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UPDATE ON THORPEX: A GLOBAL ATMOSPHERIC RESEARCH PROGRAMME

(Submitted by the Secretariat)

Summary and Purpose of Document

The purpose of the document is to update the Expert Team on the status of development of THORPEX since the previous Expert Team meeting with regard to GOS issues.

Appendices:

A. Extract from THORPEX ICSC-3 Final Report
B. Science questions where THORPEX can help The CBS OPAG-IOS ET-ODRRGOS Find Answers
C. THORPEX International Research Implementation Plan Draft – 1 June 2004 – Selected Sections

References: THORPEX International Science Plan, Draft Implementation Plan, ICSC-3 Report and other documents may be accessed via Internet at the following URL: http://www.wmo.int/thorpex.

ACTION PROPOSED

The meeting is invited to take into consideration the report in its deliberations.

DISCUSSION

BACKGROUND

1. On its previous session (November 2003, Geneva) the Expert Team on ODRRGOS discussed THORPEX and its North Atlantic experiment. In response to this briefing and the relevant decisions of CBS MG-4 the ET agreed particularly:
   - to take part in developing the THORPEX International Research Implementation Plan (2004),
   - to assist in connecting the THORPEX science opportunities as defined in the International Science Plan with future operational requirements and to provide specific NWP requirements from the operational NWP communities, and
   - to consider THORPEX results in WMO Global Observing System redesign activities.

2. The ET drafted an initial list of scientific questions that THORPEX could help to answer. The ET encouraged THORPEX to make its experimental data sets available to all NMHSs (through GTS and other means) and to allow NWP centers access to the full set of experimental data for post experiment analysis. These efforts will be supported by WWW.

3. The ET agreed on following action:

   With a strategy to learn from THORPEX, CBS representatives to request THORPEX to provide CBS with a strategy for an operational targeted observing system. CBS representative to THORPEX ICSC meeting (December 2003) to bring this forward including meteorological situations in which targeting could be useful, observing systems to be activated.

3. Mrs A. Simard, chair of CBS OPAG on DPFS, represented CBS at the 3rd ICSC meeting (December 2003, Montreal) and presented recommendations made by ET-ODRRGOS. ICSC-3 discussed cooperation with CBS (relevant sections of the ICSC-3 final report are given in Appendix A). The ICSC requested that co-chairs of ISSC lead effort in examining CBS questions to respond, which issues THORPEX would address in a course of its implementation. The above recommendations and questions were further considered by THORPEX ICSC and are taken into account in preparation of THORPEX International Implementation Plan (Appendix B).

4. The ICSC-3 approved THORPEX International Science Plan and established an ad hoc Expert Group for development of THORPEX Implementation Plan (EG-TIP) composed of senior and well-recognized members of THORPEX community, including CBS, actively participating in planning and development of the programme. The ICSC highly appreciated active involvement of CBS to THORPEX implementation planning process.

5. The EG-TIP is chaired by Dr David Rogers. Dr Jim Purdom serves as focal point for tasks most relevant to GOS:
   - Observing Systems: “Carry out field-demonstrations of prototype remote - sensing systems for future airborne and satellite deployments.”
   - Data Assimilation and Observing Strategies: “Improve the use of polar orbiting and geostationary satellite observations.” Improve the use of visible, infrared and water vapour image sequences to infer wind information.

6. The EC-LVI (June 2004, Geneva) noted with satisfaction the active collaborative efforts between CAS and CBS, which led to broadening and strengthening of cooperation between the two Commissions on the involvement of WWW in THORPEX. Recognizing that THORPEX was very relevant to the WWW research needs in all programme areas, the Council welcomed the CBS decision to take part in the development of the THORPEX International Implementation Plan. In that connection the Council appreciated that the president of CBS acted as a member of THORPEX ICSC and that the chairs of CBS OPAG/IOS and OPAG/DPFS were members of the EG-TIP. The Council requested the presidents of CAS and CBS to pursue further collaboration and to consider further practical steps to ensure effective implementation of the programme for the benefit of all Members (general summary 5.1.6).

7. The EC-LVI also stressed the important inputs that THORPEX was expected to make to the GOS redesign activities and welcomed the coordinated efforts of CAS and CBS in the organization and implementation of observing systems envisaged by THORPEX (general summary 3.1.4)

THORPEX INTERNATIONAL RESEARCH IMPLEMENTATION PLAN (TIP)

8. The THORPEX International Research Implementation Plan (TIP) will guide the execution of the programme for the next decade. TIP is under development and will be prepared by the end of 2004.

9. TIP builds on the THORPEX International Science Plan, regional plans and new opportunities to rapidly accelerate improvements in forecasting and the use of improved forecasts in social and economic decision-making.

10. General objectives of the TIP:

- Define THORPEX deliverables based on the expectations of the operational meteorological community, research scientific opportunities and the availability of resources;
- Follow the THORPEX International Science Plan and the regional science plans for Asia, Europe, North America and other regions or nations whenever their contribution to THORPEX is defined;
- Define milestones and deliverables from each of the THORPEX participants;
- Identify opportunities for collaboration between THORPEX and other programmes;
- Define decision points and the necessary steps to carry out THORPEX research and development;
- Facilitate the transition of results to operations within the Members' organizations.

11. Specific objectives of the TIP

- Connect the science opportunities of the International Science Plan with validated future operational requirements,
- Determine a key set of requirements from the operational community;
- Identify regional priorities that are consistent with the THORPEX International Science Plan and the operational NWP requirements and reconcile the regional programs to the international plan;
- Identify and compensate for gaps in the science planning;
- Identify funding requirements and funding of key programme elements, including personnel, equipment for field programmes and other research activities;

- Establish a roadmap for THORPEX activities;
- Integrate THORPEX with other relevant programs and initiatives, such as WWW, WCRP, WMO Space Programme, WMO Programme on Natural Disasters Reduction and Mitigation, International Polar Year 2007-2008, Asian Pacific Climate Programme, as well as with other organizations (ICSU, IOC) and cooperative programmes identified;
- Ensure coincidence between THORPEX and GEO framework;
- Establish clear roles and responsibilities for all of the actors in THORPEX;
- Identify national commitments to key THORPEX activities;
- Assess risks associated with the project and develop a mitigation strategy to ensure that the THORPEX goals as met.

12. Four major areas are being addressed by the TORPEX:

- Predictability and Dynamical Processes
- Observing Systems
- Data Assimilation and Observing Strategies
- Social and Economic Impacts

13. Areas of specific interest of EG-ODRRGOS:

- **Observing Systems** Task 5.2: Carry out field-demonstrations of prototype remote -sensing systems for future airborne and satellite deployments.
- **Data Assimilation and Observing Strategies** Task 6
- Predictability and Dynamical Processes Task 4.1.2: Determine the influence of flow regimes on the climatology of forecast skill;
- Social and Economic Applications Task 7.1 Social and Economic Value of Weather Forecasts.

14. The First Draft THORPEX Implementation Plan was prepared on 27 June 2004 and distributed to ICSC for open revision (deadline 15 August), including vice President of CBS Prof. Geerd Hoffmann. It is expected that draft would be broadly circulated including relevant groups of CBS OPAGs.

15. Second draft will be discussed by EG-TIP on its meeting in Beijing, China 13-15 September and prepared in October. Final draft will be prepared in November. It will be presented to CBS-XIV. ICSC will consider approval of the plan on its 4 session (December 2-4, Montreal).

16. Selected sections relevant to ET-ODRRDOS are presented in Appendix C. Full electronic PDF version of the Plan is available on the web www.wmo.int/thorpex - Implementation.

17. The Expert Team is welcomed to review the plan and provide input through Dr Jim Purdom.

APPENDIX A

(Extract from THORPEX ICSC-3 Final Report)

4. COOPERATION WITH OTHER PROGAMMES AND ORGANISATIONS *(Agenda item 4)*

4.1 Co-operation with WMO WWW *(Agenda item 4.1)*

4.1.1 Representative of CBS Mrs Simard briefed the ICSC on the major components of WWW: the Global Observing System (GOS), the Global Telecommunication System (GTS) and the Global Data-processing and Forecasting Systems (GDPFS). These systems are managed by the WMO Commission for Basic Systems (CBS, Acting President Mr. A. Gusev) through its Open Programme Area Groups (OPAG): OPAG on Integrated Observing Systems (IOS, Chair Dr. J. Purdom), OPAG on Information Systems and Services (ISS, Chair Prof. G.-R. Hoffmann), OPAG on Data Processing and Forecasting Systems (DPFS, Chair Mrs A. Simard) and OPAG on Public Weather Services (PWS, Chair Mr K. O'Loughlin).

4.1.2 The ICSC was pleased to learn about the progress achieved in strengthening collaboration between CBS and CAS on THORPEX and on both Commissions efforts to appropriately involve WWW in planning and implementing THORPEX. The ICSC noted that CBS Management Group (MG) unanimously expressed high appreciation of THORPEX as potentially very relevant to the WWW research needs in all its programme areas. Since all CBS OPAGs were to be involved in THORPEX, it was agreed that the CBS vice-president would be the most suitable high-level link. Until the election of the vice-president (IV quarter 2004), the president of CBS would act as the link to THORPEX. On behalf of the president of CBS Mrs A. Simard represented the Commission at the ICSC-3 meeting.

4.1.3 The CBS-MG particularly agreed that THORPEX provides opportunity, in particular, to exploit targeted in-situ and space-based observations, the ability to test efficacy of a multi-model global ensemble system (with leading role of WMCs, ECMWF and in collaboration of NWP centres world-wide) and to assess the value of new decision support tools, thus having great potential to contribute to future GOS and NWP system. From the other side, THORPEX success would be assured through matching its efforts with well defined operational forecasting requirements, and transforming its scientific opportunities into specific implementation and transition plans. In this connection it was noted that that a significant role for the WWW will be in the implementation of the results from THORPEX. Therefore, evolution of the THORPEX would lead to the integration of scientific results into operational practices of NMHSs.

