Program Overview[1]

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THe Observing-system Research and predictability experiment

THOR*pex*

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Executive Summary

The skillful prediction of high-impact weather is one of the greatest scientific and societal challenges of the 21st century. Recent improvements in atmospheric observing technology, data assimilation methods, numerical model formulation, and the use of ensemble techniques have led to substantial increases in forecast skill. Despite these improvements, there continue to be limitations in our ability to forecast high-impact weather events. THe Observing-system Research and *p*redictability *ex*periment (THOR*pex*) is a ten-year international research program, under the auspices of the World Meteorological Organization/World Weather Research Program (WMO/WWRP), to accelerate improvements in short-range (up to 3 days), medium-range (3 to 7 days) and extended-range (week two) weather predictions and the societal value of advanced forecast products. THOR*pex* will examine predictability and observing-systems issues, and establish the potential to produce significant statistically-verifiable improvements in forecasts of high-impact weather. The program builds upon and coordinates advances being made in the operational forecasting and basic-research communities. The weather events to be considered include systems of mid-latitude, arctic, or tropical origin, are primarily synoptic-scale, and often contain significant embedded mesoscale features. THOR*pex* is fully global in scope.

[1] This document draws on material presented in the September 2001 THORpex Proposal. It also includes input from the First THORpex Status Report issued in July 2002 following the First International THOR*pex* Workshop and the International Science Steering Committee meeting held in March 2002.

The primary objective of THOR*pex*[2] is to accelerate improvements in the prediction of high-impact weather on time scales out to two weeks. Ths will include international collaboration between the operational and research communities.

In order to accomplish this objective, THOR*pex* will:

- Contribute to the development of a dynamically controlled and interactive operational forecast system in which the forecast model and data assimilation procedure are used to provide guidance on the optimal design and utilization of the observing system. This will include the use of the new concept of targeting, whereby observations are utilized and/or supplemented where and when their impact on the quality of the analyses and forecasts is largest. THOR*pex* will provide guidance to agencies responsible for the design of the fixed and adaptive components of the regional and global observing system, including EUCOS, GCOS and NAOS.
- Advance basic knowledge of the predictability of high-impact weather. THOR*pex* research aims to address the degree to which predictive skill is limited by observations, data assimilation, forecast model error, or ensemble design at various forecast lead-times. An example is the determination of the dependence of predictive skill on inter-annual and intra-seasonal climate variability, e.g. ENSO, MJO and the Indian monsoon.
- Provide improved data sets for research activities relevant to CLIVAR, such as oceanic process studies, initialization of coupled ocean-atmosphere models, and OSEs designed to test the needs for longer timescale monitoring of the climate state over remote regions.
- Develop methods for assessing the economic and societal value of improved weather forecast skill. This will include the development and training in the use of appropriate end-user metrics. Assess the costs and user-benefits of improvements to the global observing network, and to data assimilation methods and forecast systems, as suggested by THOR*pex* research.

1. Rationale

There have been numerous recent examples of high-impact weather events that were not adequately predicted on short through medium-range time scales. On the short-range, these include: i) the series of violent wind storms over western Europe in December 1999; ii) the major U.S. east-coast snow storm in January 2000, and on the medium-range the central European rainfall leading to flooding in August 2002. Poor forecasts of such extreme events increases their societal and economic impact through damage to property, loss of life, and disruption of transportation, energy management, and agriculture. Improved numerical forecasts will help mitigate these losses by providing government agencies, the general public and business with more accurate warnings. The goals of THOR*pex* are aligned with the mission of weather services throughout the world to improve operational numerical weather prediction. Fully achieving these goals requires

[2] Acronym definitions can be found in Appendix 1.

improvements in basic knowledge concerning high-impact weather and its transfer into operational practice.

