Abstracts - 2nd European Windstorm Workshop, September 2012

Talks

Insurance Applications

1. **Delivering research to the insurance industry**
   D Whitaker, Lighthill Risk Network

The insurance industry has always retained a strong interest in understanding the impact of environmental risks in general and windstorm analysis in particular on the built environment. For the last 20 years this information has predominately been distributed thorough three large catastrophe modelling firms. This has been beneficial and necessary as the understanding of Insurance terms and conditions and data formats has been the only practical way to consume academic research. It has however limited the use of academic data.
This is about to change after the recently launched Oasis loss modelling framework. This not for profit and in time open source software will allow for academics to populate the software kernel with data that can be applied to insurance assets on the desktop of the Insurance professional. Its also a community that brings together business and academia. This talk will explain how this organisation works, what type of windstorm data it needs and how it delivers value to the Insurance, reinsurance industry's and others. It should be of interest to anyone that wishes or needs their research to have an impact on society.

2. **RMS Models of windstorm risk and windstorm clustering**
   S Jewson, Risk Management Solutions

I'll briefly introduce RMS and describe the RMS Europe Wind Storm Model (a commercial product used in the insurance industry for estimating winter storm risks).

I'll then describe a simple statistical model that allows the clustering of storms in an event set.

The model is a generalisation of the standard Poisson model, and captures correlations between storms in time and space. It is simple enough that it still allows for analytical solutions for some of the main items of interest to the insurance industry, such as the distributions for maximum and total losses.

I'll talk about how we fit the model to Europe winter storms, using observed historical meteorological data. I'll discuss the reduced return periods of 1990 and 1999 that result from the model, relative to Poisson, and show the impact of the clustering on loss distributions and reinsurance pricing metrics.

3. **Decadal-scale changes in winter cyclones and associated hazardous winds in Europe,**
   C Welker, University of Bern

In Europe and during winter, damaging and potentially life-threatening high-wind events are generally associated with mid-latitude cyclones. The scarce availability of long-term atmospheric data series has so far limited the analysis of low-frequency activity and intensity changes in European winter storms. On the basis of a novel atmospheric reanalysis, the Twentieth Century Reanalysis (20CR; Compo et al., 2011), spanning 1871 to present, we evaluate, for the winter season, the decadal-scale variability in cyclones and associated hazardous winds in Europe – with a focus on Switzerland.

In the 20CR only observations of synoptic surface pressure were assimilated. Monthly sea surface temperature (SST) and sea ice distributions served as boundary conditions. An Ensemble Kalman Filter assimilation technique

was applied. The 20CR ensemble contains 56 members. We apply the cyclone identification scheme of Wernli and Schwierz (2006) to this data set, i.e. to each individual ensemble member. This allows us to give an uncertainty estimation of our findings. For quantifying the associated "wind loss potential", we compute, again for each ensemble member, the Power Dissipation Index (Emanuel, 2005) for near-surface wind speeds exceeding the loss-relevant local 98th percentile.
For Europe, we find that 20CR shows small changes in the ensemble uncertainty of cyclone activity over time. That allows for analysing decadal-scale changes in winter cyclones over Europe. 20CR suggests increasing (decreasing) winter cyclone activity over large parts of Scandinavia and the adjacent ocean (British Isles/North Sea and parts of the Alpine/Mediterranean region) from 1871 to present. In addition, 20CR points to an increasing winter wind loss potential for Northwestern Europe.

The variability in winter wind loss potential for Switzerland is representative for large parts of Western and Northern Europe. Pronounced decadal-scale variability is found both in the frequency and wind loss potential of winter cyclones over Switzerland. The low-frequency variability is consistently represented in all 20CR ensemble members. High winter wind loss potential for Switzerland is generally associated with increased cyclone activity to the north and decreased to the south of Switzerland. We associate changes in the winter wind loss potential for Switzerland with changes in the North Atlantic SST, tropospheric temperature, and large-scale atmospheric circulation patterns. On decadal-scale time scales, the winter wind loss potential for Switzerland is positively correlated and co-varies with changes in the North Atlantic Oscillation teleconnection pattern.

Christoph Welker & Olivia Martius
Oeschger Centre for Climate Change Research and Institute of Geography, University of Bern, Switzerland

Compo, G. P., J. S. Whitaker, P. D. Sardeshmukh, N. Matsui, R. J. Allan, X. Yin, B. E. Gleason, R. S. Vose, G. Rutledge, P. Bessemoulin, S. Brönnimann, M. Brunet, R. I. Crouthamel, A. N. Grant, P. Y. Groisman, P. D. Jones, M. C. Kruk, A. C. Kruger, G. J. Marshall, M. Maugeri, H. Y. Mok, Ø. Nordli, T. F. Ross, R. M. Trigo, X. L. Wang, S. D. Woodruff, and S. J. Worley, 2011: The Twentieth Century Reanalysis project. Quarterly J. Roy. Meteorol. Soc., 137, 1-28.
Emanuel, K., 2005: Increasing destructiveness of tropical cyclones over the past 30 years. Nature, 436, 686-688.
Wernli, H. and C. Schwierz, 2006: Surface cyclones in the ERA-40 dataset (1958-2001). Part I: Novel identification method and global climatology. J. Atmos. Sci., 63, 2486-2507.

4. Providing high resolution data for a European windstorms database,
J Roberts, Met Office Hadley Centre

A collaboration between the Met Office, the University of Reading and the University of Exeter is developing a database of historical European windstorms. The database will comprise of historical cyclone tracks identified using the tracking algorithm of Hodges et al. (1995) applied to publicly available re-analysis datasets, plus higher resolution(~25km) information about the windstorm characteristics generated by the Met Office Unified Model. For a subset of the most severe storms full spatial footprint information such as spatial 10m wind speed maps will be produced in addition to useful summary statistics. For the remainder of storms summary information will be given. We will present examples of the storm footprints and summary statistics that could be provided for the catalogue, and also show results of our model validation against observations.

Julia Roberts (Met Office Hadley Centre), Hazel Thornton (Met Office Hadley Centre), Len Shaffrey (University of Reading), Kevin Hodges (University of Reading), David Stephenson (University of Exeter)

5. **High resolution footprints of European winter storms derived through dynamical and statistical downscaling**
   T Kruschke, University of Berlin

Extreme winter wind storms are major natural catastrophes leading to enormous socio-economic impacts in Europe. The impact of a single event depends on the severity and extent of the event itself but also on the region hit by the storm, i.e. its specific exposure of values and vulnerability. Hence, stakeholders, like the insurance industry, are interested in assessments of winter storm intensities and frequencies with high spatial resolution.
Dynamical and statistical downscaling is applied to both historical events from reanalyses and to operational ensemble forecasts of the European Center for Medium-Range Weather Forecast (ECMWF). Dynamical downscaling is preceeded by simulating a selection of events with the global operational NWP-model GME of the German Weather Service (DWD). The output of this model is used for running the regional model COSMO EU at a 7 km resolution. For statistical downscaling a rather simple approach of stepwise linear regressions is shown to be appropriate for deriving robust estimates of surface gusts in high spatial resolution from coarse resolution wind speeds of the surrounding grid boxes. The uncertainties of this approach are within the uncertainty range of the dynamical downscaling approach.

Kruschke, Tim[1], P. Lorenz[1], R. Osinski[1], G.C. Leckebusch[1,2], U. Ulbrich[1], T. Hofherr[3], P. Miesen[3], E. Bedacht[3], E. Faust[3]
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Meso-scale Dynamics

6. **The DIAMET Project**
   G Vaughan, University of Manchester

The DIAMET project has conducted four field campaigns in the past year to study diabatic processes in extratropical storms and their effect on the wider dynamics and impact. A brief summary of these campaigns will be given, together with a particular study of the first DIAMET case, on 16 September 2011, when a upper-level trough crossed the UK, with prominent convective rain bands developing on its eastern side.

7. **Phases in the lifecycles of European windstorms – to what extent can operational models and re-analyses capture them?**
   T Hewson, Met Office and ECMWF

A simple windstorm conceptual model will be presented that shows three types of damage swathe attributable to passage of an extreme north Atlantic cyclonic windstorm. These swathes relate to frontal location and evolution and vary in relevance for different cyclones. Their categorization is based on study of many cyclones across northwest Europe. A single cyclone may have one, two or all three swathes associated with it.