4.1.4 The ICSC welcomed the CBS MG decision to call for OPAGs' contribution to the 2^{nd} version of the International Science Plan. The ICSC noted with appreciation that CBS MG decided to take part in the development of THORPEX International Research Implementation Plan.

4.1.5 The TOSTs efforts will be strongly supported by the WWW and their results are considered as substantial input to CBS efforts on redesigning GOS. The CBS-MG encouraged THORPEX to make its experimental data sets available to major NWP centers (through GTS and other means) to allow their use in real time or for sensitivity studies and to other interested NHMSs for research. The ICSC noted that CBS MG emphasized the need to involve all WMO Regions in THORPEX experiments and that Southern Hemispheric THORPEX Observing-System Tests (TOSTs) (including South America, Africa, Australia and South Pacific) were essential components of a global campaign.

4.1.6 The ICSC noted with pleasure further progress achieved in collaboration with CBS. The Expert Team on the Observational Data Requirements and the Redesign of the Global Observing System strongly supported the THORPEX activities. It was felt that THORPEX could make important contributions to the redesign of a cost-effective GOS including strategies on how to introduce observation targeting into operations. The Expert Team prepared a set of questions (see Annex XI) that THORPEX could help to answer.

Decision 3: The ICSC requested that co-chairs of ISSC lead effort in examining CBS questions to respond, which issues THORPEX would address in a course of its implementations.

Action ICSC-3/05: Co-chairs of the ISSC to examine, in consultation with THORPEX experts, the CBS OPAG-IOS ET-ODRRGOS questions.

4.1.7 The ICSC noted with appreciation that CBS will encourage NWP centres to actively support THORPEX researches and experimentations. The Global Data-Processing and Forecast System centres are in the forefront for operational data assimilation, model development and ensemble forecasting. Each of these activities is important to achieving the goals of THORPEX.

Decision 4: The ICSC agreed that a link with the OPAG-DPFS Expert Team on Ensemble Predictions Systems was needed.

4.1.8 The Global Telecommunications System provides the primary facilities for the dissemination of observations and products. It links the several forecast centres and could be instrumental in exchanging information on many aspects of THORPEX. ICSC was invited to provide THORPEX requirements for input to development of the future WMO Information System, in particular with respect to the exchange of large volume of data (e.g. satellite observations, multi model ensembles data).

4.1.9 ICSC agreed that it would be also feasible to establish link with the OPAG PWS to join efforts on assisting NHMSs in providing reliable weather services in support of safety of life and property.

Decision 5: The ICSC agreed that a link with the OPAG-PWS would be feasible.

Action ICSC-3/06: Chair of ICSC to consider a suitable links between THORPEX and the OPAG-DPFS Expert Team on Ensemble Predictions Systems as well as with the OPAG-PWS and to make subsequent recommendation to the president of CAS.

4.1.6 The ICSC emphasized an important role of CBS in THORPEX research implementation and a major role of CBS in further operational implementation of THORPEX research results. It therefore invited CBS experts to take active part in planning of THORPEX implementation.

Decision 6: To ensure active involvement of CBS in THORPEX planning and implementation and to facilitate further operational implementation of THORPEX results.

Action ICSC-3/07: Chair of ICSC to invite CBS experts to take part in THORPEX implementation planning activities.

APPENDIX B

SCIENCE QUESTIONS WHERE THORPEX CAN HELP THE CBS OPAG IOS ET-ODRRGOS FIND ANSWERS

The ET-ODRRGOS put forward for consideration the following questions or suggestions for investigation or research in relation to THORPEX. Those marked in **bold are being addressed by THORPEX research** and reflected in first draft THORPEX Implementation Plan.

1. **What are the specific observing requirements for high-impact weather?**
2. **How should we specify the adaptive ("on the day") component of the GOS?**
3. What are the optimal spatial and temporal resolutions of AWS observation networks (e.g. value of 1-minute resolution data)?
4. **Regarding AMDAR:**
    - **What are the geographic areas where AMDAR has most input/value?**
    - **What is the optimal vertical resolution of AMDAR profiles?**
5. What constitutes validation of a "good" forecast for mesoscale NWP?
6. **What is the contribution of the Siberian Rawinsonde network to NWP and what alternative network configurations should be considered?**
7. **What are the key observation system configurations that would help to identify the sources of cyclogenesis in tropics?**
8. What is the contribution of stratospheric data on tropospheric forecasting skill?
9. What is the contribution of stratospheric in situ observation systems on tropospheric forecasting skill?
10. What is the contribution of surface soil moisture data on tropospheric forecasting skill?
11. **What are the forecasting capabilities in relation to high intensity rainfall (e.g. flooding of Yangtze River)?**
12. **What are the global downstream effects of observation targeting?**
13. What is the impact in improved assimilation in numerical models of improved cloud characterization.
14. **What strategies can CBS learn from THORPEX on how to introduce observation targeting in to operations, in particular if more than one WMO member is to be involved in the decision making process about the deployment of the special observations.**

APPENDIX C

THORPEX INTERNATIONAL RESEARCH IMPLEMENATION PLAN
DRAFT 1 June 2004

SELECTED SECTIONS

Introduction

1. Cg-LIV established THORPEX as an international research programme to accelerate improvements in the accuracy of 1-day to 2-week high-impact weather forecasts. Research topics include: global-to-regional influences on the evolution and predictability of weather systems; global observing system design and demonstration; targeting and assimilation of observations; and social and economic benefits of improved weather forecasts.

2. THORPEX establishes a contemporary organisational framework to address global weather research and forecast problems whose solutions require international collaboration between academic institutions, operational forecast centres, and users of forecasts.

3. THORPEX will contribute to the development of future operational interactive forecast systems.

4. THORPEX is developed and implemented as a part of the WMO World Weather Research Programme (WWRP). The international co-ordination for THORPEX is established under the auspices of the WMO Commission on Atmospheric Sciences (CAS) through its Science Steering Committee for the WWRP. The THORPEX International Science Steering Committee (ISSC) develops the core research objectives with guidance from the THORPEX International Core Steering Committee (ICSC) whose members are either nominated by Permanent Representatives of countries with the WMO or appointed as representatives of institutions and organisations. THORPEX is organised regionally with each region interacting to create the global programme.

5. The THORPEX International Programme Office (IPO) is established by WMO as an integral part of the Atmospheric Research and Environment Programme (AREP) Department of the WMO Secretariat and under the supervision of the Director of AREP Department.

6. The THORPEX programme activities (THORPEX development, implementation and execution as specified by the ICSC) are supported through voluntary contributions of the Governments of the WMO Members participating in THORPEX including donations to the THORPEX Trust Fund established by WMO.

7. The THORPEX Research Implementation Plan (TIP) is developed on behalf of the ICSC by a group of experts composed of members of the THORPEX community actively participating in planning and development of the programme in accordance with the Terms of Reference (Annex I). The TIP group works in close cooperation with THORPEX members, Regional Committees, the International Programme Office, and other relevant bodies.

8. The THORPEX International Science Plan (Shapiro and Thorpe, 2004), hereafter the Science Plan, is the basis for the TIP. The Science Plan establishes four interconnected sub-programmes: Predictability and Dynamical Processes; Observing Systems; Data Assimilation and Observing Strategies; and Societal and Economic Applications.

9. Each of the Science Plan sub-programmes defines a series of research tasks. The TIP summarizes the expected outcomes derived from completion of these tasks; it considers how these tasks may be accomplished, the levels of international cooperation required; the time required to completion; and an assessment of the resources required.

10. The TIP defines a global grand ensemble to prototype a multinational, multi-model ensemble prediction system. The TIP identifies a series of demonstration projects to establish the potential benefits of prototype *interactive forecast systems*.

11. The TIP defines the contribution of the THORPEX programme to the International Polar Year (IPY).

12. The TIP connects the science opportunities of the International Science Plan with validated future operational requirements

13. The TIP responds to a key set of requirements from the operational forecast community.

14. The TIP Identifies priorities developed by THORPEX Regional Committees that are consistent with the THORPEX International Science Plan and the operational NWP requirements and reconcile the regional programs to the international plan.

15. The TIP identifies requirements for funding of key programme elements, including personnel, equipment for field programmes and other research activities.

16. The TIP establishes a roadmap for THORPEX activities.

17. The TIP integrates THORPEX with other relevant programs and initiatives, such as WWW, Marine Meteorology and Oceanography Programme (MMOP), WCRP, WCP/WCAC, WMO Satellite Programme, WMO Programme on Natural Disasters Reduction and Mitigation, International Polar Year 2007-2008, Asian Pacific Climate Programme, as well as with other organizations (ICSU, IOC) and cooperative programmes identified;

18. The TIP identifies THORPEX as a user of the Global Earth observing System of Systems (GEOSS).

19. The TIP establishes clear roles and responsibilities for all of the participants in THORPEX.

20. The TIP summarises national commitments to key THORPEX activities.

1 Core Research Objectives
From THORPEX International Science Plan (Shapiro, Thorpe et al., 2004)

21. Contribute to the design and demonstration of *interactive forecast systems* that allow information to flow interactively between forecast users, numerical forecast models, data-assimilation systems and observations to maximise forecast skill. As an example, targeted observing strategies incorporate dynamical information from the numerical forecast model itself to identify when, where, and what types of observations would provide the greatest improvement to specific weather forecasts.

22. Increase knowledge of global-to-regional influences on the initiation, evolution and predictability of high-impact weather. This objective includes research on: i) the excitation of Rossby wave trains by extratropical cyclogenesis, large-scale topography, continent/ocean interfaces, and organised tropical and extratropical convective flare-ups, and their role in the consequent development of high-impact weather; ii) the dependence of predictive skill on inter-annual and sub-seasonal climate variability, e.g., El Niño Southern Oscillation (ENSO); Pacific North-Atlantic oscillation (PNA); North-Atlantic Oscillation (NAO); monsoon circulations; Inter-tropical Convergence Zone (ITCZ); iii) the relative contribution to the limits of predictive skill by uncertainty in observations, data assimilation, model formulation and ensemble prediction system design.

