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**Weather Research in Europe  
A THORPEX European Plan**

*(Submitted by George Craig and Evelyne Richard)*

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## **1. Aims and Structure of the THORPEX European Plan**

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### **a) Aims**

THORPEX: A Global Atmospheric Research Programme is an international research and development programme responding to the weather related challenges of the 21st century to accelerate improvements in the accuracy of 1-day to 2-week high impact weather forecasts for the benefit of society, the economy and the environment. The vision guiding this programme is of a Global Interactive Forecasting System (GIFS), where the elements of the weather forecasting chain are adapted continuously to the changing weather conditions and to the requirements of the users of the forecasts. This requires research into the societal and economic benefits of forecasts, and in particular how to create and exploit probabilistic information such as that produced by ensembles of forecasts, as well as new flexible observing technologies and methods for targeting and assimilating observations. Essential for this effort is a deeper understanding of global-to-regional influences on the evolution and predictability of weather systems.

The European plan builds upon the THORPEX Science Plan (ref), thus focuses on implementation – a prioritisation of the scientific aims relative to European requirements, and recommendations for actions to be initiated within Europe. The most important links to other organisations inside and outside THORPEX, and inside and outside Europe, will be documented. However, there will be no extensive discussion of European contributions to activities initiated by the global THORPEX working groups or other regional committees, as these are described elsewhere.

The plan reflects the special circumstances of meteorological research in Europe. Most important is the large number of nations, each with its own research funding structure, and its own national meteorological service. These are supplemented by trans-national organisations at the European level, including EUMETNET, EUMETSAT and ECMWF, as well as trans-national research and coordination agencies, such as the Framework Programmes, and COST.

The diversity of meteorological research in Europe influences the priorities seen in the plan, notably a significant emphasis on limited area modelling, including data assimilation, multi-model ensembles, and model development.

### **b) Structure**

The plan begins with a discussion of the needs and requirements for weather research in Europe, based on societal and economic applications. The next section identifies scientific challenges: the meteorological phenomena of greatest interest to European researchers, the particular problems associated with forecasting them, and their potential impacts. Action plans are then presented for the main THORPEX research areas: Predictability and Dynamical Processes (PDP), Observing Systems (OS), Data Assimilation and Observing Strategies (DAOS), and Societal and Economic Research and Applications (SERA). The structure of this section is slightly modified from the THORPEX Science Plan in that the OS and DAOS actions are discussed together, and a new section is introduced for the THORPEX Interactive Grand Global Ensemble (TIGGE), where issues associated with ensemble forecasting are discussed (use of ensemble for predictability studies is included in PDP).

## **2. Needs and Requirements for Weather Research**

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Although meteorology can be pursued purely out of a sense of scientific curiosity, for most of its modern history meteorologists have appealed to their science's applications and its perceived socio-economic benefits to justify the investment of money – particularly public money – in the enterprise. This fact is underlined by a cursory consideration of the government departments to which national meteorological services often report: Transport, Commerce and Defence.

While it is clear that weather forecasting provides substantial socio-economic benefits, more detailed information concerning the social and economic value of weather forecasts is not readily available. Even the broader question of which parts of the economy are most sensitive to weather has only recently been addressed in a systematic fashion. Such information is crucial for the efficient allocation of resources within meteorology, or indeed to justify to what extent society's resources should be allocated to meteorology in the first place. In other spheres, efficient allocation of resources is achieved through market mechanisms. However, because many weather forecasts are "public goods", provided for through taxes, market prices for forecasts provide only partial information about their value. Economists have developed methodologies to value non-market goods – such as contingent valuation surveys – and such tools have been employed in the context of weather forecasts. One such study estimated that U.S. households would be willing to pay a total US\$1.7 billion a year for weather forecasts (Lazo and Chestnut 2002).

The THORPEX programme is specifically concerned with the improvement of weather forecasts in the lead time of range of 1 to 14 days ahead. The needs and requirements for weather research in the context of THORPEX are thus the needs and requirements for improvements in weather forecasts for up to two weeks in the future. Intrinsic limits to the predictability of the atmosphere at these lead times mean that purely deterministic forecasts with reasonable skill are unlikely to be produced for most of the lead time range on which THORPEX concentrates – only ensemble-based and probabilistic forecasts can be realistically anticipated. The needs and requirements of THORPEX therefore hinge on the needs and requirements for improvements in medium range probability forecasting. These needs may be reduced if potential forecast users are unable to use such forecasts, either because they have nothing to gain by making decisions at medium range lead times, or because they are unable to integrate probability forecasts into their decision making.

### **Severe weather and the role of trained forecasters**

In the particular case of predicting severe weather, i.e. individual meteorological events that may cause the loss of lives and public and/or individual goods, the use of probabilistic forecasts proves problematic. When it comes to public safety, most decision makers are not comfortable with probabilistic forecasts and generally ask for the judgement of an expert, typically a trained meteorologist. This might be due to the fact that public decision makers are highly sensitive to false alarms, for strategic reasons, and at the same time express a strong need for a high detection rate, for obvious tactical reasons. From their experience both in weather forecasting and in assessing risks for particular users, forecasters are able to take into account specific needs, filter low probabilities for limiting false alarms, and highlight significant risks for improving detection. This results in an expert assessment that is not purely deterministic nor really probabilistic, but that is likely to better suit the requirements of decision makers than a full set of probabilistic forecasts. To be able to provide this type of forecast optimally the forecaster must be aware of the risks to which the decision maker is exposed, and also the constraints under which they are operating.

## **High Impact Weather – High Impact Forecasts**

Many discussions of the social and economic impact of weather tend to focus on extreme weather events, such as major storms, floods and heat waves. This is understandable as such weather extremes are highly visible to meteorologists and the public, as well as policy makers. It should be appreciated, however, that non-extreme “normal” weather can have significant social and economic consequences. The impacts are often cumulative, being the result of many frequent occurrences as opposed to relatively rare extreme events. The definition of adverse weather is also highly user dependent: calm weather may have significant economic consequences for a nation with substantial wind energy production capacity, for example.

As well as the distinction between “severe” weather and “high impact” weather, there is also an important distinction between the socio-economic impact of weather and how much of the impact can be mitigated. Headline figures for losses – both in lives and money – associated with weather events are not equivalent to the losses that might be avoided with an improved forecast. Conversely, such figures do not include those losses which *were* avoided with the information that was available. For these reasons they are not particularly useful for determining either the present value of forecasts or what their potential value might be in the future.

A small avoidable loss may mean that a high skill forecast of high impact weather may have little socio-economic benefit, whereas if the avoidable loss is considerable, then even a moderately skilful forecast could provide substantial benefits and be described as a “high impact forecast”. As with high impact weather, the impact of forecasts can accumulate over frequent but unremarkable events or it may be associated with a single significant event. For example, relatively small errors in temperature forecasts result in large cumulative losses for the European energy sector.

## **Verification**

In communicating forecasts to customers it is important that forecast verification is considered part of the communication process. Barbara Brown (reference) has presented work on performing user-oriented verification, where verification approaches are graded by the extent to which they are focused on the end user of the forecast. Tim Hewson (reference) has developed a verification measure that is designed to be readily comprehensible by the general public. This work underlines the need for National Met Services to make their verification results freely available, in a format that is user-oriented and readily comprehensible. These should be presented alongside the forecasts available to the general public so that users can readily understand the quality of the forecast they are currently using.

### 3. Scientific Challenges

The impact of weather on Europe comes through a widely varied list of “challenging” weather phenomena. The table lists the most important such phenomena, their frequency and the parameters potentially associated with societal and economic impacts.