Operational models and up-to-date re-analyses, such as ERA-Interim, are able to capture two of the damage swathes reasonably well, though the most extreme, and rarest of the three, labeled the 'sting jet' phase, needs high resolution to be successfully represented. A sting jet cyclone brought wind gusts with a return period of approximately 20 years to densely populated parts of southern Scotland on 3rd January 2012. Model handling of this event at different resolutions - down to 1.5km - will be illustrated, highlighting the strengths and

weaknesses. High-resolution surface gust observations and imagery sequences will be used to show the hallmarks of this sting-jet cyclone, using also data for other cyclones to back this up.

The challenges of predicting a sting jet cyclone in an operational environment will be highlighted, focusing on handling of 3rd January event by the Met Office operations centre in Exeter.

Studies of model handling of extreme windstorms clearly provide useful input into projects addressing the 'windstorm climate change' problem. The IMILAST project (Intercomparison of MId-LAtitude STorm diagnostics) is in this category. Within this project storm tracking algorithms have been applied to ERA-Interim. It is noteworthy that the intrinsic resolution of this analysis, about 80km, is rather broader than the Scotland sting jet discussed above. An additional, and perhaps related problem is that the pressure pattern around some intense cyclones is not well represented within this re-analysis. Using examples some of these problems will be illustrated and discussed, along with some suggestions for overcoming these in both the short and long term.

Classifying cyclone severity using different metrics is non-trivial. Aside from the resolution-related weaknesses of re-analyses that one might employ, there is also the problem of what metric(s) to use. Cyclone tracks constructed for IMILAST will be used to show that different metrics give surprisingly different sets of extreme storms.

8. Sting jets in intense winter North-Atlantic windstorms
S Gray, University of Reading

Extratropical cyclones dominate autumn and winter weather over western Europe. The strongest cyclones, often termed windstorms, have a large socio-economic impact due to the strong surface winds and associated storm surges in coastal areas. Here we show that sting jets are a common feature of windstorms; up to a third of the 100 most intense North Atlantic windstorms over the last two decades (identified from ERA-Interim data) satisfy conditions for sting jets. The sting jet is a mesoscale descending airstream that can cause strong near-surface winds in the dry slot of the cyclone, a region not usually associated with strong winds. Despite their localised transient nature these sting jets can cause significant damage, a prominent example being the storm that devastated southeast England on 16 October 1987. We present the first regional climatology of windstorms with sting jets. Previously analysed sting jet cases appear to have been exceptional in their track over northwest Europe rather than in their strength.

Authors: Sue Gray, Oscar Martinez-Alvarado, Jennifer Catto and Peter Clark

9. Diabatic processes and the structure of the warm conveyor belt
O Martinez-Alvarado, University of Reading

A warm conveyor belt is a narrow, coherent air stream that flows along the cold front of an extratropical cyclone and rises above the surface fronts. Warm conveyor belts are responsible for most of the cloudiness and rainfall that occurs during the passage of extratropical cyclones.
Their structure and evolution are determined by diabatic processes, such as latent heat release, from the condensation of moist air as it rises and radiation. Understanding how, when and where in the atmosphere these processes take place and how they affect the dynamics of the atmosphere is essential to achieve more accurate weather forecasts. The improved accuracy would be of benefit for the general public and for many other areas that depend on these results including hydrology and engineering, policy making and the insurance/re-insurance industry.

Here we investigate the relative importance of several diabatic processes in the evolution of a warm conveyor belt. As a case study we have selected a North Atlantic cyclone observed during the T-NAWDEX (THORPEX-North Atlantic Waveguide and Downstream Impact Experiment) 'pilot' field campaign on 23-25 November 2009. The analysis is performed using a new suite of comprehensive diagnostics to investigate diabatic processes in two numerical weather forecast models: the COSMO model and the Met Office Unified Model. The new suite of diagnostics comprises tracers tracking changes in the variables that determine the dynamics and thermodynamics of the system. The changes are decomposed according to the processes in the models responsible for them. We also use trajectory analysis to identify the regions where these processes are most active. We show that the warm conveyor belt can be split into two different substreams, one that turns cyclonically and forms the cloud head and another one that turns anticylonically and extends further south. The evolution of each substream is determined by different diabatic processes. We also show how these processes might have determined not only the evolution of the system itself but also that of the future downstream flow.

O. Martinez-Alvarado, H. Joos, J. Chagnon, M. Bottcher, S. L. Gray, J.
Methven, R. S. Plant and H. Wernli

10. **Storm Risk Mitigation**
    K Pearson, University of Reading

The Storm Risk Mitigation programme integration project aims to further our understanding of how the representation of storms in climate models differs from that in NWP models. We are doing this by adapting methods from the DIAMET project and applying them to situations of interest to the TEMPEST and DEMON projects. In particular, we are incorporating the technique of Potential Vorticity tracer diagnostics into the HiGEM cliimate model and running case studies of extreme precipitation events such as that leading to the Tewksbury flooding of 2007. These diagnostics enable us to determine the diabatic processes that are important in different models. These act as sources and sinks of Potential Vorticity and can lead to intensification of storms and heavy precipitation. Ultimately we intend to run HiGEM for an extended period to generate composite structures for such storms.

Statistical Approaches

11. **Assessing method related uncertainties of extratropical cyclone detection and tracking algorithms**
    C Raible, University of Bern

The ultimate aim of the IMILAST project is to improve the documentation of (i) natural variability and (ii) probable future changes in extratropical cyclone activity (Neu et al 2012). Depicting present-day cyclone characteristics of different studies show a considerable spread which partly related to the use of different reanalysis data sets and more importantly to the usage of methods which define, detect and track the cyclones differently.
Within this community effort we compare 15 cyclone detection and tracking methods in order to quantify uncertainties inherent in cyclone identification and tracking by intercomparing outputs generated by different methods. Therefore we use apply the methods to a pre-defined 20-year period of the ERA-Interim reanalysis dataset using it in its 1.5 x 1.5 resolution. The results suggest that the main features, like the geographically distribution of the cyclones illustrated by the cyclone center density agree well among the methods. However on a more regional scale, e.g., Europe and the Mediterranean, already string deviations are found. Comparing the methods track by track we find a general agreement of 50-60 % on average. Moreover, we find large discrepancies concerning total numbers of cyclones, some life cycle characteristics. To get a handle on the potential reason for these differences we will first assess the time dependence of agreement when conserving the track-by-track comparison as well applying one method on different input field (500-hPa geopotential

height, 850-hPa vorticity and sea level pressure) and constraint it to the number of cyclones. The latter will proved insights on the differences related the input data.
Please note that the comparison of the interannual variability and trends of the IMILAST project will presented by G. Leckebusch.

C. C. Raible(1,2) and the IMILAST consortium(3)
(1)Climate and Environmental Physics, Physics Institute, University of Bern, Switzerland and Oeschger (2)Centre for Climate Change, Research, Bern, Switzerland (raible@climate.unibe.ch)
(3) project homepage: http://www.proclim.ch/imilast/index.html

Neu, U., et al. 2012: IMILAST – a community effort to intercompare extratropical cyclone detection and tracking algorithms: assessing method-related uncertainties. BAMS, in revision.

12. Dependency of interannual variability and trend assessment of extra-tropical cyclones on identification and tracking methods
G Leckebusch, University of Birmingham

The IMILAST initiative aims at an intercomparison of the results from different extra-tropical cyclone identification and tracking methods on the general statistics of cyclones and their tracks. This assessment is motivated by recent publications showing partly contradicting results with respect to observed or even future trends. This effort tries to determine to what extent this is method dependent.

Extra-tropical cyclones are formed by a large variety of genesis processes and forcing conditions and thus cannot be simply described with just one single metric. To some extent, different identification methods will reflect this natural variability of occurrence of cyclones by focussing on different aspects of the individual cyclone characteristics.

This study investigates extra-tropical cyclone development and aims at a method dependent assessment of the diagnostics of natural variability, including the inter-annual variability or the longer-term linear trend. For this purpose, fifteen different “cyclone identification and tracking”-methods performed by the IMILAST team were collated and analysed. For each single method and for the multi-method mean, 20 years of ERAInterim data are investigated for track density, system density, cyclogenesis and cyclolysis.

In conclusion, it can be stated that, although large differences in absolute numbers between the diagnostic methods are found, the basic statements about e.g. inter-annual or longer-term variability are in principle coherent. This finding is even more pronounced if the characteristics of only extreme cyclones are considered.

