The Fronts and Atlantic Storm-Track Experiment (FASTEX)

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1. FASTEX and cloud systems

Improving the understanding and modelling of the interaction between clouds and radiative processes is an important goal of GEWEX, especially of its Cloud System Study component (Browning, 1994). GCSS, as this component is called, is a programme that attempts to address this problem by adapting an overall strategy to the various types of clouds. The importance of clouds in the climate system is also recognised in the Environment and Climate Programme of the European Commission. Mid-latitude cloud systems form one such important category, for the study of which a dedicated working-group led by Dr. R. Stewart has prepared specific plans. The special feature of these clouds, predominantly stratiform, is their close interaction with dynamical processes. Therefore, the study of mid-latitude cloud systems is closely related to the problem of cyclogenesis in the vicinity of the so-called "storm-tracks". A picture of the actual tracks of storms during FASTEX is shown in Fig. 1.

The internal organization of these systems is highly complex. Some of the outstanding issues are, for example, related to the vertical structure. While synoptic scale ascents are relatively

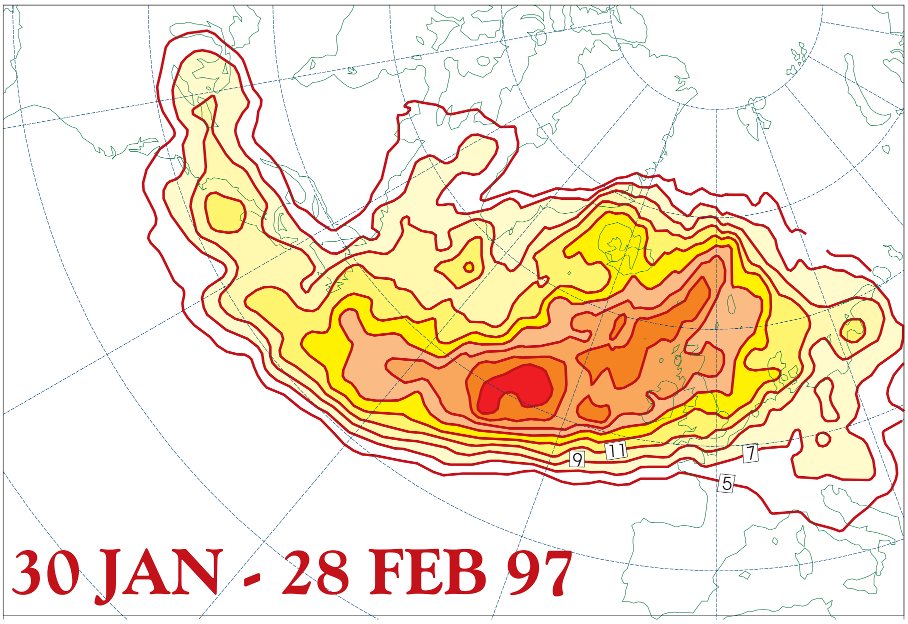

Figure 1: *Map of the density of trajectories of weather systems in February 1997, the most active part of the FASTEX field phase. Each system, defined as a vorticity maximum, is automatically tracked in the time-series of Météo-France operational analyses. This map shows the actual storm-track at that time, with a maximum of activity close to the european coasts. Figure courtesy of Ch. Baehr and F. Ayrault, Météo-France.*

simple, with often a single well defined maximum somewhere in the lower half of the troposphere, the distribution of the microphysical components appears to be organized into multiple layers. This will influence both the overall radiative budget of the cloud as a whole as well as its feed-back, through latent heating, with the synoptic dynamics.

Another aspect of the complexity is the existence of areas of mesoscale dynamical activity: bands of enhanced ascent or of convection, spread amongst the system. How is this mesoscale activity controlled by the larger scale properties or by the presence of the cloud processes themselves ? And how, in turn, does the presence of this activity modifies the averaged properties of the cloud system ? These areas of self-organization are indeed zones of very strong diabatic activity clearly ruining the homogeneity of the system with contributions to the water and energy budgets may be significant.

The GCSS programme thus identified a need for a multiscale approach to the collection of new sets of measurements as the first step towards the definition of a new representation of mid-latitude cloud systems within climate models. These observations must include an important dynamical component and have to cover different scales at the same time.

