Contrail observations from space using NOAA-AVHRR data

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Abstract

The infrared channels of the Advanced Very High Resolution Radiometer (AVHRR) onboard of the weather satellites of the NOAA series allow the detection of contrails. An automated detection scheme is described and tested against computer aided visual classifications by two experts. The algorithm seems to identify contrails within the satellite data with a skill comparable to the human observers.

Clusters of contrails within the satellite images are connected to outline regions where the atmospheric properties are favourable for the existance of observable contrails. Air traffic data shows, that over Middle Europe at least in the main flight levels most of these regions should be marked by detectable contrails. The mean areal coverage of these regions is estimated to be in the range of 10% to 20%, the cloud coverage by detected contrails was 0.9% in 60 AVHRR scenes covering Central Europe.

1. Introduction

Whether there is a relevant climatic impact of contrails is still an open question. High and optical thin cirrus clouds and also aged contrails may have a positive correlation to the radiation budget of the combined surface and atmosphere system. An increase of coverage by contrails may thus lead to warmer surface temperatures while all other cloud types lead to surface cooling. The global mean coverage by contrails is not known. Bakan [1] derived from visual inspection of AVHRR ('Advanced Very High Resolution Radiometer') data the contrail coverage of the North Atlantic region and found values up to 2% depending on season and location.

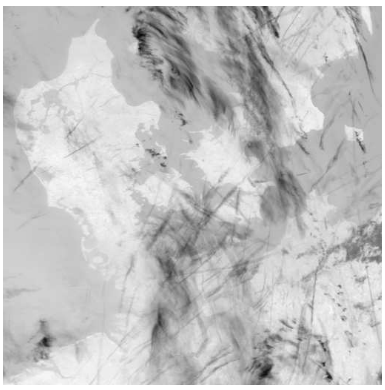

Fig. 1: NOAA-12, T(Ch. 5), May 4th, 1995. 07:43 UT.

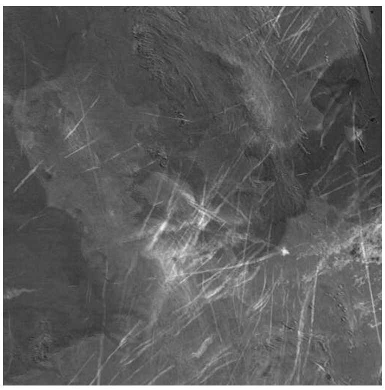

Fig. 2: NOAA-12, T(Ch.4) - T(Ch. 5), May 4th, 1995. 07:43 UT.

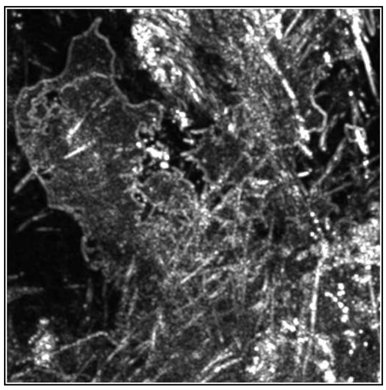

Fig. 3: Regional standard deviation of T5.

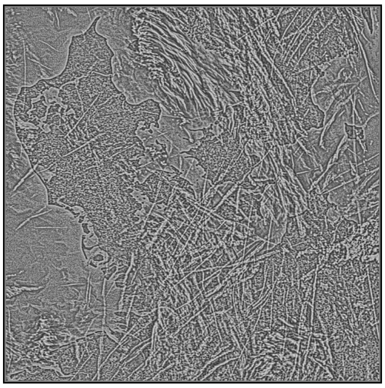

Fig. 4: Normalized temperature Ch.5.

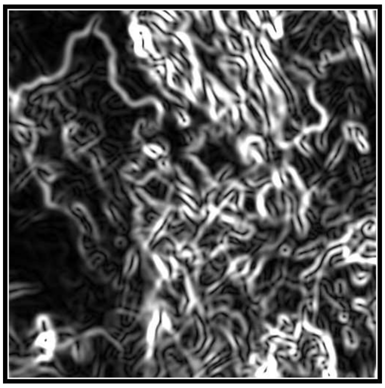

Fig. 5: Large scale maximum gradient of T5.

