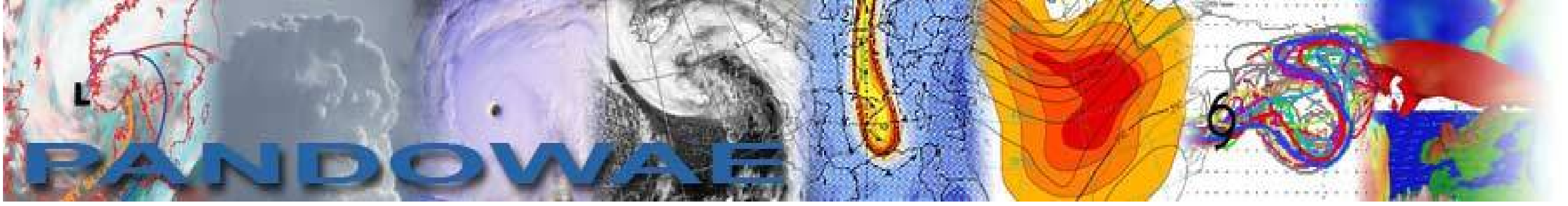

PANDOWAE
Final Symposium

Progress and Future Directions of Research on Predictability and Dynamics of Midlatitude Weather Systems

May 18-21, 2015
Karlsruhe, Germany

BOOK OF ABSTRACTS

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Research Area A:

A-K Chang: Keynote on RA-A: Rossby Wave Trains and Weather Forecasting

Keynote on RA-A: Rossby Wave Trains and Weather Forecasting

Edmund Chang

Stony Brook University, NY, USA

In this presentation, I will discuss some of our research at Stony Brook University (in collaboration with Brian Colle's group) on Rossby wave trains that are related to weather forecasting, including our effort to try to collaborate with researchers and forecasters of the National Weather Service to make use of these research in the development of tools to assist forecasters in their assessment of forecast uncertainties and error growth. Hopefully this will spur some discussions about how research results can be more effectively transitioned to the operational arena.

A-O Wirth: Overview of PANDOWAE research in RA-A

Overview of PANDOWAE research in RA-A

Volkmar Wirth

Institut für Physik der Atmosphäre, Johannes Gutenberg-Universität, Mainz, Germany

This presentation reviews the highlights from PANDOWAE research area A, which is entitled „upper level Rossby wave trains: generation, propagation and wave breaking“. The activities in this research area can be organized into five themes: (1) Basics of Rossby wave dynamics, (2) diagnosing and forecasting Rossby wave trains, (3) extratropical transition, (4) the connection of Rossby wave trains with severe weather, and (5) Rossby wave breaking.

The PV perspective proves fruitful in order to diagnose the mechanisms responsible for the amplification and/or decay of individual troughs and ridges of a Rossby wave train. Diagnosing Rossby wave trains turns out to be far from straightforward, and different techniques suffer from different drawbacks. In addition, state-of-the-art weather forecast models do not perform very well when predicting the evolution of Rossby wave trains. The extratropical transition of a tropical cyclone is an important mechanism for the generation of Rossby wave trains; on average it increases the downstream Rossby wave activity, and its dynamics may be characterized by a bifurcation thus explaining the large forecast errors often encountered. There are episodes in which severe weather over Europe is associated with an upstream Rossby wave train, but it seems difficult generalize results from individual case studies. Yet, composite studies suggest that severe weather may be preceded by a Rossby wave train also in a climatological sense. Rossby wave breaking has significant variability, with the seasonal cycle as well as the state of the stratosphere playing a role.

A-1 Gierth: Dynamics of Rossby Wave Trains in a quantitative PV-Θ framework

Dynamics of Rossby Wave Trains in a quantitative PV-Θ framework

Franziska Gierth and Michael Riemer

Institut für Physik der Atmosphäre, Johannes Gutenberg-Universität, Mainz, Germany

Rossby wave trains (RWTs) are a fundamental ingredient of midlatitude dynamics and may constitute precursors to high-impact weather events. Being of large spatial scale, RWTs may be assumed to be highly predictable flow features. Recent work, however, has shown that for medium-range forecasts there may be severe limitations to RWT predictability. As a contribution to an improved understanding of these inherent uncertainties, we develop and apply a framework to quantify different processes governing the evolution of real-atmospheric RWTs.

RWTs are investigated as potential vorticity (PV) waves on isentropes. Based on the classic Eady model, RWTs are considered as interacting waves at upper- and lower-tropospheric levels. The amplification of the wave pattern is examined in terms of advective tendencies from the upper-level wave itself, from baroclinic feedback of the low-level temperature wave and interior PV anomalies, from divergent outflow, and from diabatic tendencies due to cloud processes and long-wave radiation. Piecewise PV inversion is applied to separate the impact from the upper- and low-level waves. The diabatic tendencies are derived from the Year-of-tropical-convection data.

We present results from a case study of an RWT in October 2008. In addition to the classic picture of barotropic or baroclinically-coupled Rossby wave propagation, it is found that the divergent outflow plays a prominent role in ridge amplification. However, the diabatic tendencies show minor impact on ridge amplification. Overall, a considerable variability in the processes contributing to the evolution of individual troughs and ridges is diagnosed. We conclude with a discussion of potential implications for RWT predictability.

A-2 Methven: Defining Rossby wave propagation and wave-mean flow interaction when meridional air parcel displacements are large

Defining Rossby wave propagation and wave-mean flow interaction when meridional air parcel displacements are large

John Methven[1] and Paul Berrisford[2]

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[2]*NCAS-Climate, ECMWF*

The theory of wave propagation and wave-mean flow interaction requires a partition of the atmospheric flow into a notional background state and perturbations to it. The evolution of both components and their diagnosed ``interaction'' depends upon the partition. Here, the background state is defined in terms of two fundamental integral properties of the full flow: mass and circulation enclosed by potential vorticity (PV) contours within isentropic layers. For adiabatic and frictionless flow, the integrals are all invariant and the background state is a steady solution of the primitive equations. In this partition, all the time-dependence in the adiabatic flow is put into the perturbations which can be described by two wave activity conservation laws for pseudomomentum and pseudoenergy valid at large amplitude.

For a single neutral disturbance, even if described by nonlinear dynamics, the ratio of pseudoenergy to pseudomomentum yields a unique value which can be interpreted as its phase speed. An extension of the Empirical Normal Mode (ENM) technique is described which enables extraction of structures from re-analyses or nonlinear models which are orthogonal with respect to pseudomomentum. The meaning of these structures is explained for neutral and unstable disturbances and the results illustrated using ERA-Interim data. Periods of westward, stationary (blocked) or eastward propagation ("zonal regime") of Rossby waves are shown to be related to the speed obtained. Perhaps most surprisingly, variations in this speed are dominated by the lower boundary contribution to pseudoenergy with the westward phases being associated with stronger boundary potential temperature perturbations in planetary waves.

A-3 Giannakaki: Extreme precipitation events in northern Switzerland and an object-based spatial forecast verification tool of Rossby waveguides.

Extreme precipitation events in northern Switzerland and an object-based spatial forecast verification tool of Rossby waveguides.

Paraskevi Giannakaki and, Olivia Martius

University of Bern, Switzerland

A climatological analysis of upper-level flow structures associated with extreme precipitation events in north-western and north-eastern Switzerland is presented. Our study is founded upon a potential vorticity (PV) perspective of the tropopause-level flow (Hoskins et al., 1985). PV structures at tropopause-levels that are common to many extreme precipitation events are identified by a K-means clustering approach. The way in which the location and structure of the upper level flows affects the local distribution of the precipitation is analyzed. Moreover for each class the main forcing mechanism behind the ascent of moist air, the magnitude of the total precipitable water and the seasonal distribution are presented.

Forecasting these extreme precipitation events is a challenging task and accurate representation of Rossby waves have a great effect in the results. Piaget et al. (2015) using PV-based error metrics found that a misrepresentation of the upper level flow resulted in a high variability of the forecast precipitation with different lead times. The second part of our study is focused on characterization of forecast errors of Rossby waveguides at the tropopause-level. Enhanced PV gradients on the dynamical tropopause are co-alligned with the jet streams and can serve as waveguides for synoptic scale Rossby waves. We present a method for an object-based forecast error evaluation. Area errors, amplitude vectors and shift vectors are used for the verification of the forecasts. This method was applied for the time period 2008-2010 and a short climatology of forecast errors was produced for different forecast lead times.

Piaget N, Froidevaux P, Giannakaki P, Gierth F, Martius O, Riemer M, Wolf G, Grams CM. 2015.: Dynamics of a local Alpine flooding event in October 2011: moisture source and large-scale circulation. Accepted in Quarterly Journal of the Royal Meteorological Society.

A-4 Wolf: Dynamics of upper tropospheric Rossby wave trains and their representation in numerical weather forecast models

Dynamics of upper tropospheric Rossby wave trains and their representation in numerical weather forecast models

Gabriel Wolf, Volkmar Wirth and Ilona Glatt

Institut für Physik der Atmosphäre, Johannes Gutenberg-Universität, Mainz, Germany

Severe weather over Europe is known to be occasionally associated with long-lived upper tropospheric wave trains. This suggests potential predictability on the time-scale of a week and even longer - a potential which is far from being exploited today. As a prerequisite for improved forecasts we aim in our work to diagnose deficiencies in current weather forecast systems regarding the generation, propagation, and decay of such long-lived wave trains.

We implemented several methods to diagnose Rossby wave trains as objects. In some of these methods we found a tendency for a single Rossby wave packet to fragment into several parts. The problem can be traced back to the semigeostrphic nature of Rossby waves. Correspondingly, the reconstruction of Rossby wave train objects is less prone to fragmentation if it is done after a suitable semigeostrophic coordinate transformation has been applied.