From the North American perspective, the U.S. National Weather Service (NWS), the USWRP, and NAOS have identified forecast improvement goals for rapidly developing coastal and continental winter storms, heat-waves and cold-air outbreaks, extreme precipitation events, and land-falling tropical cyclones. Achieving these goals will require: i) optimal use of existing and anticipated satellite data, ii) creative new approaches to *in-situ* observing, iii) advanced methods for data assimilation, iv) improved deterministic and ensemble forecast models, v) increases in basic knowledge, and vi) developments in computing capability.

High-impact weather systems of particular interest for European nations include rapidly developing synoptic-scale and mesoscale cyclones, heavy precipitation events, and zones of excessive surface wind-speeds. European nations recognize that additional upper-air and surface observations over the North Atlantic are required to improve short-range weather forecasts (Graham et al. 2000). In northwestern Europe, poor forecasts of polar lows create difficulties for fishing and shipping. EUCOS has conducted limited trials of remotely piloted aircraft observations over the north Atlantic sector early in 2002. The quantity of upper-air soundings over Russia has decreased, and it is recognized that attention needs to be given to restoring this capability.

Key forecast objectives for Asian nations include improved predictions of tropical cyclones, extreme precipitation events associated with disturbances along the Mei-Yu front, dust storms, and cold-air outbreaks during the winter monsoon. Ongoing efforts by Asian nations to test new observing systems over the western Pacific, East China Sea, and Siberia, can be advanced with international coordination under the framework of THOR*pex.*

A frequent cause of forecast error results from initial-condition errors in dynamically-active, data-sparse regions (Klinker et al. 1998). For example, the largest 72-hr forecast errors occurring over western and eastern North America during three winters (1997-1999) can be attributed to initial condition errors (primarily, poor upper-air temperature and wind analyses) over regions of the North Pacific and North-American Arctic, respectively. The largest 96-hr forecast errors over western-Europe during January and February 1999 were most sensitive to initial conditions over portions of Canada. In these examples, the adjoint of a numerical forecast model was used to give a first-order estimate of forecast error sensitivity to initial conditions.

Inter-annual and intra-seasonal variations in large-scale flow regimes modulate the source regions for initial-condition and related forecast errors. During the most recent La Niña winter (1999), the largest 72-hr forecast errors over eastern North America were sensitive to initial condition errors in a region of the eastern Pacific between Hawaii and Alaska. During the El Niño winter of 1998, the most sensitive region was adjacent to the U.S. west coast. Shapiro et al. (2000) show that short-range forecast errors during the El Niño winter (1998) were smaller on average than in the La Niña winter (1999) and that changes in forecast error source regions are likely related to variations in baroclinic life cycles modulated by the El Niño-Southern Oscillation (ENSO).

Recent field programs in which targeted dropsondes were deployed in sensitive data-sparse regions include: i) the Fronts and Atlantic Storm-Track Experiment (FASTEX, Joly *et al*. 1999), ii) the North Pacific Experiment (NORPEX, Langland *et al*. 1999), and iii) the Winter Storm Reconnaissance program (WSR, Szunyogh *et al*. 2001). These programs demonstrated that short-range forecast errors in selected winter-season cases can be reduced by providing reconnaissance aircraft dropsondes and additional satellite observations. It has also been shown that the impact of targeted observations on forecast skill depends strongly on the data assimilation procedure and level of background error (Bergot 2001). THOR*pex* will extend the accomplishments of FASTEX, NORPEX, and WSR to the more general problem of testing a wide range of observing systems, using advanced targeting methods and data assimilation procedures.