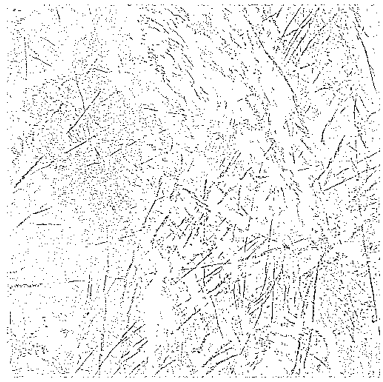

Fig. 6: first guess Mask for detection of contrails.

Local area coverage (LAC) images recorded by the AVHRR onboard of the weather satellites of the NOAA series show often linear structures which can be identified as contrails without any doubt. Best suited to identify contrails are the channels in the thermal infrared part of the spectrum i.e. channel 4 (10.3 to 11.3 μm) and channel 5 (11.5 to 12.5 μm) and the difference of the blackbody temperatures derived from this channels [2, 1]. Figs. 1 und 2 show an extreme case of contrail coverge over Denmark, southern Sweden, northern Germany and the western part of Poland. This small part of an AVHRR scene is used in the following to illustrate the contrail detection algorithm.

2. Contrail Detection Algorithm

2.1. Description

Input data for the detection algorithm are the equivalent blackbody temperature derived from channel 5 (T5) and the temperature difference between channel 4 and 5 (TD). To avoid interference with artefacts produced by remapping we use the data in the original satellite projection. Figs. 1 and 2 show an example of this data. Both datasets are filtered with an highpass kernel and normalized with the regional standard deviation STD5 and STDD(Fig. 3).

T5 is inverted. From the resulting normalized images N5 and ND (Fig. 4), the large scale maximum gradient of T5 (G5) (Fig. 5) and TD we derive a mask shown in Fig 6, which marks all pixel fulfilling each of the following requirements:

- $N5 + ND > 1.5$ (This value depends on the type of normalisation)
- $G5 < 2. * STD5 + 1$ to avoid the interpretation of edges as lines
- $TD > 0.2$

The fixed parameters this requirements where derived by an evolutionary algorithm which maximized the correlation of the resulting mask with the visual analysis of some test cases.

The sum of the normalized images $N5+ND$ is input for further filtering. We convolve the data with a line filter of 19 x 19 pixel in 16 different directions. Because of the normalization of the input data, a single threshold is sufficient to isolate connected regions, which are treated as seperate objects. Each of this objects is checked against the mask described above. To be regarded as a contrail, the remaining pixel in each object have to fulfill the following criteria:

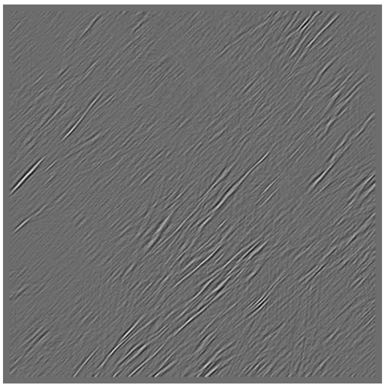

Fig. 7: Sum of normalized images convolved with line detection kernel for 45°.

Fig. 8: contrails derived for the direction 45°.

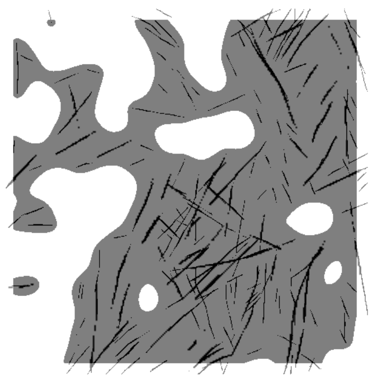

Fig. 9: Result from the contrail detection scheme.

- Ten or more pixel form the object
- the length has to be more then 16 pixel distances
- the correlation of the coordinates must be greater then 0.975

Using morphological functions we fill interrupted contrails. The results for each direction are added. The whole algorithm is then applied to the same dataset sampled every second element and line to detect wider contrails. Fig. 9 shows the result.

2.2. Verification: Comparison with visual classification

For the comparison we used AVHRR Data of the noon overpasses for the months of July and October 1990. The data covers Middle Europe. Due to the changeable satellite position the width of the dataset and the spatial resolution varies. The data has been classified by two observers using an interactive computer program, which allows to mark and store lines of variable width within an image. The result of these two classifications is given in Fig. 10. Fig. 11 shows the result of the automated classification in comparison to the mean value of the two human observers. The variability within the two datasets is comparable.

