CONSTRUCTION OF CLOUD TRAJECTORIES AND MOTION OF CIRRUS CLOUDS AND WATER VAPOUR STRUCTURES

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ABSTRACT

The motion of cirrus clouds connected to an anticyclonic system has been studied in detail and compared with radiosonde winds during one day of the ICE campaign (Oct. 18th 1989). The velocity of these cirrus clouds measured in the water vapour channel of Meteosat appears to be in good agreement with the radiosonde measurements, while the velocity deduced from the infrared images is different, often weaker. The determination of trajectories is a complementary approach for the study of the motion of clouds and of their evolution. The trajectories of the cirrus clouds observed from the ground have been constructed from a series of half-hourly Meteosat images. They show that some of the cirrus observed from the ground have a lifetime of more than 24 h. In this study, the tracking lasts longer with images from the infrared channel. Trajectories also helped to visualize the divergent motion of high level clouds in an extratropical cyclonic system observed on the same day.

Trajectories have been used to track pure water vapour structures on Meteosat images for another case (February 18th 1996). The height of several structures could be estimated with the help of analysed data. For these cases, the persistence of a trajectory and the presence of other trajectories in the vicinity could be used as a quality indicator.

1. INTRODUCTION

Cloud motions observed and measured on successive geostationary satellite images have intensively been used for deriving winds at different levels of the troposphere. These cloud motion winds are still one of the most useful satellite product assimilated in forecast models. However, these winds only show some motions in the atmosphere at a particular instant, and do not give any indications about the evolution of the tracked clouds. With the lagrangian approach, based on the computation of trajectories, a more precise image of the "life" of a cloud element or ensemble, especially its persistence, can be acquired. This approach is already used in other fields of meteorology (for example with hurricane trajectories). This method was initially developed to track clouds, but can also be applied on pure water vapour structures in cloudless regions on images in the water vapour channel.

2. COMPUTATION OF TRAJECTORIES

Basic method

The calculation of trajectories is an extension of the computation of cloud motion vectors (CMV hereafter) to a series of images. The principle of the method has been presented during the previous Winds Workshop (Szantai and Desbois, 1993). The Euclidean distance (or sum of squared differences) method is used to calculate CMV. For each position, the CMV is obtained for the minimal value of the sum of squared differences computed between a correlation window (or template, of 32 x 32 pixels) taken on the first image and a portion of a larger window (search window, of 80 x 80 pixels) taken on the second image. The position pointed by the end of each vector defines the starting position for the computation of the next vector of the trajectory, obtained from the 2nd and 3rd images of the series. This process is iterated up to the end of the series of images. On the example (fig. 2), 54 trajectories start on a regular grid in longitude and latitude. They were computed from a series of half-hourly Meteosat infrared images during 23 hours. Most trajectories show a regular motion and follow the general circulation of the cloud masses. But several trajectories (for example nr. 23, 31, 43 and 47) include inconsistent vectors, i.e. vectors with a large variation of velocity and / or direction, probably not associated to a physical motion of the tracked cloud elements.

Improved method

For the computation of each CMV, the Euclidean distances corresponding to all the possible displacements can be stored in a matrix and be represented as a surface (Euclidean distance surface). Very few authors used other information than the position of the minimal value (Anandan, 1989).

To correct inconsistent CMV, we extract all the local minima of the Euclidean distance matrix and use the vector determined during the previous step (fig. 1). The corrected CMV is given by the position of the local minimum which is closest to the end of the vector obtained during the previous iteration. If this corrected vector is of better quality (i.e. it matches quality tests on velocity and direction), the computation of the trajectory can be continued, otherwise it is stopped. A complementary test consists in interrupting the computation of the trajectory if 3 consecutive vectors were corrected.

