

# CONTRAIL AND CIRRUS OBSERVATIONS OVER EUROPE FROM 6 YEARS OF NOAA-AVHRR DATA

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## ABSTRACT

Thin ice clouds – cirrus and contrails – are analysed in a long-term 1 km data set from the Advanced Very High Resolution Radiometer (AVHRR). Here twice daily data received at DLR Oberpfaffenhofen covering most of Europe over the full lifetime of the NOAA-14 satellite from January 1995 until October 2001 is taken into account to derive high resolution contrail and cirrus cloud maps. The data presented here is part of the ongoing European Cloud Climatology (ECC). For the detection of thin cirrus the APOLLO (AVHRR processing scheme for the detection of clouds over land and ocean) scheme is applied and line-shaped contrails are recognised by a pattern recognition scheme.

Over the almost 7 year long data set we observe strong annual variations of cirrus and contrail cover. As the monthly averages of cirrus and contrail coverage are almost synchronous there is a slight correlation between the two. Within the annual cycle the distribution patterns of both contrails and cirrus change extensively. Contrail coverage on average is rather constant during the time-span analysed here, while we observe a decrease of thin cirrus coverage from 1995 to 2001. It is still an open question whether this is caused by severe observing effects due to changes of the sensor system or actually a natural effect.

## 1. INTRODUCTION

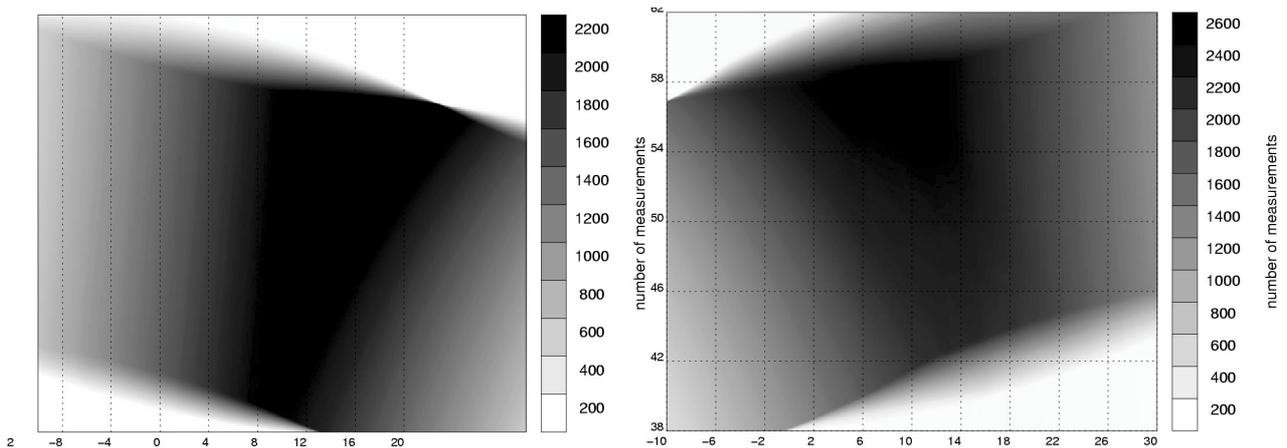
Poor knowledge on clouds is still one of the major reasons for the wide error estimates in climate change scenarios (IPCC, 2001). Contrary to water clouds thin ice clouds like contrails or thin cirrus in most situations cause a heating of the atmosphere (Meerkötter et al., 1999, Liou, 1986). Aircraft emissions may strongly trigger cirrus formation and influence its optical properties, its lifetime and thus cirrus coverage (Schumann, 2002, Boucher, 1999, IPCC, 1999). In many cases it was observed that wide cirrus shields evolve out of originally narrow contrails (Minnis, et al. 2002, Minnis, et al. 1998). On the long-term air-traffic will rise again faster than most other traffic. Through the expected increase of future air traffic and also to some extent through newer, more efficient engines the frequency of contrails is expected to rise. Thus, observation of contrails and thin cirrus clouds is needed to estimate the influence and trends of this anthropogenic effects.

