Part 2

The field experiment operations

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2.1 FASTEX Operations: from plans to reality

This Part is meant to give a first idea of how well the goals laid out in Part 1 have been reached. This section summarizes how the plans for operations were implemented. Section 2.2 summarizes the large-scale weather characteristics during FASTEX. Then, two examples of FASTEX cases are presented so as to convey an impression of the type of systems of interest and of the type of operations. An overall summary of operations and a preliminary subjective characterization of all the cases is presented in section 2.5. A short section addresses the forecasts (section 2.6). This Part concludes with some highlights of the achievements of the operations.

2.1.1 Project schedule

FASTEX aims at constructing a dataset covering 10 complete cyclone cases and some extra cases in the upstream areas covered by the Gulfstream-IV. According to the climatology (summarized in section 1.3), a period of 2 months is necessary, on average, with best chances in January. Taking extra-meteorological reasons into account, the FASTEX field season was set on the two months period January and February 1997 (see Table 1.4 in Part 1 for an overview of the project schedule).

The extra radiosoundings all around the North-Atlantic basin have been performed during the whole two months. The FASTEX ships contributed to these soundings except when in port for two or three days at the end of January. The Victor Bugaev, Suroit and Ægir will be on station for roughly two periods of three weeks. The longest cruise is that of the Victor Bugaev coming from Odessa. The aircraft were to be ready to fly from their different bases from the 6th of January 1997 until the 28th of February.

2.1.2 Operations control

FASTEX observing platforms are distributed all over the Atlantic region and yet, they need to be activated in a highly coordinated fashion. In order to achieve this, a single centre had overall control of operations. The implementation heavily relied on satellite telecommunications (with ships and even with aircraft) and numerical data networks (see Short Note 2.1 for a summary on the telecom and computing aspect of FASTEX).

The Operations Centre was located at Shannon, on the West Coast of Ireland. It is a large international airport very suitably located for catching the wave cyclones of interest to FASTEX.

Because of the large scale of the systems of interest, also because of the emphasis put on cyclone life-cycles, the FASTEX operations are more than ever before a forecast and weather monitoring problem. A recent satellite or radar picture is not enough to decide on the strategy and draft a flight plan. The high degree of coordination between the facilities, the complexity of some flight strategies require relatively precise advance notices that will be based on forecast assessment and comparisons. The main part of the work related to planning and monitoring the activities was performed by a mixed group of forecasters and scientists from the operational and research branches of several national weather services: France, United Kingdom, Canada and Ireland.

It was an important secondary objective of FASTEX to allow for direct exchanges of views, techniques, products and methods between forecasters from different origins

Short Note 2.1: Telecom and computing networks for FASTEX

by M. Chaigneau and P. Bessemoulin

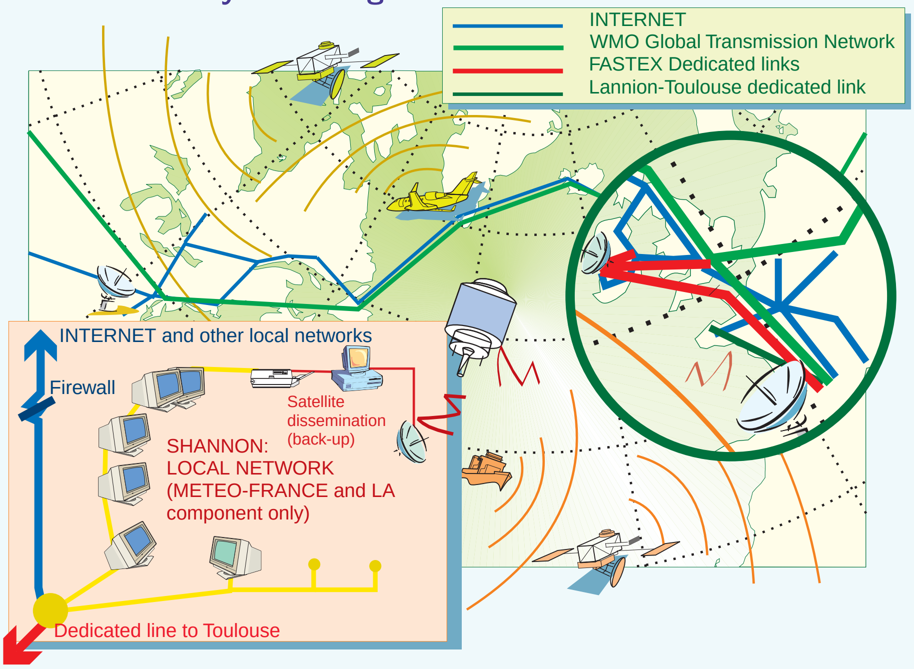


Figure SN2.1.1: *Summary of the main telecommunication links followed by the data with one example of local computing network set-up in Shannon to monitor the data and operations.*

Numerous data items, images, forecast products and so on were required in order for the FASTEX Operations Centre to operate properly. Most groups involved in running the Centre or working in it had to address a telecommunication problem between their base and Shannon, and, on the spot, had to set-up their equipment as part of a local network, all this without jeopardazing the security rules of their respective institutions.

The backbone of the weather data circulates around the globe on a dedicated network called the *Global Transmission System*, coordinated by WMO. GTS data arrived in Shannon from Dublin (via Met Éireann), Bracknell (via the UK Met Office) and Toulouse (via Météo-France), each with different products. Special dedicated data links made this possible:

- Met Éireann upgraded its dedicated link between Dublin and Shannon and extended it from the Shannon Forecast Centre to the FASTEX Operations Centre,
- the UK Met Office set-up a secured and sealed-off fast speed link between Bracknell and the FASTEX Operations Centre,
- Météo-France also set-up a fast speed link between Toulouse and Shannon,
- the other groups (from Canada and the USA mostly) deferred to the UCAR/JOSS unit to set-up an INTERNET connection between the University of Limerick and the FASTEX Operations Centre in order to tranfer information via INTERNET.

Fig. SN2.1.1 summarizes the various lines employed. It also shows an example of local computing network set-up in the FASTEX Operations Centre itself, the one from Météo-France. It included 4 workstations, one of them being provided by the Laboratoire d'Aérologie, 2 printers, 4 connections for portable PCs and one X-terminal and a few other things. This network was logically part of the Météo-France domain, but was open to the UCAR network and INTERNET via a local firewall. In the case of failure of the critical link to Toulouse, a backup with the satellite dissemination from Météo-France was also set-up (see the diagram). Met Éireann, UCAR/JOSS and the UKMO had similar looking implementations. Other impressive local computing networks were brought and installed for the maintenance and data processing of the aircraft based in Shannon. These were designed by NCAR and by NOAA/AOC respectively. They were connected via the INTERNET.

The main stream for satellite images was either via Bracknell to the specific terminal of UKMO, or via the Centre de Météorologie Spatiale of Lannion. This Centre receives data directly from both METEOSAT and the NOAA Polar Orbiting satellites. It transmits some products but it also produces new ones. All of them go on the dedicated line between Lannion and Toulouse and from there to Shannon.

A two-way fax-type link existed with each of the ships, based on satellite communications via INMARSAT mode C. Both information on operations from and to the ships and measurements from the ships went through this link. The observations were put on the GTS in Toulouse in real time.
A somewhat similar link was set-up by the NOAA groups and enabled real time exchanges between the FASTEX Operations Centre or the National Center for Environmental Prediction in Washington and the Gulfstream IV in flight. The Gulfstream IV dropsonde data, formatted in flight mostly through shear hard work by Diana Bartels, from NOAA/NSSL, was sent to Washington and immediately put on the GTS. Within minutes, it was available in Shannon and could be plotted in various ways and discussed on the phone with the flying aircraft, an extraordinary experience.

as well as discussions between forecasters and scientists. Past experience also strongly suggests that it is important that everybody have a direct access to all the available information: the alternative (to have sub-groups working in different places) strongly weakens the coordination.

The processing of the data was also to begin immediately after the completion of the missions as many investigators were at Shannon with groups of scientists and technicians from NCAR and NOAA.

These activities were managed by two bodies of senior scientists. The FASTEX Science Team was to take the major decisions (begin and end an IOP, select strategies, etc) and to oversee the planning. The Science Team, chaired by Prof. Keith Browning, is composed of representatives of the agencies funding major facilities. The other body, the FASTEX Operations Coordination Team, implemented these decisions and surveyed the status of the various components of the observing system. The Operations Coordination Team was lead by the Operations Directors, Drs James Moore and Richard Dirks from UCAR.

During an IOP, there were three types of activities going on at Shannon.

(i) During any flight, both its progress and the evolution of the weather will be monitored.

(ii) Twice a day, when new forecast products became available, the short-term planning (typically, the flight(s) of the next 24 to 36 h) were revised and the corresponding steps were taken (crew warning, Air Traffic Control warnings, small adjustments of ship positions).

(iii) Once a day, the longer-term planning was conducted, based on medium and short range forecast. It was accompanied by a detailed marine forecast for the ships covering the weather and sea state for next two days wherever they were. Outside an IOP, only the last type of activity was maintained.

The way by which the diversity of the interests and objectives of the various investigators were taken into account was simply through the usual process of proposal submission. Except that during FASTEX, proposals were examined on a daily or half-daily basis. The relevant committee was of course the Science Team.

2.1.3 The actual observing system

The previous Part of the report shows the planned observing system (Fig. 1.8). Moreover, all of its component had, in spite of numerous difficulties and uncertainties, been gathered in time. However, technical and logistical troubles always tend to make reality more unexpected and complicated than carefully devised plans imagine it to be.

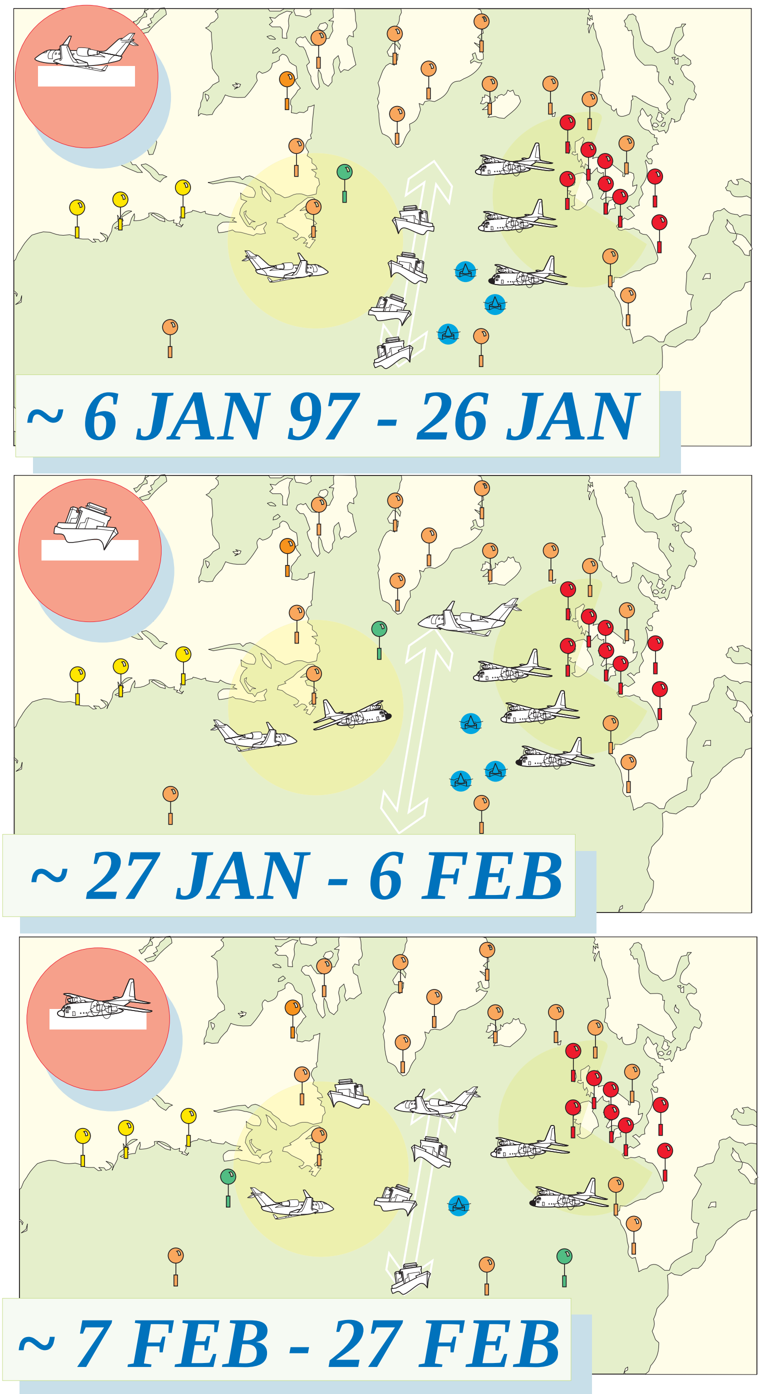


Figure 2.1: *A summary in 3 sketches of the actual observing platforms that were deployed during the field phase of FASTEX, also showing the location of the upper-air stations involved. The shaded zones refer to the areas of Fig.* **??**. *The dates are somewhat approximate, since, for example, the ships were still operating en route when calling to ports in the middle period.*

The actual observing system available during the two months field season is shown in Fig. 2.1. Roughly speaking, the observing problems divided into three periods. During the first period the Gulfstream aircraft was largely unavailable. During the second period, the ships had to call into ports. During the last period the Electra aircraft had to be withdrawn for mechanical reasons just at the start of the MSA missions in IOP 12. One of the ships (the RV Knorr) was reassigned to another project, the Labrador Sea Experiment (however, the crew still maintained a link with FASTEX and actually took part in some IOPs). On the positive side, the first period was run with four ships as planned and an intercomparison of the flux measurements took place; all the other components performed quite well. In particular, the first complex coordinated flights in the Multiscale Sampling Area were a success. In the second period, the Gulfstream became fully available and two C-130 were provided by the US-Air Force: they took part mostly to the test of adaptive observations but, to some extent, they also replaced the ships (as in IOP 9, for example). Finally, during the last period, when some of the most interesting cyclones occurred, all the available components were employed at their full potential.

2.2 Meteorological conditions

In the course of the planning of FASTEX, it was found that the notion of weather regime, as defined by Vautard *et al.* (1988), is useful for highlighting conditions favourable to the type of event of interest to FASTEX (see Short Note 1.1).

Things did not turn out along the way determined by the preliminary climatological study, as far as regime frequency are concerned. It was, with hindsight, fortunate, as will be explained. Averaged meteorological conditions relevant to the FASTEX period are displayed in Fig. 2.2. Analysed fields have been projected on the weather regime fields to determine, daily, the closest one (see Santurette *et al.* (1999)). On this basis, it appears that there were three distinct periods. The year 1997 started with a fortnight of Greenland Anticylone regime, although in practice, it was more an Icelandic ridge than a true anticyclone. The actual mean flow for this period, although close to this reference climatological regime, also had some characteristics of the highly unfavourable Blocking Regime. It was characterized by a jet-stream confined near latitude 40°N and meridionally to the west of 40°W, and more intense than in the climatology. East of this area, there was a large variability (both in the wind and geopotential, not shown) which can be attributed to the lower frequency component of the flow and marks this tendency towards Blocking. Thus systems remained at relatively southern latitudes in general but were able, on occasion, to move north-eastwards and temporarily establish a baroclinic area extending from the end of the average wind maximum to iceland. It also means that the baroclinic driving of the weather systems near the European side was quite weak (on average) and their behaviour sometimes unusual.

The second half of January was dominated by Blocking. The jet-stream was weak compared with the other two periods, but close to its climatological value (about 40 ms^{-1}). These two periods were, from an operational point of view, useful for testing the procedures and gaining experience in readiness for the suitable weather that occurred in February.

