Part 10

FASTEX (continued): the FASTEX Cloud System Study

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10.1 General conclusion

FASTEX is a research programme focused on one weather phenomena, mid-latitude cyclogenesis, but addressing several of their aspects. This programme has begun by gathering new data on cyclones, both climatologically and from special direct observations. The major deliverables of the first part of the FASTEX programme presented in this Report were:

- to achieve a two-month Atlanticwise field experiment involving many facilities including dedicated ships and aircraft spread from one side of the ocean to the other,
- to coordinate the actions from these platforms in such a way that the *same* weather systems were observed at several stages of their life-cycle,
- to collect and organize the data obtained during the field experiment into a Data Base with a wide access,
- to include in this Data Base series of objective analyses making use of the special data obtained during the field experiment.

The field phase has taken place in January and February 1997. Its logistically extremelly ambitious objectives have been successfully 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.

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: see Short Note 2.2 in Part 2).

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 to take place within the next few months.

This Data Base is, by far, the most important legacy of the project. It is a truly unique source of information on cyclogenesis. It hosts more than 400 h of research aircraft in-situ data, hundred thousands of surface ship and commercial aircraft messages, 90 000 globallly analyzed fields. Its most important asset are its 10 300 high resolution sounding profiles, including 1 600 from ships and 1 300 from dropsondes, many of them in usually barely observed areas, spread all along the storm-track: this alone puts this Data Base at the level of the most ambitious weather observing projects to date, such as TOGA-COARE. But that is not all. This exceptional source of in-situ data is complemented by 25 000 images and 4 000 processed satellite products as well as a growing number of wind profiles within the clouds obtained from the airborne Doppler radar (following the technique shown in Part 5).

Scientists from several fields and from anywhere working on or interested by the problem of mid-latitude weather systems are strongly encouraged to use this Data Base.

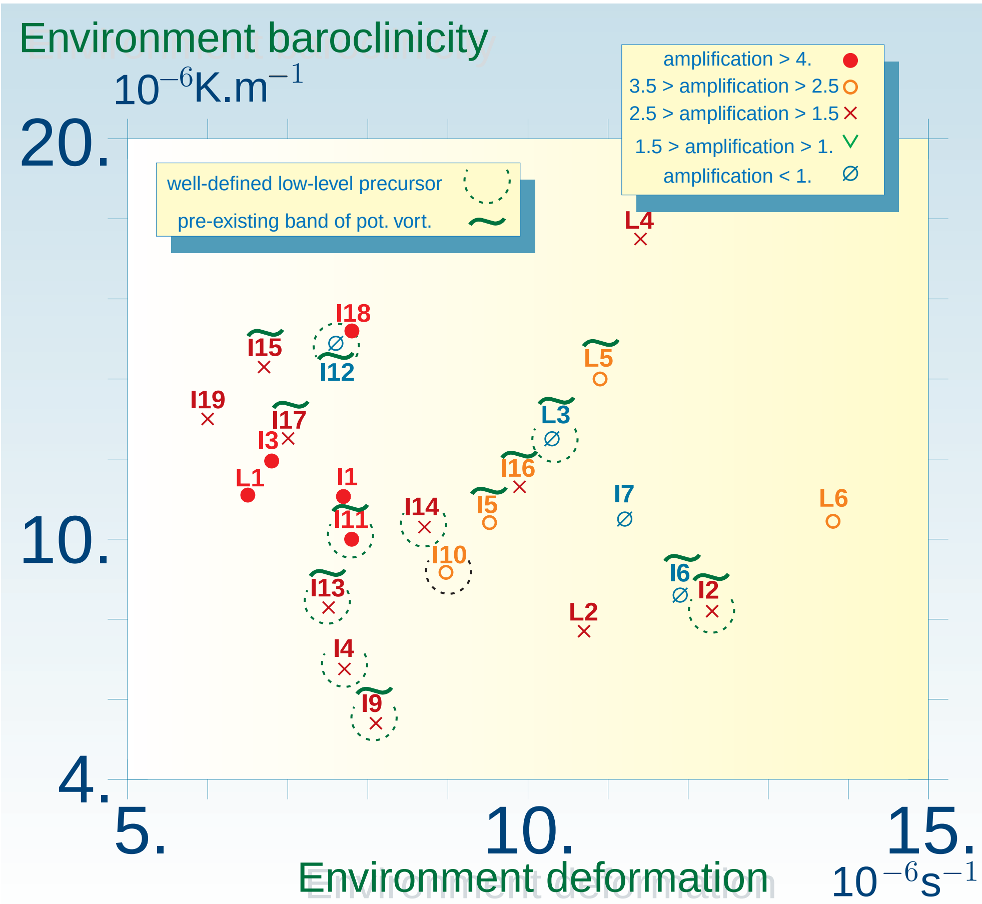
The groups involved in FASTEX have issued reports and submitted a series of article containing their first results (see Part 9). These results have been discussed at the FASTEX workshop in Toulouse, at the end of April 1998. It is planned to publish them in a special issue of the *Quarterly Journal of the Royal Meteorological Society* during the autumn 1999.