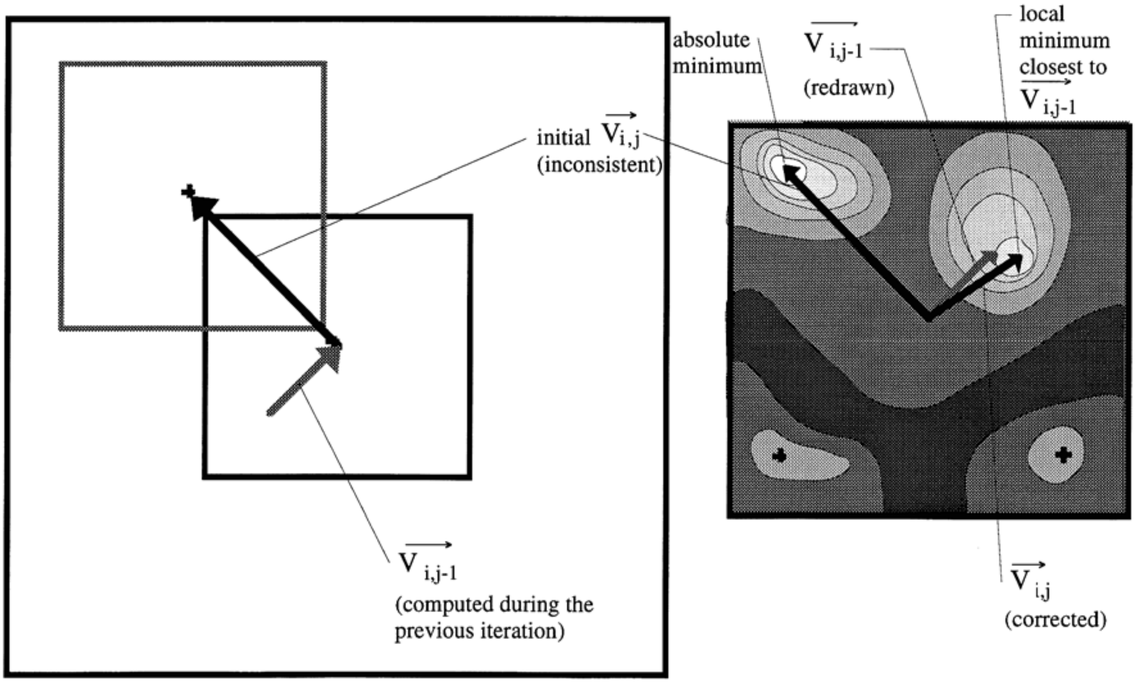


Figure 1: correction of an inconsistent cloud motion vector (jth vector) on trajectory i. The corresponding correlation and search windows (right) and the Euclidean distance surface (left) are represented with the original and corrected vectors.

On figure 3, less trajectories remain after the correction and most of them have fewer vectors. But these trajectories are more regular, without any inconsistent vector.

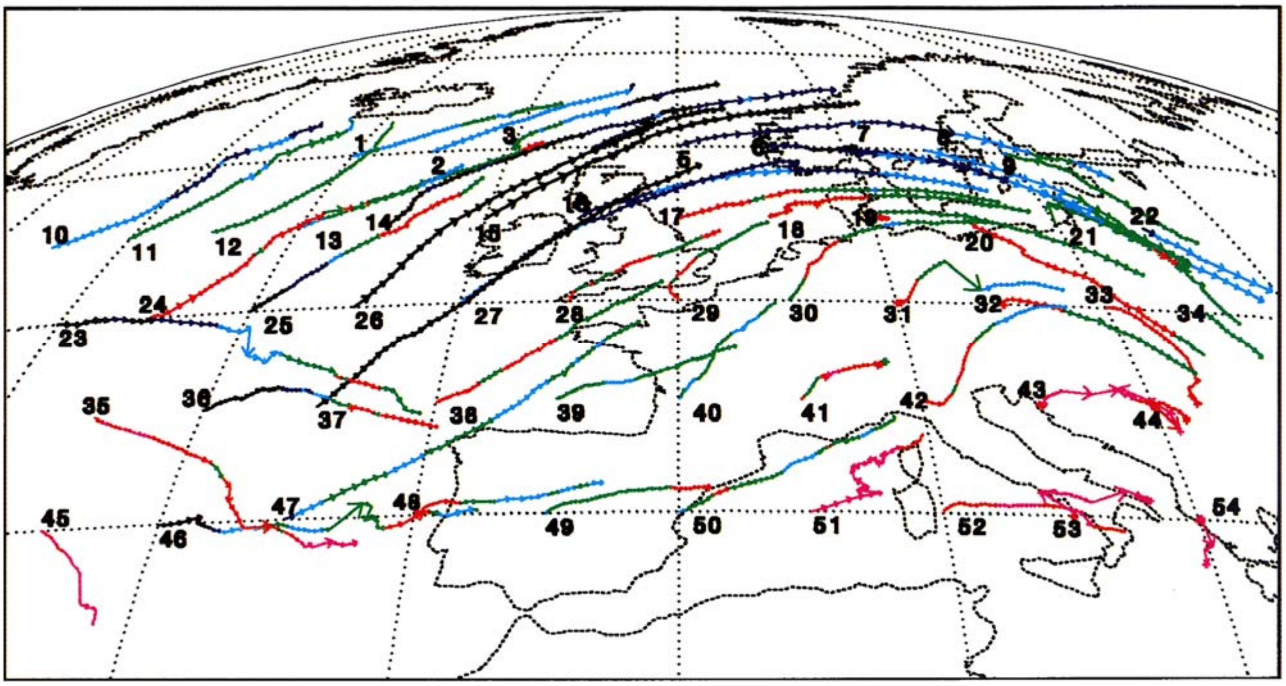


Figure 2: initial trajectories in the infrared channel of Meteosat (Oct. 18th 1989, between 0 and 23 h). Colours correspond to the brightness temperature of the cold elements inside the correlation window:
black (very cold) —> blue —> green —> red —> pink (warm, above 0°C)

