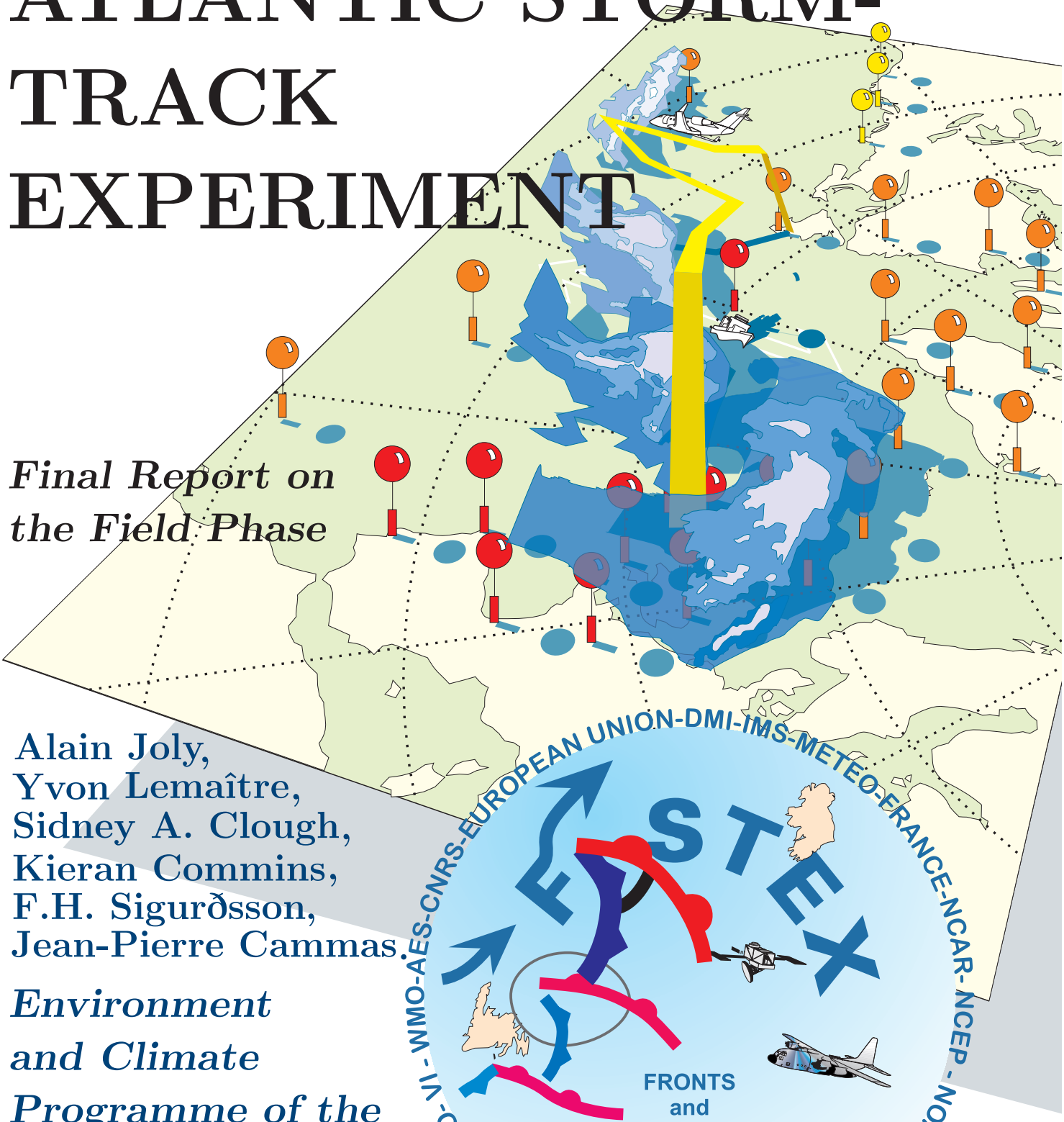
THE FRONTS and ATLANTIC STORM-TRACK EXPERIMENT



Final Report on the Field Phase

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Edited by Alain Joly,
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Production Note

