The Main BALTEX Experiment
1999 - 2001

Strategic Plan

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Contents

EXECUTIVE SUMMARY

The BALTEX (Baltic Sea Experiment) program is a joint undertaking of countries located around the Baltic Sea. The participating institutions are the national meteorological and hydrological institutes of these countries as well as many research institutions and university departments. The BALTEX program covers meteorological, hydrological and oceanographic aspects related to the energy and water balance of the Baltic Sea and its catchment region.

The aim of BALTEX is to enhance the scientific understanding of the mechanisms responsible for energy and in particular water transports within the atmosphere, the land surface including rivers and lakes and the Baltic Sea with the objective to improve weather forecast and climate models. It further studies effects of the Baltic Sea on the weather and climatological conditions around the Sea, and subsequently the influence of these on the environmental conditions and economical life in the benefit of surrounding states. The Baltic Sea region represents a transition zone between the World Ocean in the west and the vast continent in the east thus creating characteristic meteorological, hydrological and oceanographic conditions over the area.

A further particular aspect of BALTEX is the development of better modelling support for flood forecasting and the design of integrated meteorological/hydrological forecasting systems for the area. Moreover the Baltic Sea is severely polluted and requires special attention to overcome the related adverse effects. The predicted climatic changes have a relatively large uncertainty in the Baltic Sea region due to the strong natural variability of weather and climate over Northern Europe.

The two outstanding goals of the BALTEX program are

- to obtain better and more comprehensive observations from the entire Baltic Sea catchment area, and
- to develop more realistic coupled models for the atmosphere, the land surface including rivers and lakes and the Baltic Sea and the sea-ice.

These scientific objectives include the determination of the energy and water cycle in the Baltic Sea region by a combined data and modelling exercise, and the development of an advanced coupled, high-resolution forecasting system for a better handling of the complex weather and climate processes. An additional objective is the provision of a physical/dynamical framework for a future development of integrated environmental assessment and prediction systems.

As an ultimate result the expected benefits would be realised as a better service to many areas of economic life in the Baltic Sea and its coastal areas. Examples are marine operators, power industry, insurance companies, agriculture, forestry as well as authorities dealing with power and water resources, environmental questions, warning systems, climate and weather forecasting and many others.

BALTEX has even a wider dimension being a continental-scale experiment of GEWEX, the Global Energy and Water Cycle Experiment, and as such a part of the WMO World Climate

Research Program. The methodologies developed during BALTEX are expected to be transferred to other continental areas with similar characteristics in order to both improve global climate modelling and enhance regional-scale modelling within these areas.

The Main BALTEX Experiment (*BRIDGE*) will be a central element in the BALTEX program. It is suggested to be conducted as the central observational and modelling phase of the program. It is planned to take place from April 1999 to March 2001, the first six months being the pilot phase and the remaining 18 months the basic observational phase.

This plan discusses the present deficiencies in the observational systems as well as in the data assimilation and modelling systems. Numerous recommendations are made here for a beneficial realisation of *BRIDGE*. These include also administrative and financial implications. The remaining two-year period before the initiation of *BRIDGE* should be used for building up the necessary new resources and methods.

Most important issues to be considered include the functioning of the operational observational networks at their maximum capacity, enhancement of the observational systems to cover the whole study area, especially with weather radar and radio sounding data, and the organisation of special field campaigns. An equally important task is the enhancement and consolidation of the BALTEX data management structure in order to get the quality controlled observations into the data bases of the designated BALTEX Data Centres. In this context the satellite data represent a special issue. Perhaps the most challenging task is to organise the post-processing of the data. This requires the identification and nomination of those centres capable to perform extra data assimilation runs using the special *BRIDGE* data. Only then the various research groups can have relevant data for their studies which are expected to solve many of the remaining questions related with the energy and water budgets of the atmosphere, hydrosphere and ocean.

In the following the most central requirements to be realised are summarised:

Observational Requirements

- Six-hourly radio soundings from stations immediately bordering the Baltic Sea.
- Additional radiosonde stations on Gotland, Åland and Bornholm during *BRIDGE*.
- Collection of all available hydrological information from the whole study area in a timely way.
- Continuous measurement of temperature, salinity and ocean currents at the Darss and Drodgen Sills, and in the straits connecting the deep basins of the Baltic Sea.
- Production and archiving of well-calibrated composite radar-based precipitation maps in near-real time from the existing international radar network in the Baltic Sea catchment region.
- Two new weather radar installations at the eastern/south-eastern coast of the Baltic Sea.
- Designated data centres to carry out the observational data storage functions.

Modelling Requirements

- Development of advanced coupled high-resolution atmosphere-hydrological-oceanographic models.
- Two data assimilation centres to run independent delayed-mode data assimilation systems.
- Intercomparison of model results, and comparison of the latter with observations, with special emphasis on surface processes.

Administrative Requirements

- Possibilities and interests of the national meteorological and hydrological institutes to finance the *BRIDGE* need to be explored with urgency.
- A model agreement between the participating institutions and BALTEX should be designed to cover all the tasks necessary for a successful *BRIDGE*.

This action plan for *BRIDGE* does not yet provide all necessary details required to run such a complex experiment. More details will have to be worked out in the nearest future when commitments from participating institutions and agencies have been obtained and funding possibilities are successfully explored. In particular decisions will have to be made whether requirements and recommendations as given in the plan will be realised during the entire *BRIDGE* period or only during intensive observational periods to be defined.

FOREWORD

The Main BALTEX Experiment (*BRIDGE*) will be a central element in the BALTEX (Baltic Sea Experiment) program. It will take place from **April 1999 to March 2001**, the first six months being the pilot phase and the remaining 18 months the basic observational phase. The BALTEX Scientific Steering Group (SSG) in its meeting in June 1996 in Sopot, Poland, established a planning group for designing a strategic plan for *BRIDGE*.

The draft plan was considered at the fifth meeting of the BALTEX SSG in Riga, Latvia, in April 1997. The SSG reviewed the draft plan and suggested several enhancements. The revised plan was delivered to the BALTEX SSG Chairman in June 1997 and circulated among BALTEX scientists for further suggestions during the summer 1997.

In the following, the strategic plan for *BRIDGE* is presented. It also includes a basic motivation for *BRIDGE* which follows the lines of the BALTEX Initial Implementation Plan, published in March 1995, as well as the terms of reference as given by the BALTEX SSG, and the list of participants at the planning group.

A very important task after the approval of this plan is to enter into an agreement with all participating operational and other institutions on their commitments to carry out all the desired components of the plan.

This plan has benefited substantially by the in-depth review of SSG members as well as through numerous contributions from other individuals. In particular contributions by Lars Gottschalk, Oslo University, and Jarmo Koistinen, FMI Helsinki, are gratefully acknowledged.

1 INTRODUCTION

1.1 BALTEX AND ITS MAJOR ACHIEVEMENTS

The major objective of the BALTEX (Baltic Sea Experiment) program is to provide validated, coupled modelling tools for explaining and predicting the energy and water processes in the climate system, consisting of the atmosphere, continental surfaces and the oceans. The specific study region of BALTEX is the Baltic Sea catchment region extending over about 2.1 million km^2 and ranging from temperate climate zones in the south to subarctic tundra in the north. The mean annual river runoff to the Baltic Sea amounts to about 470 km^3 . The water outflow to the Atlantic Ocean through the Danish Straits is not precisely known due to considerable uncertainties of the evaporation and precipitation budgets over the Baltic Sea. To determine this waterbalance is one of the key objectives of BALTEX.

Of particular interest over continental regions is the availability of water in near-surface soil layers and in river systems. Such knowledge is required to improve the weather forecast, to warn for disastrous events and to estimate possible climate states in the future. Also the reconstruction of past-time climate states gains importance. The recent flooding catastrophe in Poland and Germany shows that still considerable amount of research work must be carried out in order to increase the preparedness of authorities to minimise the losses. The Baltic Sea is heavily polluted requiring immediate solutions to environmental problems generated. Considerable economic benefit is expected from such improved forecasts, not only for the energy, water and food supplies, flood protection and the environmental sector but also for various other branches of the industry, including insurance and tourism in sensible areas.

The Baltic Sea catchment region covers territories of as much as 14 countries and national hydro-meteorological Services, and various research institutions in more than 10 countries are contributing to the BALTEX program. It is, in particular, the participation of the Services of the participating nations which provide an immediate beneficial return of research results to environmental and economic sectors.

The BALTEX program has generated an active research covering the whole field of advanced modelling and data studies in meteorology, hydrology and oceanography for the Baltic Sea catchment region. Of particular importance has been the progress towards the development of accurate high resolution coupled models. Preparations for BALTEX started in 1991. The BALTEX Science Plan was published in 1993 followed by the Initial Implementation Plan in 1995. Major emphasis has been paid since then

- to establish modelling and data assimilation, collection and controlling capabilities at various national Services and research centres. Several scientific publications established a good international reputation of BALTEX. Particular progress has been obtained in distributed, conceptual modelling of runoff in large river systems,

- to perform atmospheric modelling for selected study periods, to intercompare results of different models and to validate these model results critically with respect to insufficiencies in both the models and available observations. Results have been obtained for several multi-months periods,

- to define, prepare and conduct field experiments with the objective to improve parameterisation schemes in the models. Such experiments will be conducted in the course of the next years over the open and ice-covered Baltic Sea and over continental regions.

The methodologies developed during BALTEX are expected to be transferred to other continental areas with similar characteristics in order to both improve global climate modelling and enhance regional-scale modelling within these areas. BALTEX is one of five continental-scale experiments of the Global Energy and Water Cycle Experiment (GEWEX) under the auspices of the World Climate Research Program (WCRP).

The BALTEX studies so far have identified a number of limitations both in the observational system and in the way observations are explored in the forecasting process. Examples of such limitations are lacking upper-air observations over the Baltic Sea such as radiosonde and sufficient radar observations, insufficient use of available satellite data as well as insufficient integration of many observations in real-time data processing. New types of very promising observations, such as GPS-based water vapour measurements are not yet incorporated in data-assimilation and forecasting systems.

1.2 THE MOTIVATION FOR THE MAIN BALTEX EXPERIMENT (*BRIDGE*)

It is now important to take advantage of modern development in observational technology, data assimilation and forecasting methods of integrated atmospheric, oceanographic and hydrological phenomena. Scientific results of the BALTEX research program strongly suggest that the exploration of these developments will be highly important for the prediction of e.g. extreme weather, river flooding, and severe ice conditions.

The Main BALTEX Experiment (*BRIDGE*) will be a central element in the BALTEX program. It is suggested to be conducted as the central observational and modelling phase of the program. **It will take place from April 1999 to March 2001**, the first six months being the pilot phase and the remaining 18 months the basic observational phase.

The meteorological, oceanographic and hydrological processes cover a wide range of time and space scales. An intense extra tropical cyclone may only influence the Baltic Sea region for one day or two while the processes regulating the supply of saline water into the Baltic Sea require decadal or multi-decadal time scales. Not all studies could be handled within one Main Experiment. However, as it was found from the BALTEX-PIDCAP study (Pilot Study for Intensive Data Collection and Analysis of Precipitation, August to November 1995) a fully integrated approach to investigate the full range of synoptic systems requires a minimum of several months. An evaluation of the full year considering the huge variability of atmospheric circulation types in particular in winter suggests a minimum of some 18 months.

The reason that *BRIDGE* is needed is essentially due to the extra resources needed for establishing the necessary infrastructure for measurements, evaluation, data processing and data assimilation. Experience from other experiments within the WCRP have demonstrated that this is the most cost-efficient synergetic approach to combine as many studies as possible within one overall framework. Main Experiments are being undertaken as part of other continental-scale experiments in GEWEX, such as CAGES as part of the Mackenzie GEWEX Study (MAGS), or the Enhanced Observational Period (EOP) of the GEWEX Continental Scale Project of the Mississippi (GCIP).

1.3 SPECIFIC GOALS OF *BRIDGE*

The two outstanding aspects of *BRIDGE* are the effective use of all relevant observational material and the use of meteorological, oceanographic and hydrological models. The purpose of *BRIDGE* is to aid access to all observations made in the study area and to enhance the use of new experimental data. Observational networks are encouraged to perform at their maximum capacity which will require additional resources from participating institutions. Another purpose is to develop the performance of current meteorological, oceanographic and hydrological models. This will take place especially through concentrating on better coupling of these models, which is a new desired aspect. Important parameters at the interfaces of the model domains include soil moisture, snow cover, sea surface temperature, sea ice, surface fluxes, precipitation and river runoff. The correct treatment of the processes involved with these parameters is seen to be very important and will yield a better usability of all models considered here. This is one of the major highlights of *BRIDGE*, and BALTEX in general.

Another basic benefit from *BRIDGE* will be the enhancement of the scientific research. A remarkable amount of high-quality analysed and assimilated data will be available together with the up-to-date models.

1.4 THE REALISATION OF THE PLAN

The plan includes a great number of requirements and recommendations regarding observational practices and arrangements, model development activities, data collection, checking and retrieval activities and data processing routines. These are parts of the everyday life of the participating organisations, but yet a great deal of extra undertakings are required. It is essential that the participating organisations, i.e. national meteorological and hydrological institutes, research institutes and universities commit themselves to fulfil the presented plan. This will require economical, technical and human resources. Only through such investments will *BRIDGE* be successful.

The remaining two-year period before the initiation of *BRIDGE* must be used, among other things, to establish the commitments of all participating institutions to carry out the tasks within their capabilities in favour of *BRIDGE*. Thus this action plan, when approved, should be made known among all potential contributors for their consideration.

2 METEOROLOGY AND ATMOSPHERIC MODELLING

2.1 INTRODUCTION

In order to meet the scientific objectives of BALTEX, two problem areas need to be tackled:

a) There exist large data-sparse areas (e.g. the Baltic Sea) for which too few observations are available in order to define the state of the atmosphere properly.

b) Some of the quantities required for budget calculations (e.g. fluxes of energy and water through the interface between the atmosphere and the underlying surface) are not observed at all.

Data assimilation systems as run within Numerical Weather Prediction (NWP) systems are in principle capable to contribute towards a solution of the above mentioned problems. They do so by incorporating the time domain into the process of defining the state of the atmosphere. A forecast model is used to advance information from previous observations forward in time. The result of the assimilation process are analysis on a regular grid which allow the calculation of the quantities required for the BALTEX project.

Although atmospheric data assimilation is in an advanced state, there are a number of deficiencies. They are either in the data assimilation schemes or in the forecast model used to advance information in time.

2.2 COUPLING OF ATMOSPHERIC MODELS TO HYDROLOGICAL AND OCEANOGRAPHIC MODELS

Present operational atmospheric forecasting systems include a very rudimentary coupling to hydrological and oceanographic models. The atmospheric forecast models include crude parameterisation schemes for the soil processes and it is known, e.g. from preliminary comparisons with hydrological models, that the performance of these parameterisation schemes is poor. Improvements can be achieved by comparing the performance of the soil parameterisation schemes, process-by-process, with output from hydrological models and by validation against hydrological observations. Based on the experiences from such process-by-process comparisons and validations, the parameterisation schemes of the atmospheric models should be improved. See also section 3.1.3 for aspects of meteorological-hydrological model coupling.

The Baltic Sea catchment area, and in particular Finland and Sweden, includes many inland lakes. These inland lakes have a significant impact on the surface latent and sensible heat fluxes, which need to be parameterised. Efforts to introduce parameterisation schemes for the effects of lakes, including the storage of heat in the lake water volumes as well as the forming and melting of lake ice, have started at SMHI (Ljungemyr et al., 1996).

The lower boundary condition for operational atmospheric forecast models over sea surfaces is presently based on initial objective analyses as well as sea surface temperatures and ice coverage, and these sea state parameters are kept unchanged for short range weather predictions (Omstedt and Nyberg, 1995). However, the spatial and temporal scales of the variation of these sea state variables in the Baltic Sea area are small enough to motivate a closer coupling between atmospheric and oceanographic models, and also for short range weather prediction. In a shorter time perspective, high resolution initial analysis of the sea state variables, e.g. on a 10-km grid, should be made available to the whole BALTEX community. Such high resolution analysis are already produced by marine forecasting offices in the Baltic Sea area. In a longer time perspective, an ocean model should be two-ways coupled to the atmospheric models during e.g. 6-hourly data assimilation and, ultimately, fully two-ways coupling between atmospheric and oceanographic models should be established. However, it has to be explored whether this could be achieved within the time period available for preparations for *BRIDGE*.

The final aim is the integration of atmospheric, hydrological and oceanographic models (see also section 4.1) into a coupled model chain for the Baltic Sea catchment region. This requires the development of more sophisticated schemes where both water and energy fluxes are realistically described and validated. This new model generation must be able to cope with the specific characteristics of the landscape in the Baltic Sea catchment region. A key issue is the sub-grid or sub-basin variabilities of processes governing the fluxes of energy and water.

2.3 DATA AND DATA ASSIMILATION DEFICIENCIES AND PROPOSED REMEDIES

The quality of analysis fields produced by data assimilation techniques is ultimately depending on the quality and information content of the input observations. The quality of the analysis fields also depends on the data assimilation techniques used to spread the observed information in space and time. Since a meteorological forecast model is an integrated component of any modern data assimilation systems, the quality of the analyses also depends of the abilities of these models to simulate atmospheric processes.

Data Void Areas

The Baltic Sea area includes significant data void areas with regard to the operational meteorological observing systems. The radiosonde network is still the most important data source for assimilation of vertical profiles of temperature, wind and moisture. After the recent closing of the radiosonde station on the Island of Gotland there is an area of approximately 700 km x 500 km close to the centre of the Baltic Sea without any operational radiosonde stations.

Considering that two stations are needed per wave-length to describe any wave, it is impossible to describe waves shorter than approximately 1200 km in the Baltic Sea area. Kristjansson (1990) studied the mesoscale storm development of 23 July 1985 over the Baltic Sea. The initial data needed to forecast this storm development include vorticity and divergence structures on significantly smaller scales. In addition, Kristjansson found a great sensitivity to the details in the initial moisture field. More recently, Huang et al. (1997) used the adjoint of the spectral HIRLAM model to show a sensitivity to the initial baroclinicity, also on scales below 1000 km, for a storm development on 15 September 1994 over the Southern Baltic Sea.

In order to fill the data void area over the Baltic Sea, three extra radiosonde stations, at the islands of Gotland, Åland and Bornholm, respectively, have to be established which should operate during *BRIDGE* (see also section 2.5). Such stations would also fulfil the need for ground truth vertical profiles, representative for the conditions over the Baltic Sea water surfaces, for validation of remote sensing data as well as for validation of data sets produced by models and data assimilation techniques. Priority should be given to the station on the Island of Gotland.