23. Contribute to the development of advanced data assimilation systems and forecast models. This effort includes: i) improving the assimilation of existing and experimental observations, including observations of physical processes and atmospheric composition; ii) developing adaptive data-assimilation and targeted-observing strategies; iii) incorporating model uncertainty into data-assimilation systems and in the design of ensemble prediction systems; iv) evaluating the utility of multi-model ensemble prediction systems.

24. Develop and apply new methods that enhance the utility of weather forecasts through: i) the use of user-specific probabilistic forecast products; ii) the introduction of interactive procedures that make the forecast system more responsive to user needs; iii) the design of and training in the use of user-specific forecast products. This research will identify and assess the societal/economic costs and benefits of THORPEX recommendations for implementing interactive forecast systems and improvements in the global observing system.

25. Perform THORPEX Observing-System Tests (TOSTs) and THORPEX Regional field Campaigns (TReCs). TOSTs: i) test and evaluate experimental remote-sensing and *in-situ* observing systems, and when feasible, demonstrate their impact on weather forecasts; ii) explore innovative uses (e.g., targeting) of operational observing systems. TReCs are operational forecast demonstrations contributing to the design, testing and evaluation of all components of interactive forecast systems. They are organised and coordinated by regional consortia of nations under THORPEX Regional Committees (e.g., Europe, Asia, North America, South America, Africa). TReCs address regional high-impact weather events, e.g., arctic storms and cold air outbreaks; extratropical cyclones over Europe, Asia, and North America; warm-season heavy precipitation over Asia, South America and Africa; organized equatorial convection flare-ups; tropical-to-extratropical cyclone transformations. TReCs require collaboration between Regional Committees. THORPEX will explore the opportunities to carry out TReCs in conjunction with major international programmes such as the African Monsoon Multi-disciplinary Analysis (AMMA) and the International Polar Year (IPY).

26. Demonstrate all aspects of THORPEX interactive forecast systems, over the globe for a season to one year, to assess the utility of improved weather forecasts and user

products. This includes the THORPEX *Interactive Grand Global Ensemble, TIGGE*, which will integrate developments in observing systems, targeting, adaptive data assimilation, model improvements and a multi-model/multi-analysis ensemble prediction system. This global demonstration will be a complementary element within the World Climate Research Programme (WCRP) Strategy 2005-2015: Coordinated Observation and Prediction of the Earth System (COPES), which itself addresses the observational and modelling requirements for climate prediction.

27. Facilitate the transfer of the results of THORPEX weather prediction research and its operational applications to developing countries through the WMO and other multilateral and bilateral mechanisms.

2 General Approach to Experimental Design

28. THORPEX is planned internationally, where each region contributes to the global aspirations and objectives of the programme. It includes regional implementation in response to the requirements and priorities of the regions. Collaborations between regions contribute to the advances in basic knowledge, of atmospheric processes and predictability, and to the development of demonstration projects, trials and benchmarks of new forecasting techniques.

29. THORPEX addresses fundamental research issues; it develops new forecasting techniques; explores new data assimilation and observational techniques, and tests, evaluates and demonstrates new forecast, observing, data assimilation, and decision support systems. The combination of basic and applied research conducted within the framework of, and in collaboration with, operational services ensures that THORPEX research findings can be readily transferred and translated to operations enabling timely improvements in the operational systems.

30. THORPEX is the key meteorological component of several external multidisciplinary programmes; e.g., the International Polar Year and proposed joint weather and climate programmes.

31. THORPEX activities are supported by the research and operational branches of National Meteorological and Hydrological Services in the participating regions; by the basic science agencies; by space agencies; and by organisations concerned with the application of science to societal and economic development. Resource mobilisation is discussed in Section 14.

3 Predictability And Dynamical Processes Tasks
From THORPEX International Science Plan (Shapiro, Thorpe et al., 2004)

32. **Predictive Skill**

- **Investigate the effect of dynamical and physical processes on forecast skill:** This objective will address dynamical and physical processes operating on various scales that contribute to errors in high-impact forecasts. Studies of Rossby wave excitation and subsequent dispersion will consider: i) the skill of forecast systems to predict Rossby wave amplitudes, ray-paths and group velocities; ii) the initiation of Rossby wave trains by organized tropical convection, extratropical cyclones and large-scale topography; iii) the initiation of tropical convection by Rossby wave-trains propagating from extratropics into the tropics; iv) the influence of physical processes (parameterised and explicit). Coherent structures, such as discrete anomalies of potential vorticity (PV), and the extratropical transition of tropical cyclones, will be investigated. Assessments will be made of the role of global teleconnections, e.g., tropical-extratropical interaction, including the factors involved in their initiation and predictability.

- **Determine the influence of flow regimes on the climatology of forecast skill:** THORPEX will assess sub-seasonal, seasonal and inter-annual variability of forecast error, ensemble spread and the distribution of observationally sensitive regions. This will include determining the dependence of this variability on flow regimes such as i) zonal or blocked states; ii) phases, and sub-seasonal variability of prominent phenomena and major teleconnections, e.g., MJO, PNA, ENSO, NAO, and QBO; iii) Rossby wave propagation and predictability will be investigated. The skill of EPS forecasts depends on the meteorological regime. For example, the skill in predicting extratropical cyclones over the eastern Pacific Ocean differs depending on the phase of ENSO (e.g., Shapiro et al. 2000). This is referred to as *regime-dependent evaluation* of forecast skill. THORPEX will fully explore this regime dependence, as this will provide substantial input to an improved EPS design.

- **Assess predictive skill at all forecast ranges, including potential predictability:** Key questions concern what are the limits of predictability and what determines these limits. THORPEX aims to address these issues, including an assessment of the various limits of predictability appropriate to defined forecast attributes, and through this assessment explore new forecasting strategies to extend these limits. Improved methods of generating ensembles will be used to investigate potential predictability, under the perfect model assumption, utilizing state-of-the-art operational forecast models to assess the potential for further improvements in predictive skill.

33. Expected Outcomes

- Advanced knowledge of the effects of the aforementioned dynamical and physical processes is essential for (i) the assessment of predictive skill and potential predictability (ii) studying the relative importance of dynamical processes (primarily related to sensitivity to the initial conditions) and the physical processes (primarily related to model errors) in the degradation of predictive skill. We expect that these efforts will lead to forecast improvements by:

    - Identifying potentially predictable forecast features

    - Improving knowledge and techniques, required to exploit the potential predictability and

- Identifying geographical regions, in which the deployment of in-situ and remote-sensing sensors and/or the improved use of existing observations is likely to lead to improvements in high-impact forecasts.

❖ Atmospheric predictability is state dependent, and because of this dependence, the efficacy of ensemble prediction can be enhanced by adaptively modifying the ensemble strategy to account for the modified nature of the prediction problem associated with particular atmospheric states. Ground breaking research has already given hints as to what may be accomplished. Of great interest in THORPEX is the dependence of predictability and forecastability upon large scale, long-lived flow anomalies, which alter the strength, and positions of stormtracks and the characteristics of the weather systems in these tracks. Teleconnection patterns like the PNA, NAO are examples of such anomalies but there exits other higher frequency anomalies, which also have significant impact on the tracks of cyclones and their intensity; e.g. the Madden-Julian oscillation in the tropics and blocking and zonal flow anomalies in mid-latitudes. Because ENSO is a pre-conditioner for many of these long-lived anomalies, the development of the understanding of the role of ENSO in modifying predictability must also be included in this task.

- This research will give information on the climatology of predictability and forecastability given a particular macro-state of the atmosphere and ocean. The specification of macro-state will include the amplitude and phase of teleconnection patterns (PNA, NAO, AO etc), the intensity of blocked and zonal flow indices in middle and high latitudes, the phase and amplitude of the MJO and ENSO and the extent and coherence of tropical convection.

- It will also determine the importance of rapid transitions in the macro-state in the predictability of weather. This information will be used to tailor ensemble prediction systems to the macro-state in order to optimize the probabilistic information obtainable for the expected range and severity of weather events conditional on the macro-state and its stability .

- Through the understanding of observationally sensitive regions in intra-seasonal and inter-annual context, provide long lead-time planning information to CBS and WMO Members for use in resource allocation with respect to GOS attributes

34. Timescale

❖ This activity will take place throughout the programme. It will take approximately two years to develop an understanding of the relationships between macro-states and predictability and forecastability. One year to design modifications of ensemble methods and an additional year to test in quasi-operational setting.

35. Approach

❖ The research efforts will support both the planning of the observational campaigns and the exhaustive scientific analysis of the observed information. Modelling is expected to play an important role in both components. While most experiments will be carried out with operational (or similar quality) models, experiments with simplified models are also expected to play some role in developing conceptual models and testing new scientific ideas and practical techniques. The use of sophisticated models is essential for minimizing the effect of model errors on the results.

- The research strategy will examine several approaches to the question of macro-state dependency of predictability and forecastability. The examination of predictability can begin studying ensembles of perturbations of climate integrations using AMIP-like prescribed SSTs. Forecastability questions are to be addressed using the historical re-forecast methodology of Whitaker. Ensembles should be constructed using the methods of the operational centres and additional methodologies (e.g., large Monte-Carlo ensembles and ensembles from ensemble filters). Bred vector/singular vector studies and adjoint sensitivities can also be brought to bear on these topics. Statistical synoptic analyses of the conditional distributions of ensemble predictions will point out the need and requirements of new ensemble methodologies. Need to deal with (conditional) systematic errors; e.g., MJOs poorly represented in models, geographic phases of climate anomalies systematically off.