We implemented and compared several methods to diagnose the horizontal propagation of Rossby wave packets: object based identification on a Hovmoeller diagram, tracking of Rossby wave packets in longitude-latitude-space, and the application of a suitable formulation of a wave activity flux. The latter turns out to be useful in providing extra information which cannot be obtained from the former two. For instance, it provides a better separation of two consecutive but distinct Rossby wave packets, and it can be used to extract information about Rossby wave breaking.

We also investigated the skill of current numerical weather forecast models to predict the evolution of Rossby wave trains in an object based metric. Combining this with our tracking algorithm allows us to extract an object based error evolution for Rossby wave trains as a function of their life cycle.

A-5 Quinting: The impact of extratropical transition on the dynamics of midlatitude Rossby waves

The impact of extratropical transition on the dynamics of midlatitude Rossby waves

Julian Quinting[1], Julia H. Keller[2] and Sarah C. Jones[2]

[1]*Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Germany*
[2]*Deutscher Wetterdienst, Offenbach, Germany*

Tropical cyclones (TCs) undergoing extratropical transition (ET) have the ability to excite and to modify midlatitude Rossby waves. Recently, the development of various diagnostic techniques and their application in case studies and in climatological studies lead to major advances in quantifying the impact of TCs on midlatitude Rossby waves and in understanding the main physical processes involved in the interaction between TCs and the midlatitude flow.

The identification of synoptic-scale Rossby wave packets (RWPs) in reanalysis data enabled us to quantify the climatological impact of TCs on the midlatitude flow. The results show a statistically significant increase of RWP occurrence frequency downstream of western North Pacific and South Indian Ocean ET events and thus highlight the impact of TCs on midlatitude synoptic-scale variability. In addition, a statistically significant increase of RWP amplitude indicates that Rossby waves downstream of western North Pacific and South Indian Ocean TCs are more intense than Rossby waves that are linked to extratropical cyclones.

The distinction between scenarios with and without downstream Rossby wave development in reanalysis data as well as in ensemble forecasts allowed us to investigate physical processes during the Rossby wave amplification through a TC. We identified two factors that are critical for the downstream flow evolution by evaluating eddy kinetic energy budgets. First, the convergence of ageostrophic geopotential fluxes between the TC and an upstream trough is relevant for the initial wave amplification which points to the importance of the phasing between the midlatitude flow and the TC. Second, the intensity and duration of baroclinic conversion from eddy available potential energy into eddy kinetic energy within the TC and along the midlatitude baroclinic zone to the east of the TC determines the intensity and duration of the future downstream development.

The presented research contributes to the understanding of the interaction between TCs and midlatitude Rossby waves in a climatological and in a predictive sense.

A-6 Archambault: Tropical Cyclone-Extratropical Flow Interactions over the Western North Pacific: Dynamics and Remote Impacts

Tropical Cyclone-Extratropical Flow Interactions over the Western North Pacific: Dynamics and Remote Impacts

Heather Archambault[1], Daniel Keyser, Lance F. Bosart, Christopher A. Davis[2] and Jason M. Cordeira

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Tropical cyclones (TCs) that recurve over the western North Pacific while undergoing extratropical transition sometimes amplify Rossby wave trains (RWTs) that disperse downstream and influence the extratropical flow pattern over North America. This presentation will illustrate the dynamics and remote impacts of recurving western North Pacific TCs in the context of objectively defined TC–extratropical flow interactions. The strength of the TC–extratropical flow interaction is defined by the strength of negative potential vorticity (PV) advection by the irrotational wind associated with the TC. Based on 292 recurving western North Pacific TCs (1979–2009), interactions are categorized as strong if they fall in the top 20% of interactions and weak if they fall in the bottom 20% of interactions.

Using composite analyses and a case study, it will be shown that during strong interactions, divergent outflow associated with the TC anchors and amplifies a downstream ridge such that a RWT amplifies and disperses across the North Pacific to North America. When this RWT reaches North America, it may trigger extreme weather. In contrast, during weak interactions, divergent outflow initiates a weak RWT that then dissipates over the western–central North Pacific, producing no discernable impact on North America.

In addition, composite analyses of strong and weak interactions will be used to show that strong interactions feature a more distinct trough upstream of the recurving TC, and stronger and broader divergent outflow associated with stronger midlevel frontogenesis and forcing for ascent. Furthermore, strong interactions are associated with more intense upper-level PV frontogenesis that promotes more pronounced jet streak intensification. The finding that stronger dynamics are associated with strong interactions is in line with the tendency for strong interactions to occur later in the season than weak interactions (late September vs. mid-August, on average), when baroclinicity is increased.

A-7 Davies: Connectivity of Weather Systems and the 2013/14 Winter

Connectivity of Weather Systems and the 2013/14 Winter

Huw Davies

Institute for Atmospheric and Climate Science, ETH Zurich, Switzerland

An exploration is undertaken of the role played by transient upper-tropospheric flow features during the extreme 2013-2014 Winter. It is shown that these features relate closely to the differing and often destructive weather extremes experienced across a wide zonal swath of the extra-tropics extending from California to Western Europe. Moreover their amplitude, recurrence and location accounts directly for the season's decidedly unusual time-mean anomaly patterns.

The features are in effect repeated manifestations of large-amplitude disturbances on the jet-stream wave-guide, and they occur sequentially, are linked dynamically, and exhibit a longitudinal (and sometimes circumpolar) connectivity. The results serve to underline the centrality and significance of the individual transient weather systems, and have ramifications for the study, understanding and prediction of seasonal climate patterns.

A-8 Schneidereit: Boreal Rossby wave breaking events: seasonal cycle and impact on weather

Boreal Rossby wave breaking events: seasonal cycle and impact on weather

Andrea Schneidereit, Dieter H. W. Peters

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This study analyse the seasonal cycle of boreal Rossby wave breaking (RWB) events and their mean impact on weather patterns. Mid- to high latitude RWBs are separated from the subtropical Rossby waves. This separation based on different dynamical causes of breaking and different influence regions of RWB in these two latitudinal bands.

The seasonal cycle of different types of extratropical Rossby wave breaking events is examined for the Northern Hemisphere north of 40°N using ECMWF re-analysis data (ERA-40). Rossby wave breaking events are identified with the focus on the background flow conditions and separated into cyclonic (anticyclonic), and poleward P1 (P2) and equatorward LC2 (LC1) types using the meridional wave activity flux, overturning of Ertel's potential vorticity and regions of diffluence/confluence of the background flow. Precipitation and wind pattern as well as the ageostrophic cross-stream Lagrangian Rossby number, which describes the potential to generate inertia-gravity waves, are used to illustrate the mean influence of Rossby wave breaking events downward into the troposphere.

The seasonal cycle shows a higher number of LC1 events in summer, whereas P1, LC2 and P2 events each have a significant winter maximum and a summer minimum. The seasonal cycle of P2 breaking occurs as mainly influenced by the North Atlantic. All breaking events are also stronger in their meridional wave activity flux intensity in winter indicating the stronger eddy momentum fluxes. Considering composites of poleward breaking events, the location of the jet exit region shifts during the breaking, is in coherence with unbalanced flow, and, in turn, generates inertia-gravity waves. Precipitation and wind gusts maxima shift from the north-westerly side of the jet exit to its north-easterly side related with the shift of the jet exit region during anticyclonic breaking events, which may have strong influences on severe weather.

AGCM (ECHAM5) model experiments with different radiative forcing due to zonally asymmetric ozone changes in the boreal stratosphere show that due to the induced changes of the backgound flow in the upper troposphere result in a westward displacement of the region of North Atlantic/European P2 RWB events.

A-9 Reynolds: Singular Vector Analysis of the January 2009 Stratospheric Sudden Warming

Singular Vector Analysis of the January 2009 Stratospheric Sudden Warming

Carolyn Reynolds[1], Lawrence Coy[2]

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[2]*NASA GSFC), USA*

The very strong stratospheric sudden warming (SSW) of January 2009 not only resulted in a rapid warming and wind reversal in the arctic stratosphere, but had a substantial effect on Northern Hemisphere surface weather, including the heaviest snowfall observed in south-eastern England in 20 years. The evolution and predictability of this SSW is investigated using singular vectors (SVs). The leading SVs are the fastest growing perturbations to a given forecast trajectory in a linear sense, and therefore have utility for predictability studies. While SVs have been applied frequently to study tropospheric phenomena, the application to stratospheric phenomena has been less common. Here, SVs, calculated using the Navy Operational Global Atmospheric Prediction System (NOGAPS), are optimized for growth at stratospheric levels over 72 hours, and are examined for selected dates before and during the SSW. It was found that the initial and final SV fields have larger horizontal structures during the SSW event than before the SSW event. A high-altitude forecast model, NOGAPS-ALPHA (Advanced Level Physics High-Altitude) was initialized with perturbations taken from the initial time SV structures and integrated for 144 hours to study growth and nonlinear changes in a highly disturbed polar vortex. When initial SV perturbations were added to the analysis during the SSW, large changes occurred in the forecast of the descent of the anomalous easterlies from the stratosphere into the troposphere. Examination of the development of SV perturbations suggests stratospheric SV growth occurs through wave action conservation as initial SV perturbations propagate into the polar vortex jet.