To assess the global effects of air traffic (IPCC, 1999) contrail coverage is one important parameter to estimate the related radiative forcing. Such studies usually are executed globally by the use of models (Minnis et al. 1999, Ponater et al. 2002, Marquart and Mayer, 2002). These models need to be parameterised to observed contrail coverages. Mostly this 'calibration' was done by the values given by Bakan et al. (1994) from visual interpretations of AVHRR data in the Europe and North Atlantic region. Since Mannstein et al. (1999) developed a fully automatic pattern recognition scheme this can be done in a more objective and operational

manner. To report very reliable contrail coverage averages a long time-series is needed, that is able to recognise and average over inter-annual changes. So far only a maximum of two years of data was analysed with this automated technique (Meyer et al., 2002a). Here this data set is strongly extended by more than a factor of three. The parallel analysis of thin cirrus clouds by APOLLO for the first time gives us the chance to compare observed occurrences of both cloud types.

## 2. METHODOLOGY

For the data presented here usually the two highest overpasses of NOAA-14 during day and night over Oberpfaffenhofen in Southern Germany are taken. These data is operationally received in the high resolution picture transmission format (HRPT, approximately 1 km resolution in the nadir) and fully archived at the DFD (Deutsches Fernerkundungsdatenzentrum). There all data sets get manually navigated and are fed into a processing chain that includes the AVHRR processing scheme for the detection of clouds over land and ocean (APOLLO). Routinely the full overpass of approximately 6000 x 2048 pixels gets processed in full resolution. The APOLLO products of each processed overpass then undergo a visual quality check at Institut für Physik der Atmosphäre (IPA). There the automated contrail processing was executed for all 2592 available day and 2126 night overpasses. Due to limited processing power the contrail detection is done with a 2048 x 2048 pixel subset of the full overpass. The tailoring of the subset centres around the receiving station. Therefore, for the selected region (figure 1), most of the ascending daytime overpasses miss data in the Northwest and Southeast, and vice versa for the nighttime. Of course, best results can be expected for the areas with highest counts. Therefore, in the following we report only results for regions where the minimum number of measurements  $n_{min}$  is sufficient to give significant results, e.g.  $n_{min} = 64$  to report on the annual average. The results for the APOLLO based thin cirrus will not suffer so much from blanked corners but due to the daily variation of the satellite ground track data quality also thins out towards the ‘Far East’ and ‘Far West’ of the maps.



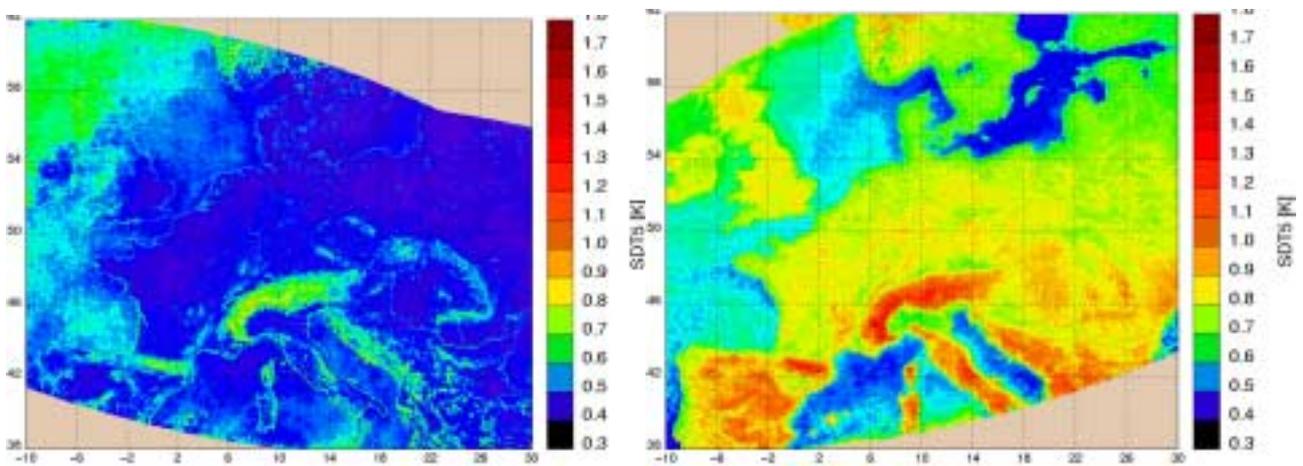
1. Fig.: Number of measurements, left nighttime overpasses, right daytime.

