DETERMINATION OF THE MASS FLUX IN CONVECTIVE CELLS OVER EUROPE

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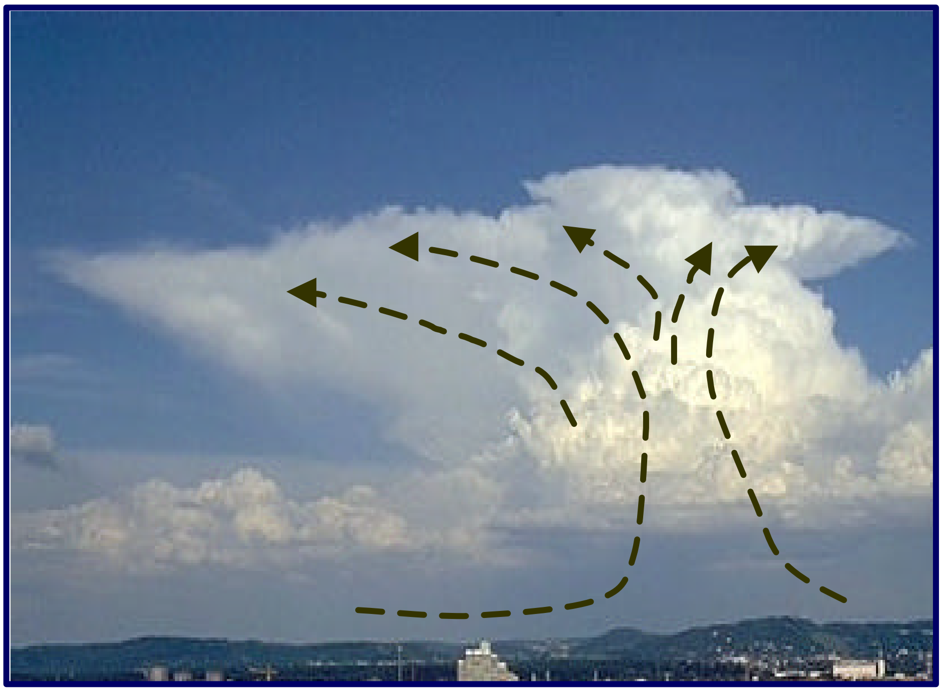
ABSTRACT

To infer the impact of airtraffic onto the upper tropospheric atmospheric trace gas composition it is necessary to quantify not only the sources and sinks but also the main transport mechanisms for the relevant pollutants. While the transport due to synoptic scale motion patterns can be effectively modelled, the deep convection in thunderstorms, which plays a prominent role in the vertical distribution of atmospheric pollutants during summertime has to be estimated by other methods. A 2 months time series of ½ hourly METEOSAT7 IR and WV data is used to identify and track the cirrus tops of convective cells. The divergence of these cloud tops can be derived from the atmospheric motion field, which we derive from the WV images using an area matching technique. This quantity is nearly not affected by the choice of the cirrus boundary and gives therefore a reasonable estimate for the vertical transport.