High-Impact Weather Phenomena and Forecast	Specific scientific challenges	Frequency Time scales	Potential Societal and Economic Impacts
PV Streamers Rossby-wave breaking	Wave-mean flow interaction; conditions? (ambient, local transient, orography) Prediction of evolution of PV streamer ? (mesoscale, interactions with surface, structure)	1/week 2-4 days	(heavy) precipitation Foehn Dust/air quality convection
Extratropical cyclones (wind, precip)	Above+ lower-mid tropospheric cond. Role of moisture and sfc fluxes Errors by initial conditions dominate	1/week 2-4 days	Wind, precipitation Snow, ice
Mediterranean Cyclones	Role of Orography, strong sfc fluxes Mesoscale upper-level structures; Why are they smaller? What determines their track? Tropical characteristics (polar lows?)	1/week (winter) 1/month (summer) 1-3 days	Precipitation Wind
Downstream impact of ET of Tropical cyclones	Interaction with jet, importance of structure of TC; Sources of uncertainty? → Perturbations of the waveguide	Atl: ~5 /yr Pac: more 3 days to 2 weeks	Increased uncertainties in forecasts (wind precip)
Deep mid-lat convection	Timing and organization, relative influence of forcing factors; relative influence of synoptics and local factors Realism of mesoscale/high-res fcs Predictability and parametrizations/explicit conv. (benefit from COPS, D-PHASE)	Time scales >=1day	Lightning Hail Heavy precip wind
Polar weather (polar lows, LLJ, arctic fronts)	Understanding / Predictability convection/snow fall, surface fluxes, clouds, PBL. Role of upper-level interaction	Events Day 1 Potentials Day 5	Snow, ice, wind
Air quality	Prediction of passive tracer transport		Air quality, health
Blocking	Quantify predictability of and understand processes responsible for onset, maintenance and breakdown? precursors to blocking? Relation to low-freq (sub-seasonal to interannual) variability?	Freq: av. <10% 5-14days or longer	Heat waves, cold spells, droughts, air quality,
Organized tropical convection	Impact on midlatitude predictability over Europe, upscale effects	14 days	Potential increase in predictability

Floods	Predictability of Large-scale triggers, extended lead time QPF, surface conditions	2-5days	floods
Orographic flow systems (tip jets, foehn, bora etc)	Role of upper-level features, air-sea / air-surface interaction, upscale effects? Mountain waves,	Potentials 1-3 days	Wind, air safety

**PV streamers** develop as a consequence of Rossby wave breaking events. Challenges are associated with understanding and predicting under what conditions and when such an event occurs. Factors seen as important for the initiation include orographic influences, vortices in the polar stratosphere, diabatic processes, the ET of tropical cyclones. The structure of a streamer is related to the time mean flow, but a breaking Rossby wave feeds back onto the time mean flow thus modifying this itself. Not clear with real world data. We need to know Questions are associated with whether a streamer develops or not, how it evolves and whether this evolution is well forecast, and how important the mesoscale structure is for the initiation of high impact weather. For the latter question, what is the relative importance of the mesoscale structure of the streamer and local processes such as the soil moisture beneath it. Issues for forecasting: if a PV streamer exists, is it being assimilated properly? Are the physical processes that may modify a PV streamer represented properly? Is the wave-mean flow interaction represented accurately?

**Extratropical cyclones** all of the factors discussed for PV streamers are important, but in addition, and very importantly, the role of moisture. One question relates to the importance of knowing the structure of the lower-to-mid troposphere structure for forecasting an extratropical cyclone. Sensitive area calculations often point to the layer around 500-700 hPa. Why is this more important than upper-levels? A further question relates to the inconsistency of deterministic and ensemble forecasts of extratropical cyclones in which sequential forecasts alternate between predictions of a strong or a weak system. The ensemble forecast tends to follow the deterministic forecast rather than providing both solutions within the ensemble. Do we understand why this happens? Is it associated with particular synoptic scale flow patterns (known to occur often with ET for example, what about other situations?) or with nonlinearity in the flow evolution. Further challenge- role of surface fluxes, but we didn't discuss this further.

**Mediterranean Cyclones** are climatologically smaller-scale than their Atlantic cousins – why? The role of orography and surface fluxes is crucial. In many cases, a PV streamer is involved in the development. Does it cut off? Challenges are associated with the relative importance of the PV streamer and localised factors such as orography or surface fluxes. The factors that determine the cyclone track are unclear. Further, what is the role of aerosol (Saharan dust) absorbed into cyclones in the eastern Mediterranean?

**Downstream impact of ET:** challenge is to quantify the relative roles of TC track, TC structure and its change during ET, and the structure of the midlatitude. How important is the upper-level PV modification due to diabatic processes, both during the TC phase and as the TC interacts with the front, in the triggering of upper-level Rossby waves.

**Deep Convection:** Challenge: predictability associated with relative roles of surface processes / synoptic-scale flow. Relation to COPS/ETReC. Datasets can be used for validation of high resolution forecasts. Question of the role of convective parameterisation vs. high resolution modelling? Mesoscale question that impacts THORPEX but not the main focus. When the convection organises and influences the large-scale flow then a THORPEX question. Question of CRMs high resolution deterministic forecasts vs. more ensemble members.

**Polar weather:** arctic fronts and low-level jets, both missing from the forecast or poorly represented. Polar lows (up to several days). Challenge: Predicting the large-scale setting in which polar lows to develop. Heavy convection and strong snowfall with cold air outbreaks. Role of surface fluxes, clouds, PBL. Timescale: 1 day. Orographic influence, upper-level forcing. Who cares about polar weather– and will they pay for forecasts? Energy companies. Fishing activities.

**Air quality:** passive tracer transport. But passive tracer transport alone is not enough to describe . Challenge to assimilate the chemical/aerosol variables. Do we have the community to deal with this? Related to inclusion of dust in forecast models (ECMWF/UKMO/others).

**Blocking:** quantify predictability of and understand processes (dry Rossby wave dynamics, moist processes, wave-mean flow: transients feeding into large-scale block) responsible for onset, maintenance and breakdown. What are the precursors? How does blocking relate to low frequency (subseasonal to interannual) variability.

**Organised tropical convection:** quantify the impact of organised tropical convection on predictability of weather systems for the Atlantic-European sector (WCRP) 14 days +

**Floods:** predictability of large-scale influences on the mesoscale extreme events. Extended timescale of QPF prediction. Downscaling. Accurate description of orography (but this is for flash floods so leave it out)

**Orographic flow (tip jets, föhn, bora, mistral, mountain waves):** exploit improved large-scale flow features at day 4+ to drive high resolution models with various representations of physical processes, for e.g. different PBL parameterisations, to predict the wind fields and the uncertainty in them. Large-scale influences on local features. Large-scale models should get the forcing right, but can't resolve the events.

#### **Other phenomena mentioned in discussion group but not in table:**

**Polar influences:** remote effects of Greenland (GFd experiment); sea-ice-atmosphere interaction (far-field); role of arctic polar jet in the excitation of RWs on the midlatitude jet, variability?, stratospheric vortex influence, role of snow cover in predictability. Carla's study showing large impact of polar observations on forecasts for Europe.

**West African Monsoon:** need an extra point in plan to raise the cooperation with the African Regional committee and AMMA to study the predictability of weather systems over West Africa and link into forecasting for health and agriculture impacts.

**Heat waves:** importance of surface atmosphere interactions; blocking (relevant flow states?); upstream vs. local triggers; predictability of duration and strength; what obs do we need to improve predictions; role of model error?

#### **ColdsSpells:**

**Heat lows:** what determines strength of heat low and nocturnal jet? What is interaction of convection and heat low? Upscale influence / interaction with large-scale flow. Variability of heat low.

#### **Predictability and Ensembles**

Challenge of determining the theoretical limitations of ensemble forecasts and communication these limitations to the users.

EPS are nonlinear models. At the long range, if the model is exact, it will sample the climatological uncertainty. Impact of initial conditions very large at ranges of 1-2 days, decreases by ~ 5 days (if model perfect). Inconsistency in ensemble forecasts initialised from sequential analyses to do with specification of initial conditions that are biased to a particular form of instability. Sample present uncertainty: nontrivial combination of current observations and previous instability history. Question: is it important to do probabilistic forecasts – if answer yes, then very important to be able to sample present uncertainty in flow, then account for model error. For longer time scales model error more important e.g. heat waves.