This amateurish typesetting realization shows what can be achieved on a small and outdated computing system (it takes a week to outdate a computing system, these days) by combining two languages, PostScript® and LaTeX 2ε.
This combination has been pushed very far in some parts of the document, where layers of LaTeX lay out are sandwiched between layers of PostScript graphics (and vice-versa elsewhere). This has been achieved thanks to an extremelly efficient implementation of LaTeX that includes (vector) Type 1 fonts and the most remarkable PostScript driver DVIPSONE developed for PC-based systems by Y&Y. Most graphics have had to be redrawn and this has been done with Corel DRAW®. The use of vector graphics has been favoured as much as possible, so that, with the Type 1 fonts for text, the final PostScript file is practically resolution-independent and ready for the best (and alas worse) printing devices. In this version, however, and for lack of room on the disk, the resolution of some photographs has probably been somewhat too much reduced. This needs to be revised if any proper printing appears to be possible.
LaTeX 2ε is the only language directly manipulated in this work, since it features a powerful interface with PostScript, in the form of the package `graphicx` developed by D. Carlisle. LaTeX has originally been developed in the USA by L. Lamport, it rests on D. Knuth's TeX, but it might be of interest in this particular instance to note that it is now mostly developed by European computer scientists (led by F. Mittelbach). LaTeX has a built-in system of cross-reference that the package `hyperref` turns into hyperlinks in the on-line version of the document. The other package employed is `multicols`, for the Short-Notes. Based on the language and these extensions, about a thousand lines of new LaTeX 2ε code has been written in order to produce the various components of the present layout. It should be noted that the level of flexibility and complexity reached in the lay-out of this document by an amateur shows that this LaTeX 2ε-PostScript combination can only be compared directly to Xpress® (see the General Summary for example), and provides a full Computer Aided Typesetting and Publishing system for a twentieth or less of the cost. Actually, there is a close equivalent implementation of LaTeX that is disseminated as a freeware.
The document has been built from contributions provided in plain ASCII or `html` files for text and Encapsulated PostScript files for most figures, although some came on paper. Redrawing was motivated by either the need to add color to black and white originals or by the size of the original `eps` file, which had to be reduced. At the cost of some time, a severe size vs. content compromise has been seeked in order to limit the storage of the basic files of the document and also in order to limit the size of the future on-line `pdf` file. The basic files are 0,8 Mo of text and LaTeX commands, 26,3 Mo of `eps` vector graphics and 8,9 Mo of bitmaps graphics and photographs in uncompressed `tif` format. On the Pentium I system employed, a LaTeX 2ε compilation of the full document takes 78 s, it is turned into a single 82.9 Mo PostScript file by DVIPSONE in 107 s. Then, Adobe's Acrobat® Distiller turns it into a 9,5 Mo `pdf` file in 510 s and this file is optimized by Acrobat Exchange in 75 s, leading to a final size of 8.8 Mo. The original printing has been done on a part by part basis on the CANON Colorlaser printer of the Centre National de Recherches Météorologiques.
The fonts in text and some figures are the Type 1 version of the 10pt Computer Modern family developed by Y&Y, while most figures are labelled using the standard PostScript fonts.
The Short Notes are based on work or material done or provided by their authors, the text is by the Editor, who takes the blame for any error he may have introduced.

Lay-out design and implementation by A. Joly, between early december 1998 and 24 march 1999.

Executive Summary

The Fronts and Atlantic Storm Track (FASTEX) project addresses several open scientific questions relating to atmospheric cyclone depressions forming in the North-Atlantic ocean and reaching the west coast of Europe. They bring there most of the water and soften the seasonal contrasts, but they are also the cause of numerous costly damages when they take the shape of storms.

The role of the clouds associated with these cyclones in the radiative and water budget of the climate system is one such questions. Others are the influence of various processes such as ocean-atmosphere interaction on their evolution, the predictability of the development of such cyclones and, more generally, the proper theoretical framework that explains these weather systems.

This report gives an account of the first years of the FASTEX project. It concentrates on the key event of this phase, the occurrence of a major field experiment in January and February 1997.

The specific objectives of the field operations were to gather data on the cloud systems by combining dropsondes and airborne Doppler radars and, above all, to perform these flights on a system previously sampled at earlier stages. In other words, FASTEX as a field programme aimed at collecting data on cyclone full life-cycles. Both these goals have been reached.