Substantial upgrades to the global satellite network during the next decade will include advanced sensors capable of observing several thousand channels, compared to current systems that observe less than one hundred. These new satellite observations are expected to improve the quality of the initial conditions in numerical weather forecast models. However, even with the addition of these more advanced sensors, it will likely be necessary to consider supplementary *in-situ* observations at certain times and in certain regions. For example, current satellite observations are limited within cloud-covered regions. Cloudy regions are highly correlated with initial-condition sensitivity (McNally 2000). Supplementary observations may also be needed over land and sea-ice surfaces. A range of new and upgraded *in-situ* observing systems are being developed that will provide observations to supplement satellite data in the key sensitive regions. These observations would potentially be of great benefit to the proposed Climate Variability and Predictability (CLIVAR) activities (http://www.clivar.org/), particularly over the Pacific and Atlantic basins. An important goal of CLIVAR is to provide enhanced atmospheric observations for: i) climate monitoring, ii) initialization of coupled ocean-atmospheric models, and iii) atmospheric and oceanic process-oriented field programs. Observations taken during THORpex would provide a very useful data set for assessing the needs for longer time scale monitoring of the climate state through Observing System Experiment (OSE) research activities. CLIVAR proposes a team approach to linking observational research to modeling activities, with the aim of determining sampling requirements needed to improve physical parameterization of processes such as deep convection and cloud-radiative feedback.

In conclusion, there is growing scientific and societal awareness that climate variations and change can alter the frequency, intensity, and location of high-impact weather events. In addition, society is becoming more vulnerable to high-impact weather because of population growth, demographic changes, and increased value of property. It is therefore imperative to increase the rate of improvement of weather forecast skill in order to keep pace with society's increasing vulnerability to extreme weather. Recent scientific and technological advances encourage us to believe that the needed improvements can be made. It is toward these goals that THOR*pex* is directed.

2. THOR*pex* Sub-programs

The research objectives of THOR*pex* are addressed through four sub-programs: i) Observing System Development and Evaluation; ii) Data Assimilation and Observing Strategies; iii) Predictability and Dynamical Processes; iv) Societal and Economic Impact Assessment.

2.1 Observing System Development and Evaluation

A central objective of THOR*pex* is to improve the use of existing *in-situ* and space-based observations. In addition, THOR*pex* will develop and evaluate new observing technology designed to improve the observational quality and coverage in critical atmospheric regions. Both existing observing systems and those under development, will contribute observations to the THOR*pex* data base. Observing-system testing and evaluation will be accomplished through a series of regional field experiments designed to address specific predictability issues. The regional experiments will provide data sets to evaluate observing strategies, data assimilation, and predictability hypotheses in particular geographic areas. THOR*pex* will collaborate with regional and global programs that require observations in remote and data-sparse regions (e.g. WSR, TAMEX-II, PACJET, CLIVAR) and with programs to calibrate and evaluate satellite observations (NAST-I, SSMIS). Observing system components and experiments are discussed below under the sub-sections: a) Satellite observing systems, b) *In-situ* and surface-based observing Systems, and c) THOR*pex* Observing System Tests (TOSTs).

a) Satellite observing systems

The current meteorological satellite observing system is comprised of a constellation of geosynchronous and polar-orbiting satellites operated by national or conglomerate space agencies. Satellite observations have become an integral part of weather forecasting systems and represent a substantial component of the global observing network. Anticipated advances in microwave sensors (e.g. GMS, Aqua and CloudSat) and hyperspectral imaging (e.g. GIFTS) and profiling will provide new opportunities and challenges.

The design of weather-satellite sensors, to be deployed over the next decade, has been completed. However, THOR*pex* research and its field programs will provide calibration and evaluation datasets to assess the impacts of existing and near-term satellite observations and will contribute to decisions regarding observational requirements for future satellites.

b) In-itu and surface-based observing systems

THOR*pex* will test and evaluate a variety of *in-situ* observing systems (e.g. driftsondes, bi-directional radiosondes, wind profilers, rocketsondes, robotic aircraft) that provide upper-air or surface observations where supplemental data are needed to complement existing satellite data. We anticipate that these *in-situ* observations will significantly improve analyses in cloudy regions, and also increase the information extracted from satellite data outside the cloudy regions by improving the background fields used by data assimilation. If verified, these results would provide further evidence supporting the development of future satellite sensors for improved observations in cloudy regions. These issues present research challenges for THOR*pex*, and opportunities to test new observing system and data assimilation approaches. The test and assessment results, together with the research in THOR*pex*, will determine which *in-situ* observing systems are used to supplement satellite observing-systems.