10.2 Some results from FASTEX

It is possible to mention briefly here results that directly relate to the initial scientific objectives, some of them being illustrated by this report.

It is worth to recall that a completely new standard of description of cyclones has been reached. The arrays of sondes can be exploited on their own and they reveal the structure of precursor structures within their environment (examples are shown in Part 2), but they can also be incorporated into coherent four-dimensional datasets (as in Part 8). Both detailed and broad features of the cyclone cloud system can be displayed in terms of 3D-wind field and precipitating areas (reflectivity) from within

Figure 10.1: *Example of systematic study of the dynamical properties of the FASTEX cases. The cases have been set into a common frame of reference using automatic tracking within the analyses. They have then been separated between perturbation and environment using a time-filter. The graphic shows a number of properties of the environment at the time of the first detection of each case. The mainframe highlight the influence of baroclinicity and deformation, but the presence of pre-existing structures, such as bands of potential vorticity P has also been examined. While the presence of such a structure does not seem to discriminate these cases (implying that the related instability is a possible but not dominant mechanism), the views put forward by Bishop and Thorpe (1994) on the role of deformation seems to have an influence. From Baehr et al. (1999).*



by the airborne Doppler radars (Part 6) and from above using satellite data (DMSP for example: its data is included in the Data Base, see Part 4). Although it is going to take some time to exploit it, this is a radical change with respect to the previous situation, where only few legs were describing — in very great details, it is true — a very small portion of the system.

The vertical distribution of precipitations within a very active cyclone has been observed by the Doppler radars (Part 5) and reveals significant horizontal variability. The transition from snow or ice particles to rain can be quite sudden and, a few hundred kilometers from there, become smooth and extending over a deep layer. Profiles of terminal fall velocity also bear the signs of the presence of large, rapidly falling ice crystals at about 3 km height, while generally small crystals are present.

One of the most interesting results can be inferred from the distribution of saturation given by the dropsondes deployed by the UK Met Office group (Part 7). These distributions are extremelly interesting because they give access to the scale of the cloud system as a whole and are precise enough to deduce information on the droplets. The simplest growth mechanism of ice crystals, sublimation, appears to dominate in these clouds, close to saturation with respect to ice. However, the sondes enable to spot areas of saturation with respect to water at extremelly cold temperature, meaning at high level. This indicates the presence of powerful ascent zones. Such areas are not exceptional and the next step is obviously to study their geographical distribution. The presence of water in upper-bands of the cloud system is a challenging modelling problem if it turns out to influence the average budget.

Consider now the other obectives:

- the air-sea measurements of Eymard *et al.* (1999) reveal that the current generation of parameterizations of turbulence underestimate the fluxes in the presence of strong winds; as a result, the wind velocity is overestimated by models as it was indeed apparent in the forecasts used during the operations. Few of the expected areas of wind larger than 30 $m.s^{-1}$ actually showed up. Given that most of the Earth surface is actually a sea surface, it is clear that these measurements, obtained in difficult conditions, exploring a new part of parameter space will have an important impact in future generations of climate and coupled models.
- the first assessments of the impact of adaptive observations are becoming available; on average, the impact is currently modest, but generally positive. It is of the order of magnitude of a major change in a numerical weather prediction system. This result has been obtained by several groups (Météo-France, ECMWF, NRL and NCEP, the last two in the USA: these results will all be in the special issue of the *Quarterly Journal*). However, that is not the goal. The goal is to significantly improve the practical predictability on specific events, not on average. Bergot (1999) shows that the adaptive observations are efficient when the quality when the quality of the initial guess field is bad and threatens the subsequent forecast. The theoretical result of Fischer et al. (1998) also demonstrates that the choice of assimilating system is critical to the impact of the observations.
- FASTEX has been a good opportunity to revisit our knowledge of the basic properties of cyclones. Using the recent re-analysis from ECMWF, Ayrault (1998) has constructed a new set of cyclone paradigms that are enterely quantitative. Their structure is described by fields and their frequency and spatial distribution is also known. This work shows that the transformation of a weak wave into a major storm is a single-mechanism process which is statistically independent of