### Detecting Contrails and Derive their Average Coverage

In this study contrails get detected by the pattern recognition algorithm of Mannstein et al. (1999). This contrail detection scheme uses brightness temperature images of channel 4 ( $T_4$ : 10.2  $\mu\text{m}$  to 11.3  $\mu\text{m}$ ) and channel 5 ( $T_5$ : 11.5  $\mu\text{m}$  to 12.5  $\mu\text{m}$ ). Ice clouds can be well recognised in images that show the temperature difference  $TD$  of the two channels ( $T_4 - T_5$ ). This effect is strongest for non-opaque ice clouds with small ice particles which are typical for young contrails. To enable a similar detection efficiency under various conditions and to avoid misdetections at coastlines or other linear structures as mountain ridges both images  $T_5$  and  $TD$  are normalised by their local standard deviation. For this normalisation we use the standard deviation in the 5 x 5 pixel surrounding,  $SDT_5$  for  $T_5$  and  $SDTD$  for  $TD$ . Both normalised images  $N_5$  and  $ND$  are then combined to the image  $N$ . This normalised image  $N$  shows contrails as bright lines. This ‘ridges’ in the image now are selected by convolution with a line detection kernel of 19 x 19 pixel size applied in 16 different directions. From these intermediate results candidates for contrail pixels are selected by parameters that check radiometric and geometric features typical for contrails. These are  $TD > 0.2$  K,  $N > 1.5$  and a gradient condition that further avoids misdetection of coastlines. Geometric checks are a minimum length of the contrail segments, which is set to 15 pixels, the requirement, that the correlation of all contrail pixels of a segment must be better than 0.975 to a straight line and the minimum number of pixels, which is fixed to a number of 10 per contrail segment. These parameters were empirically set. The characteristics of the contrail detection

algorithm strongly depend on them. Thus, to achieve a comparable detection efficiency we fixed all parameters exactly to the values mentioned in Mannstein et al. (1999). The chosen parameter setting is adapted to a rather low false alarm rate when applied to NOAA-14/AVHRR data, which are used in this paper. As it turned out that the detection characteristics of the algorithm is rather sensitive to small differences between sensors of identical construction, here we only make use of NOAA-14.

The contrail algorithm results in binary decisions on contrail or no contrail occurrence for each pixel. Partly contrail filled pixels either get classified as 'fully contrail covered' or 'not contrail covered'. Thus, actual contrail coverage may only be given as a box average or by temporal averaging. This temporal averaging is always applied for certain times of the day to enable analysis of daily cycles of contrail coverage. For this the 'local contrail frequency' is calculated from the total number of contrails detected at a certain geographical location divided by the total number of satellite observations at this location. All contrail masks were stacked separately for night and day slots for each month and further to full years. From these stacked data we derive the average contrail coverage according to the post-processing scheme for contrails described in Meyer et al. (2002a). For this procedure the average  $SDT5$  masks (see fig. 2) separately for night and day are essential. The contrail detection is influenced by the heterogeneity of the background. The detection efficiency of the applied algorithm is higher in homogeneous parts of the image than in parts where great variations occur. In cloudfree situations homogeneous areas are found over the sea or over flat land. Examples for heterogeneous situations are mountain or coast regions. In cloudy situations contrails are easier to detect above stratus cloud layers than above broken cumulus cloud fields.



**2. Fig.:** Longterm (1995-2000 ) 5 x 5 pixel standard deviation  $SDT5$  of AVHRR channel 5 (left nighttime, right daytime,  $n_{min} = 64$ ).