The whole of February, finally, was characterized by the wanted Zonal regime. It was associated with rather low total variability, meaning that it was very stable. On average, the wind at 300 mbar was 10 ms^{-1} stronger than its climatological value

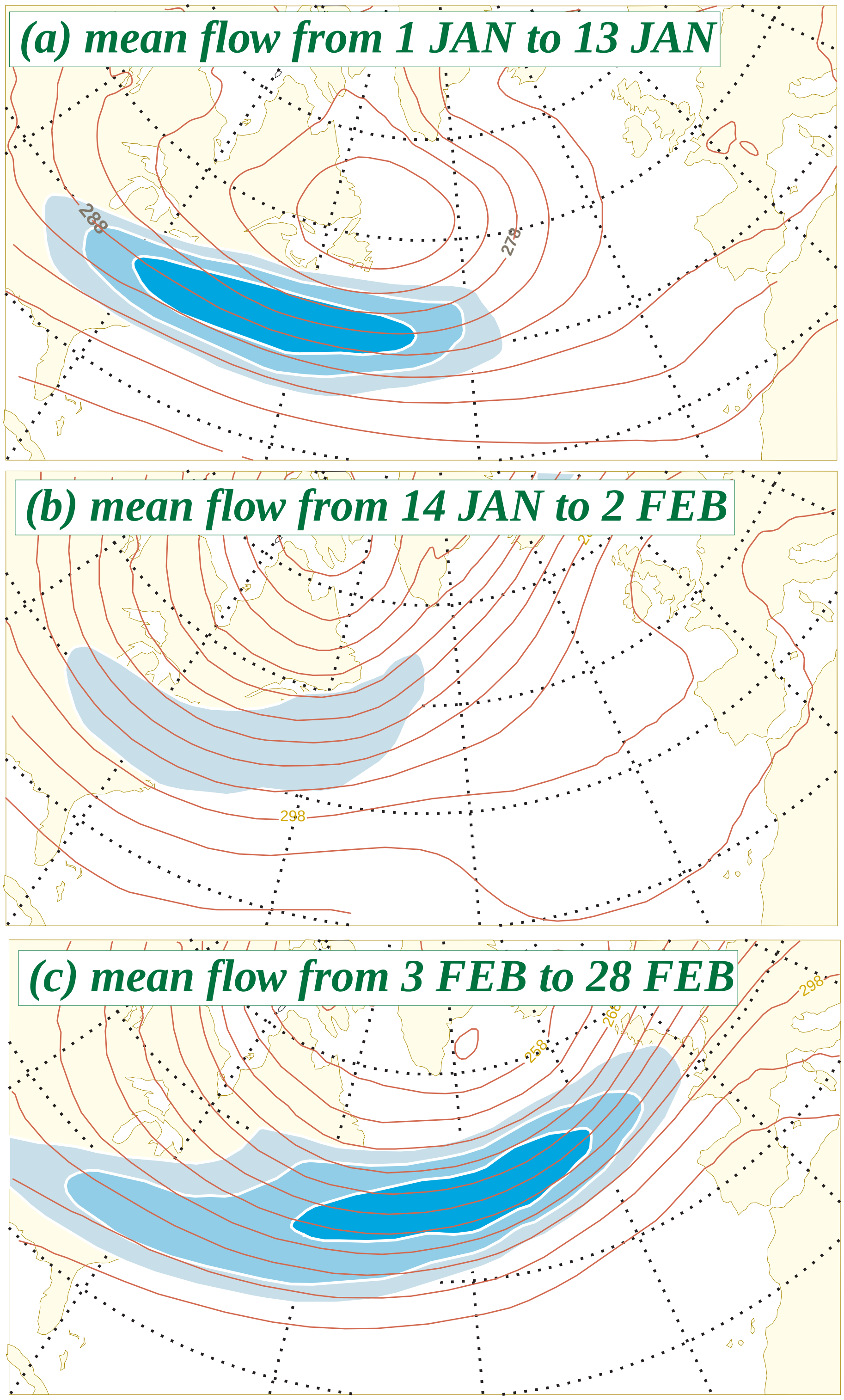


Figure 2.2: *A summary of the averaged meteorological conditions during FASTEX. Contours are 700 mbar geopotential (every 5 damgp) and the three intensities of shading indicate 300 mbar wind in excess of 40, 45 and 50 ms^{-1}. Figure prepared by B. Pouponneau, Météo-France, using the ARPEGE analyses included in the Data Base.*

(see Short Note SN1.1.1), although the overall shape of the jet-stream was close to the reference Zonal regime, with a baroclinic guide extending unbroken from Halifax to Kerry in Ireland. Around 17 February, the jet peaked at about 100 ms^{-1} for about two days. These conditions provided suitable cyclone events. People and machines were also well tuned by that time to the procedures of FASTEX.

During FASTEX, all the lows that moved over the North-Atlantic ocean were numbered sequentially. During the two months of the field experiment, about 50 lows have crossed this broad area. The density of tracks for January and February are shown in Short Note 1.2 and provide a necessary additional picture to the mean flow as shown in Fig. 2.2.

The FASTEX aircraft based in Shannon, Ireland. Photo: N. Raynal, Météo-France.

The UKMO C-130 in action. Photo: UK Met Office.

Above: the NOAA P3 in operations during a previous experiment, TOGA-COARE. Photo: B. Smull, NOAA. Right: the NCAR Electra, also during TOGA-COARE. Photo: R. Bumpas, NCAR.

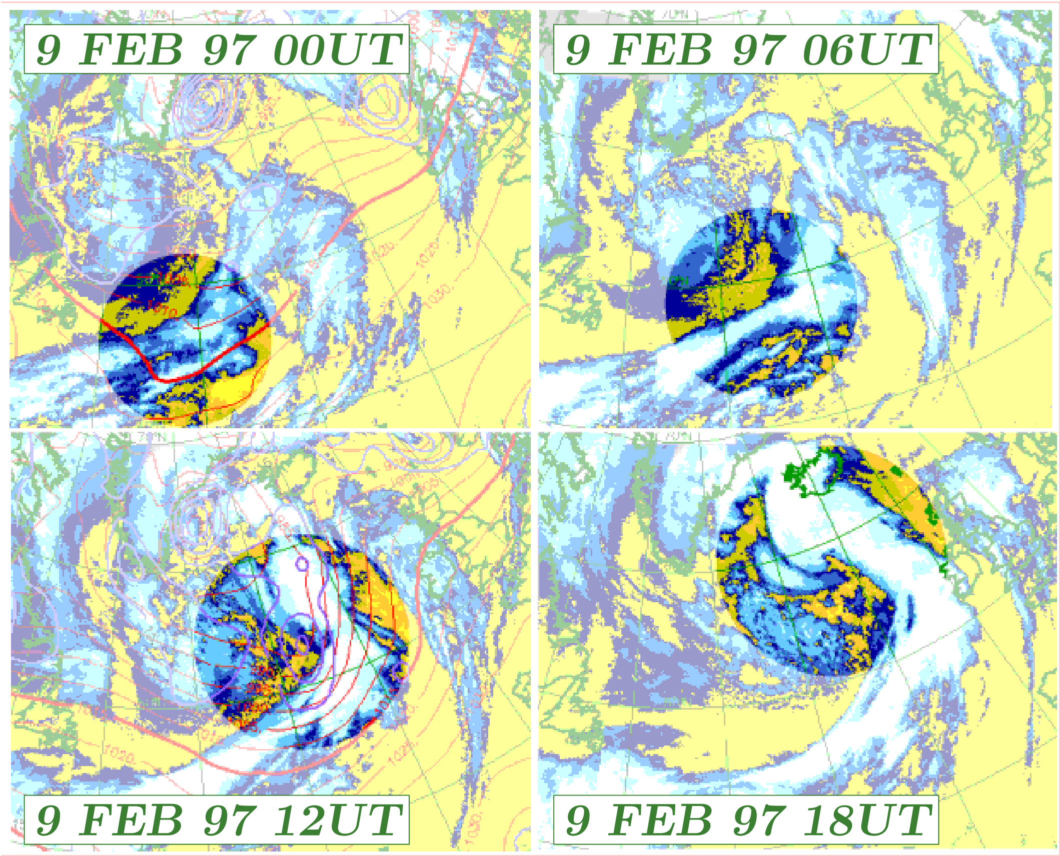


Figure 2.3: *Development of Low 34 on 9 February 1997, FASTEX IOP 12. Low 34 is encircled. Images are in the infra-red channel and are a composite of METEOSAT and GOES. On two images, two fields from the operational Météo-France analysis (that includes FASTEX data) are superimposed. The purple lines are absolute vorticity at 850 mbar from 1.5×10^{-4} s^{-1} every 0.5×10^{-4} s^{-1}. The red lines are mean-sea-level isobars, drawn every 5 mbar.*

2.3 Example of an Intensive Observations Period: IOP 12

The best way to convey a flavour of FASTEX operations is to summarize the story of one Intensive Observing Period. Because of its unique mixture of exciting meteorology and dramatic operational events, IOP number 12 is now presented.

The meteorology will be discussed first. IOP 12 was conducted on Low 34. This cyclone underwent, on 9 February 1997, the most explosive deepening of the period: roughly −54 mbar in 24h, with a phase of −23 mbar in 6h. This very rapid development goes along with a very short life-cycle. It is summarized by Fig. 2.3. The background shows infra-red images composited from both geostationary satellites GOES and METEOSAT. The figure also shows the mean-sea-level pressure and low-level vorticity analyzed by the Météo-France operational suite ARPEGE. An individual vorticity maximum can be tracked from 9 February 00UTC onwards, whereas closed isobars can be seen only when the low is fully developed, after 18UTC. The analysed sea-level pressure falls from about 1015 mbar on 8 February 18UTC to 961 mbar on 9 February 18UTC. Between 6UTC and 18UTC 9 February, Low 34 moved about 1700 km at a phase speed of nearly 40 ms^{-1}. The life-history of this system began, however, on 8 February between 00 and 06UTC. This is somewhat to see with most usual fields, including the images. However, the use of time-filtering, for example, enables a separation between perturbations and background. Precursors can then be isolated.

Low 34 was preceded by a series of active systems. It marked the end of first most active portion of the zonal regime. After it, the activity in the eastern part of the Atlantic basin subsided somewhat before building up again about a week later. Panel (a) of Fig. 2.3 shows two of the preceding lows: Low 31, a quasi-steady system close to Greenland and Low 33 north of Ireland, a rapidly evolving "typical" cyclone that, for logistical reasons, could not be considered for an IOP. This category of case is discussed in the next section.

The dynamics of Low 34 will be briefly returned to in a paragraph or so. Its associated Cloud System is discussed in more details in Part 5 and Part 6 in this Report. See also, for example, Scialom *et al.* (1999) in this issue or Chaigne (1998) and compared to a Pacific case by Lemaître and Protat (1999). Consider now how the life-cycle of this cyclone has been followed.

The first tentative plan for a possible IOP 12 on a Low 34 was drafted on the basis of the forecasts starting on 5 February 00UTC and, for the ECMWF model, 4 February 12UTC. As the Low was expected to be in the western part of the MSA on 10 February 00UTC, it is important to note that these are 120h and 132h respectively. As summarized in section 2.6 below, decisions for FASTEX were prepared using an "ensemble" of many different numerical models. Needless to say that there was a wide discrepancy in the various forecasts, but at the same time, there was enough consistency to convince the team of forecasters that a new IOP might be declared. As soon as 5 February 12UTC, a westbound flight of the Gulfstream-IV jet aircraft was planned for 8 February, a return flight on 9 February and a coordinated MSA flight of turboprop aircraft on 10 February.

The reader has now to realize that these "long-term" decisions were taken in the midst of running IOP 11 on Low 30, a case that led to long, difficult discussions because of the possibility of a wave forming in its wake. And this IOP came immediately after a series of three in a row so that a number of logistical "clocks" were running out time: days without operations had to be set into the schedule for crews to rest and for some maintenance of the aircraft. For these reasons, a choice had to be made between Low 33 and Low 34 for an IOP: the latter, which turned out to be the more interesting one, was chosen. These decisions were confirmed on the following day, that is 2 days prior to the first airborne operation relating to IOP 12, and 3.5 days before the cyclone sped into the MSA: the schedule was defined more precisely (mid-times were assigned to a number of flights)with the coordinated flights in the MSA rightly moved closer to 00UTC 10 February. The ships were informed of the likely IOP scenario and that they would have to perform 3h radiosoundings for 24 hours as from 8 February 12UTC. These decisions were taken on the basis of 96h and 108h forecasts (which are, with hindsight, generally less good than the previous ones) and the decision not to fly the turboprops on Low 33 was maintained. In this series of forecasts and the following one, Low 34 deepened to only 980 mbar, with a dispersion of 8 mbar at most, making the decision far from clear cut. On 7 February,

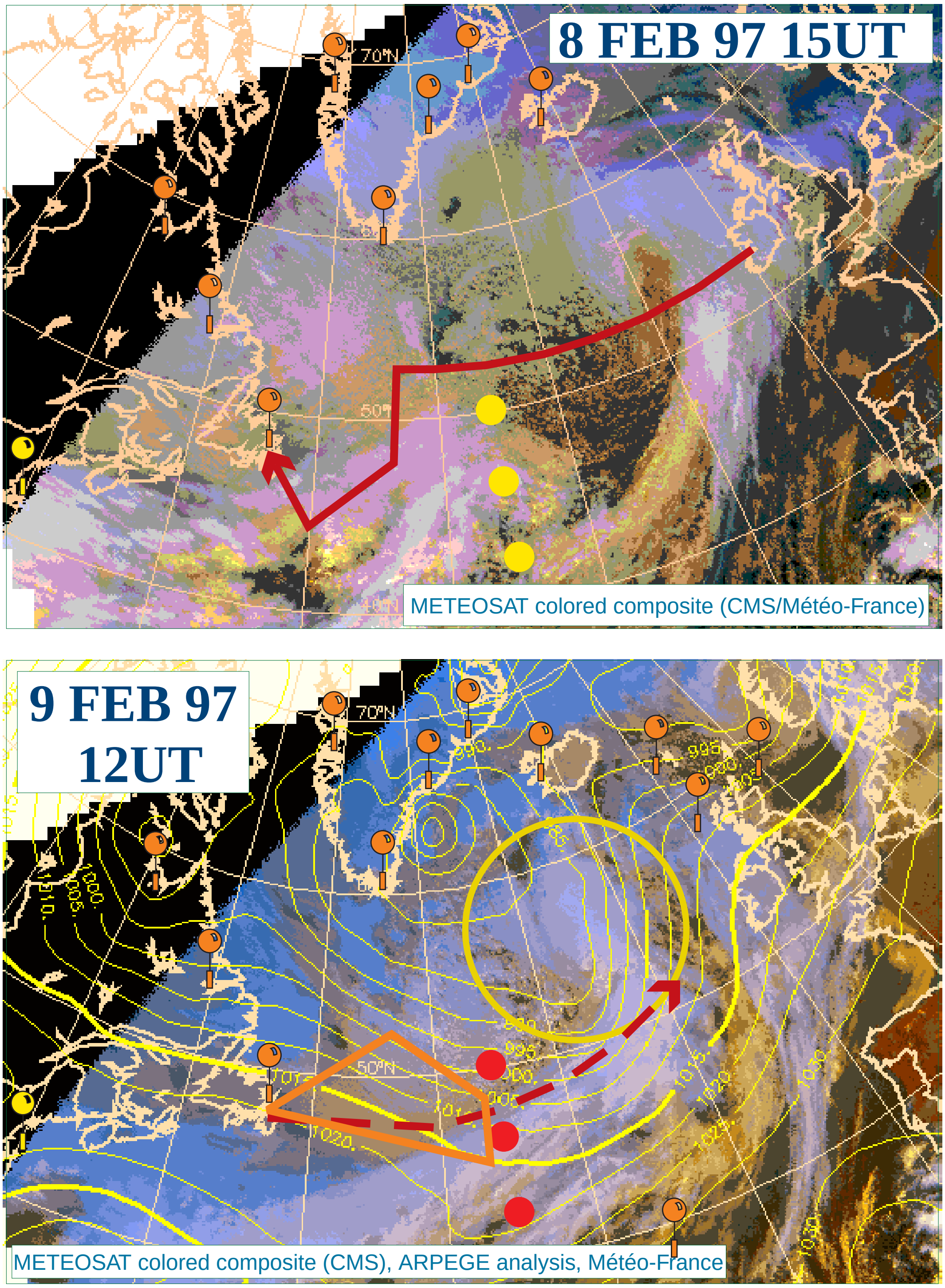


Figure 2.4, beginning.