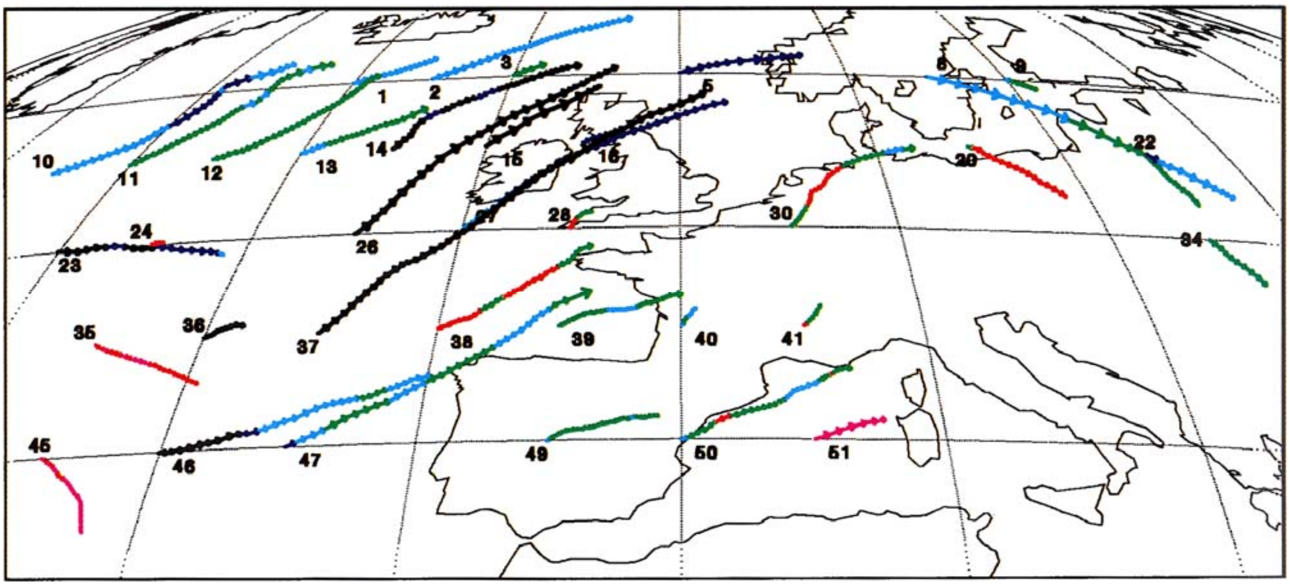


Figure 3: corrected trajectories for the same situation.

3. CLOUD TRAJECTORIES

Evolution of an extratropical cyclonic system

Trajectories starting on a regular grid in lines and columns covering an extratropical cyclonic system were computed over a period of 10 hours (Oct. 18th 1989, 13 - 23 h). A previous study (Szantai and

Desbois, 1993) has shown the divergent motion of high level clouds and their dissipation in regions ahead of this system.

Cloud elements have been tracked during 3 to 10 hours. Trajectories starting in the southern part of the depression close to its centre have the longest lifetime. Performing a selection of the cold pixels (with a brightness temperature below a chosen threshold) generally reduces the number of vector per trajectory, but enables a tracking of cloud elements more closely associated to a definite (low) pressure level.

Trajectories computed in the water vapour (WV) channel after a selection of cold pixels (of brightness temperature < 40°C) were compared with isobaric trajectories interpolated from ECMWF analysed winds at different pressure levels between 850 and 200 hPa (Szantai, 1996). A great similarity was noticed between a group of WV trajectories and their analysed counterparts at the 300 hPa pressure level. According to synoptic charts, these trajectories are located in a jet stream region.

Cirrus trajectories in an anticyclonic region

An important number of measurements on cirrus clouds were made during the ICE (International Cirrus Experiment) field campaign. On Oct. 18th 1989, radiosoundings and lidar measurements, made from several stations on the German coast of the North sea enabled a precise determination of the apparition and disappearance times of these cirrus and the altitude of their base (between 7.5 and 10 km, depending on the station and the instant of the measurement) and their top (around 11.5 km) (Ansmann et al., 1993).

a) comparison with radio soundings

The wind velocity measured by radiosondes at different levels is compared with the velocity of the cirrus clouds measured on IR and WV images at the same time. The polar diagrams of fig. 4 represent the velocity and the direction for the wind measured by 2 radiosondes and for the corresponding cloud motion vectors (with their error zone) in both channels. In this meteorological situation (with an anticyclone over central Europe), the velocity measured in the WV channel is close to the wind measured by the radiosondes at the altitude of the cirrus. On the other hand, the velocity determined in the IR channel is slightly smaller than the measured cirrus speed for a majority of radiosondes.

