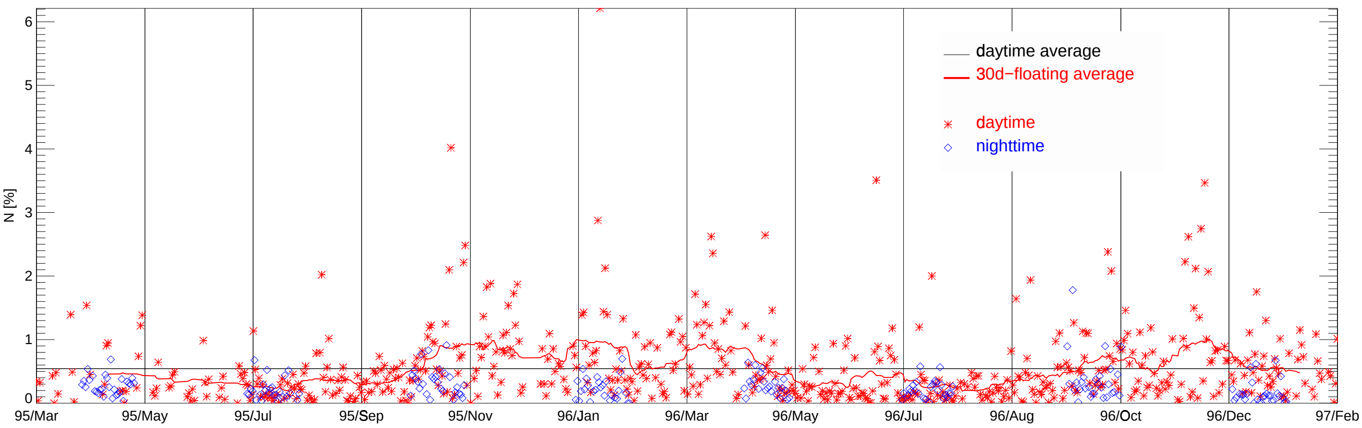

Figure 2: *Average AVHRR-derived corrected contrail coverage for the box 0°E to 20°E, 48°N to 55°N. Asterisks are noon passages, diamonds nighttime passages. The solid line shows the 30-d floating average, the dotted line marks the bi-annual average for daytime. Plotted are all values where data coverage was higher than 70 %.*

ages SN is convolved with a line filter of 19 x 19 pixels in 16 different directions. Because of the normalization of the input data, a single threshold is sufficient to isolate connected regions. These regions are treated as separate objects which might represent contrails. Each of these objects is now checked against a binary mask which combines the following criteria:

$$SN > 1.5, \quad (1)$$
$$TD > 0.2\text{K}. \quad (2)$$
$$\overline{G5} < 2 \cdot \overline{SDT5} + 1\text{K}, \quad (3)$$

where $\overline{G5}$ is the large scale maximum gradient for temperature in ch. 5 calculated in a 15 x 15 pixel vicinity, which is compared to the local standard deviation. Afterwards we recombine elongated structures disrupted by this check using morphological functions.

To be regarded as contrails, the resulting objects additionally have to consist of more than 10 pixels, must be longer than 15 pixels and must fit to the actual filter direction applied. The filtering and testing procedures are repeated for 16 directions and the results are added to a binary contrail array. The proposed scheme mainly marks contrails of a width of 1 or 2 pixels. To detect wider contrails the whole algorithm is then applied to images reduced by a factor of 2. The results of this step are again added to the final binary contrail mask.

The performance of this scheme was tested against interactive interpretations of 60 satellite images by two observers. Greatest errors are found at the off-nadir scene borders due to the reduced horizontal pixel resolution there. To diminish this effect only a scan-angle of ± 50°is used.