Spinup

A principal weakness of present operational meteorological data assimilation schemes is related to the spinup problem. The three-dimensional structure of the real atmosphere is very complex with, for example, vertical tilts of baroclinic disturbances, strong gradients across elongated atmospheric fronts and strong land-sea differences. In contrast to this, very simplified spatial structure models are used by present data assimilation schemes to spread the observed information in space (and time). This has the effect that the state of a forecast model will go through a process ‘spinup’ during the first hours of model integration. Processes like the growth of baroclinic disturbances, condensation, precipitation, turbulent mixing as well as interaction with the surface will be associated with significant systematic and random errors during this model spinup.

The model spinup problem is likely to be reduced by introduction of diabatic digital filter initialisation (Huang, 1996), latent heat nudging (Krisnamurti et al., 1993) and 4-dimensional variational data assimilation techniques (see below).

The Time Dimension

Present operational forecasting systems are based on forward intermittent data assimilation. The forecast models are integrated forward in time and at certain specified points in time, for example every 6th hour, observations are assimilated by means of a spatial interpolation of the deviations between the observed values and forecast model state variables interpolated to the positions of the observations. This has the effect that the full time resolution of many types of observations cannot be utilised and, which may be even more important, the tendency information that can be inferred from observations with high resolution in time is not utilised to modify the time evolution of the forecast model.

Non-linearities

The spatial interpolation techniques which are used in present operational data assimilation schemes are generally based on simple linear weighting techniques. This means that it is difficult to utilise observed parameters which are non-linearly related to the model state variables, e.g. precipitation data, satellite radiance data and radar radial wind vectors. Also observed information which is related to model state variables by a vertical integration, e.g. Global Positioning System (GPS)-based integrated water vapour amounts, are difficult to exploit by the linear spatial weighting with a coarse time resolution. Variational data assimilation (Le Demit and Talagrand, 1986, Courtier et al., 1994) provides a framework for utilisation of observed values which are non-linearly coupled to the model state variables.

New Data Assimilation Techniques
Research efforts are presently carried out at the weather services participating in BALTEX to overcome the weaknesses of present operational data assimilation schemes. The development work is going in slightly different directions, and this is sound for the moment since the ultimate data assimilation solution is not yet known. The HIRLAM community is developing 3-dimensional and 4-dimensional variational data assimilation schemes (Gustafsson et al. 1997) while the German weather service (DWD) is developing data assimilation based on nudging (Lorenc et al., 1991). A main principle of these new assimilation schemes is to rely more on the atmospheric model to spread the observed information in space and time. This will eventually have the advantages of reducing the model spinup by utilisation of inherent diabatic initialisation, of exploiting more efficiently observations with high resolution in time as well as making it possible to utilise more efficiently observed quantities which are non-linearly coupled to the forecast mode state variables. The new assimilation schemes will gradually be available for operational implementation from 1998 and onwards.

New Data Types
The new data assimilation methods will make it possible to utilise new observing system like GPS-based measurements of integrated water vapour (Kuo et al., 1996), precipitation and radial wind vectors from weather radars, SSM/I integrated water vapour and TOVS radiance measurements. A full area coverage of these new observations over the Baltic Sea ctchment area should therefore be established.

Soil Data Assimilation
The initial state of soil parameters, and in particular soil moisture, is another weakness of present operational data assimilation systems. Model-simulated surface fluxes of sensible and latent heat are strongly related to the definition of the initial soil moisture. In a long term perspective, the weaknesses in the simulation of soil parameters should be remedied by improving the parameterisation schemes for soil processes. In a shorter term perspective, soil parameter assimilation schemes, based on the relation between errors in soil parameters and low level forecast errors as revealed by screen-level temperature and humidity observations from SYNOP stations (Mahfouf,1991), will be exploited. The analysis of surface variables needed for the soil data assimilation should, if possible, utilize inhomogeneous analysis structure functions (Hessler, 1984).

A new strategy to estimate soil moisture fields is to assimilate land surface evaporative fraction, retrieved from satellite imagery (Van den Hurk et al., 1997). Research on this issue will be carried out in the context of *BRIDGE*, with a special emphasis on the treatment of areas which strong surface heterogeneity and high cloud occurence frequencies.

The improvement of soil moisture parameterisation will take advantage of the experience from hydrological modelling, where there is a long tradition of continuous simulation of soil moisture deficit for runoff modelling and other purposes. There are also field data available from various hydrological research basins which may be used for validation of soil moisture models.

Physiographic Data

Physiographic data are an essential part of auxiliary information for atmospheric models. Physiographic data include detailed information on orography, sea/lake and land distribution, type of land use, vegetation type and others. They are needed in the computation of the exchange of momentum, heat and water between the atmosphere and underlying surface. The use of detailed description of the surface is of crucial importance as this is the way the high resolution models are able to produce more accurate and fine-scaled results as compared with the more coarse resolution global models. A physiographic data set for Europe is being constructed within the HIRLAM project. The areal coverage of that data set would satisfy the needs of *BRIDGE* although there are areal variations in the quality of physiographic data collected.

It is obvious that the HIRLAM physiographic data set would be available to the BALTEX research community. A copy of the data set covering the BALTEX modelling area during *BRIDGE* should be made available via the BALTEX Meteorological Data Centre (BMDC).

2.4 MODEL DEFICIENCIES AND PROPOSED REMEDIES

Resolution

Over land, precipitation is heavily modulated by orography. Current forecast models are not able to capture this fine-scale structure because their horizontal resolution is not sufficient to resolve the orographic details. Therefore, it is important to develop forecast models with resolutions between 2 and 10 km (Sass et al., 1995, Steppeler et al., 1997). Likewise, in order to capture strong vertical gradients in the boundary layer and near the tropopause, the vertical resolution needs to be increased.

Boundary Layer Processes

The vertical turbulent mixing in the atmospheric boundary layer is currently parameterised by schemes of differing complexity. It is not clear how reliable the fluxes obtained with these schemes are and to what extent the errors in the atmospheric forcing for ocean models can be attributed to the parameterisation of the turbulent processes. A particular problem is the correct description of the fluxes over inhomogeneous terrain. Typically, within a model grid-square, there exists a mixture of different surfaces, such as lakes, forests, fields, meadows, and urban areas. They all imply different fluxes of energy and water between the surface and the atmosphere. On the other hand, the models expect a representative area mean flux to be provided by the parametrisation schemes. The outcome of the NOPEX experiment (see section 6.5) will certianly increase our knowledge in this area. Besides the development of more advanced parameterisations, such as schemes based on a predictive equation for the turbulent kinetic energy (Mellor et al. 1982), it is therefore important to validate the schemes by field experiments, such as LITFASS at Lindenberg (Müller et al., 1995), PEP at Östergarnsholm (Smedman et al., 1997) and NOPEX at Norunda and Marsta (Halldin et al., 1995). See also section 6 for more details on field experiments.

Soil Processes
The formulation of the surface hydrology and energy has been traditionally optimised with respect to the fluxes through the interface. This implies the danger of not treating the individual processes, such as run-off, snow-accumulation and -melt properly. The schemes need to be revised in the light of experience from process-by-process intercomparison with hydrological models.

Clouds and Precipitation
Clouds are an important component of climate and local weather. Through interaction with radiation they impact on the water and energy cycle. Therefore it is important to provide more accurate formulations of the three-dimensional cloud cover and of the optical properties of clouds. For a better modelling of precipitation, it is essential to describe the microphysics inside the clouds with some detail. Doms (1995) demonstrated the benefit of including cloud-ice in the model formulation. As precipitation is linked in a complex way to all other model variables, progress in precipiation forecasting is dependent on advances in modelling and assimilation.

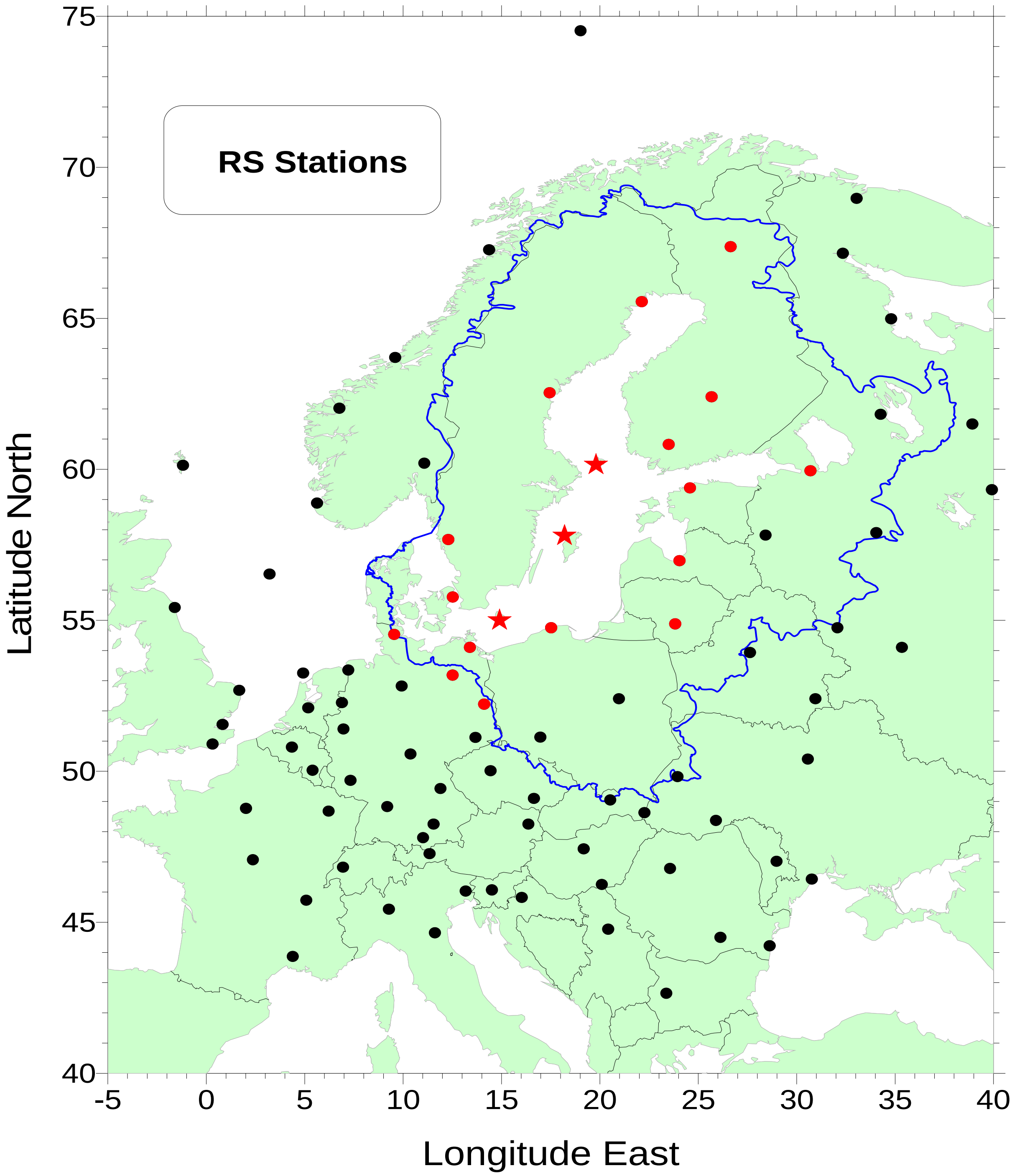
2.5 METEOROLOGICAL OBSERVATIONS

This section deals with some important *in-situ* data. For a specific discussion of remote sensing data including radar see section 5.

2.5.1 Radiosonde Data

Radiosondes are the backbone of the present composite observing system, because they provide measurements of the vertical profiles of humidity, wind and temperature. Recent observing system experiments at ECMWF (Unden 1997) have confirmed that radiosondes are the most important individual component of the observing network in the northern hemisphere. In the context of BALTEX, their unique capability to measure the vertical distribution of the moisture field is particularly important. Although the availability of radiosonde (RS) station data varies slightly from day to day there are typically more than 20 stations inside the Baltic Sea catchment region (BACAR) and about 90 in northern and mid-Europe operational (Figure 1). Unfortunately, since early 1995, at least one station at Visby on the island of Gotland was closed. This is in particular crucial because there is a large gap now with no upper-air observations over mid-Sweden and the Baltic Sea (see also section 2.3).

It is highly recommended that additional radiosonde stations should operate during the two-years *BRIDGE* period. Additional RS stations should be installed, either temporarily during *BRIDGE* or, better, on a continuous base. At first it is suggested to re-open the station Visby on Gotland. This has highest priority because Visby would provide data from the middle of the Baltic Proper and would partially close the gap in the mid-west of the Baltic Sea catchment region. Two further locations for additional RS stations are suggested:



<u>Figure 1:</u> Locations of radiosonde stations (dots) in the BALTEX modelling area (BAMAR) which made available routine upper air observations via GTS to the routine forecast service of DWD during May 1997. The total number of stations in the BAMAR for this particular month is 90. The total number of stations in the Baltic Sea catchment region (encircled by the blue line) is 23. Red dots indicate stations near to the Baltic Sea coast-line (see section 2.5.1 and Appendix 1). Red stars indicate locations at Bornholm, Gotland and Åland Islands suggested as additional stations during BRIDGE.

- on the Åland Islands
- on the island of Bornholm.

A realistic solution would be to hire automated radiosonde launching equipment requiring only a minimal human interaction roughly once or twice a week.

Radiosonde ascents are usually taken twice a day at 00 and 12 UTC (TEMP-report). At the intermediate times (06 and 18 UTC), some stations take full profiles, while others only observe the wind field (PILOT-reports). Some stations do not report at all at 06 and 18 UTC (see Appendix 1). For *BRIDGE*, an exact knowledge of the moisture field is essential. As this field varies on small spatial and temporal scales, high frequency observations are required. This was demonstrated in a recent set of experiments by Lord et al. (1997), who showed a serious degradation of forecast quality, in particular in precipitation, when halving the number of radiosonde stations over the United States. They also demonstrated that having two full ascents per day leads to a considerable improvement in forecast quality as opposed to having only one
daily ascent. Similarly, Unden (1997) reported a positive impact from the additional soundings at 06 and 18 UTC during the FASTEX experiment in the North Atlantic.

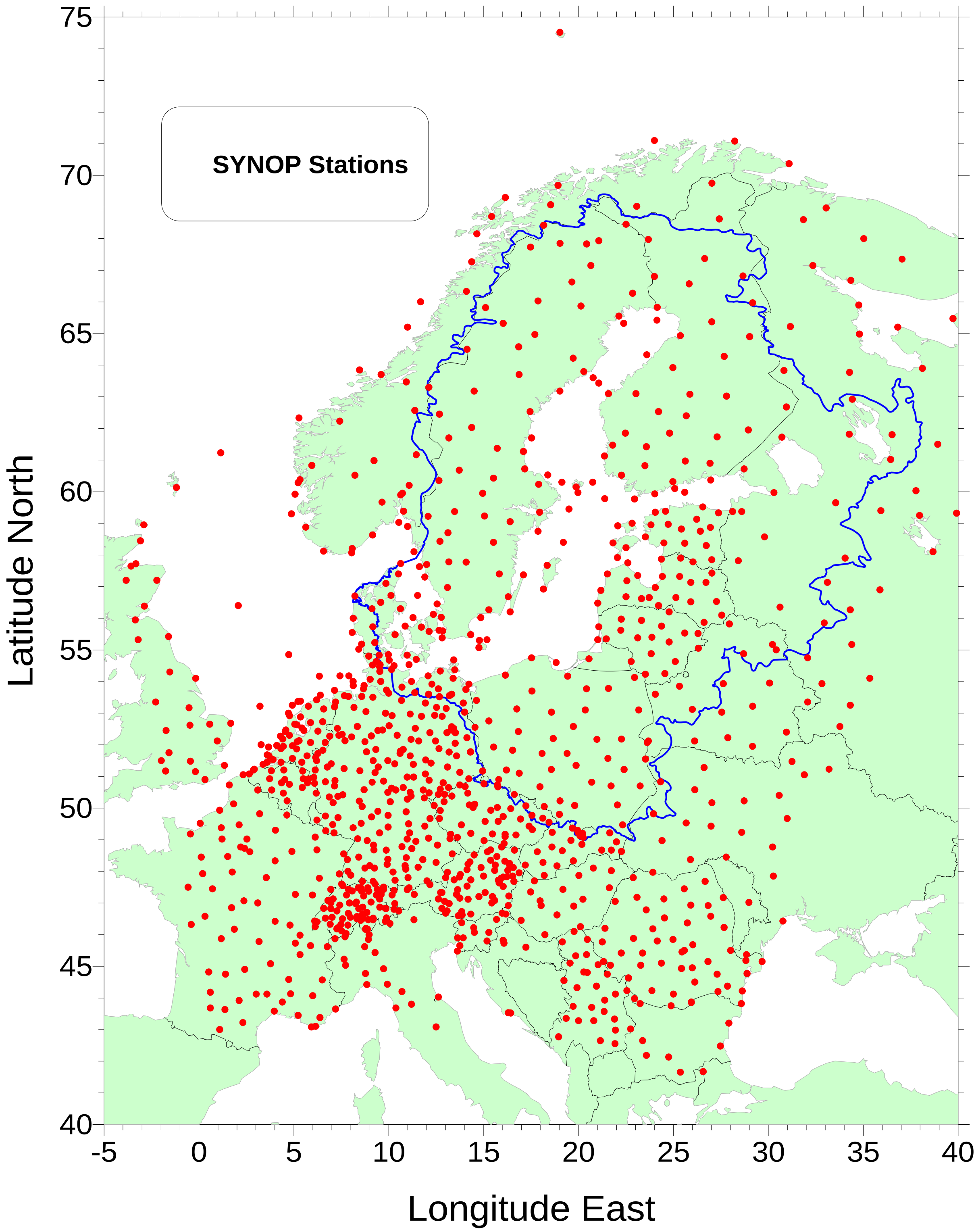
One critical aspect for BALTEX is to capture the fluxes of water and energy into and out of the atmosphere above the Baltic Sea. This requires accurate measurements of the three-dimensional structure of the humidity, wind and temperature field. These data can only be provided by radiosondes. Ideally, 6-hourly soundings from all operational stations in BACAR should be available. In view of the costs (200 ECU/ascent), it is suggested to restrict the launching of extra radiosondes to the operational stations immediately neighbouring the Baltic Sea. This would improve the calculation of fluxes and lead to better water and energy budgets for the Baltic Sea. Table 1 in Appendix 1 gives a list of these stations together with their reporting practice as monitored by DWD for May 1997. Of particular concern are the stations Tallinn and Kaunas as they currently report only once per day.