Difference between deterministic and probabilistic forecast. Deterministic, you know afterwards what you should have predicted, probabilistic you don't because you can't measure the uncertainty.

Theoretical question: resolution of probability density function with large ensemble vs. increasing the accuracy of individual member through high resolution. It is not necessarily useful to highly resolve PDF – who will use the more accurate probability? And how does one validate – need more cases to validate statistics of very large ensembles. Statement that 12 ensembles may not be sufficient – 50 almost certainly sufficient for all practical purposes. Dependence on weather of the day – variable size ensemble.

## 4. Research Priorities and Actions

### a) Predictability and Dynamical Processes

Responsible authors: Sarah Jones, Heini Wernli

#### **Synthesis of challenges**

From the detailed list of challenges associated with the individual phenomena (see *Scientific Challenges*) the following overarching/priority challenges have been identified:

- Quantify relative importance of large-scale flow vs. local forcings for predictability (of e.g. Mediterranean cyclones, deep convection, ...)
- Identify role of diabatic processes for dynamics and predictability (of e.g. extratropical cyclones, blocking, PV streamers, ...)
- Assess importance of upscale cascade for predictability in the Atlantic-European sector (e.g. organized tropical convection, extratropical eddies)
- Identify processes and their relative importance for Rossby wave triggering, propagation and breaking
- Transferring large-scale predictability to the mesoscale via high-resolution modelling
- Development of numerical model chain (including probabilistic prediction) and verification tools
- To determine the theoretical limitations of ensemble forecasts
- Identify situations leading to inconsistency in sequential forecasts and/or pronounced medium-range forecast busts
- Assess relative importance of tropical and extratropical components for predictability of downstream impact of ET

#### **Recommended actions**

##### **Action 1)**

Investigate the potential for conducting an international field experiment in autumn 2010 or 2011 (at the same time as HYMEX) to study disturbances on the North Atlantic waveguide and their downstream impacts over Europe. A preliminary name for such an experiment is

**THORPEX North Atlantic Waveguide and Downstream impact EXperiment (T-NAWDEX).**

The scientific aims of T-NADEX would be to address in the first place the triggering of waveguide disturbances by different processes and the disturbances' subsequent downstream evolution. The potential triggering processes are the extratropical transition of tropical cyclones, intense extratropical cyclones in the western North Atlantic, polar stratospheric PV anomalies, and large-scale orographic forcing. The first of these processes (ET in the North Atlantic) has maximum frequency in September/October (on average about 5 events per year, but high variability), the second (intense extratropical cyclones) occurs most frequently in winter, but also in late autumn and the two other processes are expected to be equally likely in all seasons.

The second focus of T-NADEX would be the study of the downstream impacts of the waveguide disturbances over Europe, the Mediterranean and northern Africa. During an autumn season it will be very likely that several potentially high-impact weather events occur over Europe whose predictability crucially depends upon adequate observations and modelling capabilities for the North Atlantic waveguide and its disturbances. These events include the breaking of Rossby waves (i.e. the formation of PV streamers and upper-level cut-offs), heavy precipitation (in particular to the south of the Alps), blocking over the eastern North Atlantic, Mediterranean cyclones and maybe long-range transport of Saharan dust

towards Europe. Several of these phenomena will be studied intensively within the HYMEX field campaign that addresses in particular mesoscale predictability, precipitation forecasts and hydrological applications in the Mediterranean region (**check whether these priorities are correct!**). T-NADEX would therefore be an ideal upstream component to complement HYMEX and, similarly to T-PARC, would address the trans-oceanic propagation of meteorological disturbances and its downstream impacts. Scheduled two or three years after T-PARC, the proposed experiment will profit strongly from the experiences and results from T-PARC and will include observational strategies and facilities that have been developed in the meantime.

As a novel observation platform, the German high-altitude long-range research aircraft HALO should be ready in 2010 for performing comprehensive observations in the North Atlantic waveguide area. Six HALO demonstration missions for the years from 2008 onwards have been defined recently and one of these (named HALO-THORPEX) will address the potential of the new aircraft for undertaking targeted observations. The HALO-THORPEX demo mission is coordinated by Andreas Dörnbrack at DLR Oberpfaffenhofen. A second mission, HALO-NEPTUN, aims to investigate Mediterranean cyclogenesis and is coordinated by Christoph Kottmeier, Ulrich Corsmeier at Forschungszentrum Karlsruhe.

It will be important to include a strong European (and potentially African) SERA component into T-NADEX (ideas to be developed).

#### **Action 2)**

In addition to field experiments, it is vitally important to conduct **national and/or international research programmes/projects** that address specific scientific challenges (see list above) on the basis of

- diagnosis of operational analyses, deterministic and EPS forecasts (TIGGE)
- idealized modelling and theoretical studies
- real case sensitivity studies.

Ideally, these projects should be performed by academic groupings interested in THORPEX in combination with representatives from the national weather services and/or ECMWF. They should address basic PDP research questions and, where possible, provide essential information for the planning and conduct of a T-NADEX campaign. The ERC should encourage different European consortia to prepare research proposals along these lines and provide a platform for the exchange of results.

#### **Action 3)**

A special research project has been suggested by the SERA working group to investigate the meteorological sensitivity of selected economic/societal sectors. We would strongly welcome such a **SERA/PDP pilot project**. We envisage that the SERA group would, for the selected sectors, inform the PDP group of the relevant variables, the desired forecast-accuracy and lead times. The PDP contribution could quantify the existing forecasting capabilities (deterministic vs. probabilistic, global vs. mesoscale, medium vs. short-range), identify the relevant weather phenomena and make recommendations for improvements of the forecasting system.

#### **Action 4)**

Develop a research programme to quantify the limits of the utility of ensemble forecasts, e.g. with regards to the question of ensemble size.

#### **Action 5)**

Discuss the linkage of European PDP activities with those of other regional THORPEX committees. Current priorities are (i) to develop linkages with the Asian and North American regional committees for work on PV streamers / Rossby wave triggering and propagation

and breaking / downstream impact of extratropical transition (T-PARC) and (ii) to coordinate with the African Regional Committee, in particular for PDP work in the context of AMMA taking into account the work of the PDP Interest Group on AMMA and tropical-extratropical interactions and the AMMA International WG 5 on high impact weather prediction and predictability.

## **b) Observing Systems/Data Assimilation and Observing Strategies**

Responsible authors: Jean Pailleux, Martti Heikinheimo

### *Synthesis of challenges*

. Several observing systems and technologies are currently at the edge between research and operations. In other words, they seem to have a potential for operational use, but it is still a challenging task to integrate them as operational observing systems. Two typical examples are related to lidar observing systems. An airborne lidar has a lot of potential to produce some targeted observations once an operational targeting strategy has been worked out. The wind lidar on the future ADM-AEOLUS demonstration mission (ESA) will produce for the first time wind profile information globally in real time. This type of “observing system challenges” is relevant to most of the European weather phenomena previously identified in this document.

. For several weather phenomena (mid-latitude storms, PV-streamers, Mediterranean storms,...) one needs to observe and understand more several precursors or key weather elements which often occur in cloudy areas known to be poorly sampled by satellite measurements. This point addresses the question of “optimal observing network” and of “optimal data assimilation and observing strategies” over the European seas and the Atlantic and Arctic oceans, as well as the question of observation strategy for cloudy and precipitating weather systems in Europe.

. The design and development of a general observation targeting strategy for Europe is an important challenge. Inside the European project “Eurorisk Preview”, a Data Targeting System (DTS) is being developed. One needs to consider to what extent this DTS is applicable to the different types of European phenomena (extreme or not). The deployment of targeted observations should rely on the computation of some sensitivity fields or sensitivity indicators. But one still needs to improve the understanding of the strengths and weaknesses of current sensitivity computation methods, including the extension to longer time ranges (lead time around one week). Some parts of the in-situ observing networks could be also organised in a way which supports more improved weather forecasting over Europe, for example by relying on some “sensitivity climatologies” derived by season or by weather regimes.