A-10 Brunet: Advances in sub-seasonal forecast: predictability, dynamical and physical processes

Advances in sub-seasonal forecast: predictability, dynamical and physical processes

Gilbert Brunet[1], Hai Lin[1], Jeff Knight[2] and Adam Scaife[2]

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[2]UK MetOffice, Exeter, UK

The sub-seasonal to seasonal variability at mid-latitude is characterized by weather regimes (e.g. Atlantic blockings) and large scale oscillations and patterns, like the North Atlantic Oscillation (NAO). Positive NAO phases are associated with stormy weather in the UK. Similarly tropical rainfall patterns have been correlated significantly with positive phase of the NAO in observations and model output by Lin et al. (GRL, 2005). The latter study identifies an increasing trend in this relationship for the 51 winters of 1948/49 to 1998/99. The Quasi-Biennial Oscillation (QBO) is an inter-annual tropical mode of variability that also can increase the seasonal occurrence of positive NAO phase and strength of the jet stream (Slingo et al., 2014).

The Madden-Julian Oscillation (MJO) is the dominant mode of sub-seasonal variability in the tropics, which has a direct impact on the weather in the tropical region, as it organizes convection and precipitation. It also has a significant influence on the extratropical atmospheric variability through Rossby wave propagation and thus provides an important signal source for mid-latitude weather forecasts on sub-seasonal time scales.

We will discuss recent research progress to clarify the role of these different tropical and mid-latitude modes of variability in terms of predictability and dynamical processes, weather impacts and predictive skill for the sub-seasonal to seasonal prediction problem.

1. Slingo et al., 2014: The recent storms and floods in the UK, Met Office and Centre for Ecology and Hydrology internal report, 1-27.

2. Lin, H. J. Derome and G. Brunet 2005 Tropical Pacific link to the two dominant patterns of atmospheric variability. Geophys. Res. Lett., 32, L03801.

A-11 Quandt: The representation of forecast variability associated with atmospheric blocking and extratropical transition in TIGGE

The representation of forecast variability associated with atmospheric blocking and extratropical transition in TIGGE

Lisa-Ann Quandt[1], Julia H. Keller[2], Sarah C. Jones[2], Olivia Romppainen-Martius[3]

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An empirical orthogonal function analysis and fuzzy clustering methodology is adapted to the THORPEX Interactive Grand Global Ensemble (TIGGE) multimodel ensemble prediction system (EPS) to investigate the forecast variability during large scale developments in the midlatitudes. In this way, different scenarios are extracted and the contribution of the different EPS to the entire variability is investigated. To identify the blocked latitude for certain members, the blocking index by Tibaldi and Molteni (1990) is calculated.
For the extratropical transition of five tropical cyclones in 2008 and the associated impact on the midlatiutde flow it is found that the EPS contained in TIGGE differ in their spread and development scenarios. Some of the individual EPS are generally confined to only a few scenarios, whereas others contribute regularly to almost all. TIGGE contains more development scenarios than European Centre for Medium Range Weather Forecast (ECMWF) EPS but the full range of development scenarios is only found with the ECMWF included in the multimodel EPS.
The predictability of the Euro-Russian blocking in summer 2010 is also investigated. This blocking event is linked to high impact weather by causing a heat wave in Russia and flooding in Pakistan. We focus on its onset, its decay and a period about one month after its onset which is characterised by low predictability of its western flank. It is found that the ensemble variability of the onset is influenced by differences in development and breaking of an previous blocking ridge upstream.
In our study we concentrate on the question what we can learn about the dynamics and predictability of high impact weather by using TIGGE data.

Research Area B:

B-K Gray: Keynote on RA-B: Diabatic processes in extratropical cyclones: a general overview and a detailed example of two heavily precipitating slow-moving summer cyclones

Keynote on RA-B:
Diabatic processes in extratropical cyclones: a general overview and a detailed example of two heavily precipitating slow-moving summer cyclones

Suzanne Gray, Oscar Martinez-Alvarado and John Methven

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The structure of near-tropopause potential vorticity (PV) acts as a primary control on the evolution of extratropical cyclones. Diabatic processes, such as the latent heating found in ascending moist warm conveyor belts, modify PV. Here a general overview is given and complemented by a detailed case study. We present the structure and evolution of diabatically-generated PV in two slow-moving summer cyclones, both observed using the UK's meteorological research aircraft during the DIAMET field campaign in 2012. Both cyclones had intense precipitation along their bent-back fronts but their diabatic PV evolution was very different: a 'PV tower' formed in the cyclone with lowest core pressure but not in the other cyclone. Analysis of the vertical distribution of individual diabatic processes shows clear differences between the cyclones that are restricted to a few hundreds of kilometers around the cyclone centre. In particular, enhanced diabatic activity occurs at low levels in the PV-tower cyclone. This is diagnosed as due to enhanced low-level PV modification by cloud microphysics.

B-O Wernli: Overview of PANDOWAE research in RA-B

Overview of PANDOWAE research in RA-B

Heini Wernli

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Research activities in RA-B of PANDOWAE focused primarily on improving our understanding of the relationship between diabatic processes and the life cycle of weather systems, and on quantifying the importance of diabatic processes for errors in their prediction. In terms of weather systems, a specific focus has been on tropical cyclones undergoing extratropical transition (ET), intense extratropical cyclones, and diabatic Rossby waves as a particular subcategory of extratropical cyclones. In terms of methodologies, a combination of observation-based studies, climatological investigations with reanalysis datasets and detailed numerical simulation-based case studies has proven fruitful. And finally, in terms of theoretical concepts, a combined Lagrangian and Eulerian framework using potential vorticity as a key variable have been applied in many RA-B studies. This overview presentation will highlight the complementarity of the different research approaches that were required to make progress in this complex field of atmospheric dynamics. In addition, it will show examples of key results from PANDOWAE RA-B activities, in particular (i) the important role of diabatic outflows from warm conveyor belts and recurving tropical cyclones for modifying the upper-level jet stream and the downstream Rossby wave structure, (ii) the climatological distribution of diabatic Rossby waves and the challenge in predicting their temporal evolution, (iii) the variability of large-scale moisture transport involved in the generation of high-impact precipitation events, (iv) the use of feature-based ensemble diagnostics for the flight planning in aircraft campaigns, and (v) the combined use of detailed observations and high-resolution modelling for improving our understanding of ET systems.

B-1 Rivière: Dynamical and moist processes governing the motion of extratropical surface cyclones

Dynamical and moist processes governing the motion of extratropical surface cyclones

Gwendal Rivière

Laboratoire de Météorologie Dynamique (ENS, Paris), France

Numerous winter storms hitting Western Europe have crossed the large-scale jet axis from its warm-air to cold-air side and strongly deepened during and after the jet-crossing phase. This was the case of the most violent storms hitting France over recent years (Christmas 1999 storms, Klaus in 2009, Xynthia in 2010 or Ulla in 2014).
The purpose of the study is to identify mechanisms explaining the tracks of surface cyclones, especially their cross-jet motion. A recent theory that may explain the cross-jet motion will be briefly summarized using the framework of the two-layer quasi-geostrophic model. The theory is a generalization of the so-called beta drift mechanism in the mid-latitude baroclinic context. The potential vorticity (PV) gradient associated with the large-scale jet generates PV anomalies in the upper troposphere via Rossby wave radiation which then advect the surface cyclone across the jet axis. The core of the presentation will be dedicated to the identification of the role played by moist processes in modifying the previous dynamical mechanism. Idealized mesoscale simulations of the Meso-NH model including various moist processes will be compared to each other. The moist run with full microphysics shows a more intense surface cyclone and induces a faster northeastward motion than the dry run. The partial moist run with only condensation and evaporation exhibits less latent heat release and a slower northeastward motion of the surface cyclone than the full moist run. The faster northward motion of the full moist run is explained by the stronger upper-level anticyclone due to a greater release of latent heat which induces stronger poleward advection at low levels. The faster eastward motion in the full moist run is due to the diabatically-produced positive anomaly at low levels but its effect is partially offset by the westward advection induced by the stronger upper-level anticyclone.

B-2: Schäfler: Using airborne observations to study the role of diabatic processes for forecast errors associated with mid-latitude weather systems

Using airborne observations to study the role of diabatic processes for forecast errors associated with mid-latitude weather systems

Andreas Schäfler, Andreas Dörnbrack

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Diabatic processes can strongly influence the evolution and intensity of midlatitude weather systems. These processes are associated with latent heat release due to phase transitions of water, surface fluxes, or radiative effects, and they strongly depend on the transport of water vapour. The transport of water vapor in coherently ascending Warm Conveyor Belt (WCB) airstreams is of particular importance for extratropical cyclones as it governs large parts of diabatic processes.

This presentation summarizes efforts to analyse non-routine airborne observations collected onboard a research aircraft to obtain knew knowledge on the representation of diabatic processes in NWP models and to study their role for forecast errors.

We present case studies on observations during different stages of the WCB ascent. The representation of moisture in the inflow region in the lower troposphere is investigated and the impact of water vapour errors on the larger scales is discussed. Additionally the representation of ascending WCB air masses is investigated. An outlook to future research activities is given.

B-3 Doyle: Sensitivity and Predictability of High-Impact Extratropical Cyclones

Sensitivity and Predictability of High-Impact Extratropical Cyclones

James D. Doyle, Carolyn A. Reynolds, Clark Amerault, P. Alex Reinecke

Naval Research Laboratory, Monterey, USA

We explore initial condition sensitivity and predictability aspects of several extratropical cyclones, Xynthia (2010), Klaus (2009), and the St. Jude's Day Storm (2013), which had a severe impact on Europe. We highlight how higher- and lower-latitude interactions contribute to the development of these cyclones. The adjoint, tangent linear, and nonlinear models for the atmospheric portion of the nonhydrostatic COAMPS are applied with 45 and 15-km resolution nested grids. The adjoint sensitivity results for all three storms underscore the importance of a plume of low-level moisture of sub-tropical origin. The adjoint diagnostics indicate that the intensity of severe winds in these storms just prior to landfall was especially sensitive to perturbations in the moisture and temperature fields and to a lesser degree the wind fields. Only a relatively small region of water vapor within an atmospheric river present at the initial time for all three storms was critically sensitive for the development of all three cyclones, in spite of the large differences between the storms in their structure and developmental evolution. We also place the results from these three storms in the context of a very active waveguide that occurred during December 2013-February 2014, which serves to further highlight the importance of low- and mid-level moisture sensitivity along water vapor plumes. The results of this study underscore the need for accurate moisture observations and data assimilation systems that can adequately assimilate these observations in order to reduce the forecast uncertainties for these high-impact extratropical cyclones. However, given the nature of the sensitivities and the potential for rapid perturbation and error growth, the intrinsic predictability of severe cyclones such as Xynthia, Klaus, and the St. Jude's Day storm is limited.