c) THORpex Observing- System Tests (TOSTs)

Regional field experiments will be conducted to test observing and forecast systems in conditions leading to high-impact weather. These experiments will address specific regional forecast requirements and provide test-beds for new observing systems, assimilation schemes and targeting methodologies. Co-ordination of the regional field experiments will reside with regional committees. The proposed THOR*pex* Observing-Systems Tests will include:

i) A **European** North Atlantic Experiment in October to November, when cyclones that have undergone tropical to extratropical transformation have historically been characterized by low predictive skill and high societal/economic impact. Another experiment would take place in December to March, when smaller, rapidly-developing cyclones form in the mid-Atlantic storm track and affect north-west Europe. Polar lows and Greenland-lee vortices develop in regions with lower density of conventional observations and subsequently impact northern European weather. On the medium-range, there is known sensitivity of European forecasts to perturbations over the Canadian Arctic, a continental region of limited satellite and upper-air coverage.

ii) A **North-American** Experiment in mid-winter, during the period of highest vulnerability to east and west-coast cyclones and mid-continent Canadian arctic outbreaks and blizzard conditions. This range of forecast problems will require experiments both over the Pacific storm-track and North America. The timing of these experiments will be influenced by the sensitivity of north-American high-impact weather to the phase of ENSO and its intra-seasonal variability.

iii) An **Asian** Experiment during late spring and/or summer to test the regional impact of THOR*pex* experimental observing systems, data assimilation methods, and model parameterization improvements. For medium and extended-range timescales this will include the use of coupled atmosphere-ocean models, forecasts of land-falling tropical cyclones, and extreme precipitation events in the Indian monsoon and along the Mei-Yu front. There is also interest to improve medium and short-range forecasts for the Asian dust storms that have severe impacts on visibility and air quality over the region. For shorter forecasts timescales, THOR*pex* will collaborate with other relevant WWRP programs. A further experiment will take place during the cool season, when cold-air outbreaks and severe dust storms occur.

iv) A Tropical Experiment during winter-spring over the east-Indian and west-Pacific Ocean equatorial "warm pool" to observe the impact of large-scale tropical convection on low and high-latitude weather systems. In particular, this region is frequently dominated by the Madden-Julien Oscillation (MJO), which is known to substantially influence mid- and high-latitude weather throughout both hemispheres on the medium and extended- range time scales. Enhanced observations of the initiation and subsequent evolution of the MJO and other-large scale tropical convective events would provide a much needed data set to evaluate the current numerical model deficiencies in simulating these disturbances, and provide a more complete observational basis for assessing their impact on the extratropics.

2.2 Data-Assimilation and Observing Strategies

A significant component of forecast error originates from errors in the analysis. These analysis errors arise from both the observations (instrument error and representativity error) and approximations in the data assimilation process (e.g. statistical assumptions and background error). THOR*pex* will conduct research into improving both observing strategies and the data assimilation process.

THOR*pex* will exploit the new concept of targeting to address the observational issues described above. Targeting is the process of identifying those regions in which observations would maximally improve the skill of a weather forecast using knowledge of the “flow-of-the-day” or, more generally, dynamically-determined information from the forecast model itself. Such observations are called targeted observations, and the regions that targeting identifies are referred to as sensitive regions. Having identified sensitive regions, supplementary observations can be taken to increase forecast skill. A further consequence of successful targeting is that insensitive regions can be identified where observations can be safely thinned. Thus, targeting facilitates the most effective utilization of observational resources and thereby allows the identification and deployment of an optimal observing system.