. Even if a good strategy is derived for computing sensitive areas or sensitivity indicators on a day-to-day basis, or even if a deployment strategy is also able to deploy good extra observations in some of these areas, this is not sufficient to guarantee an improvement of the forecasts. An additional challenge is to assimilate these data properly into the NWP models. Current data assimilation systems are based on structure functions which are “optimal in a global statistical sense”, but not adequate for many sensitive areas affected by an atmospheric flow or weather features which are strongly anisotropic in space. Structure functions are close to isotropy in most of the operational data assimilation systems (although a 4D-VAR helps in producing more realistic structure functions) and then the assimilation of observations is sub-optimal in many areas affected by strong jets, vertical wind-shears, high temperature gradients, etc.... In addition, operational NWP in Europe is characterized by a wide variety of data assimilation methodologies, which makes it more difficult to converge towards a general “European data assimilation and observing strategy”. However, operational NWP in Europe has now built a wide variety of numerical tools around the variational algorithms which are now used in many forecasting centres. These tools represent an important potential for tackling collectively the following double problem: (i)

Deploy targeted observations at the right place/time; (ii) Use these observations properly in the data assimilation systems.

. One needs to study more which observations are useful for improving weather forecasts over Europe at medium range and beyond (say, from day 5 to day 14). This may imply for the European community to put more efforts for observing regions which are far away from Europe, such as Africa, tropical Atlantic and polar regions. The data from all appropriate campaigns should be used to investigate this predictability aspect (AMMA, IPY, non-European Thorpex campaigns).

. In order to handle properly several high impact weather phenomena over Europe at short-range and very short range, one needs to model them correctly down to the kilometre scale. Operational high resolution data assimilation techniques are not as mature as large-scale global meteorological data assimilation systems, they are not adequate yet to meet high impact weather prediction requirements. One aspect of this challenge is related to the use of meso-scale observing systems (GPS surface networks, radars...) and to the assessment of their impact on the forecasts through Observing System Experiments (OSE). The main components of the Global Observing System (GOS) have been regularly assessed quantitatively through OSEs during the last 10 or 20 years. However OSE on meso-scale observations are still in the infancy.

. Another aspect of the challenge is related to the algorithmic aspects of data assimilation: at high resolution, the algorithms have to be run more frequently and more rapidly than at global scales, using the additional meso-scale information... and without destroying the overall field consistency provided by the last run from the global data assimilation and forecasting system (necessary to provide at least lateral boundary conditions). This means that a good meso-scale data assimilation system has to cope with a wide range of scales from the global ones down to the kilometre resolution. Variational techniques are in principle very efficient to treat this problem, but they may not be sufficient on their own. For example, a single 4D-VAR may be too expensive in computer resources.

. With increasing resolution in NWP models, the importance of the correct representation of the earth's surface increases. For example more realistic and up to date characterisation of the soil moisture, vegetation state, snow and ice cover will lead to smaller biases in simulated surface energy fluxes. Consequently the observation requirements may need to be refined to meet the needs of future NWP systems. One needs to refine the specific requirements for sampling the atmospheric boundary layer, the solid earth - vegetation surface layer as well as for seas and oceans. More work is needed on the data assimilation techniques related to surface observations, and to assess their role on predictability. This last challenge addresses several aspects related to predictability at meso-scale, probabilistic forecasts and non-linearities in several processes relevant to data assimilation.

### ***Recommended actions***

Although some of the above challenges cannot be addressed by very precise actions, the following planned actions (for the next 5 or 7 years) should bring significant progress on many points.

#### **Action 1):**

**One should ensure that DLR airborne lidar can be deployed in the Thorpex-PARC campaign, with operational assimilation issues being considered.** Another aspect of this lidar action is related to the wind measurements from space, and to the ADM-AEOLUS demonstration mission from ESA announced for 2008-2011. **ECMWF, Météo-France and**

**Met Office should report on the impact of ADM-AEOLUS data on global NWP to the Thorpex European Regional Committee, as soon as possible once the data are available. Other NWP centres are invited to collaborate on this action as soon as possible, considering the limited life time of the mission.**

The lidar technology is currently the best example of observing system which requires a “significant push” towards operational meteorology. Actions as precise as this one have not been identified for other instruments in this document: however several other technologies may deserve a similar “push”.

**Action 2):**

**Noting the limited use of satellite soundings in cloudy areas, encourage the Eumetnet programme E-ASAP to concentrate more on cloudy areas.** This requires to study a simple adaptive programme along the line: “make less radiosonde launches when the sky is clear and more when the sky is overcast”. The strategy could be made more efficient and more sophisticated through a better understanding of precursors, and through the experience and information accumulated in campaigns such as E-TReC and COPS.

**Action 3):**

**Encourage the Eumetnet programme OPERA to exchange in real time surface precipitation composites, 3D reflectivity data as well as Doppler wind data.** These are huge data volumes and their use in real time requires quick and frequent exchange. The assimilation of some information contained in these radar data set is also an important action in the context of the development of NWP models at kilometre scales. Moreover, in the near future, the radar information may appear useful also for larger scale models, including the global ones; this would justify even more **to put substantial efforts on the use of radar information**. Nowadays, satellite data represent a big amount of information entering the global models; but at meso-scale, **important efforts are still needed to exploit the high resolution satellite information**, such as the one contained in the imagery.

**Action 4):**

**Develop a European DTS (Data Targeting Strategy) starting from the legacy of A-TreC 2003 (in terms of practical experience) and from the Eurorisk-Preview DTS (WP3320 in the organisation of this European project).** Apply this DTS to E-TreC 2007 (including COPS and Medex campaigns), to selected IPY projects, and draw experience to improve the system. Review and improve targeting capabilities using the Eurorisk-Preview 2008 field campaign. Further develop these methods and converge to a practical operational system for targeted observations. In parallel, an action should be undertaken to establish comprehensive sensitive area climatologies for selected types of weather phenomena, different seasons and different weather regimes. These climatologies should then be used as scientific inputs for optimising the surface-based observing networks as well as optimising the use of some satellite data (“adaptive thinning and quality control”, which means that the use and the quality control of satellite data would be dependent on these sensitivity climatologies).

**Action 5):**

**Coordinate research activities in Europe on data assimilation methodologies in order to get a better understanding of which observations and sampling strategies will improve the forecasts in targeted sensitive areas.** As an example, one needs to ensure that the current works on the data assimilation structure functions will provide significant improvements to make the best use of observations in the sensitive areas (without degrading the use of observations outside the sensitive areas). More generally, during the last 15 years, Europe has developed many variational assimilation systems which are now operational in most of the NWP centres (3D-VAR or 4D-VAR). These systems include tools such as adjoint operators, singular vector computations, etc... which can identify sensitive areas/structures, and can be tuned and refined in order to assimilate data properly in the

sensitive area. Ensemble techniques in data assimilation can also help in this particular problem where the identification of the analysis uncertainty in some areas is crucial.

**Action 6):**

**Encourage improvements in surface-based observing networks in polar and tropical regions.** For the upper-air networks, AMDAR can be considered for the North polar cap, and for the tropics both AMDAR and ASAP can be considered, not forgetting the potential operative use of e.g. driftsondes now used mainly in research campaigns. The experience gained in AMMA, and later IPY and Thorpex-PARC should be used to get recommendations for additional observing components in these regions. To be fully exploited, each campaign data set (including the metadata), should be made available to the NWP groups, and (as far as possible) be made available in real time on the GTS. Also EUCOS (and its sub-programmes E-ASAP and E-AMDAR) should consider longer forecast ranges in their design/development works (sofar they have considered mainly the short-range forecasts, i.e; up to about day 3).