B-4 Čampa: Processes leading to heavy precipitation in the western Mediterranean region

Processes leading to heavy precipitation in the western Mediterranean region

Jana Čampa, Luisa Röhner, Ulrich Corsmeier, Kai-Uwe Nerding, Claus-Jürgen Lenz

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The project PANDOWAE-MED focuses on the dynamics of Mediterranean cyclones and convection and on the factors that determine their predictability.

On the larger scale, the main interest was in the upper-level precursors and moisture transport. The most frequent weather situations leading to strong precipitation in different regions in the western Mediterranean were identified with a trough over the western Europe being responsible for the most precipitation. Such a situation is favourable for strong moisture transport from the Atlantic basin into the Mediterranean. During the HyMeX (Hydrological cycle in Mediterranean Experiment) field campaign in 2012, several heavy precipitation events (HPE) occurred in the western Mediterranean. Using lagrangian trajectories and collected data from buoys, pressurized balloons, radiosondes and rain gauges, different air masses arriving into the precipitation regions were investigated.

On the small scale side, the focus was on the initiation of convection leading to high impact weather and the stochastic processes influencing the predictability of such events. Several model studies of HyMeX events and earlier cases focussing on diabatic processses will be presented. Sensitivity studies highlight the importance of processes such as surface evaporation, formation of a convergence zone and orography for precipitation. To access the predictability of such a HPE, we performed different ensemble studies. With uncertainties in initial conditions as well as with stochastic perturbations in the cumulus convection scheme of the numerical weather prediction model COSMO (Consortium of small scale modeling), we aim to better forecast such an HPE concerning the natural variablity of convective clouds.

B-5 Grams: The role of weather systems and associated diabatic processes in downstream flow sensitivity and midlatitude high impact weather

The role of weather systems and associated diabatic processes in downstream flow sensitivity and midlatitude high impact weather

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The atmospheric circulation in the midlatitudes is governed by large-scale Rossby waves. Recent research shows that diabatic processes play a crucial role in modifying the midlatitude Rossby wave guide and influence remote weather systems. In this overview, selected cases of various weather systems, with focus on extratropical transition (ET), are studied to explore how diabatic processes influence downstream flow sensitivity and may lead to midlatitude high impact weather (HIW). Model datasets are investigated using potential vorticity and Lagrangian trajectory diagnostics. Model simulations initialised from composite fields help to achieve a more general picture.

During ET the low-level circulation of the transitioning tropical cyclone (TC) advects warm-moist air poleward, which impinges on the midlatitude baroclinic zone. Thereby the convective ascent in the TC inner-core gradually transforms into slantwise ascent, not unlike a warm conveyor belt (WCB). This important process maintains strong diabatic outflow near the tropopause, resulting in substantial ridgebuilding and jet acceleration directly downstream of the ET system. The downstream flow response is highly sensitive to the phasing of the ET system with midlatitude features, such as troughs. In favourable conditions, a pronounced Rossby wave (RW) train develops, potentially triggering HIW in regions far downstream of ET. The downstream flow sensitivity is quantified to an equivalent reduction of midlatitude forecast skill by around two days.

ET is often accompanied by diabatically driven weather systems, such as predecessor rain events (PREs), diabatic Rossby waves (DRWs), or downstream WCBs. The upper-level outflow of these weather systems likewise modifies the midlatitude RW guide. This suggests that diabatic outflows of weather systems associated with strong latent heat release are generally important for modifying the upper-level midlatitude flow and for triggering downstream RW dispersion.

Further, it is illustrated how ET alters HIW in North America and in Europe. A novel metric, quantifying HIW directly related to an individual weather system, climatologically shows that TCs undergoing ET are by far the category of cyclones, that produce most local extremes during their life-cycles. Lastly, the centennial Central European floods in June 2013 are used as a non-ET example of how large-scale RW activity, individual cyclones, and unusual WCBs interact to produce HIW.

B-6 Lentink: Structural changes of Typhoon Sinlaku (2008) during its extratropical transition, using observations and modeling

Structural changes of Typhoon Sinlaku (2008) during its extratropical transition, using observations and modeling

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Extratropical transition (ET) of tropical cyclones (TCs) has been investigated in several studies. General structural changes and processes involved in the evolution are known. Still, a lot of uncertainty can be found while forecasting ET.

During the T-PARC field campaign (autumn, 2008) one objective was observing ET in order to better understand its mechanisms, which was achieved with Typhoon Sinlaku. Measurements could be performed during the entire evolution and in different regions of the storm, so that an extensive data set is available. For completion the TC is simulated with the high resolution non-hydrostatic regional forecast model COSMO (COnsortium for Small-scale MOdeling). Sinlaku is therefore an interesting case to get a better understanding of the development of processes during ET.

The main question in this research is: how does the structure of the ET system change as Sinlaku becomes more strongly influenced by the midlatitude flow? In a first phase of observations, the core region became asymmetric in a similar way as previous studies of tropical cyclones in vertical wind shear. In a second phase, the influence of the baroclinic zone was more important. Warm-frontal development occurred, which led to forced ascent that triggered deep convection in a potentially unstable environment. A convective burst modified the PV structure of Sinlaku. The complex development in between the two phases will be shown based on a simulation of Sinlaku.

B-7 Martinez-Alvarado: Rossby-wave forecast errors: the influence of diabatic processes

Rossby-wave forecast errors: the influence of diabatic processes

Oscar Martinez-Alvarado[1], Erica Madonna[2], Suzanne L. Gray[1] and Hanna Joos[2]

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Rossby waves are key elements in the atmospheric circulation and manifest through a ridge/trough pattern in the tropopause region. Recent work has shown that both the amplitude of upper-level Rossby waves and the tropopause sharpness decrease with forecast lead time over several days in some operational weather forecast systems. In this contribution, the amplitude reduction of Rossby waves in forecast systems is investigated through a forecast error case study.

A companion paper by Madonna et al. shows, in this case study, that (i) the 320-K PV forecast error that develops over a five-day forecast is associated with errors in forecasts of warm conveyor belts and (ii) essentially the same error development can be found in different operational high-resolution and ensemble forecast systems. Exploiting this forecast error robustness across modelling systems, an investigation into the physical processes responsible for forecast error development was performed. This investigation was carried out through bespoke simulations with the Met Office Unified Model, enhanced with tracers of diabatic processes modifying potential temperature and PV. The process analysis consisted of a comparison between a sequence of short-range simulations, serving as a proxy to the realised flow, and a contemporaneous forecast.

The results show clear differences in the way potential temperature and PV are modified in warm conveyor belts between proxy and forecast. Further insight is obtained by comparing the effects of individual diabatic processes (e.g. radiation, convection) in the upper-level ridge development between the proxy and forecast. These results demonstrate that differences in potential temperature and PV modification in the proxy and forecast translate into very different atmospheric evolution paths, one close to reality and one far away from it. The results also highlight the uttermost importance of accuracy in the numerical representation of diabatic processes to enhance the accuracy and range of weather and climate forecasts.

B-8 Boettcher: The importance of moist-diabatic PV generation for extratropical cyclones: PV towers and diabatic Rossby-waves

The importance of moist-diabatic PV generation for extratropical cyclones: PV towers and diabatic Rossby-waves

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Diabatic processes provide an important source for elevated low-tropospheric PV in extratropical cyclones. Together with an upper-level stratospheric PV anomaly and a warm anomaly at the surface, the diabatically produced PV serves as the middle part of intense extratropical cyclones' so-called PV towers. At their mature stage, the three parts of PV anomalies align to a vertical tower that provides for the strong cyclonic rotation. In this project, the different contributions to the formation of PV towers have been investigated in a climatological sense. It has been found that the amplitude of the segments of PV towers varies for different phases of the intensification, and in different regions and seasons. The regions where the moisture, which finally led to the moist-diabatically produced part of the PV tower, evaporated from the ocean extends over fairly large areas along the tracks,and the moisture uptakes mainly occur during the 72 hrs prior to the cyclones' mature stage.

Moist-diabatically produced PV can also act as a key part of the self-maintaining mechanism of a special kind of extratropical cyclones, the diabatic Rossby waves (DRWs). DRWs are low-level cyclones located at a baroclinic zone in a region of sufficient moisture supply. They steadily re-generate their PV anomaly downstream of the system by isentropic lifting followed by saturation and condensational heat release. With this mechanism DRWs exhibit a fast propagation speed eastward. It could be shown that in some cases, DRWs can serve as precursor to explosive cyclone intensification. This involves the interaction of the low-level DRW with an upper-level disturbance, which was found to be a very sensitive process leading to reduced forecast skill. Furthermore, a 10-year global DRW climatology has been calculated where their seasonal occurrence, tracks, genesis situations and intensification could be determined.

