**Introduction: Pat Harr, Naval Postgraduate School; Chris Davis, NCAR; Brian Golding, Met Office** THORPEX has been a major contributor to the advancement of weather forecasting capability, especially global NWP. Its structures (eg TIGGE) are increasingly used in wider research. It is important for these structures to continue & to be guided toward achieving further advances in the post-THORPEX era. However, some important areas were omitted from THORPEX, and other areas have gained in importance as a result of external change. The HIW project needs to address these, focussing particularly on small time and space scales, on the environmental, human & economic impacts of weather, and on the need to communicate weather forecasts in ways that ensure that produce beneficial responses. There are major challenges in developing a proposal that simultaneously contains attractive science questions, increases societal resilience & meets funders' priorities.

**Forecasting for Aviation: Klaus Sturm, DWD**
Aviation faces many challenges which require enhanced weather forecasting information, including: contrail impact on climate; noise near airports; wake vortices; thunderstorms. The need is global. Progress requires close co-operation between research, operations & IT services. Key forecast requirements are for up to 3 days ahead.

**Forecasting for renewable energy: Renate Hagedorn, DWD**
As renewables form a larger component of the generating mix, the network management problem changes from demand as the only weather-dependent unknown, to both demand and supply. Unexpected events can jeopardise safety of the grid Key forecast requirements are for up to 2 days ahead.

**Forecasting for disaster management: Renate Hagedorn, DWD**
Response agencies need early warning to enable assessment of need & preparation of response. There is a need to address issue of vulnerability.

**Flood forecasting with TIGGE: David Richardson, ECMWF**
Progress in hydrological prediction has been focussed through HEPEX. HEPEX has identified the following issues: Use of multiple hydrological models; short range issues (flash flooding); impacts on fire & health; additional variables needed in TIGGE to drive hydrological models

**Communicating Forecasts Charles Ewen: Met Office**
Users perceive accuracy to be less important than understandability. 28% of the public never take any action as a result of seeing a weather forecast. Key issues for acceptance: message, medium, format

**Unlocking Socio-Economic Benefits: Rebecca Morss, NCAR**
People want to know: What it means for me; What it means for my family; What do I need to do. Vulnerability = Susceptibility to harm = Exposure + Sensitivity. Sensitivity is a function of demographics, is related to coping capacity & is dynamic & complex. Integration of meteorology & social science means using both qualitative & quantitative research. Users have very different perceptions of likelihood of an event when a warning is issued. Shock tactics may persuade more people to act, but also create resistance. Issues are different in different places, so multiple studies are needed. Need to be able to track end-to-end value.

**Predictability & Dynamical Processes: Heinli Wernli, ETH Zurich**
Hazard error may result from synoptic scale error. Accuracy of diabatic processes is crucial. Need to link operations & universities; observations & modelling. Challenges in scale interactions and interactions with the water cycle.

**Predictability & Dynamical Processes: Edmund Chang, Stonybrook Uni**
Rossby Wave Trains are excited by extratropical TC transitions & winter cyclones. They drive the cyclone scale and hence downstream impacts. They are difficult to define and need object-oriented analysis & verification.

**Observations: Roger Swinbank, Met Office**
Primary role of satellite observations shown by forecast sensitivity tools. Targeting has been shown to be positive for TCs, but no benefit for winter storms.

**Observations: Stefan Klink, DWD/EUMETNET**
Developments in progress include aircraft humidity sensors, use of radar networks and novel surface observations collected for non-meteorological purposes. Timeliness and quality control are key issues. High space/time resolution for convective scale models.

**Data Assimilation: Tijana Janjic-Pfander, DWD**
The convective scale poses new challenges to data assimilation: faster development, spatially varying covariance functions, new observation types, non linear, non Gaussian statistics, multiple scales.

**Nowcasting / Convective-scale NWP: Brian Golding, Met Office**
Information contained in the analysis of observations is valuable for short time scale high impact weather events. Convective-scale NWP offers improvements in capability at these ranges, but this will depend on solving issues in data assimilation, ensemble prediction, modelling and product generation.

**Medium Range Prediction: Erland Kallen, ECMWF**
Enormous advances have been made in medium range synoptic scale prediction capability in recent years.

**Ensemble Forecasts: Richard Swinbank, Met Office**
Convective scale ensembles are now providing information on uncertainty in the storm-scale forecasts. Propose a Predictability & Ensemble Forecasting WG to pull together work on TIGGE, TIGGE-LAM & S2S archives. Challenges include: resolving convection, uncertainty, resources → resolution / members / domain; presentation, seamless products at different lead times

**Forecasting aerosol & chemistry: Bernhart Vogel, KIT**
Using COSMO-ART, Bernhard showed how weather forecasts can be improved and extended to new variables such as volcanic ash, pollen and dust by including aerosols in operational models. He presented a roadmap to quantify the effect of online coupled aerosols on the forecast of visibility and aircraft icing.

**Verification: Martin Gober, DWD**
High Impact Weather provides only small samples for verification requiring novel approaches. Spatial methods have grown in importance due to the "double penalty" problem. New methods of comparing models have also been developed, aiming for a seamless verification capability.

**Discussion: Themes**
The HIW project has the aim of advancing the science needed to increase global resilience to weather-related hazards and their impacts. It needs to include research in: convective-scale weather forecasting, environmental, economic & human impacts, communication, verification and predictability. However, to gain the necessary cross-disciplinary inputs, it needs a matrix structure, with impact areas on one axis and science disciplines on the other. Cross-cutting issues are: observations, NWP & role of the forecaster.