**Action 7):**

**Coordinate research and development activities in Europe on data assimilation and on the use of ensemble in data assimilation.** The first goal of this action is to stimulate the work on meso-scale predictability (including for convective systems). Another goal is to bring the meso-scale data assimilation systems and ensemble prediction systems to the level of maturity of the present global systems, and then to understand more the sources of forecast uncertainties at the kilometre resolution. Ensemble data assimilation, even at the global scale, is still an emerging activity in Europe., which requires coordination. A direct output of ensemble data assimilations is a technique for computing flow-dependent structure functions (which then vary in space and time, according to the meteorological situation). There is a clear link between this action and the preceding action on improved structure functions in sensitive areas. Finally this action is clearly an action which is part of both the PDP and DAOS activities (see section of the plan on PDP). In Europe this action should build on TIGGE and on the EPS (Ensemble Prediction System) projects which are already coordinated in Europe by the Eumetnet programme SRNWP (Short Range Numerical Weather prediction) and some NWP consortia.

**Action 8):**

**Develop a strong European activity on OSE (Observing System Experiments), especially for high resolution observing systems,** relying on the existing Eumetnet SRNWP network and its different consortia (HIRLAM, ALADIN,etc...). For global OSEs, the activity is already developed to a large extent, with ECMWF deeply involved. The collaboration on global OSE remains important and should be encouraged. As OSE are expensive both in computer and human resources, this type of activity should include and encourage simpler statistical techniques to evaluate the information content which is brought by one particular observing system to one particular data assimilation system (these techniques are cheaper than OSE and they have already been used).

## **c) Societal and Economic Research and Applications**

Responsible authors: Mark Roulston, Frederic Atger

### *Synthesis of challenges*

The challenges underlying the effect application of weather forecasts to societal and economic needs have been reviewed in Chapter 2.

### **Recommended Actions**

Recommended activities within the Societal and Economic Research and Applications section of the European THORPEX plan are divided into four levels. These levels are based on estimates of how quickly the activities can commence, as well as how long it is likely to be for the activities to produce results. Level 1 activities could commence almost immediately, while higher level activities depend partly on the results obtained from Level 1 activities. Some Level 4 activities, however, could commence independently of other activities, although it is anticipated that they will not yield results until towards the end of the THORPEX programme.

#### **Level 1 Activities**

- (a) *Non-comprehensive review of current forecast usage.* An immediate review of the current usage of weather forecasts should be conducted. Forecast providers should be asked, where possible, to identify which sectors are currently using weather forecasts, with a particular emphasis on medium range forecasts. Profiles of user interest and user expenditure on weather forecasts as a function of forecast lead time should be compiled.
- (b) *Contingent valuation study of forecast value to European households.* Contingent valuation surveys should be designed and conducted to estimate the current value of weather forecasts to European households. Particular emphasis should be placed on estimating this value as a function of forecast lead time and unbundling the value of short range forecasts from medium range forecasts.
- (c) *Econometric study of weather sensitivity of European industrial sectors.* An econometric study of the sensitivity of the output of the European economy to weather variability should be conducted. The study should evaluate this sensitivity by sector and country.
- (d) *Study of forecaster perception and usage of medium range products.* European Met Services should conduct coordinated internal studies of how their forecasters perceive the value of medium range forecast products, particularly ensembles, and how they use these products in the preparation of forecasts. The information from these studies should be shared and collated in a single review.

#### **Level 2 Activities**

*Prototype projects with current users of medium range forecast information.*

Current users of medium range forecasts (as identified in Level 1 Activity a.) should be engaged in collaborative prototype projects. These projects should determine how these users are currently using medium range forecast products and also assess whether the currently available products could be exploited more effectively in their decision-making and

risk mitigation. In particular, the use of ensemble-based and probability forecasts should be investigated.

### **Level 3 Activities**

*Studies of potential utility of medium range forecasts to non-users.*

Forecast users who currently use short range forecasts but not medium range information (as identified from Level 1 Activity a.) should be engaged in collaborative studies to determine whether medium range forecasts may assist them in their decision-making.

### **Level 4 Activities**

- (a) *Review of the history of weather forecast valuation efforts.* A review of previous attempts to ascertain the socio-economic benefits of weather forecasts should be conducted.
- (b) *Studies of how internal decision-making structures affect forecast value.* The impact of how internal organisational structures affect decision-making and thus potential value of forecast information should be investigated.
- (c) *Studies of how design of institutions affects forecast value.* The influence of institutional structures on the way that weather information is used and its potential value should be studied. For example, how the design of energy trading markets or insurance markets affects energy companies' ability to make use of medium range information, or how the allocation of civil defence responsibilities to different parts of government might affect the effectiveness with which they can use weather information. The question of whether such institutional structures are optimal should be addressed.
- (d) *Comparative study of organisational structure of European Met. Services.* A study to compare the internal organisation of European National Met. Services and their relationships to government departments should be conducted. The issue of how this organisation affects the services' ability to exploit the value of weather information at different forecast lead times should be addressed.

### **References**

Lazo, J.K. and Chestnut, L.G. Economic Value of Current and Improved Weather Forecasts in the U.S. Household Sector, Stratus Consulting, 2002.

## d) TIGGE – Global and Regional

Responsible authors: Richard Swinbank, Stefano Tibaldi

The THORPEX Interactive Grand Global Ensemble (TIGGE) is a framework for international collaboration in the development and testing of ensemble prediction systems. At the time of writing, the global part of the TIGGE project is well underway, but the regional component of TIGGE (TIGGE-LAM) is still at an early planning stage. The main issues affecting TIGGE depend upon the relevant time and space scales. We have divided this plan into two sections, to highlight the different priorities for the global and regional parts of TIGGE project. The first section highlights those issues affecting global models, with forecast timescales up to about two weeks, while the latter section focuses on issues affecting regional-scale models for short-range forecasts (up to about 3 days).

We have taken Global TIGGE first because the global part of the project is already in hand, while TIGGE-LAM is still at the planning stage. However, in Europe the National Met Centres form a unique collection of expertise in regional modelling, including several limited-area ensemble forecast models. Europe is thus especially well-placed to contribute to the regional component of TIGGE.

### Global TIGGE (up to two weeks)

Although TIGGE is a global project, there is strong potential to use the medium-range global ensembles to improve the prediction of high impact weather over Europe, especially for week 2 (8-14 days ahead). There is already a strong European involvement in the TIGGE project. The (UK) Met Office is providing output from 15-day ensemble forecasts to the TIGGE database. ECMWF is also acting as a data provider, but in addition is hosting one of the three TIGGE archive centres and the TIGGE project website (<http://tigge.ecmwf.int/>). Météo-France also plans to contribute ensemble forecasts to TIGGE.

## General Actions

**Action:** All European Met Services which currently run global medium-range ensemble forecasts should add their forecast data to the TIGGE databases, following the standards defined by the GIFS-TIGGE working group.

**Action:** The current (phase 1) TIGGE entails data providers sending their data to three global archive centres (ECMWF, NCAR and CMA), using archiving systems already available at those centres. It is proposed that, in phase 2, a more sophisticated and efficient archive system would have the data distributed between more archive centres and have users access the data via a common portal. This would require additional software development and funding. This funding needs to be secured and phase 2 needs to be implemented over the next few years.

## Meteorological considerations

The following meteorological phenomena are considered to be most important for the use of Global TIGGE forecasts in Europe. (Numbers in brackets give indicative priorities; 1 is most important.)

- Extra-tropical cyclones (1). Includes windstorms resulting from vigorous Atlantic depressions primarily affecting NW Europe. Also PV streamers which may lead to cyclogenesis in the Mediterranean.
- Influence of the tropics on the extratropics (2). The extra-tropical transition of tropical cyclones has an important influence on cyclonic development in the Atlantic sector.

More generally, Rossby wave trains originating from the tropics bring storms to mid-latitudes. On a longer timescale, but still within the THORPEX two-week timeframe, improvements in the simulation of the tropical Madden-Julian Oscillation (MJO) should allow better forecasting of the tropics on mid-latitudes.