THOR*pex* will develop targeted observing methods that incorporate dynamical information and properties of the data assimilation system, including the adjoint of data-assimilation procedures and ensemble-based Kalman filters. The limits of current targeting strategies will be identified and lead to the design of new methodologies that incorporate moist and other physical processes, data assimilation process, observational representativeness error and model error. New methods are required for targeting in medium and extended-range forecasts. Targeting includes the addition of observations in certain regions at certain times, or intensive sampling of a region for periods of several days or weeks, e.g., flow regime targeting.

THOR*pex* will investigate sampling rates and spatial/spectral filtering of satellite data including targeting specialized observations (such as rapid-scan wind products) into certain regions. In addition, strategies will be developed and tested for processing, in an adaptive sense, the large (and potentially overwhelming) amount of data expected from new satellite hyperspectral sounders. The development of methods to extract the maximum meteorological information content from satellite observations will be a THOR*pex* research priority. Improved strategies for targeting *in-situ* and satellite observing systems will be developed with a special focus on cloudy regions where current-generation satellite data are limited in vertical resolution. Research radar aircraft will be used to survey precipitation systems to obtain observations for assessing the potential impact on weather forecasts of next-generation cloud and precipitation radars on satellites.

Targeting research will allow the identification of critical gaps in the global observing network. Gaps in observing coverage may refer to limitations such as the lack of cloud-track wind observations in high latitudes, density (spatial and temporal) of the operational radiosonde network, scarcity of satellite data below upper-cloud layers, or other factors. Research will be carried out to identify geographical regions where new permanent observing systems would provide the greatest improvement to weather forecasts, e.g. the maritime continent and the Arctic. In addition, targeted observations may also be carried out in conjunction with various CLIVAR activities, such as the proposed CLIVAR oceanic-process studies, which would benefit from enhanced THOR*pex* observations.

Aspects of targeting to be further developed include:

- Consideration of whether different targeting methods are required for targeting of: i) satellite observations or ground-based observations data, ii) weather regimes, and iii) linear versus fully non-linear development.
- Evaluation of the relative benefit of localized high-resolution targeted data as compared to coarser resolution regional data.
- Acquisition of over-sampled data sets for *a posteriori* targeting.
- Development of targeting methods for different flow regimes for the week-two forecast problem.
- Improvement of first-guess analyses through short-range, high-resolution forecasts in targeted regions.

THOR*pex* will carry out research on improved methods for data assimilation. This will include contributing to the development and testing of advanced data assimilation techniques for the improved use of existing satellite and *in-situ* observations over oceanic and arctic regions, including improved covariance estimation, 4d-Var development, ensemble Kalman filters, moisture assimilation, and advanced procedures for assimilation of targeted data. The development of data-assimilation methods would be enhanced by collaboration with related activities proposed in CLIVAR, which seek to improve the initialization of coupled ocean-atmosphere models for research, as well as seasonal and inter-annual forecasting purposes.

THOR*pex* will perform observing-system experiments with real and "virtual" observations to determine optimal observing and data assimilation strategies for improved predictions of high-impact weather and contribute to the development of new and innovative operational data assimilation systems and model parameterizations. Observing System Simulation Experiments (OSSEs) with "virtual" data and Observing System Experiments (OSEs), using archived data from winter storm field programs (e.g., FASTEX, NORPEX, WSR) and THOR*pex* data from THOR*pex* Observing-System Tests (TOSTs) will be conducted to determine: i) optimal sampling patterns for satellite and *in-situ* observations; ii) potential forecast impact of new observing systems; iii) requirements for observations in terms of horizontal, vertical and temporal resolution, and accuracy of key variables. This will involve using high-resolution (e.g. 25 km) "nature" runs.

2.3 Predictability and Dynamical Processes

THOR*pex* will carry out research studies on predictability and dynamical processes to determine which spatial and temporal scales of motion must be better observed, analyzed, parameterized, and simulated for the improvement of weather forecasts, including ensemble products. THOR*pex* aims to establish to the degree to which predictive skill is limited by observations, data assimilation, forecast model error, or ensemble design at various forecast lead-times, and with various skill metrics (e.g. precipitation and cloud, surface temperature and wind). An objective is to utilize ensemble methods to identify flow regimes within which high-impact weather events are inherently more difficult to predict. These regimes may occur on periods of days or weeks (e.g., blocking or blocking transition), or on seasonal and inter-annual cycles (e.g., ENSO and North-Atlantic Oscillation).