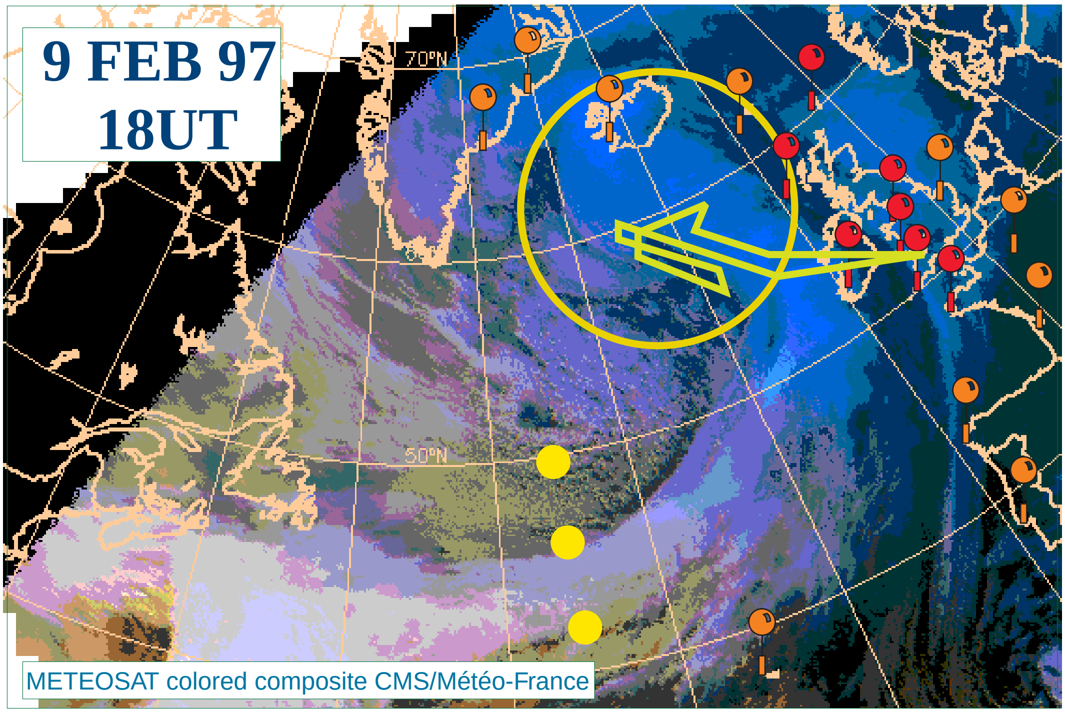
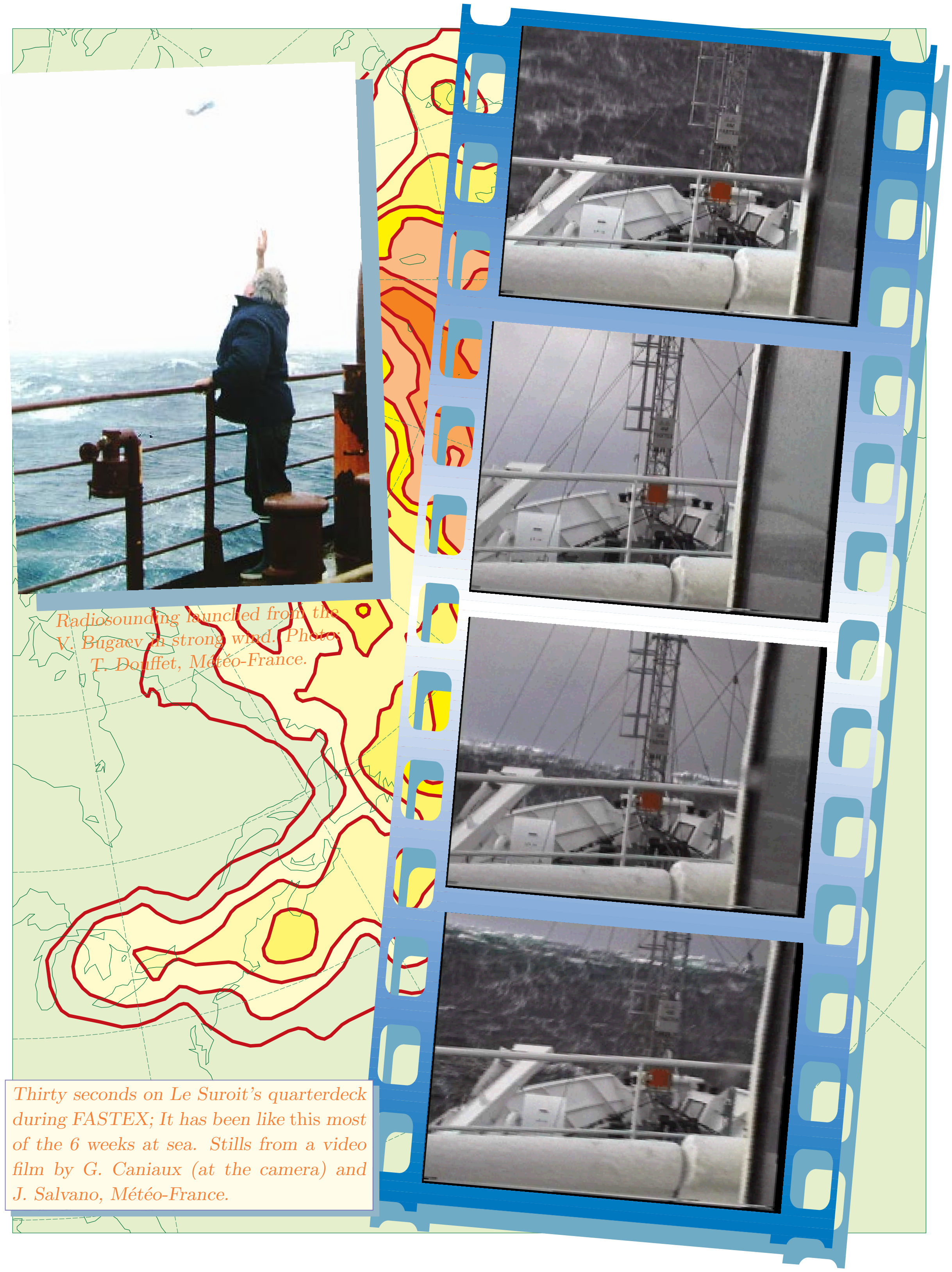


Figure 2.4: *A summary of operations during IOP 12. The lines show flight tracks (dark red: Gulfstream; orange: US C-130; green-yellow: UK C-130). The large dots show the ships location, performing intensive radiosoundings when red. All upper-air stations shown (balloon symbols) were operating every 6h except the red ones which were operating every 3h. The difficult and eventful St-John's–Shannon flight of the Gulfstream IV on 9 Feb is dashed; no data were taken. The backgound images are multichannel composite images from METEOSAT prepared by the Centre de Météorologie Spatiale, Météo-France. See also summary 3.15, page 112 in Part 3.*

the day prior to the beginning of IOP 12, the discrepancy between the various forecasts remained quite large and Low 34 still appeared to be unexceptional except in the 72h ARPEGE forecast. These are signs that the case could be a promising one for testing the adaptive observation strategy: specific targets for this system were determined by the various groups involved in this aspect of FASTEX: the NRL in Monterey, NCEP in Washington, ECMWF in Reading and Météo-France in Toulouse. Contacts were made between the project headquarters at Shannon and Washington to try to coordinate "targeting" flights between aircraft already based in St-John's and the Gulfstream-IV, set to join them on 8 February. The divergence amongst forecasts led two scenarios being considered: one close to the original plan, the other focused on a new system, called Low 34B, that was not present previously (and that did not turn up in the real world), but which required a delay of about 12h in a number of flights. A few more soundings were ordered from the ships.

The forecasts available in the early morning of 8 February showed a much better agreement between the various models and now predicted Low 34 with a minimum pressure between 953 mbar and 968 mbar, with little dispersion as to its location. On this basis, two flights dedicated to adaptive observations were prepared, one from the



Radiosounding launched from the V. Bugaev in strong wind. Photo: T. Douffet, Météo-France.

Thirty seconds on Le Suroit's quarterdeck during FASTEX; It has been like this most of the 6 weeks at sea. Stills from a video film by G. Caniaux (at the camera) and J. Salvano, Météo-France.

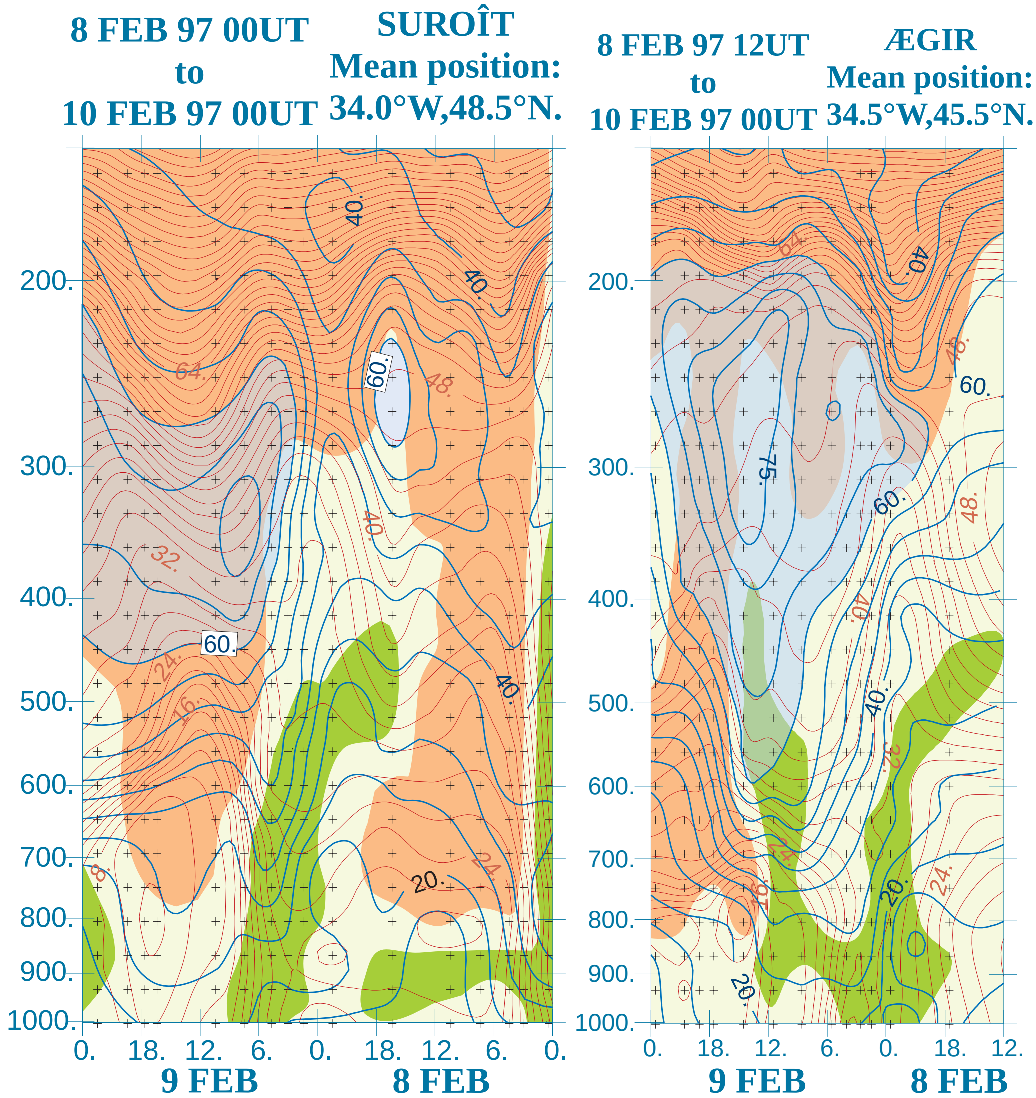


Figure 2.5: *Vertical-time cross-sections derived from the radiosoundings taken from RV Suroît (left) and CC Ægir (right) during IOP 12. The time scale has been reversed so that the figures are suggestive vertical cross-sections with West to the left and East to the right. The heavy blue lines show the wind speed every 5 ms^{-1}, shaded above 60 ms^{-1}. The light dark-red lines are θ_w every 2 K. Light orange shading marks the location of very dry air (less than 40 % relative humidity). Green shading indicates likely cloudy areas (more than 80 % relative humidity). The small crosses indicate the data points. The analysis has been performed with spline functions. Figure built from the soundings from the FASTEX Data Base by G. Desroziers, Météo-France.*

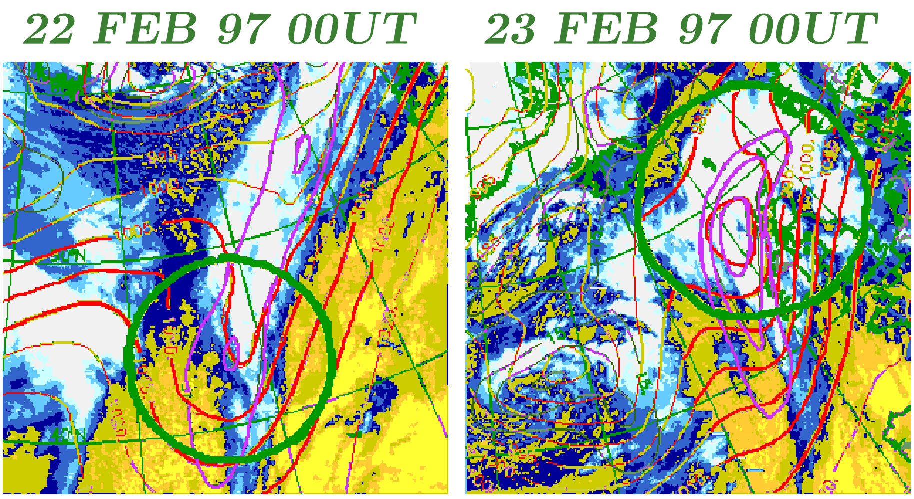
Gulfstream-IV (upon reaching the western Atlantic on that same day) and another by a USAF C-130 about 24h later, on 9 February. The Gulfstream data were also intended to study the early stages of the formation of Low 34. The next step in the plan was to collect data on the rapidly deepening phase using ship soundings and the return flight of the Gulfstream-IV back to Shannon on 9 February, at about 15UTC.

Finally, the three turboprops were to sample the mature system in the evening of 9 February while 8 upper-air stations along the west coast of Europe would be launching 3-hourly soundings.

