OBSERVATIONS AND DATA ASSIMILATION: THORPEX FIELD PROGRAMS

Authors: Patrick A. Harr, Department of Meteorology, Naval Postgraduate School, Monterey, CA

Chun-Chieh Wu, Department of Atmospheric Sciences, National Taiwan University, Taipei, Taiwan

ABSTRACT

An objective of THe Observing Research and Prediction EXperiment (THORPEX) was to develop science and implement plans to meet regional forecast needs in Asia, North America, Europe, and the Southern Hemisphere. As such, THORPEX regional committees were formed to propose, organize, and implement field projects and forecast demonstration projects related to improving forecasts of high-impact weather specific to each region. Over the THORPEX time period, programs were conducted that spanned from each pole to the tropics. While the geographic settings varied greatly, the objectives of each campaign were consistent with the THORPEX goals of improving prediction from 1 day through 2 weeks for the benefit of society and the economy of each region.

1. INTRODUCTION

In THORPEX, it was recognized that improvement to forecasts of high-impact weather would be dependent on increased understanding of key dynamical processes associated with forcing factors such as Rossby-wave activity and diabatic influences. Much of these activities were focused in the Predictability and Dynamical Processes (PDP) working group of THORPEX. It was also recognized that increased predictability required improved representation of key processes in numerical forecast models, which required careful use of observations to define initial conditions for numerical integration. Many of the THORPEX field campaigns were then constructed to be combined efforts between the PDP and Observation and Data Assimilation (ODA) THORPEX communities.

Field campaigns conducted within THORPEX typically required unique techniques for obtaining observations of key processes that may be related to a variety of spatial and temporal scales. Additionally, experiments were designed to not only identify key observations but to place those observations such that their spatial and temporal distributions were consistent for improved initial conditions. These observations often required new data assimilation techniques to be explored for increasing the utility of observations in the numerical integrations.

Early in the THORPEX cycle, it was clear that much high-impact weather had global origins that projected onto regional conditions. Therefore, there was a link between longer time intervals and near global connections to short time period and regional impacts. Specific factors such as the leading edges of Rossby wave trains and diabatic forcing of divergent flow were identified as representative of these global-regional linkages that often lead to high-impact weather. In this summary of the THORPEX Field Campaign Session, several programs are summarized to provide examples to the global aspect of THORPEX-related technology, retrieval of complex data sets, and their usage in the prediction ob high impact weather.

2. GLOBAL PROGRAMS

The THORPEX field campaigns were deeply rooted in subgroups of the PDP and ODA. In particular, the Predictability and Dynamics of Weather systems of the Atlantic-European sector (PANDOWE) highlighted the generation, propagation, and evolution of upper-level Rossby wave trains. Additionally, research investigated the roles of moist processes as modifying factors to wave train evolution and impact on the larger-scale circulations. While PANDOWAE provided a framework for experimentation based on dynamical and physical processes, the Year of Tropical Convection (YOTC) and the International Polar Year (IPY) typified the global extent of investigations of regional high-impact weather events.

While it was not possible to include reports on all THORPEX-related field campaigns, the sessions dedicated to this topic are comprised of key arctic, tropical, and midlatitude programs together with reports on technological advances that provided the capability by which operations could be planned and observations taken and interpreted.

2.1 International Polar Year (IPY)

Under the umbrella of the IPY, the Concordiasi field program provided observations over the Antarctic continent to improve satellite data assimilation, improve model representation of physical processes over the Antarctic, and provide observations of troposphere-stratosphere processes and exchanges. The joint effort between the United States and France employed zero-pressure balloons that provided dropsonde coverage from high altitude while circumnavigating the south pole.

While Concordiasi was the sole experiment conducted over the Antarctic, several programs were conducted over the Arctic. The Greenland Flow Distortion Experiment (GFDex) examined the Greenland tip jet, barrier winds, and polar lows. The Storm Studies of the Arctic (STAR) examined gap flow, air-sea interactions, and topographic impacts over the eastern Canadian arctic. In the presentation to be given at the Conference, the results from GFDex will be examined from the perspective of forecast model improvement. In particular, sensitivities to observational error covariances are examined in relation to the topographic influence of Greenland. There is sensitivity to location of dropsonde observations in relation to coastal and high-altitude interior locations.