The Fronts and Atlantic Storm-Track Experiment (FASTEX, Joly et al., 1997, Joly et al., 1999) is a field experiment project that has been partly designed to address these requirements. FASTEX is a relatively large international programme associating most countries of the North-Atlantic basin. It originated in France and the United Kingdom in 1994, but key scientific

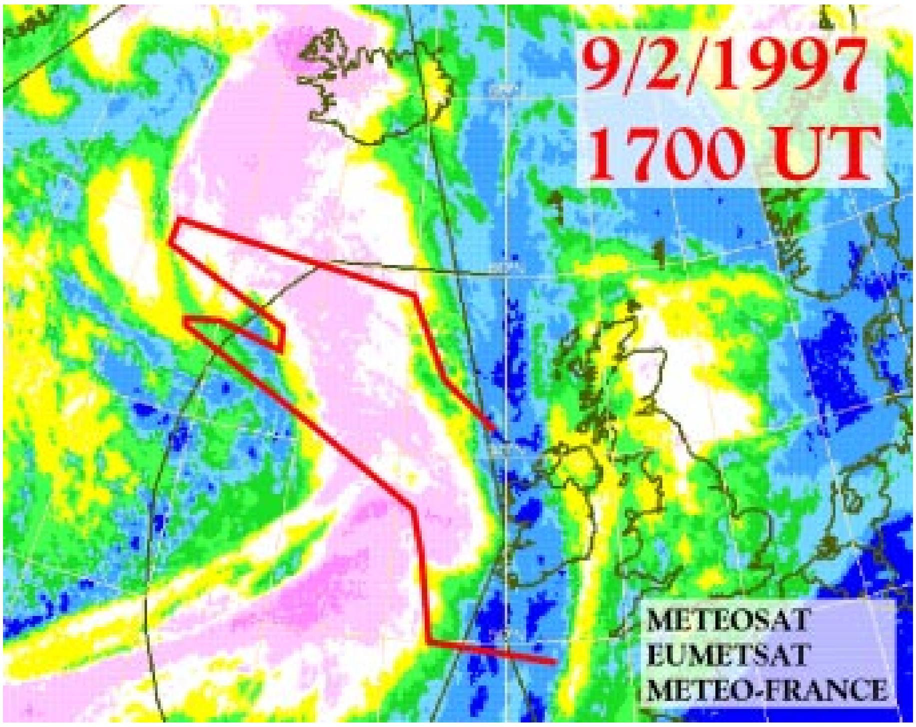

Figure 2: *METEOSAT infra-red image of the FASTEX IOP12 cyclone, 9 February 97 at 17UT. The heavy solid red line is the system-relative flight-track of the P3 aircraft over that system.*

and practical contributions were quickly added by groups from the United States, Canada and many others. Because it has links with both the study of climate and with cyclogenesis forecast, FASTEX is also supported by WMO.

The headlines of the scientific objectives are:

- to document cyclone cloud systems in the spirit explained above,
- to enable progress in the knowledge of the dynamics of "second generation" cyclones that form over the ocean (away from the coasts), at the end of the storm-track rather than at its entrance,
- to perform a feasability study of an "adaptive observation strategy" (Snyder, 1996) with a view to improve cyclone predictability,
- to document turbulent air-sea exchanges in the presence of strong winds and relate these to the subsequent involvement of these air masses in the process of cyclone and cloud generation.

In other words, the focus of FASTEX is on the *life-cycle* of cyclones (on the synoptic and sub-synoptic scales) as well as of some of their components such as clouds, cloud-bands, etc.