- Blocking (2). The simulation of blocking, particularly in the North Atlantic is crucial to forecasting persistent weather patterns over Europe. Reliable forecasting of the maintenance and/or breakdown of blocks is a priority.
- Heatwaves (2). The European meteorology of recent years has underlined the importance of being capable of predicting the onset and the lifetime of heatwaves (often linked with Euro-Atlantic blocking). Such phenomena have been shown to have sometimes extremely important societal impact.
- Floods (2). For medium-range forecasting, it is important to be able to capture persistent, larger-scale periods of wet weather (or periods of snow-melt) that could lead to fluvial floods.
- Polar influences (3). The IPY and its component projects, such as GFDex, should help our understanding of high-latitude influences on mid-latitude weather systems.

**Action:** While the scientific understanding of these issues is primarily the concern of the PDP area of THORPEX, it is important that knowledge is fed through to the implementation of improvements in the numerical weather prediction models used for forecasting.

## Ensemble forecasting science

There are several scientific and technical issues that should be addressed within the TIGGE project to improve the use of ensemble forecasts. In this section we highlight several areas where research and development **actions** are needed, focusing primarily on the requirements for global medium-range forecasts. Priorities are given in brackets.

- Extreme event probability estimation and verification (1). Much of the high-impact weather that THORPEX focuses on is fortunately rare. Problem of calibrating rarer events, i.e. relating forecast probabilities to actual outcomes. Consideration should be also given to the problem that it might turn out to be impossible to verify really rare events.
- Spread - skill relationship (1). The common perception is that a high ensemble spread corresponds to a low confidence forecast, and low spread to high skill. This may be true if the ensemble spread is well related to errors in initial condition and model error. But it would not be true if, for example, errors in the initial conditions or model formulation errors are not captured by perturbations. So, this issue is related to the representation of both initial condition errors and model errors.
- Multi-model calibration (1). When combining forecasts from multiple models, differing biases (both mean and higher order moment errors) need to be accounted for by calibrating the individual forecasts before combining them (for example making use of a Bayesian combination approach). Research is needed on the best ways to correct biases; while past cases (recent forecasts, reforecasts of previous years) can be used to estimate "climatological" biases, it is hard to take good account of flow-dependent biases. To an extent, the multi-model technique is beneficial because different models have different types of systematic errors. Work is needed to determine the best way of accounting for inter- as well as intra- ensemble variability.
- User-oriented verification of non-extreme events (2). For many users non-extreme events are more important than extreme events, not least because they are more common. For example, forecasts of temperature and winds affect forward energy prices. Such events will be easier to verify reliably than extreme events, but work is required to develop verification methods that are better related to socio-economic costs to users.

- Stochastic physics (2). As mentioned above, part of the benefit of multi-model ensembles is to allow for model errors by combining forecasts from several models with different types of model error. Stochastic physics schemes also attempt to account for model errors by adding in random variations that “target” uncertain aspects of the physical parameterizations. At the moment, stochastic physics schemes are rather crude. Further work is needed to develop stochastic physics schemes that are better at representing model errors.
- Intelligent diagnostics (2). Ensemble forecasts produce a vast amount of data, which is hard for forecasters and end-users to interpret. To make the best use of the output, a suite of “intelligent diagnostics” needs to be developed. For example, the ensemble forecast output can be automatically analysed to characterise features including extra-tropical cyclones and fronts (see Fig X1). By combining this with tracking software, forecasters can be shown how different features are likely to develop over a period of several days. Later in the forecast, beyond the lifetime of features identified in the initial analysis, this type of analysis can indicate likelihood of windstorms. Another approach is to characterise the large-scale circulation patterns. Figure X2 illustrates a forecast of objective Grosswetterlagen patterns from the Met Office ensemble (this analysis method was developed with support from COST733). Further diagnostics should be developed, perhaps aimed at specific user groups.
- Initial perturbation methods (3). At present, several methods are in use to generate initial perturbations for ensemble forecasts, e.g. singular vectors, error breeding and Ensemble Transform Kalman Filter. Further research work is needed to ensure that the perturbations capture the uncertainties in the initial conditions as well as possible, including reasonable geographical variations of amplitude.
- Ensemble Comparison (3). Although it is not directly part of TIGGE, the TIGGE database facilitates comparison between different ensemble prediction systems (e.g., relative performance for specific processes such as MJO or blocking). This can be used to inform developers of each EPS to enable them to address specific shortcomings.

### **Regional TIGGE (up to 3 days)**

Limited-area ensemble prediction systems will be an important component of the future THORPEX Global Interactive Forecast System (GIFS). Our focus is the combination of regional models that encompass a large part of Europe, and the adjoining North Atlantic, with sufficient resolution to represent mesoscale features (i.e. a grid length of around 10 km or better). Even with likely improvements in computer technology over the next few years, we envisage that higher resolution models (~1 km grid-length) will still be limited to the national level. Regional-scale multi-model techniques could be extended to these very high-resolution models at a later stage.

The GIFS-TIGGE working group first started considering plans for the regional component of TIGGE in March 2006. This part of TIGGE is known as TIGGE-LAM (Limited Area Models). The TIGGE-LAM panel of experts, which is currently being formed, will draw up implementation plans for TIGGE-LAM. It is envisaged that the TIGGE-LAM project will encompass the following

- To facilitate exchange of initial and boundary conditions between ALL global ensembles and ALL LAM ensembles by agreed standard data formats and contents
- To agree content and standard format of LAM ensemble data for wide exchange and evaluation
- To exchange meta-data through a common Internet site
- To explore which Centres are willing to take a leading role in offering routine boundary conditions, relocatable LAM ensembles, archiving services, dissemination, etc., for a TIGGE-LAM

However, the development of the full range of these facilities is not necessary for an initial European regional component of TIGGE. Since there are already several ensemble forecasting partnerships in Europe, a first phase of a regional TIGGE system could be developed by exchanging and combining forecasts from regional ensemble prediction systems that already exist. There would need to be a coordination of output fields (as has been done for TIGGE-Global) and model domains (to maximise overlap). Subsequent phase(s) of the project could exploit more general facilities to exchange initial and boundary condition data and research the benefits of doing so for the improvement of short-range forecasts.

A prerequisite is the need to define the objectives of TIGGE-LAM. Then we should consider how best to achieve them – with specific reference to Europe, as well as more general needs for research on limited-area multi-model ensemble forecasts. As an alternative to the simple combination of output from pre-existing regional ensembles, we could also consider further development of the following approaches:

- An ensemble made up of single high-resolution models, as in the SRNWP PEPS project;
- The use of different combinations of initial and boundary conditions and limited area models (e.g. as used at SREPS project at INM, **Fig X3**).

This set of possibilities is not exhaustive. We need to consider how the benefit of combining ensembles compares to the cost (technical resources and time taken).

## General Actions

The **actions** required can be summarised as follows:

- Define key requirements – specifically for Europe
- Design TIGGE-LAM system to address those requirements
- Secure funding
- Implementation plan

These actions need to take place in close collaboration with SRNWP and EWGLAM, which represents the European Met Services' interests in development of short-range numerical weather prediction.

## Meteorological considerations

The following meteorological phenomena/issues are considered to be most important for the use of short-range regional ensemble forecasts for Europe. (Numbers in brackets give indicative priorities; 1 is most important.)

- Dynamic QPF (1). Qualitative Precipitation Forecasts are important particularly for the prediction of flooding. The main emphasis for short-range forecasting is the prediction of pluvial floods – those related to localised strong rainfall events. Also important is the effect of orography on rainfall.
- Polar Lows (2). Polar lows are much smaller and more transient than regular mid-latitude depressions. However, they typically produce severe weather in the form of heavy precipitation, usually falling as snow, and strong surface winds.
- Extra-tropical cyclones (2). The formation and effects of Mediterranean cyclones is particularly important. There are also plenty of short-term forecasting issues associated with severe storms of small geographical extent. Also the interaction of cyclones with orography.
- Convection (3). While the modelling of convection is important in regional scale models, because of its importance to QPF, this is felt to be even more important for finer scale models.

**Action:** It is important that research be directed to improving our scientific understanding of these issues, and that the resulting knowledge is fed through to the implementation of improvements in the numerical weather prediction models used for forecasting.