The actual operations managed on this case are summarized by Fig. 2.4. Low 34 behaved more or less as anticipated from the 48h or so forecast runs. The Gulfstream-IV properly sampled the predictability “target”. As was often the case, this target was located, at low levels, in the warm air to the south-east of the system of interest. The ships, although fully in the track of the cyclone and accompanying gale force winds, managed to perform the required soundings. The USAF C-130 flight on 9 February sampled the wake of Low 34 in case Low 34B showed up (the data may help explain why it did not). However, shortly after the Gulfstream-IV took off from St John’s for what might have been an optimal flight sampling the structure of a deepening cyclone, one of its electric generators stopped functioning. The flight was completed safely, albeit with much anxiety and without a number of equipment and functions, but, of course, invaluable soundings were lost. However, there was still the possibility to study the detailed structure of the cloud system with dropsondes from the C-130 and both airborne Doppler radars. The UKMO C-130 and the P3 aircraft took off successfully but the mechanical problem of the Electra prevented it to join them. Radio communications with the other two turboprops allowed for in-flight adjustment of the plans to compensate for the absence of the Electra. Then, the C-130 met numerous difficulties with its first dropsondes. However, they were solved and a successful operation resulted. In spite of all these problems, valuable data were obtained at various stages of the evolution of Low 34 . Operations on this case had been planned over a period of 4 to 5 days and lasted two days only. In a number of other cases, the actual operations covered three days continuously and, in the case of the linked IOPs 9 and 10, four days consecutively, plus a several more days upfront for planning.

Fig. 2.5 illustrates features of interest during the development of Low 34, as seen from the ships. The Ægir Coast Guard vessel was directly in the path of the cyclone and its low-level thermal structure clearly shows up, between 0 and 6 on 9 February in the form of a narrow warm conveyor belt. Most interesting, however, is the tropopause anomaly that can be seen moving above the Ægir during the evening of 8 February. As shown in the figure, this anomaly is on the wrong side of the low for constructive baroclinic interaction. Analyses show that it took place earlier on 8 February, but the upper-level anomaly moved eastward at 43 ms^{-1}, while the surface precursor, a warm maximum in the soundings from the Ægir travelled at 19 ms^{-1}. The rapid development was due instead to the influence of a second upper-level anomaly, more intense, that can be seen in the soundings from the Suroît ship at 12UT on 9 February.

The importance of the two successive baroclinic interactions has been demonstrated by Chaigne (1998). He shows, using potential vorticity inversion, that if this second upper-level feature is removed, Low 34 does not develop. He also shows that if the surface precursor generated on 8 February is removed, Low 34 again does not develop. From the point of view of the dynamical objectives of FASTEX, this case shows the reality and importance of transient baroclinic interaction between two features as well as the fact that a strong cyclone does not emerge from continuous growth. Rather, it grows in steps and each can involve different features. This indicates that one needs to be very careful when defining a system of interest. This case illustrates one of the conclusions from the climatological work of Ayrault (1998): rapid deepening involves two *independent* precursors at least: one in the lower troposphere, the other at the tropopause.



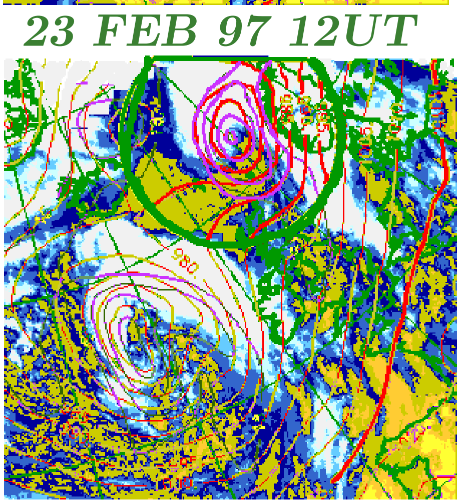


Figure 2.6: *Development of Low 42B on 22 and 23 February 1997, prior to Low 44 that was the subject of IOP 18. The latter can clearly be seen on panel (c) to the south-west of the circle. The phase of rapid development was highly uncertain at the time a choice had to be made between these two cases. This a typical case of interest for FASTEX that has to be included, with hindsight, in the collection. Contour definition and interval as in Fig. 2.3.*

2.4 The Lesser Observations Periods during FASTEX

According to the previous section critical decisions regarding IOP 12 were taken 3 days before the system even existed. Difficulties raised by the differences between forecasts have been alluded to, as well as those resulting from operational constraints. It was because of the operational constraints that Low 33, although the type of system of interest to FASTEX, was not the subject of intensive observations: the rapid succession of IOPs 9 to 11 imposed a break in the operations.

Yet Low 33 was by no means totally deprived of special observations. 54h prior to Low 33 entering the MSA, a long flight of an USAF C-130 from St-John's covered the broad area around 50°W and 45°N where the low started to form later. The ships were on the track of this low as well and performed 8 soundings per day on 7 and 8 February as Low 33 developed. And finally, as the Gulfstream flew towards St-John's on 8 February, it sampled the same low, still undergoing deepening, with a series of dropsoundings, providing a minimum set of data in the MSA. These are the components of a mildly successful IOP and so this case has been included in the FASTEX set. It was, indeed, labelled IOP 11A.

Low 33 is not an isolated case. After the field phase was completed, a second set of systems was added to the main FASTEX Intensive Observations Periods: the

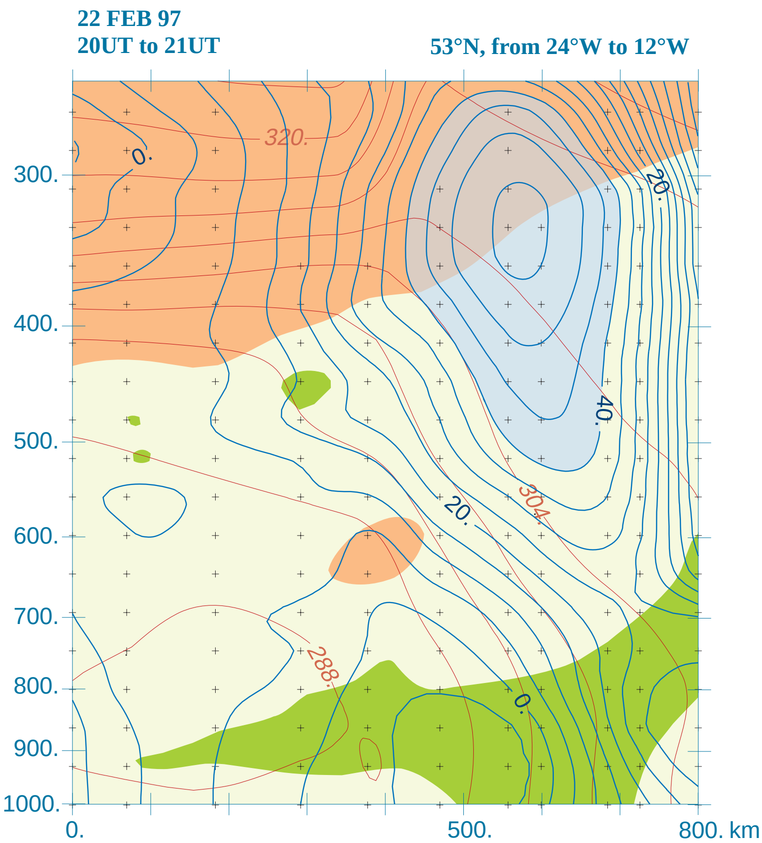


Figure 2.7: *Vertical cross-section derived from the dropsoundings taken from the Gulfstream-IV aircraft at the end of a flight part of IOP 18, but describing the cyclone 42B that was not selected for an IOP. Contours and shading are as in Fig. 2.5, except θ_w drawn every 4 K and the wind is shaded when larger than 40 m.s^{-1}. The analysis has been performed with spline functions by G. Desroziers (Météo-France) using the FASTEX Data Base.*

FASTEX Lesser Observations Periods (FLOP). They fall into two categories: the first is made up of the cases like Low 33 that were only partially covered for logistical reasons. The second category is, given the objectives of the project, quite an important one: it contains the cases only partially covered because they were wrongly anticipated from the forecasts. They epitomise the "FASTEX dilemma" mentioned in section 1.6 Since FASTEX is about understanding predictability, looking back on these cases can be helpful. Figure 2.7 illustrate a case falling in the second category, one model only having predicted its existence at the time a decision had to be made for an IOP 18. This figure also shows the capabilities of the Gulfstream-IV to map cyclone-scale features. These two cases are now included in this series of interesting cases as FLOP 2 and FLOP 5.

The story of IOP 12 is successful because the decisions taken early were confirmed and turned out to be the right ones. One cannot expect this to have been true all the time. Fig. 2.6 shows a cyclogenesis event belonging to this second category. At an early stage, an assumption has been made in order to choose between two cyclones (Low 42B shown on the figure and Low 44 that was the subject of IOP 18: it can be seen on panel (c) of Fig. 2.6) that turned out to be wrong. Low 42B is of a high priority for FASTEX because it is undoubtedly what a synoptician would call a frontal wave. Furthermore, the prediction of its evolution has been very difficult. Low 42B formed along the meridionally oriented cold front of Low 42 during the night between 21 and 22 February. However, most of 22 February, it moves northward along the front without really developing. It appears, on the satellite images, as a thicker

Short Note 2.2:
Surface fluxes in the North-Atlantic Current during FASTEX

by L. Eymard, G. Caniaux, H. Dupuis and L. Prieur

An oceanic component has been added to FASTEX: CATCH *(Couplage avec l'Atmosphère en Conditions Hivernales, Atmospheric Coupling in Winter Conditions)*. It was performed from the research vessel Le Suroît, near 47°N and 40°W, an area characterized by the presence of the warm North-Atlantic Current (NAC) in a cold surrounding water.
CATCH aimed at studying the surface fluxes variability related to the passage of atmospheric fronts, of the role of strong sea surface temperature gradients associated with the North-Atlantic Current and of the parameterization of surface turbulent fluxes in strong and changing direction wind. The first results of the analysis of the ship data, relocated in the major mesoscale features, is presented in details in Eymard et al. (1999). They have been obtained by combining buoy measurements, satellite data and meteorological output together with the direct observations. The surface turbulent and radiative fluxes are derived from ship measurements and compared with model and satellite estimates.
The turbulent fluxes from the ship have been obtained using the inertial-dissipative method. A bulk algorithm has then been derived and the results of this parameterization are compared to other previously published ones. Fig. SN2.2.1 shows the results for the momentum fluxes. For this parameter, it appears that existing schemes systematically underestimate the stress.
The major novelty of this dataset is that it contains observations at large wind speeds (between 20 m/s and 30 m/s) under a variety of temperature and stability conditions. This area of the parameter domain has seldom been explored in the past. Results such as those shown in Fig. SN2.2.1 may have a dramatic impact in climate simulations, especially in coupled simulations.

About the authors:
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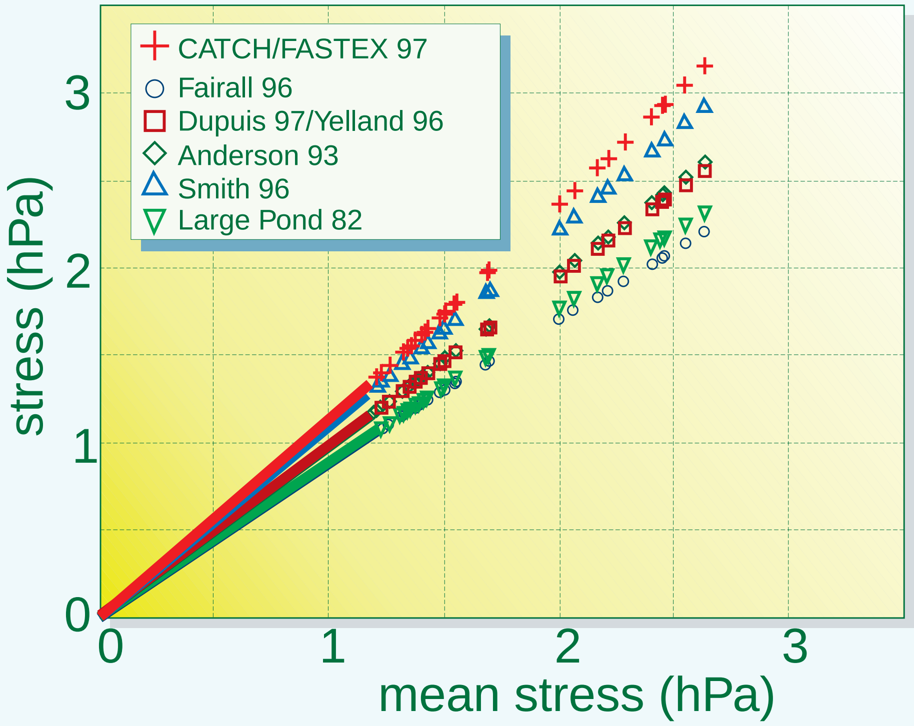
Figure SN2.2.1: *Scatter plot of the momentum fluxes calculated from 6 bulk flux formulae according to the mean flux.*



section of the frontal cloud band. And then, during the night between 22 and 23 February, it deepens rapidly and took, at the same time, a more usual shape.

The choice between Low 42B and Low 44 was made on 20 February on the basis of a series of 72h (84h for ECMWF) forecasts. One model, the UK Met Office global one this time, moderately developed Low 42B, the others not. Non developing cases were to be included in the FASTEX set, but they had already been met at that time. Although the transition from repressed development to explosive growth is of obvious interest as well, it was thought to be too uncertain. It is only on the 24h forecasts and less that things changed, but the operations on Low 44 were decided already. However, as was done on Low 33, Low 42B was sampled by a series of dropsondes from the Gulfstream-IV in the MSA on the evening of 22 February: the resulting section is shown as Fig. 2.7. This case therefore benefits from the improved background obsrvations as well as from special observations. It can be studied practically as any of the more standard IOP cases and is included in the FASTEX set as FLOP 5. It should also be noted that IOP 18 on Low 44 is important in the FASTEX sample, since it is a very well documented case of a life-cycle occurring on the northern side of the baroclinic zone. A transition from restrained growth to explosive deepening has been observed in IOP 19.

2.5 Summary of operations and overview of cases

The scene is now set for taking a broader perspective and presenting the complete set of FASTEX cases. There are 25 of them: 19 IOPs were declared and run as such, 6 LOPs were included at the end of the field phase, when the whole period was reassessed (FASTEX was initially planned to allow the study of 10 cases). Almost all cases concentrate on a particular type of cyclone or on a feature such as front that did not allow for a cyclone to form. All these cases are in line with the objectives of the project: the sole exception is IOP 8. IOP 8 took place, during the blocking period, when no cyclone could possibly reach the eastern Atlantic. In order to maintain a minimum of activity, a flight from the Gulfstream was set up and directed towards Greenland in order to document upper-level lee waves. However, apart from the fact that the flight intersected a coastal front, this IOP is difficult to include in the summary tables.

The achievements of the field phase of FASTEX are summarized in Table 2.1. Part 3 provides more detailed information on each FASTEX case (including IOP 8): key dates and locations, flights and other operations.