B-9 McTaggart-Cowan: Diagnosing Moist Isentropic Ascent with the Baroclinic Moisture Flux

Diagnosing Moist Isentropic Ascent with the Baroclinic Moisture Flux

Ron McTaggart-Cowan, John Gyakum, Ayrton Zadra, Richard Moore

Environment Canada, Dorval, QC, Canada

Atmospheric phenomena associated with the isentropic upgliding of moist air have come under enhanced study recently because of their potential impact on precipitation and cyclogenesis. These phenomena include diabatic Rossby vortices (or waves), atmospheric rivers, and predecessor rain events. In each case, air parcels from a warm tropical or subtropical moisture source impinge on a pre-existing baroclinc zone and ascend adiabatically until reaching saturation. The primary driver for this ascent is isentropic upgliding as the poleward-flowing moist airstream overrides the midlatitude front. Each of these phenomena can be responsible for the production of heavy rain, while latent heating following parcel saturation can lead to surface pressure falls and the propagation and amplification of initially small perturbations.

The baroclinic moisture flux (BMF) is a diagnostic quantity that is constructed to highlight regions in which these moist ascent processes dominate. As the vertical component of the moisture flux derived from the adiabatic method for vertical motion estimation, the BMF responds to the combined presence of the moisture flux and isentropic ascent. In this study, the form of the BMF is derived and applied to conceptual models of relevant atmospheric phenomena to illustrate the expected structure and evolution of the diagnostic under different conditions.

Case studies of relevant atmospheric phenomena are used to determine whether the BMF responds in real-data cases as expected based on the initial canonical analyses. Thereafter, a climatology of the BMF is used to evaluate the ability of this quantity to identify regions and seasons in which moist isentropic ascent is an important processes for the local climate. Preliminary comparisons with existing climatologies of the relevant atmospheric pheomena serve as subjcective assessments of the utility of the BMF as a diagnostic tool for the investigation of processes associated with moist isentropic ascent.

B-10 Moore: Heavy Precipitation Events Associated with Recurving North Pacific Tropical Cyclones: Can We Isolate Disparate Features?

Heavy Precipitation Events Associated with Recurving North Pacific Tropical Cyclones: Can We Isolate Disparate Features?

Richard Moore[1,2] and Ron McTaggart-Cowan[3]

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Recurving tropical cyclones (TCs) tend to favor the onset of heavy precipitation that is distinct from the precipitation associated with the TC circulation. Such heavy precipitation often occurs in conjunction with two types of meteorological phenomena: the predecessor rain event (PRE) and the diabatic Rossby vortex (DRV). A PRE is defined as a mesoscale to subsynoptic scale precipitation system featuring an average rainfall rate greater than 100 mm / 24 h that is displaced 500–2000 km poleward of a TC. They tend to occur in regions where significant ageostrophic ascent associated with upper-level forcing is present. In contrast, a DRV is defined as a short-scale, diabatically dominated moist baroclinic cyclone that grows without significant upper-level forcing.

The overarching goals of this work are twofold: i) quantify the climatological characteristics of DRVs and PREs in association with recurving TCs in the west North Pacific, and ii) provide a better understanding of the impact of the midlatitude structure on the predisposition for DRV or PRE genesis. The former will be accomplished via an analysis of 10 years of data, investigating all cases of a recurving TC in the western North Pacific. The latter will involve a composite analysis of relevant dynamical fields.

Furthermore, we will leverage the existence of a new and novel parameter: baroclinic moisture flux (BMF). BMF is a diagnostic quantity that is constructed to highlight regions in which isentropic upgliding (i.e. minimal upper-level forcing) is the dominant process for air parcel ascent. As such, it is well suited to differentiate scenarios conducive to either DRV or PRE occurrence.

Research Area C:

C-K Leutbecher: Keynote on RA-C: On research aimed at improving ensemble forecasts

Keynote on RA-C: On research aimed at improving ensemble forecasts

Martin Leutbecher

ECMWF, Reading, UK

Ensemble forecasting emerged in the early 1990s as a discipline in NWP in order to quantify forecast uncertainties in a flow-dependent way and to maximise the predictable information particularly at lead times where random errors of single forecasts can be as large as or bigger than the predictable signal.

The talk will start with a review of what ``good'' and ``better'' actually mean when we talk about the skill of ensemble forecasts. This will be followed by a summary of selected research highlights that influenced the operational configuration of the medium-range/monthly ensemble forecast system at ECMWF and research considered to be relevant for deciding its future evolution. This research comprises the representation of initial conditions, the representation of model uncertainties and the configuration of the forecast model itself.

C-O: Craig: Overview of PANDOWAE research in RA-C

Overview of PANDOWAE research in RA-C

George Craig

Meteorologisches Institut, Ludwig-Maximilians-Universität München, Germany

This talk presents highlights of six years PANDOWAE research on ensembles and adaptivity.

C-2 Swinbank: Latest Developments of the Met Office Global and Regional Ensemble Prediction System (MOGREPS)

Latest Developments of the Met Office Global and Regional Ensemble Prediction System (MOGREPS)

Richard Swinbank, Anne McCabe and Susanna Hagelin

UK MetOffice, Exeter, UK

The Met Office Global and Regional Ensemble Prediction System (MOGREPS) consists of a 2.2km convective-scale ensemble to produce short-range for the UK, which is nested in a 33km global ensemble. Both ensembles are currently run four times a day with 12 members.

During 2014/15 both the global and UK ensemble have been upgraded to use a new dynamical core, known as ENDGame. Currently MOGREPS-UK is run as a downscaler, entirely driven by the global ensemble. During the next year, the UK ensemble will be upgraded to use the UKV analysis and an initial implementation of stochastic physics that is designed to better capture the uncertainties in forecasts of fog and low cloud. The talk will include results showing the impact of these changes.

With the installation of new high-performance computing capacity, further enhancements are being considered, which are likely to include higher resolution model and running a small ensemble every hour – with products taken from a lagged ensemble.

C-3 Kober: The concept of a multi-scale ensemble system

The concept of a multi-scale ensemble system

Kirstin Kober, George Craig

Meteorologisches Institut, Ludwig-Maximilians-Universität München, Germany

A multi-scale ensemble forecasting system enables the examination of the impacts of uncertainty on both small and large scales on the predictability of high impact weather. Within PANDOWAE (Predictability ANd Dynamics Of Weather Systems in the Atlantic-European Sector) such a multi-scale ensemble system was proposed, focusing on variability caused by convection. This contribution will summarize results addressing several aspects of this system.

The large-scale variability is provided by a selection of 10 members of the global IFS ensemble prediction system (EPS) of ECMWF. Within each of these 10 members, ten COSMO (Consortium for Small-scale Modeling) model runs with 7 km horizontal resolution are nested. The 100 high resolution forecasts use the Plant-Craig stochastic convection parameterization to represent convective variability.

The skill of this part of the ensemble system (100 members) was investigated and compared with observations, with focus on precipitation forecasts. Neighbourhood verification techniques were applied to compare the skill of the stochastic realizations with the standard Tiedtke convection scheme. Results show that in weak forcing situations the forecasts with the Plant-Craig scheme are superior to the Tiedtke forecasts, especially for high precipitation thresholds.

For the last component of the multi-scale EPS representing small-scale variability COSMO experiments with 2.8 km horizontal resolution were nested into the 7 km members with perturbations to the convective boundary layer. The amplitude of the variability is determined based on physical processes affecting the initiation of convection in the boundary layer including surface heating, subgrid-scale orography or cold pools. Perturbations based on these processes are added to the tendencies and analyzed. The basic version representing variability due to surface heating is found to improve the precipitation forecasts in weak forcing situations.

C-4 Arbogast: Mid-latitude cyclone dynamics and ensemble prediction

Mid-latitude cyclone dynamics and ensemble prediction

Philippe Arbogast, Carole Labadie, Pierrick Cébron, Laurent Descamps, Marie Boisserie

Météo-France, CNRM, Toulouse, France

Ensemble forecasting is a numerical approach that is used to provide a discrete estimate of the predicted probability density function of the atmosphere. Such a system must take into account initial uncertainties and model errors. Some aspects of initial condition perturbation techniques, model error and the use of ensemble forecasts as dynamical diagnoses will be reviewed:

- I will discuss to what extent ideas coming from dynamical meteorology such as PV thinking influenced and could influence in the future initial conditions perturbation techniques.
- Model error related to diabatic processes is also to be taken into account by ensembles and often justifies some further calibration. Diagnoses of systematic error of some aspects of mid-latitude cyclone developments within a 30-year hindcast will be shown.
- An other application of ensemble forecasting is to provide sensitivity of an aspect of the forecast to the initial conditions. Different techniques applied to some case studies will be presented and illustrated using the TIGGE (Thorpex Interactive Grand Global Ensemble) database.

C-5 Rodwell: Reliability in Ensemble Data Assimilation

Reliability in Ensemble Data Assimilation

Mark Rodwell

ECMWF, Reading, UK

Key attributes of a probabilistic forecast system are its reliability and resolution. This talk focuses on reliability - the desire for forecast probabilities to agree with observed frequencies. The motivation for considering reliability in ensemble data assimilation is the realisation that reliability at short forecast ranges is necessary for reliability at longer ranges. Two key aspects within ensemble data assimilation can be optimised to improve reliability: the assignment of observation error variances, and the parameterisation of 'stochastic physics' - which accounts for deficiencies in a model's initial-state error growth rate. The focus on short time-scales is also beneficial because it leads to a localisation of the assessment of deficiencies in this error growth. A `reliability budget' is derived to show how these aspects represent components of the eventual forecast error - with a residual that highlights deficiencies in a system's reliability. Results demonstrate how stochastic physics can be more aware of the local meteorology - such as regimes that are convective or characterised by a time-mean balance between dynamics and radiation. An example of sensitivity of reliability to the assignment of observation error will also be discussed. The conclusion is that it is desirable, essential and possible to assess initial-state error growth (by the non-linear forecast model) and observation error assignment within an ensemble of data assimilations, and that this will facilitate the development of more seamless ensemble data assimilation/forecasting systems.