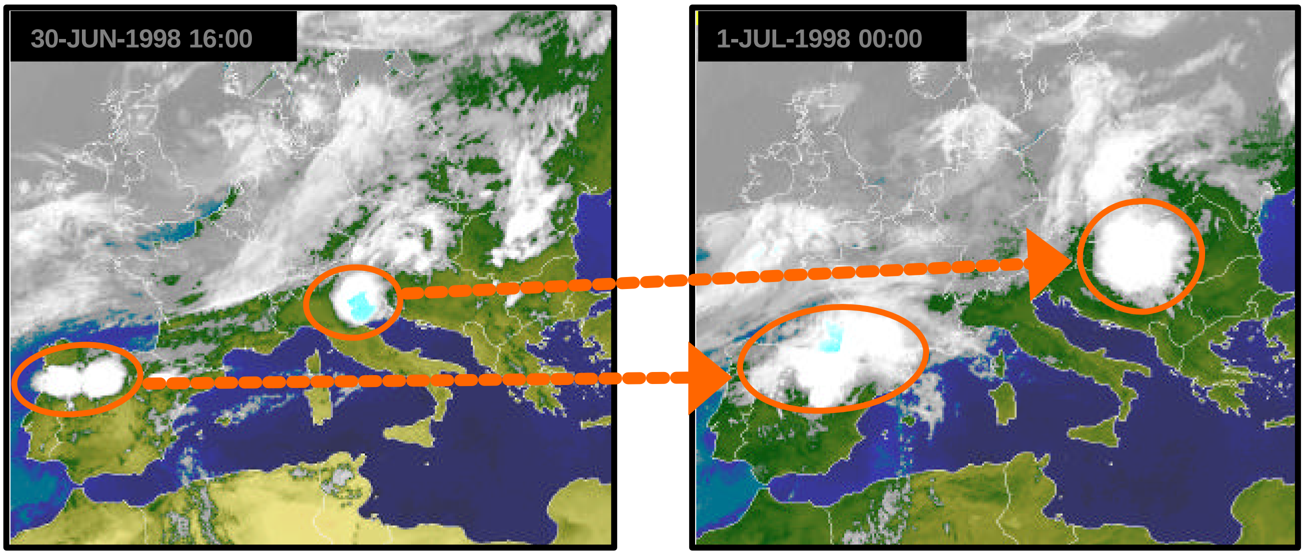


1. **Figure: A typical convective cell. Indicated is the dominant mass flux**

1. OVERVIEW

The vertical air-mass exchange and therefore also the vertical transport of constituents with sources close to the surface, like aerosol, nitrous oxides and others into the upper troposphere is often dominated by convective cells. These cells are usually found in a spatial and temporal scale which is not resolved by atmospheric standard observations and models. Therefore in transport models the effect of convection is usually parameterised. In this work we use METEOSAT data to locate strong convective events in position and time in order to support a regional transport model and interpret airborne measurements in the upper troposphere to discriminate between NOx advected from the surface, produced by lightning and emitted by air traffic.

The basic assumption is, that the vertical air-mass flux leads to an horizontal spreading of the cirrus cloud on top of the convective cell (Ebert and Holland, 1992), which can be determined in successive METEOSAT images. Figure 2 shows the displacement and the spreading of the cirrus tops of several convective cells within 8 hours.



2. **Figure: Horizontal spreading of cirrus tops**

The vertical mass flux is then proportional to the growth rate of the cloud area dA/dt and can be estimated by