2.5.2 Surface Data

The dissemination of surface SYNOP data via GTS is well developed in Europe. At present, 8 countries in the BACAR are sending SYNOP observations from all existing stations via GTS. In Belarus and Russia data from only part of all existing stations are presently disseminated via GTS. The substitution of manned SYNOP stations by automated weather stations is an ongoing process in many countries in Europe. Part of the data from automated stations are disseminated via GTS. Enhancement of the amount of SYNOP data on GTS has recently been achieved through activities of the BMDC (e.g. for Sweden). For a map of SYNOP stations in both the BACAR and the BALTEX Modelling Area (BAMAR) see Figure 2.

Climate stations provide for a reduced set of meteorological parameters at reduced frequencies, normally three times per day. A particular important parameter measured at climate stations is the daily sum of precipitation.

Surface meteorological observations from Voluntary Observing Ships (VOS) and marine platforms like buoys are essential for BALTEX, they provide the only meteorological ground



<u>Figure 2:</u> Locations of synoptical stations (red dots) in the BALTEX modelling area (BAMAR) which made available routine surface observations via GTS to the routine forecast service of DWD during May 1997. The total number of stations in the BAMAR for this particular month is 1085. The total number of stations in the Baltic Sea catchment region (encircled by the blue line) is 325.

truth observations on a regular base. However, observational density is sparse, there are typically less than 20 individual VOS observations per day available in real time on GTS from the entire Baltic Sea. An increased number of delayed VOS observations are available from international archives like the COADS (Comprehensive Ocean Atmosphere Data Set, see e.g. Woodruff et al. 1987). COADS data may be used to calculate climatological estimates of meteorological surface parameters and energy budget components such as evaporation at the Baltic Sea surface (Isemer 1995).

There are plans to install new weather buoys in the Baltic Sea. These data would be extremely important for *BRIDGE*.

2.5.3 Precipitation Data

Precipitation is among the key parameters in BALTEX and different precipitation data and products are required to meet the objectives of BALTEX. Standard gauge measurements are available from SYNOP stations. However, the bulk of gauge measurements are taken at climate stations and at specific precipitation stations. These data are available only in delayed mode and are in general kept at national archives and are not distributed to international data centres operationally. It is important to note that on average in the Baltic Sea catchment region the number of non-GTS precipitation stations is higher by roughly a factor of 10 compared to the number of SYNOP stations. Most of these precipitation stations measure daily sums, however, also 12-hourly (in general at SYNOP stations) and also 6-hourly sums are available. Specific efforts have been undertaken in BALTEX to collect gauge measurements from as many as possible stations in the entire BACAR into one archive at BMDC. For the PIDCAP period, August to November 1995, daily precipitation measurements from more than 3800 stations in the 10 BALTEX countries could be made available at BMDC (see Figure 3). Data from this enhanced gauge network are required for the *BRIDGE* period. Present efforts at BMDC, the BALTEX Secretariat, and at various national Meteorological Services are aiming at establishing a continuous precipitation data base from this enhanced network for the period 1996 onwards. Inclusion of data back to 1980 is suggested for hydrological modelling purposes but needs further implementation efforts and will be the task of BHDC.

The Global Precipitation Climatology Centre (GPCC) operating at DWD in Offenbach, Germany, disseminates gridded precipitation datasets for the global landsurface on a monthly routine basis. These datasets provide monthy total precipitation in mm as well as in percentages of the normal values for 1961-1990. From 1998 onwards, these products will be available on a 1-degree by 1-degree grid for Europe. Daily analyses can be prepared on special request also from 1998 onwards. These are based on all real-time data received via GTS. The results are available within two months after observation and will be useful for *BRIDGE* as large-scale background data.

At a number of synoptic and other stations precipitation is continuously recorded using e.g. ombrometers. In Germany, there are about 70 of these stations, which produce digitised data. Using ombrometer records instantaneous rain rates may be obtained which is required e.g. for remote sensing validation purposes. An inventory of all existing ombrometer stations in the Baltic Sea catchment region is required and continuous precipitation records from all these

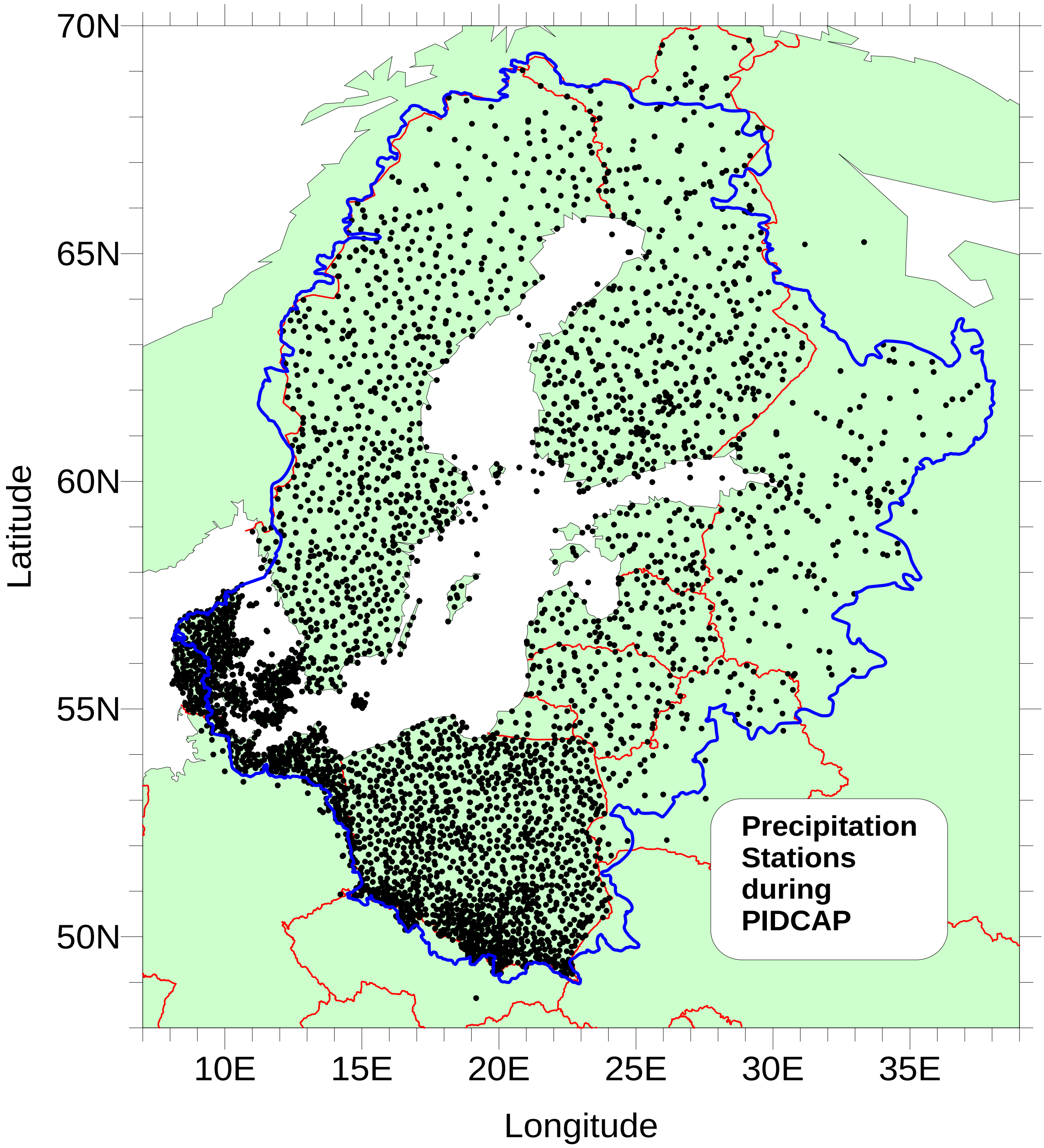


Figure 3: Locations of precipitation stations during PIDCAP. Daily precipitation sums from more than 3800 stations located in the Baltic Sea catchment region have been collected into the archives of the BALTEX Meteorological Data Centre.

stations will have to be stored at BMDC for dissemination to the BALTEX research community.

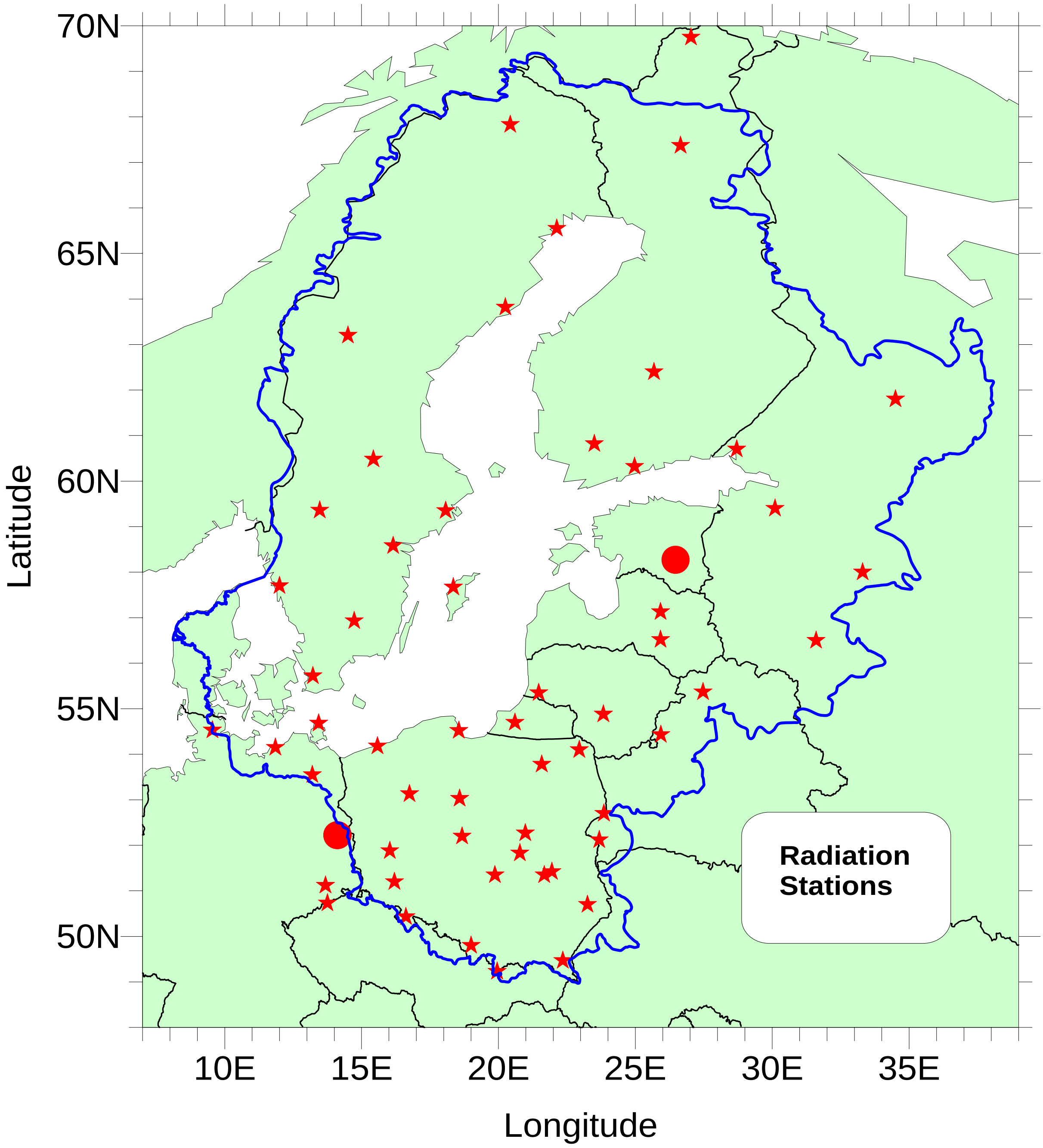
As part of the BALTEX research program specific ship rain gauges (Hasse et al., 1997) have recently been installed on 4 ferry boats, at an automatic weather station north of the island of Darss, and on the small island Östergarnsholm in the middle of the Baltic Sea. The ferry boats run regularly on a route from Travemünde, Germany to Helsinki, Finland. These ship gauges are especially designed to compensate for the instruments flow distortion bias under high wind speed conditions, which is important when measuring precipitation on a running ship. These data can be used for verification of model output and adjustment of remotely sensed precipitation, both from radar and satellite. At present, these data are processed at Institut für Meereskunde (IfM), Kiel, and are stored for dissemination to BALTEX data users at BMDC. Financial aspects need to be solved for a continuous maintenance and extension of these measurements.

2.5.4 Surface Radiation Data

The importance of surface measurements of radiation fluxes is obvious for *BRIDGE*, and for BALTEX in general. Surface net solar radiation provides the primary energy input for land surface processes and to heat up the ocean. Surface radiation measurements are required to calibrate and validate satellite radiance measurements. Surface measurements are also urgently required for validation of model estimates.

Recognising requirements for high-quality surface *in-situ* data the WCRP is conducting as part of GEWEX the Surface Radiation Project (SRB) to combine satellite data such as from the ISCCP and ERBE to estimate the downward shortwave fluxes at the surface, longwave downward irradiance and emittance, and the net radiation flux at the surface. A Baseline Surface Radiation Network (BSRN) was established to provide a worldwide network to continuously measure radiative fluxes at the earth's surface. Over 30 stations located throughout the world are planned for BSRN. In Europe, three stations (Carpentras, France; Spitzbergen island, Norway; Payerne, Switzerland) are measuring and archiving data for the BSNR archive at present, two stations are soon to become operational as BSRN stations (Lindenberg, Germany; Budapest, Hungary) and one station is a candidate (Toravere, Estonia). All stations provide already measurements of some surface radiation quantities and for example Toravere has decade-long records which have been exploited also for BALTEX studies (Keevallik and Tooming, 1996, Russak, 1996). However, only two BSRN stations at maximum will provide surface radiation measurements during *BRIDGE*.

In addition to BSRN national weather services maintain radiation stations in different countries in the Baltic Sea catchment region (Figure 4). Information on these stations is preliminary and needs completion. Also, the quality of the presently available surface radiation data must be checked. An inventory of those stations which maintain international standards and which will perform continuous measurements in the future must be established. The continuous preparation and delivery of hourly and daily data from the latter stations to the BMDC should be guaranteed by national data suppliers. Additional pyranometer stations including



<u>Figure 4:</u> Locations of radiation stations in and near the Baltic Sea catchment region. Almost all of these stations provide at least daily values of global radiation and diffuse sky radiation. This station inventory is probably not complete. The read enlarged dots give locations of the BSRN stations Lindenberg, Germany at 52.2N/14.1E (soon to become operational), and Toravere, Estonia at 58.3N/26.5E (candidate station). See section 2.5.4 for details.

automatic data storage facilities should be installed in data sparse regions (e.g. in Russia and Belarus).

The data quality of the radiation data must be assured. It is suggested that BMDC provides the quality-control in order to offer a homogeneous surface radiation data set to the BALTEX scientific community.

2.6 SUMMARY OF RECOMMENDATIONS

In summary the following activities are recommended for the meteorological component of *BRIDGE*:

R2.1: Encourage two groups, e.g. the HIRLAM community and DWD, to run two independent, delayed-mode data assimilation systems for *BRIDGE*.

R2.2: Take steps to obtain 6-hourly RS soundings from the 16 stations immediately bordering the Baltic Sea (see Appendix 1 for a list of stations).

R2.3: Take steps to operate additional RS stations on Gotland, Åland and Bornholm, respectively.

R2.4: Take steps to complete the operational GTS dissemination of the full SYNOP surface data telegrams in 3-hourly intervals from all existing stations in both the Baltic Sea catchment region and the BALTEX modelling area.

R2.5: Take steps to maintain the operational precipitation gauge station network in the Baltic Sea catchment region and the data availability, as was achieved during PIDCAP.

R2.6: Additional ship rain gauges should be installed on ferry boats and masts in different parts of the Baltic Sea.

R2.7: Marine meteorological observations from vessels, automatic lighthouse stations and buoys, on islands, and at other marine stations should be intensified for calculating fluxes and verification of models.

R2.8: In order to have a validation for fluxes calculated from assimilated fields, take steps to maintain the measurements at the sites of field campaigns like Östergarnsholm, Lindenberg, NOPEX, BASIS, and others.

R2.9: Establish a physiography data centre function for collection and merging of a high resolution orography, land use, vegetation type and soil texture data base.

R2.10: The existing data on physiography covering the *BRIDGE* study area should be acquired from the HIRLAM project and made available through the BMDC.

R2.11: Groups that will carry out the delayed mode data assimilation should make quality control information, produced by the data assimilation (quality flags), available to the users of the assimilation data.

3 HYDROLOGY

3.1 HYDROLOGICAL MODELS

3.1.1 Background

Traditionally straightforward streamflow simulation has been the main focus in hydrological modelling. This has resulted in a number of relatively simple hydrological models, which have proved to be well-suited to solve a number of practical hydrological problems such as hydrological forecasting or design studies. An overview of such models has recently been presented by Singh (1995). Many of these models are classified as conceptual (Nash and Sutcliffe, 1972) and include a fair amount of empirism. They normally require careful calibration by which model parameters are adjusted to optimum values, before the models are ready for use.

Along with the growing interest in more complex problems where the models are stretched beyond their range of calibration or where simply is no possibility to validate the models, more physically based hydrological models have been requested. The problem is particularly pronounced in connection with climate modelling or any problem where not only the water balance, but also the energy balance has to be solved. Most soil-vegetation-atmosphere-transfer schemes (SVAT-models) used in climate models are by necessity of this category. It has been popular to classify hydrological models as conceptual or physically based (Beven, 1989; Bergström, 1991; Refsgaard, 1996). Today it seems to be more relevant to distinguish between water balance - and combined energy and water balance models.