36. Level of International Cooperation

- A loose federation of interested researchers with ties to the operational centers is needed. The academic research community can play a role in this topic of research. coordinated experiments under an umbrella project like the seasonal forecasting comparisons (Shukla {REFERENCE?}) and PROVOST {EXPLAIN?} can be the international coordinating vehicle.

37. Key Players

- The task will be predominantly carried out by the academic community, though the support of the operational centres in making the models available, and collecting and distributing the data is essential. In the United States, for example, we hope that NSF will play a leading role in supporting the research of the academic community. Support is needed to build the computational infrastructure needed for experimenting with sophisticated models at academic institutions, should also be considered by the funding agencies. The operational centres may also need some financial help to build the storage capacity necessary for the collection of data, and to provide at least a modest level of model support to the academic community. Free and open exchange of data between the participants is a key requisite.

38. Infrastructure Requirements

- Computational resources. Access to models and infrastructure (adjoint tools, re-forecast and AMIP databases, access to experimental database)
- Open access to data

39. Links to other programmes

- This will link with WMO CBS as well as the various satellite operators (CEOS and CGMS) and sensor developers (through CIMO). The key link being through the identification of what needs to be measured and to what precision.

- WWW, GCOS, WCP

40. **Ensemble Predictions**

- **Investigate the role of model errors in forecasting.** This research will involve the quantification of **the contributions of initial condition and model uncertainty to forecast errors**: The development of numerical modelling and ensemble perturbation techniques forecast systems depends critically on accurate estimates of the sources of forecast error attributable to initial condition uncertainty and forecast-model uncertainty. Research will quantify the influence of all sources of forecast error and their associated mechanisms for growth, on different space and time scales and for different variables and different meteorological phenomena. This includes the uncertainty associated with numerical schemes and physical parameterizations. Improved estimates of the relative contribution of the various sources of forecast error growth will lead to improved probabilistic forecasts and products. The focus of this research should be the identification of the different sources of model related errors that can lead to model improvements in terms of (i) either correcting the problems, or if that is not possible, (ii) modifying the models so when they are used in an ensemble mode, they will properly represent model related uncertainty.

- **Investigate the effects of initial-condition uncertainty on forecasts:** Forecast errors can grow rapidly upscale from initial uncertainties in the small-scale motions. However, analysis and forecast uncertainties are dominated by slower-growing, but more energetic, larger-scale motions. THORPEX will address the relative roles of these, and other sources of initial uncertainty in limiting forecast skill. Knowledge accumulated in these studies will be used in the further development of initial perturbation schemes for ensemble forecast systems.

- **Develop improved ensemble-prediction systems:** Improved ensemble perturbations are required to accurately represent uncertainty in all aspects of the initial state, including land and ocean surface conditions. Advanced methods must be developed to account for case dependent variation in analysis uncertainty; the effect of un-parameterized, unresolved phenomena on the resolved scales in ensemble forecast systems; and uncertainties in forecast model formulation, including numerical and parameterization uncertainties. This research will include investigations of multi-model and multi-parameter ensemble prediction methods, as well as stochastic parameterizations.

- **Explore the potential for using adaptive methods in ensemble generation.** Research related to the configuration of ensemble forecasting systems, with the possibility of changing the configuration as a function of weather regime or user requirements will be investigated. Issues to be addressed include the optimal choice between resolution vs. membership, and weather choices regarding the number of ensemble members etc can be made on an adaptive basis.

- **Multi-centre ensemble research.** Recent research shows that there is useful additional ensemble spread contributed by multi-model or multi-parameterization ensembles. However, these techniques are mostly *ad-hoc*, and it is not clear if their benefit is from the diversity of forecast models, the differences in initial conditions provided by different forecast systems, the cancellation from different biases in the model used, or a combination of all of the above. This research will contribute to the development and evaluation of an ensemble system that is based on a combination of ensemble generated by various NWP centers. Such an approach has a potential benefit of using different techniques to for data assimilation, ensemble generation, and NWP modelling, thus providing additional ways of sampling forecast uncertainty. Multi-model, multi-analysis and multi-national ensemble, referred to here as the THORPEX *Interactive Grand Global Ensemble, TIGGE (See* *Section 8* *for the technical details on the design and implementation of TIGGE)*. It is anticipated that a prototype TIGGE Experimental Prediction Centre will be established to produce ensemble predictions of high-impact weather, wherever it may occur, on all predictable time-ranges, with easy access for the global user community.

41. Expected Outcomes

- Provide guidance for the design of improved observation systems and observing strategies, addressing questions such as whether observations should be targeted in localized regions of rapid forecast error growth, or whether it is preferable to reduce initial uncertainty at the larger scales by distributing observations over broader areas?

- Improve operational ensemble forecast systems in terms of their statistical reliability (reduced bias) and resolution (higher skill). This in turn will result in enhanced socioeconomic utility of forecasts to be tested in various demonstration projects.

- Validate the TIGGE prototype operational global multi-centre ensemble system relative to the constituent ensembles generated at individual NWP centres as well as against existing higher resolution single NWP forecasts.

42. Timescale

- Ensemble research on a continual basis.

- TIGGE related research will take place on a continual basis, initially focusing on basic issues such as bias correction of constituent ensembles before their combination into a grand ensemble, and later focusing on development of advanced user interface. The TIGGE feasibility assessment by Dec. 2004; TIGGE Planning by July 2005; Initial TIGGE limited data access by July 2006; TIGGE advanced data access by July 2007.

43. Approach

- Use existing, and develop new ensemble-based and other techniques to separate initial and model errors in NWP forecasts. Trace the source of model errors to different aspects/components of NWP models. Work on reducing identified problems by model improvements.

- Using OSSE and other techniques, study the properties of analysis errors/uncertainty. Investigate to what extent existing initial ensemble perturbation techniques represent analysis uncertainty.

- Compare existing, and develop new techniques for representing initial and model uncertainties.

- Carry out ensemble experiments to test the effect of different configurations on traditional probabilistic forecast skill and socio-economic value. Study alternative approaches for adaptive use of computational resources (eg, running higher resolution models in areas/cases of high societal impact).

- Establish 2-4 centres worldwide where multi-centre ensemble data can be deposited, archived, and made available to research and user community; Develop and use bias correction techniques to be applied on the constituent ensembles prior to their combination into a grand ensemble; Develop forecast products and advanced interactive interrogation tools to access and utilize forecast information; Establish standard verification and evaluation tools that can facilitate exchange of scientific information among different participants.

44. The THORPEX announcement of Opportunities for Access to Data from Operational Centres

- There exists a great wealth of data from operational forecasting system in the leading NWP centres of the world. To name only a few the NCEP/NCAR and ERA-40 reanalyses, the archive of operational analyses and forecasts and very extensive sets of research forecasts (e.g. The DEMETER forecasts at ECMWF), are underexploited by the academic community. There has been a perception that access to these data is difficult. This has been true in the past, but it is changing rapidly.

- THORPEX will promote a better use of these data by adopting an approach similar to the promotion of satellite datasets by space agencies. It will issue a generic announcement of opportunity, containing a precise catalog of available data in all participating Centres, a list of scientific issues that deserve particular research (with a clear link with THORPEX scientific questions).

- Proposals for investigations using particular datasets available at the NWP Centres will be invited. A THORPEX-appointed committee will rank the proposals according to THORPEX Science priorities.

- The NWP Centres will endeavour to help the best research projects in order to provide them with an effective quick and free access to the necessary data and the necessary assistance for interpretation when needed. In parallel, THORPEX will issue recommendations to funding agencies to support the corresponding proposals.

- The Announcement of Opportunity will be written under the auspices of THORPEX ICSC by a group of representatives from the participant NWP Centres, with advice from the THORPEX ISSC regarding research priorities.

- The selection of proposals will be organized on a regional basis by evaluation panels appointed by the THORPEX regional committees. Each participating Centre will explain how it will help the successful applicants to develop their research.

45. Level of International Cooperation

High. Significant interaction and exchange of products between operational centres and between research centres.

46. Key Players

- Major research and operational centres,
- Academic communities

47. Infrastructure Requirements

- Identify existing global analysis / reanalysis and forecast / reforecast data bases that can be used in this part of the THORPEX research. Create table with short description and specifics of available data sets, along with contact information and access and cost information. Examples: NCEP/NCAR global reanalysis; NCEP regional reanalysis; ECMWF global reanalysis (1-2); CDC reforecast ensemble data set; etc

- Establish 2-4 centers for TIGGE data depository and data access. Issues to be addressed: (1) Participation. (a) Agreement among major operational centers to share their ensemble forecasts for research applications; (b) Permission from participating centers to allow the use of their ensemble in generation of forecast products in TIGGE, to be used in THORPEX demonstration projects; (c) Permission from participating centers for use of their ensemble data in operational fashion after completion of THORPEX research program; (2) Infrastructure. Indentify NWP centers interested in hosting one of the TIGGE centers; (3) Develop detailed plans regarding the configuration of the TIGGE system (how many centers contribute, how many members, what temporal/spatial resolution, how many cycles per day, etc); (4), Develop plans for needed architecture to support planned configuration (current and future) regarding computer, personnel, telecommunication, etc resources; (5) Secure funding to cover expenditures

- ❖ Explore use of GLORIAD and grid computing techniques for exchanging large amounts of data for research purposes

48. Links to other programmes

- TIGGE - Strong link with most THORPEX field programs and demonstration projects; also with HEPEX and other research projects, as well as NMHSs and other interested users

- This will link with WMO CBS as well as the various satellite operators (CEOS and CGMS) and sensor developers (through CIMO). The key link being through the identification of what needs to be measured with what precision.