The data obtained in this way has been organized into a Data Base and scientists from anywhere can access it at *http://www.cnrm.meteo.fr/fastex/.*

The detailed organization of the core of the cyclones is accessible. It is shown that they are extremelly inhomogeneous and the consequences of this fact are now being assessed. The project has also produced a new climatology of cyclones, the first real time implementation of adaptive observation and its assessment as a mean of making certain the forecast of damageable cyclogenesis. The study of the objectives relating to clouds is continued under the project FASTEX Cloud System Study.

General Summary and Overview

The Fronts and Atlantic Storm-Track Experiment is an atmospheric science project that focuses on the mid-latitude cyclones that form and develop over the North-Atlantic ocean and eventually hit the West Coast of Europe (as illustrated by Fig. A). These cyclones provide most of northern Europe's resources in water. They are also, however, responsible for the most damaging weather over large areas, such as floods and strong winds.

On the long time scales, the Atlantic mid-latitude cyclones play a key role in shaping the climate of Western Europe. They are the main rainmakers in this area, and, in close relationship, they also are the main cloudmakers. Cyclones act within the climate system both individually and as a population. As the latter, they strongly interact with the very large scale flow: they contribute to maintening, for periods of several days to several weeks, the same large scale pattern and as a result, they travel along the same track: this observational fact has led to coin the name "storm-track".
These periods of continuing weather pattern are called weather regimes. The storm-tracks are the zones of most active energy and water exchange in mid-latitudes, hence their importance in the global climate balance. The activity of storm-tracks embodies essentially the collective impact of cyclones. However, cyclones can reach such extreme values in wind and rain generation that they can, individually, also influence the longer term evolution: individual events are, for example, suspected of causing regime transitions.
For the same reason, namely their ability to generate large winds and rainfalls over large areas for relatively long times, mid-latitude cyclones are critical to the economy.

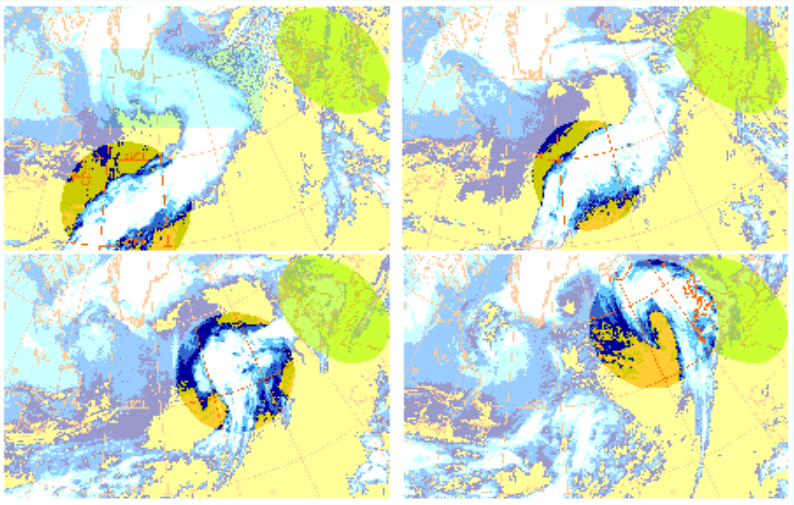
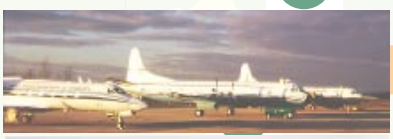


Figure A: 36h of weather evolution in the Atlantic during a period of zonal weather regime (one image every 12 h). A "second generation" low forms along the front of its parent (blue shading, top left panel) and reaches Europe (green shading) while developing rapidly, and its characteristic cloud system takes shape and expands. This phenomena is the main character of FASTEX. The original GOES and METEOSAT images have been retrieved on line from the FASTEX Data Base. The dates are 7 and 8 February 1997.

On both the time scales of climate and of daily weather, mid-latitude cyclones offer open scientific questions. The Fronts and Atlantic Storm-Track Experiment (FASTEX) has been set-up to bring useful contributions to several of them.
The areas of particular interest to FASTEX are:

Figure B: Some of the observing facilities that took part to the field phase of FASTEX. From top to bottom: the 3 aircraft based in Shannon, Ireland, the Icelandic Coast-Guard Ægir, the launch of a radiosonde from the Bugaev in mid-ocean. (Photos: N. Raynal, P. Bessemoulin and T. Douffet.)