Table 1: *Major facilities and participating institutions*

Facility	instruments, functions	owner, crew's home institution	Funding agency
CC ÆGIR	radiosoundings	Icelandic Coast Guard (IS)	EC
RV KNORR	radiosoundings, profilers, fluxes	Woods Hole (USA)	NOAA
RV LE SUROÎT	radiosoundings, profilers, fluxes	IFREMER (F)	CNRS, EC
RV V. BUGAEV	radiosoundings	UkrSCES (Ukraine)	Météo-France
C-130 (UK)	dropsoundings	UK Met Office	UK Met Office
C-130 (USA)	dropsoundings	US Air Force	US Air Force
ELECTRA	Doppler radar	NCAR (USA)	CNRS, NSF
GULFSTREAM-IV	dropsoundings	NOAA (USA)	NOAA, Météo-France, CNRS, NRL
LEARJET	dropsoundings	FIC (USA)	NSF
WP-3D (P3)	radars (1 Doppler), dropsoundings	NOAA(USA)	NOAA, CNRS, Météo-France
Increased soundings on a regular basis	6h soundings	CAN, Greenland, IS, IE, UK, F, SP, Azores (P), Bermuda, DK	Countries, WMO, EC
Increased soundings on alert	6h soundings 3h soundings	USA IE, F, UK	NCAR, NOAA Countries
Buoys	surface obs.	EGOS	EGOS
Operations Centre at Shannon	monitoring, forecast	Aer Rianta (IE)	EC
Staff of Shannon Ops Centre and Scientific crews	forecasters, scientists	CNRS(F), CMC(CAN), JCMM(UK), Met Eireann(IE), Météo-France(F), NCAR(USA), NOAA(USA), NRL(USA), UCAR(USA), UCLA(USA), UK Met Office(UK)	Institutions, NSF, EC
Staff of US targeting operations	forecasters, scientists	MIT(USA), NCEP(USA), NCAR(USA), Penn State U.(USA), U. of Wisconsin(USA)	NOAA, NSF

Agencies without direct participation: European Commission (EC), European Group on Ocean Station (EGOS), National Science Foundation (USA), World Meteorological Organisation (WMO).

Selected Country Codes: CAN: Canada, DK: Denmark, F: France, IE: Ireland, IS: Iceland, P: Portugal, SP:Spain.

2. FASTEX operations and cases

2.1 Observational strategy

The basic observational strategy of FASTEX is to employ successively *in time* but over the *same* weather system the various facilities distributed over the North-Atlantic area. In summary, jet aircraft sample with dropwindsondes the incipient conditions or early stages of cyclogenesis. These measurements can then be relayed by very frequent soundings taken by ships located near 35°W. Up to 4 ships are involved: the Icelandic Coast-Guard ship Ægir, the US RV Knorr, the french RV Suroît and the ukrainian RV Victor Bugaev. The ships are kept in the vicinity of the main baroclinic zone. Finally, mature cyclones and waves are observed in great details by a small fleet of instrumented aircraft: the UKMO C-130, mostly equipped for dropsounding and the NOAA P3 and NCAR Electra, essentially using radars and in-situ microphysical instruments. However, the overall environment of the systems of interest is also being sampled in greater details than is usual: most upper-air observing stations, including ships equipped for semi-automatic en-route radiosounding, perform 6-hourly soundings throughout the FASTEX field season. Operations are directed from an especially designed centre located at Shannon airport, Ireland. Table 1 shows the main facilities and their sponsors.

2.2 Weather conditions and cases

The FASTEX field phase took place in January and February 1997. In terms of weather activity, this period was characterized by three successive large-scale regimes: the first two weeks or so, the storm-track was located to the south, with a rather short maximum. This was followed by a blocking period, with very little cyclone activity in the Eastern Atlantic. Then, a zonal regime established itself for the whole of February, culminating about the 18th. Between 40 and 50 storms occurred during these two months (Fig. 1), most of them running over the ships, making life and work on board extremelly difficult.

FASTEX Intensive Observing Periods (IOP) were declared on 19 occasions, aiming 18 of these storms. It turned out to be difficult, however, to organize a proper chaining of observations such as in the ideal case. In terms of the quality of the tracking of a cyclone life-cycle, the best cases are IOP 2, 5, 9, 10, 11, 12, 15, 16, 17 and 18. Something very close to the ideal plan was achieved with IOP 17, one of the strongest system to hit Europe, between the 18th and the 20th of February, except that the NCAR Electra aircraft was missing due to mechanical reasons. The good cases for the cloud system study are IOP 1, 5, 9, 10, 12, 16 and 18: this means a combination of dropsondes and radars measurements with a good sampling succes rate of the airborne Doppler radar.

