Joint Centre for Mesoscale Meteorology, Reading, UK

Research strategy and programme

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1. Introduction

This is the first Research Programme issued by the Joint Centre for Mesoscale Meteorology (JCMM) following its enlargement in October 1992. It should be read within the context of the JCMM Prospectus, issued in October 1992, which describes the motivation and expertise of the JCMM and the tools available to it. This document combines a broad description of the long term strategy and rationale underlying the main projects within the JCMM with a more detailed description of specific plans for the year commencing April 1993. This should be regarded as an evolving draft: it is intended that it will continue to be refined over the coming year/years as the JCMM activities develop and new opportunities become apparent.

The research is presented under four main Programme Areas:

- Mesoscale Systems
- Mesoscale Modelling
- Cloud Processes
- Radar and Satellite Observations

2. Aims and Objectives

2.1. The central aim of the JCMM is to obtain a better understanding of weather systems and processes occurring at and below the mesoscale. This is a prerequisite for improved weather and climate prediction. To accomplish this aim it is necessary to develop and exploit routine and specialized observations together with high resolution models in the analysis of mesoscale weather systems.

2.2. The aim may be broken down into a number of broad objectives as follows:

- to develop conceptual and analytical models of mesoscale weather systems
- to develop observing techniques and algorithms for the interpretation of remote sensing observations, especially algorithms for cloud, precipitation and water vapour
- to undertake special field experiments to reveal the fine scale structure and evolution of weather systems
- to develop cloud resolving models for use in studies of cloud systems in the context of the international GEWEX Cloud System Study
- to use cloud resolving models to derive realisations of cloud systems and parametrizations for larger scale weather and climate models

- to validate and carry out limited development of mesoscale models, with particular reference to the representation of cloud, precipitation and land surface processes

- to use mesoscale models in case studies to increase understanding of mesoscale processes and the predictability of mesoscale weather systems.

2.3. The primary approach is to develop an integrated view, rather than focus on observational data analysis for its own sake or numerical modelling per se. The range of expertise available within the JCMM helps this to be achieved. Projects are to be designed to answer tractable process-orientated questions. Descriptive models, theoretical models, and concepts encapsulating new understanding will be generated.

2.4. In order to capitalize on the new understanding, two further steps are necessary:

- to express the ideas and models in a form that is amenable to practising weather forecasters and climate researchers and to receive useful feedback from them to aid in the systematic diagnosis of model failures.

- to produce improved parametrizations, formulations and configurations for the next generation of operational NWP and climate models.

3. Scope and rationale of the JCMM research over the next several years

3.1. Mesoscale Systems

3.1.1. Mesoscale phenomena for study

Important phenomena for study include mesoscale convective systems, polar lows, fronts and frontal waves, mountain flows, mesoscale response to underlying variations, interactions of cloud physics and radiation, mesoscale dispersion and inertia-gravity waves. These systems pose important problems in weather forecasting, and understanding will result from an interplay of theoretical research, observational programmes and mesoscale modelling.

3.1.2. Mesoscale theory

3.1.2.1. The rationale for theoretical research is to achieve a better understanding of the basic processes in mesoscale weather systems. Complex numerical models and observational campaigns produce data that need to be interpreted in terms of physical concepts. The central objective of theoretical meteorology is to reduce complicated atmospheric systems to simple theoretical ideas. The tools of theory involve not only the laws of physics but also simplified numerical modelling of key processes.

3.1.2.2. Theoretical issues of current concern involve the following questions:

- are potential vorticity (PV) concepts useful in describing mesoscale weather systems and their interaction with the large scale flow? PV is often conserved by air parcels; lack of conservation gives a good indication of the existence and role of diabatic and frictional processes.

- what is the dynamical role of cloud and radiative processes on the mesoscale and synoptic scale? There is clear evidence that these processes have a dominant effect on the structure and organization of weather systems such as cyclones.

- how are mesoscale instabilities, such as barotropic, baroclinic, and symmetric instability, modified by the presence of larger scale forcing such as background deformation? This has an important bearing on the evolution of, for example, frontal cyclones.

- which factors determine the response of the mesoscale flow to the presence of mountains? The dynamics of mountain waves including the drag exerted when they break is an important factor.

- how are mesoscale circulations modified by flow over heterogeneous surfaces? The aggregation of surface fluxes is an important unresolved theoretical issue of considerable importance to mesoscale and climate modelling involving the interactions between the boundary layer and the mesoscale.