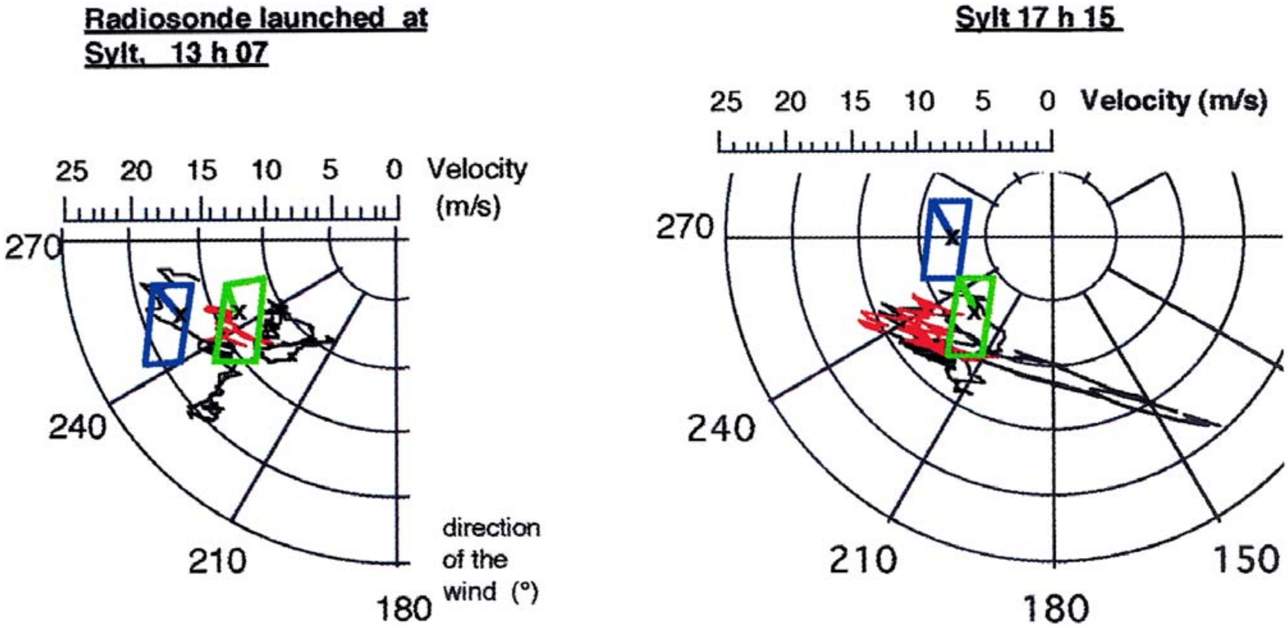


Figure 4 : polar diagrams of the wind measured by 2 radiosondes launched from the station of Sylt (red: at the levels of the cirrus cloud, black: above and below this level) and the cloud motion vectors (X, surrounded by a parallelogram indicating the error zone) measured in the IR (blue) and WV (green) channels.

b) trajectories of cirrus

Trajectories starting at the time and from the position of launch of radiosondes have been computed from series of IR and WV images covering 48 hours (fig. 5a and 5b). Each trajectory is composed of 2 parts : after the launch of the radiosonde (in black) and before (in grey ; in this case, trajectories were computed backwards in time, hence the opposite direction of the vectors).