the initial formation of the wave. The genesis of a new wave can, on the other hand, involve several different mechanisms. Some of them have not been studied so far (see Short Note 1.5 for a summary). Baehr et al. (1999) have checked that these "new" types are present in the FASTEX sample, so that they can be studied both theoretically and with observations.

- Chaboureau and Thorpe (1999) verify, in a number of FASTEX cases, that the early stages of the formation of a cyclone are controlled by the larger scale properties such as the deformation. This is a complex time-dependent stability problem that has been studied theoretically only recently (Bishop and Thorpe, 1994) but is clearly very important. This is confirmed in the more systematic but less detailed study of Baehr et al. (1999) (Fig. 10.1).
- Arbogast and Joly (1998), Arbogast (1998) and Mallet et al. (1999) have also clearly and directly established the essential role of cyclone precursors. They truly determine the existence of many a storm, and they do that in ways that can be much more complex than anticipated by Sutcliffe (1947) and Petterssen and Smebye (1971) on poorly documented case studies. The full scale observation system set up for FASTEX that never left cyclones out of areas of increased observations combined to new analysis tools such as the inversion of potential vorticity has allowed, for the first time, the actual and unambiguous, step by step breakdown description of the generation of a new north-Atlantic cyclone (see Short Note 2.3 for an example). In the case of Low 41 (see section 3.21), for example, a low-level to low-level interaction at a distance has been revealed by using several inversion-like techniques.

Apart from a number of historical papers mentioned also in Part 1, the articles cited here are listed in the project bibliography (Part 9).

Very few studies have been undertaken, so far, that attempts to exploit the full FASTEX sample of cases. the detailed studies, on the other hand, have addressed a few of the cases. Many more results can still be expected.

10.3 About other benefits

This short section attempts to bring out the benefits of the FASTEX project beyond the normal contributions to the progress of science, such as the publications listed in Part 9, or the ability of the project to provide its deliverables.

Consider first the small world of atmospheric scientists. FASTEX has been successfully designed and implemented by a small group of European scientists. It benefited, of course, from the scientific and technical input from our more experienced colleagues from the other side of the Atlantic, as well as from the most remarkable professionalism of their aircraft and instrument teams. Indeed, FASTEX would not have been possible without their strong support. Yet, it remains that the initiative came from Europeans, that the project was attractive enough for our american and canadian colleagues to find an interest in it and that, roughly speaking, things turned out to keep very close to the very first plans. The backbone of the coordination structure required for the project in Shannon, most notably the weather forecast and a number of data communication lines has been organised, set-up and run successfully by European groups. Most large scale experimental projects are initiated by the american community, so that the situation created by FASTEX is exceptional enough to be noted.