Recently the problems of scale, sub-grid variability and macro-scale modelling have come into focus since the water cycle has been identified as a key issue in climate modelling, and research focuses now on the linking of hydrological and atmospheric models (Wheater et. al, 1993; Blöschl and Sivapalan, 1995; Wood 1995). Scaling and macroscale modelling are also problems which have to be addressed by the Continental Scale Experiments (CSEs) carried out under the GEWEX research umbrella, such as the GCIP (Mississippi), the LBA (Amazon), the MAGS (Mackenzie) and the BALTEX (Baltic Sea) programs. The typical scale of the catchments of these CSEs is in the order of magnitude of millions of km^2 and they cover some of the major river basins of the earth. This scale in hydrological modelling has to be handled to meet the objective of GEWEX, i.e. to understand the global energy and water cycle.

Within the BALTEX scientific community both climate models and hydrological models are available and being developed. These models cover a range of approaches from simpler conceptual water balance models to advanced combined energy and water balance models of SVAT type (BALTEX 1996a). The first category of models have their roots in the operational needs of the hydrological services, while models focussing on energy and water balance often have been developed within NWP modelling schemes.

3.1.2 Model deficiencies

The SVAT schemes used in meteorological models and the traditional hydrological models come from, at least, two different schools, which is reflected in the way the models are formulated, validated and used. These schools represent a lot of experience which is not fully explored today. For example, the energy balance and evapotranspiration often are treated in a very rudimentary way in hydrological models while snow conditions, soil moisture and runoff generation could be improved in the SVAT component of many meteorological models. It is further important to note that the time resolution in most hydrological models are 24 hours while meteorological models operate with higher resolution to be able to solve the energy fluxes correctly.

As proper model validation is crucial for the confidence in a model, it is a critical aspect of the model development process. It is also a very difficult one. Experience in both atmospheric modelling and hydrological modelling has shown that it is easy to make a simulation match observations with a variety of model structures or with a variety of parameter settings in the same model. There are also frequent examples of models with compensating inconsistencies which make them work well for the wrong reason. The validation of large scale land surface/hydrology models suffers from the same difficulties and, in addition to this, the scale problem has to be addressed in a proper way. New problems are also introduced in international basins as the measurement and data processing standards might differ.

The new modelling needs, and in particular the introduction of combined energy and water balance models, have made traditional hydrological model validation based on runoff records obsolete. New types of data are required to build up confidence in the new type of models. Of particular interest is the validation of internal model processes such as snow accumulation and melt, soil moisture, groundwater dynamics and runoff generation in different parts of a basin.

3.1.3 Suggested Activities

Process oriented model intercomparison and validation
The hydrological modelling part of the Main BALTEX Experiment will focus on the intercomparison and validation of the representation of individual processes of the surface energy and water balance and soil water dynamics of atmospheric and hydrological models. Another focus is the modelling of the surface components of the water balance of the entire Baltic Sea catchment region.

Today the possibilities to meet the requirements on more detailed model validation have increased thanks to the availability of areal information from remote sensing and other sources. Satellites can provide more detailed field data on snow cover and airborne instruments can offer snow water equivalents. There are also a number of field studies, such as the NOPEX project in Sweden and Lindenberg in Germany, where atmospheric fluxes are measured. This should be fully exploited in this process. Data from Östergarnsholm will also be useful as representative for large lakes as well as for the Baltic Sea.

A number of hydrological model intercomparisons have been carried out, for example by the World Meteorological Organization (WMO, 1975, 1986). SVAT models have been compared in a similar way within the PILPS (Henderson-Sellers and Brown, 1992) project. In these cases the emphasis has been on comparison rather than validation although some useful insight into the realism of the different models has also been gained.

Due to different requirements of different models the intercomparison within *BRIDGE* will be split into two phases:

1. intercomparison and validation of hydrological models,

2. intercomparison and validation of the representation of individual processes of the surface energy and water balance and soil water dynamics of atmospheric and hydrological models.

The intercomparison of hydrological models (Phase 1) will cover, at least, ten years of daily data and will be carried out in the special test basins identified by the BALTEX Hydrology workshop in Warsaw (BALTEX, 1996). The intercomparison and validation of SVAT models and hydrological models will start at the beginning of *BRIDGE* and will focus both on large scale data and data that are available from the field experiments (NOPEX and at Lindenberg).

The following main processes will be subject to intercomparison and validation:

- The modelling of snow accumulation.
- The modelling of snow melt.
- The modelling of frozen ground.
- The modelling of interception.
- The modelling of evapotranspiration and sensible heat flux.
- The modelling of soil moisture dynamics.
- The modelling of runoff generation and routing.
- The modelling of the influence of lakes and swamps on runoff.
- The modelling of ice on lakes and the influence of ice on river runoff.
- The modelling of groundwater flow.

The representation of the sub-grid or sub-basin variability of these processes and fluxes will also be subject to analyses.

It has to be emphasised that properly performed model intercomparisons are major undertakings, which require careful planning and a fair amount of resources.

Macro-scale hydrological modelling

There is a need for macro-scale hydrological modelling for the entire Baltic Sea catchment region to get a first estimate of the main water balance components and as a tool to calculate river runoff to the Baltic Sea in near-real time. There is normally a time-lag of months or even years until runoff observations are processed and made available. The modelled runoff from hydrological models of the entire basin will also be compared to the runoff formation in climate models.

Work on macro-scale hydrological modelling for the Baltic basin is in progress and preliminary results have, for example, been presented by Lohmann et al. (1996) and Bergström et al. (1996). These preliminary applications will be improved by the introduction of a more complete data base for a period before and during *BRIDGE*. It is recommended that other hydrological modellers model the entire basin as well, in order to improve our understanding in the uncertainties in the estimates of the basin-wide water balance components.

During *BRIDGE* the macro-scale hydrological models will provide a service to the oceanographers as they will be used to calculate daily runoff data for the sub-basins of the Baltic Sea catchment region in near-real time.

Coupled modelling
The intercomparison and validation will reveal inconsistencies in the different modelling approaches and will bring the meteorological and the hydrological modellers closer together. It is also a way of linking the climate models to hydrological observations such as snow, soil moisture and runoff, which previously have been used in hydrological model development. The process will also help hydrological modeller to develop more realistic energy and water balance schemes, which are of importance for the modelling of snow conditions and evapotranspiration, among other things. It is thus obvious that the development of coupled models will benefit greatly from the process oriented model intercomparison and validation.

SVAT routines of atmospheric models usually calculate runoff as a residual term of the water balance. This is seldom compared to observed flow. The macro-scale hydrological modelling has the great potential to serve as a validation tool as it links the output from atmospheric models to observations of river runoff.

In the long run the aim is to integrate the hydrological modelling into a coupled hydrological-meteorological model system for the Baltic basin. This requires the development of more sophisticated hydrological parameterisation schemes where both water and energy fluxes are realistically described and validated. This new model generation must be able to cope with the specific characteristics of the landscape in the Baltic Sea catchment region, with its mosaic of boreal forests, lakes and swamps in the north and east and patchy agricultural character in the south. Conditions in high mountains have to be modelled both in southern Poland and in north-western Scandinavia. A key issue in this hydrological model development will thus be sub-grid or sub-basin variabilities of processes governing the fluxes.

See also sections 2.2 and 4.1 for further discussions on coupling.

3.2 HYDROLOGICAL DATA

3.2.1 Background

A strategy for hydrological data sampling was outlined by the BALTEX Hydrology workshop in Warsaw (Appendix 1 in BALTEX 1996). The idea was to collect data for the entire catchment in a basic network of some 100 stations and to have more complete data coverage in some special study basins (Odra, Daugava, Neva, and Torneälven, Figure 5). These basins will be the main basis for hydrological model intercomparisons and validation. The proposed length of record of collected data is preferably from 1970 onwards or, at least, from 1980 onwards. The collection of the data will be the task of the BALTEX Hydrological Data Centre, BHDC, which is run under the responsibility of SMHI in Norrköping.

The BALTEX hydrological data sampling strategy further suggests collection of other hydrological data such as snow data, soil temperatures, soil moisture, lakes and ice conditions if these data are easily available. The responsibility of these data will be shared between the BALTEX Meteorological Data Centre (BMDC) and the BHDC. Organisation of the BMDC is the responsibility of the German Weather Service (DWD) in Offenbach.

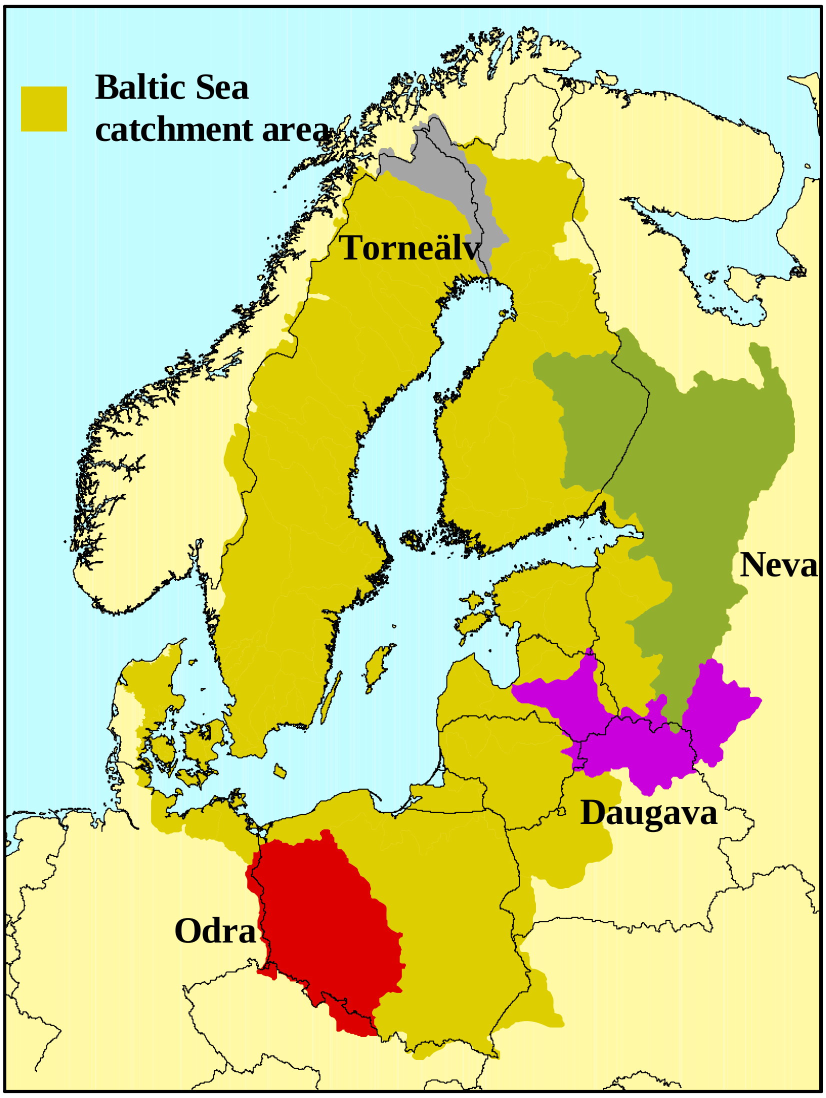
The BHDC will further develop a database on meta-data including information on catchment characteristics such as soil and vegetation and specific information about the hydrological stations.

3.2.2 Deficiencies of the Data

The relatively long records required for hydrological modelling are related to the information value in a runoff record when used for model calibration. Experience has shown that 10 years of data normally is sufficient in this respect, provided these data cover a period of adequate variability. As the hydrological models use meteorological input data the record length of these have to match the runoff records. This means that a relatively complete set of meteorological data will be required for those basins where hydrological models are tested. This problem has been identified by the BALTEX community and initiatives to collect the necessary data have been started.

The fragmentary character of other hydrological data is another limitation of the sampling strategy of BALTEX. In particular, a more complete coverage of data on snow, soil moisture and soil temperature would be very beneficial for the validation procedures suggested as a main effort in hydrological modelling. Other important information is the date of freezing and break up of ice on rivers and lakes.

Runoff data are now continuously being collected by the BHDC since the start of the BALTEX research period and this will be continued until its end, thus including *BRIDGE*. However, these data are only available after some time lag. This is due to the procedures of the national hydrological institutes and other suppliers, and due to necessary corrections,



<u>Figure 5:</u> Locations of catchment regions of rivers Torneälv, Neva, Daugava, and Odra, which are recommended as special BALTEX study basins.

mostly caused by ice-jamming. The availability of other hydrological data such as snow conditions and soil moisture may also suffer from long delays for various reasons.

Although the data delivered to the BMDC and the BHDC are supplied by national institutes there is always a risk for inconsistencies. The situation is complicated by the fact that data come from different sensors and that there may exist different processing routines. This issue is of particular importance for precipitation measurements during snowfall.

3.2.3 Proposed Improvements of the Hydrological Data Base for BRIDGE

It is proposed that the BALTEX strategy for climate data is supplemented so that the data better meets the requirements of the hydrological modellers. This means that a complete set of meteorological data is collected for the special hydrological test basins (Odra, Daugava, Neva and Torneälven) under the responsibility of the BHDC. The period should at least be from 1980 onwards and over the entire BALTEX program period. The BMDC should further aim at a complete climatological data set for the entire BALTEX modelling region for the period of *BRIDGE*.

Efforts should be spent on the collection of supplementary hydrological information, in particular on snow, soil moisture, soil temperature and freezing and break up of ice. Before the start of the experiment an inventory of possible sources of information should be made and based on this information additional field measurements should be initiated. Potential contributors in this respect are the national hydrological services, the water resources industry or authorities, agricultural universities or similar.

During *BRIDGE* macro-scale hydrological models shall be available for near-real-time supply of simulated river runoff to the oceanographers of the BALTEX community.

The BMDC and the BHDC must spend some effort on the control of the quality and consistency of the respective data bases. Recommendations concerning corrections and indications of inhomogeneities shall be forwarded to the users. Special attention will have to be given to the observations of solid precipitation.

3.3 SUMMARY OF RECOMMENDATIONS

In summary, the following activities are recommended for the hydrological component of *BRIDGE*:

R3.1: An intercomparison and validation of hydrological models should be carried out for, at least, a 10 year period of data in the special hydrological test basins (Odra, Daugava, Neva, Torneälv).

R3.2: Intercomparison and validation of the representation of individual processes of the surface energy and water balance and soil water dynamics of atmospheric and hydrological models should be carried out.

R3.3: Macro-scale hydrological models should be developed for the entire catchment region of the Baltic Sea as a tool for estimating the overall water balance, as a validation tool for climate models and to provide oceanographers with near-real-time runoff data during *BRIDGE*.

R3.4: The BALTEX strategy for climate data should be supplemented so that the data better meets the requirements of the hydrological modellers.

R3.5: The BMDC should aim at a complete climate data set for the entire BALTEX modelling region for the period of *BRIDGE*.

R3.6: Efforts should be spent on the collection of supplementary hydrological information, in particular on snow, soil moisture, soil temperature and ice conditions.

R3.7: The BMDC and the BHDC should spend some effort on the control of the quality and consistency of the respective data bases.

R3.8: A new hydrological model generation should be developed for the specific characteristics of the landscape in the Baltic Sea catchment region, with emphasis on the effects on water and energy fluxes of sub-grid or sub-basin variabilities of processes.

4 OCEANOGRAPHIC AND SEA ICE ASPECTS

4.1 INTRODUCTION

To calculate the energy and water budget of the Baltic Sea, the utilisation of coupled atmosphere-ice-ocean numerical models with hydrology included is necessary. From the oceanographic point of view, the components ice, ocean and atmosphere are strongly interacting, whereas, to the hydrology less distinct re-coupling exists. River runoff has a regional impact on the local salinity distribution, and also effects the water mass exchange with the North Sea due to its volume flow and dynamics. The atmosphere provides the forcing for the ice-ocean system, namely momentum, salt and heat fluxes which include precipitation and evaporation as well as radiation. In case of an ice-free ocean these fluxes act on the ocean surface, in case of ice, the fluxes act on the ice surface and the ocean receives a modified forcing depending on ice dynamics, ice thickness and concentration and an additional snow cover. The ocean, in turn, supplies heat and momentum fluxes to the lower ice surface. A re-coupling of the ocean to the atmosphere is provided by sensible and latent heat fluxes. In case of ice, the oceanic heat flux is strongly reduced or even prevented. The back-scattered short-wave radiation is strongly effected by the increased albedo. If there is an additional snow cover, the heat exchange of the snow-ice-ocean system with the atmosphere is even more complicated.

In recent years rather sophisticated models of atmosphere, ice and ocean for the Baltic Sea have been developed. However, the coupling of the different components has only just begun. In principle, the coupling processes are well known, but in practice a unique description of the exchange processes is lacking. The models may be coupled directly via the fluxes calculated by the atmospheric models or the fluxes may be calculated by using bulk formulas. But uncertainties in these fluxes may lead to an unphysical drift of the coupled system. A similar effect is notable from unresolved physical processes in the models of the different components, and as special problem from the almost unknown initial conditions of the ocean. To keep the coupled system on track, a so-called flux correction may be necessary, which means the coupled system is partially relaxed to observations. Sea surface temperature (SST) observations may be used for such a flux correction. By means of infrared satellite radiometers the two-dimensional surface temperature distribution of the Baltic Sea can be obtained in cloud-free situations.

Besides these coupling problems, the oceanic numerical models need to be improved with respect to mixing processes in the ocean. The utilisation of data assimilation techniques and more sophisticated parameterisations of turbulent mixing may remedy these deficiencies. However, both techniques need high resolution hydrographic measurements.

In view of the Main Baltic Sea Experiment, which aims at determining the energy and water cycle for a 18 months period, there are deficiencies in numerical models as well as in observational data which should be remedied. At least some of the problems have to be taken care of during the preparation phase of the experiment.

4.2 DEFICIENCIES IN OBSERVATIONAL DATA

4.2.1 Remote Sensing

Infrared SST maps are important for model assimilation and verification. Weekly infrared SST maps of the whole North and Baltic Sea area are available from the BSH Hamburg. These maps are created by combining satellite overpasses during one week. They have a horizontal resolution of 2 km. For cloudy areas the SST values are substituted by data from areas where the sky is cloud-free. Averaging of SSTs is being performed under cloud-free conditions. Weekly SST maps are available from January 1993 onwards.

The SST information may be integrated into the ocean model by data assimilation, i.e. sea surface temperatures of the ocean model are relaxed to observed SSTs. This is mainly done to keep the SST as close as possible to observations, and to avoid an unphysical drift of the oceanic mixed layer temperature which may arise from uncertainties of atmospheric and oceanic fluxes. SST maps are also useful for model verification. Especially, individual overpasses (at least daily SST maps) may be useful to verify processes like meso-scale eddies and upwelling.