The THORPEX Arctic Weather and Environmental Predictions Initiative (TAWEPI) was a program dedicated to forecasting over the Canadian arctic. A focus of TAWEPI was to develop and validate a high-resolution regional numerical model over the Canadian Arctic. As such, processes related to sea ice, ozone, arctic clouds, and coupling with sea, ice, and ocean currents.

Finally, the Norwegian IPY program examined the utility of targeted observations with respect to polar lows in addition to various physical processes related to high latitude maritime weather conditions. This included cloud - radiation feedback processes, latent heat release, and use of a high resolution numerical ensemble prediction system.

Through the combination of several high-latitude THORPEX-related observing programs, new results are leading to the development of improved weather prediction systems over polar regions. These improvements are in conjunction with increased understanding of physical processes, predictability, and data assimilation over the Arctic and Antarctic regions.

2.2 Year of Tropical Convection (YOTC)

The objectives of YOTC are to increase understanding of processes controlling the organization of tropical convection and its interaction over a variety of spatial and temporal scales. An overarching goal is to improve the representation of multi-scale convective interactions in numerical models via improved data assimilation, process definition, and vertical and lateral exchanges of heat and momentum.

Although no field campaign was conducted under the umbrella of YOTC, it is considered here as it was an important virtual campaign based on the specification of a comprehensive data base based on global numerical analyses and forecasts. Special emphasis was placed on archival and specification of subgrid-scale tendencies by which physical processes as represented in high-resolution global weather prediction models could be examined. The YOTC experiment period spans several years in which the ENSO cycle, Madden-Julian Oscillation, monsoon systems, and synoptic-scale tropical waves underwent significant variation and seasonal changes. These variations provide for a wide range of conditions by which YOTC-provided analysis and forecasts can be used for diagnosis and initial conditions related to a variety of physical and dynamical processes.

In keeping with the YOTC virtual experiments, several long-term numerical experiments were conducted as part of the YOTC program. These included the Cascade Project in the United Kingdom, in which YOTC data were used to provide initial and boundary conditions for study of the diurnal cycle of convection over the Indian Ocean. Several projects were conducted to examine simulations and hindcasts of the MJO in relation to sensitivity to ocean coupling and climatic variations.

While no physical field program was conducted under the YOTC portion of THORPEX, the virtual field campaign is unique and instrumental in providing for increased understanding of physical and dynamical processes related to tropical convection and its organization and interaction across a range of spatial and temporal scales. Additionally, several THORPEX-based regional field campaigns have benefited directly from the YOTC data base to provide for studies of sensitivities to observations and initial conditions for high-resolution simulations.

2.3 Regional Field Campaigns

2.3.1 Hydrological cycle in Mediterranean EXperiment (HyMeX)

Heavy precipitation events (HPE) frequently impact the Mediterranean. Flash-floods, landslides and mudslides during these HPE cost several millions of euros in damage and many casualties. Within the framework of the 10-year international HyMeX program dedicated to the hydrological cycle and related processes in the Mediterranean, a major field campaign was dedicated to heavy precipitation and flash-floods from September to November 2012. The 2-month field campaign took place over the Northwestern Mediterranean Sea and its surrounding coastal regions in France, Italy and Spain. The observation strategy was aimed at documenting four key components leading to heavy precipitation and flash-flooding in that region: (i) the marine atmospheric flows that transport moist and conditionally unstable air towards the coasts; (ii) the Mediterranean Sea as a moisture and energy source; (iii) the dynamics and microphysics of the convective systems; (iv) the hydrological processes during flash-floods. Specific Intense Observations Periods (IOPs) were conducted using aircraft and ground-based observations. Associated modeling studies have been conducted to increase understanding of atmospheric process, HPE, flash floods and general numerical prediction validation and improvement.