G.C. Leckebusch, J. Grieger, U. Ulbrich, S. Kew, X. Wang and the IMILAST-Team

13. Wind storms in ensemble forecasts
U Ulbrich, University of Birmingham

The probability of the occurences of severe European winter storms is usually estimated from historical meteorological records, for example using station data or reanalysis datasets. Uncertainties arising from this approach are, inter alia, related to the rather short record of data representing the present day climate. In the present study, it is attempted to reduce uncertainties considering storm events in operational ensemble forecasts. This approach assumes that storms in the ensemble are developing from the same large scale situation as the observed ones, and can thus be considered additional possible realizations of the real world

storms. The Ensemble Prediction System (EPS) of the European Center of Medium-Range Weather Forecast (ECMWF) was used. It consists of up to 51 model runs, starting twice a day and each integrated over 10 days. The identification and characterisation of storm systems over the European region is done using a wind field tracking algorithm developed by Leckebusch et. al. (2008). The measure for the storm severity used is based on the cube of local relative exceedances of the local 98th percentile of 10m wind speed. Thus, it is related to storm damage which, according to previous studies, can be estimated from combining this quantity and the distribution of economic values. The measure of storm severity used here is Integrated spatially and temporally over each storm episode.
It is shown that the distributions of the general storm properties in the EPS agree well with ERA-Interim reanalysis. A single ERA-Interim storm is represented in the EPS in several members in a range of possible storm properties (severity, size, duration), but there are also storms in the EPS that cannot be assigned to an observed storm event. Return periods of rare and severe events are estimated.

U. Ulbrich[1], R. Osinski[1], G.C. Leckebusch[1,2], T. Kruschke[1], P. Lorenz[1], T. Hofherr[3], P. Miesen[3], E. Bedacht[3], E. Faust[3]

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14. Extremes in European windstorms in the Met Office seasonal and decadal predictions
L Hermanson, Met Office

The Met Office has a large collection of forecasts and retrospective forecasts (hindcasts) created for its seasonal and decadal prediction research. These contain many realisations of winters consistent with present-day climate and so provide a larger data set than the one realisation that is observations. We identify winters with extreme NAO conditions to study the storms that make up those seasons and the climate factors that lead to the extreme conditions. We are also interested in so-called black swans, events with major impacts that have not yet been observed. These include events such as a low of unprecedented depth or windstorms in parts of Europe where they have never been found before.

15. Clustering of windstorms: dynamical background, diagnostic studies and associated impacts
J Pinto, University of Cologne

Windstorms are the most important nature hazard affecting Europe. While many studies have analysed the natural variability and possible trends in frequency and intensity of windstorms, the time clustering of events (seriality) is less studied. Under particular large-scale atmospheric conditions, several storms may develop and affect Europe within a comparatively short period. Examples for such periods are January/February 1990, December 1999 and January 2007, where an intense polar jet extended towards Europe, directing the storms successively towards Western Europe. In this study, large scale conditions leading to such “storm families” and hence to the time clustering of windstorms are analysed. Clustering is quantified based on cyclone tracks and potential loss estimates derived from reanalysis data. It is evaluated how far the occurrence of clustering depends not only on the region considered, but also on the intensity of the event. Finally, the implications of clustering to the construction of a windstorm event set for Europe are examined. Families of storms are simulated with the COSMO-CLM RCM and the resulting wind signatures are analysed. The pros and contras of considering cyclone families versus single events are discussed in terms of potential losses and consequences for insurance contracts.

16. **Understanding the behaviour of extra-tropical cyclones of extreme intensity**
    T Economou, University of Exeter

Understanding the behaviour of extra-tropical cyclones of extreme intensity is important both from a scientific but also a re-insurance perspective. We investigate storm
tracks from a re-analysis data set and wish to quantify the behaviour of intensity both in space and time. To that end, spatio-temporal extreme value models are implemented to storm pressure nadirs
in order to make inference and understand the behaviour of extreme lows. Preliminary results indicate that whereas the spatial distribution of nadirs is adequately captured, the temporal behaviour of extreme nadirs in more complex that originally thought.

Climate Variability and Change

17. **How might extratropical cyclones change in the future?**
    L Shaffrey, University of Reading

Intense extra-tropical cyclones are one of the major weather risks inthe mid-latitudes. High winds and extreme precipitation from extra-tropical cyclones can result in windstorm damage, flooding and coastal storm surge. Understanding the impacts of climate change on extra-tropical cyclones is critical to assessing future weather risk.

TEMPEST is a 3-year research project that is part of the NERC Storm Risk Mitigation directed programme. The aim is to provide an improved understanding of how climate change and natural variability will affect the generation and evolution of extra-tropical cyclones. In this talk some of the first results from the TEMPEST project will be presented. This includes the representation of intense extra-tropical cyclones and their response to climate change in the CMIP5 (Fifth Coupled Climate Model Intercomparison Project) climate models and new understanding of some the processes driving regional changes in extra-tropical cyclones.

18. **How model-dependent are climate change projections of storminess?**
    D Stephenson, University of Exeter

Projections of future climate-related risk rely on simulated output from a small set of global climate models - samples of opportunity known as *multi-model ensembles* (MME).

A natural starting point is to describe MME output using a fixed-effects ANOVA model. The heuristic approach of averaging model runs can be shown to equal the mean response from an ANOVA model having model-scenario interaction effects. However, the presence of model-scenario interactions can make it difficult to infer future changes in the real climate. If the interaction effect is small then easier to interpret two-way models with no interactions are possible.

These modelling ideas are illustrated by fitting ANOVA models to Atlantic and European storm track densities simulated by climate models in the recent CMIP5 multi-model experiment. The model-dependency of the response will be presented.

David B. Stephenson and Phil Sansom

19. **Storm tracks and their feedbacks on global climate**
    D Brayshaw, University of Reading

The extra-tropical storm tracks play a fundamental role in the climate system and in the transport of heat from the tropics to the poles. However, relatively little is understood about the processes that maintain the storm tracks and how relatively small changes in that forcing can cause planetary-scale changes in climate. This

presentation outlines new research combining output from two state-of-the-art atmospheric GCMs and an idealised model in order to understand how the storm tracks and their energy transports are affected by - and feedback upon - changes in the equator-to-pole atmospheric heating gradient. Initial simulations suggest that even relatively modest imposed changes (~1PW) equator-to-pole ocean heat transport can produce dramatic changes in storm track structure, cloud/radiative feedback and, consequently, global-mean surface temperature (~20oC).

20. A multi-model perspective on the future response of North Atlantic and European cyclones
G Zappa, University of Reading

The future response of North Atlantic cyclones to climate change and its socio-economic impact on Europe is very uncertain. Previous studies do not agree on whether extratropical cyclones will intensify in a warmer world, and climate models are traditionally affected by biases in simulating the North Atlantic climate which might affect the confidence in their projections. Here we address such model uncertainty by providing a multi-model systematic assessment of the biases and of the future responses of North Atlantic cyclones in 20 CMIP5 models. The number and the dynamical intensity of cyclones - measured as T42 vorticity and wind speed at 850mb - are separately quantified by applying a cyclone tracking algorithm. Due to data unavailability, this approach has not been adopted in previous multi-model assessments.
We find that CMIP5 models have systematic biases in both the spatial distribution and the dynamical in- tensity of cyclones. However, in spite of these biases, CMIP5 models show broad consensus on the future changes in North Atlantic cyclones, as revealed by comparing the RCP4.5 (2070-2099) and the HISTORICAL (1976-2005) simulations. For instance, CMIP5 models agree in indicating a decrease in the dynamical intensity of cyclones in winter (DJF). However, the stormtrack becomes more zonal and extended into Europe so that a slight increase in the cyclone intensity is locally found in Northern France and Germany. In summer (JJA), models agree in indicating a reduction in cyclone number and intensity on the southern flank of the North Atlantic stormtrack. The difference between the DJF and JJA responses is interpreted in relation with the changes in the large scale baroclincity, and particularly that driven by Arctic surface temperature change. The impact of the model biases on the future projections are analysed and discussed.

Authors: G. Zappa, L. Shaffrey, K. Hodges, P. Sansom, D. Stephenson

21. Sensitivity of the North Atlantic storm track to regional drivers of change
B Harvey, University of Reading

The initial stages of an investigation into the response of the extra tropical storm tracks to 21st century forcings are presented. In particular, we focus on the wide spread present in the responses of the North Atlantic storm track between different climate models.