- which are the important factors determining the organization of deep moist convection? Frequently convection is organized into a small number of intense long-lived storms whilst on other occasions it is more disorganized and intermittent in character; wind-shear, large-scale forcing and surface fluxes are likely to be important.

- do mesoscale weather systems evolve as instabilities of the synoptic scale flow or are they initiated by local finite amplitude forcings from the synoptic scale? This is particularly relevant for mid-latitude cyclones and upper-level structures.

- can limits be found for deterministic predictability of mesoscale weather systems as they have been for the synoptic scale?

3.1.2.3. In the tropics, such systems as African Easterly waves, squall lines and tropical cyclones are to be examined. As with mid-latitude systems, an understanding of diabatic processes is crucial in the development of any theories. The weather systems occurring over North Africa in the summer offer a particular challenge, because of complicated interactions between convection, topography, diurnal effects and dynamics. With regards to tropical cyclones the air-sea interaction process is to be examined closely.

3.1.3. Mesoscale observations

3.1.3.1. Supporting observational studies will be carried out using routinely available data supplemented by intensive measurements from research aircraft with dropsondes and in-situ measurements, along with special ground-based measurements from radiosondes and radars. The C-130 facility is critical to this programme and has provided insights not available through models or theory alone; development of the use of lightweight air-deployed radiosondes will further increase its utility. Combined use of the aircraft with the Chilbolton radar will provide opportunities for studying the interaction of microphysical processes with the dynamics. Participation in and organization of international observational campaigns such as FRONTS-NEXT will be a major component of the JCMM programme. FRONTS-NEXT is concerned with frontal cyclones and cyclogenesis, and will involve both European and North American groups. Major field experiments are time consuming and expensive and they will be undertaken only infrequently, after theoretical studies have clarified what questions are to be addressed.

3.1.3.2. A programme of research is also planned to examine convective systems in the Tropical Pacific, using wind profiler data. The measurements obtained from the profiler will be compared with NWP products from the Met. Office and ECMWF. Of particular interest are waves in the easterlies which are thought to be mainly convectively driven and sometimes evolve into tropical cyclones.

With advice and assistance from the Data Assimilation group in FR-Division, Bracknell, JCMM scientists will use data assimilations as a tool for getting the best out of various kinds of mesoscale observations. Before this can be done, however, it will be necessary to determine whether:

(a) the mesoscale model before assimilation of any special data does represent features that are consistent with conceptual models of mesoscale phenomena,

(b) assimilation can make the mesoscale model fit the data, while still retaining the coherence of these features, and

(c) the resulting model state is indeed useful for diagnostic studies pertaining to the generation and testing of conceptual models.

Assuming a satisfactory outcome to these three steps, it will then be possible to use data assimilation as a tool to help us gain a better understanding of the mesoscale phenomena.

3.1.3.3. There is a need to measure the impact of high resolution observations from special programmes on the representation and prediction of mesoscale features generated by NWP models, and to evaluate the potential value of new observing techniques for resolving specific atmospheric phenomena. Analysis methods that operate only on observed data will be used to:

- obtain 'quick-look' analyzed fields during field experiments.
- investigate the effective scale resolution of observing systems.

- provide estimates of observed features for comparison with conceptual models and NWP model data.

- provide benchmark analyses as a basis for evaluating the impact of mesoscale data assimilation techniques on the diagnostic analysis of observed features.

3.2. Mesoscale Modelling

3.2.1. Mesoscale models are suitable vehicles for providing understanding of mesoscale weather systems including those systems driven by the cloud and precipitation processes which so often dominate mesoscale behaviour. However, these same mesoscale models and indeed numerical prediction and simulation models on all scales suffer from the inadequacy of the parametrization of physical processes. One of the main issues facing the atmospheric science community at present is the inadequacy in the model predictions of cloud and precipitation and, in particular, the sensitivity of model predictions to the parametrization schemes. This applies to weather and climate prediction models alike. Thus a key issue for the JCMM will be to evaluate the predictability of cloud and precipitation and to devise improved parametrization schemes. An improved scheme is required for the full range of models used by the Meteorological Office as part of its Unified Suite but, because of the mesoscale variability of cloud and precipitation, the best test bed for the research is a mesoscale model.

3.2.2 Various versions of the hydrostatic Unified Model and non-hydrostatic mesoscale model will be run to investigate mesoscale predictability. Issues affecting mesoscale predictability which require investigation are:

- Are the parametrizations adequate? Do processes such as slantwise convection require parametrization in current operational mesoscale models or can they be resolved? How sophisticated does the representation of cloud and precipitation microphysics have to be?