Additionally to the heterogeneity and false alarm correction spatial averaging according to Meyer et al. (2002a) is applied to reach statistically more relevant results. To give this averaging more meaning it is either related to the viewing geometry of a ground-based observer assuming a cloud height of 10 km above ground (GND) or alternatively averaging over a much bigger area for the view from 'top of atmosphere' in a height of 50 km above ground (TOA).

### Thin Cirrus derived by APOLLO

The APOLLO (AVHRR processing scheme for the detection of clouds over land and ocean, Saunders and Kriebel, 1988) distinguishes between several different cloud types. For the comparison with contrails thin cirrus clouds are most interesting. Only these get investigated here. The thin cirrus clouds presented here are defined by the cloud product type 'ice cloud' derived from the improved APOLLO version according to Kriebel et al. (2002). Thick high level clouds are a separate cloud type which is not analysed in this paper .

To be classified as 'thin cirrus' AVHRR pixels first must pass the Infrared Gross Temperature Test (IGT). IGT requires that the equivalent blackbody temperature  $T5$  is below a dynamically set threshold. Then the main criteria for the detection of thin cirrus by APOLLO is the T45-test which is positive, if the temperature difference  $TD$  of channel 4 minus channel 5 is above a certain threshold, which depends on the satellite viewing angle.

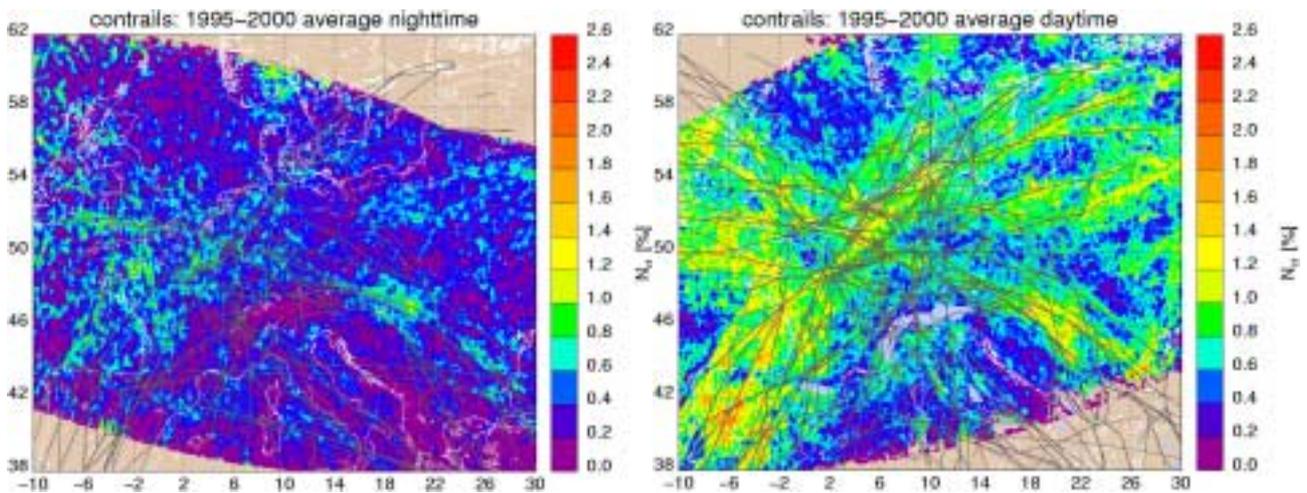
The average cloud coverage for the thin cirrus then is computed by averaging the remapped thin cirrus coverage data of each day to monthly percental averages. In this case no further spatial averaging as with the more sparse contrails was applied.

### 3. RESULTS

Processing of cirrus and contrail data sets is applied in satellite projection. Thereafter, both data sets get remapped to a 1 km grid covering the region from 34N to 72N and 11W to 32E. Due to the limited contrail processing region, we reduce the displayed data to the region from 38N to 62N and 10W to 30E. This area of almost 8 Million km<sup>2</sup> covers most parts of Europe.