2.5.1 Potential for cloud-system and mesoscale studies

This category of objective has suffered from the premature withdrawal of the Electra. Nonetheless, good datasets were collected from the very start of the field phase as indicated in the last three columns of Table 2.1. This is due, to a large extent, to the high degree of cooperation achieved very early in the project by the scientists involved as well as to their ability to explain their operations to the aircraft crews. The success is also attributed to the development, by the JCMM and NSSL scientists of software to perform system-relative, multiple-aircraft flight planning. The complexity of coordination resulted from the need subsequently to analyse the structure of the core of the cyclones with quasi-regular flight pattern in system-relative space. In one configuration, the same sampling area was to be covered by both dropsondes and

Table 2.1: *Summary of operations on each FASTEX case*

	Soundings at 3 successive stages	Upstream data for targeting	Ship data for targeting	Upstream data for dynamics	Ship data for dynamics	MSA sampled with dropsondes	Airborne Doppler data in MSA	3hourly European west-coast soundings
IOP 1	–	–	–	–	end ampli	●	ss ∗∗	∗∗
LOP 1	–	–	24h	–	beg ampli	–	–	∗∗
IOP 2	●	36h	48h	–	–	●	mi ∗ ∗ ∗	∗∗
IOP 3	–	48h	24h	gen	ampli	–	–	∗∗
IOP 4	–	–	48h	–	organ	–	–	∗∗
IOP 5	●	48h	36h	–	organ	●	mi ∗∗	∗∗
IOP 6	–	–	18h	–	beg sup	●	–	∗∗
IOP 7	–	–	18h	–	front	● ●	ss ∗ ∗ ∗	∗∗
IOP 9	●	42h	(C130)	ampli	(circl)	●	mi ∗∗	∗ ∗ ∗
IOP 10	●	18h	30h	gen	beg gen	●	ss ∗ ∗ ∗	∗ ∗ ∗
IOP 11	●	36h	18h	beg ampli	front	● ●	ss ∗∗	∗∗
LOP 2	●	48h	18h	–	ampli	●	–	–
IOP 12	●	30h	12h	rear gen	beg ampli	●	ss ∗∗	∗ ∗ ∗
IOP 13	–	48h	48h	circl	beg dec	–	–	–
LOP 3	–	48h	48h	–	beg gen	–	–	–
IOP 14	–	48h	24h	–	beg dec	–	–	–
IOP 15	●	24h	18h	rear	ampli	●	ss ∗∗	∗
IOP 16	●	24h	12h	–	beg gen	●	ss ∗ ∗ ∗	∗ ∗ ∗
LOP 4	–	48h	24h	–	clust	–	–	∗ ∗ ∗
IOP 17	●	42h	18h	ampli 1	wave	● ●	ss ∗ ∗ ∗	∗ ∗ ∗
LOP 5	–	–	36h	–	beg gen	●	–	–
IOP 18	●	36h	12h	gen	ampli	●	mi ∗∗	∗ ∗ ∗
LOP 6	–	48h	36h	–	beg dec	–	–	∗ ∗ ∗
IOP 19	●	30h	24h	wave	sup waves	●	–	∗∗

Abbreviations for life-cycle stages:
- beg: early step of stage
- gen: genesis
- rear: rear (western) component
- circl: soundings all around system
- clust: cloud cluster
- ampli: amplification, deepening stage(s)
- organ: organisation, "shaping"
- sup: suppression (of waves)
- dec: decay.

Symbol ● means "yes" or "present"
Symbol ● ● marks that 2 sets are available.

Targeting lead times: the figures are orders of magnitude based on the life-cycle of the systems. They are not the exact values employed by a particular targeting group.

Coverage in the MSA:
- ss: systematic survey
- mi: mesoscale investigation
- ∗∗: 70–80% sucess rate of sampling
- ∗ ∗ ∗: 100% success rate of sampling.

From IOP 12 onwards, the Electra is removed.

European west-coast radiosoundings:
∗ means that only the UK stations actually on the west coast were active.
∗∗ means that only the stations actually on the west coast were active.
∗ ∗ ∗ means that all the participating stations were active.

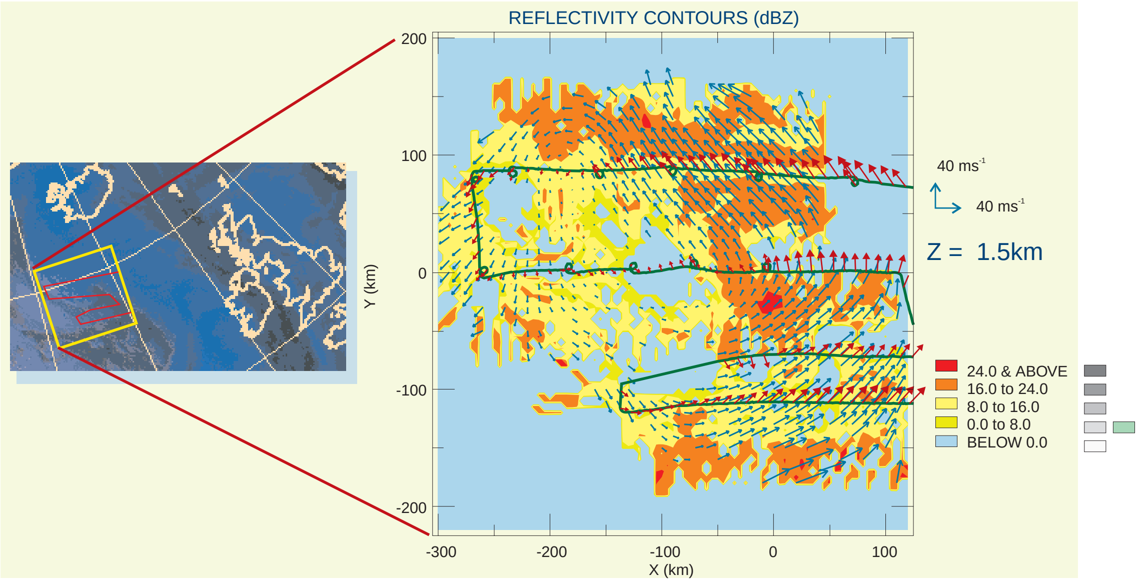


Figure 2.8: *METEOSAT multichannel composite image of Low 34, during IOP 12 (left), as in Fig. 2.4. Airborne Doppler analysis of winds at 1.5 km retrieved with the MANDOPA technique over the bow indicated on the satellite image. Shading on the radar image shows the reflectivity. Figure prepared by A. Protat, from CETP: see Part 6 for further details and results.*

adjoining airborne Doppler radar swaths. This mode of operation, called "systematic survey" was tested in the very first IOP. It turned out to be successful from this first attempt (see the work of Jorgensen *et al.* on this IOP). The flight planning problem is not simple and its proper handling by scientists and crews is one significant accomplishment of the project.

Systematic survey patterns have been achieved on 4 occasions with three aircraft and another 4 occasions with two aircraft. Bouniol *et al.* (1999) present results of such a flight made during IOP 16. In four other IOPs, detailed observations of of mesoscale features embedded within the cyclones were obtained by airborne Doppler radars in an environment sampled by dropsondes from the C-130. Some early results are presented in this Report (Part 5, 6 and 7). This is close to the target 10 cases. Fig. 2.8 illustrates the flow organisation within the cloud head of Low 44 (during IOP 18) derived from the P3 tail radar at NOAA/NSSL.

2.5.2 Potential for air-sea interaction studies

This component of FASTEX started as a kind of opportunistic adjunct to the project. Its contribution to studying the complex influence of surface fluxes on cyclogenesis addresses a not well resolved question. At the same time, its contribution to the problem of parameterizing properly these fluxes in the presence of high sea and under strong winds is more clear-cut: see Short Note 2.2 for a brief overview of the results in the domain of parametrization. In this area, a truly unique data set has been gathered by the Suroît and Knorr research vessels. The required conditions have been met (indeed, the ships were hit, on average, by a cyclone every other day) in a wide sample of vertical stability and temperature conditions. The reader is referred to the overview of Eymard *et al.* (1999) to see that this topic should soon benefit from FASTEX data. These results have direct implication for climate simulations.

2.5.3 Potential for dynamical meteorology studies

The primary objective of the field operations was to collect special data, in the form of vertical profiles, at three or more stages of the evolution of a number of cyclones. The first column of Table 2.1 shows that this was achieved in 12 cases. The criteria for success are: special soundings have been taken successively in *(i)* the Far Upstream Area either at an early stage of the weather system of interest or in a likely sensitive area for predictability; *(ii)* the Midstream Area, mostly by the ships or by the Gulfstream or a C-130; and *(iii)* in the Multiscale Sampling Area, the last two being within or close to the weather system.

There is, of course, a hierarchy amongst the succesful cases, depending on the number of successful soundings, their location in space and time with respect to the system, the presence of upper-level data or the number of samples collected. The most comprehensively observed one is IOP 17. It took place from 17 to 20 February. The weather system, Low 41, formed off the East-Coast of America from multiple precursor features. It was tracked for 67h, over a distance of 5500 km. The ships were properly located, the Suroît having been moved in time to be on the track of this low. They managed, in spite of the wind and the sea, to perform soundings every 90 minutes as the low moved over them. Five successive flights were performed and another earlier flight, on the 16th, can perhaps also be included, from the predictability point of view. During three of these flights, dropsondes were launched from above the tropopause. About 400 soundings were taken in and around Low 41, 230 of which were made from the ships and the aircraft. Dynamically, this low illustrates many of the features or behaviour that led to FASTEX: non-spontaneous genesis in a complex environment, multiple phases of growth, temporary tendency to split into two lows with forecast development of these centres varying greatly between models and explosive deepening. Some of these features are discussed in the studies of Cammas *et al.* (1999), Mallet *et al.* (1999a, 1999b).

It can be said, therefore, that the key experimental objective of FASTEX has been reached. There are, furthermore, significant data for addressing more focused dynamical issues. There are a number of rapidly developing cyclones (see Table 2.2 for a summary) but, as a control for checking current ideas on the way development can be hindered under certain circumstances, there are a few non-developing systems as well (see the work of Chaboureau and Thorpe (1999) and Baehr *et al.* (1999). As will be discussed below, a large number of types of systems has been collected; several critical features or phases have been directly observed, such as the genesis of a wave (IOP 10), a number of cases of the amplification phase, jet inflows and outflows. The most characteristic ones are listed in columns 4 and 5 of Table 2.1.

2.5.4 Potential for adaptive observations studies

A large amount of data are available for impact studies on predictability. Column 2 of Table 2.1 lists the cases for which datasets have been obtained in the Far Upstream Area; the corresponding forecast range is also given. Note that in relative terms the quality of short-range forecasts for some FASTEX cyclones was below that of longer lead time forecasts. The data from the ships can be used in studies of

Short Note 2.3: Precursor anomalies of cyclogenesis in action

by Ph. Arbogast

The model of cyclogenesis put forward by the Bergen School around 1920 (e.g. Bjerknes and Solberg, 1922) has been widely accepted and was the dominant one in the mid-thirties in operational forecasting. The search for a theoretical basis for this model also opened the way towards linear normal mode stability analyses.

By the end of the thirties, however, different views began to emerge. They are summarized by Sutcliffe (1947) and by Petterssen et al. (1955). The approach, called development, considers that cyclones result from the amplification, sometimes dramatic, of pre-existing and finite-amplitude features present in the atmosphere. The most well known synoptic model in this family is the one of surface cyclogenesis triggered by an upper-level anomaly in the form of a vorticity maximum. This proposal directly opposed the one expressed by, for example, Bjerknes and Holmboe (1944): for them, a cyclone actually starts as an unstable wave in the Polar Front close to low levels, propagates upward and generates the upper-level vorticity maxima. There is a continuing thread of studies that attempt to support the one or the other point of view. The discussion was, furthermore, soon muffled down by the success of the linear normal mode baroclinic instability model. An important landmark in this line is the paper by Petterssen and Smebye (1971) that presents cases representative of both points of view: quasi-linear, possibly surface triggered ones are called Type A and the ones triggered by an upper-level feature are called Type B. The latter are the most convincing ones and the conclusion states that, according to the author's (considerable) experience, they are the most frequent.

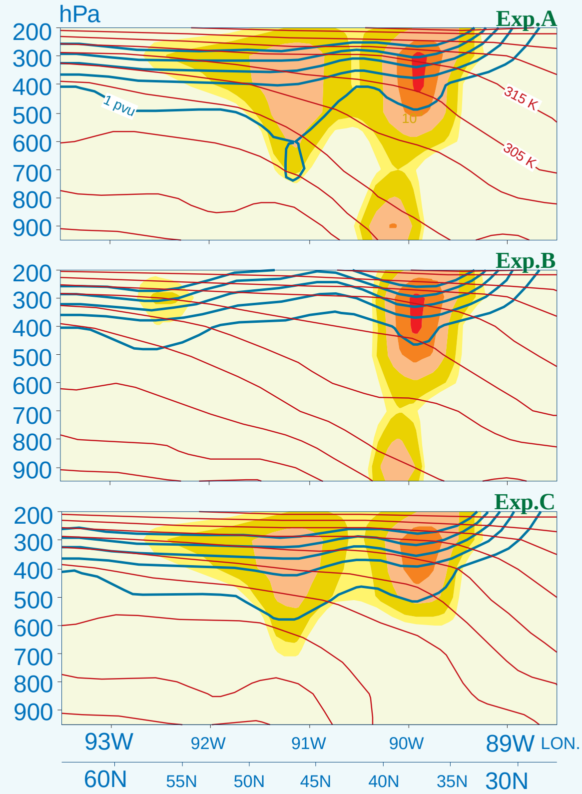
This paper clearly made the point that upper-level triggered cyclogenesis were most probably real. However, the direct proof that a given structure at a given time is the actual *cause* of a cyclogenesis event could not be obtained for lack of a proper theoretical tool.

This tool is provided by the emergence of *potential vorticity inversion and attribution*. It is summarized in Short Note 1.6. The building up of implementations of these ideas that can be employed to study actual cases is recent and accompanies the FASTEX programme. The first popular one is due to Davis and Emanuel (1991) and Davis (1992). It has been employed mostly in a diagnostic way. At a given time generally preceding a cyclogenesis event, a number of anomalies are isolated within the flow and their influence on the other parts of the flow at that time is diagnosed. Previous synoptic studies were not very different except that "influence" effects could be computed only globally and not definitely *attributed* to a particular anomaly.

FASTEX offered a good opportunity to make the next step towards the first direct proof that the presence of a given anomaly determines the development of a cyclone. This step consists of removing or adding anomalies in initial conditions and simulate the resulting time evolution with a realistic, finite-amplitude model of the atmosphere.

In this perspective, a new potential vorticity inversion code has been prepared at Météo-France. It is designed to interact directly with the operational ARPEGE primitive equation model. The inversion technique employed is also a new, variational one. The variational approach has been chosen initially because it can handle the presence of areas of negative potential vorticity (Arbogast and Joly, 1998). It can also easily be organized into a framework open to several formulations of the balance condition and the corresponding definition of potential vorticity.

Figure SN2.3.1: *Vertical cross-sections roughly meridional along 90°W, 16 February 1997. The fields are potential temperature θ (red contours, interval 10 K), potential vorticity (blue contours, interval 1 PVU) and vorticity (shading, outermost value 0.4 $\times$ 10^{-4} s^{-1}, interval 0.2 $\times$ 10^{-4} s^{-1}. Top panel: ARPEGE analysis. Middle panel: one upper-level structure has been removed using potential vorticity inversion. Bottom panel: the low level structure cut by the section has been removed in turn. At this time, Low 41 does not exist.*



One of the best documented case in the FASTEX sample is Low 41 in IOP 17 (see section 3.21 in Part 3, page 118 for a summary of this case). Low 41 is a definitely new system that appears on the warm side of a complex jet-inflow, developing surface front area between 6UT and 12UT, 17 February. Cammas et al. (1999) provide a detailed synoptic-dynamic study of the case. The search for precursors of Low 41 must be performed at an earlier time, for example, at 12UT, 16 February. Looking at maps, many features could be pointed out: this is one of the interesting aspects of this case. If the idea of development induced by a specific anomaly is to be proved, its influence must be shown and, simultaneously, the non-influence of neighbouring anomalies must also be shown. It is in the course of a systematic search that the mechanism of the genesis of Low 41 has been uncovered. The long-wanted result has been obtained, but it is accompanied by an unexpected surprise (Arbogast and Joly, 1998b).

Figure SN2.3.1 shows a small selection of possible precursors, seen in a vertical cross-section. At least three distinct features can be seen. The ability of potential vorticity inversion to manipulate the initial conditions in a consistent way is clearly shown on this figure, where two possible precursors are removed in turn. Others have been tested for influence, including large-scale ones: in all but two cases, no significant impact on the subsequent life-cycle has been shown.