Most of the cases are various forms of baroclinic developments, illustrating at the same time the importance of this mechanism and the diversity in its realizations, including a wide range of scales. These include a straightforward life-cycle (development followed by slow decay) as in IOP 14, multiple developments as in IOP 13 or 17, upscale growth near jet-stream exit as in IOP 3 and 15, “bomb-like” deeepening in quite a few cases. Other systems include a frontal wave (IOP 10), a cold air cyclone interacting with the jet-stream (IOP 18), cold-air vortices (IOP 2, 4, 5). There are also “control cases” of repressed frontal waves, such as IOP 7. Table 2 proposes a subjective classification of the systems met during FASTEX.

Table 2: *Subjective synoptic characterization of the FASTEX cases*

	Comma cloud-like feature	Second generation wave	Rapid development stage	Clear stage of baroclinic interaction	Suppressed waves (stable front)
IOP 1	–	front	–	●	–
IOP 2	●	front	–	–	slow gen
IOP 3	–	–	●	●	–
IOP 4	●	–	–	–	–
IOP 5	●	–	–	–	–
IOP 6	–	tempo	–	–	●
IOP 7	–	tempo	–	–	●
IOP 9	–	jet/front	–	●	–
IOP 10	–	front	–	–	–
IOP 11	–	–	●	●	–
IOP 12	–	jet/front	● ●	●	–
IOP 13	–	–	–	●	–
IOP 14	–	–	–	●	–
IOP 15	–	jet/front	●	●	–
IOP 16	–	jet/front	●	–	–
IOP 17	–	jet/front	●	●	–
IOP 18	●	–	●	●	–
IOP 19	–	front	●	●	tempo

Symbol ● means "yes" or "present"
An entry in column 2 means that the system started as a second generation wave. It gives an idea of its environment, "front" being obvious, "jet" meaning presence of a jet-streak or entrance, "tempo" meaning that waves existed temporarily or, in the case of IOP19, temprarily hindered.

2.3 The FASTEX Data Base

The data, however, is already available to the scientific community. It is organized in a network of data bases around a FASTEX Central Archive. The latter is a Data Base built and located in Toulouse by Météo-France. It can be accessed at:

http://www.cnrm.meteo.fr/fastex/ .

The most important processed datasets are available (for research and educational purpose only) directly from there: high resolution radiosoundings from regular and special stations and ships, high resolution dropsoundings, surface observations, surface flux measurements, buoys, in-situ aircraft observations, numerous satellite images and radiance, wind retrieved from Doppler radars during 360°turns of aircraft (Jaubert et al., 1999)

The data base also offers the most complete documentation of FASTEX, the instruments and of the operations.