2.3.2 The DIAbatic influences on Mesoscale structures in ExTratropical storms (DIAMET)

The cold conveyor belt and sting jet are often found equatorward and rearward of a cyclone. Detailed observations of the mesoscale structure of these features are important for identifying regions of high-impact weather that may rapidly evolve over small spatial and fast time scales. During DIAMET, in-situ and dropsonde observations were obtained during two research flights through a cyclone. A numerical weather prediction model was used to link the strong wind regions with three types of “air streams”, or coherent ensembles of trajectories: two types are identified with the cold conveyor belt that hooks around the cyclone center. A third air stream is identified with a sting jet that descends from the west of the cyclone. Observations of chemical tracers indicate that the cold conveyor belt and sting jet air streams are distinct air masses even when the associated low-level wind maxima are not spatially distinct. In the model, the cold conveyor belt experiences slow latent heating through weak resolved ascent and convection, while the sting jet experiences weak cooling associated with microphysics during its subsaturated descent. Diagnosis of mesoscale instabilities in the model shows that the cold conveyor belt passes through largely stable regions, while the sting jet spends relatively long periods in locations characterized by conditional symmetric instability (CSI). The relation of CSI to the observed mesoscale structure of the bent-back front and its possible role in my butt banding is discussed.

2.3.3 THORPEX North Atlantic Waveguide and Downstream Impact Experiment (T-NAWDEX).

Over the past years airborne observations constituted an important component of THORPEX. The DLR research aircrafts Falcon and recently the new airborne platform HALO participated in several airborne campaigns that directly originated from THORPEX or that provide a strong link to relevant topics. These past campaigns concentrated on observations used to investigate the importance of diabatic processes for the predictability in the extratropics. A case study shows water vapor lidar observations in the inflow of a warm conveyor belt and highlights the sensitivity of the structure of the extratropical cyclone and the dynamics at upper levels to the low level humidity. Additionally Lagrangian observations in WCBs over Europe quantify diabatic processes along WCBs.

To extend the observations of such diabatic factors, an international field experiment THORPEX North Atlantic Waveguide and Downstream Impact Experiment (T-NAWDEX) is planned in September and October 2016. The science objectives are strongly motivated by the results from the previous campaigns. Flights with HALO will be conducted over the North Atlantic to investigate the triggering of disturbances along the North Atlantic wave guide, their subsequent evolution and the associated downstream impacts over Europe..

2.3.4 THORPEX Pacific Asian Regional Campaign (T-PARC)

The THORPEX Pacific Asian Regional Campaign (T-PARC) was a multi-national field campaign that addressed the shorter-range dynamics and forecast skill of high-impact weather events in one region (Eastern Asian and the western North Pacific) and the downstream impact on the medium-range dynamics and forecast skill of another region (in particular, the eastern North Pacific and North America). Although many significant weather events occur over eastern Asia and the western North Pacific, the focus of T-PARC was on various aspects of typhoon activity, which included formation, intensification, structure change, motion, and extratropical transition. Because of the significant impact of typhoon activity on the region of eastern Asia and the western North Pacific, T-PARC was comprised of several affiliated programs. The experimental design for T-PARC addressed three primary components: (1) A tropical measurement strategy to examine circulations of the tropical western North Pacific monsoon environment as they related to tropical cyclone formation, tropical cyclone intensification, and tropical cyclone structure change. (2) Extratropical transition (ET) and downstream impacts was based on the poleward movement of a decaying tropical cyclone and the resulting intense cyclogenesis that results from its interaction with the midlatitude circulation. (3) Identification of regions in which extra observations may reduce numerical forecast error growth associated with forecasts of tropical cyclone track over the western North Pacific. Results addressed multi-scale factors in tropical cyclone formation, impacts of tropical cyclones on midlatitude flow characteristics, and the role of in situ observations in improving tropical cyclone track forecasts.