3. Regions of potential contrails

Over Middle Europe we detect contrails usually in clusters. The typical width of these clusters is in the order of 100 km, the shape is often elongated. We conclude, that these clusters mark regions where the state of the atmosphere within the cruising levels is suitable for the formation of persistent contrails. The atmospheric conditions for contrail formation are extensively described in [3]. For the persistence of contrails a steady lifting of the air parcel seems to be an additional requirement.

Under unchanged atmospheric conditions, the areal extent of these regions sets an upper limit to contrail coverage in case of increased air traffic. Due to the uncertainties in the humidity measurement of radiosondes in this altitudes, and the subsynoptic scale of this regions of potential contrails, a direct determination from standard observational data seems to be not feasible.

Due to the dense air traffic over Middle Europe, we can assume that most of the regions of potential contrails are also marked by them. The scheduled flights from May 4th 1995 from 1.5 h before the satellite overpass at 7:43 UT are schown in Fig. 12. The flightroutes

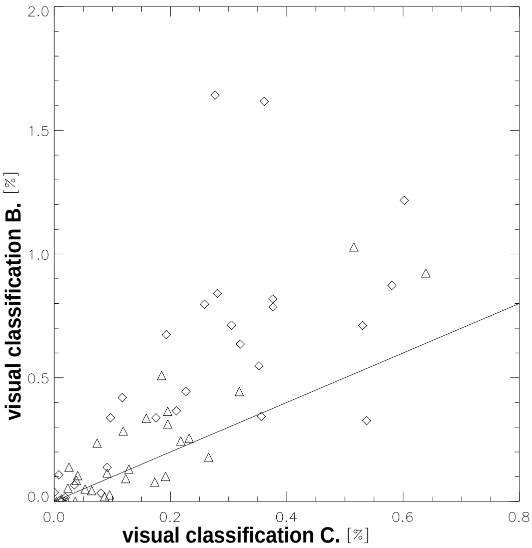

Fig. 10: Comparison of two independent visual classifications

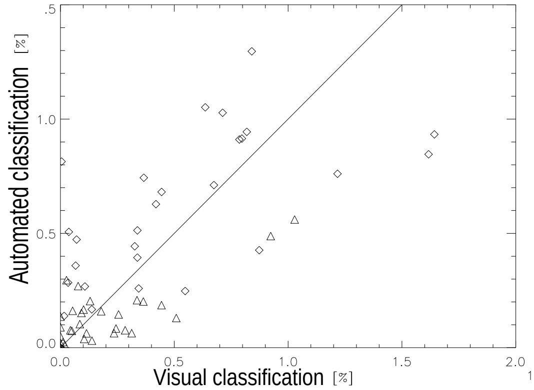

Fig. 11: Comparison of the automated contrail detection scheme to the mean value of the two visual classifications