In coupled atmosphere-ice-ocean modelling, infrared SST data are particularly useful for heat flux corrections.

For the simulation of ice, SAR (Synthetic Aperture Radar), infrared and visible satellite data are useful to determine the ice extent and to verify the movement of the ice edge (Leppäranta et al., 1995).

4.2.2 River Runoff

Runoff data, at least from the largest rivers, are necessary both to investigate the local dynamic effect of fresh water load into the Baltic Sea, and to estimate the water balance. Because today's numerical oceanographical models resolve the ephemeral dynamic processes in the Baltic Sea, the runoff data should be provided daily. SMHI has set up a runoff data base which covers the period 1950-1990 and which covers 86% of the total runoff (Bergström and Carlsson, 1994). Such kind of data should be made available for the whole experiment period and also for the time from 1990 onwards. From model simulations over several years, climatological changes in the water mass balance of the Baltic Sea may be inferred. River runoff has an important impact on the local salinity distribution, and it determines in combination with vertical mixing processes the salinity in the upper layer of the Baltic Sea. The vertical salinity distribution (position of the permanent halocline) in turn has an important impact on the potential heat content of the Baltic Sea, thus effecting the energy balance in the Baltic Sea. The volume flow of the total runoff reaches maximum values of 2 km^3 /day which leads to an increase of the mean sea level of about 0.5 cm. The induced surface outflow through the Danish Straits may exceed 10 cm/s.

4.2.3 Inflow/Outflow through the Danish Straits

To estimate the resulting fresh water export through the Danish Straits, regular continuous recording of profiles of temperature, salinity and currents should be undertaken. Profiles should be taken at two positions, namely at the Darss Sill and at the Drodgen Sill, with a time resolution of 10 minutes for salinity and temperature and at least one hour for the currents. Time series and assimilation should last at least one year, better two, without interruptions to resolve the weak baroclinic circulation which is overlaid by strong barotropic fluctuations with a time scale of some 10 days. Without using numerical models, one observational platform within the Darss and Drodgen Sill and the Great Belt will be too sparse, at least, two or more station are necessary to resolve the complex spatial structure of salinity and currents (Fischer and Matthäus, 1996).

To run high resolution oceanic circulation models a high accuracy for the driving forces is required (Lehmann, 1995). In particular, to use numerical models in combination with assimilation, highly accurate wind forcing for the whole Baltic Sea area is necessary to simulate the currents through the Straits properly. The estimation of the net runoff through the Danish Straits by using numerical models with data assimilation requires an accurate estimation of the total river runoff for the whole Baltic Sea catchment area. To cover highly fluctuating effects daily runoff data will be necessary.

Measurements of temperature, salinity and currents are currently carried out at the positions Darss and Drodgen Sill. The Darss Sill measurement unit will be in operation for the whole BALTEX time period. Whether this is also true for the positions Great Belt and Drodgen Sill has to be clarified.

Additionally, sea level data are of importance to verify simulated surface elevations and to assimilate them into oceanic circulation models.

4.2.4 Advection, Mixing and Heat Storage in the Baltic Sea

River runoff, precipitation minus evaporation (P-E), together with the vertical flux of salinity through the permanent halocline determine the salinity in the brackish upper water layer of the Baltic Sea. To monitor the fluctuations of the surface salinity due to changes in the fresh water balance, measurements of salinity, at least in the main basins, should be accomplished. Because of the small variations in salinity, an accuracy of 0.01 PSU for salinity measurements of the characteristic water masses are required. Measurements should last 1-2 years. For BALTEX, salinity measurements will be carried out by the Institut für Ostseeforschung Warnemünde (IOW) in the Arkona Basin starting in 1998. To achieve a more complete picture of ‘longterm’ salinity variations in the Baltic Sea such kind of measurements should be accomplished by the local institutions, because of logistic reasons. To get an idea of the spatial variability supplementary hydrographic measurements from research vessels should be carried out several times per year. Regular recordings of temperature, salinity and current profiles in the deep basins and the important channels (e.g. Stolpe Channel, Gotland Basin, Gulf of Riga, Gulf of Finland, Gulf of Bothnia) together with supplementary high resolution hydrographic measurements are extremely useful to determine the variability of these parameters. To resolve the meso-scale features the supplementary measurements should resolve the distance specified by the internal Rossby radius which is about 2 - 10 km in the Baltic Sea. The planned field experiment DIAMIX (Diapycnal Mixing in the stratified ocean, see section 6.3) is expected to create data sets for evaluation of the distribution of kinetic and potential energy on space and time scales down to dissipation scales.

The purpose of such a database is twofold. Firstly, the data can be used to verify results of numerical models, and secondly, the data may be assimilated into the models to achieve a coherent picture of temperature and salinity evolution in the Baltic Sea. The evolution of the mixed layer will also be documented, and together with atmospheric fluxes, such a data base will be extremely useful for the calibration of mixed layer models and the parameterisation of internal turbulent mixing. This is also true for the calculation of budgets and in particular the storage of heat and fresh water in the Baltic Sea.

The combination of temperature, salinity and current measurements allows an estimation of the turbulent state of the sea by calculating measures of turbulence, e.g. Richardson Number. Current measurements can be achieved by using ship-bound ADCPs. Turbulent structures can be measured directly by using a special turbulence sonde (EDP-probe; Enhanced Dissipation Profiler; Stips 1996) which can be launched from a research vessel.

4.2.5 Sea Ice Measurements

The evolution of the ice in the Baltic Sea is well documented by the national ice services, but there are certainly measurements missing from which the plastic behaviour of the ice can be inferred. For heat budget calculations measurements of ice albedo and heat conduction through the ice are also necessary. The influence of snow cover on the heat flux through the ice and corresponding changes in the albedo should also be investigated by field measurements. Some of these problems will be covered within the BALTEX projects BASIS (Baltic Air-Sea-Ice Study) and BASYS/SP6 (Baltic Sea and Sea-Ice Modelling). Within ZIP-97

(Zooming Ice Physics, part of Ice State project/MAST II) two specific objectives on local ice cover deformation and meso-scale ice dynamics will be investigated. The specific aims are to describe and model the processes involved in local ice deformation and to incorporate these into the governing equations of meso-scale ice dynamics and to identify a set of parameters which is adequate to describe an ice state and which can be derived from remote sensing and meso-scale modelling.

To verify numerical ice models SAR satellite images are particularly useful (Leppäranta et al., 1995). From SAR images the spatial ice velocity field can be determined. During BEERS (Baltic Experiment for ERS-1) ERS-1 SAR was used for ice mapping in the Baltic Sea. From a comparison of the obtained ice displacement field with an ice dynamics model it was demonstrated that the overall ice velocity field could be reproduced with a Hibler plastic rheology.

4.2.6 Measurements of the Solar Attenuation in the Sea

The solar attenuation in the open sea is an important parameter in determining the mixed layer temperature, and hence the energy balance at the surface. Measurements should be undertaken to verify atmospheric fluxes of short wave radiation and the evolution of the sea surface temperature.

4.2.7 BALTEX Oceanographic Data Centre

A BALTEX Oceanographic Data Centre is needed to archive information on existing oceanographic data and their availability.

4.3 DEFICIENCIES IN NUMERICAL MODELS

Nowadays, different types of general ocean circulation models for the Baltic Sea are in preparation or are already used for simulation of the circulation and the water mass exchange with the North Sea. Some of these models are coupled to ice models. Up to now a full coupled atmosphere-ice-ocean model for the whole Baltic Sea is not available. However, first attempts to couple a ice-ocean model with an atmospheric model have been undertaken (Omstedt and Nyberg 1995). Different ice models are also available. An ice model intercomparison will be performed within BASYS/SP6.

4.3.1 General Ocean Circulation Models

In general, the models are based on primitive hydrodynamic equations and combine meso-scale dynamics and thermodynamic processes driving the motion in the Baltic Sea. The models are used to study the response of currents and sea level to direct forcing by wind and wind-induced changes of sea level in the Kattegat, the latter leading to exchange flows through the Danish Straits. Some of the models further describe the response of the circulation to forcing by river runoff, and precipitation and evaporation. This includes also the relatively weak circulation due to baroclinic gradients caused by the inflow and further advection of saline water from the Kattegat.

A general problem of performing runs with these circulation models is the memory and CPU time requirements to simulate the Baltic Sea response on a long term basis. The coast line as well as the complicated bottom topography, strong horizontal as well as vertical salinity and temperature gradients require high vertical and horizontal resolution. To resolve the meso-scale dynamics and processes in the narrow Danish Straits properly, a horizontal resolution of order of the half internal Rossby radius (at least of order of the Rossby radius) is required.

Another problem arises from the western boundary condition. Some of the models simply prescribe a mean surface elevation at the most western boundary, some models are embedded in North Atlantic or North Sea models with a coarser grid, and some models use a telescoping grid to extent the model to a wider area.

To drive the models, accurate atmospheric forcing is essential for the modelling to derive confidential results. This forcing is provided by general atmospheric circulation models. The latter models have different deficiencies which are described in the atmospheric model section (see section 2).

Vertical turbulent mixing is generally parameterised in the general ocean circulation models. There are several turbulent closure schemes available. The most sophisticated scheme is a mixed layer model based on the k-epsilon closure (e.g. Buchard and Baumert 1995). Two equations have to be added to the ocean model. The first describes the turbulent kinetic energy (TKE), and the second calculates the dissipation rate of TKE. The improvement of modelling mixing processes in the ocean leads to an increase of computer CPU time and memory requirements. Simple closure schemes (e.g. depending on the Richardson number) underestimate turbulent mixing in the mixed layer, and hence, the evolution of the heat content in the ocean is underestimated. Furthermore, turbulent mixing has an impact on the vertical distribution of temperature and salinity, thus effecting also the advection of temperature and salinity.

To improve model simulations data assimilation may be utilised. The field of data assimilation ranges from re-initialisation of 3-dimensional temperature and salinity distribution on the one side to nudging of observations to modelled parameters on the other side. By using data assimilation with the adjoint method, optimised forcing field fields may also be derived, in addition to the improved modelling results. Data assimilation using the adjoint method is however up to now not feasible for a 3-dimensional numerical simulation with a proper horizontal and vertical resolution.

4.3.2 Ice Models

Within the BALTEX project BASYS/SP6 (Baltic Sea and Sea-Ice Modelling) different ice models for the Baltic Sea are compared (Omstedt and Nyberg, 1996, Haapala and Leppäranta 1996). Different advection schemes are tested, because the normally used central differences scheme is prone to creating negative ice thickness. Different descriptions of ridged and level ice are also tested. There is also a need to test different approaches for the ice rheology, which determines the viscous-plastic behaviour of the ice. The description of a snow cover must also be improved. An important shortcoming of the ice models is the temporal lag of the melting period. Although, the amount of melt rate is simply proportional to the heat flux into the ice pack, the parameterisation of the albedo and attenuation of solar radiation within ice and snow needs further investigations. For coupled ice-ocean simulations the effects of ice coverage on the ocean boundary layer (OBL) should be investigated. At least, some of the ice model problems will be covered within the BASYS/SP6 and BASIS project.

4.4 SUMMARY OF RECOMMENDATIONS

In summary, the following activities are recommended for the oceanographic component of *BRIDGE*:

R4.1: Infrared as well as visible and SAR satellite images are needed for model verification and assimilation.

R4.2: Daily runoff data, at least from the largest rivers, should be made available for numerical modelling purposes.

R4.3: Continuous profiling measurements of temperature, salinity and currents at Darss and Drodgen Sills as well as in the Great Belt are necessary to determine the water balance through the Danish Straits.

R4.4: The BALTEX Oceanographic Data Centre (BODC) should gather all available sea level data from the coastal stations of the Baltic Sea.

R4.5: Oceanographic models, with the use of data assimilation methods, need to be developed and applied for the calculation of the net outflow through the Danish Straits.

R4.6: Recordings of temperature, salinity and current profiles in the deep basins and at the important channels (e.g. Stolpe Channel) together with supplementary high resolution hydrographic measurements should be accomplished.

R4.7: Appeal to all Baltic Sea countries to intensify their measurements of temperature, salinity and sea levels during the *BRIDGE* period.

R4.8: Install some meteorological/oceanographic buoys in the central part of the Baltic Proper and its sub-basins that should be recording during the *BRIDGE* period.

R4.9: DIAMIX (see section 6.3) should be regarded as a pilot project for an intensive study of vertical mixing and advection in the Baltic Sea. Similar measurements should be carried out in other deep basins of the Baltic Sea.

R4.10: Understanding the role of sea ice on the circulation of the Baltic Sea and the water mass exchange with the North Sea will benefit from the BALTEX projects BASIS and BASYS/SP6 and also from the ZIP-97 (Ice State project/MAST II).

R4.11: Measurements of the attenuation of solar radiation in the open sea should be accomplished.

R4.12: Vertical turbulent mixing parameterisation in the numerical models should be improved.

R4.13: Data assimilation should be incorporated into general ocean circulation models.

R4.14: Atmospheric forcing data should be made available together with daily SST and ice charts.

R4.15: A model intercomparison of the different Baltic Sea models should be performed.

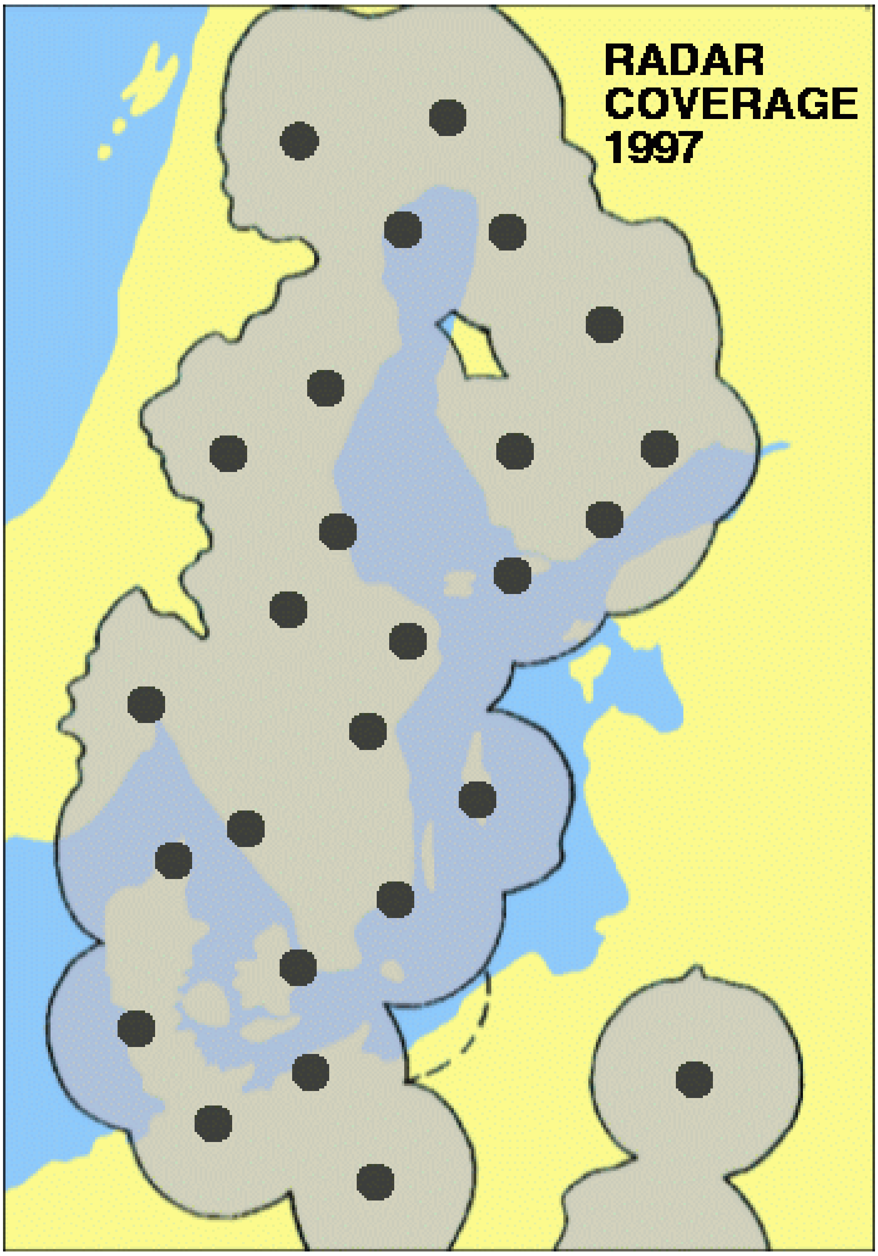
R4.16: Ice models should be tested against different advection schemes. The description of the viscous-plastic behaviour should be tested with respect to high horizontal resolution. The description of snow has to be taken into account.

5 REMOTE SENSING DATA

5.1 RADAR DATA

Accurately known precipitation fields over land and sea are crucial for meteorological, hydrological and oceanographical model verifications and for high-quality climatological data. Weather radar is the only technique which can measure precipitation with high temporal and spatial resolution simultaneously (e.g. Cluckie and Owens, 1989, Joss and Waldvogel, 1990, Collier, 1996). Radars also produce wind speed and direction, deformation and divergence soundings at more places and with higher resolution than radiosondes, provided that there are enough scatterers (insects or hydrometeors) in the layer of interest (e.g. Wilson et al.. 1995).

A relatively dense digital weather radar network covers the western part of the BALTEX area, including larger parts of the Baltic Sea. Figure 6 represents roughly the mean annual detection coverage of precipitation measurements (individual radar ranges are approximately 170 km) as the coverage area correlates strongly with the actual height of the precipitating systems: The detection radius in shallow winter precipitation is smaller (80-150 km) while in warm air mass rain it reaches often the nominal measurement ranges of 240-250 km. It is obvious that the radar network can be the primary source for high resolution precipitation fields in the Baltic Sea catchment region during *BRIDGE*. However, this can be achieved well only if the infrastructure and research actions given below will be performed. These actions are described in more detail in the BALTEX Radar Research plan (BALTEX 1996 b).



<u>Figure 6:</u> Estimated average yearly weather radar coverage in the BALTEX region and locations of operationally networked digital radars (dots). Local obstacles near the stations lead to deformations of the ideal circular form of the radar range. Actual detection range of precipitation in each measurement case can be larger or shorter than that shown in the figure (see text).