- What extra features can be resolved or predicted more accurately with higher resolution, eg squall lines, tornadoes, fog and frontal waves? What resolution should be used in the next generation of operational models? Does increased horizontal and vertical resolution provide benefits that outweigh the costs?

- Is the dynamical formulation of the current unified model adequate? At what resolution does a non-hydrostatic formulation become essential?

- How much can the skill be improved with better initial and boundary (including surface) conditions? How accurate can the current models be, given the limitations of inadequate observations to define the initial conditions?

- Is mesoscale predictability severely limited by using a small high resolution domain?

Detailed case study investigations will be carried out to address these issues. Where possible these will take advantage of mesoscale observations acquired in special field programmes.

3.2.3. These studies will be carried out by a small group with specialist experience in the development of mesoscale models; however, the group will benefit from and work closely with other groups within the JCMM with expertise in the theoretical and observational aspects of mesoscale processes, especially cloud and precipitation, as well as groups in APR and FR Divisions at the Met. Office, Bracknell. This work will lead to improved parametrization schemes which will be applicable to the various versions of the Unified Model. It will also lead to the definition of the required resolution, formulation and configuration of future operational models, thereby enabling the operational products to benefit directly from a range of research expertise.

3.3. Cloud Processes

3.3.1 The work of this group will be concerned mainly with convective cloud systems. Convective systems redistribute heat, moisture and momentum and they generate gravity waves. These processes must be represented in large scale models, but unfortunately such cloud systems are neither well resolved nor well observed. Their effects must therefore be parametrized, and, moreover, observations alone are not enough to determine the parametrizations. A numerical model that resolves the main dynamical features of convective systems can be used to study these processes and diagnose their large scale effects. Such a cloud-resolving model itself requires parametrizations, but these are on a much smaller scale than those in GCMs, closer to the scales which can be observed. A combined observation and modelling programme will be undertaken to develop and validate a cloud-resolving model. That model will then be used to validate and develop parametrizations of the effects of convective clouds in large scale models.

3.3.2. The observations component of the programme will use data from the C-130 aircraft to further our understanding of microphysical, radiative and turbulent processes in cumulonimbus clouds. These same clouds will be simulated in the cloud-resolving model and the observations will be used to validate the cloud-scale parametrizations. This will require observational estimation of amounts of the various bulk water and ice species (eg cloud water, cloud ice, rain, snow, graupel, hail) and conversion rates between them together with measurements of the up/downdraught strengths and environmental profiles. Safety implications are likely to limit what can be achieved and so initial experiments will be aimed at refining the observational programme.

3.3.3. The parametrization of the large-scale effects of cloud systems within GCMs is a critical issue now being addressed internationally by means of cloud-resolving models under the aegis of the GEWEX Cloud System Study (GCSS). The JCMM work will contribute to the aims of the GCSS. Amongst the specific questions needing to be addressed are:

- Is momentum transport by convection an important unresolved process in GCMs? If so, how should it be parametrized?

- Is gravity wave generation by convection an important unresolved process in GCMs? If so, how should it be parametrized?

- How sensitive are cloud model simulations to a) resolution and b) representation of microphysical processes?

- How can we verify the rates of conversion between bulk water species which are assumed in the cloud scale model parametrization?

- Can the cloud-resolving model represent the water budget of a convective system accurately?

3.3.4. The success of the cloud resolving modelling studies depends on greatly increased computer resources becoming available over the next few years. Availability of CRAY time is likely to limit the pace of progress with this essentially long term strategic programme.

3.4. Radar and satellite observations

3.4.1. Radar Component

3.4.1.1. Observations of the kinematic and microphysical structure of frontal and convective precipitation systems, needed in support of the research described in Sections 3.1, 3.2 and 3.3, can be provided by means of Doppler and polarisation radar techniques obtained from the Chilbolton radar. Using data collected during situations of isolated convective showers, widespread slantwise ascent, and line convection, the problems to be tackled would include:

- Initialisation. What is the effect of initialising numerical models with the more accurate and highly resolved Doppler winds and precipitation data?

- Verification.
  - Do NWP models predict the correct vertical profile for precipitation?
  - Are the regions of snow and graupel observed by the radar correctly predicted by the models?
  - Does the wind field evolve in the manner predicted?

- Parametrizations of cloud physics. Different parametrization schemes will be explored in an attempt to diminish the disagreements between predictions and observations.

- Ground based measurements of rainfall. Data from the UK operational radar network currently identify the areas of rain, but the quantitative rainfall rates derived are less credible. The physical causes of these errors are well known, but are difficult to remedy with the present operational radars. Case studies with the Chilbolton radar have confirmed that polarisation techniques can identify and correct them. Studies will be undertaken to determine whether such improvements could be achieved on an operational unmanned system.