Diagnostic studies will be performed on the life cycles and predictability of high-impact weather systems. THOR*pex* will diagnose the dynamical processes through which errors on various scales amplify and propagate (e.g., energy conversions, Rossby-wave dispersion and instability mechanisms). For example, Langland et al 2001 discuss the effects of a downstream amplifying Rossby-wave packet in the development of the poorly predicted 25 January 2000 U.S. east-coast snowstorm. The excitation mechanisms of Rossby-wave trains, e.g., tropical convection; baroclinic wave growth; large-scale orographic effects, will be considered. It is important to identify inter-annual and intra-seasonal planetary flow regimes that influence weather events with low predictive skill and high societal and economic impact.

Tropical convection is often initiated by extra-tropical Rossby-wave propagation into the tropics. Conversely tropical convection can excite energy propagation from the tropics to the extratropics. THOR*pex* will explore to what extent improved extratropical observations lead to improved forecasts of tropical convection and associated tropical weather systems (e.g., tropical cyclones; Madden-Julian activity). Equally, THOR*pex* will examine whether improved observations and assimilation of tropical convection will contribute to extended-range predictive skill globally.

The relative importance of model error and initial condition error in the growth of forecast errors will be determined at various lead times. This includes the effect of upscale energy transfer from poorly resolved and parameterized scales on the predictability of the resolved systems. The assessment of weaknesses in model parameterizations of sub-grid-scale physical processes, and the development of improvements to those parameterizations, may require field campaigns zto collect high-resolution.

THOR*pex* predictability and dynamical-processes research will also address issues such as:

- Forecast skill improvements for both extreme events and every-day forecasts. For extreme events, techniques are being developed to refine target zones based on ensemble forecast guidance.
- Week-two forecast skill that is significantly limited by model error arising from uncertainties in physical parameterizations (e.g., deep convection, boundary-layer and cloud processes, and cloud-radiation interactions). THOR*pex* should also consider including explicit convection in extended-range forecast models. Develop climatologies of inter-annual and intra-seasonal variations in forecast error sensitivity and associated flow regimes. Assess whether the week-two forecast problem requires a coupled atmosphere-ocean prediction system and detailed ocean observations.
- The use of stochastic climate forecasts to plan, several months in advance, for deployments of additional observing resources in particular regions.
- The influence of organized intra-seasonal tropical convection (including Madden-Julian Oscillations and east Pacific equatorial convective flare-ups) and the effects of tropical-extratropical teleconnections on extended-range predictability.
- Whether targeted mesoscale observations, including cloud and precipitation, are necessary for improved regional-scale forecasts or large-scale predictability.
- The development a PV perspective of predictability, e.g., sensitive regions as PV anomalies, as well as singular vectors.

2.4 Societal and Economic Impact Assessment

The societal and economic impact sub-program of THOR*pex* will assess the costs and benefits of providing improved forecasts of high-impact weather. This will include:

a) ***Assessment of routine and high-impact weather events and forecasts***

The assessment will quantify the costs and effects of daily and episodic, high-impact weather, providing a baseline to quantify the actual and potential value of forecasts and forecast improvements. It will also help to identify potential users of forecast improvements in the weather-sensitive commercial sector. In addition, forecast parameters that the assessment finds to have significant impact may be incorporated into verification measures as discussed below.

b) Use and value of forecast Information

THOR*pex* researchers will evaluate the use and value of current and improved forecasts by performing case studies for various public and private users. Each case study will examine the decisions that a user or class of users makes with weather information.