As can be seen in Figure 6, no radar information is available over the eastern portion of the Baltic Sea and the territories of the Baltic States, Russia, Belarus and southern Poland. Actually there are 3 digital weather radars in the St. Petersburg region in Russia which are not connected to any data network but operate only locally. There is also one non-operational doppler radar system available in Poland for which the required infrastructure still needs to be built up. For the purposes of *BRIDGE* there is a strong need to establish a complete radar coverage of the Baltic Sea - and at a later stage over the entire water catchment area of the Baltic Sea.

Due to the vast amounts of three-dimensional data from all BALTEX radar systems it is reasonable to establish a central BALTEX Radar Data Centre (BRDC) where all relevant data products will be stored for a time period covering the intensive observational periods of *BRIDGE*. According to the BALTEX radar plans (BALTEX 1996 b), SMHI would be the data centre for Doppler wind soundings and gridded dBZ values, obtained every 15 minutes, and for 3-hourly accumulated precipitation fields. The reflectivity factor and accumulated precipitation products from individual radars should be integrated into optimal composite products covering the region in Figure 6 with resolution of 2 x 2 km^2. These horizontal products will be the main radar contributions to BALTEX. The raw 3D radar volumes would be available only at originating institutes. Due to practical difficulties in post-processing vast amounts of 3D radar data, the use of it should be restricted to reasonable limits in time and space.

Although the presently available radar data is good for monitoring relative precipitation variations in time and space, absolute accuracy of precipitation products must be increased to meet the requirements of hydrological use and applications in numerical model verifications. Many of the quantitative error sources and algorithms to correct them are already reasonably well known or are under active research on a national level, applicable to one radar system. However, there is no common research and implementation plan to apply these corrections uniformly in all BALTEX radar systems. The most important factors which should be diagnosed and corrected (if necessary) in all BALTEX radar products are the following:

- elimination of ground and sea clutter, especially in cases of anomalous propagation (Lee et al., 1995);
- errors in the electrical calibration of each radar system (Joss et al., 1996);
- sampling difference between radar measurements aloft and precipitation at ground level i.e. the vertical reflectivity profile. The affecting physical processes are evaporation, melting and growth of hydrometeors (Joss and Lee, 1995);
- water phase of precipitating hydrometeors (liquid, solid, mixed), detected by radar, should be known at ground level when radar reflectivities are transformed to precipitation intensities (Smith, 1984). This can be implemented by a simple statistical model. The model variables can be e.g. temperature and humidity at the height of 2 m from the ground, and the altitude of ground above the sea level. The horizontal distribution of the variables can be analysed from the measurements of (automatic) weather stations together with high resolution topographical data and forecasted NWP fields.

Even after these corrections the best estimate precipitation field is usually not the radar measured nor the gauge measured distribution but the optimally integrated gauge and radar field

(Collier, 1996). An agreed and tested method to do this integration should be implemented (see e.g. Barbosa,1991; Rosenfeld et al., 1995).

5.2 WATER VAPOUR ESTIMATES USING GPS DATA

A potential recent enhancement of the meteorological observing system is through the use of ground-based GPS receivers to determine tropospheric water vapour (Bevis et al. 1992). This method uses the so-called wet atmospheric propagation delay of radio signals in the atmosphere, which is an unwanted source of error in geodetic applications of the GPS, but may be explored to derive estimates of vertically integrated tropospheric water vapour (IWV) above a GPS station (Elgered et al., 1991, Carlsson et al., 1997). GPS observations of IWV provide for a unique combination of temporal and spatial resolutions, and of accuracy. In the Nordic countries exist several national permanent GPS networks, altogether some 40 stations. At present, IWV is not derived operationally for this network. Data from 25 of these stations in Sweden and Finland have recently been used to monitor IWV during the PIDCAP observational period, August to October 1995, with a time resolution of 5 minutes and an accuracy of 1-2 kg/m² (Carlsson et al., 1997). Data assimilation of IWV into atmospheric models has been demonstrated (Kuo et al., 1993, 1996) and is planned for the assimilation runs during *BRIDGE*.

Efforts should be undertaken to guarantee the availability of continuous GPS data coverage during *BRIDGE* and a continuous processing of IWV data. It would be important to identify a single data processing and archiving centre for these data. Such a centre could be maintained by either Chalmers University in Sweden or at SMHI, or in collaboration. This necessitates an agreement between BALTEX and the external data supplier at Chalmers.

5.3 SATELLITE REMOTE SENSING

5.3.1 Introduction

Satellite data will play an important role during BALTEX because of their ability to fill gaps in the surface based network. Because of the high latitude of the area, geo-stationary satellites can only provide limited coverage, so that emphasis will be given to polar-orbiting systems. Only satellites firmly planned to be operational during *BRIDGE* will be considered. The plan presented represents a somewhat conservative attitude. New possibilities developing before and during *BRIDGE* will be carefully studied with a view for a potential enhancement of the data base.

The role of satellite data within *BRIDGE* will be five-fold:

1. Provision of data to determine the components of the energy and water budget of the Baltic Sea catchment area (BACAR) (e.g. the radiation balance at the top of the atmosphere),

2. Provision of data for assimilation into regional atmospheric, oceanographic and hydrological models or sub-models (e.g. sea surface temperature, atmospheric temperature, and humidity profiles from analysed TOVS data) within the BALTEX Modelling Area (BAMAR).

3. Provision of data for the validation of model derived parameters (e.g. surface temperatures, cloud cover, ice cover).

4. Provision of geomorphologic and vegetation data to be used in SVAT (Soil-Vegetation-Atmosphere-Transfer) sub-modules which are part of atmospheric and hydrological models.

5. Finally, *BRIDGE* will provide a unique opportunity for the satellite community to develop, test, and improve retrieval methods in an area with an exceptional heterogeneity in surface properties and atmospheric conditions.

Atmospheric models which are foreseen to be used in *BRIDGE* do not or are not yet able to take full advantage of available satellite data for assimilation. While the operationally available products like humidity and temperature profiles from TOVS (Tiros Operational Vertical Sounder) or satellite-derived sea surface temperatures are used by some assimilation schemes, other available sounder data like the SSM/T (Special Sensor Microwave/Temperature) for temperature profiles and SSM/T2 (Special Sensor Microwave/Temperature2) for humidity profiles are not used. These data are particularly useful because the DMSP (Defense Meteorological Satellite Program) satellites cover different times compared to the TOVS data measured onboard the NOAA (National Oceanographic and Atmospheric Administration) satellites. The main reason seems to be the lack of a retrieval system as advanced as e.g. the one existing for TOVS. Another problem was for a long time the availability of the data at near-real time.

New assimilation schemes, which utilise satellite radiances directly, will simplify the use of such data. Such schemes are used at ECMWF (European Centre for Medium Range Weather Forcasting) and are under development at SMHI (Swedish Meteorological and Hydrological Institute).

It can be foreseen that there will be a wealth of satellite data available during *BRIDGE* and during the period prior to the experiment. The main deficiencies concerning these data will be the general availability due to commercial interests, the lack of data centres dedicated to the collection, processing and archiving the data for *BRIDGE* in a usable form, and the lack of appropriate validated algorithms for the retrieval of the desired parameters.

5.3.2 Satellite Data Reception, Processing, and Storage

The main obstacle for researchers using satellite data is the huge amount of work necessary to transfer the raw data in quantities which one can relate to by models (e.g. radiances), to navigate the data, and to store the data. In practice many groups do this work by their own, even develop their own software and keep their own data archive. Another problem is the general availability of data. Thus for best use of satellite data during and prior to *BRIDGE* it would be the best to establish one satellite data centre for the collection, processing and archiving of all available satellite data at least in the form of calibrated and geo-located physical parameters.

Alternatively, a distributed satellite data function could be envisioned consisting primarily of a co-operation of the larger existing satellite processing centres within the participating meteorological and hydrological services (e.g. DWD and SMHI), because a large part of the satellite data of interest for *BRIDGE* feeds already into their data assimilation streams. To ensure the access to satellite data, which are not used by the services, links should be established to other European satellite data centres like the DFD (Deutsches Fernerkundungsdatenzentrum), ESA (European Space Agency), or EUMETSAT (European Organisation for the Exploitation of Meteorological Satellites) and the distributors of non-European satellite data like NASDA (National Space Development Agency of Japan), NASA (National Aeronautics and Space Agency), NOAA , the GUS and Russian space organisations, ISRO (Indian Space Research Agency).

It is proposed to initiate and organise for *BRIDGE* a co-operation between these data centres in order to enable easy and free access to the necessary data for the interested research groups within BALTEX. BALTEX research groups should be helped in the way that not each individual group or scientist shall negotiate with the satellite data holders. Instead a joint mechanism shall be created so that all approved BALTEX research groups can order the data they need in a suitable form and format by referring to a contract between a central BALTEX function (e.g. the BALTEX Secretariat), and each satellite data holder. This contract and related data exchange and processing agreements and procedures are referred to as the BALTEX satellite data function elsewhere in this plan.

In order to identify the necessary data and data products it is also important to identify as early as possible those research groups, who are pondering to contribute to BALTEX and *BRIDGE* by the use, development or validation of satellite data retrieval methods.

5.3.3 Satellite Data to be Used in Assimilation

Due to the relatively high latitude of the BALTEX-area polar-orbiting satellites provide the highest quality data and also an increased time resolution. Best known and used are the TOVS (Tiros Operational Vertical Sounder) retrieval products - temperature and humidity profiles - which are assimilated in several forecast models. At present, only temperature profiles are used. The humidity profiles are of very low quality and mostly not used. During *BRIDGE* the NOAA satellites will be equipped with the AMSU (Advanced Microwave Sounding Unit) microwave sounder, and it can be expected, that improved algorithms will be available during *BRIDGE*, and that the quality of the retrieved moisture profiles will be improved. Some forecast centres use their own cloud analysis scheme based on AVHRR (Advanced Very High Resolution Radiometer) data, but assimilation into the models is not yet common. Efforts are also made to use the AVHRR-derived vegetation index to model the time dependent vegetation parameters in SVAT models, and land surface evaporation estimates.

Of growing importance is the impact of data from the Special Sensor Microwave/Imager (SSM/I) on the DMSP satellites (Defense Meteorological Satellite Program). Over water surfaces total precipitable water (PW) is already used and methods to assimilate integrated cloud liquid water are under development at ECMWF. PW estimates from the network of the existing GPS (Global Positioning System) stations, which obtain their information from the path delay to the GPS satellites are also under consideration. Finally the sea surface temperature, which can be obtained from different sources in various resolutions in time and space, is used in assimilation schemes.

Operational products also exist from METEOSAT like cloud statistics, cloud winds and upper tropospheric humidity. However, all derived parameters are restricted to the area within 55 degrees great circle around the satellites foot point due to increasing errors caused by the large viewing angle. Only one of these, the cloud motion winds, are used so far in some fore-cast models. The SEVIRI (Spinning Enhanced Visible and Infrared Imager) instrument on the METEOSAT Second Generation (MSG) satellite will have twice the spatial resolution, twice the time resolution, and four times the number of channels (including practically the AVHRR channels) than the current METEOSAT-VISSR (Visible Infrared Spin Scan Radiometer) in-strument. Unfortunately, the satellite will be even under best conditions not operational before the end of 2000.

Soil properties, together with land use and vegetation, are crucial parameters to physically model the land surface-atmosphere interactions. Most of the necessary parameters are still only known for certain areas. It is important to improve the data basis for *BRIDGE*. A major problem with such data is the inhomogeneity and data void areas. A common data base for BAMAR (BALTEX model area) could be constructed with the help of high-resolution reflec-tance data from relevant

satellites, e.g. LANDSAT (Land Application Satellite, operated by NOAA or NASA), IRS (Indian Remote Sensing Satellite, operated by ISRO), or SPOT (Satellite Pour L'Observation de la Terre, operated by CNES, Centre National de l'Etudes Spatiale). Since surface charac-teristics determine the fluxes, these need to be known at a spatial resolution corresponding to their variability, which is generally much higher than 1 km.

Sea surface temperature for parts of the BALTEX modelling region is derived from AVHRR data operationally on a daily bases by DFD in approximately 1x1 km^2 resolution and by BSH in 2x2 km^2 resolution. SST is also operationally retrieved by some national weather services from NOAA-AVHRR measurements. The most precise SST measurements can be obtained from the along-track scanning instruments (e.g. ATSR, Along Track Scanning Radiometer) on ERS-1/2) operated in combination with altimeters, but these data are not operationally available.

The distribution of sea-ice, especially in the Baltic Sea, can change rapidly due to atmos-pheric forcing. Sea-ice cover is needed as fixed boundary condition by atmospheric models; some ocean models like the one at IFM (Institut für Meereskunde, Kiel) predict sea-ice. Thus sea-ice cover and sea-ice characteristics are needed for both assimilation and validation. Cur-rently

sea-ice concentration is derived by subjective combined analysis of satellite data and ship reports compiled into maps. Satellite-based high-resolution data of sea-ice cover (with a reso-lution about 1 km) can only be derived from visible observations and SAR measurements. The first have the highest coverage (at least once per day) but are restricted to day time and cloud-free scenes. SAR data have a much higher spatial resolution (20 m as opposed to roughly 1 km) but coverage is far less than once per day due to the small swath width of SAR instruments.

Cloud motion winds are produced from METEOSAT data by EUMETSAT operationally, but evaluation is restricted to regions south of about 60° N. Thus data will be available for a large part of the BALTEX modelling region (BAMAR), but only for part of the Baltic Sea catchment region (BACAR). The feasibility of a special *BRIDGE* product series should be investigated, covering the total model area at highest time (half-hourly) resolution. Similar modifications to the operational program have been made for other experiments (e.g. FASTEX).

5.3.4 Satellite Data to be Used for Validation

The earth radiation budget (ERB) at the top of the atmosphere (TOA) is a key parameter within the framework of BALTEX. The most rewarding purpose is validation of atmospheric models. Satellite estimates of ERB are currently not directly available because of the lack of instruments, but estimates are derived from the cloud and temperature and humidity profile information stored in the ISCCP (International Satellite Cloud Climatology Project) climate data sets. More direct measurements will be again available from the SCARAB (Scanner for Radiation Budget) radiometer on the Russian RESURS-0 (launch planned 1997) satellites.

Cloud parameters (cloud cover, cloud top-height, reflectivity) are operationally retrieved from METEOSAT data by EUMETSAT but currently only south of about 60 degrees North. Cloud analysis is operationally performed on the basis of NOAA-AVHRR with different algorithms by several meteorological services.

The assimilation of derived rain rate poses some problems due to the non-linear relation to other model parameters. Although large efforts are made to assimilate rain intensities the main use will be for validation. While satellite derived instantaneous precipitation over open ocean areas is of similar quality than radar-derived rainfall, there are problems over land areas. Satellite retrieval of rain is an ongoing task between international research groups. Different comparison projects like PIP (Precipitation Intercomparison Project) 1-3 and AIP (Algorithm Intercomparison Project) 1-3 have been conducted but no firm recommendation exists which satellite/sensor data and which algorithm should be used.

Snow cover of land surfaces in principle can be retrieved from several satellite sensors. Daylight observations in the visible spectral region are an obvious and easy to use source. This source is used operationally by several meteorological services being a by-product of cloud retrieval algorithms. Experimental algorithms exist to derive snow depth from DMSP-SSM/I measurements, but these algorithms need local calibration. There is also a great deal of experience among hydrologists in the use of this satellite information as field support data for hydrological models used for forecasting of river flow.

5.4 SUMMARY OF RECOMMENDATIONS

R5.1: In order to cover the Baltic Sea take steps to install two additional weather radar systems, whose suitable locations are e.g. near Gdansk, Poland and at the Latvian coast. Start also actions to merge the existing locally operating radars into the international digital data network.

R5.2: Establish a BALTEX Radar Data Centre (BRDC) prior to *BRIDGE*, responsible for collecting and distributing precipitation and wind measurements from individual radars and producing optimal composite products from them.

R5.3: Take actions to create and apply operationally, in near-real time, agreed-upon algorithms and procedures which remove or reduce the most severe errors from the national radar-based precipitation fields and integrate them optimally with gauge data.

R5.4: Take steps to agree on products, formats, programs and transmission routines to collect data at BRDC from all weather radars in the Baltic Sea catchment region during *BRIDGE*, free of charge.

R5.5: Identify a BALTEX GPS Data Centre, responsible for collecting, processing and distributing atmospheric parameters derived from GPS data. Take steps to enhance the existing GPS network

R5.6: The research groups pondering to contribute to BALTEX and *BRIDGE* with projects related to the application or development of satellite retrieval techniques should be identified and asked to specify their needs concerning satellite data reception, processing, and storage.

R5.7: Establish a BALTEX satellite data function, primarily based on links between the BALTEX satellite research groups and satellite data holders, e.g. the meteorological and hydrological services and other agencies.

R5.8: The BALTEX satellite data function should be responsible for collecting, pre-processing and distributing satellite data not being distributed over the GTS and should enable easy and free access to satellite data and products for all BALTEX groups.

R5.9: Upon the data requirements of *BRIDGE* further links to other satellite data centres should be established to extend the data source accordingly.

R5.10: Existing schemes to combine and homogenise land surface characteristic data sets with the help of satellite reflectance data should be evaluated for their use in the BALTEX area.

R5.11: The availability of processed SCARAB data for the derivation of at least the radiation budget at the top of the atmosphere should be assured.

R5.12: The cloud statistics product by EUMETSAT should be extended to include most of the BACAR.

6 FIELD EXPERIMENTS

A mutually beneficial form of relation between *BRIDGE* and field experiments is recommended. Thus an exchange of data between relevant experiments active during *BRIDGE* is an excellent way of co-operation. A clear need for BALTEX is to get as much as possible flux measurement data from smaller scale field experiments for model validation purposes. Such field measurement projects should be actually encouraged both in land and in sea areas. They should preferably cover long periods of time to produce useful information. A suitable service from the BALTEX-side would be the output from data assimilation runs in favour of the smaller scale studies.

Field experiments to be mentioned in this context include both specific BALTEX and BALTEX-related experiments. The former include BASIS, PEP and DIAMIX, which have either been started or are planned to be conducted within 1998 and/or 1999. Other important BALTEX-related field experiments include e.g. LITFASS, planned and conducted by DWD, and NOPEX/WINTEX, which is a component of IGBP-BAHC.