The T-PARC observations were assimilated in a number of global and regional models to draw conclusions on the benefit of targeted dropsonde observations for typhoon and mid-latitude forecasts, to evaluate different targeting strategies and to evaluate the potential of lidar instruments for the initialization of weather prediction models. In addition, airborne lidar cloud top observations were used to develop a height correction method for AMVs that is now tested using CALIPSO observations. Major findings from these studies include: (a) Targeted dropsondes overall improve typhoon track predictions, but their impact significantly depends on the assimilation system; (b) targeted dropsondes only have a small impact on mid-latitude forecasts and the impact is mainly due to improved typhoon tracks that indirectly lead to mid-latitude improvements; (c) dropsondes in the targeted vicinity of typhoons have the largest impact, whereas the impact of dropsondes in distant sensitive regions and the core and eyewall region is small; (d) wind lidar observations have a comparably high impact, which underlines high expectations for the ADM-Aeolus satellite lidar and suggests considering the deployment of wind lidars on commercial airplanes in the future (e) the average impact of water vapor lidar observations is small, but forecasts can be affected considerably under certain conditions; (f) lidar cloud top observations can be used to adjust the height assignment of AMVs and by this significantly reduce their wind errors.

3.0 UNIQUE THORPEX FIELD CAMPAIGN ADVANCEMENTS

As defined above, many THORPEX-related field campaigns addressed the utilization of observations for improved prediction of high-impact weather. To facilitate the planning of adaptive observations during field programs, the ECMWF developed the Data Targeting System (DTS) as an interactive web-based system to allow users in different centres to participate in real-time adaptive control of the observing system with a minimum of manual effort. The DTS provided a facility to efficiently manage the data targeting process from weather event selection to issuing requests for additional observations, and has been used in several THORPEX field campaigns. The DTS enables users to a) identify potential high-impact weather events, in particular cases with large uncertainty; b) request computation of sensitive areas (regions where additional observations are likely to have most impact in reducing the forecast uncertainty); c) identify and issue requests for additional real-time observations; and d) monitor the observation requests and confirm their subsequent deployment.

Field campaigns using the DTS have been able to issue requests for additional radiosonde ascents from 20 different participating countries, and for AMDAR aircraft observations and radiosondes from ASAP ships participating in the EUMETNET observing program. In addition, the DTS has allowed users to identify sensitive areas for research aircraft observations. The DTS was used in a long-term quasi operational trial (EURORISK

PREVIEW) as well as in field campaigns, including summer and winter THORPEX-Pacific Asian Regional Campaign (T-PARC), and most recently MEDEX and HyMeX campaigns to study the predictability of high-impact weather over the Mediterranean.

An interactive three-dimensional (3D) visualization of ensemble weather predictions is a highly desired product for weather forecasting during aircraft-based atmospheric field campaigns. Research flights with high-flying aircraft require the flight route to be planned several days in advance, hence, being able to assess the uncertainty of the forecast on which a flight is based is very valuable. Since the targeted upper-level features are of an inherently three-dimensional nature, it seems natural to aid their identification with three-dimensional visualization methods. The "Met.3D" system is a novel forecasting tool that makes recent advances in 3D and uncertainty visualization available to the forecaster. Interactive 2D and 3D visualization elements, displaying forecast meteorological fields and uncertainty measures derived from the ECMWF ensemble prediction system, enable the meteorologist to quickly identify atmospheric features relevant to a flight and to assess their uncertainty. The Met.3D was applied during the 2012 T-NAWDEX-Falcon field campaign, a project that aimed at taking in-situ measurements in warm conveyor belts (WCBs). To predict a 3D "probability of WCB occurrence", p(WCB), a method based on Lagrangian particle trajectories computed on the ensemble wind field is proposed. The major challenges for development were to efficiently compute uncertainty measures from the terrain-following ECMWF model grids varying with each ensemble member, finding the best compromise between p(WCB) accuracy and computational demand, exploiting available graphics hardware to compute visualizations from the prediction data at interactive frame rates, and building a "bridge" from 2D views familiar to meteorologists to 3D views.

4.0 CONCLUSIONS

The THORPEX-related field campaigns have lead to study of factors and processes related to the forcing and predictability of high-impact weather over high-, mid-, and tropical latitudes. During the Conference Session, discussion will concentrate on advances related to THORPEX campaigns and these will be included in the final report conclusions.