The simulations run for the third phase of WCRP's Coupled Model Intercomparison Project (CMIP3) generally agree on the nature of the change to extra-tropical storm tracks during the 21st century in that both the southern hemispheric and the Pacific storm tracks shift poleward, along with their associated jet streams. This is consistent with the expected expansion of the Hadley cell. The response of the North Atlantic storm track, however, seems to be harder to pin down; there is a wide spread between the models as to even the qualitative nature of the response.

We are using the UK Met Office's HadGAM model to pick apart the physical mechanisms that may be important for changes to the North Atlantic storm track. Several mechanisms have been suggested to contribute to the changes including changes in tropical precipitation, changes in the land-sea temperature contrast, changes in the North Atlantic sea surface temperatures and changes in Arctic sea ice coverage. For this initial stage of the project we have focussed on the impact of the last two. In particular, we ask to what extent the differences in

storm track responses between the models are caused by the spread in the North Atlantic sea surface temperature changes over the 21st century and/or the changes in Arctic sea ice coverage.

Synoptic-scale Dynamics

22. **Things Your Professor Told You That Were Wrong About Cyclones and Fronts**
    D Schultz, University of Manchester

What you have been told by your professors in your meteorology class is wrong. Important decisions are made every day using with an outdated conceptual model of mid-latitude cyclones. This model makes incorrect predictions about the structure and evolution of fronts and cyclones, yet we as a community still tolerate its weaknesses, we teach it to our students, and we communicate using it with the public. This model had its heyday, but it's long been time for a replacement. But, no substantial competitor has arisen to challenge its hegemony. In this talk, you will see one component of a new paradigm to replace the Norwegian cyclone model, specifically addressing the occlusion process.

23. **The role of large-scale atmospheric flow and Rossby wave breaking in the evolution of extreme wind storms over Europe**
    J Hanley, University of Stockholm

The relationship between large-scale atmospheric flow and the evolution of the most extreme Continental European wind storms is investigated. A cyclone identification and tracking algorithm is used to generate a climatology of winter cyclones from the ERA40 dataset for the period 1958-2001. From this climatology, the top 25 most destructive Continental European wind storms are selected using a significant power dissipation measure. 22 of the top 25 storms are subjectively grouped as having a similar trajectory and evolution. A temporal MSLP composite over the selected storms illuminates their relationship with the NAO; it shows their genesis during a period of persistently high NAO, which reaches its peak 2.25 days before the storm's peak intensity and which then shifts to the East to a position where the Icelandic low is centred over Scandinavia and the Azores high is shifted closer to the Iberian peninsula. A temporal composite of potential temperature on the 2-PVU surface suggests that this NAO shift is the result of cyclonic wave breaking to the north and anti-cyclonic wave breaking to the South penetrating further to the east than during a climatological high-NAO event. This creates favourable conditions for the developement of our selected storms through; (i) an intrusion of cold air from the north colliding with an intrusion of warm air from the south, producing a region of high baroclinicity off the coast of Europe, (ii) creating an extremely strong upper-level jet which plays an important role in the intensification stage, (iii) steering them to Continental Europe. An index has been created to measure the correspondence of a given MSLP field over the North Atlantic with the composited MSLP pattern of the 22 selected storms. In measuring this index for each day in the ERA40 dataset, we can quantify the number of days in which this pattern was closely matched.We can also measure the decadal variation in this index and compare it to the observed decadal variation in Continental European storm frequency. Finally, we compare the usefulness of this index as a predictor of these events compared to using a threshold value of the daily NAO index.

24. **Diagnosing the Influence of Diabatic Processes on the Explosive Deepening of Extratropical Cyclones over the North Atlantic Ocean**
    P Knippertz, University of Leeds

The relative roles of baroclinic and diabatic processes for explosive deepening of extratropical cyclones have been debated for a long time, mostly on the basis of case studies. Here we present a powerful diagnostic approach to the problem, which is based on a combination of an automatic cyclone tracking with a special

version of the classical pressure tendency equation (PTE) that relates changes in surface pressure to contributions from horizontal and vertical temperature advection as well as diabatic processes, i.e., mainly latent heat release in clouds. Along the entire track of a cyclone, the PTE is evaluated in a 3°x3° box from the surface to 100 hPa centred on the location the storm is moving to within the next time step. The great advantage of this new approach is the easy applicability to large gridded datasets, even if diabatic tendencies are not explicitly available as in many reanalysis products.

The strengths and limitations of the method are illustrated here through application to several explosively deepening, damaging winter storms over the North Atlantic Ocean. Data used are 6-hourly ERA-Interim re-analyses. For better interpretation of the results, the PTE analysis is complemented with other classical cyclogenetic factors, i.e., the strength of the polar jet and the equivalent-potential temperature θ_e at 850 hPa in the warm sector.
The main conclusions from this analysis are:

- The time evolutions of the actual core pressure of the storm and the 6-hourly pressure changes in the moving box used to evaluate the PTE show structural similarities that are dominated by the explosive deepening.
- The vertical advection term is positive throughout the entire lifecycle of all storms indicating the dominance of ascent downstream of the cyclone center. It is (over-) compensated by negative contributions through warm advection and diabatic heating.
- Storms “Martin” and “Kyrill” are dominated by baroclinic processes with contributions of diabatic processes to the total negative tendencies of around 30%.
- Despite comparable jet strengths, similar tracks relative to the jet, and equally high θe values at 850 hPa in the warm sector, storms “Lothar” and “Klaus” show much larger contributions from diabatic heating to the deepening of around 60%.
- Storm “Xynthia” stands out as a system with an unusual SW–NE track into Europe, which appears to have benefited from a complicated split jet structure in the later development stages. It is associated with high θ_e values and shows very large diabatic contributions.
- In the long run, the PTE analysis will be applied to longer timeseries from both reanalysis and climate model data to generate robust statistics across a broader range of cyclone intensities and development types. This will for the first time allow a systematic investigation of the relative contribution of diabatic processes to storm intensification in recent and future climate conditions.

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25. Xynthia: analysis of an exceptional extra-tropical cyclone
P Ludwig, University of Cologne

Between end of February and early March, winter storm Xynthia has affected South Western Europe causing storm damage and flash floods along the Breton coast. The uniqueness of this storm refers to its path and the area of origin, being far southward of the usual North Atlantic storm track. In order to understand the course of the event, the storm development is first analysed by means of ERA-Interim data. An interesting feature is that Xynthia did not cross the polar jet. In fact, the existing split jet structure was responsible for enduring upper level divergence in the vicinity of the cyclone. The southerly area of origin (30N) raises the question to what extent latent heat release (LHR) contributes to the deepening and evolution of Xynthia. Therefore, sensitivity studies with the regional model COSMO-CLM have been carried to verify the amount LHR has on the cyclone development. First, a control simulation covering broad areas of the North Atlantic Ocean with a horizontal

resolution of 0.22° shows the development of the storm in very good agreement with the development represented in the reanalysis data.
In different sensitivity studies, the influence of LHR is examined. In a first approach, the sea surface temperature (SST) in the initial model fields was reduced in steps of 1K to a maximum decrease of 5K compared to the original SST field. The lowering of the SST was implemented only in the model area where Xynthia underwent massive deepening. The results show that the minimum core pressure remains about 10hPa higher than in the control simulation, while dynamical aspects like jet configuration did not change significantly. Another approach to quantify the amount of LHR on cyclone development is to disable the temperature increment due to latent heat effects. Finally, the energetics are examined to provide information about the environmental energy transfers being accountable for the evolution of the storm.
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26. How capable are climate models in representing severe, extra-tropical windstorms?
T Trzeciak, University of Leeds

Despite the enormous advances made in climate change research, robust projections of the position and the strength of the North Atlantic stormtrack are not yet possible. In particular with respect to damaging windstorms, this incertitude bears enormous risks to European societies and the (re-)insurance industry. Previous studies have addressed the problem of climate model uncertainty through statistical comparisons of simulations of the current climate with (re-)analysis data and found that there is large disagreement between different climate models, different ensemble members of the same model and observed climatologies of intense cyclones. The use of different horizontal and vertical resolutions, as well as different approaches to measure storminess further complicate comparison between the results from different studies.