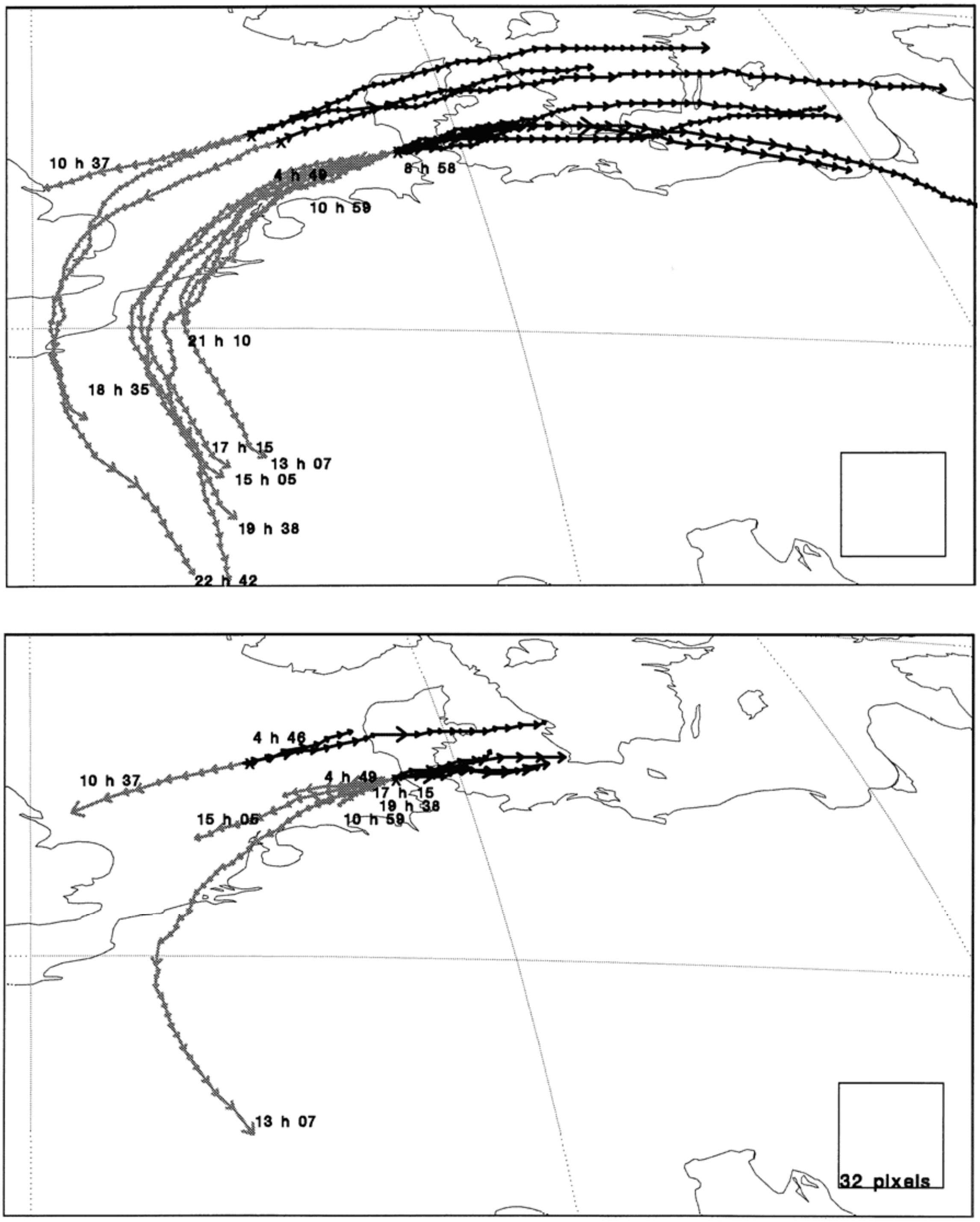


Figure 5a and b : trajectories of cirrus in the IR (top) and WV channel (bottom) on Oct. 17 - 19th 1989. Launch times of radiosondes on the 18th are indicated close to the place of apparition of the tracked cirrus cloud. Black : part of the trajectory after the launch time of the radiosonde; grey : before. The square indicates the size of the correlation window.

Cirrus elements could be tracked on a period up to 47 hours on the IR channel. Trajectories have generally less vectors in the WV channel due to the lesser quality of the corresponding images (WV images are noisier over this period). Cirrus clouds are tracked over a shorter period when 16 x 16 instead of 32 x 32 pixels correlation windows are used.

4. TRACKING OF WATER VAPOUR STRUCTURES

The aim of this study is to estimate the height and the quality of water vapour motion vectors in cloud free areas.

Data

The Meteosat IR and WV images used in this study are centred on Feb. 18th 1996 over 48 hours and cover parts of the south Atlantic and south Africa.

Analysed wind, temperature and relative humidity (from ECMWF) were used as complementary data for comparisons with water vapour motion vectors (WVMV hereafter) and brightness temperatures of the cold parts of the tracked structures. The contribution function of the water vapour corresponding to the observed brightness temperature was reconstructed from analysed temperature and humidity profiles with a simple radiative transfer model (Schmetz and Turpeinen, 1988) for some vectors along selected trajectories.

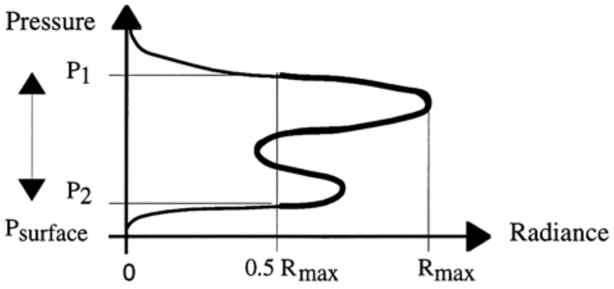
Pressure level attribution

The pressure level of the tracked WV element can be estimated in several ways from analysed data:

- the pressure level at the equivalent blackbody temperature P_{EBBT} (i.e. where the observed brightness temperature is equal or closest to the analysed temperature).

- the best fit level P_{BF}, i.e. the pressure level where the vector difference between the WVMV and the analysed wind vector is minimal.

- the pressure level of the weighted analysed wind P_{WW} (fig. 6)



This part of the contibution function (starting at the 2 levels where 50 % of the maximum radiance emitted at any level is first reached) is used as a weighting function to compute the weighted analysed wind

Figure 6 : part of the contribution function used for the determination of the weighted analysed wind (bold).

Computation of trajectories in the infrared and water vapour channels

Trajectories start on a regular grid in lines and columns also used by EUMETSAT to compute cloud motion winds and other satellite products (Climate Data Set (CDS)) (fig. 7). Trajectories show different motions in both channels (fig 8a and 8b). WV trajectories are concentrated over the ocean and are directed in a south-east, then eastward direction. In the same region short trajectories in the IR channel reveal different motions associated to low level clouds (especially a counterclockwise rotation south of Africa). The upper left part of the images (the Atlantic west of south Africa) appears as a dry region in the WV channel, where only 2 short trajectories could be computed, while the IR trajectories show the persistence and the north-westward motion of low level clouds.