6.1 BASIS

Baltic Air-Sea-Ice Study (BASIS) aims at an improved understanding and modelling of energy and water cycles during winter conditions by conducting a winter field experiment in the ice edge zone of the Baltic Sea in February-March 1998. The study is carried out as a co-operation of five institutes from Finland, Sweden and Germany. BASIS will be the first field experiment in the Baltic Sea covering the various branches of physical oceanography, sea ice research, marine meteorology and remote sensing. We will collect data particularly of the

- exchange of heat, water and momentum between the air, ice and sea,
- structure of atmospheric and oceanic boundary layers and their interaction with the exchange processes,
- ice motion and the atmospheric and oceanic driving forces, and
- interaction between thermodynamic and dynamic processes in the air, sea and ice.

Research vessels, research aircraft and helicopters, meteorological balloon stations and a good set of automatic weather stations, turbulence equipments, and drifting buoys will be used. Analyses of the data sets will result in improved remote sensing algorithms and, in particular, better parameterisations of air-ice-ocean interaction processes for development, validation, and optimisation of the coupled atmosphere-ice-ocean models. The duration of the project as planned at present is 1997-2000.

6.2 PEP

PEP (Pilot study of Evaporation and Precipitation in BALTEX) is designed as a pilot experiment to *BRIDGE*, with the specific scope to study precipitation and evaporation over the sea. For determination of precipitation at sea *BRIDGE* needs to rely in particular on radar measurements. To test, improve and validate radar estimates of precipitation against in situ measurements, a pilot study prior to the *BRIDGE* is necessary. At the same time PEP will provide data sets for the improvment of numerical models over the sea. PEP is designed to sharpen our tools for *BRIDGE*.

The measurements in PEP will be concentrated along a transect from the northern coast of Germany to southwestern Finland. For an 18 month period PEP will provide a comprehensive set of actual evaporation data measured with the eddy correlation technique at 4 well-exposed sites (among them the small island Östergarnsholm east of Gotland) as well as precipitation, measured with micro rain-radars. This data set will be used within PEP for validation of routines for evaporation in several models. The precipitation data will also be used for calibration of weather radars.

6.3 DIAMIX

DIAMIX is a planned oceanographic field experiment to evaluate the dynamics of wind-forced DIApycnal MIXing in the stratified ocean. It will concentrate on measurements of vertical mixing and advection in the Gotland Basin. It is intended to estimate the distribution of kinetic and potential energy in an experimental box extending from the shoreline of the island Gotland to the maximum depth of the eastern Gotland Basin. DIAMIX is planned so far for the year 1998. It is foreseen to conduct a summer experiment with a seasonal, essentially thermal stratification in the surface layers, and a winter experiment when the water is homogeneous down to the halocline at about 60 m depth. Each of the experiments should last for about 2 weeks.

The measurements will comprise moorings with current meters and CT-sensors and continuous ADCP and CTD recordings. Four ships are expected to participate. Two of these will do continuous CTD and ADCP measurements along transects perpendicular to the coast. Vessel-mounted ADCP and a vertically undulating vehicle carrying the CTD are planned to be used. The distance between transects will be about 4 nautical miles, and each ship will cover four transects a day. The other ships will take CTD profies and profiles of turbulent dissipation from the sea surface to the sea bed in many verticals each day. The meteorological measurements during PEP (see section 6.2) at Östergarnsholm and elsewhere will provide high-quality meteorological data and independent estimates of the air-sea exchange of heat, water and momentum.

The DIAMIX data sets will be useful for testing ocean circulation models with respect to e.g. meso-scale dynamics. There are several suitable models available, particularly the 3-dimensional circulation model at IfM Kiel (Lehmann, 1995) or models at other research institutions (e.g. FIMR, SMHI, or IOW) presently participating in BALTEX.

6.4 LITFASS

The scientific objective of LITFASS (Lindenberg Inhomogeneous Terrain - Fluxes between Atmosphere and Surface - a Long-term Study) is to determine and to model and parameterise the fluxes of momentum, heat, water and other substances, representative for the horizontal scale of the order of 10 km over heterogeneous land surfaces (Müller et al., 1995). Sub-grid scale heterogeneity in the characteristics of the land surface, in the forcing conditions as well as in the resulting fluxes will be taken into account. The LITFASS project is divided into three different sub-projects:

- development of a non-hydrostatic model with a grid-size of 100 m,
- experimental investigations within a 20 km x 20 km area around the Lindenberg Observatory,
- data management.

LITFASS is planned and conducted by DWD. The planning foresees LITFASS to be executed in stages from 1995 up to the year 2000. The investigation area for LITFASS is located around the Lindenberg Observatory of DWD southeast of Berlin. This region exhibits a moraine landscape with heights above sea level between 40 m and 120 m, which is typical for large areas in the southeast part of the Baltic Sea catchment region. The LITFASS area is fixed around the central point of one grid-box of the Deutschland-Modell (DM), which is the high-resolution (15 km x 15 km) operational forecast model of DWD.

Within this area an extensive measuring program will be conducted (Foken et al., 1997). The monitoring network includes all parameters to validate micro-α-scale, non-hydrostatic atmospheric models. Accordingly, a high resolution of precipitation measurements, particularly with a sample time up to 1 minute, as well as global radiation measurements for an indication of clouds will be realised. Measurements of ground water and runoff offer the possibility to study the coupling of hydrological and atmospheric models. Additional parameters like soil moisture, leaf-area-index and stomatal resistance will be measured at selected places.

The establishment of the LITFASS-Energy-Balance-Stations will be of high priority. Five of these stations will be installed over agricultural fields, in a forest and on a lake. All relevant parameters will be measured or observed at these stations so that the turbulent fluxes can be calculated with SVAT and boundary-layer models. For validation purposes extensive measuring periods with eddy-correlation techniques will be conducted.

The LITFASS-Local-Model (LLM) is an essential component of LITFASS. It serves in strong conjunction with the measurements to determine explicitly the fluxes of momentum, enthalpy, water, and other substances over the LITFASS area. The LLM is a very high resolution (96.5 m in the horizontal), non-hydrostatic model developed by DWD (Steppeler et al. 1997). The physics package of the LLM is almost entirely taken from the DM but will be changed successively and adapted to the specific tasks in LITFASS.

Research institutes in Germany and other countries are presently planning contributions to LITFASS. A field measuring campaign for BALTEX is planned for the summer of 1998, using facilities of LITFASS.

6.5 NOPEX/WINTEX

A clear need for BALTEX is to get complete measurements of flux and state variables of the water and energy balances from smaller scale field experiments for validation of process formulations in models. NOPEX is devoted to studying land-surface-atmosphere interaction in a northern European forest-dominated landscape (Halldin et al., 1995). The NOPEX main study region was selected to represent the southern part of the boreal zone. Central Sweden is situated in the middle of the densest part of the northern European boreal forest zone. The main NOPEX region is centrally situated in the Baltic Sea catchment region around Uppsala, Sweden. WINTEX is a part of NOPEX intended to study the wintertime boreal landscape. A northern NOPEX region has been established around Sodankylä in northern Finland. The two regions for surface experiments are representative for the northern parts of the study region for the BALTEX project and can provide data for model validation. Parts of the planned field experiments for NOPEX will be finalised before the launching of *BRIDGE*, but field campains are planned until the year 2001.

NOPEX is specifically aiming at investigating fluxes of energy, momentum, water, and CO_2 between the soil, the vegetation and the atmosphere, between lakes and the atmosphere as well as within the soil and the atmosphere on local to regional scales ranging from centimetres to tens of kilometres. This is done by:

- Providing improved parameterisation schemes of exchange of water, energy and carbon between the land surface and the atmosphere in hydrological and meteorological models from the meso-scale to larger scales.
- Studying the use of satellite and airborne remotely-sensed data for evaluation of surface fluxes and states by supplying hard data on the ground truth.
- Quantifying the size of terms in the surface energy balance as well as in the water and carbon balances from different types of land cover, during both daily and annual cycles.
- Explore methods for aggregation and disaggregation of parameters between three spatial scales; patch scale, intermediate scale and regional scale. Patches may be topographical elements, land-use classes, infiltration areas, exfiltration areas etc.
- Fostering a new community of land-surface experimentalists capable of carrying out experiments in places with bad infrastructure and harsh climate.

7 DATA MANAGEMENT AND EXCHANGE POLICY

7.1 BALTEX DATA CENTRES

A practice to collect operational meteorological data (i.e. near-real-time GTS data and non-real-time data such as precipitation and radiation data) has already been created in the context of BALTEX, the DWD having the role of the BALTEX Meteorological Data Centre (BMDC). The BALTEX Hydrological Data Centre (BHDC) has been implemented at SMHI and has recently defined its data sampling strategy. The establishment of the BALTEX hydrological data base is in progress. The Finnish Institute for Marine Research (FIMR) serves as a centre for metadata (BODC) collecting information about existing oceanographic data sources. It is planned to establish a sea level data base from all existing coastal stations at the Baltic Sea (BALTEX 1997).

A clear drawback with the hydrological data is the great delay in receipt of the data into the BHDC. The delay may be even a couple of years, and every effort shall be made to remedy this. In the case of oceanographic data the existence of several data sources in numerous research institutions makes the systematic use of these data laborious. A minimum requirement is to get a comprehensive summary of all existing oceanographic data that is likely to be available during *BRIDGE* as well as the conditions under which these data would be available for research in other institutions.

BALTEX needs a central radar data centre where all relevant data will be stored. Reflectivity, precipitation and Doppler wind products should be stored for a time period covering the intensive observational periods of *BRIDGE*. A BALTEX Radar Data Centre is a desired feature. According to the preliminary plans, SMHI would be the data centre for Doppler wind soundings, gridded dBZ values and 3-hourly accumulated precipitation estimates.

The Data Centres must select optimum ways to store the data in data bases. An easily accessible description of the data base systems used (e.g. via the Internet) is required together with summaries of the data they contain. BMDC has recently started to monitor the establishment of the BALTEX meteorological data base (BMDC, 1997).

Besides the observational data bases in the designated Data Centres, mentioned above, there will be data bases containing analysed and assimilated data as gridded fields. The BMDC should take care of the archiving and distribution of field data. The BALTEX research community needs to know how these data are accessed, which formats are used and what possible conversion programs are needed. Also the transfer mechanisms must be agreed on, e.g. FTP, internet, diskettes or tapes.

The mentioned BALTEX Data Centres are supposed to continue their roles during and after *BRIDGE* and be in place to service all BALTEX-approved research activities. The Data Centres should be able to handle all additional data that is created during *BRIDGE*. This necessitates the maintenance of effective data retrieval and access mechanisms in favour of the data users.

The Data Centres should also have methods to monitor the collection of the agreed upon data in order to initiate requests of missing data as soon as possible.

7.2 QUALITY CONTROL OF OBSERVATIONAL DATA

Observations to be inserted into the delayed-mode BALTEX data assimilation process have to be quality-controlled in the same way as the operational data in the context of normal NWP routines. The use of the DWD and HIRLAM NWP systems is assumed. Real-time or near-real-time data which are not used in the data assimilation process (e.g. precipitation measurements at SYNOP stations) need to be quality-controlled by the BMDC. It is expected that other delayed data are quality-controlled by the data suppliers before submission. This will be reviewed by the responsible Baltex Data Center before distributing the data.

A basic requirement is that data distributed by BALTEX Data Centres must be quality-controlled, either by the data suppliers or through operational or additional procedures at the Data Centres. Information on the type and degree of control must be distributed together with the data.

7.3 DATA EXCHANGE POLICY

General guidelines for the data exchange policy within BALTEX were outlined in the BALTEX Initial Implementation Plan (BALTEX 1995, page 64). Based on these guidelines a central requirement for the data exchange policy related to *BRIDGE* is that all data obtained during *BRIDGE*, through either operational networks or field experiments and process studies, should be available as freely as possible for non-commercial research purposes within the BALTEX scientific community. This requirement also includes results from numerical experiments as well as the codes and algorithms developed during *BRIDGE*.

In order to facilitate the data exchange between the different data suppliers on the one side and data users on the other side specific BALTEX Data Centres have been implemented (see section 7.1). For *BRIDGE* additional Data Centres and data centre functions are suggested (see sections 2 and 5).

In practice, most of the data and information which are transmitted by the data suppliers, in particular those from national operational networks, and stored at the BALTEX Data Centres are subject to property rights or other legalities and, hence, to certain access restrictions. An entirely unlimited data exchange is therefore difficult to achieve. Rules and procedures for the exchange of BALTEX data between BALTEX Data Centres (in particular BMDC and BHDC) and data users have been determined through *formal agreements* between data suppliers and the BALTEX Data Centres. These rules have to be confirmed and accepted by data users, who wish to have access to BALTEX data. This confirmation is through a BALTEX *Data License Agreement* to be signed by both the data user and the BALTEX Data Centre before BALTEX data will be made available by the Data Centre. Examples of the *formal agreement* and the *data license agreement* used by BMDC may be found in BALTEX (1997, Appendix 12).

An important condition of both the *formal agreement* and the *data license agreement* is that BALTEX data will be passed only to *registered* BALTEX Data Users. Identification of authorised BALTEX Data Users will be done by members of the BALTEX SSG. A list of authorised BALTEX Data Users will be registered at the BALTEX Secretariat which provides copies of the list to the BALTEX Data Centres. Registration as a BALTEX Data User is performed upon request of the user and is subject to an approved procedure (BALTEX 1997, Appendix 13).

It is anticipated that this procedure will be taken over for other BALTEX Data Centres or data centre functions to be implemented for *BRIDGE*, if the respective data and information to be exchanged obey similar access restrictions.

It is however stressed that an entirely free data exchange without the mentioned regulations - e.g. directly between data suppliers and data users via FTP or other means - is strongly preferred in all cases where access to data is unlimited in terms of legal rights and financial requirements.

There is no agreed procedure for scientific radar data exchange between the BALTEX countries except the NORDRAD co-operation between Finland, Norway and Sweden. For scientific purposes it is very important that such data exchange is not loaded with financial expectations.

Data from field experiments may obey specific project-internal exchange policy rules, which may differ from experiment to experiment. For example, NOPEX data are not freely available immediately after the experiment to all users (Halldin and Lundin 1994). Presently, the data is available exclusively to NOPEX subprojects, having been accepted by the NOPEX Executive Committee, during an 18-months period after the end of the campaign. Acceptance as NOPEX
subprojects can be obtained by BALTEX science teams with interests in common with NOPEX. Similar regulations hold true also for e.g. BASIS. After the necessary quality check and archiving, the experimental data of BASIS will be disposed for BALTEX Data Centres. Before the final archiving at the data centre the data are flagged for limited access for a specific period after the field experiment. Data from PEP will be free shortly after the field experiment after the usual evaluation.

7.4 SUMMARY OF RECOMMENDATIONS

R7.1: During *BRIDGE*, BALTEX Data Centres for meteorological, hydrological, oceanographic, GPS and radar data should be implemented. BALTEX satellite and physiography data centre functions are recommended.

R7.2: An agreement with these designated and recommended Data Centres and data centre functions should be reached in order to define the data services available.

R7.3: Data and information exchange between data suppliers and registered BALTEX data users should be without any restrictions.

R7.4: In cases where access to data is limited in terms of legal rights and financial requirements the existing procedures and agreements already in operation with BMDC and BHDC should be taken over.

8 FINANCIAL SOLUTIONS

The scientific working groups formed under the umbrella of BALTEX have been relatively successful in receiving research funds from the EU research programs. This has been beneficial even for some new experimental observational systems such as the GPS humidities. However, t is not evident that external funds would be generally available for enhanced operational observational activities. Therefore, the participating meteorological and hydrological institutes are expected to play a key role in financing the additional and enhanced observational programs. The most expensive subprograms are clearly the increase of radio sounding activities and extension of radar data coverage over the Baltic Sea.

A cost-effective solution for the radiosonde option is to hire automated launching equipment from manufactures. The training and consumables are another cost item.

Regarding the extension of the Baltic radar network, the BALTEX Radar Working Group strongly indicates the need to have two new Doppler radar sites. The suggested sites are in Poland and Latvia. Possible funding mechanisms are that the countries involved are able to make the investment and/or other countries participate in the purchase. In the latter case the possibilities of foreign aid programs should be studied. It should also be noted that the purchase of two radar installations would mean a marked positive impact on national industries of the manufacturing countries giving a special justification for funding from these countries. Several countries have plans to enhance their national radar networks. In this context it would be also sensible to consider the priorities of new radar installations as in some cases an investment outside the own territory might prove to be an equal opportunity.

An operative use of radars would yield benefits for the weather service of neighbouring countries if the radar data would be available in a real-time mode. This could give possibilities to distribute the running costs arising from the maintenance of the radar installations.

The access to some non-real-time data in participating countries have proved to be an issue. External funding for the data collection has not been received. A solution to this may require additional measures to be taken, although the expectation is that all data should be available for BALTEX free of charge on a multi-lateral exchange basis.

The BALTEX related data processing and data storage functions require additional activities, and thus costs, which unavoidably mean an extra load to the responsible centres.

8.1 RECOMMENDATION

R8.1: The possibilities of the national meteorological and hydrological institutes to finance *BRIDGE* should be explored with urgency noting the long lead times required by financial planning. The costs should be seen as an investment for a higher quality service to be given by the institutes in the benefit of their customers.

9 ADMINISTRATIVE SOLUTIONS

The realisation of the plan for *BRIDGE* requires that all participating meteorological and hydrological institutes (from Belarus, Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden) commit themselves to fulfil all the requirements placed on them. The requirements include observational programs, data storage functions and data processing aids. Further, research institutions and university departments (list of probable participants to be defined) are important players as many of them have capabilities and plans for field measurement campaigns and observational data production.

An ideal solution would be to list the responsibilities that each participant accepts to take. This would include observational programs to be offered (with detailed content giving parameters to be provided, station lists, quality and quantity of data, way of submission, formats, timetables etc.) and services to be provided (data storage, processing capacity, data transfer mechanisms). The commitment would include the responsibility for the costs implied.

Through the agreements the access to all BALTEX data for all recognised BALTEX data users would be given. A focal point in each participating organisation would be needed.

In order to make *BRIDGE* more known and interesting for research institutions around the Baltic Sea it would be advisable to produce a short pamphlet about the undertaking. It should highlight the great scientific potential that the joining into the project would give to participating organisations.

9.1 RECOMMENDATION

R9.1: A model agreement between the participating institutions and the BALTEX project should be drafted to include all actions which the institutions wish to commit themselves.

10 RELATION TO OTHER GEWEX CONTINENTAL-SCALE EXPERIMENTS

BALTEX is one of five Continental-Scale Experiments (CSEs) which have been established as part of the hydrometeorology project-section in GEWEX (the Global Energy and Water Cycle Experiment) and is as such a part of the WMO World Climate Research Program.