One weakness of such statistical evaluations lies in the difficulty to separate influences of the climate model's basic state, which will be governed by slow processes such as ocean circulations or sea-ice transport, from the influence of fast processes such as energy fluxes from the ocean or latent heating on the development of the most intense storms. The former might generate a bias in storm counts through an incorrect occurrence frequency of storm-prone initial conditions, while the latter could generate a similar bias due to the lack of crucial dynamics of extreme cyclone intensification due to over-simplistic model physics or insufficient horizontal resolution. Compensating effects between the two might conceal errors and suggest higher reliability than there really is. Therefore, separating sources of uncertainty is an important step towards a more reliable interpretation of climate projections and towards targeted improvements of future model generations.

A possible way to separate influences of fast and slow processes in climate projections is through a "seamless" approach of hindcasting historical, severe storms with climate models started from predefined initial conditions and run in a numerical weather prediction mode on the time-scale of several days. Such a cost-effective case-study approach, which draws from and expands on the concepts from the Transpose-AMIP initiative, is currently undertaken in a recent project at the University of Leeds funded by the AXA Research Fund. Main aspects of interest are the overall quality of the climate model hindcasts, as compared to operational forecasts and reanalysis data, and the identification of systematic biases, which if known could be potentially used to develop calibration techniques for post-processing climate model output from longer simulations. The general concept of the numerical experiments conducted in this project and some first results will be presented at the worksh!
op.

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27. The unusual sequence of storms leading to precipitation records and floods in southern Iberia in December 1876

R Trigo, University of Lisbon

The first days of December 1876 were characterised by extreme weather conditions that affected the south-western sector of the Iberian Peninsula (IP), leading to an all-time record flow in both large international rivers running from Spain to Portugal, Tagus and Guadiana causing serious flood damage. These events resulted from the continuous pouring of precipitation registered between 29 November and 7 December, due to the consecutive Atlantic low-pressure systems and their associated frontal systems that reached the Iberian Peninsula. However, the floods were amplified by the occurrence of anomalously wet October and November months, as shown by recently digitised time series for both IP countries.
For two recently digitised stations in southern Portugal (Lisbon and Évora), the values of precipitation registered during the first week of December 1876 was so remarkable that when we computed daily accumulated precipitation successively from 1 to 10 days, the episode of 1876 always stood as the maximum precipitation event, with the exception of events in February 2008 in the Lisbon precipitation (Fragoso et al., 2008) and October 1944 in Évora (in both cases for daily precipitation only).
Based on different data sources, including historical Portuguese and Spanish newspapers, meteorological data recently digitised from several stations in Portugal and Spain and the recently available 20th Century Reanalysis (Compo et al., 2011), it was possible to assess the damage and the atmospheric circulation conditions associated with this event. The synoptic conditions were represented by 6 hourly fields of complementary variables, namely; 1) precipitation rate and mean sea level pressure (SLP); 2) precipitation rate and CAPE; 3) wind speed intensity and divergence at 250 hPa, 4) wind speed intensity and divergence also at 850 hPa; 5) air temperature at 850 hPa and geopotential height at 500 hPa; 6) wind speed barbs and specific moisture content at 850 hPa. Movies with all these variables were obtained for the 10-day sequence that spans between 29 November and 7 December.

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Posters

Stormtracks, Climate Variability and Change

1. **Analysis of storm track sensitivity to key driving forces in Reanalysis and CMIP5 data**
   J Lehmann, PIK Potsdam

Substantial discrepancies exist in the representation of mid-latitude storm tracks between GCMs and compared to reanalysis data. It is not generally known whether mismatches are due to differences in the driving forces (e.g. lower and upper tropospheric poleward temperature gradients and water vapour content) or due to different sensitivities of the storm activity to these driving forces. Here we present preliminary results of storm track activity in 20th century reanalysis data and 20th and

21st century CMIP5 model output. The synoptic-scale kinetic energy is derived for each individual month by bandpass filtering daily wind field data using a bandpass width of 2-6 days. We extract storm track characteristics such as position of zonal-mean peak-amplitude, meridional width and third order moments and compare the results for different models and reanalysis data. Regression analysis of these parameters enables us to determine the sensitivity of storm tracks to lower and upper tropospheric poleward temperature gradients and water vapor content. Our ultimate aim is to derive physically based semi-empirical equations which capture the first-order dynamics of storm tracks in terms of the aforementioned key parameters. Calibrated using observational data, such equations would provide independent estimates of possible future changes in storm activity as well as uncertainty estimates for future scenarios. In addition, they should give insight into the origin of contrasting storm track behavior in different GCMs.

2. **Winter Storms in Twentieth Century Reanalysis and its Decadal Variability**
   S Wild, University of Birmingham

Since the 1960s a steadily increase in North-Atlantic/European Storminess was observed until the mid-90s of the last century. This high level of storm activity and its related losses were strongly discussed in the light of anthropogenic climate change. Recent scientific research, investigating the 20th Century Reanalysis (1871-2008), reveals that North-Atlantic/European Storminess might be underlying a long-term positive trend with unprecedented high values in recent decades (Donat et al., 2011). This is partly not in common with local station observations (e.g. in the Netherlands) and questions concerning the coherence of different storminess measures are not answered yet. On the other side, reasons of multi-decadal variability of storminess are not fully identified and a broader understanding of storm variability is missing. Both problems might be linked.

On one side, this study thus aims to develop a comprehensive understanding of storm variability for the last ca. 140 years in three steps: research area 1 will concentrate on coherent physical mechanisms leading to extreme storminess on synoptic scales as well as on multi-decadal scales. Thus, the link between surface based trend signals and steering mechanisms in the mid-troposphere will be investigated. Research area 2 focuses on the role of large-scale precursor situations to wind storms and analyses in how far known teleconnection pattern (NAO) are consistent with the storminess signal identified. Research area 3 will specifically investigate in how far a maximum of storminess at the beginning of the last century compares to the latest peak in activity.

On the other side, based on such a comprehensive understanding of forcing mechanisms and variability, decadal predictability of winter wind storms may arise. As part of the *MiKlip* initiative this study will thus focus also on this aspect to build a decadal forecasting system.

For both objectives the assessment of decadal predictability of synoptic-scale European winter wind storms in terms of their frequency and intensity in the new *Twentieth Century Reanalysis* (20CR) is thus firstly performed .

Two different event tracking schemes were applied to this dataset. One scheme identifies extra-tropical cyclones, based on MSLP and its laplacian, the other is based only on surface wind speeds, thus identifies storm events diagnosed as extensive areas of extreme (>= local climatological 98th percentile) wind speeds. Both approaches deliver estimates of frequency and intensity of the same meteorological phenomena.

Based on these two approaches, the period of 1871-2008 (ONDJFM) is investigated with respect to decadal variability and extremes of winter storm frequency and intensity. Additionally taking into account the *HadISST1.1* dataset, which was used to force the 20CR, atmospheric and oceanic variability patterns like the *North Atlantic Oscillation* and the *Atlantic Multidecadal Oscillation* are analyzed regarding their relationship to frequency and intensity of European winter storms. The physical mechanisms behind these relationships are also investigated, starting with those already known from studies of the seasonal predictability of winter storms.

Potential differences in the physical steering mechanisms as well as in the large-scale conditions will be addressed. The findings should be discussed in the context of detection and attribution of anthropogenic climate change signals.

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3. How important is the contribution of extratropical cyclones to Northern Hemisphere precipitation?
M Hawcroft, University of Reading

Extratropical cyclones contribute significantly to the total precipitation climatology of the northern hemisphere. These cyclones are often associated with heavy precipitation events and are the primary temporal modulator of precipitation distribution in many regions. An objective feature tracking algorithm is used to locate cyclones and the precipitation associated with these cyclones is extracted to quantatively assess their contribution to total precipitation. Climatologies are produced from the Global Precipitation Climatology Project daily dataset and the ERA-Interim reanalysis. The magnitude and spatial distribution of precipitation associated with extratropical cyclones and their percentage contribution to total precipitation is closely comparable in both datasets. In some regions, the contribution of these cyclones is in excess of 80% of the total climatological precipitation. The relative contribution of the storms with highest maximum intensity to total precipitation is more significant in the winter than the summer seasons, with over 20% of total storm associated precipitation contributed from the most intense 10% of storms.