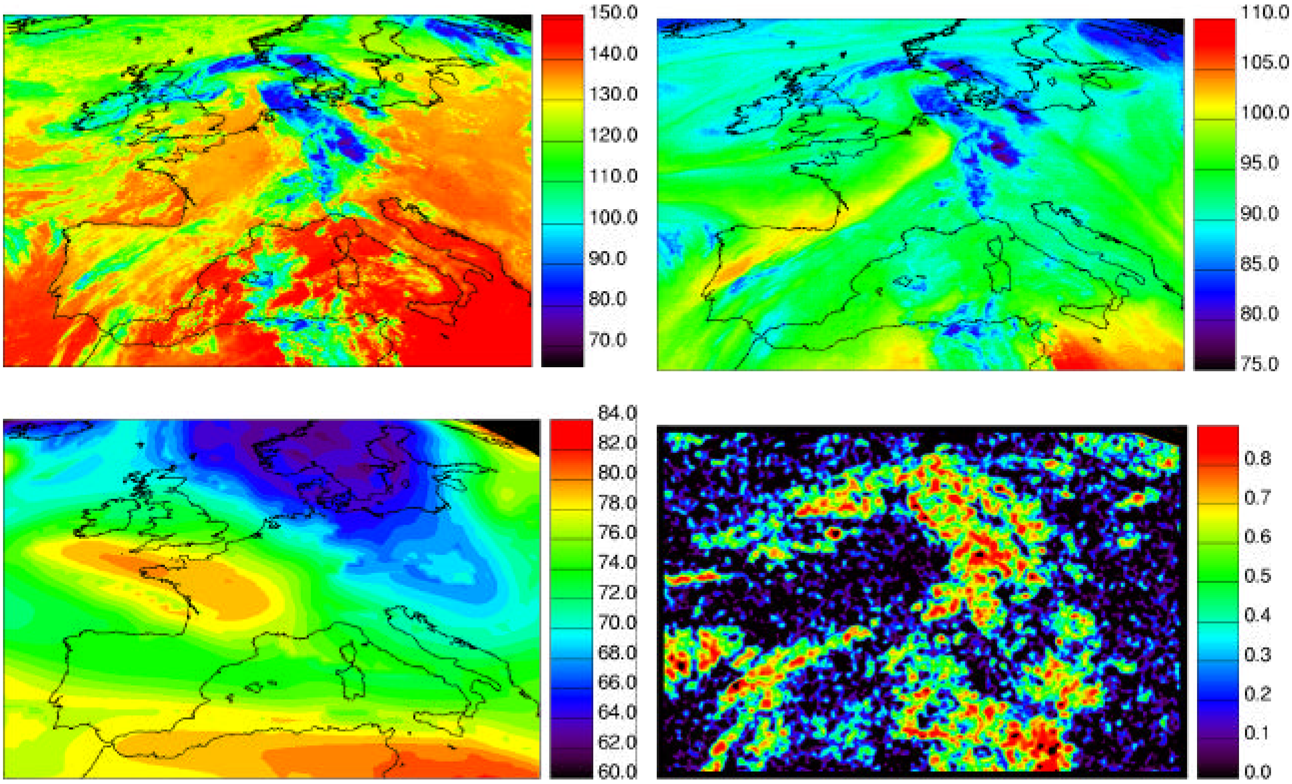
$$dM/dt = \rho \, \Delta z \, dA/dt$$

With the air density ρ, the estimated thickness of the cloud layer Δz. Necessary to perform such an analysis for a series of METEOSAT images is the identification of cirrus clouds and strong convective cells and a method to track these cells. As a preparation for future measurement campaigns within the framework of the German Contrace project (Convective Transport of Trace Gases into the Upper Troposphere over Europe) we analysed the two summer months June and July 1998, where many of the necessary data was available from a measurement campaign within the EU funded EULINOX (European Lightning Nitrogen Oxides) Project.

2. DATA PROCESSING

a) Cirrus and high cloud detection

To be independent from daylight conditions we decided to use only the IR and WV channel of METEOSAT (Fig 3, upper left and right) and neglect the information given by the VIS channel. In addition to the satellite images a data set of static tropopause temperatures extracted from ECMWF data by P. van Velthoven (KNMI) was available 3 hourly and interpolated to the 1/2 hourly satellite images in their projection and scaling (Fig.3, lower left)