Build a bridge between weather and climate forecasting: State of the art global weather forecasting out to 10-15 days is currently carried out with Atmospheric General Circulation (AGCM) models that are forced with Sea Surface Temperature Anomalies (SSTA) observed at initial time, that are projected and damped toward climatological conditions as AGCM integrations proceed. In these integrations, the dynamical, two-way interaction between the ocean and atmosphere is ignored. Therefore these integrations cannot be used for longer term weather or climate predictions. Numerical seasonal and longer range climate integrations, on the other hand, are carried out with coupled ocean-atmosphere models, often using the same, or very similar atmospheric models as those used in weather forecasting. Though these integrations start with the analysed state of the ocean, the atmosphere is often initialised with arbitrary initial conditions. As a result, these integrations are useless in terms of weather forecasting. There are a number of reasons for the current disjoint approach to numerical weather and climate forecasting, including the different emphasis observed atmospheric and ocean initial conditions, and model errors receive in the two fields.

49. Expected Outcome

- ❖ It is argued here that the current dual approach is detrimental to developments in both weather and climate forecasting. As the forecast methods are refined, methods used in weather and climate forecasting must converge. Advantages of a joint weather-climate modelling effort include:

- Skill improvement. Forecasts in the short range are affected primarily by atmospheric initial conditions, while those in the long range by ocean initial conditions. For the intermediate time ranges (7-60 days), however, the evolution of the coupled system critically depends on initial conditions for both the oceanic and atmospheric initial conditions. It follows that a joint approach considering information from both initial conditions is necessary for improved skill in this important forecast range.

- Shared scientific knowledge and resources. The research proposed here offers a tangible approach to bridging the gap between weather and climate forecasting activities in terms of scientific understanding of the processes involved.

- Shared infrastructure and technical capabilities. In the course of the collaborative work, the weather and climate forecasting communities will share their mutually applicable data assimilation, modelling, ensemble, forecast display, and product development methods, enhancing research and operational activities in both areas.

- Seamless suite of products. The proposed research will result in the use of a joint forecast system for both weather and climate applications, allowing the construction of a seamless suite of probabilistically based forecast products.

Computational savings. The joint approach also allows a more economical use of operational computer resources. If the proposed research is successful, the same coupled ocean-atmosphere modelling system can be used both for weather and climate forecasting, making costly ensemble integrations with both systems for the same time period obsolete.

50. Timescale

- 10-year research programme, with first phase focusing on more fundamental research while second half on transitioning research results into operational practice.

51. Approach

- Using a coupled ocean-atmosphere model for weather forecasting puts new constraints on accessibility to oceanic observational data. Observed ocean data needs to reach operational centres in a matter of hours, instead of days or weeks. Possible ways of greatly accelerating the transfer and quality control of oceanic observations need to be found.

- New initialisation and coupling techniques need to be explored that can equally serve the needs of the weather and climate forecast applications.

- As an alternative to the use of full ocean models that raise more challenges in terms of initialisation and coupling methods, as an intermediate solution, the use of mixed-layer ocean models coupled to AGCMs will be explored.

- Ensemble initial and model perturbation techniques that can provide consistent perturbation fields for both parts of the coupled system will be explored.

- Study the performance of different proposed coupled forecast systems in terms of their ability to simulate and forecast intra-seasonal variability both in the atmosphere and ocean, in the 7-60 day time range.

- In order to better understand the shortcomings of coupled numerical forecast systems, carry out studies with simple linear, stochastically forced inverse models. Comparison of performance of simple models with systems based on comprehensive models developed in the course of the research. Conduct well designed model inter-comparison studies.

- Continuing studies with simple linear, stochastically forced inverse models. Comparison of performance of simple models with systems based on comprehensive models (coupled atmosphere-ocean models including data assimilation) used for monthly and seasonal prediction operationally and in research mode. Conduct well designed model inter-comparison studies.

- Steps:

  1) Step one is straightforward application of Sardeshmukh [REFERENCE?] model to reanalysis re-forecast database.

  2) Next step is to quantify the NWP forecast model and coupled -model prediction errors associated with heating patterns in operational models.

  3) Third, identify sensitivities of heating profiles to initial state errors to partition error sources into model errors and IC errors.

  4) Fourth examine potential gains in predictive skill using mergers of observations or statistical model results to understand the downstream effects of more accurately forecasting tropical heating related mid-latitude sub-seasonal anomalies.

  5) Last determine efficacy of targeting to resolve both IC uncertainties in atmosphere ocean state and random and systematic model error.

52. Level of International Cooperation

- There will need to be a high level of international cooperation in order to effectively exchange data/results, and to conduct inter-comparison studies.

- Data Assimilation, adjoint tools and operational modeling capabilities require operational centres to cooperate (NCEP, ECMWF etc). Observing experiments in western Pacific will require Asian/Australian cooperation.

53. Key Players

- Operational Centres,
- Universities,
- CLIVAR Working Group on Seasonal to Inter-annual Prediction (WGSIP),
- JSC/CAS Working Group on Numerical Experimentation (WGNE).

54. Infrastructure Requirements

- Ability to communicate easily.
- Ability to readily exchange data.
- High level of computing resources to conduct model runs and diagnostics.
- Ability to conduct meetings.

55. Links to other programmes

- Operational Centres, WCRP, Universities, WWW

56. Observing Systems Tasks

57. **Develop and test new delivery systems for deploying *in-situ* sensors:** These systems include: i) stratospheric balloons; ii) piloted and unmanned aircraft; iii) rocketsondes; and iv) bi-directional radiosondes. Systems (i-iv) have the potential to provide additional soundings over oceans and remote regions, e.g., the Tibetan Plateau; Polar regions. The evaluation will include an early assessment of deployment logistics, the ability of systems to complement other observing strategies, and the cost of various measurement approaches. To be successful, the development of these delivery systems will often require concurrent sensor developments.

58. Expected Outcomes

- A potential outcome from this research task is the delivery of additional/new or upgraded operational observing systems for numerical weather prediction. Such operational observing systems could be utilized on a routine basis as part of the global observing system or in a targeted manner to improve the prediction of specific types of high impact weather events. Some systems may not be viable operationally, but they could be critical for supporting THORPEX research tasks, as such systems may provide a less costly alternative to undertaking large numbers of in-situ soundings from research aircraft. For example, without becoming operational tools, innovative delivery systems will allow determination of the impact of obtaining data over remote locations in cloudy, forecast sensitive regions, while the bi-directional radiosonde and the airborne deployment of low-cost, miniature sensors could be utilized to test the strategies to reduce representivity errors. A possible outcome of this research is that observing systems are not viable for either research or operations, but careful engineering and scientific evaluation of proposed efforts should minimize the likelihood of this outcome.

- Assessment of an observing system's viability (does it work and perform as required).

- Assessment of potential for a system to contribute to the GEOSS.

59. Timescale

- 3 to 5 years

60. Approach

- The implementation requires firm, multi-year funding commitments for key developments beginning early in the lifetime of THORPEX as such efforts have a time-scale of ~3-5 years from inception to completion. Selection of developments should include both systems to be used early in the lifetime of the programme and more visionary efforts meant to provide systems that complement satellite systems deployed near the end of the lifetime of THORPEX. For example, if winds within and below clouds is one of the most difficult variables to sense from space at the end of the ten-year lifetime of THORPEX, relatively low-cost in-situ sensing systems could be designed to specifically observe the wind field in clouds. All these funding commitments need to recognize the hardware and software engineering development, the cost of expendables, and the considerable human investment needed to overcome logistical hurdles, such as gaining access to launch sites or aviation approvals.

- The testing of such systems will likely begin with engineering experiments and proof of concept tests, moving toward deployments in TOSTs and finally in TReCs. Funding requests for significant field efforts and large numbers of expendables, such as might be utilized during a TREC, requires different lead times depending upon the nation and/or agency funding the effort. During these tests, efforts should be made to have the data reach the operational centers in real-time as early as feasible in the testing schedule. Another point to consider is that implementation of this task requires close relationships between observing system researchers and those working in the other areas of THORPEX as the expected outcomes for this task (i.e., determining the operational or research value of a systems) depend on determining the impact of these data sets in numerical forecast systems and their value to society through improved prediction of high-impact weather.

- If the research establishes the value of additional in-situ measurements, careful evaluation of the operational path for such measurements needs to be considered. For example, it may prove cost-effective to have these measurements taken operationally by existing technology, such as expanding the number of ASAP vessels or aircraft taking flight level data, rather than resorting to newly developed research technology. The research activities in this instance would justify, for example, the substantial investment in launch systems for these ASAP vessels.

61. The THOPREX Observing System Announcement of Opportunity {*Dave Parsons*}

62. Level of International Cooperation

- ❖ The implementation of this task requires considerable international cooperation. Consider the example of deploying driftsondes systems for THORPEX for a Pacific experiment. Currently the systems are being developed in the U.S., but a Pacific deployment would require cooperation with Asian nations in order to obtain permission for launches, launch facilities and logistical assistance. Assistance of local weather service of national administrations (including the military weather institutions if necessary) would greatly reduce the costs of such deployment relative to solely depending upon U.S. technical staff relocated to Asia. Following launch, permission to deploy dropsondes from such a system and, in some cases, even flying the balloon-gondola system over a region requires national and international air-traffic approvals Decision on when to deploy dropsondes would require input from researchers and operational staff aiming to improve forecasts over North American, Europe and/or Asia.

63. Key Players:

- ❖ Relative to large number of institutions conducting meteorological research, the expertise to conduct these types of developments resides in relatively few research laboratories, private industry and a few universities. If the developments are carried out by a research laboratory or a university, the transition to large number of sensors and delivery systems will almost certainly require the involvement of private industry.

- ❖ WMO WWW Programme, WMO CBS, CIMO and JCOMM.

- ❖ Other field efforts that may be interested in deploying these types of systems such as AMMA, AMI, and IPY.

64. Infrastructure Requirements:

- ❖ In-situ data is relatively small in volume relative to satellite data sets and the output from operational models. Hence the infrastructure requirements for this task will be more associated with setting up agreements and infrastructure associated with launch sites, air traffic safety, and international agreements to cover the costs of expendables in regional experiments.