3.4.1.2. Global measurements of rainfall and cloud cover, including their vertical distribution, are necessary if we are to be able to understand the global climate system and develop models capable of reliably predicting any future climate change. The only practicable way that such global data can be acquired is by satellite; rainfall rates and vertical profiles of rain and cloud inferred from passive microwave sensors tend to be rather qualitative, but active microwave (radar) systems in space will provide important data that complements the radiometer measurements. The development of these new radar techniques and the interpretation of the global data present major scientific challenges. The first satellite borne microwave radar will be launched in 1997, and higher frequency spaceborne cloud radars are being planned under the aegis of GEWEX for mapping vertical cloud structure. The JCMM group will exploit observational facilities such as the C-130 aircraft and the Chilbolton radar in the development of algorithms for these various microwave techniques. The installation of a millimetre wavelength cloud radar on the C-130 aircraft will be considered for regional studies of cloud structure and in support of international activities to develop spaceborne cloud radar.

3.4.2. Satellite component

3.4.2.1. Data from current meteorological satellites remain under-exploited. For example, the time evolution of cloud systems may be studied in detail with the help of half-hourly images from geostationary satellites: whereas in mid-latitudes this is likely to be supplementary to conventional observational systems, in data-sparse tropical areas the satellite data may be the only way to provide input and validation for models of mesoscale cloud systems. The mid-latitude studies will be carried out mainly as part of the Mesoscale Systems Programme (para 3.1) whereas the tropical studies will be undertaken within the Radar and Satellite Observations Programme Area.

3.4.2.2 Interpretation of the satellite data is partly based on comparisons made within field campaigns. Examples of such campaigns include EFEDA 1991 (Echival Field Experiment in a Desertification threatened Area 1991) and the HAPEX-Sahel 1992 experiment. Continued studies of data from these and future experimental programmes will improve our understanding of the relationships between observations of the surface and near-surface layers and of the heat and moisture fluxes that act as inputs to mesoscale and larger systems.

3.4.2.3 The data from satellites will also contribute increasingly to GEWEX-related studies of aspects of the hydrological cycle, over a range of time and space scales. On scales from 100km upwards, statistical methods are already useful for the estimation of rainfall and evaporation using data from current meteorological satellites: further developments are expected in such methodology, and also in the incorporation of data from new sources, particularly in the microwave. Preliminary studies of data from the 19 and 35 GHz channels of the SSM/I instruments, despite their known limitations, also indicate the possibility for providing useful information on soil moisture in semi-arid regions. To improve the information available on the scale of river catchments, and more locally, understanding of rainfall events on the mesoscale is required. Effects of topography on the rainfall from given cloud types will be investigated with the use of models and surface observations in addition to the satellite data.

4. Specific Project Activities Planned for 1993/94

4.1. Mesoscale Systems Group (Senior scientists: Thorpe, Clough, Craig, Pedder, (Dugdale)).

4.1.1. Observations component

4.1.1.1. Analysis of FRONTS 92 observations of frontal waves. Results of 3-D objective analyses of dropsonde observations for one of the Intensive Observing Periods (IOP3) will be combined with imagery and other data to indicate the dynamical structure of a frontal wave and the distribution of the associated precipitation. These analyses will be interpreted in terms of dynamical theories of the formation and growth of frontal waves and embedded mesoscale structures. The observations from two other Intensive Observing Periods will also be analyzed and interpreted in terms of mesoscale and microphysical processes.

4.1.1.2. Studies of the assimilation of mesoscale data (see also para 4.1.2.7). Observations and analyses from FRONTS 92 and FRONTS 87 will be made available to the Data Assimilation Group at Met. Office, Bracknell for collaborative studies of assimilation of mesoscale data. The data from FRONTS 87 will consist of dropsondes plus ground-based Doppler data obtained by French groups.

4.1.1.3. Acquisition of new observations addressing aspects of frontal structure. Case studies of the mesoscale structures of frontal systems will be carried out on an opportunity basis using special ground-based radiosonde observations from several stations combined with Chilbolton and other Doppler radar measurements and possibly C-130 observations.

4.1.1.4. Planning for FRONTS NEXT. Preliminary planning for the Anglo-French FRONTS NEXT observational campaign in 1996 will be pursued with METEO-FRANCE. A lightweight radiosonde facility will be developed by the end of 1994 in readiness for this campaign.