C-6 Homar: Mediterranean high-impact weather, physical mechanisms and predictability

Mediterranean high-impact weather, physical mechanisms and predictability

Víctor Homar Santaner, Romero, R., Garcies, L., Carrió, D.

Universitat de les Illes Balears, Palma de Mallorca, Spain

Mediterranean high-impact weather comes in a variety of forms. Besides the "severe weather" general definition universally adopted from the United States atmospheric community, the Mediterranean possesses an additional meteorological threat in the form of torrential rainfall and catastrophic flooding. After more than 50 years of research on atmospheric predictability following the pioneer work of Edward Lorenz in the early 1960s, enormous progress has been done for medium range forecasts (synoptic and planetary scales).

However, operational offices still struggle nowadays to issue reliable yet useful forecasts of hazardous meteorological phenomena. The battle against chaos for socially valuable forecasts at longer lead times has two main fronts: on the one side, improving the representation of the atmospheric state in our forecasting systems; and on the other, coping with the inherent uncertainty associated with any forecasts. Conclusions derived from research conducted during the MEDEX and HyMeX Mediterranean projects along these basic objectives will be presented. Numerical experiments reveal the main physical mechanisms acting on the generation of severe phenomena, highlighting the primary role of the geography of the Mediterranean and the usefulness of the ingredients conceptual models. Also, we present the singularities the region presents to benefit from the use of 4DVAR techniques.

Conversely, ensemble generation techniques imitating large scale methods fall short in encompassing the subsynoptic variability and mesoscale error growth. In this context, fast growing modes and dynamical sensitivity methods fail in providing useful information for ensemble generation and targeting decision-making. Discussion about these topics will be encouraged and promoted.

C-7 Weissmann: Adaptive observing strategies for airborne remote-sensing observations

Adaptive observing strategies for airborne remote-sensing observations

Martin Weissmann, Florian Harnisch

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This project of PANDOWAE phase 1 intended to develop, apply and evaluate adaptive observing strategies with particular emphasis on the potential of airborne lidar instruments for improvements of numerical weather prediction (NWP) models. The THORPEX Pacific Asian Regional Campaign (T PARC) 2008 offered a unique observational data set to investigate the impact of different observations on typhoon forecasts and their impact downstream in mid-latitudes during episodes of extra-tropical transition. The observations included dropsondes from four aircraft and the first airborne wind and water vapour lidar observations near tropical cyclones. Several assimilation studies were conducted, mainly with the ECMWF global modelling system, to assess observing strategies for typhoon forecasts as well as the potential of lidar observations for NWP.

Major findings from these studies include: (a) Targeted dropsondes overall improve typhoon track predictions, but their impact significantly depends on the assimilation system; (b) targeted dropsondes only have a small impact on mid-latitude forecasts and the impact is mainly due to improved typhoon tracks that indirectly lead to mid-latitude improvements; (c) dropsondes in the vicinity of typhoons have the largest impact, whereas the impact of dropsondes in distant sensitive regions and the core and eyewall region is small; (d) wind lidar observations have a comparably high impact, which underlines high expectations for the ADM-Aeolus satellite lidar; (e) the average impact of water vapor lidar observations is small, but forecasts can be affected considerably under certain conditions.

After PANDOWAE phase 1, research on assessing observation impact and the assimilation of remote-sensing observations has been continued in the framework of the Hans-Ertel Centre for Weather Research, now with a focus on convective-scale NWP. Ongoing research includes tools for ensemble-based estimates of observation impact as well as the assimilation of cloud-affected satellite observations in the infrared and visible spectrum.

C-8 Keller: Singular Vectors and the impact of observational data and perturbation methods on forecasts for tropical cyclones and their extratropical transition

Singular Vectors and the impact of observational data and perturbation methods on forecasts for tropical cyclones and their extratropical transition

Julia Keller, D. Anwender, S. Lang, S. Jones

Institute of Meteorology and Climate Research, Karlsruhe Institute of Technology, Germany

Forecasts for tropical cyclones (TC) and their extratropical transition (ET) often suffer from errors, caused by initial condition uncertainty and deficiencies in model formulation. Revealing the role of observational data and ensemble perturbation techniques in reducing forecast errors was a key component of PANDOWAE-ET.

Ensemble forecasts address the uncertainty by means of perturbation techniques, like singular vectors (SV), ensemble data assimilation and stochastic physics schemes. Different aspects of the perturbation techniques are investigated with regards to TC forecasts. It is found that the dynamics and structure of SVs in the vicinity of TCs are sensitive to model resolution and the consideration of diabatic processes. For Hurricane Helene (2006), this sensitivity manifests in significant changes in the 3D-structure and growth rates of the SVs near the TC. The contribution of the various ensemble perturbation techniques, implemented in the ECMWF EPS, to ensemble spread associated with TCs varies with forecast lead time. Although the structure of the perturbations is quite different initially, they quickly converge towards a TC displacement and intensity-change pattern.

Data denial experiments reveal the impact of targeted and modified satellite observations on ET forecasts in the ECMWF and MeteoFrance model. Prior to ET, denying data in SV regions yields the strongest impact at the SV's optimization time over Europe, while denying data in boxes around the ET event yields an even stronger impact after 4 days. Once ET is completed, the ET areas may overlap with midlatitude sensitive regions and observing them is equally important. The strongest impact over Europe is obtained by denying data in regions of SVs, targeted on Europe. Additional observations in these regions could distinctly improve forecasts in the presence of ET. Although the global influence of additional, satellite-based water vapor measurements is not clear, they positively impact forecast quality during three selected ET events.

C-9 Wiegand: PV Streamers – forecast quality, predictability, dynamics and HIW events

PV Streamers – forecast quality, predictability, dynamics and HIW events

Lars Wiegand[1], Arwen Twitchett[2], Conny Schwierz[3],Peter Knippertz[4]

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The equatorward breaking of Rossby waves is a frequent feature of the synoptic-scale circulation over the North Atlantic. It often creates elongated potential vorticity (PV) streamers, which can cause high-impact weather events ranging from heavy precipitation in Northwest Europe and the Mediterranean region to Saharan dust outbreaks. The projects summarized in this contribution explore the huge dynamical information content of long-term data from the European Centre for Medium-Range Weather Forecasts operational ensemble prediction system (EPS) and from the recently established THORPEX Interactive Grand Global Ensemble (TIGGE) specifically for the dynamics, forecast quality and predictability of PV streamers.
The main conclusions from this work are: (i) The EPSs shows a generally underdispersive behaviour for subtropical PV streamers. (ii) Forecast errors are reduced by about 50% when each TIGGE centre's own analysis is used instead of the ECMWF analysis, particularly in regions of large PV gradients. (iii) There is a tendency of too weak Rossby wave breaking and therefore a north-ward shift of subtropical PV streamers in the forecasts. (iv) Precipitation forecasts that are closest to the observed precipitation have the least streamer forecast errors (in position and size). The evidence suggests that the position and structural features of the PV streamer within the model has an effect on the quality of the forecasted precipitation. (v) For a heavy-precipitation case in the Mediterranean region ensemble-mean multi-model forecasts appear accurate enough for a successful severe-weather warning in contrast to some single-model EPSs. (vi) Diabatic processes upstream early in the forecasts appear to be more important than blocking downstream for strengthening subtropical PV streamers in the medium range.
The results and the analysis tools developed in these projects have improved the understanding of PV streamers and their impacts, and have advanced the verification of EPSs, which can both contribute to an improvement of numerical forecasting of high impact weather in the long term.

C-10 Evans: Clustering TIGGE forecasts for extratropical transition: A comparison study

Clustering TIGGE forecasts for extratropical transition: A comparison study

Jenni Evans

Penn State University, USA

Various clustering approaches, each with its own strengths and weaknesses, have recently been applied to ensemble forecasts for the extratropical transition of tropical cyclones. In this study, we compare four different clustering approaches for distilling TIGGE multi-model EPS forecasts of the ET of Hurricane Sandy (2012) into a reduced set of forecast scenarios. The techniques used comprise a path clustering applied to the TC track (GEO), to the temporal evolution of its structure (CPSN), and to a temporal evolution of the mid-latitude flow pattern (EOF-Path), as well as point clustering applied to the mid-latitude flow at a specific forecast time (EOF).

In this study, we (i) demonstrate how storm-focused and large-scale circulation-based clusters can distill the wealth of information provided by an ensemble forecast into a small number of meteorologically meaningful storm and synoptic evolutions and (ii) investigate the differences among the four clustering approaches in terms of ensemble membership and resulting synoptic scenarios. One of the questions addressed is whether or not the methods examined result in nearly identical cluster assignments – and thus development scenarios – or whether each clustering method captures unique divisions among ensemble members

C-11 Klocke: Scales of moisture variability and transport in an ensemble of ICON simulations with resolutions ranging from large-eddy resolving to global NWP-like

Scales of moisture variability and transport in an ensemble of ICON simulations with resolutions ranging from large-eddy resolving to global NWP-like

Daniel Klocke

Deutscher Wetterdienst, Offenbach, Germany

The variance and covariance of vertical velocity and moisture in a set of simulations with different degrees of idealization and a range of resolutions is analyzed. The modes of variability in dependence of resolution and the heterogeneity of the boundary conditions can limit the variability and lead to limitations in the interpretation of results. The simulations are compared to measurements from the HOPE campaign which took place in the west of Germany during spring 2013. A particular focus is on the ability of ICON with parametrized convection to represent the vertical moisture transport.