65. **Carry out field-demonstrations of prototype remote –sensing systems for future airborne and satellite deployments:** This effort will include observations from airborne radiometers, scanning radars and lidars to obtain: I) individual remote-sensor profiles for comparison with simultaneous *in-situ* soundings; ii) area-averaged profiles that simulate existing and future satellite's field-of-view. The initial demonstrations will be through TOSTs within diverse geographical regions and meteorological conditions: a significant requirement for satellite remote sensing system calibration and evaluation.

66. Expected Outcomes

- ❖ Evaluation of feasibility for a remote sensing system to be tested on a research satellite platform.
- ❖ Evaluation of a prototype remote sensing system's performance and an assessment of its potential contribution (generally from a research satellite platform) if added to the operational arm of the space-based GOS
- ❖ Guidance for optimisation of the satellite-observing portion of the GOS.

67. Timescale

- ❖ This activity will occur throughout the program, but will in most cases be linked to well-defined research satellite activities such as GPM, ADM, GRACE.

68. Approach

- ❖ Data sets from identified ground, aircraft and space-based remote sensing systems will be collected, archived and evaluated. In some instances this will require experimental design for the prototype system (aircraft) to be evaluated with respect to a TOST.
- ❖ In other instances, as space based research satellites, the operation of a sensor over specific regions and at selected times may to be coordinated. Generally space agencies develop AOs for research with respect to a new satellite's instrumentation; science teams are formed and major amounts of background work are done prior to the research instrument being launched.
- ❖ Then extensive cal/val activity takes place, and in some instances, as with AIRS and MODIS, data are made available to interested users on an operational basis.
- ❖ It is incumbent on THORPEX, likely in conjunction with the WMO Space Program, to make sure appropriate coordination occurs with the various space agencies.

69. Level of International Cooperation

- ❖ Coordination will occur mainly through the appropriate THORPEX entity and the various satellite agency or agencies.

70. Key Players

- THORPEX experimental design entities, major GDPFS Centres and space-based component of GOS through CGMS and CEOS.

71. Infrastructure Requirements

- Depending on the activity this could range from aircraft logistics and support to data archive, data delivery and capacity at GDPFS Centres

72. Links to other programmes

- WMO Space Programme and –WWW Programme, International science groups such as ITWG, IPWG and IWWG. Links to other programs could also be conceived to mean programs underway within GEWEX, etc or those coordinated through CEOS such as the Coordinated Enhanced Observing period (CEOP). In any case, such activities are generally well defined, and WMO is active in the relevant coordination groups (CEOS, IGOS, CGMS, GEO). So, the active and strong linking of THORPEX to the WMO Space Program is very important. For example support for various activities could be sought through the "High Level Consultative Meetings on Satellite Matters" held in the early part of each year in Geneva, as well as through (expected to be) a new Expert Team on Satellites within the OPAG IOS that will be proposed to CBS, November 2004. The Argo float programme is an important input to THORPEX through data assimilation into ocean models that provide ocean boundary conditions for the longer-range THORPEX forecasts.

4 Data Assimilation and Observing Strategies Tasks

73. Improved Use of Observations

Beyond the improvement of the use of the temperature and wind information, the challenge of the current decade is to progress in the assimilation of the water cycle in its three phases. The tasks below, which are relevant for the conventional and the currently assimilated observations are likely to be more important for the water cycle. They will require enhanced international collaboration between the academic and operational research communities.

a. **Quantify observing -system errors:** Estimate observation errors, especially errors of representativeness, which are likely to be flow -dependent and correlated between nearby observation locations. Test the effects of improved observation-error statistics on forecast skill. The representativeness error depends on the model resolution and on the physical parameterization (e.g. representation in the NWP models). Generic representations are still to be developed.

b. **Develop methods for efficient utilization of high-volume datasets**: Develop and test adaptive methods for thinning large datasets so that the most useful observations are retained. Develop techniques for assimilating high-resolution observations, including proper characterization of horizontal correlations and averaging (or *super-obing*) of nearby measurements. Develop techniques to extract the maximum information content from hyper-spectral sounders, and other observing systems when, for example, it is computationally impractical to assimilate radiances from all channels.

c. **Improve the use of geostationary satellite observations:** Improve the use of visible, infrared and water vapour image-sequences, both from geostationary and polar orbiting satellites, to infer wind information. This may require innovative approaches, such as interactive height assignment methods or the use of imagery sequences directly in the assimilation. Improve the use of satellite data in cloudy regions and over land.

d. **Improve assimilation of physical processes:** New methods to assimilate certain satellite observations (e.g., those from active microwave sensors and cloud and precipitation imagery) are required in order to infer physical processes such as diabatic heating.

74. Expected Outcomes

- Information and guidance will be provided to satellite operators on how to best use the adaptive observing capability of their geostationary satellites in synergy with polar and other low earth orbiting satellite systems.
- Assimilation of satellite derived rainfall, atmospheric motion vectors, land surface properties, surface temperature, vertical temperature and moisture as well as cloud information into NWP models. This will require substantial improvements in the areas of data assimilation, parameterization and model physics.
- In synergy with other activities in THORPEX, improved use of satellite data in regional and global scale NWP leading to better forecast.
- Guidance for optimisation of the GOS.

75. Timescale

- These major activities will continue throughout the experiment.

76. Approach

- Most necessary will be improvements in the areas of data assimilation, parameterisation and model physics, particularly of the water cycle.

- Coordination with GODAE will be beneficial.

77. Level of International Cooperation

- Enhanced international collaboration between the academic and the operational community will be a key component

78. Key Players

- Satellite operators and GDPFS centres

79. Infrastructure Requirements

- Access of the NWP operational and research data assimilation systems to the academic community

80. Links to other programmes

- Improved data assimilation will contribute to the CLIVAR programme through improved re-analyses

81. **Targeting Techniques**

❖ **Refine targeting strategies:** Perform observing system experiments (OSEs) and Observing system simulation experiments (OSSEs), including demonstrations with data sets from field experiments, to evaluate and refine targeting strategies.

❖ **Generalise existing targeting techniques:** Account for non-linearity and non-normality, especially for medium-ranges and/or in flow regimes where physical processes such as moist convection and clouds play a dominant role.

❖ **Test targeting algorithms for a wide range of weather systems:** Candidate forecast problems include: i) hurricane track and intensity forecasts; mid -latitude summer heavy rainfall episodes; iii) and extended range (week-two) predictions. This should include research on the dynamical processes that propagate information spatially and temporally between the targeted regions and the selected weather events.

❖ **Design observational networks**: Develop and test systematic and objective techniques for the design of observing networks**.** Quantify the required accuracy and resolution for the measurement of various quantities, and evaluate trade -offs between accuracy and resolution, or between resolution and areal coverage.

82. Expected Outcomes

❖ Evaluations of the impact of targeting strategies on the reduction of forecast errors. This will require evidence utilising forecast re-runs that are plentiful enough to achieve statistical significance. In this context the term targeting is being used in the widest possible way.

❖ The development of more accurate theoretical/numerical methods of targeting including relaxation of the assumption of linearity and other restrictions inherent in current techniques.

- This should test sensitive area predictions for a wide variety of weather types, systems and geographical areas. It will provide outcomes that show targeting methods have a wide applicability and validity. It will also give a dynamical understanding of how perturbations in sensitive regions propagate and develop to affect the verification region forecast.

- This topic will address how observations should be deployed or used within sensitive regions. The outcomes will include recommendations to other groups concerned such as CBS and JCOMM/GOOS on how to design the global observing system to include an adaptive component. The relative merits of different deployment and utilisation strategies will be provided. For this purpose the global observing system as a whole will be considered, included surface-based, in-situ, satellite and airborne components.

83. Timescale

- The OSEs needed to evaluate targeting strategies will occur in association with, and following, various TReCs. The first of these is the North Atlantic TReC from mid October to mid December 2003. Further TReCs are envisaged in all regions on about a yearly cycle. OSEs will be carried out when TReC observations become available. OSSEs will be carried out at a lesser volume as there are real difficulties in interpreting the generality of results from OSSEs. For this purpose a nature run from a very high resolution global model will be needed as the first step in a set of OSSEs.

- This is the theoretical research and the timescale is hard to quantify. It is hoped that new relevant results will emerge all the way through THORPEX with an emphasis on achieving breakthroughs in the first half of the programme.

- The timeline for this is the same as that for (a) as the outcomes will emerge as a range of regional TReCs are completed.

- This will occur in the second-half of THORPEX as the research on targeting strategies, their development and evaluation will need to be done first before design of new deployment of the observational network is possible.

84. Approach

- OSEs (and to a lesser extent OSSEs) will need to be carried out. This will often be in association with TReC observing campaigns, with most research to be carried out after the fieldwork.

- New targeting techniques involve theoretical research developments. We need to stimulate research projects on this topic in universities, research institutes and in NWP centres.

- The design of observational networks requires a wide set of OSEs to be performed with various deployments of the global observing system. This will follow on from the research done in sub-task a) and it will rely on the existence of a wide range of targeted observational datasets to incorporate. Any suggestions for revisions to the operational network will need to be backed up with statistically sound evidence of high-impact weather forecast improvements. This re-design of the global observing network will be a final outcome at the end of THORPEX.

85. Level of International Cooperation

- OSSEs and OSEs can be performed by individual countries but they rely on the international cooperation necessary to carry out the TReC collection of targeted observational datasets and prediction of the location of sensitive regions. In addition computation of sensitive area locations will need to be done by those able to do this as a service to countries carrying out TReCs.

- ❖ International cooperation will be needed to acquire a sufficiently large number of examples of weather forecast improvements with targeted observations. The observing system being a global resource can only be re-designed with the full agreement of the global meteorological and oceanographic community. To do this there will need to be a set of requirements from WWW CBS and GOOS/JCOMM that have to be agreed by global discussion, (e.g. at a high-level conference) so that the suggested re-design will be accepted by all. This final part will involve government level discussion.