M.K. Hawcroft, L.C. Shaffrey, K.I. Hodges and H.F. Dacre

4. The growing impact of the storm tracks on the European energy system
D Brayshaw, University of Reading

Securing reliable electricity supplies sufficient to meet demand is an important concern for modern economies. With the rapid growth of renewable energy generation (particularly wind), it is vital to understand the impacts of weather and climate variability on both supply and demand at national and international scales. It is shown that storm track related co-variability of temperature, wind-speed and precipitation has a demonstrable and increasing impact on the British and European electrical systems, with potentially significant implications for investment in weather-sensitive renewables, their operation and subsequent risk-management. Ongoing and future research directions are discussed.

Statistical Approaches

5. Development of a European Windstorm Event Set using a Combined Dynamical and Statistical Downscaling Approach
A Giorgiadis, Aon Benfield

Winter storms cause very high insurance losses in Europe. In order to allow for a valuable risk assessment, both storm frequency on a large scale and storm and gust intensity on a small scale are precondition for construction of loss estimation tools. The presented common effort between research and insurance consists of a large scale identification of intense storms for both historical (reanalysis) data and present day climate simulations in order to extend the statistical basis of extreme events to a number of 10000 storms. For historical storms, dynamical downscaling is performed with the regional climate model COSMO-CLM. Since dynamical downscaling is not feasible for 10000 events, a statistical downscaling tool is derived from large scale storm tracks, historical storms in the period 1960-2010, defined from potential loss estimation based on NCEP reanalyses, re-simulated in a two-step nesting approach using COSMO-CLM 4.8 in 0.165° and 0.0625° resolution with ERA-forcing and from observations. A method of a combined probabilistic downscaling and MOS technique is proposed for the enhancement of gust speed estimations. The methodical procedure is presented along with results and a quality check for both spatial and temporal correctness, considering errors in terms of RMSE and the form of gust distributions in order to provide gust estimations which are unbiased in comparison to the observations.

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6. Statistical Downscaling of Large-Scale Wind Signatures Using a Two-Step Approach
R Haas, University of Cologne

Downscaling global scale climate data is an important issue in order to obtain high-resolution data desired for most applications in meteorology and hydrology and to gain a better understanding of local climate variability. Statistical downscaling transforms data from large to local scale by relating punctual climate observations, climate model outputs and high-resolution surface data. In this study, a statistical downscaling approach is used in combination with dynamical downscaling in order to produce gust characteristics of wind storms on a small-scale grid over Europe. The idea is to relate large-scale data, regional climate model (RCM) data and observations by transfer functions, which are calibrated using physically consistent features of the RCM model simulations. In comparison to purely dynamical downscaling by a regional model, such a statistical downscaling approach has several advantages. The computing time is much shorter and, therefore, such an approach can be easily applied on very large numbers of windstorm cases provided e.g. by long-term GCM model simulations, like millennium runs.

The first step of the approach constructs a relation between observations and COSMO-CLM signatures with the aim of calibrating the modelled signatures to the observations in terms of model output statistics. For this purpose, parameters of the theoretical Weibull distribution, estimated from the observations at each test site, are interpolated to a 7km RCM grid with Gaussian weights and are compared to Weibull parameters from the COSMO-CLM modelled gust distributions. This allows for an evaluation and correction of gust signatures by quantile mapping. The second step links the RCM wind signatures and large-scale data by a multiple linear regression (MLR) model. One model per grid point is trained using the COSMO-CLM simulated and MOS-corrected gusts for selected wind storm events as predictands, and the according NCEP reanalysis wind speeds of the surrounding NCEP grid points as predictors. For validation purposes, the model is again applied on NCEP reanalysis data. The statistical model is able to reproduce well the observed regional scale wind signatures. Afterwards, the statistical model is applied to ECHAM5 climate simulation data to generate large numbers of

downscaled wind gust signatures at high spatial resolution. For further analyses, statistical values as mean, minimum and maximum wind gust speeds are compared at every grid point.

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7. A novel cyclone tracking algorithm optimized for intense multicenter cyclones
R Caballero, University of Stockholm

Previous studies have proposed to define the size or extent of a cyclone as the area enclosed by the outermost SLP contour containing only the SLP minimumin question (Wernli & Schwierz, 2006). We extend this definition by introducing the concept of a 'common system', defined as a cyclone which has two or three such SLP minima within its outermost contour. The aims of extending the definition in this manner are; 1) To better capture the full size of such cyclones 2) To improve their tracking by allowing for a smooth continuation of a single track rather than tracking each SLP minima separately which can result in track splitting; this is achieved by appropriate 'track reconnections' in a post-processing step. An additional benefit of our method is that it allows us to compute cyclone merging and splitting statistics for a given cyclone climatology. Using this cyclone tracking and identification method, we compute a climatology of winter cyclones from the ERA40 reanalysis dataset for the period 1958-2001. We show a strong relationship between cyclone intensity and 'common system' frequency, with almost 80% of the top 10% of cyclones constituting a 'common system' at some point in their lifetime. Similarly, we show a strong relationship between cyclone intensity and track reconnection, cyclone merging and cyclone splitting – confirming the importance of our method for identifying and tracking intense cyclones. Using our 43 year climatology, we investigate the most rapidly intensifying cyclones, also known as 'Bombs'. We compare the traditional measures for identifying these cyclones based on SLP deepening over 24 hours with a measure based on SLP gradient intensification over 24 hours. Based on this comparision, we propose using the SLP gradient based method for 'Bomb' identification. We then use this measure to answer the question: are the most intense cyclones, based on their peak SLP gradient over their lifetime, also the most rapidly intensifying or do they reach their peak intensity more gradually over a longer period of time?

8. An Extra-tropical Cyclone Atlas: A tool for illustrating cyclone structure and evolution characteristics
H Dacre, University of Reading

Extra-tropical cyclones play a significant role in determining the day-to-day weather conditions in many parts of the world through their associated wind and precipitation patterns. Their typical evolution characteristics are therefore of great interest to both educators and researchers of extra-tropical cyclone dynamics. The structure and evolution of extra-tropical cyclones, as viewed from the surface, was first described by Bjerknes and Solberg (1922) who developed a conceptual model of cyclone evolution. Conceptual models are widely used in educational meteorology courses throughout the world to illustrate qualitatively the basic structure and evolution of extra-tropical cyclones.

The aim of this work is to introduce and promote the use of a comprehensive set of quantitative analyses describing the structure and evolution characteristics of 200 composited north Atlantic cyclones from 1989-2009. It is hoped that both teachers and researchers of extratropical cyclone dynamics will make use of the analysed fields in the atlas which is freely available via the storms project webpage www.met.rdg.ac.uk/~storms. Some examples of how this atlas could be used for teaching are provided.

9. **Detection Of Events Impacting The Insurance Industry In WRF Driven By ERA Interim (EURO-CORDEX Project).**
   M Deroche

A methodology aimed at detecting extreme European winter storms has been developed using a catalogue of ten reference storms known as extremes for the insurance industry. The used thresholds are defined from the distributions of the maxima of three variables: the Relative Vorticity at 850 hPa, the Mean Sea Level Pressure Anomaly and the ratio of the 10m wind speed over its 98th percentile. Once events for each variable are detected, we look for common events and define them as potentially damageable events. Insofar, the methodology has been applied to the ERA Interim and NCEP2 datasets, giving satisfying results: the number of common events is greatly smaller than the number of detected events for each variable and allow us to isolate potentially damageable events (including the ten reference) from other detected events. A set of simulations of WRF, driven by ERA-Interim has been achieved for the EUROCORDEX project. Those simulations have horizontal resolutions of 12 km and 50km, and span 20 (hindcast) to 30 (control) years. We apply our detection methodology to this new dataset. Then we compare distributions of the maxima as well as the final detected event between the Euro-CORDEX and ERA Interim datasets.

Madeleine-Sophie DEROCHE, Francis CODRON, Pascal YIOU, Mathieu CHOUX

10. **Modelling the Relationship Between the Frequency and Severity of Extra-Tropical Cyclones**
    A Hunter, University of Exeter

There is evidence of a relationship between the severity and frequency of Northern Hemisphere extra tropical cyclones for certain regions. Climate indices such as the North Atlantic Oscillation (NAO) have already been shown in the literature to affect the frequency and severity of European extra tropical cyclones separately though little work has been done to investigate the joint frequency-severity relationship. The sign and magnitude of the correlation varies between regions, in particular over Northern Europe there is strong evidence of positive correlation between frequency and severity.
Members of Exeter Storm Risk (XStoR) have been using the NCEP CFS, and ERA40 reanalysis datasets to investigate the underlying climate which drives the relationship between the frequency and severity.