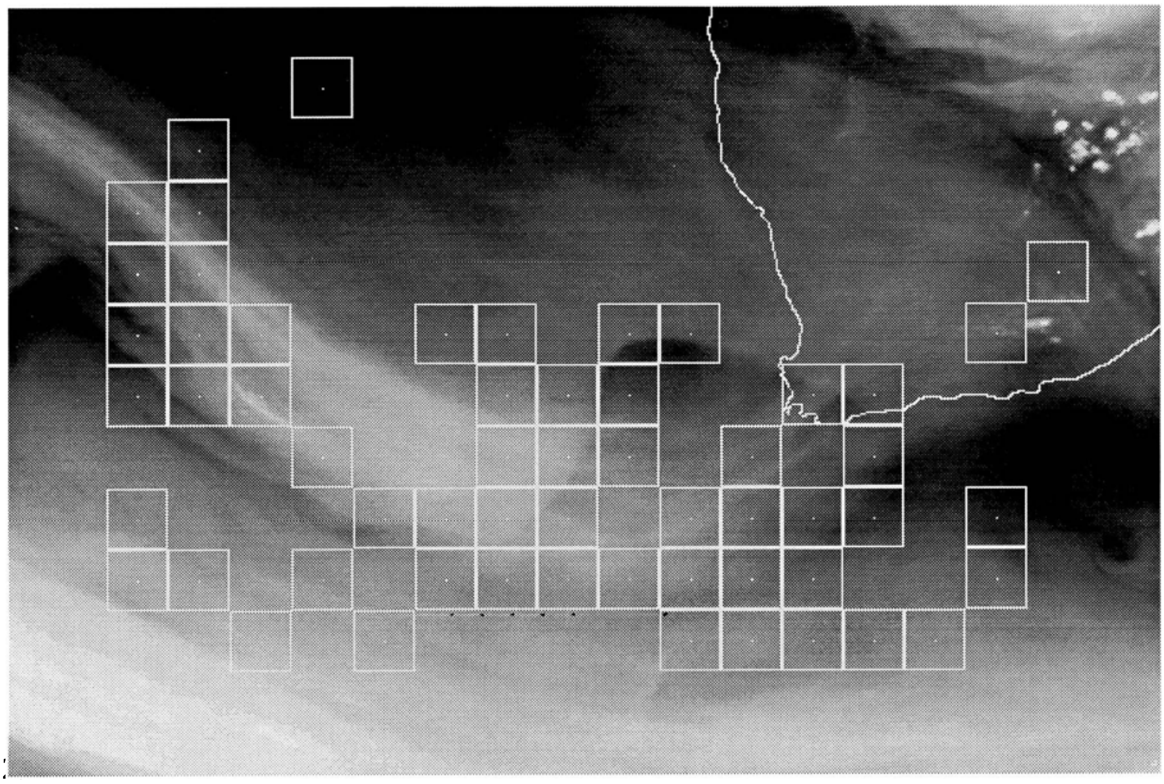


Figure 7 : situation for the start of the trajectories in the water vapour channel (February 18th 1996, at 10 h 30). The south African coast and the correlation windows (squares with dot) at the start of water vapour trajectories are also represented.

Study of selected trajectories in the water vapour channel

4 WV trajectories were selected and studied in detail. The evolution of clouds or water vapour structures has been observed on the series of correlation windows along each trajectory.

- Along trajectory 94 (start at 5 h 30, end at 23 h 30), a medium or high level cloud is tracked and can be observed on the consecutive correlation windows (fig. 9a). It is also visible on the corresponding squares of pixels in the IR channel, but is not tracked in this channel (the tracked elements are low level clouds). The different pressure levels measured along the trajectory at 6, 12, 18 and 0 h are consistent and indicate a pressure level around 375 hPa, they correspond to the peak of the contribution function (fig. 9b).

- Trajectory 76 starts from the position just north of trajectory 94, but has a shorter duration (between 5 and 16 h). The contribution functions along the trajectory (at 6 and 12 h) have a similar aspect and the different pressure levels are close to each other and to the level estimated for trajectory 94, though no medium or high level cloud is present.

- Along trajectory 82, the separation line between 2 air masses of different characteristics (temperature and / or humidity) is tracked (fig. 10a). The large discrepancy between the 3 pressure level indicators do not enable any height level attribution (fig. 10b). In this case, the observed velocity does not correspond to the wind velocity at any pressure level.

- Trajectory 104 can be separated in 2 parts: first, the trajectory is oriented south-eastwards, before taking the eastward direction of the general flow of the water vapour masses. The height estimations are different on each part (at 12 and 18 h). In this case, the trajectory corresponds to the tracking of different structures at different heights; this is reflected by the change in direction of the trajectory and the evolution of the contribution function.