#### Contrail Coverage

The long-term average coverage of line-shaped contrails is derived from the 6 complete years of NOAA-14 data 1995 to 2000. The high amount of overpasses during the full time allows to display the results (fig 4.) in the high resolution (GND). The overlaying flight data in Fig. 4 is based on actual flights during 2 days in 1995 reported from EUROCONTROL. To select flights relevant for contrails the data set was filtered for flights in the flight level interval 260 to 440 (approximately height: 8 to 14 km). To show the flights that are typical for the times of the satellite overpass the time range between 23 and 04 UT was selected for the comparison to the nighttime data and 10 to 15 UT for daytime. The pattern fits surprisingly good. Obviously, contrails mostly get detected very close to the major air routes. This is a hint that most of the contrails detected by the pattern recognition scheme are relatively young contrails that did not drift far away from the region where they were originally produced. Thus, we assume that many contrails detected by the scheme are only few minutes old. Only few contrails older than about half an hour are recognised. After 30 min a contrail produced in an air mass with a wind speed of 50 m/s will drift almost 100 km away. Usually then it will be too fuzzy and often bend to get detected by the line-filters applied in the algorithm. Thus, it must be concluded that only a part of the actual contrail cover is given here. The values refer only to the better detectable line-shaped contrails.

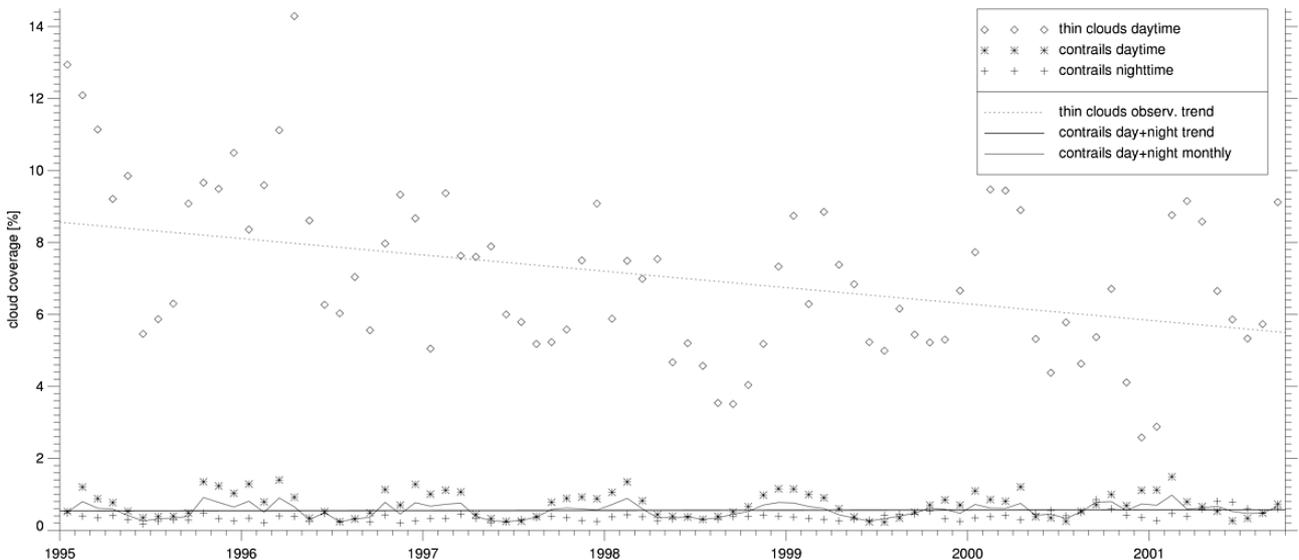


3. Fig.: Longterm average of the coverage by line-shaped contrails with an overlay of flights from EUROCONTROL data of April 23 and May 5 1995 (left: nighttime, right: daytime)