Alasdair Hunter, David Stephenson, Theo Economou, Phil Sansom

11. **Quantifying the relevance of cyclones for precipitation and wind extremes in central Europe**
    S Pfahl, ETH Zurich

Mid-latitude cyclones are often accompanied by strong surface winds and heavy precipitation causing severe damages. In this study, it is quantified how many of the precipitation and wind extremes in central Europe are directly associated with a cyclone, based on the ERA-Interim reanalysis dataset for the period 1989-2009. Such an event-based climatological approach complements previous case studies, which established the physical relationship between cyclones and extreme weather events.

At each central European target grid point, the 99th percentiles of six-hourly ERA-Interim precipitation and 10-meter wind gust velocity are calculated, and all dates with precipitation or gust speed larger than the respective percentile are identified as extreme events. Cyclones are identified from ERA-Interim sea level pressure fields as two-dimensional features with a finite size, determined by the outermost closed pressure contour comprising one or several pressure minima. To quantify the link between cyclones and extreme events, the conditional frequency of cyclone occurrence at all grid points in Europe is determined during extreme precipitation (wind storm) events at a target location.

In general, the maxima of this conditional cyclone frequency are much larger than the climatological cyclone frequency at the respective grid point, indicating a strong linkage between cyclones and both precipitation and wind gust extremes. Cyclones over the North Sea typically are associated with extremes in Germany, whereas Mediterranean cyclones mainly affect regions south of the Alps. For extreme precipitation, the maximum of cyclone occurrence is often close to the location of the extreme events, but for wind storms it may be further afar, indicating that trailing fronts are more important for wind than for precipitation extremes.

The results from this study can help to understand how wind storms and heavy precipitation in central Europe may respond to shifts of the storm tracks with global warming.

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12. The representation of extreme UK wind events in the TIGGE database
N Earl, University of East Anglia

The establishment of The Interactive Grand Global Ensemble (TIGGE) database in 2008 has facilitated research on the most severe extra-tropical cyclones and the representation of such storms in the global model analyses and forecasts of major centres. We use a 1980-2010 UK station database of daily maximum gust speeds (Hewston and Dorling, 2011; Earl et al, in review) to identify the most significant wind events in the period 2008-10 overlapping with the TIGGE database. We categorise these events in terms of the associated mesoscale features within extra-tropical cyclones and assess the degree to which global models faithfully simulate the severest winds using ECMWF analyses as a baseline. We will present the conclusions arising from this work.

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13. Forecast quality and predictability of severe extra-tropical cyclones
J Owen, University of Leeds

Severe extra-tropical cyclones are the most damaging weather phenomena affecting Europe, frequently causing fatalities and severe economic losses. Reliable forecasts of such events on timescales of several days are crucial to warn the population and allow mitigating action to be taken. Funded by the AXA Research Fund, this project evaluates the seamless prediction of the chosen cyclones. The NWP results presented here will serve as a benchmark for simulations with state-of-the-art climate models run in NWP mode at the University of Leeds. This study investigates how accurately historic damaging and/or intense storms over Europe were forecast by operational numerical weather prediction (NWP) models.

An automatic tracking algorithm is used to identify the cyclones from gridded fields of mean-sea level pressure. The first step was to examine the evolution of the storms and the synoptic conditions in which they developed based on re-analysis data from the European Centre for Medium-Range Weather Forecasts (ECMWF). The next step is to evaluate forecast performance by the ECMWF, UK Met Office and GFS deterministic models looking at core pressure evolution and track for different forecast lead times. Finally, ECMWF ensemble predictions are used to investigate the predictability of the investigated storms through examining the forecast spread.

First results indicate that the quality of the forecasts varies widely across the storms; however, they confirm previous studies in that the cyclones' core pressures are generally less well predicted than their position. Furthermore, there is an apparent relationship between core pressure and forecast spread. The extent to which these differences can be related to the type of storm is currently under investigation. Additionally, the magnitude of the forecast errors will be compared to those of less intense cyclones to see whether the most intense systems stand out in terms of their forecast quality and predictability.

Dynamics and Case Studies

14. Diagnosis of the 1941 February 15th Windstorm and Related Impacts in the Iberian Peninsula
M Liberato, University of Lisbon

On February 15th 1941 a windstorm burst on Portugal with exceptional intensity. The storm caused significant damage and disruption, making a direct hit on Lisbon while destructive winds affected the whole of Portugal. It has been considered one of the top five most severe windstorms across Europe during the 20th Century (Muir-Wood, 2011).

The windstorm occurred through the afternoon into the early evening on a Saturday and many people were outside in the storm. A total of at least 130 people are known to have died in the storm. A major storm surge was driven up the Tagus estuary, combining with strong wave action driven by the southwesterly winds to cause flooding on the northern coast of the estuary.

Damages in Portugal from this windstorm were estimated to be "half the national budget". Estimates of damage in the storm suggest the total damage to the country was the equivalent of around EUR 5 Billion in 2009 while the total equivalent damage in Spain (including the destruction of Santander) was around EUR 1-1.5 Billion in 2009.

In this work we assess the synoptic evolution and impacts of the 1941 February 15th windstorm. It was characterized by the presence of a major Atlantic low with a strong jet stream situated along its southern flanks which triggered the formation of a rapidly-intensifying daughter storm propelled to the east by the jet stream. The analysis of the Atlantic cyclone characteristics, namely its track, cyclogenesis, deepening rate and cyclolysis is based on the cyclone detecting and tracking algorithm developed for the Euro-Atlantic region (Trigo, 2006). The objective methodology, which identifies and follows individual lows, is applied to 6-hourly geopotential data at 1000-hPa from each of the 56 ensemble members of the Twentieth Century Reanalysis (20CRv2) dataset for the Euro-Atlantic sector, provided by the U.S. Department of Energy, Office of Science Innovative and Novel Computational Impact on Theory and Experiment (DOE INCITE) program, and Office of Biological and Environmental Research (BER), and by the National Oceanic and Atmospheric Administration Climate Program Office. Additionally the 20CRv2 reanalysis allow the assessment of the synoptic evolution, dynamical characteristics and the main impacts of this storm that provoked extreme impacts and considerable economical losses over Iberia.

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15. Reassessing the deadliest storm that struck Portugal; 25 November 1967
R Trigo, University of Lisbon

The storm that struck the Lisbon region between the 25 and 26 November 1967 was the deadliest natural hazard since the 1755 Lisbon earthquake. The sudden floods that occurred during the night between the 25 and early morning of 26 November took everybody by surprise as most of the victims were at home sleeping and didn't notice the accumulation of water in small river streams. The main cause for these catastrophic floods is related to the large amount of precipitation registered during a few hours on the night of 25 November. The official number of dead people was 495, but at that time the regular newspapers were strictly controlled by the government and the catastrophe numbers could have been kept lower for political reasons. Nevertheless, to the best of our knowledge this extreme meteorological episode was never studied in detail.
The storm was identified using the cyclone detecting and tracking algorithm developed to the Euro-Atlantic region by Trigo (2006). This methodology was applied to Z1000 dataset from the ERA-40 reanalyses at the 1.125º horizontal resolution to assess the track characteristics, as well as the cyclogenesis, deepening rate and cyclolysis. ERA-40 reanalyses data were also used to compute a 6-hourly sequence of weather fields, namely precipitation rate, mean sea level pressure, CAPE, wind speed and wind divergence at 250 and 850 hPa geopotential height levels, air temperature at 850 hPa and geopotential height at 500~~h~~ hPa, wind speed barbs and specific moisture content. This analysis provided an in-depth characterization of the synoptic conditions promoting the outcome of the event, mainly explained by the intense subtropical storm that passed over the area. Finally using a high-resolution (10km) dynamical downscaling approach based on the MM5 model, we have evaluated some of the phenomena gone at a more local scale in order to evaluate the sequence and the severity of the events at a much finer detail.