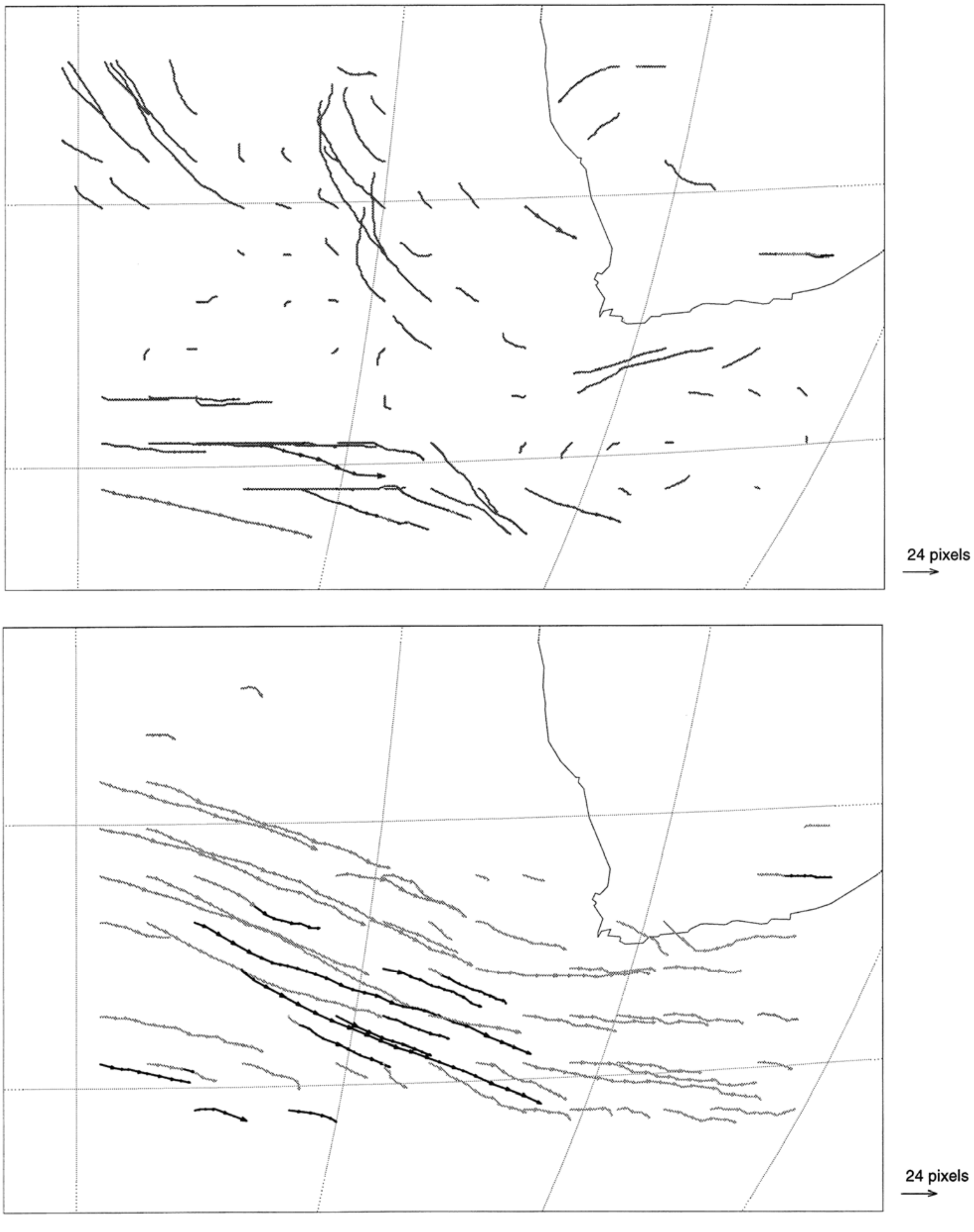


Figure 8 a and b : infrared (top) and water vapour trajectories (bottom) computed between Feb. 18th, 10 h 30 and Feb. 19th 1996, 17 h 30. Dark vectors correspond to a lower brightness temperature of the tracked clouds or structures.