The Canadian Mackenzie GEWEX Study (MAGS) is planned as a series of large-scale hydrological and related atmospheric and land-atmosphere studies to be conducted during 1992-1998 in the Mackenzie River basin.

The overall goal of the GEWEX Continental-Scale International Project (GCIP) is to improve climate models by bridging the gap between small scales appropriate for modelling discrete processes over land and large scales practical for modelling the global climate system. The GCIP study basin is the Mississippi River basin.

The Large-scale Biosphere Atmosphere Experiment in Amazonia (LBA) is a comprehensive international research initiative designed to improve the understanding of the climatological, ecological, biogeochemical and hydrological functioning of the Amazon River basin in Brazil.

The aims of the GEWEX Asian Monsoon Experiment (GAME) are to understand the role of the Asian monsoon as a major component of the global energy and water cycle and to improve the seasonal forecasting of monsoon and regional water resources, along with the feedback processes associated with the variability of the monsoon.

The major GEWEX objectives are common for all CSEs. The recently formed GEWEX Hydrometeorological Panel (GHP) is co-ordinating plans and focus on the scientific issues related to the development and implementation of the CSEs. Main Experiments are being undertaken as part of the other CSEs, such as CAGES as part of MAGS, or the Enhanced Observational Period (EOP) of GCIP. Synchronous Main Experiments (like *BRIDGE* and CAGES) in all (or at least some) of the CSEs may be an option to provide data sets from different test beds on the globe useful for e.g. providing ground-truth for satellite applications. Based on the present time planning of *BRIDGE* and Main Experiments in the other GEWEX CSEs it appears that *BRIDGE* will be conducted later than most of the other studies. There is only little time overlap with in particular the planned MAGS and GCIP activities, while co-ordination with LBA and GAME seems to be possible in principle.

It is expected that probably the greatest benefit comes from learning from the other more advanced CSEs how to e.g. organise data bases, handle satellite and other large data sets, make agreements between participants, and how to monitor the Main Experiment.

10.1 RECOMMENDATION

R10.1: It is recommended that BALTEX representatives present the *BRIDGE* plan at the forthcoming meeting of the GEWEX Hydrological Panel in September 1997 and also at the next GEWEX SSG meeting in early 1998, in order to investigate possibilities and requirements for closer co-operation and co-ordination with the other Continental-Scale Experiments as well as other GEWEX programs.

11 LIST OF RECOMMENDATIONS

Chapter 2

R2.1: Encourage two groups, e.g. the HIRLAM community and DWD, to run two independent, delayed-mode data assimilation systems for *BRIDGE*.

R2.2: Take steps to obtain 6-hourly RS soundings from the 16 stations immediately bordering the Baltic Sea (see Appendix 1 for a list of stations).

R2.3: Take steps to operate additional RS stations on Gotland, Åland and Bornholm, respectively.

R2.4: Take steps to complete the operational GTS dissemination of the full SYNOP surface data telegrams in 3-hourly intervals from all existing stations in both the Baltic Sea catchment region and the BALTEX modelling area.

R2.5: Take steps to maintain the operational precipitation gauge station network in the Baltic Sea catchment region and the data availability, as was achieved during PIDCAP.

R2.6: Additional ship rain gauges should be installed on ferry boats and masts in different parts of the Baltic Sea.

R2.7: Marine meteorological observations from vessels, automatic lighthouse stations and buoys, on islands, and at other marine stations should be intensified for calculating fluxes and verification of models.

R2.8: In order to have a validation for fluxes calculated from assimilated fields, take steps to maintain the measurements at the sites of field campaigns like Östergarnsholm, Lindenberg, NOPEX, BASIS and others.

R2.9: Establish a physiography data centre function for collection and merging of a high resolution orography, land use, vegetation type and soil texture data base.

R2.10: The existing data on physiography covering the *BRIDGE* study area should be acquired from the HIRLAM project and made available through the BMDC.

R2.11: Groups that will carry out the delayed mode data assimilation should make quality control information, produced by the data assimilation (quality flags), available to the users of the assimilation data.

Chapter 3

R3.1: An intercomparison and validation of hydrological models should be carried out for, at least, a 10 year period of data in the special hydrological test basins (Odra, Daugava, Neva, Torneälv).

R3.2: Intercomparison and validation of the representation of individual processes of the surface energy and water balance and soil water dynamics of atmospheric and hydrological models should be carried out.

R3.3: Macro-scale hydrological models should be developed for the entire catchment region of the Baltic Sea as a tool for estimating the overall water balance, as a validation tool for climate models and to provide oceanographers with near-real-time runoff data during *BRIDGE*.

R3.4: The BALTEX strategy for climate data should be supplemented so that the data better meets the requirements of the hydrological modellers.

R3.5: The BMDC should aim at a complete climate data set for the entire BALTEX modelling region for the period of *BRIDGE*.

R3.6: Efforts should be spent on the collection of supplementary hydrological information, in particular on snow, soil moisture, soil temperature and ice conditions.

R3.7: The BMDC and the BHDC should spend some effort on the control of the quality and consistency of the respective data bases.

R3.8: A new hydrological model generation should be developed for the specific characteristics of the landscape in the Baltic Sea catchment region, with emphasis on the effects on water and energy fluxes of sub-grid or sub-basin variabilities of processes.

Chapter 4

R4.1: Infrared as well as visible and SAR satellite images are needed for model verification and assimilation.

R4.2: Daily runoff data, at least from the largest rivers, should be made available for numerical modelling purposes.

R4.3: Continuous profiling measurements of temperature, salinity and currents at Darss and Drodgen Sills as well as in the Great Belt are necessary to determine the water balance through the Danish Straits.

R4.4: The BALTEX Oceanographic Data Centre (BODC) should gather all available sea level data from the coastal stations of the Baltic Sea.

R4.5: Oceanographic models, with the use of data assimilation methods, need to be developed and applied for the calculation of the net outflow through the Danish Straits.

R4.6: Recordings of temperature, salinity and current profiles in the deep basins and at the important channels (e.g. Stolpe Channel) together with supplementary high resolution hydrographic measurements should be accomplished.

R4.7: Appeal to all Baltic Sea countries to intensify their measurements of temperature, salinity and sea levels during the *BRIDGE* period.

R4.8: Install some meteorological/oceanographic buoys in the central part of the Baltic Proper and its sub-basins that should be recording during the *BRIDGE* period.

R4.9: DIAMIX (see section 6.3) should be regarded as a pilot project for an intensive study of vertical mixing and advection in the Baltic Sea. Similar measurements should be carried out in other deep basins of the Baltic Sea.

R4.10: Understanding the role of sea ice on the circulation of the Baltic Sea and the water mass exchange with the North Sea will benefit from the BALTEX projects BASIS and BASYS/SP6 and also from the ZIP-97 (Ice State project/MAST II).

R4.11: Measurements of the attenuation of solar radiation in the open sea should be accomplished.

R4.12: Vertical turbulent mixing parameterisation in the numerical models should be improved.

R4.13: Data assimilation should be incorporated into general ocean circulation models.

R4.14: Atmospheric forcing data should be made available together with daily SST and ice charts.

R4.15: A model intercomparison of the different Baltic Sea models should be performed.

R4.16: Ice models should be tested against different advection schemes. The description of the viscous-plastic behaviour should be tested with respect to high horizontal resolution. The description of snow has to be taken into account.

Chapter 5

R5.1: In order to cover the Baltic Sea take steps to install two additional weather radar systems, whose suitable locations are e.g. near Gdansk, Poland and at the Latvian coast. Start also actions to merge the existing locally operating radars into the international digital data network.

R5.2: Establish a BALTEX Radar Data Centre (BRDC) prior to *BRIDGE*, responsible for collecting and distributing precipitation and wind measurements from individual radars and producing optimal composite products from them.

R5.3: Take actions to create and apply operationally, in near-real time, agreed-upon algorithms and procedures which remove or reduce the most severe errors from the national radar-based precipitation fields and integrate them optimally with gauge data.

R5.4: Take steps to agree on products, formats, programs and transmission routines to collect data at BRDC from all weather radars in the Baltic Sea catchment region during *BRIDGE*, free of charge.

R5.5: Identify a BALTEX GPS Data Centre, responsible for collecting, processing and distributing atmospheric parameters derived from GPS data. Take steps to enhance the existing GPS network.

R5.6: The research groups pondering to contribute to BALTEX and *BRIDGE* with projects related to the application or development of satellite retrieval techniques should be identified and asked to specify their needs concerning satellite data reception, processing, and storage.

R5.7: Establish a BALTEX satellite data function, primarily based on links between the BALTEX satellite research groups and satellite data holders, e.g. the meteorological and hydrological services and other agencies.

R5.8: The BALTEX satellite data function should be responsible for collecting, pre-processing and distributing satellite data not being distributed over the GTS and should enable easy and free access to satellite data and products for all BALTEX groups.

R5.9: Upon the data requirements of *BRIDGE* further links to other satellite data centres should be established to extend the data source accordingly.

R5.10: Existing schemes to combine and homogenise land surface characteristic data sets with the help of satellite reflectance data should be evaluated for their use in the BALTEX area.

R5.11: The availability of processed SCARAB data for the derivation of at least the radiation budget at the top of the atmosphere should be assured.

R5.12: The cloud statistics product by EUMETSAT should be extended to include most of the BACAR.

Chapter 7

R7.1: During *BRIDGE*, BALTEX Data Centres for meteorological, hydrological, oceanographic, GPS and radar data should be implemented. BALTEX satellite and physiography data centre functions are recommended.

R7.2: An agreement with these designated and recommended Data Centres and data centre functions should be reached in order to define the data services available.

R7.3: Data and information exchange between data suppliers and registered BALTEX data users should be without any restrictions.

R7.4: In cases where access to data is limited in terms of legal rights and financial requirements the existing procedures and agreements already in operation with BMDC and BHDC should be taken over.

Chapter 8

R8.1: The possibilities of the national meteorological and hydrological institutes to finance *BRIDGE* should be explored with urgency noting the long lead times required by financial planning. The costs should be seen as an investment for a higher quality service to be given by the institutes in the benefit of their customers.

Chapter 9

R9.1: A model agreement between the participating institutions and the BALTEX project should be drafted to include all actions which the institutions wish to commit themselves.

Chapter 10

R10.1: It is recommended that BALTEX representatives present the *BRIDGE* plan at the forthcoming meeting of the GEWEX Hydrological Panel in September 1997 and also at the next GEWEX SSG meeting in early 1998, in order to investigate possibilities and requirements for closer co-operation and co-ordination with the other Continental-Scale Experiments as well as other GEWEX programs.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADCP	Acoustic Doppler Current Profiler
ADEOS	Advanced Earth Observing Satellite
AIP	Algorithm Intercomparison Project
AMSU	Advanced Microwave Sounding Unit
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
BACAR	Baltic Sea Catchment Area
BAHC	Biospheric Aspects of the Hydrological Cycle, IGBP subprogram
BALINEX	BALTEX Land Surface Experiment at Lindenberg
BALTEX	Baltic Sea Experiment
BALTRAD	BALTEX Radar Network
BAMAR	BALTEX Model Area
BASIS	Baltic Air-Sea-Ice Study
BASYS	Baltic Sea and Sea-Ice Modelling
BEERS	Baltic Experiment for ERS-1
BHDC	BALTEX Hydrological Data Centre
BMDC	BALTEX Meteorological Data Centre
BODC	BALTEX Oceanographic Data Centre
BRDC	BALTEX Radar Data Centre
BRIDGE	The Main BALTEX Experiment, planned for 1999-2001
BSH	Bundesamt für Seeschiffahrt und Hydrologie, Hamburg
BSRN	Baseline Surface Radiation Network
CAGES	Canadian GEWEX Enhanced Study
CNES	Centre National de l'Etudes Spatiale
COADS	Comprehensive Ocean Atmosphere Data Set
CPU	Central Processing Unit
CSE	Continental Scale Experiment
CT	Conductivity - Temperature
CTD	Conductivity - Temperature - Depth
dBZ	Measure of reflectivity factor (Z) in logarithmic units
DFD	Deutsches Fernerkundungsdatenzentrum, Oberpfaffenhofen / Germany
DIAMIX	Diapycnal Mixing in the stratified ocean; Field experiment in BALTEX
DM	Deutschlandmodell, operational NWP model of DWD
DMSP	Defense Meteorological Satellite Program
DWD	Deutscher Wetterdienst, Offenbach / Germany
ECMWF	European Center for Medium Range Weather Forecast, Reading / UK
ECU	European Currency Unit
EDP	Enhanced Dissipation Profiler
ENVISAT	First Environmental Satellite
EOP	Enhanced Observational Period
EOS	Earth Observing Satellite
ERB	Earth Radiation Budget
ERBE	Earth Radiation Budget Experiment
ERS	European Remote Sensing Satellite (ESA Program)

ESA	European Space Agency, Darmstadt / Germany
EU	European Union
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FASTEX	Fronts and Atlantic Storm Track Experiment
FIMR	Finnish Institute of Marine Research, Helsinki / Finland
FMI	Finnish Meteorological Institute, Helsinki / Finland
FTP	File Transfer Program
GAME	GEWEX Asian Monsoon Experiment
GCIP	GEWEX Continental-scale International Project
GEWEX	Global Energy and Water Cycle Experiment
GHP	GEWEX Hydrometeorological Experiments Panel
GKSS	GKSS Research Centre, Geesthacht / Germany
GMT	Greenwich Mean Time
GPS	Global Positioning System
GTS	Global Telecommunication System
GUS	Gemeinschaft Unabhängiger Staaten,
HIRLAM	High Resolution Limited Area Model
IGBP	International Geosphere Biosphere Program
IOW	Institut für Ostseeforschung, Rostock-Warnemünde / Germany
IRS	Indian Remote Sensing Satellite
ISCCP	International Satellite Cloud Climatology Project
ISRO	Indian Space Research Organisation
IWV	Vertically Integrated Water Vapour
LANDSAT	Land (Remote Sensing) Satellite
LBA	LAMBADA-BATTERISTA Experiment for Amazonia
LITFASS	Lindenberg Inhomogeneous Terrain Fluxes between Atmosphere and Surface - a DWD long-term Study 1995 - 2000
LLM	LITFASS Local Model
MAGS	Mackenzie River GEWEX Study
MAST	Marine Action in Science and Technology
METEOSAT	European Meteorological Satellite Series of EUMETSAT
MSG	METEOSAT Second Generation
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NOAA	National Oceanic and Atmospheric Administration
NOPEX	Nordic Pilot Experiment
NORDRAD	Nordic Weather Radar Network
NWP	Numerical Weather Predciction
OBL	Ocean Boundary Layer
PEP	Pilot Study of Evaporation and Precipitation in BALTEX
PIDCAP	Pilot Study for Intensive Data Collection and Analysis of Precipitation
PILPS	Project for Intercomparison of Land Surface Parameterization Schemes
PIP	Precipitation Intercomparison Project
PW	Precipitable Water
RS	Radiosonde
SAR	Synthetic Aperture Radar
SCARAB	Scanner for Radiation Budget
SEVIRI	Spinning Enhanced Visible and Infrared Imager

SMHI	Swedish Meteorological and Hydrological Institute, Norrköping/Sweden
SPOT	Satellite Pour L'Observation de la Terre
SRB	Surface Radiation Project
SSG	Science Steering Group
SSM/I	Special Sensor Microwave/Imager
SSM/T	Special Sensor Microwave/Temperature
SST	Sea Surface Temperature
SVAT	Soil-Vegetation-Atmosphere-Transfer
SYNOP	Synoptical Surface Observation
TEMP	Upper-level Temperature, Humidity and Wind Report from a Radiosonde Station
TKE	Turbulent Kinetic Energy
TOA	Top of the Atmosphere
TOVS	TIROS Operational Vertical Sounder
UTC	Co-ordinated Universal Time
VISSR	Visible and Infrared Spin-Scan Radiometer
VOS	Voluntary Observing Ships
WCRP	World Climate Research Program
WINTEX	Winter Experiment in NOPEX
WMO	World Meteorological Organization
ZIP	Zooming Ice Physics

APPENDIX 1

Table 1: List of 16 RS stations immediately bordering the Baltic Sea, which are currently performing radio sounding ascents. The last four columns indicate the number of ascents per day (at 00, 06, 12 and 18 GMT) based on DWD monitoring statistics for May 1997. During *BRIDGE* 4 RS ascents per day at 00, 06, 12, and 18 GMT from all 16 stations are required.

WMO Id : WMO station identification number,
Latit. : Latitude North, in 1/100 degree,
Longit. : Longitude East, in 1/100 degree,
NN : Station height above sea level (m).

Station Name	WMO Id	Latit.	Longit.	NN	00	06	12	18
LULEA/KALLAX	02185	6555	2213	34	x	x	x	x
SUNDVALL-HARNLSAND FLYGPLATS	02365	6253	1745	6	x	x	x	x
GOTEBORG/LANDVETTER	02527	5767	1230	155	x	x	x	x
SODANKYLA	02836	6737	2665	179	x		x	
JYVASKYLA	02935	6240	2568	145		x		x
JOKIOINEN	02963	6082	2350	103	x		x	
KOEBENHAVN/ JAEGERSBORG	06181	5577	1253	42	x		x	
SCHLESWIG	10035	5453	0955	48	x		x	
GREIFSWALD	10184	5410	1340	6	x		x	
MESSZUG WITTSTOCK	10272	5320	1252	74	x	x	x	
LINDENBERG	10393	5222	1412	98	x	x	x	x
LEBA	12120	5475	1753	2	x		x	
TALLINN	26038	5938	2458	34	x		x	
ST.PETERBURG	26063	5995	3070	78	x		x	
RIGA	26422	5697	2405	7	x			
KAUNAS	26629	5488	2383	77	x			

APPENDIX 2

Terms of Reference of the *BRIDGE* Planning Group

- to prepare an overall plan for the Main BALTEX Experiment in BALTEX,
- to identify deficiencies in the present observing system in the BALTEX modelling region and propose improvements,
- to identify deficiencies in the present data assimilation and modelling systems and propose improvements,
- to suggest appropriate actions towards finding realistic technical, administrative and financial solutions,
- to undertake necessary coordination and consultation with the other GEWEX Continental Scale Experiments and relevant WCRP activities,
- to propose a suitable way of combining specific BALTEX field experiments and the Main Baltic Sea Experiment, and thereby to seek close coordination with other projects, like NOPEX, LITFASS, and others,
- to finalise the report prior to the next BALTEX SSG, April 1997.

APPENDIX 3
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