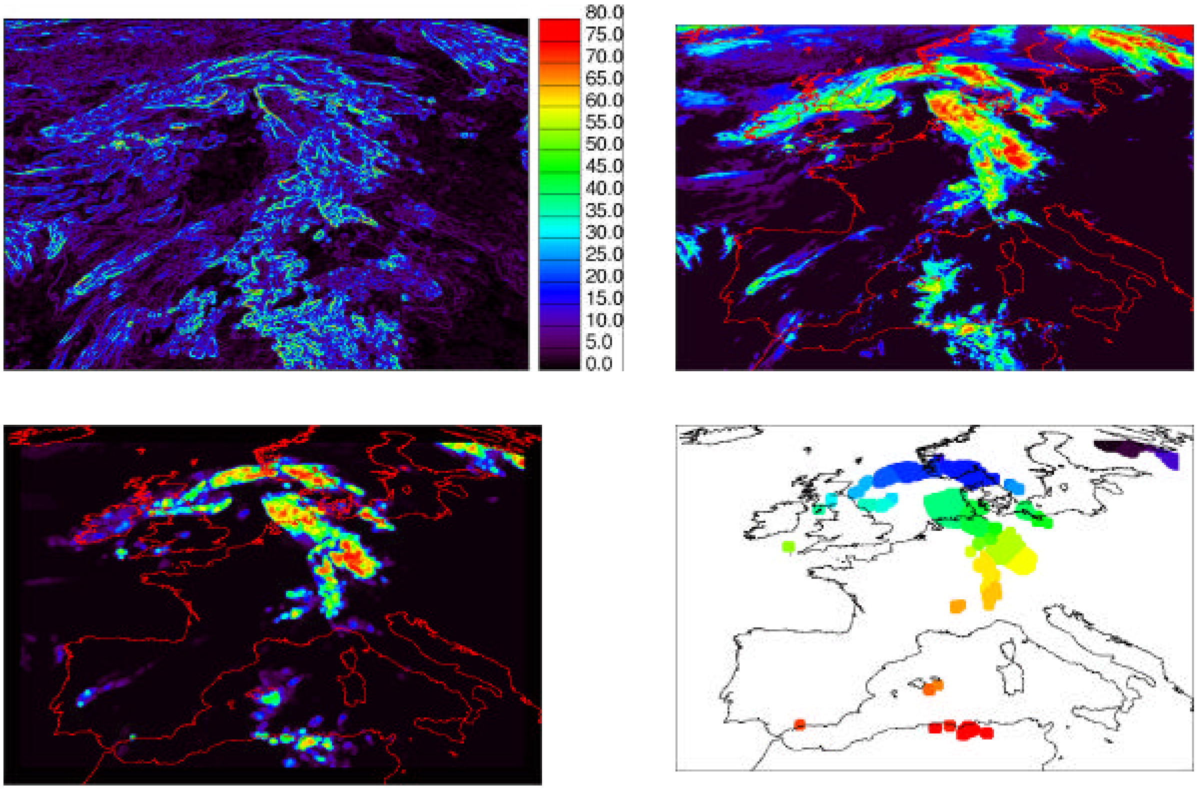


3. Figure: METEOSAT IR and WV temperatures (upper left and right), static tropopause temperature interpolated from ECMWF data (lower left, all temperatures in K-146) and regional correlation coefficient (lower right).