- the cyclones influence climate partly through the impact on the radiative budget of the large cloud systems that they generate; the internal structure of these cloud systems is quite rich, involving organizations on many scales and a number of two-way interactions with dynamical processes; the details of these organizations, the way they bear on the average properties of the system as a whole (as a climate model should see them, in short), the mechanisms involved in these cloud-dynamics interaction are, to a large extent, unknown;
- the interaction between the underlying ocean and the storm-track is also an area where better data and better understanding are required; very little is known, for example, about turbulent fluxes in the presence of extreme winds at sea;
- a remarkable, if somewhat worrying, property of mid-latitude cyclones is that, on the daily weather time scale, they successfully challenge the state-of-the-art forecasting techniques of the moment, and this has been going on for more than a hundred years; in other words, in the presence of the risk of rapid cyclogenesis, the predictability of the atmosphere drops dramatically, we are nearly completely blind even to its immediate future, and progress in this particular domain is very, very slow; scientists are, however, beginning to understand why this is so;

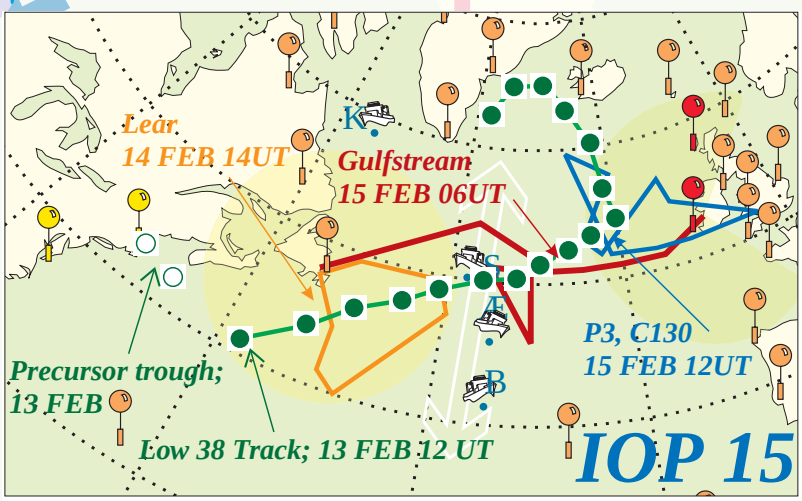


Figure C: One example of a FASTEX Intensive Observing Period: the facilities are employed in succession along the track of the cyclone of interest. All cases are presented in this framework in Part 3.

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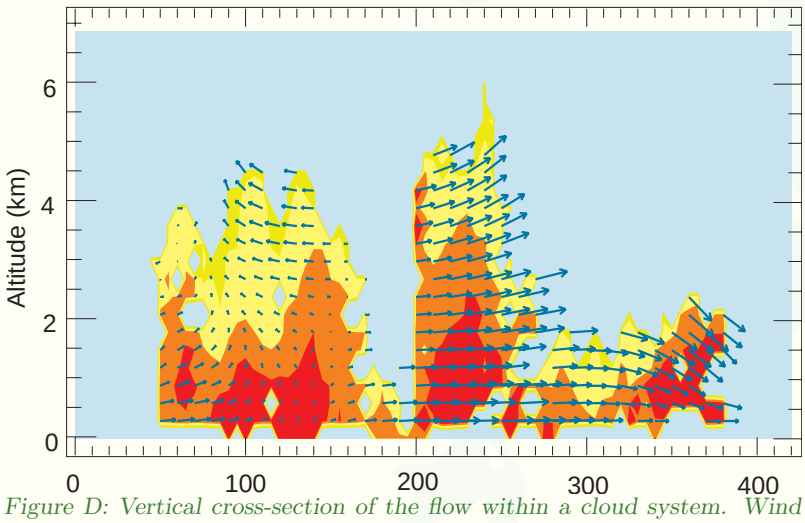


Figure D: Vertical cross-section of the flow within a cloud system. Wind vectors obtained from airborne Doppler radar data. Shading: reflectivity showing the precipitating areas. Result from the CNRS/CETP group.

an enterely new approach of observation combined to the most recent data assimilation techniques may allow a decisive breakthrough and this has been actually tested as part of FASTEX; however, one may have to face the fact that this short predictability limit is an intrinsic property of nature. In this case, only a statistical approach is available to us: this situation would put an end to the dream of a deterministic forecast, a unique and certain future fully determined by observing today's weather;

- a common meeting point of these topics are the dynamical processes operating within cyclones and between the cyclones and their environment, so that any aspect of the cyclone problem has to, at some stage, deal with available cyclone theories; it turns out that important changes have taken place in this area in the past decade and the idea that cyclones result from the spontaneous release of the instability of its environment (in the sense of fluid dynamics) now appears to be a bit short sighted.