This will involve evaluation of the user's success with respect to their goals. A norm related to the forecast parameters in the user's decision model will be used to assess the quality of both current forecasts, and those produced with improved observing and forecast systems. Improved forecasts can be simulated using archived forecasts, "virtual data", or evaluated from field tests of THOR*pex* observations. The results will assist governments and international agencies on the future allocation of resources for improved weather services.

c) Development of verification measures

The statistical metrics used by operational forecast centers to evaluate forecast skill are, in many cases, not directly relevant to those public or private end-users who use weather forecasts to make decisions. For example, norms such as the anomaly correlation are often used to evaluate model skill, but have little or no direct meaning to many potential forecast information users, such as utility companies or highway departments. THOR*pex* will therefore quantify forecast improvements using a wide range of parameters.

For some forecast parameters, verification measures may be already established or simple to develop; for example, an energy company might be interested in the distribution of errors in heating degree days, or in one or more statistics that summarize the error distribution. For other parameters, such as precipitation, researchers may need to develop modified or new verification measures that are relevant to one or more users, yet are efficient, reliable, and possess other desirable characteristics discussed in Murphy (1997).

The concept of "end-to-end" forecasting (Smith et al. 2001) considers the direct prediction of economic variables that have a weather dependent component. Its goal is to translate uncertainty in the weather into uncertainty in the quantity of interest to the user (e.g., energy demand). Previous work in the field has considered rather simple cases of forecasting to make binary choices (for example, whether or not to salt an icy road) using cost-loss analysis. However, new techniques are developed for economic situations where the outcome is a continuous variable (e.g., demand) and where the decision is also a continuous variable (e.g., production). Smith et al. (2001) show how probabilistic forecasts of demand can be used to make production decisions and produce probability density functions for the profit of a given business activity. These and other new techniques for assessing the societal and economic benefit of weather forecasts will be used and developed as part of THOR*pex.*

Particular societal and economic assessment research issues are to:

- Quantify the potential marginal value to users of the improvements in weather forecast skill brought about by THOR*pex* research.
- Educate users about the utility of probabilistic forecasts
- Carry out "end-to-end" assessments of tailored forecast products for specific user sectors, e.g., energy; transport; food; tourism.
- Develop appropriate user metrics for quantifying forecast skill, e.g., hours lost; tons of CO_2 saved; dollars saved. Develop a definition of high-impact weather in terms of user metrics e.g. news coverage, potential for loss making. (By weather we mean the condition of the atmospheric environment, e.g., drought; heat/cold stress; flood; run-of-the-wind).

3. The THOR*pex* Global Experiment

The THOR*pex* Global Experiment aims to integrate new and existing observing and forecast systems to test the predictability and assimilation advances made from the THOR*pex* research and regional field experiments. It will demonstrate the potential for improved operational forecasts on all predictable spatial scales, and time-scales out to two weeks using enhancements to the global observing system. Through this accomplishment, THOR*pex* will assist national weather services and agencies in their ongoing mission for permanent enhancements to the observing system and improved forecasts of high-impact weather. The Experiment will most likely take place in 2009-2010.

The THOR*pex* Global Experiment will deploy the full suite of experimental and operational observing systems. This will include *in-situ* systems (driftsonde, UAVs, rocket-buoy and profilers), spatial and temporal enhancements of data provided by satellite systems, and operational and bi-directional radiosonde soundings targeted at 6-hourly intervals over sections of Russia, North America, and Asia. Data collected in THOR*pex* will be available in near real-time and archived by NCAR/JOSS, and at operational forecast centers. The THOR*pex* data archive will be an invaluable resource for operational and basic research.

The Global Experiment will last up to one year. It is an intensive effort to obtain a comprehensive observational data set over the entire globe and detailed analysis of the forecast impact of these observations. The timing of the Global Experiment will be dictated, in part, by the deployment of certain critical satellite observing systems (e.g. GIFTS or COSMIC). An observing system upgrade of this geographic scope and duration has not been previously attempted in any program. The Global Experiment therefore has the potential to demonstrate unprecedented gains in forecast skill of high-impact weather. THOR*pex* continues and extends the accomplishments and visionary thinking represented in the First GARP Global Experiment, FGGE (Gosset 1979).