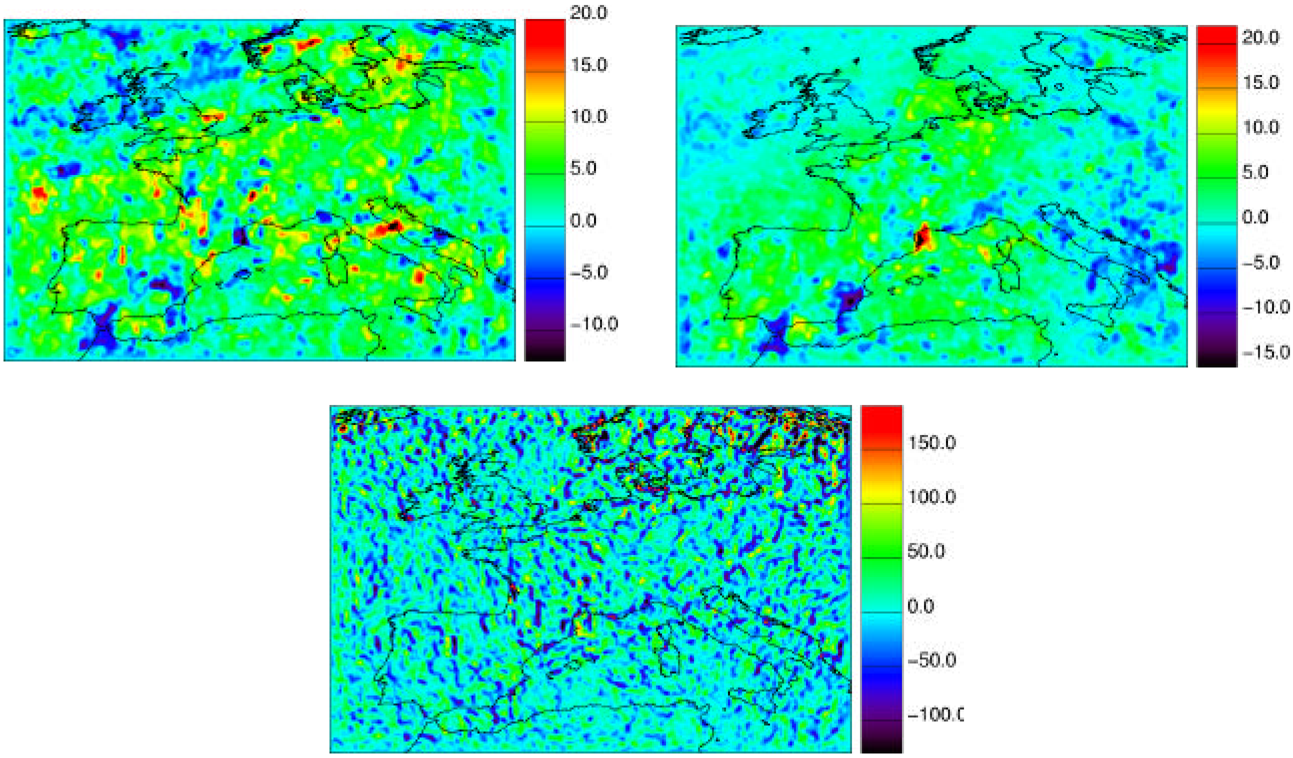
The main high cloud detection criterion is the regional spatial correlation coefficient between the IR and WV channels. A positive correlation coefficient greater then 0.2 indicates that the WV channel shows the same small scale spatial structure as the IR channel, which is usually a cloud in the upper part of the troposphere. Of course the exact cut-off altitude is determined by the local temperature and water vapour profile. We use a rotational symmetric gaussian weighted version of the correlation coefficient to avoid rectangular artefacts at small scale disturbances (Fig. 3, lower right). The effective size of the area under consideration has a diameter of 5-10 pixels. As we were not interested in very thin cirrus clouds in addition the IR temperature has to be lower than the WV temperature plus 18 K and lower than the tropopause temperature plus 16 K. As we need a later stage the IR temperature gradient at the cloud edge for the discrimination of strong convective events, we also included also the pixels with a strong horizontal gradient(Fig. 4, upper left). These criteria are combined into a cirrus mask(Fig. 4 upper right, which is smoothed and then used to identify single cloud objects – i.e. contiguous areas that are filled with cirrus. To allow for the detection of convective cells within frontal zones, we split large cloud objects if there are several local temperature minima within (Fig.4, lower right).

b) CLOUD tracking

In order to be able to track the upper level clouds we first derive from consecutive WV images fields of displacement vectors using an area based, pyramidal image matcher. In contrast to the usual method, where useful targets are selected before their positions are matched, we first match the large scale structures and refine the matching in later steps in order to get a displacement vector for every pixel (see Fig. 5, upper images). This enables us also to calculate the divergence of the aparent motion field(Figure 5, lower image). The displacement field is then used to map the cloud objects onto the next image and determine the overlap



4. Figure: IR temperature gradient (upper left), combined cirrus criteria (upper right), cirrus criteria smoothed and truncated (lower left) and selected cirrus objects (lower right)