There are new observational requirements attached to each of these topics. There are also new observational facilities that become available, such as airborne Doppler radars that can give access to the internal structure of cloud systems. For these reasons, one of the first significant step of the FASTEX project has been to set-up and run a major two months field project (Fig. B). Its specific objectives were to document the life-cycle of North-Atlantic cyclones, in order to deliver the data needed to address the topics listed above.

The project and its basic plans emerged from French and British groups in 1993. They attracted scientists from the United States of America, Canada, Ireland and a number of other countries and organizations, including the European Commission and the World Meteorological Organization. This was needed by the scale of the observational challenge: tracking about 10 cyclones from their birth in the western or middle ocean to their mature stage close to the European coasts (Fig. C).
The field phase of FASTEX thus took place in January and February 1997. Beside a significant overhaul of the operational observing network, up to 4 ships had been positioned in the middle of the Atlantic, up to 7 instrumented aircraft were available on air fields on both sides of the ocean. This observing system was coordinated by a special Operations Centre located at Shannon, Ireland.
The observing period has reached the following goals:

- about ten mature and developing cloud systems and related cylones have been sampled by airborne Doppler radars (Fig. D) and dropsondes;

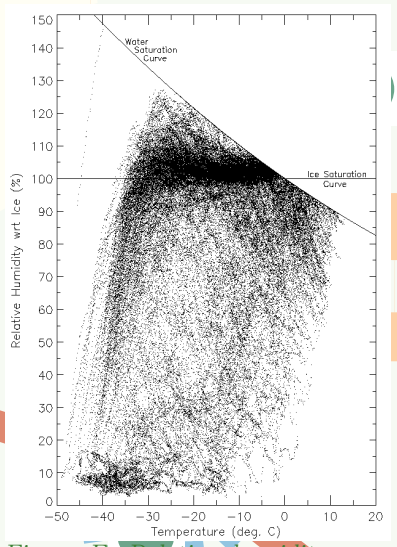


Figure E: Relative humidity measurements from the UK C-130 dropsondes were able, in FASTEX, to discriminate between saturation with respect to ice (dominating) and to water. Result from the JCMM group.

for about half these cases, the structure of the system has been observed on scales unheard of so far with in-situ data; this was the data required to make some progress on the internal organization of large stratiform cloud systems (Fig. E);

- about ten cyclones have been observed at several key stages of their life-cycle with radiosondes and dropsondes, thus enabling the documentation of life-cycles, which is central in modern cyclone theory and impacts all other topics;
- the new approach to observation suggested by recent work on the predictability of cyclones has been tested for the first time in real time and with real facilities on real cases;
- unique datasets have been obtained by the ships on turbulent fluxes under strong winds and high seas, but also on oceanography-related topics.

The data collected during this field experiment has been gathered into a Data Base. This critical task has been coordinated by the Toulouse Météo-France GAME group, but has involved all participants. This Data Base has been opened *three-weeks* after the end of operations to the scientific community *at large* (it is not restricted to FASTEX participants) on the INTERNET at http://www.cnrm.meteo.fr/fastex/. This Data Base has many assets to offer to any person interested in mid-latitude cyclones: more than 10,000 high-resolution, checked, in situ soundings spread all along the storm-track (not just on its beginning or end), a remarkable collection of remotely sensed data and a full series of analyzed fields combining the obervations into a coherent set (Fig. F) are three examples. The first scientific results will be published at the end of 1999 in a special issue of the *Quarterly Journal of the Royal Meteorological Society*. However, the scientific work on the data is currently going on and will so for a few years. The present report is meant to provide some reference information on the field phase and to show some of the first results, especially those relating to the organization of the cloud systems.