C-12 Selz: Simulation of upscale error growth from convection comparing high-resolution results and different convection schemes

Simulation of upscale error growth from convection comparing high-resolution results and different convection schemes

Tobias Selz, George Craig

Meteorologisches Institut, Ludwig-Maximilians-Universität München, Germany

Predictability of the atmospheric flow is intrinsically limited by upscale growing uncertainty from convection, even if the initial state was perfectly known. We investigate this process for a convective summertime weather event over Europe using a limited area model at different resolutions and different representations of convection.

First we show results from high-resolution simulations that explicitly resolve the convection. Second, by repeating these experiments at lower resolutions and using a standard convection scheme we show that the initial error growth rate as well as the eventual large-scale error reduces, indicating an intrinsic overconfidence of such model settings. Finally we demonstrate that by using a stochastic convection scheme (Plant-Craig), the upscale error growth found in the convection permitting simulations can be reproduced even with much coarser grid lengths.

These results suggest that with the Plant-Craig convection scheme the upscale effects of convective uncertainty can be reasonably well simulated without the need to resolve the convection. This opens up the opportunity to investigate the practical importance of upscale error growth in global models without the excessive computational effort of resolving convective clouds.

Abstracts of posters – PANDOWAE Final Symposium

Research Area A:

P1-1 Ruti: The World Weather Research Programme: A 10 years vision

The World Weather Research Programme: A 10 years vision

Paolo Ruti

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Weather prediction has achieved immense progress, driven by research and increasingly sophisticated telecommunication, information technology and observational infrastructure. Predictive skill now extends in some cases beyond 10 days, with an increasing capability to give early warning of severe weather events many days ahead. Ensemble methods now routinely provide essential information on the probability of specific events, a key input in numerous decision-making systems. Partly because of these advances, the needs of the users of weather services have simultaneously diversified to encompass “environmental” prediction products such as air quality or hydrological predictions.

But as the science advances, critical questions are arising concerning, for example, the possible sources of predictability on weekly, monthly and longer time-scales; seamless prediction; optimal use of local and global observing capabilities; and the effective use of massively-parallel supercomputers. The science now is primed for a step forward informed by the realization that there can be predictive power on all space and time-scales arising from what are currently poorly-understood sources of potential predictability.

WWRP, working in partnership with others will ensure the implementation of a research strategy towards the seamless prediction of the Earth system from minutes to months. Three projects will be the pillars of this strategy in the next 10 years:

• the WWRP Polar Prediction Project (PPP) that aims to promote cooperative international research enabling development of improved weather and environmental prediction services for the polar regions on time scales from hours to seasonal;
• the Subseasonal to Seasonal Prediction Initiative, a joint WWRP/WCRP (World Climate Research Programme) project, aims to improve forecast skill and enhance knowledge of processes on the subseasonal to seasonal timescale with a focus on the risk of extreme weather, including tropical cyclones, droughts, floods, heat waves and the waxing and waning of monsoon precipitation; and
• the High Impact Weather (HIWeather) project to promote cooperative international research to achieve a dramatic increase in resilience to high impact weather worldwide by improving forecasts for timescales of minutes to two weeks and enhancing their communication and utility in social, economic and environmental applications.

P1-2 Baumgart: Finite-amplitude evolution of forecast errors: Dominance of barotropic dynamics?

Finite-amplitude evolution of forecast errors: Dominance of barotropic dynamics?

Marlene Baumgart, Michael Riemer and Franziska Gierth

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Rossby wave trains (RWTs) and mid-latitude weather systems are intimately coupled. The general view prevails that RWTs exhibit a large degree of predictability that may be inherited by individual, smaller-scale weather systems. In fact, however, small forecast errors (in size and amplitude) may grow and amplify, projecting onto the scale of Rossby waves and making the reliable medium-range prediction of RWTs a challenge for operational forecast systems. Actually, "forecast busts" in Europe have been linked to the misrepresentation of the Rossby wave pattern. Many open questions exist about the dynamics of the error growth that will partly be addressed by this study.

We here focus on the amplification and upscale growth of finite-amplitude errors, say from forecast time 36h to 5-7 days. A Lagrangian PV-error tendency equation, recently derived by Davies and Didone, is evaluated to examine the error evolution. Extending Davies and Didone's framework we here quantify the contribution of different processes to forecast-error growth, specifically: (quasi-)barotropic dynamics, baroclinic interaction, upper-level divergent outflow, and diabatic modifications of PV.

Two contrasting scenarios are analysed: an Atlantic RWT leading to wave breaking over Europe and the development of a Mediterranean (tropical) cyclone, and a baroclinically-developing RWT in the North Pacific. Interestingly, it is the (quasi-)barotropic processes that dominate the error growth in both cases. In the Atlantic, the divergent flow, usually associated with latent heat release in the mid-troposphere, plays a significant role for the error evolution also, whereas the (direct) diabatic modification is less important. The secondary importance of baroclinic interaction in our quantitative analysis challenges the prevailing view that forecast error growth on the synoptic scale is predominantly associated with baroclinic instability.

P1-3 Zheng: Applying fuzzy clustering analysis to assess uncertainty and model performance in forecasting cool season high-impact weather over the U.S. east coast

Applying fuzzy clustering analysis to assess uncertainty and model performance in forecasting cool season high-impact weather over the U.S. east coast

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Cool-season extratropical cyclones near the U.S. East Coast often have significant impacts on safety, health, environment and economy to this most populated region. Hence it is crucial to forecast these high-impact weather (HIW) events as accurately as possible, including in the medium-range (3-7 days). Ensemble forecasting systems are applied in operations to show an envelope of likely solutions for HIW systems. However, it is generally accepted that ensemble outputs are underused in NWS operations partly due to the lack of verification to assess model biases and efficient tools to communicate forecast uncertainties. In this study, we have applied a fuzzy clustering tool to diagnose the performance of different modeling systems in forecasting HIW using multi-model ensembles and to communicate uncertainties.

To illustrate the application of the fuzzy clustering tool in verification and separation of scenarios, the “2015 blizzard” is first explored using the multi-model ensemble including 90-members from ECMWF, Canadian Meteorological Center and NCEP ensemble datasets. Fuzzy clustering analysis based on the Principal Components of the two leading Empirical Orthogonal Function patterns of the 1- to 6-day ensemble forecasts are computed to group ensemble members into N (in our case 5) clusters. For after the fact verification, the analysis can be included as an additional ensemble member in the computation. We then examine 60 cool season HIW cases (2008–2015) using TIGGE ensemble data to statistically assess the performance of different modeling systems in capturing the scenario that includes the analysis. In actual operational application of the fuzzy clustering tool, the ensemble mean can be included as an additional member to objectively identify members that are closest to the mean. In summary, the clustering tool can efficiently separate different scenarios in a multi-model ensemble in targeted regional domains, and can be used as a tool to assess model performance.

P1-4 Giannakaki: Forecast errors of Rosbby waveguides: An object-based spatial forecast verification tool and a short climatology of forecast errors

Forecast errors of Rosbby waveguides: An object-based spatial forecast verification tool and a short climatology of forecast errors

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The significance of upper level Rossby wave trains (RWTs) for weather forecasting has long been recognized. Moreover the existence of the upstream Rossby wave precursors to extreme weather events indicates a potential for enhanced predictability on the medium-range time-scale. Spatially localized areas of high PV gradients at the tropopause are co-located with the jet streams and can serve as waveguides for the precursor RWTs. Location or amplitude errors in the forecast of Rossby waveguides can result in inaccurate locations of RWTs and therefore a misforecast of high-impact weather events (Piaget et al., 2015). Our study is focused on the characterization of forecast errors of Rossby waveguides at the tropopause-level. We present an object based spatial forecast verification tool which compares form, amplitude and location characteristics of waveguide objects in the analysis and in the forecast. The tool can be used with any forecast and verification source. In this study the application was demonstrated using ERA-interim reanalysis and IFS forecast of ECMWF, for the time period 2008-2010 and for five different forecast lead times. Results suggest that, the IFS model underestimated the PV gradient field and the area errors increased with the forecast lead time. Location error vectors pointed to a systematic northerly bias of the waveguides in the forecast compared to ERA-interim. Easterly or westerly phase errors of the waveguides were occurred with the same likelihood.

Piaget N, Froidevaux P, Giannakaki P, Gierth F, Martius O, Riemer M, Wolf G, Grams CM. 2015. Dynamics of a local Alpine flooding event in October 2011: moisture source and large-scale circulation. Accepted in Quarterly Journal of the Royal Meteorological Society.

P1-5 Keller: Sensitivity of the downstream impact to the eddy kinetic energy budget of transitioning tropical cyclones

Sensitivity of the downstream impact to the eddy kinetic energy budget of transitioning tropical cyclones

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The extratropical transition (ET) of a tropical cyclone (TC) may strongly impact the midlatitude wave pattern by amplifying or triggering a Rossby wave train and my thus facilitate high impact weather events even in regions lying far downstream of the transitioning TC. The processes involved in the transition and interaction are often not well represented in numerical weather prediction (NWP) systems. As a result, predictability for downstream regions is frequently reduced during ET. A better understanding of the important processes and their representation in NWP systems will help to overcome those issues in predictability. Our study aims to identify the impact of a transitioning TC as an additional source of kinetic energy on the modification of the midlatitude flow and the associated forecast uncertainty. We employ ECMWF ensemble forecasts to gain multiple solutions for the interaction of two transitioning TCs with the midlatitude flow. By determining the sensitivity of the amplifying downstream wave train to the eddy kinetic energy (Ke) budget within the ensemble, we are able to identify the role of the ET in modifying the midlatitude flow configuration. Specific features of the Ke budget associated with the transitioning cyclone are found to have a significant impact on the amplification of the downstream wave train, while the Ke budget of the upstream midlatitude flow seems to be of secondary importance. We further seek to link the identified dependencies to predictability in downstream regions.