## Ensemble forecasting science

There are several scientific and technical issues that should be addressed within the Regional TIGGE project to improve the use of limited-area ensemble forecasts. In this section we highlight several areas where research and development **actions** are needed, focusing primarily on the requirements for regional short-range forecasts. Priorities are given in brackets.

- Initial perturbation methods for LAM (1). Currently most LAM EPS systems rely solely on global EPSs to generate IC perturbations. Methods to generate perturbations in the ICs specifically for LAMs should be developed (ETKF? Others?), bearing in mind the need to maintain consistency with the BCs derived from global models. Methods developed for a given LAM ensemble should aim at fully accounting for the IC uncertainty typical of that particular system
- Spread – how well is it related to skill? (1) The common perception is that a high ensemble spread corresponds to a low confidence forecast, and low spread to high skill. This may be true if the ensemble spread is well related to errors in initial condition and model error. But it would not be true if, for example, errors in the initial conditions or model formulation errors are not captured by perturbations. So, this issue is related to the representation of both initial condition errors and model errors and it is of particular importance in regional modelling and for smaller scales. For such scales the very existence of the spread-skill relationship is sometimes questioned, in particular as far as rainfall and near-surface parameters are concerned.
- Multi-model calibration (1) When combining forecasts from multiple models, differing biases (both mean and higher order moment errors) need to be accounted for by calibrating the individual forecasts before combining them (Bayesian approach?). Research is needed on the best ways to correct biases, which is an even harder problem for smaller scales and hence regional models. While past cases (recent forecasts, reforecasts of previous years) can be used to estimate “climatological” biases, it is hard to take good account of flow-dependent biases. In a European regional context, a possible approach would be to use biases that depend on the large scale circulation (e.g. grosswetterlagen). To an extent, the multi-model technique is beneficial because different models have different types of systematic errors. Work is needed to determine the best way of accounting for inter- as well as intra- ensemble variability and how it is affected, for example, by different physical parameterisation packages (e.g. deep convection).
- Optimal use of resources (1) In a multi-model LAM environment the problem of trade-off between resolution and area integration (to allow for limited area overlaps) is a concrete one. For a given cost, forecast centres could either run a single-model ensemble for the most relevant domain to their users or a multi-model ensemble for a larger domain of relevance to several forecast centres. We need to compare the performance of lower-resolution multi model ensembles with higher-resolution single model ensembles. Severe events, however, will probably always require resolution higher than a given threshold. The speed, and ease, of data exchange is also a particular factor for short-range forecasting. There are several of factors that need to be balanced when deciding the best approach, including
  - Model resolution
  - Domain size
  - Number of ensemble members
  - Benefits from use of multi-model ensembles

➤ Timeliness of data exchange

- Extreme event probability estimation and verification (2). Much of the high-impact weather that THORPEX and TIGGE focus on is fortunately rare. Flash floods should be given particular attention in the regional context. The problem of calibrating rarer events, i.e. relating forecast probabilities to actual outcomes, could be exacerbated by considering limited areas. Consideration should also be given to the possibility that it might turn out to be impossible to verify really rare events.
- Probability for weather phenomena - derived parameters such as fog (2) The problem of deriving probability forecasts for derived parameters such as fog, visibility, cloud types and height, etc., needs to be considered. This is also an issue for near surface parameters such as soil temperature, soil moisture content, 2m T and RH for further hydrological modelling.
- Stochastic physics (2). As already mentioned, part of the benefit of multi-model ensembles is to allow for model errors by combining forecasts from several models with different types of model error. Stochastic physics schemes also attempt to account for model errors by adding in random variations that “target” uncertain aspects of the physical parameterizations. At the moment, stochastic physics schemes are rather crude and tend to concentrate solely on random variations of the tuneable parameters. Further work is needed to develop stochastic physics schemes that are better at representing model errors, including formulation errors.
- Intelligent diagnostics (3) Diagnostic techniques (to be turned into common diagnostic packages) need to be developed, and in particular for precipitation. The space-time scales at which LAMs can be on average considered reliable should be assessed, along with their seasonal and geographical dependence. The usefulness/need to re-aggregate predicted precipitation from very high resolution models for further hydrological models should be considered. Attention should be paid to specific diagnostic for near-surface parameters and derived parameters such as fog, visibility, cloud types and height. Feature-based diagnostic techniques are also relevant for short-range forecasts.
- Single LAM Ensemble intercomparison (3). Although it is not directly part of TIGGE, the TIGGE-LAM database will facilitate intercomparison between different LAM ensemble prediction systems (e.g., relative performance for specific processes such as convection). This can be used to inform developers of each EPS to enable them to address specific shortcomings.

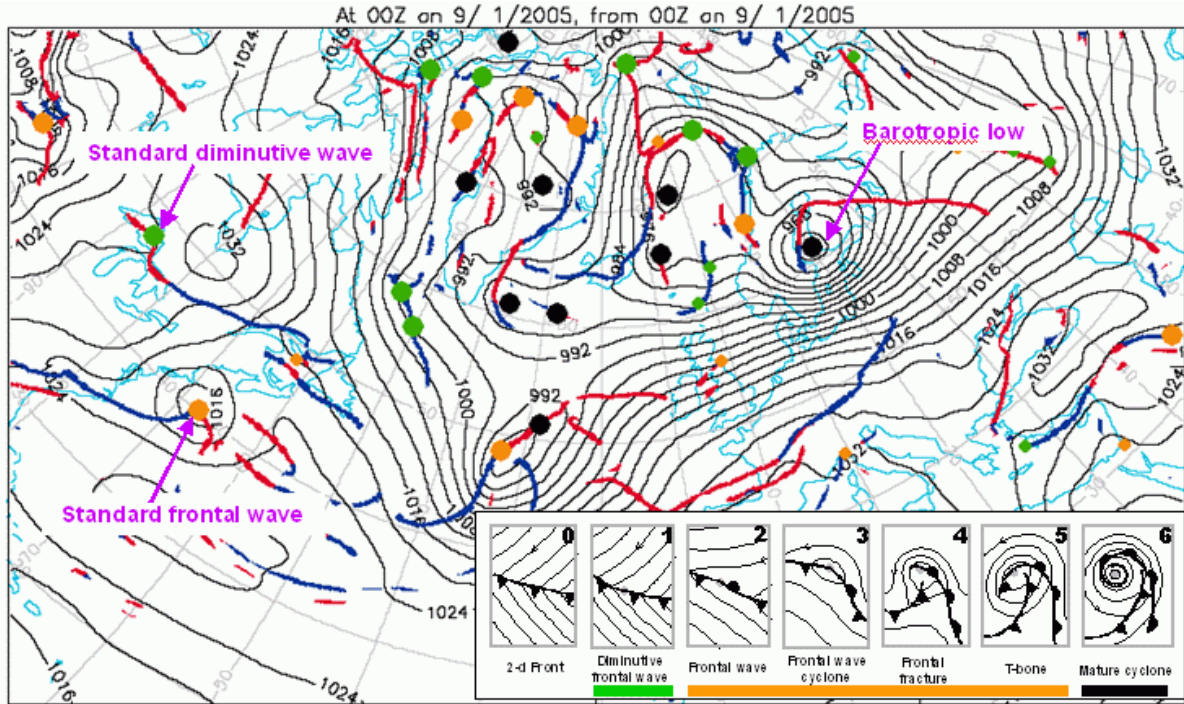


Figure X1 Example of objectively identified fronts and cyclonic features, based on ECMWF EPS data from 00Z on 9<sup>th</sup> January 2005. The different colours marking cyclonic features indicate different stages in their life-cycle, as shown in the inset.