4.1.1.5. A strategy for acquiring and archiving satellite and radar imagery will be developed to optimize the effectiveness of the different JCMM groups using these data.

4.1.1.6. Case studies exploiting the JCMM display facilities. Analyses of weather systems will be carried out using NWP model products, radar and satellite imagery and other data sources within the JCMM display system to study mesoscale events and features of interest. NWP model products, imagery and other data will be routinely evaluated and archived to support such studies. The case studies will be concerned with the influence of synoptic environments on the formation and growth of frontal waves and other phenomena, and the relation of the observed behaviour to that expected from theoretical studies.

4.1.1.7. Potential vorticity, water vapour imagery and severe weather. The relationship between high-PV stratospheric intrusions, water vapour imagery, and a variety of severe weather events will continue to be investigated. The use of PV charts and WV imagery in forecasting will be developed in a collaborative project with CFO Bracknell.

4.1.1.8. Analyses of land-atmosphere fluxes. Analysis of near-surface micro-meteorological data and high resolution remotely sensed data from the HAPEX-Sahel experiment will be made to obtain a better understanding of the surface to atmosphere energy fluxes across transition zones. Surface layer models will be used to help in these analyses and their use for upscaling of fluxes to scales of a few kilometres will be investigated. The results are expected to contribute to the parametrization of surface fluxes on scales suitable for use in mesoscale atmospheric modelling.

4.1.2. Theory component

4.1.2.1. Potential vorticity ideas. The use of potential vorticity ideas will be extended using a new analogy with the theory of electrostatics. This is being applied to the dynamics of frontal waves and tropopause PV strips to deduce the strain rate due to remote vorticity sources. The theory provides a new way to attribute parts of the flow to individual PV anomalies.

4.1.2.2. Dynamics of polar lows and tropical cyclones. Two and three dimensional, cloud-resolving models will be used to study the interaction of individual convective elements with large-scale polar low or tropical cyclone circulations. The philosophy of this investigation is to distinguish between aspects of the flow that are determined by fundamental dynamic and thermodynamic constraints, and those that are sensitive to the detailed properties of the interacting processes. Such an understanding can potentially form the basis of new approaches in modelling and diagnosing such systems, and in the short term can be used to identify requirements for the parametrization of processes such as radiation and microphysics.

4.1.2.3. Case studies of polar lows. A number of case studies of polar lows will be examined integrating all available data to assess the usefulness of existing theoretical concepts in analysing and forecasting observed systems. This work is carried out in collaboration with members of the Atmospheric Radiation Analysis Group of the Laboratoire de Météorologie Dynamique (ARA/LMD).

4.1.2.4. Mesoscale pollution dispersion. Studies of mesoscale pollution dispersion will continue including the explicit representation of vertical transport in deep cumulonimbus clouds. The Met Office non-hydrostatic mesoscale model is being used to describe the passage of frontal systems over a pollution source. An extension to include chemical species will be considered.

4.1.2.5. Effects of topography. The structure and dynamics of flow along the Alps will be studied using the JCMM non-hydrostatic sigma coordinate model. A particular focus will be the effect of frictional processes on drag, mountain waves and potential vorticity structure. Both flow parallel and flow normal to the Alpine chain will be considered. This research is collaborative with DLR Oberpfaffenhofen. Airflow over and around mesoscale islands will be also studied.

4.1.2.6. Mesoscale modelling within the TIGER Programme (Terrestrial Initiative in Global Environmental Research). In collaboration with the Institute of Hydrology, the JCMM is using the mesoscale Unified Model to study the aggregation and disaggregation of surface fluxes over heterogeneous terrain. Several of the so-called 'Golden Days' from the 1992

HAPEX-Sahel experiment will be simulated. The aim is to establish credible methods to combine fluxes available at about 15km horizontal scale so as to give average fluxes over a 100 km grid typical of a GCM. Simulations on an even finer scale will be made to represent more closely the field observations.

4.1.2.7. Mesoscale modelling within the HYREX Programme (Hydrological Radar Experiment). In collaboration with the Institute of Hydrology, the JCMM will use the mesoscale Unified Model to investigate mesoscale forecasts of precipitation in the light of radar and raingauge observations. The observations will be used to evaluate the performance of the model (see also para 4.2.1.1). Ways of assimilating these data into the model will be considered (cf para 4.1.1.2). Also preliminary consideration will be given to the feasibility of linking the mesoscale meteorological model to a hydrological model. A possible outcome of this research will be a better methodology for the very-short-range forecasting of precipitation incorporating all available data and theoretical concepts. Liaison will be maintained with the NIMROD Project in FR Division at Bracknell.