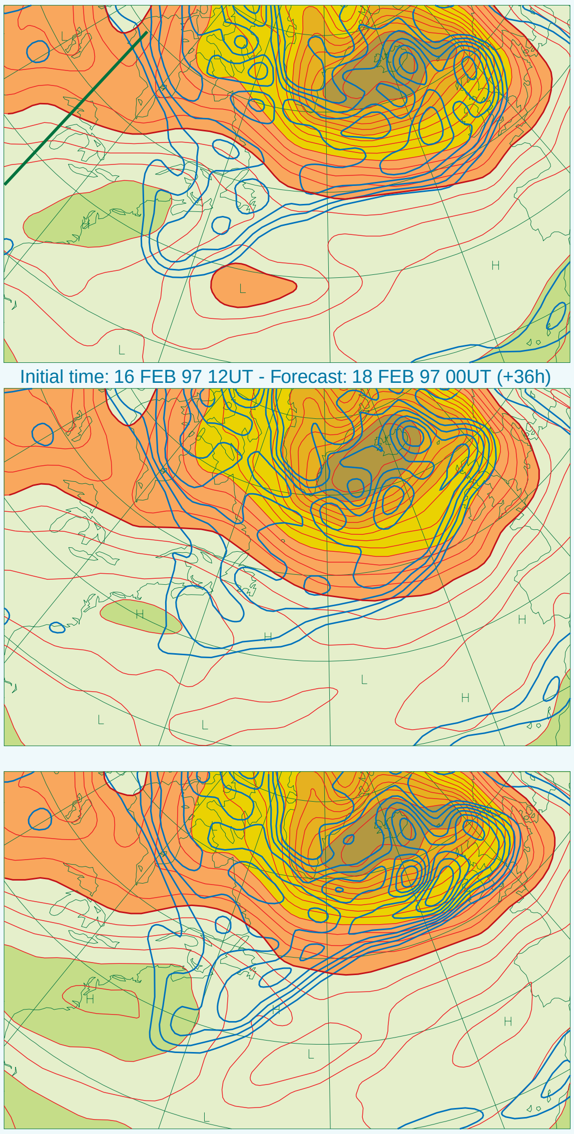
The top panel of Fig. SN2.3.2 shows the reference evolution, 36 h after the analysis. Low 41 is then about 12 to 18 h old. Removing the upper-level anomaly as in the middle panel of Fig. SN2.3.1 leads to the complete removal of Low 41 (middle panel). Conversely, removing the other upper-level anomalies does not have this impact. This result is, therefore, the first direct proof of the correctness of the views of Sutcliffe, Petterssen and a few others.

But the actual mechanism is not exactly the one first put forward by Sutcliffe. Indeed, *leaving in* the only critical upper-level anomaly and removing the low-level one that is shown in the cross-section, it appears that the formation of Low 41 is just as severely hindered (bottom panel). The action of the upper-level precursor is not direct. Its direct effect is to enable the low-level system to survive through a weak baroclinic interaction. And it is the low level system, approaching the jet-front complex from the north-west that triggers Low 41. This part of the scenario has been studied in greater details by Mallet et al. (1999).

It remains that FASTEX has proved unambiguously that cyclogenesis results from the influence at a distance of pre-existing, finite amplitude structures interacting with other such structures, specifically here, the strong baroclinic zone in the western Atlantic. All the forms of finite amplitude interactions may, however, come into play and the Type B of Petterssen appears to be one specific kind among others.

The use of such ideas does not, however, solve the forecast problem. It geatly helps the interpretation of existing data and the rating of model runs. However, for the forecast to be correct, two conditions must be met simultaneously: the distribution of possible precursor structures must be exact *and* the amplitude of the competing, rapidly growing structures supported by the large-scale flow component alone must be *strictly* exact, since otherwise the small errors here will amplify and introduce significant phase and amplitude errors in the interactions between the precursors.

Figure SN2.3.2: *ARPEGE has been integrated forward with the modified initial conditions shown in Fig. SN2.3.1 and others. The maps show the three corresponding 36 h forecasts. The fields are mean sea level pressure (red contours and shading, interval 5 mbar, thicker contour 1015 mbar) and potential vorticity at 300 mbar (blue contours, interval 1 PVU). Top panel: simulation started from the analysis, reasonably close to the analysis given the lower resolution employed. The plane of the cross-section of Fig. SN2.3.1 is also shown. Mid-panel: simulation without the critical upper-level precursor. Bottom panel: simulation without the low level precursor.*



Short Note 2.4:
Implementation and evaluation of adaptive observation in FASTEX

by T. Bergot, G. Hello and S. Malardel

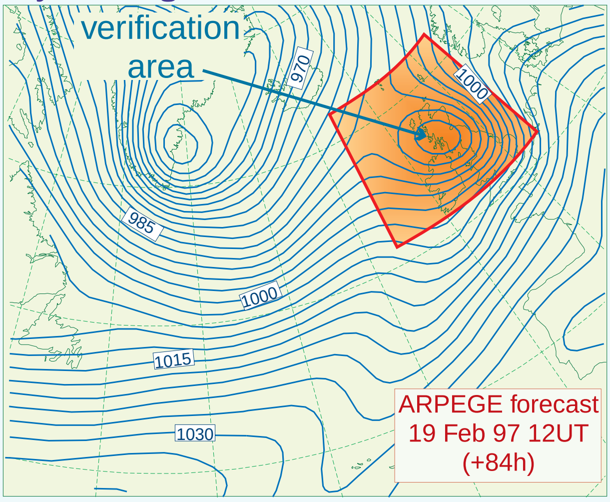


Figure SN2.4.1: *An early forecast for 19 Feb. 97 12UT, made from the analysis of 16 Feb. 00UT (the range is 84h) showing a possible Low 41. The low resolution system employed in real time is then asked "where should we observe on 17 Feb. 18UT in order to improve specifically the following (42h) forecast of Low 41 ?" in the verification area. The field shown is the pressure at the mean sea level, interval 3 mbar. The model employed is ARPEGE on a regular grid at resolution T63.*

Figure SN2.4.2: *The answer to the question asked with Fig. SN2.4.1 is shown here by considering the isolines: they represent the 700 mbar temperature perturbation of the most unstable singular vector that can develop between 17 Feb. 18UT and 19 Feb. 12UT (the amplitude is arbitrary; negative contours are dashed). A small error on the amplitude of this 3D perturbation will amplify as rapidly as this perturbation and is likely to wreck the forecast. A flight plan designed to collect extra data where this structure has a maximum amplitude at that time is superimposed, the dots showing where dropsondes were to be launched. This flight plan was proposed before the Gulfstream flew to StJohn's, but had to be confirmed several times afterwards, using more recent forecasts.*

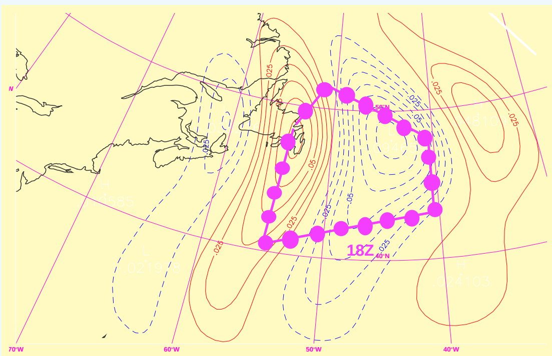
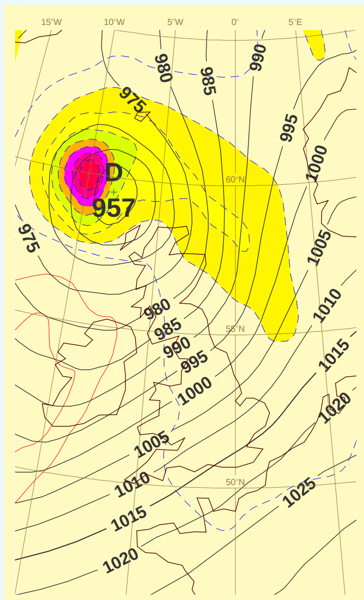


Figure SN2.4.3: *The dropsonde data obtained during the 17 Feb. flight has been used operationnaly as well as after the field phase, in a better controlled environment. The figure shows the impact of this dropsonde data (shaded area, interval 2 mbar) on a high resolution forecast derived from a suite run without any of the special FASTEX data, except this particular flight. The impact in this case is to change the amplitude towards a better, less deep, value.*



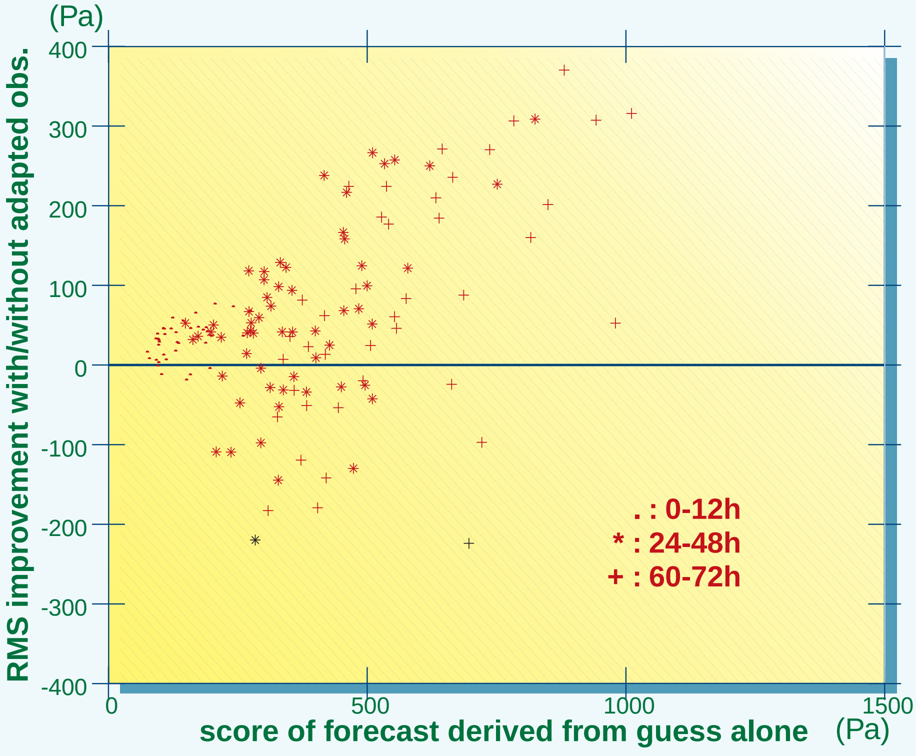
An actual example of implementation of the idea of adaptive observation, as defined for example in Short Note 1.8, is given by Figures SN2.4.1 (the forecast to make sure of and to improve), SN2.4.2 (the critical structure and area for this particular forecast and the resulting flight actually performed) and SN2.4.3 (the impact of the data collected during this flight). The US Naval Research Laboratory and ECMWF also performed rather close calculations. The NOAA National Center for Environmental Prediction proposed a different approach, based on score threat and the ensemble prediction (Bishop and Toth, 1998).

Given the many operational constraints (aircraft regulations, need to take observations close to 0, 6, 12 or 18UT, etc), many parameters of the target finding algorithm had to be changed, and the calculations often repeated. The Météo-France group has properly anticipated these practical problems. The NRL suite also had some flexibility, but its use was hindered by the time lag between Ireland and California.

All the groups involved in this first experiment with adaptive observation based on pre-defined algorithm undertook, after the field phase, to study the impact of the data. Using current assimilation techniques (essentially Optimal Interpolation and 3D-VAR, see Part 8 on Data Assimilation), this impact has been found to be, on average, positive but weak. However, adaptive observation has been proposed to improve the forecast on particular events, not on average. Figure SN2.4.4 shows one of the results of Bergot (1999) obtained in this perspective: assuming that the score of forecast derived from the raw guess field provides a measure of predictability, the figure shows that adaptive observation can significantly improve the situation when the predictability is low. When it is high, on the other hand, adaptive observation may be difficult to handle, as it can have a negative impact.

The next step is to combine adaptive observation with 4D-VAR. One reason is that, according to the feasability study of Bergot et al. (1999), many observations in the critical area are required to maximize the impact and current assimilation method force a severe selection when one does not wish to introduce phase errors: not all the data, by far, has been employed in these studies. The theoretical work of Fischer et al. (1998) also suggests that, with flow dependent covariances functions as in 4D-VAR, the impact can be extremelly positive.

Figure SN2.4.4: *One important result from a systematic study of the impact of the adaptive observation flights on the subsequent forecast is shown on this figure. The improvement of the RMS score of surface pressure over Europe due to the adaptive observations (vertical axis, positive for actual improvement, negative for a negative impact on the forecast) is plotted as a function of an a posteriori measure of the quality of the guess field. It appears that adaptive observations can be very efficient when the quality of the guess is poor, but are neutral or even detrimental when the guess field is good.*



predictability at the shorter ranges. They are very often well located with respect to sensitive areas.

An important aspect not reflected in this table is the experience gained in the actual practice of "targeted observing". The feasibility of real-time adaptive observing has been demonstrated, but the degree of flexibility required is very significant.

An example of target determination, associated flight plan and impact of the data collected as a result is presented in Short Note 2.4, together with an example of overall assessment. See also Short Note 1.8 for the theoretical perspective opened by adaptive observation.

The effectiveness of this strategy is further discussed in the work of Szunyogh *et al.* (1999), Bergot (1999), Bishop and Toth (1998), Langland *et al.* (1999), Buizza and Montani (1999) and Pu and Kalnay (1999).

Table 2.2: *Subjective synoptic characterization of the FASTEX cases. The cases are summarized in Part 3 of the report. On the screen version, the page numbers are hypertext links.*

	Comma cloud-like feature	Second generation wave	Rapid development stage	Clear stage of baroclinic interaction	Suppressed waves (stable front)	See page
IOP 1	–	front	–	●	–	99
LOP 1	–	jet/front	–	–	–	100
IOP 2	●	front	–	–	slow gen	101
IOP 3	–	–	●	●	–	102
IOP 4	●	–	–	–	–	103
IOP 5	●	–	–	–	–	104
IOP 6	–	tempo	–	–	●	105
IOP 7	–	tempo	–	–	●	106
IOP 8	–	–	–	–	–	107
IOP 9	–	jet/front	–	●	–	108
IOP 10	–	front	–	–	–	109
IOP 11	–	–	●	●	–	110
LOP 2	–	front	–	●	–	111
IOP 12	–	jet/front	● ●	●	–	112
IOP 13	–	–	–	●	–	113
LOP 3	–	front	–	–	–	113
IOP 14	–	–	–	●	–	114
IOP 15	–	jet/front	●	●	–	115
IOP 16	–	jet/front	●	–	–	116
LOP 4	●	–	–	–	–	117
IOP 17	–	jet/front	●	●	–	118
LOP 5	–	front	●	–	–	119
IOP 18	●	–	●	●	–	120
LOP 6	–	fronts	–	–	–	121
IOP 19	–	front	●	●	tempo	122

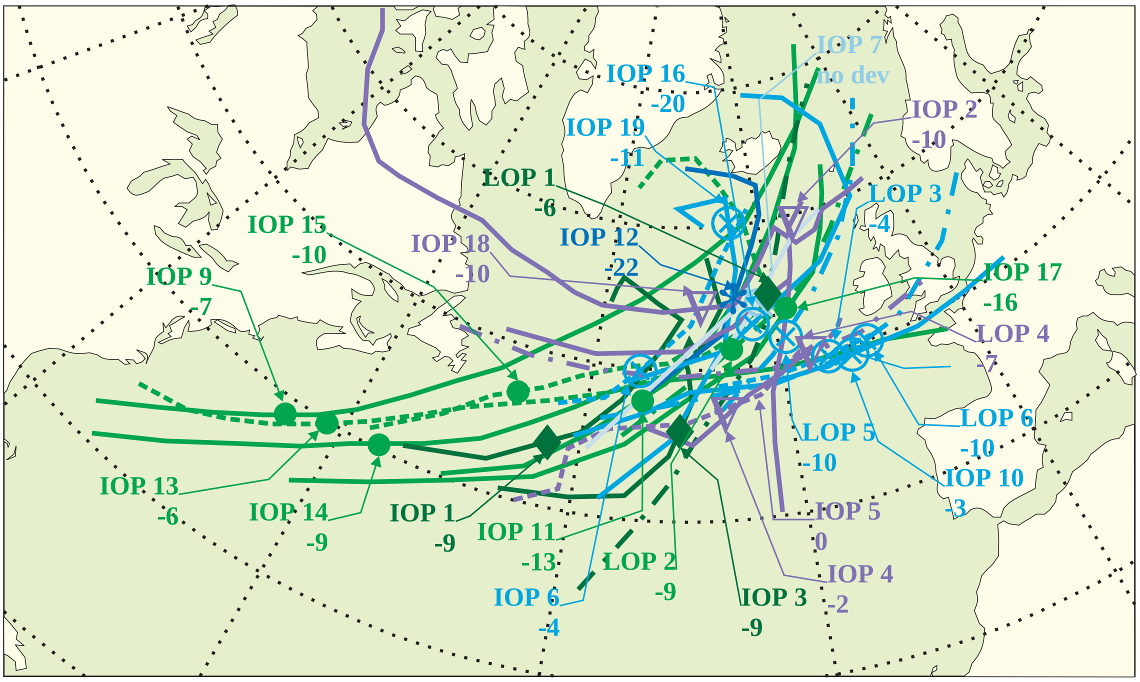
Symbol ● means "yes" or "present"
An entry in column 2 means that the system started as a second generation wave. It gives an idea of its environment, "front" being obvious, "jet" meaning presence of a jet-streak or entrance, "tempo" meaning that waves existed temporarily or, in the case of IOP19, temporarily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

2.5.5 The FASTEX cases

Another important aspect is the sample of cyclone types that was covered by these measurements. One of the ideas underlying FASTEX is that there is a large variety of cyclones (Ayrault, 1998) and no such thing as a single type (for example, a system growing on a front, always going through the same set stages and having the same structure, as imagined earlier in this century). There is no single "typical" FASTEX cyclone. It is important that the FASTEX sample reflects this diversity.