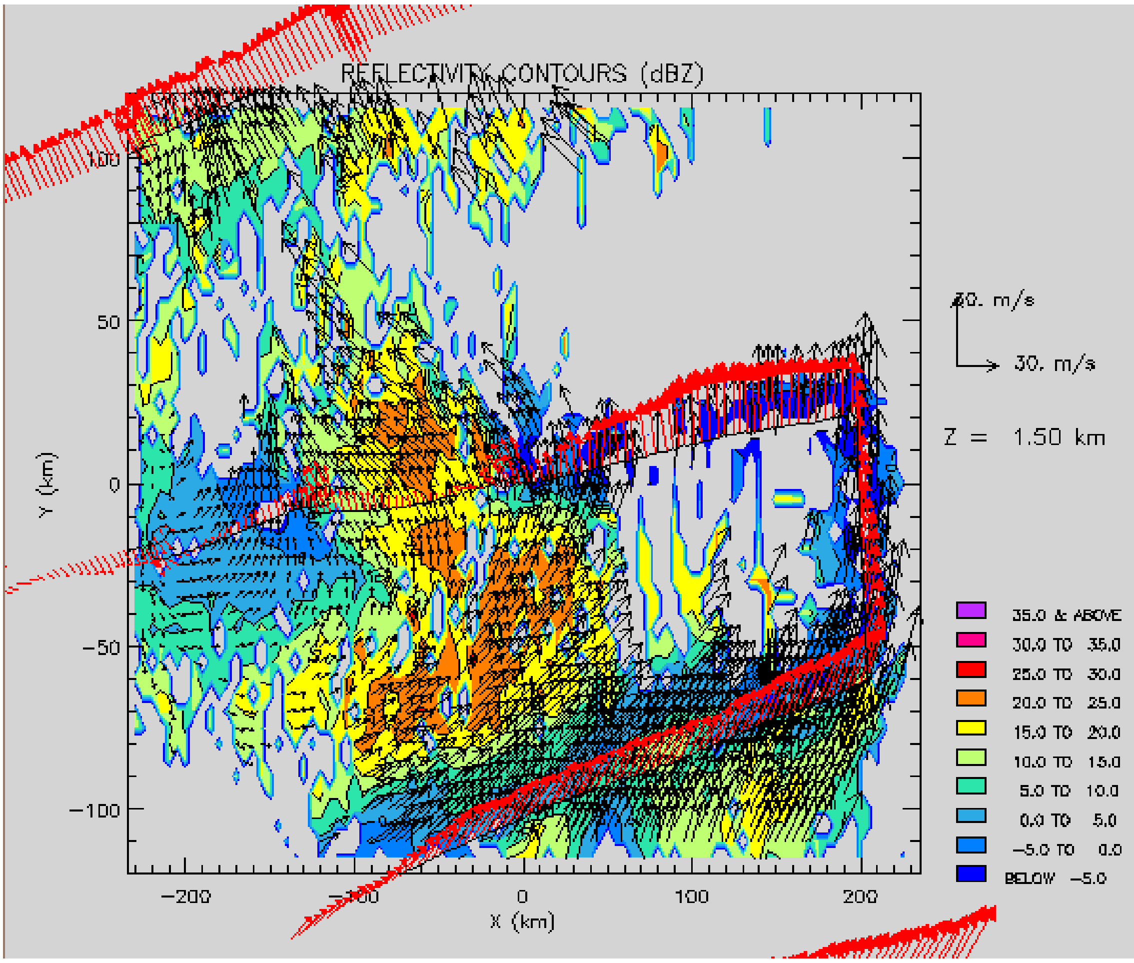

Figure 3: *Horizontal cross-section of the reflectivity field and of the wind field deduced from (Tail) Doppler radar data in the cloud head region for IOP12 at 1.5 km using the MANDOP analysis. The P3 aircraft trajectory and selected in situ wind measurements are superimposed. Figure obtained by Y. Lemaître, CETP.*

3. Cloud study: sample results

During the FASTEX experiment then, 2 airborne Doppler radars (the US NOAA P3-43 airborne Doppler radar instrumented with the French dual beam antenna and the US NCAR Electra aircraft equipped with the French/US ASTRAIA/ELDORA Doppler radar) were involved in the eastern area of the FASTEX setting. They aimed at sampling cloudy and precipitating areas of FASTEX cyclones. The multiscale sampling strategy of these aircraft is meaningfull in coordination with the British C130 aircraft launching dropsondes.

The scientific objectives attainable by these instruments are twofold:

(i) to scrutinize dynamical, thermodynamical and microphysical processes involved in these

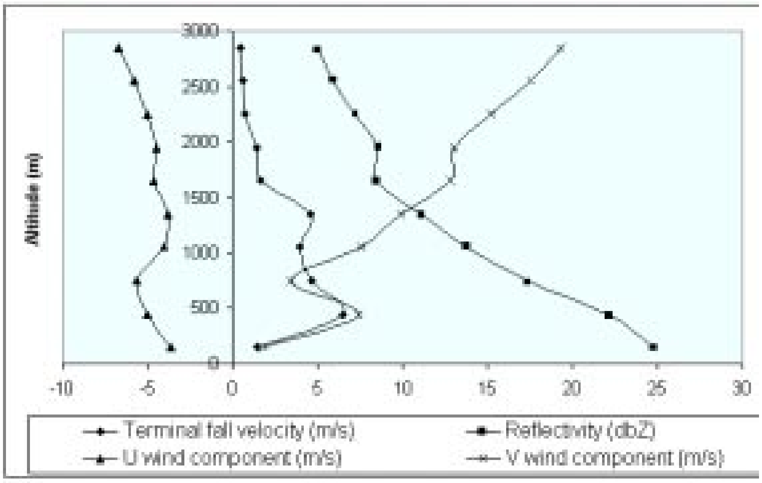

Figure 4: *Vertical profiles of wind, of terminal fall velocity and reflectivity deduced from a circular trajectory using the DAVAD analysis. Figure obtained by G. Scialom, CETP.*

cloudy and precipitating regions,

(ii) to improve longwave radiative transfer calculation and distribution of heating throughout the atmosphere.