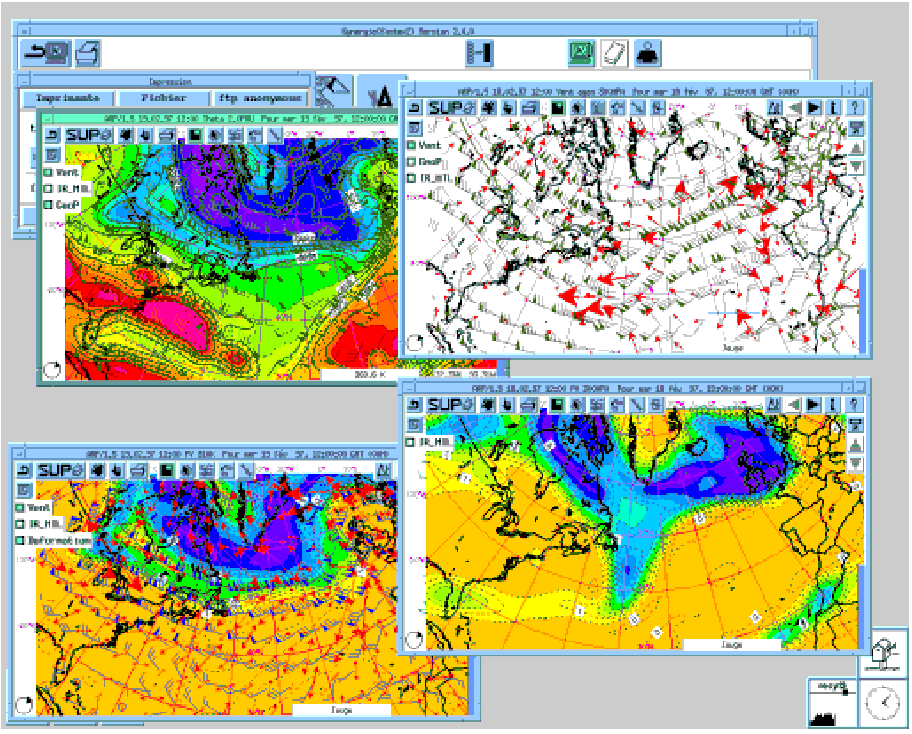


Figure 10.2: *Running FASTEX implied that forecasters and scientists speak the same language and discuss the weather in a similar framework. It has been chosen, at Météo-France, to modify the operational weather display system SYNERGIE rather than use a research display terminal, so that this common framework is now employed operationally. The figure shows a SYNERGIE session with some of the products that are now employed daily but were typical of the research world in 1994: the thermal and height distribution on the $P = 2$ PVU potential vorticity surface (the dynamical tropopause) (top left), direct display of the ageostrophic velocity (top right) contributed by the Laboratoire d'Aérologie (a University laboratory), the deformation field (bottom left), both of them enabling a much better analysis of the wind field and potential vorticity P on pressure p or isentropic θ surfaces.*

It is also worth noting that, in terms of know-how, european scientists have shown, during the FASTEX operations, that they were able to run in a proper way such large facilities as the several ships in mid-ocean and the jet as well as the turboprop aircraft. One can then but note that the next natural step, here, would be for the european community as a whole to coordinate the renewal of its observing platforms in such a way that FASTEX-like programmes can be mastered in Europe from A to Z: compared to FASTEX, this requires more independence in the access to, typically, long range aircraft.

As shown clearly by Parts 5 and 6, the french group from the Centre d'étude des Environnements Terrestre et Planétaires fully masters the airborne Doppler radar technology, from both the side of the instrument (the dual beam antennas of both the P3 and the Electra have been developed by this group) and its data processing.

Beyond the running of the ships and aircraft, the most expensive component of FASTEX has to do with the many radiosondes and dropsondes needed. Most of them by far successfully used the recent GPS technology, and most of them have been produced by the European company VAISALA and its american subsidiary of the same name. One of the dropsonde type employed has been developed by NCAR in the USA, but the other one is the result of close cooperation between the UK Met Office and VAISALA all along the planning phase of FASTEX. The last tests and adjusments took place during the first flights of the Met Office C-130 under maximum pressure but finally gave access to new standards, as shown in Part 7 of the Report.

Beyond the small world of atmospheric scientists, there is the slightly larger world of operational weather forecast, the products of which have an obvious impact on the public at large.

In this area, there are one or things worth mentioning. The forecast component of the Shannon Operations Centre required, by design, many people from the different groups (from Canada, France, Ireland and the United Kingdom). In most groups, some kind of rotation of the people have been organized. As a result, FASTEX can be seen as a successful training action that allowed a number of operational forecasters to:

- interact directly with scientists working on the same weather systems as the forecasters, but sometimes with quite different approaches,
- interact directly with forecasters from the other groups,
- discover and use the forecasting tools from the other groups, that often implement the vision that different services have of operational forecast.

In this instance, the Canadian contribution has been most noted and appreciated in the sense that it is the system for which the control of the forecast suite by the forecasters is the most effectively implemented. It should be repeated here that the forecast group as a whole has been most efficient and that the daily meetings between forecasters offered a very nice example of active and effective international collaboration.

In order to fully appreciate the meaning of this training action, one must have in mind that the "conceptual world" of the scientists has been evolving considerably this past decade (this is summarized in section 1.2 in Part 1 of this Report) and it is through actions similar to this one that the best of these ideas become to be employed beyond research. It is our belief that these new concepts are useful for interpreting rapidly and properly a given situation, the evolution of which is, nowadays, given by model simulations. The work of forecasters is now a typical decision taking process based on the assessment of the numerical products available.