86. Key Players

- ❖ NWP centres and academic institutions, which are able to run operational forecast systems with and without targeted observations and/or strategies. Currently only a handful of NWP models are able to compute the location of sensitive regions in real time. It will be necessary for these particular centres to provide NWP centres, which cannot predict sensitive regions, with these predictions, particularly for the operation of TReCs in their region. The following is a list of centres capable of sensitive area predictions currently: Met Office, ECMWF, Météo France, NCEP and NRL.

- ❖ Predictability researchers in operational and academic institutions.

- ❖ NWP centres and NMHSs, which are controlling the global observing system deployment (e.g. EUCOS project in Europe). Also satellite agencies such as ESA, EUMETSAT, NASA, NASDA will need to be involved concerning any alternations to satellite scanning patterns or proposals for new space-based instruments.

87. Infrastructure Requirements

- ❖ Access to NWP forecast systems including observational databases, data assimilation and forecast models will be essential. Computer time will need to be allocated to the OSSEs and OSEs – these are substantial computing resources.

88. Links to other programmes

- ❖ Assistance from WGNE will be advantageous. Links needed with WWW CBS and GOOS/JCOMM for re-design of the global observing system.

89. **Adaptive data assimilation**

The following four tasks are described in the continuity of the current development programs of most NWP centres. Nevertheless it has to be pointed out that fundamental research is likely to be required to achieve a breakthrough in the assimilation of the water cycle. The difficulties are many-fold: the governing equations are stiff and nonlinear; the attractor has a complex structure; the observations are of poor quality relative to the mass/wind field; the representation of the deep convection is one of the weak points of the NWP models

a. **Improve background-error covariances in existing assimilation schemes**: Test improved, flow-dependent models of background-error covariances in techniques like 3DVar and 4DVar. As an example, the lambda-shape of the mid-latitude depression is information, which is not used in the Jb term.

b. **Develop methods for cycling flow-dependent background errors:** Develop and test assimilation methods that explicitly allow for changes in background-error covariances from one analysis to the next, such as Kalman-filter/4DVar hybrids or ensemble -based schemes.

c. **Develop adaptive quality control**: Develop and test adaptive quality control algorithms that can utilize information provided by flow -dependent background-error covariance estimates.

d. **Incorporate model uncertainty into data assimilation procedures**: Develop and test ways of incorporating the effects of model uncertainties leading to systematic forecast errors and the effects of unresolved scales into the specification of background-error covariances for data assimilation schemes. Develop statistical algorithms to "tune" model uncertainty in assimilation algorithms and to diagnose and correct model bias.

90. Expected Outcomes

91. Timescale

- ❖ These major activities will continue throughout the experiment.

92. Approach

- ❖ Most necessary will be improvements in the areas of data assimilation, particularly of the water cycle.

93. Level of International Cooperation

- ❖ Enhanced international cooperation between academic and the operational community will be a key component.

94. Key Players

- ❖ NWP centres and academic labs

95. Infrastructure Requirements

- ❖ Access to the NWP operational and research data assimilation systems to the academic community.

96. Links to other programmes

- ❖ Improved assimilation will contribute to the CLIVAR programme through improved analyses.

5 Social and Economic Applications Tasks

97. **Social and Economic Value of Weather Forecasts**

a. **Identify high-impact weather forecasts:** This effort will identify the global-to-regional weather forecasts that have major effects on selected sectors of society and economies within various geographical regions. It will address the effects of recent high-impact weather forecasts, and the *economic consequences* (e.g., property damage; loss of crops and/or livestock; interruption of transportation services) and *human consequences*, e.g., personal injury, illness from heat/cold; contamination of drinking water by floods; damage to electric power distribution. Studies will investigate which forecast improvements would be of the greatest *marginal value*, e.g., the greatest added value to the users and society in mitigating losses, increasing gains, or otherwise improving the management of resources. Evaluations will be made of the accuracy of forecasts and responses to subsequent weather forecast products and the value of potential improvements will be assessed from the perspective of a range of current and potential weather-sensitive sectors.

b. Assess the impact of improved forecast systems: The above identification of high-impact weather forecasts will provide the basis for estimating the marginal value of improvements to forecast systems.

c. Develop advanced forecast verification measures: The development of user-relevant verification of weather forecast information is a prerequisite to evaluating the societal and economic impact of improved forecast systems. Many of the current verification measures used by operational forecast centres to evaluate forecast skill, e.g., 500-mb anomaly correlations between the model forecast and the model analysis, are of limited value to those who use weather forecast information to make decisions for the benefit of society and economies. The appropriate verification measures vary with the user's requirements. *User relevant forecast measures* include: i) site - and time-specific measures (e.g., time of passage of a front; transition from rain to frozen precipitation; timing of air pollutants above/below critical concentrations); ii) integrals over space and time, e.g., transportation travel times; power-generation efficiency; hours of air pollutants above critical concentrations; duration of hazardous high or low temperatures. Such measures are often a nonlinear function of multiple meteorological variables (e.g., wind speed; temperature; humidity; visibility; sea state) and non-meteorological variables e.g., type of equipment in place; topography; land use. The advanced verification measures developed within this Sub-programme will be used by other THORPEX Sub-programs and by operational forecast centres to evaluate forecast–system improvements using methods that are relevant to the value that a range of users derives from forecasts.

98. Expected Outcomes

A quantitative understanding of the value of high-impact weather forecasts for various developed, developing and least developed economies sufficient to inform governments' policies, and to engage industry in business reengineering to increase efficiency, through the use of weather (and climate) information.

a. (i) International searchable database / electronic bibliography of studies of the topics listed in the statement of task (including past studies and those specifically related to THORPEX), categorized by type of weather event, geographic region, socio-economic sector, forecast lead time, etc. (ii) For each participating THORPEX country, a brief (but comprehensive) list of the high-impact weather forecasts of greatest interest, to be published in THORPEX documents and synthesized into a THORPEX definition of "high-impact weather forecast" for each region. (iii) Prior to each THORPEX field campaign, an evaluation of the high-impact weather forecasts of greatest interest to the campaign, including analysis of the factors listed in the statement of task and the major users of those types of forecasts

b. Case studies estimating the marginal value of THORPEX-relevant improved forecasts to specific users, for a variety of types of weather forecasts and lead times, for specific user groups and socio-economic sectors, in multiple geographic regions (using archived or OSSE data). Estimates of the marginal value of the improved real-time forecasts produced in THORPEX field campaigns, for multiple user groups and SE sectors.

c. Suite of user-relevant verification measures for specific forecast applications, user groups, or socio-economic sectors, including the types listed in statement of task. Small set of integrated global forecast verification measures, based on socio-economic use/value of forecasts or risk, that have been thoroughly tested and are ready to implement by NMHSs around the world to complement existing standard measures.

99. Timescale

a. (i) Initial bibliography/database completed within 3-4 years, with new materials being added on a continual basis thereafter; (ii) Initial lists within 1-2 years, synthesis into THORPEX definition of high-impact weather forecast within 3 years, revisions as needed; (iii) Starting as soon as each field campaign begins planning, completed several months prior to the field campaign.

b. Throughout THORPEX linked to advances in the forecast systems

c. Throughout THORPEX

100. Approach.

Studies of marginal improvements to forecast systems will be made for: i) various types of weather forecasts and lead times; ii) diverse user groups or societal/economic sectors; iii) different geographic regions. Estimates will be made of the marginal value of improved weather forecast information from databases, such as: i) archived forecasts for past weather events; ii) Observing System Simulation Experiments (OSSEs): iii) forecasts from THORPEX field campaigns. These studies will estimate the range of marginal gains to be derived from a variety of forecast system improvements within different sectors of society

a. (i) Partial bibliographies already exist. The United States Weather Research Programme (USWRP) Societal Impacts Programme (SIP) is starting to build a digital library of these studies, building off existing bibliographies and adding new material. THORPEX may expand these databases to develop a bibliography that addresses high impact weather forecasts in all THORPEX regions through a partnership with the USWRP SIP Digital Library to extend it to high-impact weather forecasts of interest around the world, by having NMHSs, researchers, etc. around the world submit references and materials. (ii) Develop lists of high impact weather forecasts and synthesized definitions through THORPEX regional committees. (iii) Each field campaign will have a specific sub-element to coordinate accomplishing this task, in order to assist real-time allocation of field campaign resources (e.g., for targeted observations) and provide the necessary background information for socio-economic researchers to study socio-economic impacts of field campaign.

b. Assessing the impact of improved forecast systems depends largely on understanding how weather forecasts are used in decision-making. Case studies will be developed to combining the ensemble forecasts, decision-support systems and users of these systems. THORPEX sponsored decision-support conferences and workshops will bring together researchers, developers of ensemble weather prediction systems, developers of decision-support tools and decision-makers to further the understanding of how to fully realise the potential of probabilistic forecasting to mitigate and reduce the impact of weather related disasters and to improve economic performance. The first workshop will focus on the use of probabilistic weather forecasts in low probability high-risk decision-making (see Annex II).

c. As above, develop verification measures for specific applications of forecasts pertinent to the end user of the information. The emphasis here will be on verification measures for the forecast application rather than the forecast.

101. Level of International Cooperation

- There is a critical need to transfer skills from developed to developing economies.
- Need best available forecast products from leading numerical weather prediction centres and the skills of the developers of decision support systems applied to both developed and developing economies weather sensitive industries and social systems.

102. Key Players

- Public sector consumers - Ministries of finance, emergency managers, water and sanitation, environment, energy, agriculture, tourism, policy
- Private sector consumers – energy, water, agriculture, tourism, finance
- World Bank, Development Banks
- Major NWP Centres
- Applied Research Community – physical and social scientists, economists
- WMO WWRP/WGNE Joint Working Group on Verification
- WMO Public Weather Services Programme

103. Infrastructure Requirements

- Access to EPS output
- Reanalysis and forecast databases.
- Access to existing decision support tools

104. Links to other programmes

❖ National efforts, such as the USWRP SIP.
❖ Various ongoing WMO applications programmes, including Disaster Prevention and Mitigation programme, IPCC.