These objectives need to access to 3D dynamical, thermodynamical (pressure and temperature) and microphysical fields (precipitation production, cloud or saturation deficit, precipitation mixing ratio, snow mixing ratio, rain mixing ratio, etc.), to estimate crucial physical parameters (such as PV, forcings, and ageostrophic winds), and to quantify budgets of mass, momentum, heat and moisture at different scales. These fields can indeed be derived from the measurements performed during the experiment.

Doppler radar data collected during FASTEX are presently processed to obtain a composite ensemble of elaborate fields (dynamic, thermodynamic and microphysical fields) at various scales of motion in order to study multi-scale interaction involved in waves, cyclones and rapid secondary cyclogenesis sampled during this experiment, and to provide a rather unique set of validation data of nearly all the aspects of organisation of mid-latitude precipitating systems.

Some results of IOP12 are now shown. This IOP (09 February 1997) was devoted to the sampling of a cyclogenesis. Fig. 2 gives the Iinfra-Red Meteosat picture of this cyclogenesis. The cloud head rolling up around the secondary low pressure center is well evidenced on this picture. The relative aircraft trajectory (relative to the secondary low) of the P3 aircraft involved during this IOP is superimposed. As explained previously, the sampling strategy was in particular devoted to get an overall view of the system. Combining several legs we can obtain a nice picture of the feature of the low on the mesoscale. This aircraft pattern allowed to scrutinise some dynamical aspects of the warm front, of the low pressure area for the IOP12, and of the so-called cloud head region. Fig. 3 gives a zooming view of this latter area in the cloud head region as deduced from the tail Doppler radar data using the MANDOP retrieval technique (Scialom and Lemaître, 1990) adapted to aiborne radars. Several features are well identified, the