Along the same line, it has been chosen, at Météo-France, to modify the operational display system SYNERGIE with these concepts in mind, rather than bring a research tool and train the forecasters on it. As a result, the training in question has happened in Shannon, but instead of returning to an environment from which dynamical concepts are largely absent, the forecasters have found, on their operational terminal, the same environment as in Shannon and these dynamical concepts are becoming more and more popular, as they are found actually useful. This is the case, in particular, in winter. The monitoring of storms for the benefit of our countries has been, in this respect, improved on the same (short) time scale as the part of the FASTEX programme detailed here.

Another benefit of FASTEX has been the extensive use of the ensemble prediction provided by the European Centre for Medium-Range Weather Forecast for the medium-range outlook in Shannon. It has been shown, in particular, that the seven-day prediction of the weather regime is effective. The success, here, must, obviously, be credited to ECMWF, but FASTEX has allowed a significant number of people to realize the effective jump that has been made in this area.

On a time scale that goes beyond that of this report, but much shorter than that of climatic research, the most serious possibility of direct economical benefit lies with the potential of adaptive observation to secure the forecast of extremelly rapid cyclogenesis events, something that even the most recent models and data assimilation techniques still do not offer (as has been seen these last two winters). At this stage, it is not fully clear what form will take the operational implementation of adaptive observation. There are several possibilities:

- it can be used to improve the control of active remote sensing instruments, or to perform a more clever thinning of the data provided by passive instruments,
- it can lead to the development of a truly adaptive component of the observing system, based either on ships and aircraft of opportunity (but employed very differently from the current practice) or on remotely controlled "sondes", although this sounds a bit like science fiction, at least for european budgets,
- it can also, and more realistically, help improving existing data assimilation algorithm, since these do not, currently, make direct use of the yet computable predictability informations required to adapt the observing system.

The benefit to operational forecast of these ideas can safely be expected to be within the next five years.

10.4 The FASTEX Cloud System Study project

This section now returns to the more familiar small world of research. Indeed, the scientific benefits of the FASTEX data set are only just beginning to be collected. A significant effort is put into several of the scientific objectives listed in Part 1, such as, for example, predictability.

However, this Report is concluded by focusing again on those objectives relating to the cloud systems, their evolution and structure.

10.4.1 Overview

The FASTEX-Cloud System Study (FASTEX-CSS) aims at producing a complete life-cycle description and understanding of the FASTEX cloud-cyclone system. The aim of FASTEX-CSS is to exploit the FASTEX data to describe, in as complete a way as possible, the cloud systems associated with cyclones, their initiation, evolution and the role of the synoptic environment in that development.

Based on these results FASTEX-CSS will provide a multiscale synthesis of the cloud-cyclone system enabling tuning of cloud parameterization and validation of climate models.

A set of reference cloud classification during the life-cycle of frontal waves will be produced.

There will be an intercomparison of mesoscale numerical models of FASTEX cyclones, exploiting sophisticated cloud physics representation.

This will allow the validation of regional and cloud-scale models of the cyclone/cloud system. In addition a set of reference FASTEX simulations suitable for parameterization tuning (cloud and marine boundary layer structure) will be produced which will lead to an improved cloud physics parameterization scheme for such clouds for use in climate models.

The FASTEX-Cloud System Study Project is funded by the European Commission under the contract ENV4-CT97-0625.

10.4.2 Project components

Initiation and evolution of cloud systems

(i). Using the MANDOPAS scheme, both radar and dropsonde data are now being used to cover both clear air and precipitation regions at the Centre des Environnements Terrestre et Planétaires from CNRS, concentrating on IOP 12 and IOP 16. The long-term aim is to retrieve microphysical fields.