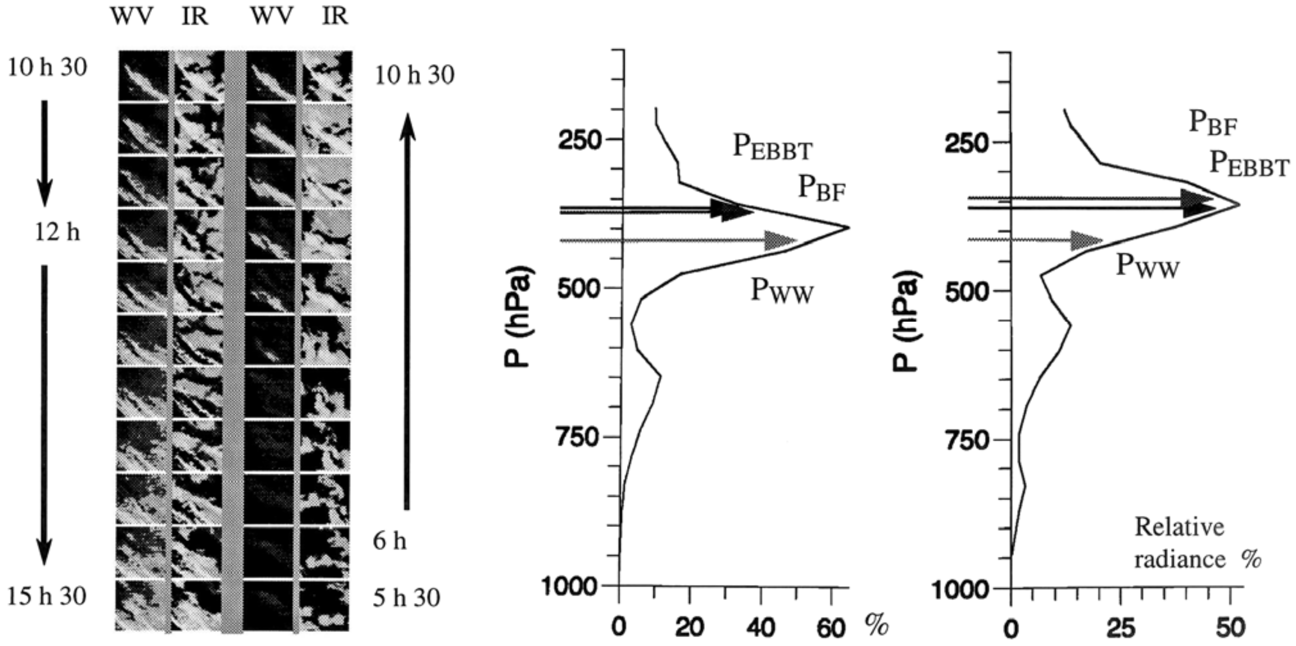


Figure 9a and b : consecutive correlation windows in the WV channel and the corresponding pixels in the IR on part of trajectory 94 (left) ; contribution functions and the estimated pressure levels at 6 and 12 h (right).

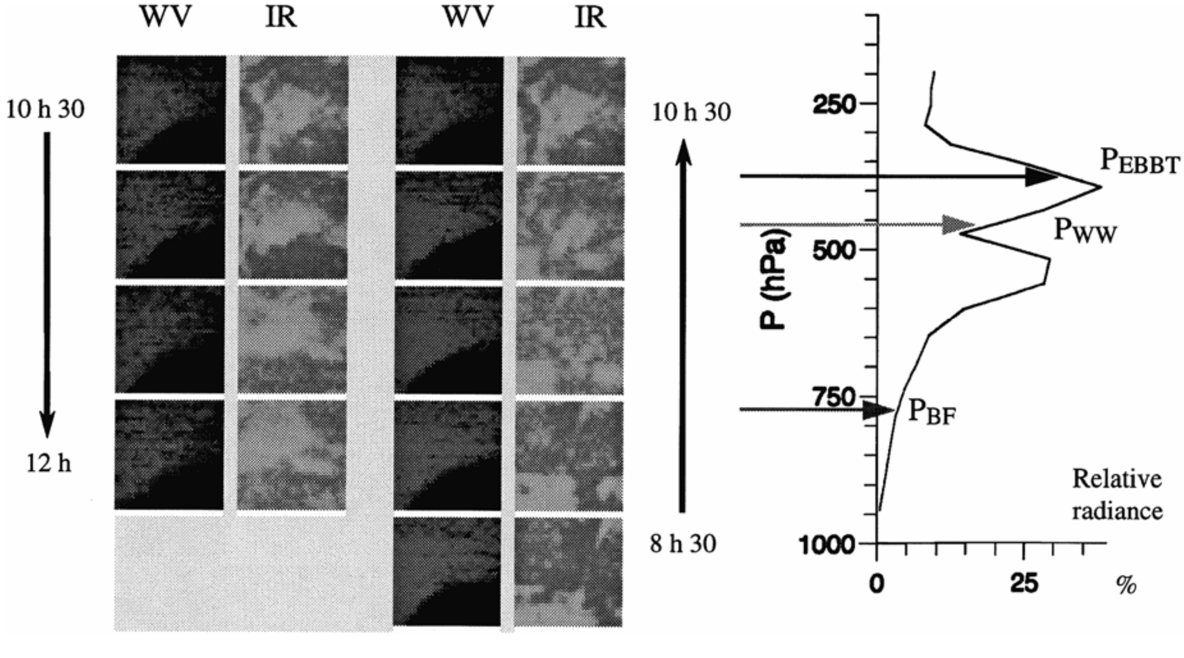


Figure 10a and b : consecutive correlation windows in the WV channel and the corresponding pixels in the IR on part of trajectory 82 (left) ; contribution function and the estimated pressure levels at 12 h (right).

5. CONCLUSIONS

Cloud elements and WV structures can be tracked for periods of 24 h or more in various meteorological situations with a method based on the computation of the Euclidean distance between image elements.

With the help of trajectories, the divergent motion of the high level clouds of an extratropical depression has been observed during about 10 hours before the dissipation of cirrus clouds ahead of the system.

The trajectory of several cirrus clouds observed from the ground during the ICE campaign has also been reconstructed. In this anticyclonic area, some cirrus have been tracked during 47 hours, but the duration of the tracking is variable (and also dependent of the meteorological situation). This is a first step for the study of their life cycle.

In the WV channel, trajectories help to define the environment in space and time of the tracked elements. When trajectories persist over a long time, i.e. several hours (temporal consistency) in areas where several trajectories are grouped and show a similar motion (spatial coherence), a better attribution of the pressure level can be expected.

ACKNOWLEDGEMENTS

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