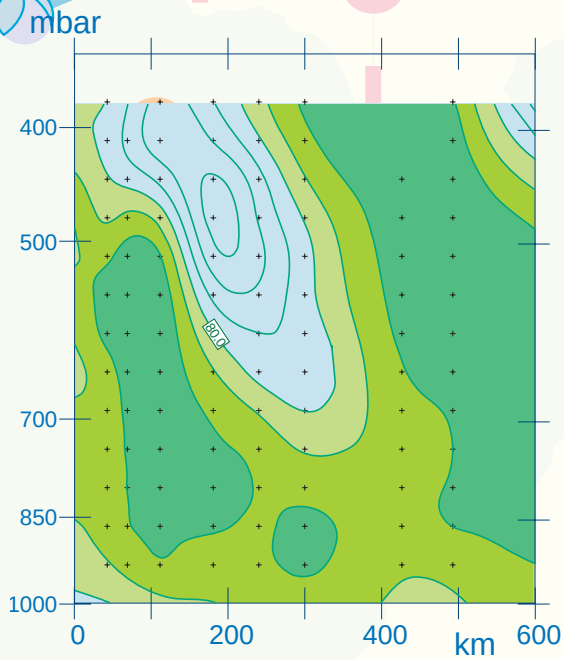


Figure F: Vertical cross-section of the structure of a cloud system derived from the 4D-VAR data assimilation of dropsondes: a dry intrusion that is not in the initial guess field but in the measurements only is reasonably described. Result from the Météo-France group.

The Editor's Note

This report is primarily the document requested by Article 6 and Article 10 of Annex II of the contract ENV4-CT96-0322 between the European Commission and the five partners of the EC-FASTEX project, one of the components of FASTEX. Following the terms of Article 10, this report couvre tous les travaux, les objectifs, les résultats et les conclusions *and it begins with a general summary of the project.*

It offers a good opportunity, in fact, to gather in a single document the most significant features of our project. This is what I have tried to do with the help of the contributors of the various parts.

The main line of the report deals with the objectives and deliverables as they were accepted as part of the Environment and Climate Programme: an event, the field phase of FASTEX (Parts 2 and 3), the resulting Data Base (Part 4) and the first results on cloud system structure (Parts 5 to 8). This information is given in the main text.

In order to try to make this useful to people getting acquainted with FASTEX and the available data or currently working on FASTEX, the report contains a graphical summary of each case (Part 3), which was built early in 1997, prepared in french, but remained essentially unpublished.

However, this is only one part of FASTEX. Although a significant delay has been introduced, I have added, in the form of short-notes, information on the other aspects of FASTEX, in the hope to turn this document into a reference about the first years of this 10 years or so project.

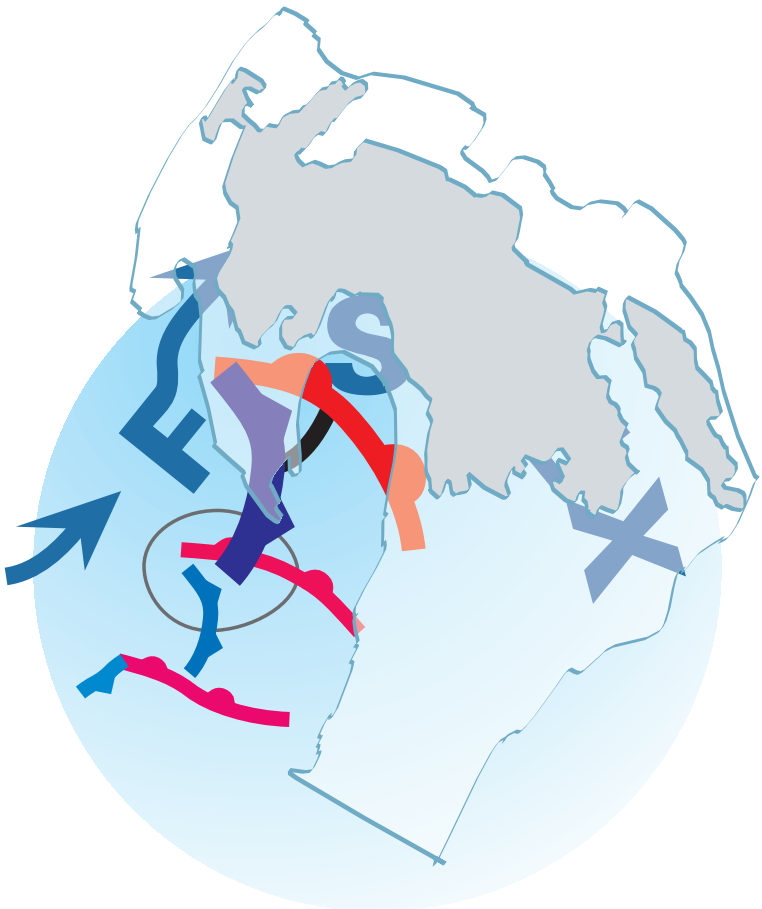
I would like to thank the European Commission, and in particular, Drs Ghazi and Brüning, for supporting FASTEX. The Commission has always been aware of the full extent of FASTEX, and in particular, its implications for weather forecasting have never been ignored. The readers should know that, for example, the Commission asked me to help them prepare a press release at the end of the field phase, and they *insisted that this should be focused on adaptive observation, which is, indeed, a "hot" scientific topic. I am grateful to them for this openness.*