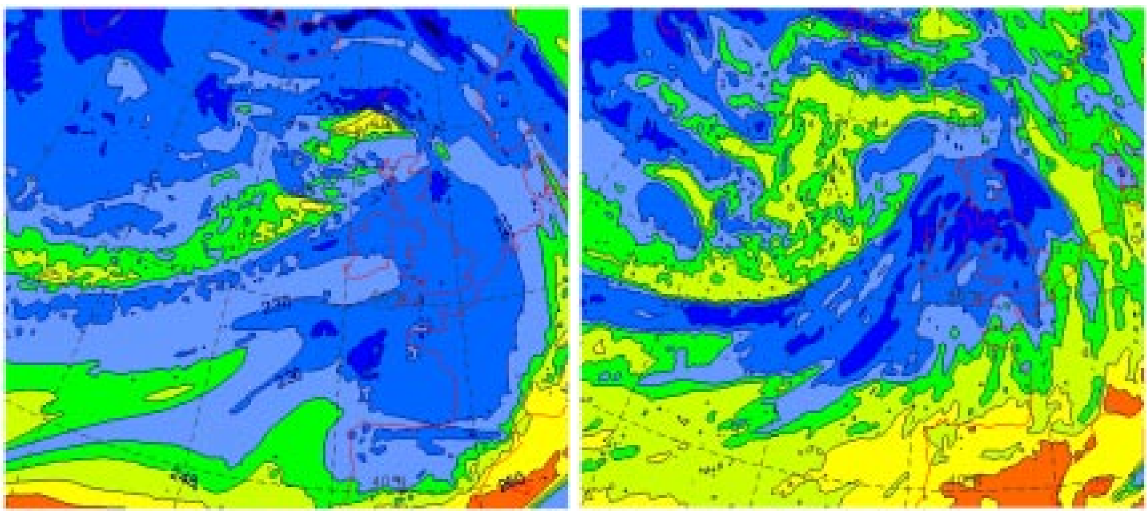
(ii). The Irish Met Service is involved in the analysis of ozone ascents from Valentia and the HIRLAM model will be used once 4D var system is in place.

(iii). The cloud field classification is being developed at the Laboratoire d'Aérologie in Toulouse in collaboration with the Laboratoire de Météorologie Dynamique. The 3I method is being used based on a pattern recognition technique.

(iv). The UK Met-Office is extending to theta surfaces its iterative successive correction method to analyse dropsonde data from IOP 16. The ice sublimation hypothesis discussed in Part 7 is being developed using the static stability field. This approach also aims at integrating with Doppler radar data.

(v). DNMI works on slantwise convection in IOP 11 at 00Z on 6 February 1997. These experiments are going to 0.2°× 0.1°resolution in future.

Figure 10.3: *A preliminary result from FASTEX-CSS: direct comparison between a high-resolution global model simulation of IOP 16 (left panel) (for a summary of IOP 16, see section 3.19, page 116) and the brightness temperature measured by the METEOSAT satellite (right panel). The simulated brightness temperature is the outgoing infra-red flux produced by the radiative scheme of ARPEGE. It combines the profiles of temperature, humidity and the diagnosed cloudiness. The model is Météo-France ARPEGE, run at T213, C=3.5, which means that the resolution is equivalent to T740, and with 41 levels. The image is obtained after a 24 h simulation. Images provided by Ph. Lopez, Météo-France GAME.*



Mesoscale modelling

(i). The mesoscale model intercomparison project is taking shape (Fig. 10.3). It is coordinated by Philippe Lopez, from Météo-France/GAME. Such mesoscale simulations are needed for: tuning the free parameters of the cloud schemes, validation, intercomparison, and to compare with SSM/I and radar and dropsonde data. Three cases are IOPs 11, 16 and 17. GAME will provide 4D-VAR re-analysed data by the end of January (first case) and February (second case) at 80 km resolution in GRIB format. Models will run at 10 km and output a variety of quantities. Models that would be involved are: the UK Unified Model, HIRLAM and MESO-NH (Météo-France and CNRS non-hydrostatic model).

There is a potential for extending this intercomparison to the GCSS Working Group 3 (stratiform clouds).

(ii). The Irish Met Service will perform extended sensitivity tests for various IOPs to parameterization schemes for clouds and surface layer processes.

(iii). DNMI investigates the evolution of the boundary layer within a cold-air outbreak part of IOP 17.

(iv). UPS/LA will use the MESO-NH model for IOPs 11, 16 and 17. This model has 3 cloud ice variables.

Multi-scale synthesis

(i). The Reading group had been looking at the 3 cloud heads of IOP 16 and the attendent transverse circulations. Analysis of dropsonde data on θ_w has been performed. In IOP 16 there was evidence of SCAPE (Slantwise CAPE) but little CAPE (Convective Available Potential Energy).

(ii). The Reading group also plans to use the extended energy concept to examine the dynamical role of regions of reduced static stability in triggering cyclogenesis. An important quantity to be output from the mesoscale model intercomparison component is (diabatic) heating which is important for this dynamical study.