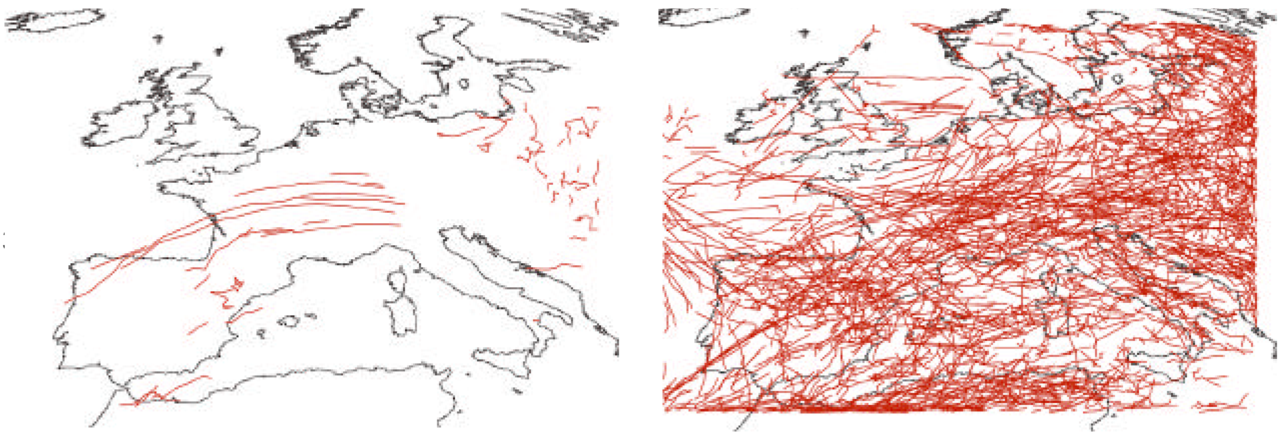


5. Figure: Horizontal and vertical displacement (upper left and right) and aparent divergence field (lower)

between old and new cloud. By this we can track clouds, detect new clouds and finish clouds that do not appear within the new image.

c) Detection of strong convective cells

According to Morel et al. (1997) a good indicator for strong convective systems is a high horizontal temperature gradient at the beginning of the lifetime of a convective system. We have chosen the lifetime maximum of the mean peripheral gradient of the clouds as criterion to select the strong convective cells. As we where not able to transfer the threshold given by Morel et al (1997) to our gradient values, we have chosen the threshold in a way that most of the remaining cloud systems have their starting point over land. In Fig. 6 the centres of gravity for all selected clouds are connected for one day (Junes 1st 1998, left) and for the whole period (June and July 1998, right).