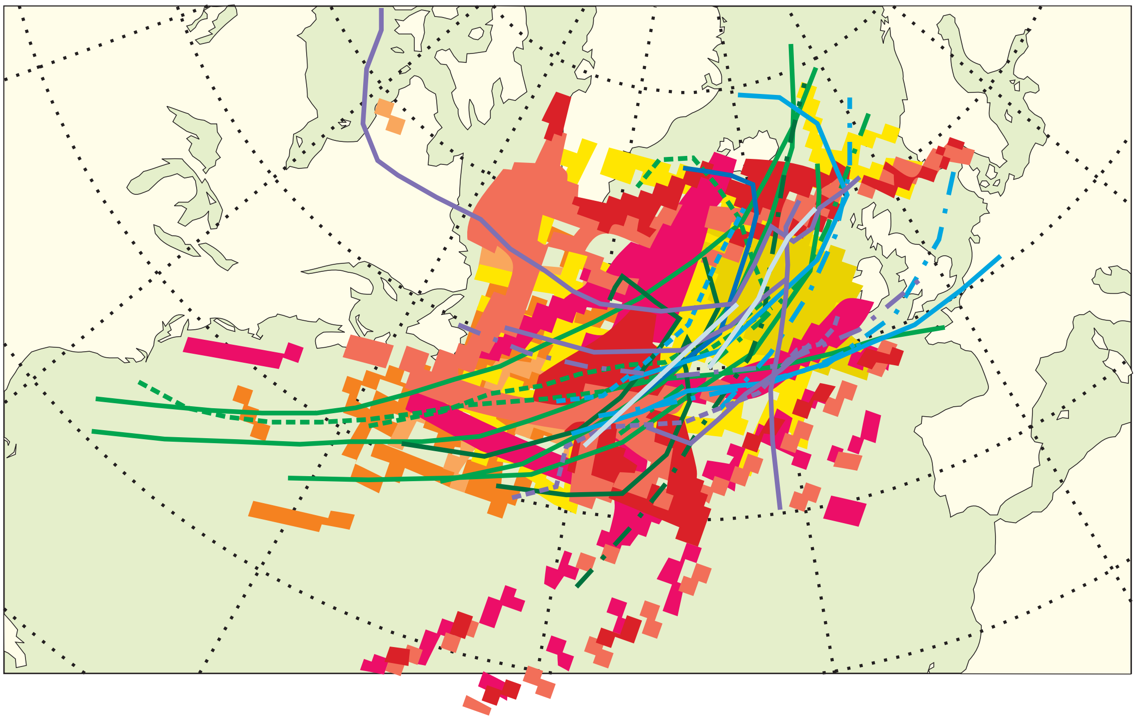

Figure 5: *This map shows the trajectories of the systems sampled during FASTEX (a different color is used for the various types identified in Table 2) together with the distribution of data obtained from the aircraft and ships involved in FASTEX. The map shows that the tracks are generally enterely covered: the mid-ocean gap does not exist during FASTEX and the mature phase is extremelly well covered by the C-130 dropsondes. Map compiled by G. Jaubert (data) and A. Joly (tracks)*

strong airflow associated with the dry intrusion, the cyclonic airflow around the cloud head. The comparison between these preliminary winds deduced from radar data and in situ measurements shows a very good agreement which qualifies the dynamical retrieval.

Fig. 4 gives an exemple of vertical profiles of wind, of terminal fall velocity, and of reflectivity obtained in the cloud head region.

4. Conclusion

The logistically extremelly ambitious objectives of the field phase of FASTEX have been succesfully reached: about 10 cyclones have been tracked at various stages of their life-cycle and about the same number of fully developed cloud systems have been sampled by a combination of in-situ and Doppler radar observations. Partial coverage of nearly as many cases has also been performed. This success is illustrated by Fig. 5, showing a map of data coverage superimposed with the tracks of the FASTEX cases. Extremelly interesting data for other objectives has been gathered, such as the surface fluxes observed in extreme conditions of wind and sea state (Eymard et al., 1999).

The main deliverables of the project were the field experiment and the data base. The data base has been opened to the *whole* of the scientific community via INTERNET a few weeks after the end of the field operations and is close to be completed. A CD-ROM dissemination is planned for the first half of 1999. Analyses including a fair amount of special data are part of the Data Base and 4D-VAR re-analyses experiments have started (Desroziers et al. 1999).

The groups involved in FASTEX have issued reports and submitted a series of article containing their first results (see below). It is planned to publish them in a special issue of the *Quarterly Journal of the Royal Meteorological Society* during the autumn 1999.

However, the scientific exploitation of FASTEX is only just beginning. The cloud system study objectives are organized by a new EC project, called FASTEX Cloud System Study that has recently started. Partnership has been extended to other groups and countries, such as, for example, Norway. The FASTEX-CSS project, coordinated by A.J. Thorpe (University of Reading), includes the retrieval of wind and microphysical parameters in a number of cloud systems sampled as well as the validation of a microphysical parameterization scheme using both this data and detailed simulations.

FASTEX project contacts:

The FASTEX World Wide Web home page and Data Base:
http://www.cnrm.meteo.fr/fastex/

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Acknowledgments

The FASTEX project is involving many groups and scientists. During the FASTEX operations, the Principal Investigators on the ships were L. Eymard, G. Caniaux and P.O.G. Persson. The aircraft operations were conducted, from a scientific point of view, by J.P. Cammas, S. Clough, K. Emanuel, R. Gall, D. Jorgensen, R. Langland, M. Shapiro, C. Snyder, R. Wakimoto. Field operations were coordinated by P. Bessemoulin, K. Browning, J.P. Chalon, R. Dirks, P. Mascart, J. Moore. The Data Base project is led by G. Jaubert. The FASTEX field phase has been supported mostly by the Centre National de la Recherche Scientifique, Institut National des Sciences de l'Univers, France, the European Commission, under the Environment and Climate Program, Météo-France, the National Oceanic and Atmospheric Administration, USA, the Naval Research Laboratory, USA, the National Science Foundation, USA and the UK Meteorological Office.

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