4.1.2.8. Frontal dynamics and evaporation. The role of evaporation of falling snow in frontal regions is being considered in the context of simplified models of frontogenesis. An objective is to investigate the interaction between local density current dynamics at the front and the mesoscale frontal circulations. The connection between the dynamics of an active cold front and a mid-latitude squall line will be pursued.

4.1.2.9. Parametrization of slantwise instability. Currently operational weather forecast models do not attempt to parametrize slantwise instability in baroclinic zones. A method of parametrization based on a non-flux convection scheme, is being devised and tested in global forecast models. Both saturated and dry slantwise instability occur extensively in these models and including a parametrization scheme will affect the location and timing of precipitation. It will also affect the moisture budget of the modelled atmosphere.

4.2. Mesoscale Modelling Group (Senior scientist: Ballard)

4.2.1. Development of Improved Mixed Phase Cloud and Precipitation Scheme for Unified Model

4.2.1.1. This work, which will be carried out in consultation with the Cloud Physics Group at MRF, will enhance the current scheme, from an environmental temperature-dependent diagnosis of cloud phase to one that separately predicts water and ice phases. Schemes used in other climate and mesoscale models, as well as cloud scale models, will be reviewed and a proposal made for a new scheme, or schemes, for use in the Unified Model. This will include consideration of the formation processes for the separate phases and the most appropriate advection schemes (especially advected variables) as well as the precipitation microphysics. Special attention will be paid to the formulation of melting, which is important in determining the phase of surface precipitation. The initial assumption is that a single scheme will be used for all resolution and timescale versions of the Unified Model but the report will also consider whether separate schemes have got to be used for climate and mesoscale resolutions. A prime candidate will be a scheme implemented in the non-hydrostatic model which is appropriate for both long and short time-step models.

4.2.1.2. The new scheme will be verified in case studies using 1D and 3D model simulations, with emphasis on skill of prediction of phase of surface precipitation and the impact on the moisture budget, in particular the supercooled cloud water content. Work undertaken in, and in collaboration with, projects in paragraphs 4.1.1, 4.1.2, 4.3 and 4.4 will provide valuable input to this project. A scheme acceptable to all users of the model will be selected and coded and a revised scheme will be made available by Spring 1994 for the 2nd frozen version of the Unified Model.

4.2.2. Investigation of Mesoscale Predictability

4.2.2.1. Predictability of cloud and precipitation. The impact of increased vertical and horizontal resolution and domain size on skill of forecasts will be investigated. In particular high vertical resolution mesoscale model forecasts will be run and compared with operational resolution forecasts to investigate whether slantwise convection occurs in the models and whether parametrization of slantwise convection is needed in the mesoscale configuration of the Unified Model. This may also provide guidance on the formulation of the parametrization scheme. This will be linked with work on slantwise convection in other groups at the JCMM, and at the APR Division Bracknell and Hadley Centre. This work will include case study investigations, where possible taking advantage of field study investigations both within and outside the Met. Office. Cooperation is planned with the Data Assimilation Group at the Met. Office Bracknell and Mesoscale Systems Group of the JCMM to investigate the predictability of frontal waves using IOP3 of FRONTS 92 but other cases will be used if they prove more suitable for addressing the above aims.

4.2.2.2. Influence of orography on frontal precipitation. Global and Limited Area versions of the Unified Model will be run from ECMWF analyses to investigate the performance of the model in predicting the severe weather associated with the so-called Papal Front of 3 May 1987 on the northern side of the Alps. The observed front exhibited squall-line characteristics. If the results are encouraging, the investigations may be extended to include higher resolution forecasts. This will also provide input to the joint Met. Office/Reading University Summer School on 'Orographic Processes'. Results will be compared with forecasts from the ECMWF model.

4.2.2.3. Diagnostic modelling studies of severe convection. A specific investigation will be undertaken in collaboration with FR Division, Bracknell, of the development of severe weather associated with an active cold front over the UK on 12 November 1991 using the non-hydrostatic model at fine resolution nested within the mesoscale Unified Model.

4.3. Cloud Processes Group (Senior scientist: Kershaw)

4.3.1. Modelling component

4.3.1.1. Development of microphysical parametrizations. The cloud-resolving model will be used to simulate individual convective storms. By the start of the year, a bulk scheme involving 5 species (cloud ice, cloud water, rain, snow, graupel) should have been implemented. Validation and development of that scheme will be the main task. The aims are to examine interactions between dynamical and microphysical processes and to assess their sensitivity to the parametrization of the ice phase, and to validate the model by making comparisons with observations (see para 4.3.2) and with other models. For comparison with other models, case studies will be selected from the published work of other groups, and results exchanged.