#### Long-term Variations of Contrail and Thin Cirrus Cover

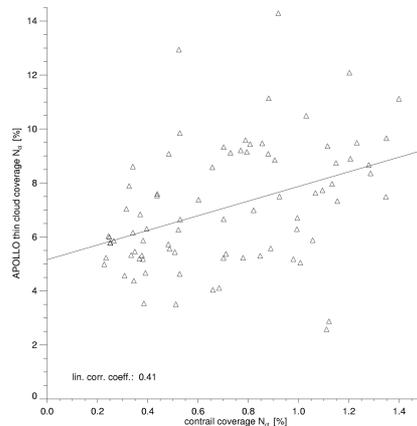
In fig. 4 a 81 month containing time-series of monthly means for day- and nighttime contrail coverages and thin cirrus coverage is shown. The timeseries refers to the central part (6W to 26 E and 42N to 54N) of the maps displayed in figs. 6 and 7. Especially the daytime contrail coverage shows a strong annual cycle with an amplitude of close to 2. Daytime thin cirrus has a similar annual cycle with an amplitude greater absolutely, but less in relative measures. Nighttime contrail cover is relatively constant throughout the year. In the past 6 years it is slightly rising by 0.042% per year and reaches 0.51% at the end of the timeseries, which is more than a doubling from the beginning of 1995. Contrary daytime contrail coverage seems to decrease by about the same amount (-0.034%/a). The combination of night and day contrail coverage leads only to a very small increase of 0.0043%/a. That means the average contrail coverage in this region starts with 0.54% in January 1995 and ends with 0.57% in September 2001 which is less than 1% total increase of contrail cloudiness during the observing period.

Most conspicuous is the strong decrease trend of  $-0.45\%/a$  for thin cirrus. The longterm average of approximately 8% total cloud cover is rather low for cirrus clouds over Europe. This is mostly because this cloud type often occurs when other are also present so that these more dominating cloud types block out thin cirrus. The strong decrease during the lifetime of NOAA-14 could also have technical reasons rather than a true decrease of cirrus clouds.



4. Fig.: Timeseries of contrail and cirrus cloudiness for the full NOAA-14 lifetime. Data refers to the region 6W to 26 E and 42N to 54N.