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16. The deepest extra-tropical cyclone ever recorded: The role of diabatic heating and of Greenland's topography
L Odell, University of Leeds

A study of the most intense extra-tropical cyclone ever recorded, reveals that diabatic heating played an integral part in rapid cyclogenesis and magnitude of the North Atlantic storm. Latent heating produced mid and upper-tropospheric divergence and generated a lower tropospheric PV anomaly that phase-locked with a deep upper-tropospheric anomaly. The combined effect of which, slowed downstream propagation and lead to explosive deepening of 78 mb in 24 hours. A pressure tendency diagnostic was applied to the so-called Braer Storm. Results show diabatic processes contributed 55% of negative surface pressure tendency due to net column heating throughout the deepening and up to 80% during 6 hours of most rapid pressure falls. WRF model simulations of The Braer Storm show that without diabatic heating effects; a much weaker, poorly organized cyclone develops with an ill-defined thermal structure. Precipitation pattern is inadequately resolved and the resulting cyclone's path shifts further south-east. The consequence of reducing Greenland to sea level on cyclone intensity is found to be small, but a significant change in the track produces a life threatening storm over Western Europe.

17. Sting jets in cyclone Friedhelm: an investigation of key mechanisms and processes

L Baker, University of Reading

The jet across the North Atlantic was exceptionally strong throughoutDecember 2011. The DIAMET (DIAbatic influences on Mesoscale structures in ExtraTropical storms) field campaign was fortunate to take place during the period with strongest baroclinicity when a succession of fast-moving storms crossed the UK. The cyclone that hit Scotland on 8 December 2011 (cyclone Friedhelm) was the most severe of these storms, and the UK research aircraft flew through its core, dropping sondes and making in situ measurements. The structure of this storm, and the location of the strongest winds, led to speculation that this storm contained a sting jet. If so, this is the first time that a sting-jet storm has been observed using a research aircraft. The sting jet is a mesoscale descending airstream that can cause strong near-surface winds in the dry slot of cyclones, a region not usually associated with strong winds. Here we present analysis of cyclone Friedhelm using observations and Met Office model forecasts demonstrating the existence of a sting jet and the important mechanisms involved in the generation and evolution of the sting jet. We use a novel heating and moisture tracer diagnostic to clarify the role of evaporation in the descending sting-jet air, and characterise the instability of the air parcels associated with the sting jet using diagnostics for conditional symmetric instability and conditional instability.

Laura Baker, Oscar Martinez-Alvarado, Suzanne Gray and John Methven

18. High Winds in Extratropical Storms: The Role of Microphysics

T Baker, University of Leeds

Extra-tropical cyclones are an integral part of the weather in north-western Europe and can be associated with heavy precipitation and strong winds. While synoptic-scale aspects of these storms are often satisfactorily forecast several days in advance, mesoscale features within these systems such as bands of heavy rain or localized wind maxima are significantly less well understood and predicted by operational forecasts. The improvement of our knowledge and the predictability of these features is one of the key goals of the UK consortium project DIAMET (DIAbatic influences on Mesoscale structures in ExtraTropical storms). This project combines hi-resolution NWP (Numerical Weather Prediction) analysis with data collected from the Facility for Airborne Atmospheric Measurements (FAAM) BAe146 research aircraft along with other remote and in-situ measurements.

This study analyses the effects of microphysics on the mesoscale dynamics within extratropical storms, in particular the high wind areas around occluded fronts wrapped around the core of a matured cyclonic storm. It has been hypothesized that evaporation and melting of hydrometeors in this region can lead to downward momentum transport and thereby increase near-surface winds (sometimes referred to as sting jets). The main tool for this study is the Weather Research and Forecasting (WRF) model. High-resolution simulations are run for several cases from the DIAMET field campaigns to examine how the development of strong winds around occluded fronts is affected by the microphysics. The model results using different microphysics schemes are compared with the observational data from the BAe146 aircraft and other sources such as wind profilers and radiosondes. In initial model simulations of a secondary frontal wave observed during the 2009 T-NAWDEX pilot flights, the microphysics in the parameterization scheme used has a large impact on the winds observed around the hook of the occlusion. The advanced double-moment Morrison and Thompson schemes show 12-hour mean 10m winds about 50% higher than the simpler WSM3 (WRF single moment) scheme in this area. These results suggest that ice processes could play an important role in the downward transport of momentum in this part of the cyclone. Further results from this and other cases from the field campaigns will be presented at the conference.

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19. **New diagnostics for analysing diabatic processes in extratropical cyclones**
    O Martinez-Alvarado

Diabatic processes are those in which heat is transferred, such as radiation and latent heat release. These determine the evolution of the atmosphere through the modification of mesoscale circulations and vice versa. Despite their key importance to the atmoshperic evolution, diabatic processes cannot be directly resolved in numerical weather forecast models. Instead, they have to be parameterised in terms of resolved variables at grid scale. Basic research into the ways these processes and the atmosphere interact in numerical models and in reality is key to improve the quality of weather and climate forecasts.

Here we present a new suit of comprehensive diagnostics to investigate diabatic processes in numerical weather forecast models. The diagnostics comprise tracers tracking changes in the variables that determine the thermodynamics and moisture content of an atmospheric system. The changes are decomposed according to the diabatic processes responsible for them. These suit of diagnostics is applied to a North Atlantic cyclone that ocurred on 30 September 2009 during the first DIAMET (DIAbatic influences on Mesoscale structures in ExtraTropical storms) field campaign. We show the relation between the structure of the cyclone and the relative importance of different diabatic processes in producing the total modification of its thermodynamical properties.

O. Martinez-Alvarado and R. S. Plant

20. **Diabatic maintenance of a mesoscale band of heavy precipitation observed during the DIAMET field campaign**
    J Chagnon, University of Reading

Heavy precipitation and severe winds in frontal cyclones are often localised to mesoscale structures (e.g., line-element convective rain bands, sting jets) that are embedded within the larger-scale cyclone. Large amounts of diabatic heating and cooling take place within these mesoscale structures, due primarily to the latent heating from phase changes of water, but also from radiation and frictional processes. The large spatial gradients of heating and cooling can drive a localised circulation which may influence the subsequent evolution of these mesoscale structures. The physical processes giving rise to the diabatic heating and cooling are parameterized in numerical weather prediction (NWP) models. Their representation and effect on the grid-resolved flow are therefore sources of uncertainty in NWP models. This presentation will demonstrate the origin and consequences of diabatic heating on a mesoscale band of precipitation that was observed during the DIAMET (DIAbatic influences on Mesoscale structures in ExTratropical cyclones) field campaign. On 24 September 2011 (DIAMET IOP3) an intense band of precipitation was observed in the warm sector of an extratropical cyclone to the west of Scotland. Dropsonde sections were performed across the precipitation band by the NERC-FAAM BAe-146 research aircraft. High resolution simulations of the case have been conducted in the Met Office Unified Model (MetUM). Diabatic contributions to the simulated potential vorticity (PV) have been diagnosed using a set of passive tracers in the MetUM. The PV tracer analysis demonstrates that the rain band was associated with a band of diabatically-generated PV due to latent heating from the convection and large-scale cloud schemes. This presentation will include a synthesis of the observational and numerical analyses of this rain band and will discuss the dynamical mechanisms linking the maintenance of the rain band to diabatic processes.

Jeffrey Chagnon, John Methven, Sue Gray

University of Reading

21. Climatology and significance of diabatic Rossby-waves
M Bottcher, ETH Zurich

Diabatic Rossby waves (DRWs) are low-tropospheric positive potentialvorticity (PV) anomalies that are continuously regenerated through diabatic processes, leading to a rapid propagation often along an intense baroclinic zone. It has been hypothesized that DRWs can be important precursors for rapid cyclone development. Previously, the mechanism of DRWs has been studied mainly in idealized channel flows.
A climatology of DRWs over the years 2001-2010 is presented using ECMWF analyses. For this purpose a tracking algorithm is created that selects positive PV anomalies in the lower troposphere and identify them as a DRW whether they are located over a baroclinic zone, propagate fast and are not forced by upper-level waves for certain time steps. It is shown that DRW events occur more frequently over the Pacific than over the Atlantic basin whereas the percentage of explosively deepening DRWs is higher in the Atlantic basin. The number of DRWs that intensify explosively is evaluated against the number of all explosively intensifying extratropical cyclones.
In a second part simulations with a regional model of a DRW case that occurred in December 2005 over the North Atlantic involving an explosive pressure deepening are presented. An atrifical experiment concerning the latent heat release is shown that leads to a decay of the DRW. Eventually, a new cyclone in a favourable position develops by dry dynamics that overexceed the pressure drop of the cyclone that was supported by the DRW as precursor.

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