105. **Estimate costs and benefits of improved forecast systems**: Estimating the costs and benefits of implementing potential THORPEX advances in daily forecast operations will require: i) estimating potential forecast improvements from various forecast system implementations; ii) estimating marginal costs and benefits of the improvements; and iii) combining this information in a way that can be used in making decisions on the design of forecast systems. In order to provide these estimates, the Social and Economic Applications (SEA) Sub-programme will build on existing methods for evaluating costs and benefits, using the information provided by the SEA research described above. The Sub-programme will also identify the information from other Sub-programmes required to develop such estimates, e.g., detailed estimates

of costs of implementing different observing systems; a comprehensive evaluation of expected forecast improvements, measured with user-relevant verification measures.

106. Expected Outcomes

- ❖ Quantitative demonstration that the benefits of improved forecasts (ensemble predictions) outweigh the costs to determine the lower bound on the expected benefit.

107. Timescale

- ❖ Throughout THORPEX

108. Approach

- ❖ Use the method of threshold (current capability) and objective (perfect skill obtained from a retrospective analysis) forecasts to determine the maximum value of a forecast applied to specific sectors. Then use the actual expected improvement in the forecast to determine the true value of the forecast product.

109. Level of International Cooperation

- ❖ Forecast benefits will be specific to individual economies. Standard methods to quantify benefits need to be developed within the international community then applied to specific countries and regions.

110. Key Players

- ❖ Basic and Applied research community – physical and social scientists, economists
- ❖ Public sector consumers - Ministries of finance, emergency managers, water and sanitation, environment, energy, agriculture, tourism, policy
- ❖ Private sector consumers – energy, water, agriculture, tourism
- ❖ World Bank, Development Banks
- ❖ Major NWP Centres
- ❖ WMO Public Weather Services Programme

111. Infrastructure Requirements

- ❖ Access to country and region specific decision support systems, social and economic data bases
- ❖ Reanalysis and forecast databases

112. Links to other programmes

- WMO Natural Disasters Prevention and Mitigation Programme; IPCC.

113. **Develop new user-specific weather products:** THORPEX SEA research will develop new methods to translate predicted meteorological parameters into quantities of interest to specific user sectors, so that improvements to forecast systems will be responsive to society's diverse weather information needs. This will include developing methods where the outcomes of interest to users are continuous functions of meteorological conditions and where operational probabilistic forecast information can be utilized. Studies on improvements in current probabilistic forecast systems will provide information on multivariate, spatial and temporal information critical to many social and economic applications. In addition, SEA research will develop methods to overcome current barriers to improved use and value of weather forecast information,

e.g., difficulties utilizing probabilistic forecasts in decision-making; warnings integrated over space or time scales incommensurate with user requirements.

114. Expected Outcomes

- Suite of new decision support and consequent assessment tools
- Full utilisation of probabilistic weather information in decision-making.
- Demonstrable mitigation and reduction of disasters and increase in economic efficiency using new tools.

115. Timescale

- Phase I 2004 – 2006, using current skill, expand the use of forecast products in social and economic sectors
- Phase II 2007 – 2012, using advanced forecast techniques developed through THORPEX to provide maximum benefit to social and economic sectors

116. Approach

- Beta-test new products derived from the forecast system in a series of industry trials.
- Beta-test new products derived from the forecast system in a series of trials in the public sector, engaging all of the necessary actors (see key players below).

117. Level of International Cooperation

- Essential to test and apply advances in developed, developing and least developed economies

118. Key Players

- Basic and Applied research community – physical and social scientists, economists
- Public sector consumers - Ministries of finance, emergency managers, water and sanitation, environment, energy, agriculture, tourism, policy
- Private sector consumers – energy, water, agriculture, tourism
- World Bank, Development Banks
- Major NWP Centres
- WMO Public Weather Services Programme

119. Infrastructure Requirements

- EPS output from operational and research centres

120. Links to other programmes

- NOAA RISAs, IRI
- NCAR Research Applications Programme (RAP)

6 THORPEX Interactive Grand Global Ensemble

121. The Framework

TIGGE will provide a framework for international collaboration in the development of ensemble prediction systems (EPSs) and is also planned to provide the main prediction tool in the THORPEX Forecast Demonstration Projects. These activities will constitute the international development and testing of the Future Global Forecasting System.

It is now feasible to consider the prospect of a multi-national ensemble system, distributed through the global community, which could provide appropriate predictions of high-impact weather, anywhere in the world, on all predictable time ranges. TIGGE will provide the coordinated effort required to evaluate this potential.

The initial basic components of TIGGE will be global ensembles run to around 14 days, including those run currently at a number of operational centres. These will be collected in near real time and stored in a common format in a number of central data servers for access by researchers in operational centres and the academic communities. This will facilitate research on combination and intercomparison of different systems; it will become straightforward, for example, to compare the value of multi-model ensembles with those based on perturbations of a single model. Easy access to long series of data is necessary for applications such as bias correction and the optimal combination of ensembles from different sources; these will be accumulated as the TIGGE archive grows during the project.

Interactivity is a key new feature of TIGGE. In principle, as uncertainty varies from day to day, so should the observing-assimilation-forecast system, to provide the response appropriate for the current situation. Extra observations could be called on in 'sensitive areas', ensemble size and resolution adjusted, and regional ensembles run as and when needed; all these adapting in real time to meet user needs. Such efforts require cooperation on a global scale, which the TIGGE framework will provide.

Technological developments including grid computing and high-speed data transfer networks (e.g. GLORIAD) give the potential for the flexible response that would be needed to meet these changing demands on computing resources, although real-time constraints and high-speed high-volume data transfers present a significant challenge.

At the same time, much research is needed on the scientific aspects of interactivity, including:

- Observation targeting - some methods of sensitive area prediction such as the ETKF will benefit directly from the large ensemble size available in TIGGE; other methods will not rely directly on TIGGE. Other aspects of targeting are covered elsewhere in the THORPEX plans.

- Are there different 'optimal' configurations for different situations (e.g. relative benefits of resolution and ensemble size); how would the requirements vary from day to day.

- Links between global and regional ensembles, including the provision of appropriate boundary conditions, how global ensembles can be used for 'on-demand' requests for regional ensembles, whether global ensembles can guide the real-time composition of regional ensembles ('representative members').

We also plan that TIGGE will be used in real time during the THORPEX demonstration projects. The timeframe for these FDPs will allow for 2-3 years of near-real-time TIGGE development before real-time availability is required. By the time of THORPEX FDPs (in ~2008) enough data and experience will have been gained to use TIGGE in real time as the main forecast tool, providing both global and regional quantifications of weather uncertainties to use in decision-making.

122. Expected outcomes

- Enhanced collaboration on development of ensemble prediction, internationally and between operational centres and universities
- New methods of combining ensembles from different sources and of correcting for systematic errors (biases)
- Understanding of the feasibility of interactive ensemble system responding dynamically to changing uncertainty (including use for adaptive observing, variable ensemble size, on-demand regional ensembles) and exploiting new technology for grid computing and high-speed data transfer.
- Test (through FDPs) concept of TIGGE Prediction Centre to produce ensemble-based predictions of high-impact weather, wherever it occurs, on all predictable time ranges.
- A prototype of the Future Global Forecasting System.

123. Timescale

Runs throughout the 10 years of THORPEX. Infrastructure development will depend on scientific requirements and available funding/resources from data archiving centres. Initially ensemble data collected in near-real time. Real-time running planned for FDPs

124. Approach

A Scientific Steering Committee (SSC) will direct the development of TIGGE and will report directly to the THORPEX ICSC. Working Groups (WGs) will be established to coordinate the different TIGGE activities:

- **Initial Conditions**
    - Comparison of methods including singular vectors, breeding, ETKF. Investigation of multi-analysis aspects.
- **Model uncertainty**
    - Development of methods for representing model uncertainties, including multi-model compared to perturbed parametrisation, stochastic physics.
- **Probability forecasts**
    - Development of probabilistic predictions from TIGGE. Bias correction, optimal combination of members from different sources.
- **Impacts/Applications**
    - Uses of ensemble forecasts, including user requirements and training
- **Infrastructure and data policy**
    - Procedures and protocols for access to data. Infrastructure required to achieve scientific aims.
- **HEPEX**
    - This is a major potential application of TIGGE, coordinating the provision of atmospheric ensemble data for the hydrological requirements of the HEPEX community, so warrants a dedicated WG.
- **Interactivity**
    - Applications to observation targeting; limited area ensembles; flexible ensemble composition.

Establish Scientific Steering Committee and Working Groups. Define scientific requirements for TIGGE dataset, then plan and develop infrastructure accordingly. WG research plans will be developed concurrently and work will begin with available data.

A joint US/Canada multi-centre ensemble is already under development. This aims to be a joint operational prediction system, while TIGGE has a wider research aim, it is likely that some of the infrastructure considerations, such as common data formats and data archiving policy, will be useful for TIGGE.

125. Level of International Cooperation

High – expected to include all major NWP centres, universities, and for impacts and exploitation of ensemble data many NHMSs in all regions

126. Key Players

Initially depends on major NWP centres for supply of ensemble data, on 3-4 regional centres willing to act as main archiving sites; then on groups developing limited-area ensembles and applications.

127. Infrastructure requirements

Needs data archival centres (ideally 3-4 mirror sites; one each in N America, Europe, Asia, Australia) and infrastructure needed to maintain these and allow continual addition of data and easy access to archived fields. This will be costly for the host centres and no external funding has been identified, so at present it relies on self-funding from the participants.

128. Links to other programs

CBS ET on EPS (Ken Mylne, chair) and other CBS groups as appropriate; WCRP (COPES)