More or less in real time, B. Pouponneau, from Météo-France, prepared a basic atlas of maps based on the operational analyses made during FASTEX which included a significant amount of special FASTEX data. These maps were soon complemented by satellite images provided by the Data Base group (see Part 4). This enabled a subjective classification of the cases to be performed based on the morphology of the system and its environment (Table 2.2). It is meant to be used as a double-entry table: one can look for a short meteorological definition of a given IOP or LOP or alternatively, find in the table which IOP or LOP may provide data on a given type of weather system.

Figure 2.9: *Map showing the trajectories of the cyclones of interest to FASTEX, the location of maximum deepening and its amplitude in mbar/6h derived from the ARPEGE analyses. The trajectory lines and symbols marking the location of maximum deepening indicate the different types of cyclones resulting from the subjective classification of Table 2.2. Dark blue line and asterisk: IOP 12 (largest deepener); Blue lines and circled crosses: end-of-stormtrack cyclones in IOP, LOP are dash-dotted blue lines; purple lines and open triangles: comma-cloud like features, LOP are purple dash-dotted lines; Green lines and filled circles: baroclinic waves in zonal regime, LOP are dashed; Dark green lines and diamonds: baroclinic waves in southern zonal regime; light blue lines and empty sign: non developing waves. These trajectories have been constructed by gathering togather the individual trajectories that can be found in Part 3.*



Short Note 2.5: The forecast routine during FASTEX

by The forecast team from the Centre Météorologique Canadien, the Joint Centre for Mesoscale Meteorology, Met Éireann and Météo-France

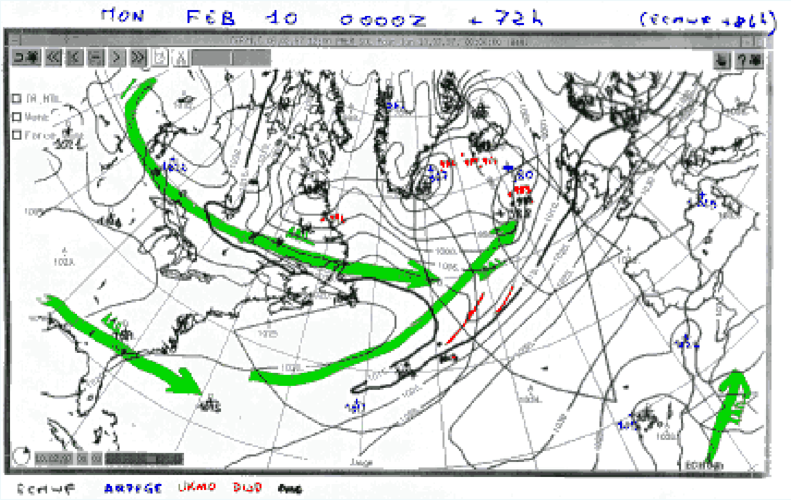


Figure SN2.5.1: *Example of one of the raw components entering the preparation of the consensus forecast: on a transparency based on the previous day's ECMWF forecast, the location and amplitude of the lows in the different models are plotted by the various groups. The example shown is one of the forecast preparing for IOP 12 (see Section 2.3).*

2.5.1 The main schedule and activities

The daily forecast routine set-up all along the field phase was resting on the following basic steps:

0600UT–0730UT Representatives from each group analyse their own numerical forecast products derived from the 00UT observation network. The Météo-France group, in particular, prepares the background transparencies for the summary of low location and amplitude.

From about 0700UT, some more specialized tasks also begin, such as the specific forecast for the ships in the Atlantic or the interpretation of the ensemble forecast from ECMWF (see Short Note 2.6 for one of the products).

0730UT–0800UT Each group completes the series of low location and amplitude summary (Fig. SN2.5.1). The resulting product is a daily series of 6 transparencies covering analysis (Fig. SN2.5.3) time up to 5 days ahead showing the potential cases of interest as well as the possible options and uncertainties.

0800–0830UT Discussion amongst forecasters. The aim is to turn the summary on low locations and amplitude as well as all the details collected within each group into a coherent presentation of the situation, summarized by the "consensus forecast" product (Fig. SN2.5.2). The discussion is led by the group's speaker at the briefing.

0830–0900UT The briefing is being prepared. The consensus forecast is drawn, the images and products to be shown during the briefing are transferred to the appropriate machines.

0900UT–0940UT Daily weather briefing, described in more details below. The presentations were made by each group in turn, with changes every three days. The audience is the whole FASTEX group at Shannon: scientists, implementation group, the Science Committee, etc.

0940–1030UT The forecast work splits into several activities. Bulletins are written, for example for the ships. A specific 48 h forecast is prepared for each of the ships at sea, so this was generally a long task. Sometimes, operations were running in parallel: this also required specific short-range tasks, such as local evolution monitoring.

The main body of forecasters discusses in front of their respective screens fine points of the current or future weather events with the scientists who are preparing their proposals and come with questions.

1030–1100UT Forecasters attend the daily planning meeting, since they may have, sometimes, to clarify issues. The decisions taken at these meetings also strongly influence future work: aircraft operations typically require special attendance.

1100–1230UT The various bulletins are finalized and sent, a number of groups complete their pages for the World Wide Web, products are archived.

When an Intensive Observation Period was running (or when several of them were overlapping, as happened several times in February), additional monitoring tasks were ran, mostly regarding the aircraft flight: detailed weather forecast for the flight itself, with sometimes briefing of the crew, including the usual discussion of conditions at the main landing places and the alternates, and also a preparation of documents describing the conditions during the flight at a level of details specific of this kind of weather projects. This information was either printed and given to one or two crew members or gathered on a personal computer, such as for the flight planning programmes.
Furthermore, during the preparatory stages of an IOP, an update briefing was prepared during the afternoon, starting at about 1530UT. The briefing was held at 1730UT or 1800UT and looked somewhat like a reduced version of the morning briefing, focusing only on solving the uncertainties that led to such or such option.

2.5.2 The Daily Weather Briefing

The briefing featured the following components:

- A GOES and METEOSAT composite image animation (in the "infra-red" or "water vapour" channels) of the previous 24 h is shown. The domain covers the East of North America, the North-Atlantic ocean and western Europe. This product was essentially prepared by the Centre de Météorologie Spatiale in Lannion (France).
- A quasi-hemispheric geopotential map or series of maps is presented in order to give an idea of the planetary scale circulation.
- The surface pressure and frontal analysis on the North-Atlantic is then shown as a transparency. This map usually came from the Central Forecast Office of Bracknell (UK).
- The consensus forecast is presented: the summary transparencies are followed by the expected trajectories of the various lows. As indicated above, the period covered extends from 0 to 5 days ahead.
- Some forecast products representative of the most likely scenario and the possible most likely alternate are then shown, generally in the form of animations on some kind of computer projected on the screen. The products shown vary greatly from day to day.
- The situation of the ships is then recalled and the weather outlook for them is given. The ships went through a storm every other day on average during the field phase.
- the medium-range outlook derived from ECMWF ensemble prediction closes the briefing.

Figure SN2.5.3: *The analysis corresponding to the forecast of Low 34A of IOP 12 (see Section 2.3 and 3.15) of Fig. SN2.5.1 and SN2.5.2. It is interesting to note that, even at this stage, there are some differences between the various numerical weather prediction systems.*

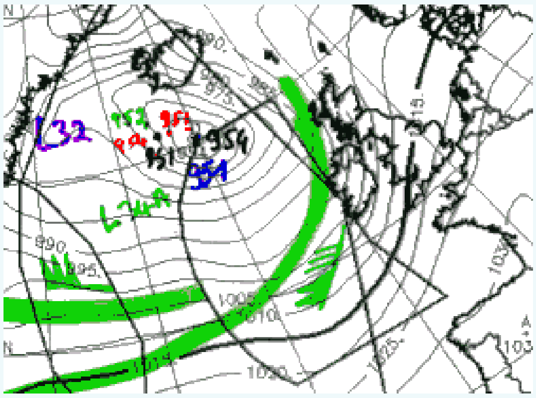
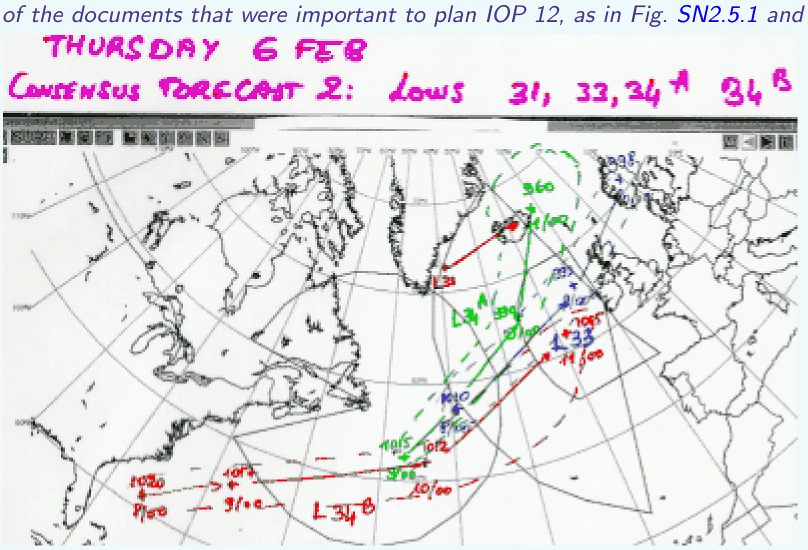


Figure SN2.5.2: *Example of the product called "consensus forecast" resulting from the collective model discussion: the most likely track of lows of interest to FASTEX is drawn, together with some indications on the uncertainties. This example is also one of the documents that were important to plan IOP 12, as in Fig. SN2.5.1 and Section 2.3.*



FASTEX is primarily oriented towards cyclones forming well within the oceanic storm-track, in contrast to East-Coast cyclogenesis as studied in programmes such as ERICA (Hadlock and Kreitzberg, 1988) or CASP (Stewart, 1991). The cyclones in FASTEX could be called, using traditional synoptic parlance, frontal waves. However, a more general description might be second generation cyclones, suggesting they form in the wake of another system (considered to be the parent, although this may not be always correct). This is the label retained in Table 2.2, and the parent structure is indicated for cyclones falling in this category of primary interest. An even better description would be end-of-stormtrack cyclones, which simply locates them geographically in a broad sense. Different views relating to the definition and description of these cyclones can be found e.g. in Kurz (1995) in relation to satellite imagery, Hewson (1997) for determining waves automatically or Ayrault *et al.* (1995) and Ayrault (1998) for composite structures extracted from long series of analyses. Figure 2.9 shows a summary of the tracks of all the major cyclones during FASTEX.

Table 2.2 shows that, apart from the non-developing and temporary small amplitude cyclones, there was a mixture of three types of systems forming well over the ocean in the FASTEX sample:

1. cold-air cyclones dominated by convective activity and characterized by their comma-shaped cloud system north of the main baroclinic area (or storm-track, roughly),
2. actual frontal cyclones and
3. cyclones forming within a complex environment combining a low-level front-like feature and an upper-level jet-streak or jet-entrance.

A case is entered in the first column when either a comma-cloud was involved in a life-cycle as precursor or the case itself was a comma cloud. The table also indicates the cases that developed explosively, using in a broad way the criterion of Sanders and Gyakum (1980): a phase of deepening equal to or larger than 24 mbar in 24h. The presence of such a phase is shown by a dot in the “Rapid development stage” column. This happened on 9 occasions.

Table 2.2 identifies those systems that had a clear-cut phase of baroclinic development during their life-cycle. It means that the development of the cyclone benefitted from baroclinic interaction with an upper-level structure, typically an upper-level cyclonic anomaly: such cases are labelled as having a “clear stage of baroclinic interaction”. Cyclones having as their only feature this characteristic type of evolution (the simplest cyclones, in that sense) are not the most frequent ones: IOP 3, 11, 13, 14. Most cases add another degree of complexity to simple baroclinic interaction, either when they are generated or by undergoing several phases of growth (see Baehr *et al.* (1999) for a detailed documentation of this process). IOP 14 probably shows the simplest life-cycle, with a phase of growth in the western Atlantic followed by slow decay (however, this low is also the only one to have been clearly advected from the american continent to the ocean, so its past history may be more complex).

The last column of Table 2.2 lists the cases where structures such as fronts bacame wavy but the waves did not develop (dot), or developed very slowly (slow gen) or saw their development temporarily checked (tempo).

Table 2.2 illustrates two levels of diversity or complexity in the FASTEX sample: the existence of different types and the idea of complex life-cycles leading the same system to change type. Contrast IOP 10, that remains a frontal wave throught its marine life cycle with IOP 12, that starts in the same category and ends as a full-scale

Ukrainian participants to FASTEX talking in the radiosounding reception and monitoring room of the V. Bugaev. Photo: T. Douffet, Météo-France.

The Ægir calling to the Irish port of Cork for refuelling and crew relief at the end of January. Photo: P. Bessemoulin, Météo-France.

A rare opportunity: a radiosounding is launched in fair weather on the V. Bugaev. Photo: T. Douffet, Météo-France.

On board the V. Bugaev under the most frequent conditions: uniform grey sky, waves flattened by strong winds. Photos: E. Gizard, Météo-France.

storm. Another example is IOP 18, that turns into a major storm while beginning away from the main baroclinic area. Another subjective classification of the FASTEX cases is provided by Clough *et al.* (1998).

2.6 Forecasts during FASTEX

The forecast activity during the FASTEX field phase was, by design, an experiment within the experiment. The requirements were quite demanding: (1) produce once, and sometimes twice a day, medium-range forecasts of cyclone tracks, (2) refine forecast life-cycles enough to prepare flight plans, (3) monitor the evolution using fine-mesh models and satellite imagery in real time and over a long period.