6. Figure: Cloud tracks (centre of gravity) for June 1st 1998 (left) and June and July 1998 (right)

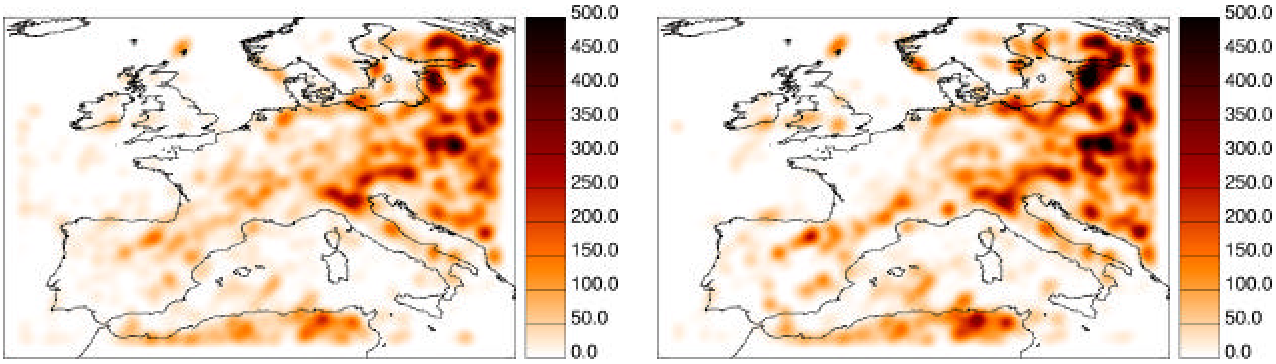
4. RESULTS

For the strong convective cells we determined the rate of area change between the consecutive time steps and integrated the positive values at the pixel position of the centre of gravity of the cloud at the later time step. As we had no convincing argument for the selection of a certain temperature difference to the tropopause temperature to determine the cirrus area, we used several threshold values with the result that the resulting rate of area change did strongly depend on the chosen threshold. A different way to access the spreading rate was offered by the divergence field resulting from the WV image matching. Giving similar results (Fig 7, right), the integration of the divergence over the cloud area was not very sensitive to the chosen temperature threshold. The strong peak in divergence in the first hour of the day is obviously caused by the WV channel stray light problem described by Köpken (2001). The stray light patch in the WV images is interpreted by the image matcher as motion with a strong divergence.

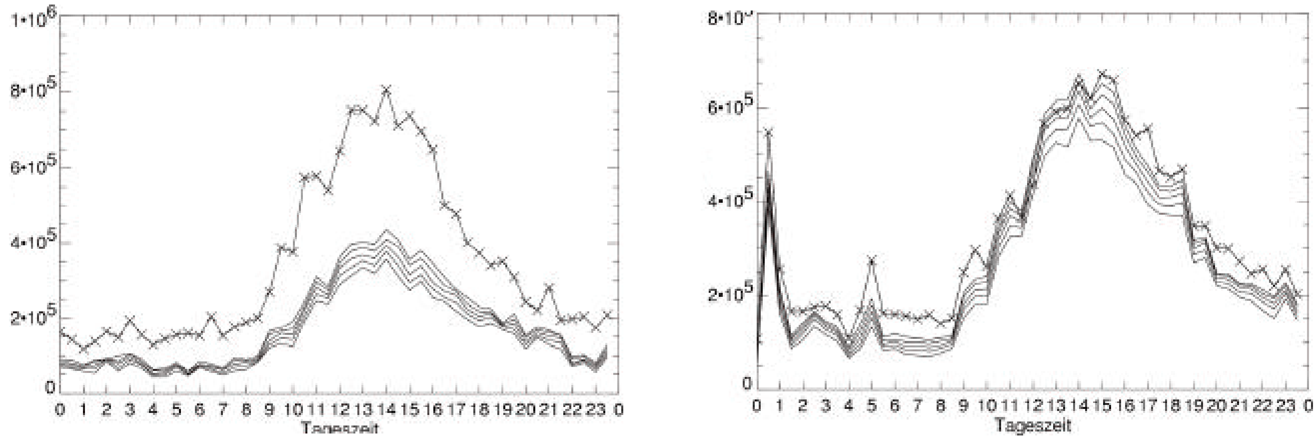
To account for the unknown inflow area (and to create better images) we distributed the values using a gaussian function with a half width of apr. 6 pixel (Fig 7, both).

5. OUTLOOK

The proposed method allows to detect strong convective events with a high temporal (1/2 hour) and spatial resolution (~ 50 km). Therefore it is suited to support regional transport models of atmospheric tracers, which cannot resolve these scales. In combination with a detailed inventory of surface pollutants it will enable us to interpret airbourne measurements within the CONTRACE summer campaign, which is planned for 2003. Perhaps it will be possible to use already MSG data to determine the mass flux in convective cells over Europe.



7. Figure: Integrated area growth (left) and integrated divergence (right) of convective clouds in km^2/pixel for June and July 1998



8. Figure: ½ hourly values for area growth (left) and integrated divergence (right) of convective clouds for the whole cirrus clouds (x) and different thresholds.

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6. BIBLIOGRAPHY

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