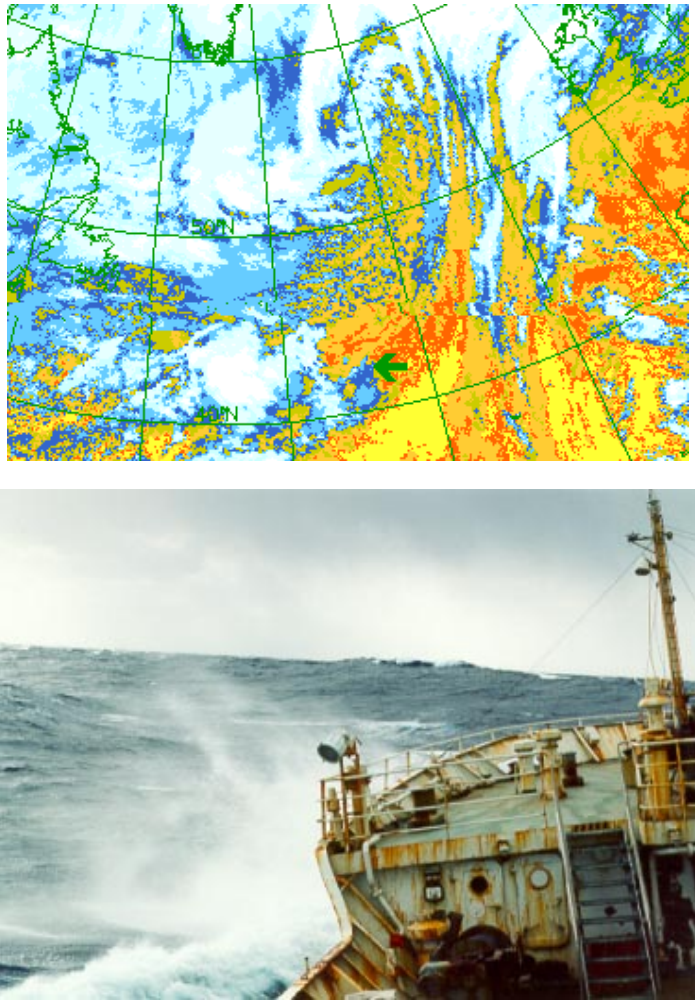
I also deeply thank Alain Protat, Yvon Lemaître, Geneviève Jaubert, Georges Scialom, Sid Clough and Gerald Desroziers who gave me essential contributions to this report.

This document has been prepared enterely numerically, so that it is available in the form of one or several files in (protected) `pdf` *format as part of the documentation in the Data Base. This probably is its best chance to get one reader.*

This report is, finally, a tribute to all those who have given time, ideas and sometimes taken risks in the course of FASTEX. I hope that it will ultimately find its way to them.

If I can include all the information that I would like to put in it, my only remaining regret about this report will be that, following Article 6, it is written in "english" (although probably only Part 7 is truly in english). It is certain that the english literature will not get any better thanks to us, and furthermore, I must say that I am not convinced that this will help reading it.





FASTEX seen from a distance of 36 000 km from the surface, with a new weather system forming (top) and going to meet a ship (arrow), all a nice and picturesque scene, and FASTEX seen from the ship, the research and weather ship Victor Bugaev (bottom), picturesque but less nice. The ship was painted afresh (white) about three weeks before. Photo by Emmanuel Gizard, Météo-France.

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