(iii). The Iceland Met Institute concentrates on the IOP 8 Greenland wave case and other cases that have their development influenced by Greenland.

These research tasks develop one or two aspects only of the scientific topics that can be addressed with the FASTEX data. This Report, it is hoped, will be a useful landmark in the course of the long-term FASTEX programme, but, as the above lines are meant to suggest there is still a large potential to derive from the data collected during the field phase of FASTEX.

While the climate-related results will ultimately join, as a modest contribution, the many process studies that are still needed to monitor, understand and forecast the dynamics of climate, the daily use by the national weather services involved in FASTEX will sooner turn and is already turning the ideas and tools mentioned in this Report into actual contributions to improving the difficult forecast of strong winds and/or strong rains over Europe associated with cyclogenesis.

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The FASTEX World Wide Web home page and Data Base:
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Appendix A

List of acronyms

Table A.1: *List of Abbreviations/Acronyms*

ACARS	Aircraft Automated Reporting System
AES	Atmospheric Environment service
AMDAR	Automated Meteorological DAta Relay
ARGOS	Argos is a satellite-based location and data collection system dedicated to monitoring and protecting the environment
ARPEGE	Action de Recherche Petite Echelle Grand Echelle
ASAP	Atmospheric Sounding Automated Program
ASCII	American Standard Code for Information Interchange
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic data
BUFR	Binary Universal Format (GTS data format)
CD-ROM	Compact Disc - Read Only Memory
CERSAT	Centre ERS d'Archivage et de Traitement
CETP	Centre de l'Environnement Terrestre et Planetaire
CLS	Collect and Locaton per Satellite
CMM	Centre de Météorologie Marine
CMS	Centre de Météorologie Spatiale
CNES	Centre d'études Spatiales
CNRM	Météo-France's Centre National de Recherches Météorologique
CNRS/LA	Centre National de la Recherche Scientifique/Laboratoire d'Aérologie
COST	Coopération Scientifique et Technique (European cooperation in the field of scientific and technical research
CSG	Core Steering Group
DMI	Danish Meteorologic Institut
DMS	Database Management System
DMSP	Defense Meteorological Satellite Program
ECMWF	European Center for Medium Range Weather Forecasts
EGOS	European Group of Oceanic Stations
ERS	European Space Agency's environmental satellite
ETL	NOAA's Environmental Technology Laboratory
FASTEX	Fronts and Atlantic Storm-Track Experiment
FCA	FASTEX Central Data Archive
FDA	FASTEX Data Archive
FTP	File Transfer Protocol
GDC	NOAA's Global Drifter Center
GMEI	CNRM's Groupe de MEtéorologie Instrumentale
GOES	Geostationary Operational Environmental Satellites
GRIB	Gridded Met information - Binary
GPS	Global Positioning Systm
GTS	Global Telecommunications System
HIRLAM	Hi-Resolution Limited Area Model
HRPT	High Resolution Picture Transmission
IcMS	Icelandic Meteorological Service
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
IFS	ECMWF's Integrated Forecast System
INM	Instituto National de Meteorologia (Spanish Weather Service)
INMG	(Portuguese Weather Service)
INSU	Institut des Sciences de l'Univers
IOP	Intensive Observational Period
IR	InfraRed
IrMS	Irish Meteorological Service
JCMM	Joint Center for Mesoscale Meteorology
JOSS	Joint Office for Science Support
KNMI	Meteorological Service of the Netherlands
NCAR	National Center of Atmospheric Research
NESDIS	National Environmental Satellite Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NPS	US-Navy's Naval Postgraduate School
NSSL	NOAA's National Severe Storms Laboratory
NWS	NOAA's National Weather Service
PERL	Standard 2-minute 360°turn
PI	Pricipal Investigator
PYREX	PYRenean EXperiment
QC	Quality Control
QCF	Quality Control Format
RAF	NCAR's Research Aviation Facility
SCEM	Météo-France's Service Central d'Exploitation Météorologique
SSMI	Special Sensor Microwave Imager
SVP	Lagrangian surface drifter
TOVS	TIROS Operational Vertical Sounder
UCAR	University Corporation for Atmospheric Research
UK	United Kingdom
UKMO	United Kingdom Meteorological Office
USA	United States of America
USAF	USA's Air Force
USGS	US Geographical Service
VIS	VISible
WMO	World Meteorological Organisation
WV	Water Vapor
WWW	World Wide Web

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