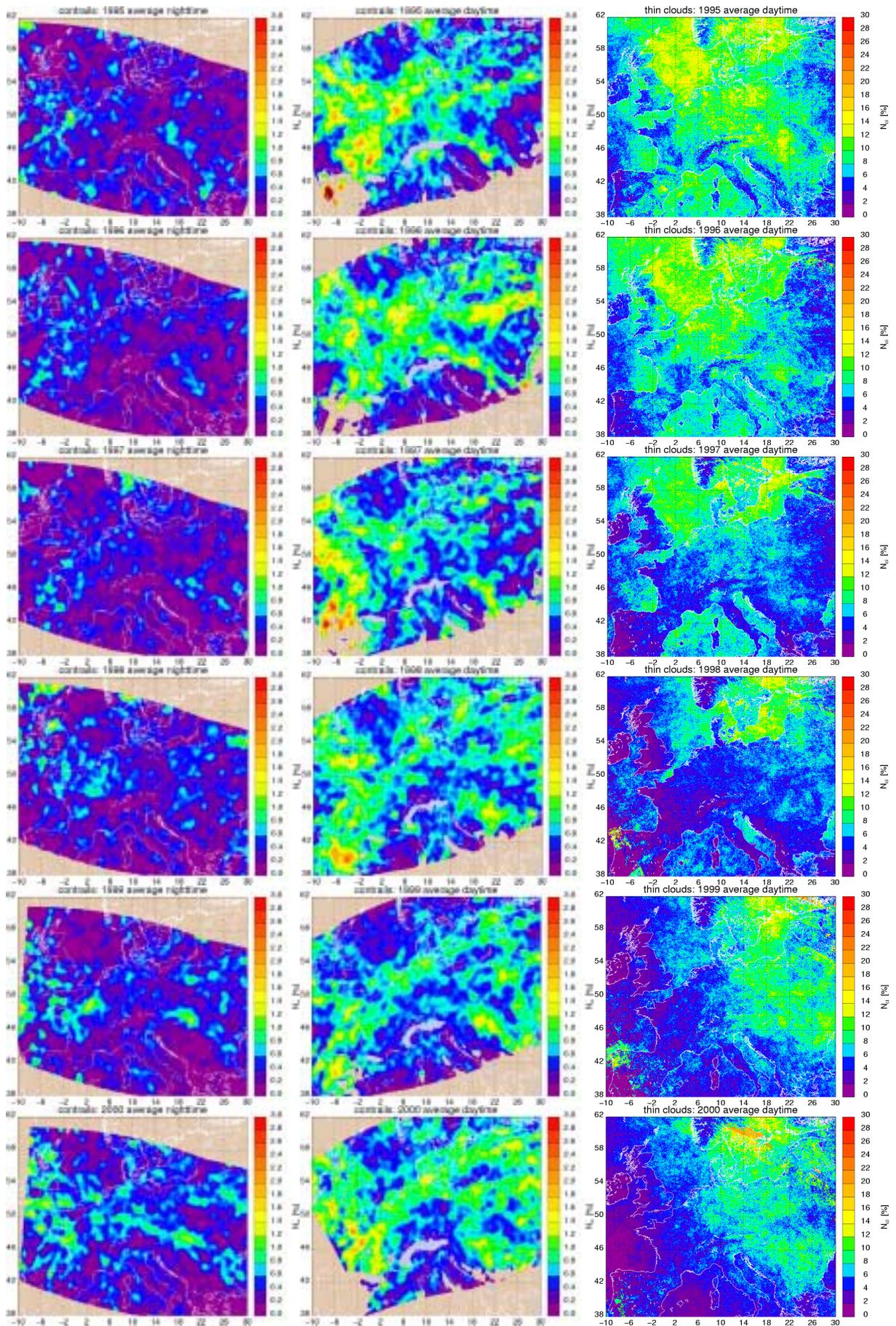
Fig 5. Shows a scatter-plot of the monthly averages of daytime contrails against daytime thin cirrus. A poor correlation of 0.41 can be recognised between the two data sets. This probably has its main reason in a similar annual cycle.



5. Fig.: Correlation of monthly averages of contrail cover with thin cirrus cloud cover. Data refers to the region 6W to 26 E and 42N to 54N and all 81 months of NOAA-14 data.