4.3.1.2. Development of radiation parametrizations. This is a new project, the first stage of which will be to review what has been done in similar models. Then a simple parametrization of long-wave cooling at cloud top will be implemented and tested in simulations of particular storms. The impacts of this on the dynamics, and hence on the vertical profile of latent-heat release and on the lifetime of the clouds, are key issues. Other areas that may be addressed during the year are the radiative impact of broken cloud fields, and the diurnal variation of convection.

4.3.1.3. Diagnosis of large-scale effects. The cloud-resolving model will be used to simulate ensembles of convective systems. The large-scale transport properties of such systems will be studied. Comparisons will be made with single column versions of a GCM in an attempt to diagnose errors in the GCM parametrizations in different convective regimes (mid-latitude/tropical; forced/unforced). Key areas of study will be momentum transport by convection and by waves generated by convection, and heat and moisture transports, including interactions of surface fluxes with convective downdraughts.

4.3.2. Observations component.

4.3.2.1. The C-130 aircraft will be used to make microphysical and radiative measurements in and around cumulonimbus clouds, mainly in cold air outbreaks, in and around the UK. Twenty three hours of flying time have been allocated in 93/94. The intention is to study individual cases of deep convection. These measurements will be used to validate and develop the parametrizations of radiation and cloud physics in the model. Experimental data obtained by other research groups, including data from TOGA-COARE and from the Chilbolton radar, will also be used as the opportunity arises.

4.4. Radar and Satellite Observations Group (Senior scientists: Illingworth, Milford, Dugdale, Ibbetson)

4.4.1. Radar-based studies

4.4.1.1. Case studies of precipitation systems. Analysis of the Doppler and polarization data from the Chilbolton radar during IOP3 of the FRONTS 92 Project will be continued. Estimates of the 3-D wind field will be compared with the precipitation measurements. Further Chilbolton observations of frontal precipitation, including during line convection, are planned (cf para 4.1.1.3). The observed precipitation profiles and windfields will be compared with those predicted from mesoscale models using different parametrizations of the cloud physics (cf. paras 4.1.2.7 and 4.2.1).

4.4.1.2. Verification of estimates from space of mid-latitude rainfall. This research relates to the validation of space-based rainfall estimates of rainfall over the UK: validation for tropical systems is undertaken within the TAMSAT Team (see para 4.4.2.1). Initial studies in the UK have shown that the depression of the 85 GHz brightness temperatures over land is surprisingly well correlated with frontal rainfall. The vertical structure of the precipitation as revealed by the Chilbolton radar will be used in a multi-level radiation model to predict the brightness temperature and to compare with the temperatures actually detected by the overflying satellite. Various methods of estimating the background brightness temperature on different days will be explored.

4.4.1.3. Improving radar estimates of rainfall. Work will continue to develop and verify the algorithms that use additional polarization parameters to improve the estimates of rainfall. The feasibility of incorporating such techniques within the existing C-band operational weather radar network will be considered. These techniques promise to be able to correct for the enhanced return due to melting snow (the bright band) and also to identify the spurious returns due to anomalous propagation. A new parameter, the differential phase shift will also be examined. This can provide estimates of rain in the presence of heavy ground clutter. It should also improve estimates of rainfall in severe thunderstorms by distinguishing the reflectivity due to rain from the larger contribution to the reflectivity due to hail. Liaison will be maintained with the FRONTIERS group within FR Division at Bracknell.

4.4.1.4. Support for calibration of AMSU-B radiometers. Data from the Chilbolton radar will be analyzed to give vertical profiles of precipitation particle type in support of further calibration flights by MRF of the AMSU-B MARSS radiometer package mounted on the C-130.

4.4.1.5. Clear air studies. The sensitivity of the Chilbolton radar has been improved. It is now able to detect returns and measure Doppler velocities extensively within the clear boundary layer as well as within clouds. In the coming year observations will be analyzed to establish how these data can be used, for example in the study of boundary layer fluxes. The desirability and feasibility of combining these measurements with in situ surface flux measurements will also be considered.

4.4.1.6. Cloud measurements at 14 and 35GHz at Chilbolton. Radar systems operating at 14GHz and 35GHz will be mounted on the Chilbolton dish in 1993 so that studies of the radar returns from clouds such as cirrus and stratocumulus can be made. The aim is to see how radar parameters are related to variables such as liquid water content and effective particle radius, which control the radiative properties of such clouds. Confirmation of the radar inferences will be achieved by means of coincident C-130 aircraft flights. Measurements of cirrus clouds will also be undertaken as part of EUCREX.