Accurate visual inspection by zooming and optimizing the contrast confirms the assumption that many contrails still are undiscovered by the algorithm. In spite of the normalization the automatic scheme with its fixed parameters is inferior to the human eye in adapting to the specific contrasts in parts of the image. Thus the observer is able to recognize many more mostly weak and fuzzy contrails. But contrail coverage derived from a set of AVHRR-images by two trained observers differed by a factor of 2, which shows that visual inspection is highly subjective. With this algorithm we reach a detection efficiency defined as the ratio of correct contrail detections to the amount of all visually recognized contrails of 30% to 50%. Testing the algorithm on data from Newzealand with negigible air-traffic resulted in an absolute false alarm rate in the order of 0.1%.

RESULTS

The contrail detection algorithm is applied to AVHRR-images of NOAA-14 covering Central Europe. For the given results we processed 660 daily noon scenes from April 1995 to February 1997.

To calculate the regional AVHRR-derived contrail coverage N, the contrail masks are resampled to a common projection with 1 km resolution and added up. The counts of the stacked contrail masks are divided by the number of possible detections and filtered with a circular gausskernel of 50 pixels. We have chosen this radius to represent the visibility range of a ground-based observer. Additionally the derived contrail cloudiness is corrected for yearly averaged inhomogeneity of the background. As described by Mannstein et al.[7] this procedure adapts the reduced contrail detectivity to values which could be obtained above a thermally homogeneous background. If the background is too inhomogeneous (eg. here the Alps and Southern Europe), it is not possible to derive meaningful values for the contrail coverage.

The average for the corrected daytime contrail coverage in the whole dataset (Fig.1) amounts to 0.5% ± 0.25%. The spatial pattern of the algorithm-derived contrail coverage agrees with the contrail observations by Bakan et al.[1]. They also obtained the maxima in the North-Atlantic flight corridor with declining contrail cloudiness to the Eastern and Southern parts of Europe. The absolute value for contrail cloudiness observed by in [1] is on the average 1.6 times higher than the annual mean of the contrail coverage we derived. This may be an effect of analyzing different years, but we assume, that the deviations of absolute values may arise from the applications of two different methods. This comparison indicates that trained human observers are more effective in contrail detection.

An advantage over the analysis of given in [1] is the higher spatial resolution. Some heavily flown air traffic routes can still be recognized in Fig.1). Maxima of contrail coverage of 1.0% and higher are found over Wales, The Channel, The Netherlands and over Hungary.

Fig. 2 shows the daily variation of the average contrail coverage in the area between 0°E and 20°E, 48°N and 55°N. For the absolute values of daily contrail coverage we estimate an error in the order of a factor 2.

As the 30-d floating average in Fig.2 suggests, there are remarkable annual variations with a minimum below 0.2% during summer and a maximum close to 0.9% during winter and spring. But annual variations of detection efficiency might have influenced the results.

Additionally we analyzed NOAA-14 night scenes (0145 UTC ± 50 min) for the midseason months. We found a mean nighttime contrail coverage of 0.24%, while the daytime contrail coverage for the same period on daytime was 0.70% (Fig.2). Thus contrail coverage at night is about one third of the daytime noon coverage.

CONCLUSIONS

The mean of the heterogeneity-corrected AVHRR-derived contrail coverage reached 0.5% ± 0.25 % over Western Europe. We recognize strong temporal and spatial variations in contrail coverage which match those derived by Bakan et al.[1]. Absolute values derived here are smaller by a factor of 1.6 which is of low significance due to analysis of different time-periods. Large differences of the two investigations can also be explained by an overestimation of the visual interpretations, but also by the poor detection efficiency of the automated scheme.

For the midseason month within this period we derive a nighttime contrail coverage of 0.2% which has to be compared to 0.7% for the same period from AVHRR-noon-passages. The observed annual cycle has its maxima during winter and spring, but might still be influenced by a differing detection efficiency.

Beyond this the scheme is not able to detect atypical contrails such as very wide spread and fuzzy ones, which are hard to distinguish from natural cirrus. These man made cirrus clouds might have an important influence on the regional climate.

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