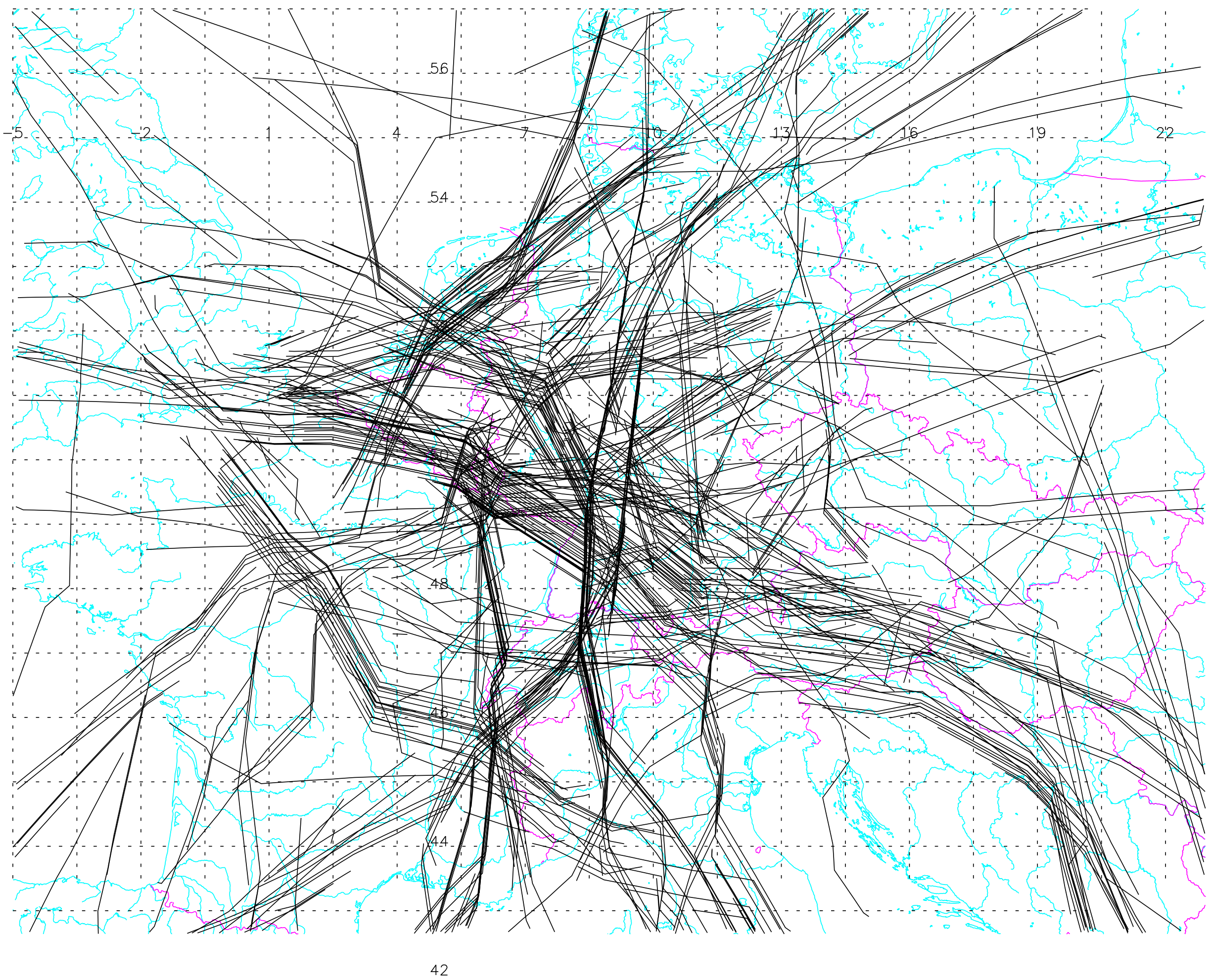

Fig. 12: Air traffic over Middle Europe May 4th 1995, 06:13 - 07:43 UTC, only flights above flight level 200 (20000 feet). A windspeed of 30 kn from NNE is assumed for the whole area.

are shifted to simulate a windspeed of 40 kn from NNE, which was measured on this day over northern Germany in the 300 hPa level To estimate the minimum extent of those regions we use the morphological image processing operators "erode" and "dilate" with a circular template of 25 pixels radius. The result is shown in grey in Fig 9: The regions where the algorithm found contrails are connected, while those regions without contrails within a distance of 25 pixels are left blank. The preliminary inspection of 60 AVHRR scenes from July and October 1990 over Central Europe showed that this regions cover about 10%, while the coverage with contrails is 0.9%. These numbers are preliminary, but longer time series are now being processed, which will lead to statistically significant data.

4. Conclusions

An algorithm was developed, which allows the automated detection of contrails from AVHRR LAC data. As the AVHRR is flown on the operational meteorological satellites of the NOAA series since 1979, and the LAC data are received and archived at numerous receiving stations around the world, this algorithm makes it possible to produce worldwide statistics on contrail coverage. In regions with dense air traffic it is also possible to estimate the regions of potential contrail.

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References

[1] S. Bakan, M. Betancor, V. Gayler, and H. Grassl. Contrail frequency over Europe from NOAA-satellite images. *Annales Geophysicae*, 12:962–968, 1994.

[2] Thomas F. Lee. Jet contrail identification using the AVHRR infrared split window. *Journal of Applied Meteorology*, 28:993–995, 1989.

[3] U. Schumann. On conditions for contrail formation from aircraft exhaust. *Meteorologische Zeitschrift, N.F.*, 5:4–23, 1996.