4.4.1.7. Installation of 94GHz radar at Chilbolton. Spaceborne radars proposed as part of the GEWEX programme operate at 94GHz. Design and construction of such a radar will proceed during 1993 for mounting on the Chilbolton dish in 1994.

4.4.1.8. Interpretation of radar returns from clouds. Calculations of the expected radar reflectivities and attenuation at frequencies of 3, 14, 35 and 94GHz will be carried out using cloud spectra observed with the C-130 aircraft. There are two aims: firstly, to predict whether an airborne cloud radar could gather useful data for developing and verifying cloud models, and, secondly, to estimate the ability of a spaceborne radar to provide data for climate studies.

4.4.2. Satellite-based studies

4.4.2.1 Studies of African rainfall using Meteosat data. Meteosat data covering the rainy seasons in seasonally arid regions of Africa will continue to be archived. Further uses of the cloud statistics, including comparison between years, will be developed and related to raingauge observations. These data, together with a set of standard vegetation index images, will provide material for identifying the influence of topography on the storm statistics over a number of years, and the likely effects on agriculture and hydrology.

4.4.2.2. Diagnostic and modelling studies of African rainstorms. Semi-automatic extraction of the life histories of storms in seasonally arid Africa will be used to identify the factors influencing the intensity, life time, and tracks of such storms. Models to link these with large scale meteorological features, including easterly waves, will be developed and validated with the help of such data. A hierarchy of models is available at Reading University for examining these systems. For example the Reading University Global Spectral model is currently being used for this purpose. A GCM version of this model which includes simple physics is also available. There are several other research models of varying complexity with and without moist physics and boundary layer schemes. Such models must adequately represent diurnal and local effects. They will help not only in local forecasting, but also in the representation of mesoscale contributions to the large scale fluxes to and from the atmosphere.

4.4.2.3. Evaporation studies. The combination of information derived from Meteosat and NOAA imagery, and such microwave data as may be obtained routinely, is expected to improve day to day information on the soil (and atmospheric) water budget. Algorithms for rainfall, evaporation and soil moisture, for operational use in seasonally arid Africa, will be developed and tested.

5. JCMM research in other UK universities

5.1. University of Leeds

5.1.1. Mesoscale flow over orography and gravity wave dynamics. New theoretical models for strongly stratified flow over orography will be used to develop parametrizations for gravity drag. This work will be supported by the use of linear and nonlinear numerical models for flow over real orography. Field experiments to measure the pressure drag on hills using microbarographs will continue, following the experiment in Cumbria in November 1991. An experiment on Kintyre is planned, probably for late 1993. Laboratory experiments on stratified flow over orography will be carried out in collaboration with J.C.R. Hunt at Cambridge and I. Castro at Surrey. Finally, work will continue on the use of the Met. Office's radiosonde data archive to develop a climatology for gravity waves over the UK.

5.2. UMIST

5.2.1. Transport processes in cumulus. Observations will be made of the vertical transports of momentum, heat and water in fields of cumulus. These will include the cloudy regions and the clear air between clouds. Preliminary investigations suggest that the profiles of the fluxes are very sensitive to the presence of weak inversions or dry layers and that, although in-cloud fluxes are much higher, the layer-average fluxes are comparable with those found in layer clouds. Attempts will be made, using observations of cloud fields from the C-130 (para 3.3.2), and observations of isolated clouds from the UMIST Cessna, to quantify the turbulent fluxes and the fluxes due to organised cloud structures. Observations will be used to verify cloud simulations made using the cloud-resolving model at Reading (para 3.3.1).

5.2.2. Cloud glaciation processes. Observations suggest that some maritime clouds with low droplet concentrations glaciate at much higher temperatures than would normally be expected. The observations will be interpreted with the aid of simplified models in order to determine the relative importance of microphysical factors (eg droplet concentration) and dynamical factors (eg circulation of cloud particles in adjacent updraught and downdraught regions). Collaboration will be maintained with the Cloud Physics Group of the MRF. The results will be used to assist in the development of improved parametrizations for use in cloud-resolving models (sec 4.3.1.1).

CURRENT JCMM INTERNAL REPORTS

This series of JCMM Internal Reports, initiated in 1993, contains unpublished reports and also versions of articles submitted for publication. The complete set of Internal Reports is available from the National Meteorological Library on loan, if required.

1. **Research Strategy and Programme.**
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