**PPP project: Thomas Jung, Alfred Wegener Inst**
10 yr project 2012-21 consisting of: Forecasting System Research (obs, DA, modelling - inc sea ice, ensembles); Underpinning Research (probability & diagnostics, teleconnections); Service-oriented research (SERA, verification). Focussed Year Of Polar Prediction 2017-8 will produce a major observational & modelling dataset to support research. Links with HIW through teleconnections → regime changes → blocking → HIW

**S2S: Andrew Robertson, IRI**
5yr project 2013-7, with extension option, to improve skill & understanding with emphasis on HIW. Contributes to GFCS. Uses IRI/Red Cross concept of Ready-Set-Go. Science issues: Sources of predictability, MJO, Teleconnections, Monsoon, Rainfall, Polar, Stratospheric processes. Modelling issues: resolution, coupling, systematic errors, initialisation, ensembles, spread/skill, verification. Benefits: operational services, GFCS, dissemination, decision making, early warnings, lives/properties saved. Sub-projects: Monsoon, MJO, Africa, Extreme Weather, Verification. Links: GFCS, WCRP/WGSIP, CLIVAR/ GEWEX/ WGNE, YOTC, CBS

**T-NAWDEX: Andreas Schafler, DLR**
Scheduled for 2016 to study lifecycle of Rossby waves over the North Atlantic. Germany: diabatic interest, small scale control, UTLS, ADM Aeolus satellite
USA: UTLS, forcing of waveguide perturbations, predictability, scale structure: micro ←→ synoptic; Case study of 12/9/12 extratropical transition.
Link with HIW project through Rossby wave breaking → HIW over Europe

**CBS/SWFDP, Ken Mylne, Met Office**
Three SWFDPs exist and several more are planned with an aim of rolling out the concept to all countries without a NWP capability. Based on the cascade model of global NWP centres disseminating data to regional interpretation centres that provide guidance to NMSs. A key customer for HIW project.

**Lake Victoria project: Brian Golding, Met Office**
Over 3000 lake users are believed to die each year from severe weather on the lake. NMSs have access through the Nairobi regional centre to Meteosat imagery, UK lightning network data, and UK 4km LAM outputs. A trial of forecast delivery by mobile phone has established

that it is feasible to provide useful advice to Lake users. However, without observations on the Lake, we can neither understand the processes nor relate the severe surface weather to remote observations, nor validate the model. A proposal has been submitted to NSF, with support from WWRP, to mount a field experiment with multiple radars and other equipment, to address these issues.

**Breakout Group discussions**

Breakout groups convened to identify key impacts, science objectives, partners and funding opportunities in areas representing different types of weather impact: environmental (flood), economic (energy) and human (transport):

**Environment group feedback – focus on floods**

Floods require coupling of weather science with hydrology and storm surge science.
Priority science areas: multi-scale modelling; predictability; initialisation
Research objectives:

Probabilistic timing, duration & amount of intense precipitation
Appropriate success measures
Understanding of moist processes, error sources, error growth, predictability,
Warm Conveyor Belts, Rossby Wave Trains, regime changes
Cloud microphysics, including the role of aerosols
Dynamical & statistical downscaling
Tropical precipitation and the diurnal cycle of precipitation
Quantifying uncertainties in forecast & observations
Communicating forecasts so they are understood and at appropriate scales.

Partners: social scientists, decision makers, operational centres, HEPEX, YOTC, GEWEX, GASS, GLASS

**Transport group feedback – focus on aviation**

Impacts

*Aviation:* airport operations, aviation scheduling (on local and broad scale), safety (ground operation and air operation), airport closing
*Ground transportation:* safety (land and sea), economics, inconvenience, road services and access

Weather Sources:

*Aviation:*
- wind (direction, gusts, sustained)
- precipitation (rate)
- cloud (ceiling height, fog)
- lightning

*Ground transportation:*
- wind (gusts, sustained),
- precipitation (rate, total)

Timescales range from: nowcasts (mins) of downburst → convective scale (hrs) of squall lines → synoptic scale (days) winter storms
Science issues are:

Multi scale → initialisation; obs network design
Evaluation → decision model / user risk / value / changing behaviour
Communication → reduction of ensemble data to usable products

Partners: Global System Devt division of NOAA; SESAR/NextGen

**Energy group feedback – focus on renewables**

Demand depends most on temperature & radiation. Forecasts required to 15 days ahead.
Production depends most on winds, radiation, precipitation. Forecasts required from first 6 hours for wind power ramps up to 15 days.
Distribution faults depend most on frozen precipitation, high wind & lightning and are required several days ahead.
Weather phenomena: blocking, cold-air outbreaks, wind-chill, large-amplitude waves, frontal structures & convection, anti-cyclones, cyclones, tropical cyclones
Science questions: predictability, quantifying uncertainty, measure of success; Probabilistic forecasting of cloud, precipitation amount/type, fog; products for different users in the management chain, implications of commercial issues.

**General Discussion**

Strategy: Science, driven by the aim of achieving a step change in global resilience to weather impact, for example on Environment (flooding); Transport (aviation); Economics (energy) – this list may need to be extended to cover all important impact areas, eg including agriculture, health.
Scope: Understanding & multi-scale modelling of hazards & impacts, communication, evaluation
Related initiatives: GEWEX, SWFDP, HEPEX, SESAR/NextGen, NSF/SEES; GEO; NHP; NOAA-ESPC; FfIR; DOWNSTREAM, ISDR
Potential funders: World Bank, EU, NSF, RCUK, poss NGO links, eg International Federation of Red Cross; Foundations.
Major elements: T-NAWDEX, Lake Victoria, SCMREX, La Plata, NASA-OUTFLOW, Weather Ready Nation
Need regular engagement with stakeholders, both through a Liaison group attached to the Steering Committee and through workshops/conferences etc.