GWL Probability Table (Number of GWL Events summed over all ensemble members each day)  
initialised at 12 UTC on 05 September 2006

GWL	6 Sep	7 Sep	8 Sep	9 Sep	10 Sep	11 Sep	12 Sep	13 Sep	14 Sep	15 Sep	16 Sep	17 Sep	18 Sep	19 Sep	20 Sep	Description
WA	1	1	1										1	1	2	Anticyclonic Westerly
WZ										1	2	2	2	1	3	Cyclonic Westerly
WS																South-Shifted Cyclonic Westerly
WW				1		2	3	5	6	5	5	4	3	3		Maritime Westerly (Block E. Europe)
SWA							1	2	2	3	3	4	3	1		Anticyclonic South-Westerly
SWZ										1	3	3	3	5	3	Cyclonic South-Westerly
NWA	23	23	21	14	1											Anticyclonic North-Westerly
NWZ																Cyclonic North-Westerly
HM		2	5	5	4	3	2	2	1							High over Central Europe
BM							1	2	2	2	2	2	2	2	2	Zonal Ridge across Central Europe
TM																Low over Central Europe
NA																Anticyclonic Northerly
NZ																Cyclonic Northerly
HNA																Icelandic High, Ridge C. Europe
HNZ																Icelandic High, Trough C. Europe
HB																High over the British Isles
TRM													1	1		Trough over Central Europe
NEA																Anticyclonic North-Easterly
NEZ																Cyclonic North-Easterly
HFA			2	3	4	5	4			1	1					Scandinavian High, Ridge C. Europe
HFZ									1	1	1	3	2	3		Scandinavian High, Trough C. Europe
HNFA			3	4	4	3										High Norway-Iceland, Ridge C. Eur.
HNFZ																High Norway-Iceland, Trough C. Eur.
SEA		2	11	11	11	8	6	4	4	4	4	2	2	2		Anticyclonic South-Easterly
SEZ							1	1	2	2	2	1	2	1		Cyclonic South-Easterly
SA					1	1	2	1	1	1	1					Anticyclonic Southerly
SZ													2	2	2	Cyclonic Southerly
TB																Low over the British Isles
TRW																Trough over Western Europe

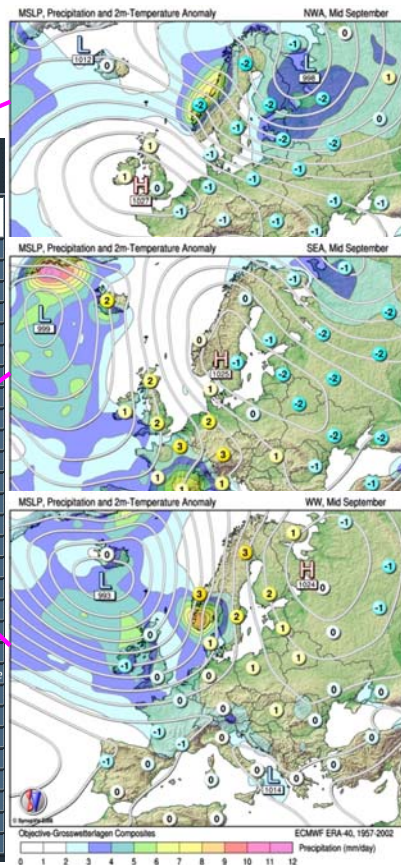


Figure X2 Example of objective identification of large-scale circulation patterns (grosswetterlagen) from the Met Office medium-range ensemble forecasts

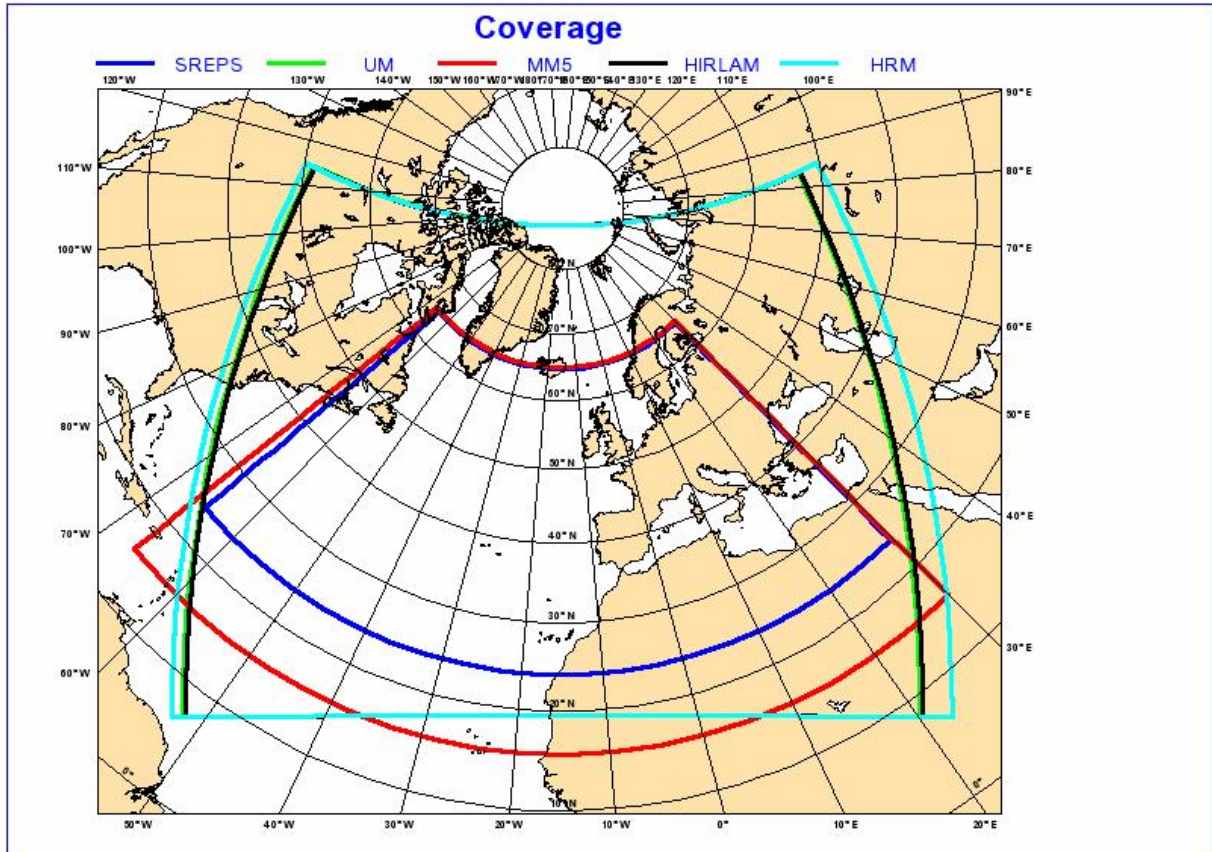


Figure X3 Coverage of the different models used by the INM SREPS project; the blue outline shows the area for which post-processed output is produced.

## **5. Organisation and Cooperation**

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At present this chapter exists only as a skeleton, to indicate where plans need to be made. It is hoped that the priorities listed in the previous chapters will provide a constructive basis for future discussions.

### **a) Ongoing organisation of THORPEX European Regional Committee**

1. Executive Committee – co-chairs + 4 or 8 WG chairs + Ex officio (EUMETNET, EUMETSAT, IPO)
2. Special sessions at conferences such as EGU and EMS
3. Side meetings for open discussion at conferences

### **b) Links to THORPEX Regions**

1. Africa
2. North America

### **c) Links to external organisations**

1. EUMETNET
2. EUCOS
3. SRNWP
4. EUMETSAT

### **d) Participation of East-European countries**

1. The participation of the East-European countries in THORPEX lies in their best interests, as it would allow them for preparation to use effectively and flexibly (according to their particular needs) advanced future forecasting tools (which will have increased meteorological value and will respond much better to the needs of users) and serve better their national communities.
2. This participation would also serve other THORPEX participants, increasing the overall scientific potential of the project, and providing access to local knowledge.
3. THORPEX can significantly help in building scientific groups, capable of participating in research and development tasks of the project and to respond to national needs, via promoting cooperation on all significant levels: national (involving close cooperation between national meteorological services, national research institutes and universities), sub-regional (involving cooperation between East-European countries) and European.
4. European funding for regional cooperation and growth can be used to support and augment the cooperation, allowing to establish such scientific groups and allowing their further development.