### Inter-annual Variations: Are ice cloud patterns changing?

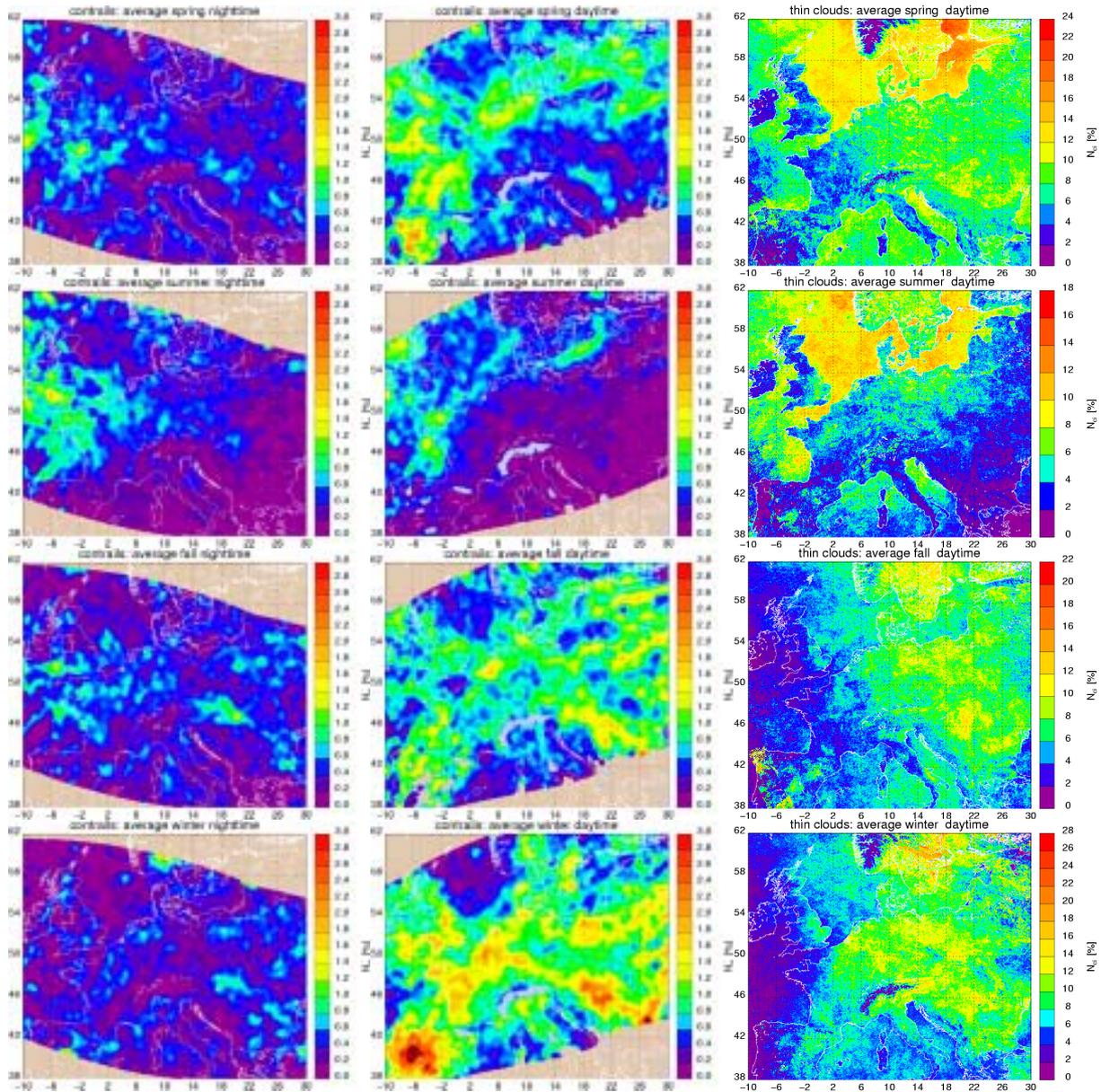
In fig. 6 maps of the annual averages of contrail coverage and thin cirrus cover for the years 1995 to 2000 are shown. There are strong variations in the occurrence of thin cirrus, while contrail patterns seem to stay more stable. Conspicuous is that air-traffic during the nighttime seems to increase mainly towards the Atla-



6. Fig.: Inter-annual variations of contrail (left and middle column) and thin cirrus cover (right).

antic flight corridor. The reason for this might be that the overpass times of NOAA-14 get very late (around 5 UT). This means that it is likely that we now see already some incoming traffic from North America in the nighttime data. This could explain the relative strong increase of nighttime contrails mentioned above.

### Annual Cycle



7. Fig.: Annual variations of contrail (left and middle column) and thin cirrus cover (right).

## 4. DISCUSSION & CONCLUSIONS

The larger data set presented here confirms results of Meyer et al. (2002a) which are based on only 2 years of AVHRR data. Therefore the analysed region could be slightly enhanced and it provides better opportunities for comparison to contrail coverage simulated by global models.

During night in summer we observe a relatively high contrail coverage, this is extremely sensitive for contrail radiative forcing. During daytime the contrail coverage over land is rather low. This may be explained by stronger convection during this season. Similar to our contrail observations over Southeast Asia. (Meyer et al., 2002b).

Nighttime contrail coverage shows slight increase, while daytime contrail coverage decreases approximately by same amount. Main reason seems to be NOAA-14 drift towards later overpass times mainly in the years 2000 and 2001. No real trend in contrail cloudiness noticeable in the analysed 6 years of data. Obviously significantly less thin cirrus clouds get detected by APOLLO in the later years of NOAA-14. Also much more thin

cirrus is recognised over sea than land. This at least partly seems to be an observational error that might be handled by a post-processing-scheme similar to Meyer et al. (2002a).

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