4. THOR*pex* Management and Organization

The THOR*pex* International Science Steering Committee (ISSC) was convened in 2002 (membership in Appendix 2). The ISSC includes international experts in data assimilation, observing systems, numerical modeling, predictability, phenomenology, atmospheric dynamics, societal-economic impacts, and forecast product end-users from government and industry. The international THOR*pex* program management will be carried out by the International Core Steering Group (ICSG), formed in 2002, composed of representatives from countries (currently: Australia, Canada, China, France, Germany, India, Japan, Republic of Korea, Russia, UK and USA) that have a particular interest in THOR*pex*. Consideration of adopting THOR*pex* as a WMO program will be made at the WMO Executive Council meeting in June 2003. A THOR*pex* International Program Office will be established in Geneva after THOR*pex* is adopted as a WMO program. The THOR*pex* International Science Plan will be completed early in 2003. Regional THOR*pex* management and science committees (e.g. for North America, Europe, Asia, Australia) will refine regional objectives, facilitate the participation of scientists in the program and provide regional funding agency guidance.

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Appendix 1: Acronyms

ATD	Atmospheric Technology Division
BOM	Bureau of Meteorology
CDC	Climate Diagnostics Center (NOAA)
CIMSS	Cooperative Institute for Meteorological Satellite Studies (Univ. of Wisconsin – Madison)
CLIVAR	Climate Variability and Predictability
CMA	Chinese Meteorological Administration
CMS	Canadian Meteorological Service
COSMIC	Constellation Observing System for Meteorology, Ionosphere and Climate
DNMI	Norwegian Meteorological Institute
ECMWF	European Centre for Medium-Range Weather Forecasts
ENSO	El Niño – Southern Oscillation
ESIG	Environmental and Societal Impacts Group (NCAR)
EUCOS	The European Composite Observing System
FASTEX	Fronts and Atlantic Storm-Track Experiment
FGGE	First GARP Global Experiment
GARP	Global Atmospheric Research Program
GCOS	Global Climate Observing System
GIFTS	Geostationary Imaging Fourier Transform Spectrometer (NASA)
GMS	Geostationary Meteorological Satellite
GPS	Global Positioning System
GSFC	Goddard Space Flight Center (NASA)
IPO	Interagency Program Office
JMA	Japan Meteorological Agency
JOSS	Joint Office for Science Support (UCAR)
LaRC	Langley Research Center (NASA)
MJO	Madden-Julian Oscillation
MMM	Mesoscale and Microscale Meteorology Division (NCAR)
NAO	North Atlantic Oscillation
NAOS	The North American Atmospheric Observing System
NASA	National Aeronautic and Space Administration
NAST-I	NPOESS Atmospheric Sounder Testbed-Infrared
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction (NOAA)
NESDIS	NOAA Environmental Satellite Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NORPEX	North Pacific Experiment
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRL	Naval Research Laboratory
NSF	National Science Foundation
NWS	U.S. National Weather Service
OSE	Observing System Experiments

OSSE	Observing System Simulation Experiment
PACJET	Pacific Landfalling Jets Experiment (ETL)
SHMI	Swedish Hydro-Meteorological Institute
SSMIS	Special Sensor Microwave Imager/Sounder
TAMEX	Taiwan Area Mesoscale Experiment
THOR*pex*	THe Observing system Research and predictability experiment
TOSTs	THOR*pex* Observing System Tests
USWRP	U.S. Weather Research Program
WMO	World Meteorological Organization
WSR	Winter Storm Reconnaissance (NOAA)
WWRP	World Weather Research Program (WMO)

Appendix 2: Membership of the THOR*pex* International Science Steering Committee as of 1 September 2002

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