The forecasts were prepared at Shannon operations centre by teams from four groups: the Canadian Meteorological Center, the Irish Meteorological Service, Météo-France and the UK Meteorological Office. An important aspect of this exercise was the cross-exchange of tools, concepts and approaches between members of these groups. All groups brought to Shannon their familiar working environments, namely their model output, display systems, etc. Most of the participants seemed pleased with this approach and learned a lot from each other.

The diversity of models extended beyond the ones provided by these participating groups: the ECMWF model was available from several sources (for example, the

Short Note 2.6: The forecast of weather regimes

by G. Hello, F. Lalaurette, P. Santurette

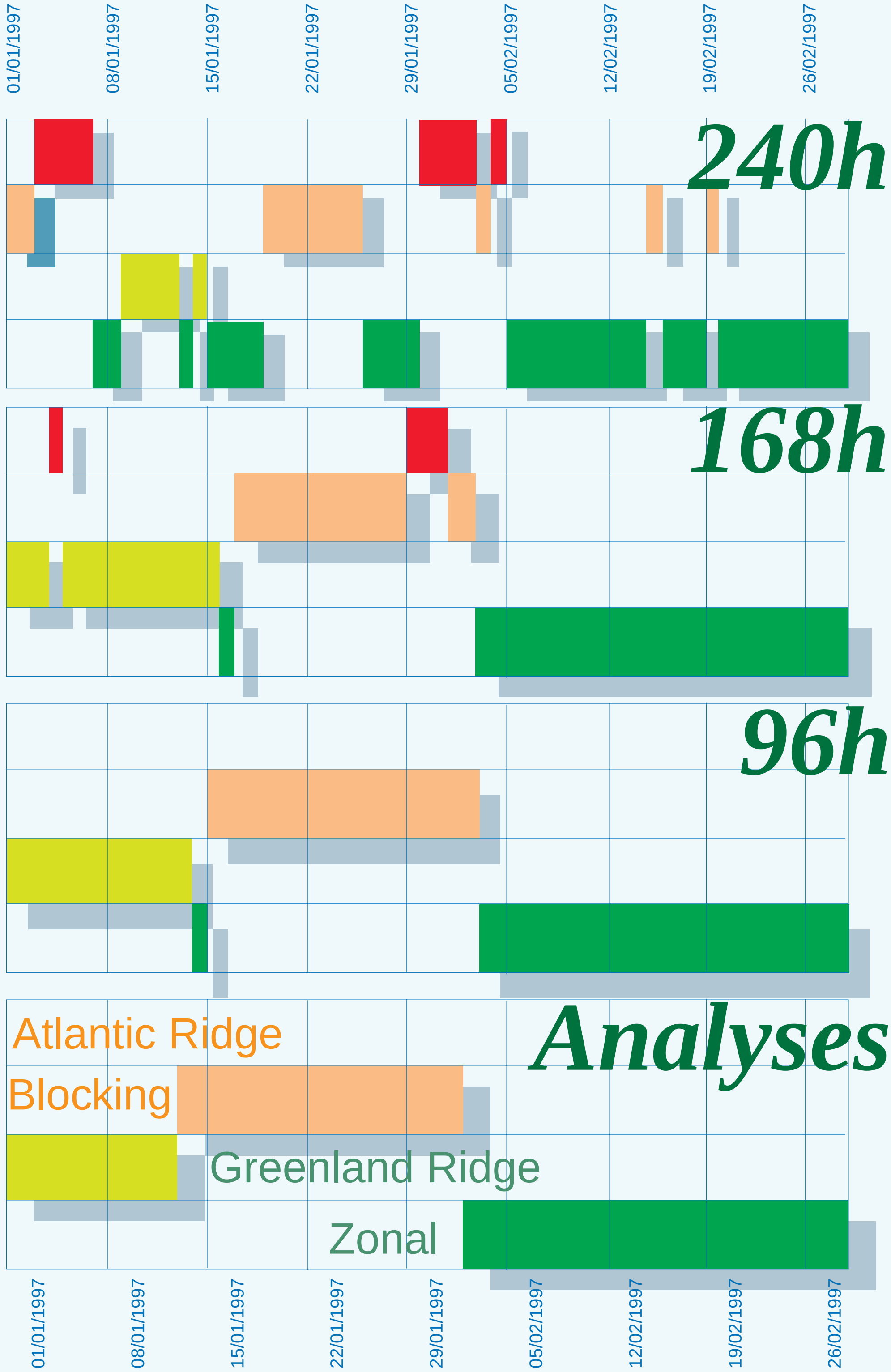
The relevant weather pattern on the time scale of the week is, as explained in the Short Note 1.1, the weather regime. This as well as Short Note 1.2 and Fig. 1.4 in Part 1 reveal the strong connection between the occurrence of cyclones in the eastern Atlantic and the regime. It will not come as a surprise, as a result, that the advanced planning of FASTEX relied on a medium-range forecast of weather regime.

The basis for this forecast is the ECMWF Ensemble Prediction. During the field phase, it was made of 50 trajectories obtained with a T106L31 version of ECMWF IFS/ARPEGE model, plus the reference high resolution forecast (Molteni et al., 1996). The trajectories are initialized using singular vectors. ECMWF provided several products derived from the Ensemble Prediction for FASTEX (special classification, single maps, etc).

The Laboratoire de Prévision of the Operational Division of Météo-France has developed, from these products, a projection on the weather regime patterns shown in the Short Note 1.1. Each trajectory is projected, so that for each range, an empirical probability of occurrence of the four regimes is available. The forecasted weather regime is simply the most frequent one in the sample of 51. It is easy to add an information on uncertainty based on the size of the full distribution of frequencies (the larger is the majority of the forecasted regime, the most likely is the forecast).

The results are shown by Fig. SN2.6.1. It appears that the weather regimes are predicted very well up to day 7. This is a remarkable, practical result. It is a significant achievement of the ECMWF approach to medium-range forecast. It also embodies the current limit of predictability: while the forecast as implemented delivers a kind of deterministic information on the regime, the latter is only the large scale part of the flow: the characteristics of the finer scale features, including the cyclones, are known only statistically, either from the climatology associated to the regime or to the high-frequency information that can be extracted from the Ensemble Forecast.

Figure SN2.6.1: *Distribution of weather regimes forecasted during FASTEX using the ECMWF Ensemble Prediction, analyzed (bottom) and at 4, 7 and 10 days respectively.*



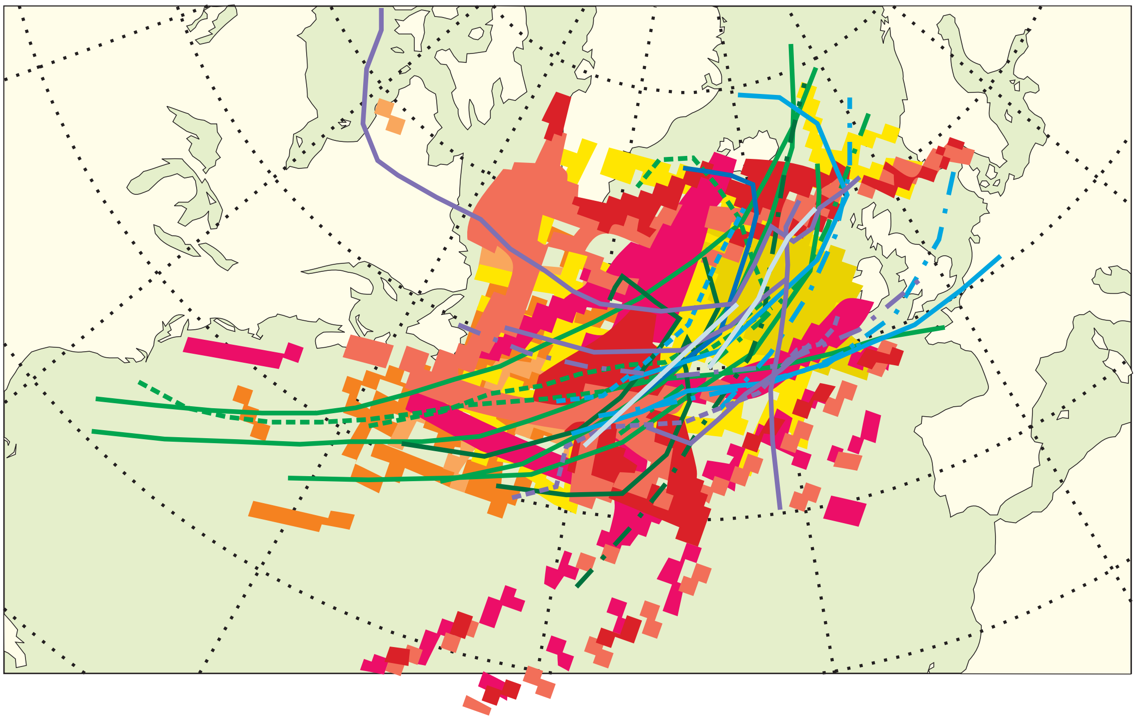


Figure 2.10: *A summary of FASTEX: the trajectories of the lows of interest to the project (as in Fig. 2.9) are superimposed on the distribution of the vertical soundings taken by the ships (reddish zones) and by the aircraft (other shaded areas). This is only a part of the FASTEX data, but the fitting indicates the life-cycle tracking has been quite effective. Distribution areas provided by G. Jaubert, (Météo-France) and shown in more details in Part 4.*

Irish Met Éireann provided the 00UTC ECMWF run) and the Deutscher Wetterdienst model was also employed on the longer ranges. On occasions, results from US models were also available.

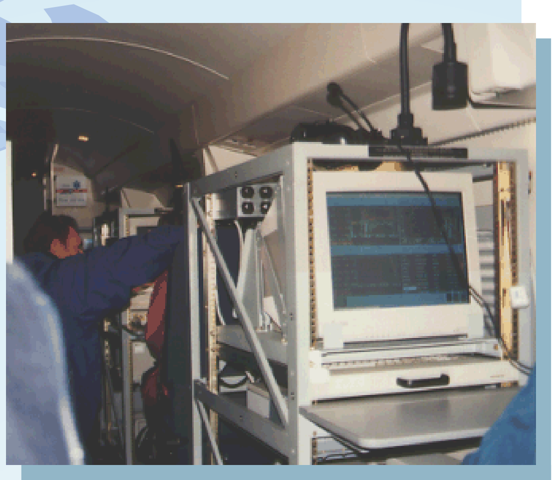
The main outputs of the forecast teams were: (1) a medium-range forecast based on the ECMWF ensemble, expressed in terms of weather regimes (as defined in section 2.2), (2) maps of the dispersion of cyclone centers predicted by the different models, (3) a consensus 4-day forecast of cyclone tracks resulting from comparing and discussing all the available models explicitely identifying the uncertainties, for example by adding error-bars to the cyclone tracks, (4) a detailed 2-day forecast including winds and sea-state for each of the ships and (5) detailed weather information for each of the planned flights. An example of consensus forecast and the backbone schedule are presented in the Short Note 2.5.

2.7 Concluding remarks

The experimental objectives of FASTEX as a field project, as defined in section 1.5, have been fulfilled, this statement being justified by most of this Part. A number of cyclones have successfully been multiply sampled as they crossed the North-Atlantic. The cases sampled in this way and those observed in much more detail in the Multiscale Sampling Area, do reflect some of the variability of recent mid-latitude cyclone

Briefing, or rather debriefing the MSA flights after IOP 5: P. Hildebrand from NCAR summarizes the events of the past day and the Shannon people listen. All briefings took place here. Photo: N. Raynal, Météo-France.

Head forecaster B. Benech in front of the twin-screen SYNERGIE workstation: a picture of the Shannon set-up prepared by Aer Rianta inside the air terminal. Photo: N. Raynal, Météo-France.



D. Jorgensen from NOAA inside the Gulfstream-IV in flight during IOP 6, trying to support D. Bartels, also from NOAA, preparing the TEMPDROP messages. Photo: F. Lalaurette, Météo-France.

Above: the Electra shortly after landing at Shannon. Leading the group: R. Wakimoto, from UCLA. Photo: N. Raynal, Météo-France. Left: the NOAA P3 ready to fly at night from Shannon. Photo: N. Raynal, Météo-France.

classifications typologies. Real time adaptation of the observations to areas critical to improving predictions for cyclones have actually been done for the first time. A unique turbulent fluxes dataset has been collected from the ships. The data have been made available to all within a short time scale.

There are other positive aspects of FASTEX. Between 1993 and 1996, as part of the preparations for the field season, focused scientific studies have been undertaken that proved to be useful to the project: the climatological study of Ayrault *et al.* (1995) determined the optimal period of year, locations and schedules, the idealized observing system experiments of Fischer *et al.* (1998) showed the necessity of the ships, Bishop and Toth (1998) provided some theoretical basis to adaptive observation, Bergot *et al.* (1999) directly addressed practical issues relating to its implementation. In fact, numerical tools and techniques are now reaching a stage where many aspects of costly projects like FASTEX can and should be simulated beforehand. As shown by the overall schedule (Table 1.4), too short a time has been allowed for these studies. New tools for retrieval of 3D-fields on the mesoscale have also been prepared at that time. They combine Doppler radar measurements and other sources such as dropsondes (Protat *et al.* 1997, Protat *et al.* 1998, Montmerle and Lemaître 1997) Training forecasters and flight track planning scientists for FASTEX was carried out in the UK and France during the winter preceding the experiment: this is done for other projects and remains a condition of success. But one can now go much further than this and test the impact different distributions of platforms or observational procedures and limit the consumption of expensive resources for trial or test runs.

The mode of operation of the forecasters was successful thoughout the project — actually, the forecasting routine was started early in December 1996, another condition of success. The consensus forecasts have proved to meet the needs of the project.

Another result is the demonstration of the feasibility of weather ships to be tied to the slowly migrating baroclinic area. Data systematically reaching upper-levels invaluable from a dynamical meteorology point of view have been obtained by the ships catching key components involved in the process of cyclogenesis. Current and future data impact studies add to the critical but successful character of this component of FASTEX (see e.g. Janisková *et al.* (1999) and Desroziers *et al.* (1999), a flavour of which is given in Part 8 of this Report).

The daily running of FASTEX has shown the usefulness, indeed the necessity, of computer aided flight planning. It was required for the MSA operations in order to meet the multiple constraints: the intrinsic complexity of the reference flight patterns, the actual weather and the logistical and air safety regulations. It was found compulsory for operating the Gulfstream because most objectives required its full range. (The computer programs for the MSA were developed by the NSSL and JCMM groups, the one for the Gulfstream by the Laboratoire d'Aérologie.)

Above all, the field phase of FASTEX as a whole has demonstrated the feasibility, despite the manifest difficulties, of a coordinated multi-base, multi-objectives observing system covering a whole ocean and closely associating scientists and meteorologists from many different countries. One way of summarizing the effectiveness of the tracking of the North-Atlantic cyclones is given by Fig. 2.10, where the overall distribution of the soundings taken from the FASTEX main platforms is superimposed on the system trajectories: apart from the earliest phases of some of the cyclones, tracks and data distribution remarkably overlap throughout the ocean: for two-monts, the Atlantic data gap has been filled.

Acknowledgment

This summary of FASTEX operations is dedicated to the many who were involved in it in one way or another: in launching radiosondes at unsocial times and/or in remote locations, monitoring logistical components of FASTEX such as money, goods and peoples' movements, producing and disemminating special products from numerical models and remote sensors, maintaining computers and telecommunication lines, producing forecasts, flying and maintaining aircraft, pushing back the limits of plans and regulations, and navigating and maintaining ships and their instruments in incredible conditions.

We also acknowledge constant and friendly support of the Aer Rianta staff in Shannon as well as the understanding of air traffic control authorities especially in Shannon, Prestwick, Gander and New-York.

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