P1-6 Keller: The Extratropical Transition of Typhoon Choi-Wan (2009) and its role in the formation of high impact weather in North America

The Extratropical Transition of Typhoon Choi-Wan (2009) and its role in the formation of high impact weather in North America

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Some days after the ET of Super-Typhoon Choi-Wan (2009), significant weather events were recorded in North America. An early autumn heat wave occurred along the West Coast, with record maximum 2m temperatures in California and the Pacific Northwest. In contrast, record minimum 2m temperatures were reported from stations in Colorado, Texas and New Mexico. Additionally, some regions in the southeastern US experienced record-breaking precipitation amounts.

Previous studies indicated the potential role of the transitioning TC in amplifying the downstream midlatitude wave train. However, these studies did not investigate the relative contributions of the transitioning TC and of a frontal wave, with which the TC merged during ET, on the development in the downstream midlatitudes. By conducting PV surgery experiments with the regional COSMO model, we are able to reveal the contributions of a) the TC, b) the frontal wave and c) the merger between TC and frontal wave to the amplification of the midlatitude Rossby wave train and the associated high impact weather in downstream regions.

Our study identifies the contributions of the synoptic systems, based on the eddy kinetic energy budget. A gradual contribution is found with the merger of Choi-Wan and the frontal wave resulting in the strongest amplification of the wave train, followed by the impact solely due to the TC. The high impact weather over North America, which resulted from the strongly amplified wave train would have been less in magnitude and shifted in space without the contribution of Choi-Wan.

P1-7 Madonna: Rossby-wave forecast errors: the role of warm conveyor belt outflows

Rossby-wave forecast errors: the role of warm conveyor belt outflows

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Rossby waves are key elements in the atmospheric circulation and manifest through a ridge/trough pattern in the tropopause region. During their life-cycle they can amplify and finally break, leading to high-impact weather patterns such as the formation of stratospheric potential vorticity (PV) streamers.
The dynamics of Rossby waves can be modified by diabatic effects, for instance by latent heat release in warm conveyor belts (WCBs). Typically WCBs reach the tropopause level with low PV values (~0.5 pvu) and are able to amplify upper-level Rossby waves and contribute to the formation of PV streamers downstream.

The aim of this study is to investigate, in a case study, the relationship between errors in Rossby waves and errors in WCB outflows, using ECMWF operational analyses and high-resolution forecast with different lead times.
To evaluate forecast errors, the difference in PV on the 320-K isentrope are calculated. WCBs are identified from comprehensive trajectory calculations that select air parcels in the vicinity of cyclones with a minimum ascent of 600 hPa in 48 hours. Three aspect of WCB errors are quantified: the error in the produced PV anomaly, the error in the amount of ascending WCB trajectories and the error in the outflow location.

The results show an error in the location of the WCB outflow, which is too far to the south and the east. In addition, the PV anomaly produced by the WCB is too weak and it is related to a wrong ridge structure, where the ridge building results too weak. The findings are consistent through different forecast lead times. Moreover, similar behaviours are found in all the ECMWF ensemble members as well as in the ensemble of the Met Office Unified Model, and indicate common systematic errors across forecast systems.

The causes for the wrong ridge development are further investigated and the results are shown in Martinez-Alvarado et al. (2015) in this symposium.

P2-1 Martius: Towards understanding the mid-latitude waveguide

Towards understanding the mid-latitude waveguide

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Synoptic-scale Rossby waves are propagating around the hemispheres along their waveguides, i.e. gradients of potential vorticity (PV), through the advection of PV across the waveguides. Two points of view regarding the nature of these waveguides exist. The first viewpoint sets the waveguide equal to the PV gradient of the basic state flow. The basic state flow is defined as the time independent component of the flow and is often assumed to correspond to a low-pass filtered representation of the instantaneous flow. The second viewpoint does not distinguish between the wave and the waveguide, i.e. it is not based on a separation of the flow into a basic state and deviations therefrom. From this viewpoint the waveguide corresponds to the instantaneous PV gradients of the full PV field and these gradients are strongest and most coherent along the dynamical tropopause.

Here we try to shed some light on these dichotomous concepts. We will address questions such as: How sensitive is the first waveguide concepts to the exact definition of the background? What insights on the mechanisms of synoptic-scale Rossby wave propagation can we gain from the two points view?

To illustrate the waveguide concepts and to address these questions, a four-day period from 26 to 29 November 2008 is investigated in detail. The flow is separated into a background-state and an instantaneous deviation from the background flow. A PV inversion is performed to retrieve the flow field associated with the background PV field and the instantaneous PV anomalies. The advection of the background and the instantaneous PV field by the background flow and by the instantaneous PV anomalies are then calculated. We then discuss the contributions of these different advection terms to wave propagation.

P2-2 Pantillon: Impact of North Atlantic hurricanes on episodes of intense rainfall over the Mediterranen

Impact of North Atlantic hurricanes on episodes of intense rainfall over the Mediterranen

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A tropical cyclone that leaves the tropics can impact the weather in the midlatitudes: either directly, by transitioning into an extratropical cyclone, or indirectly, by modifying the midlatitude circulation; the cyclone can also impact the predictability of the weather in the midlatitudes. All three cases occurred for North Atlantic hurricanes during the HyMeX field campaign over the Mediterranean in Autumn 2012.

The impact of Hurricanes Leslie and Rafael is investigated in Meso-NH model runs. Control runs are compared to sensitivity runs in which the hurricanes are filtered out from the initial conditions. The hurricanes amplify Rossby wave trains and their downstream breaking, which impacts episodes of intense rainfall over the Mediterranean. However, the hurricanes decrease the intensity of the forecast rainfall.

The impact of Hurricane Nadine is investigated in the ECMWF ensemble forecast. The ensemble members are clustered into different scenarios, which reveal the crucial interaction between Nadine and a cut-off low. While the (erroneous) scenario of strong interaction predicts Nadine to be steered towards the Iberian Peninsula, the (correct) scenario of weak interaction predicts an episode of intense rainfall over the Mediterranean.

These results suggest that most North Atlantic hurricanes that leave the tropics weakly impact episodes of intense rainfall over the Mediterranean, while some hurricanes strongly impact the predictability of the episodes.

P2-3 Quandt: Predictability of the Euro-Russian block in summer 2010 regarding Rossby wave trains and wave breaking

Predictability of the Euro-Russian block in summer 2010 regarding Rossby wave trains and wave breaking

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Atmospheric blocking is linked to long lasting precipitation and temperature anomalies, which sometimes lead to high impact weather events. Even if a block can be seen as high predictable system regarding its persistent character, its onset and its decay are marked by low predictability.

TIGGE (THORPEX Interactive Grand Global Ensemble) forecasts consisting of 93 members from three EPS are used to investigate the predictability of the Euro-Russian blocking in summer 2010. This blocking event is linked to high impact weather by causing a heat wave in Russia and flooding in Pakistan. We focus on its onset, its decay and a period about one month after its onset which is characterised by low predictability of its western flank.

With the help of an empirical orthogonal function analysis and fuzzy clustering methodology the main scenarios are extracted for comparison. Moreover, the blocking index by Tibaldi and Molteni (1990) is calculated to identify the blocked latitude for certain members.

The main emphasis of the investigations is on forecast variablity of blocking regarding the different representation of Rossby wave trains and Rossby wave breaking. For blocking within the Euro-Atlantic sector, wave trains from the Pacific may strongly influence the building of the block. The direction of Rossby wave breaking is important as it effects the meridional jet displacement which can precondition the development of a block. TIGGE provides us with a large number of different scenarios that we can compare to identify the dynamical processes which are crucial to blocking life cycle.

P2-4 Riboldi: A climatological perspective on the role of the "phasing" of tropical cyclones and midlatitude flow features during extratropical transition

A climatological perspective on the role of the "phasing" of tropical cyclones and midlatitude flow features during extratropical transition

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Extratropical Transition (ET) refers to the gradual transition of a tropical cyclone (TC) into an extratropical system and the physical and dynamical processes governing the interaction of the former TC with midlatitude flow features such as upper level (UL) troughs. ET often substantially alters the hemispheric-scale midlatitude flow configuration and may trigger high impact weather locally and in downstream regions.

Previous studies based on individual (real and idealised) ET cases showed that ET is very sensitive to the phasing between the TC and midlatitude flow features. However, so far there any robust climatological study has investigated this aspect.

This project aims to give a comprehensive picture on the role of the phasing between the ET system and midlatitude flow features. Therefore a "geometrical" perspective is adopted: ET cases are classified with respect to features observed in the geometry of the large-scale flow, such as bifurcation points.

The employed technique is demonstrated with three archetypal ET cases and using ERA Interim data. Identification and tracking of trough objects allows the creation of an "ET phase space", where TC tracks are examined in a frame of reference relative to the trough propagation. Employing this technique to a larger track dataset (e.g. IBTrACS) allows a systematic investigation of the role of the phasing in the occurrence of forecast uncertainty during ET, and in triggering of downstream Rossby waves leading to high impact weather in regions far away from the actual ET event.

P2-5 Schneidereit: High impact weather over Eurasia in summer 2010: two extreme cases

High impact weather over Eurasia in summer 2010: two extreme cases

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The summer 2010 was characterised by several extreme weather events like the Russian heat wave and heavy precipitation events in Pakistan and in North China. The dynamical causes of the Russian heat wave and heavy precipitation in China are analysed in more detail using ERA-Interim re-analysis data and observations.

The heat wave in summer 2010 was characterised by a long-persisting blocking high over Russia causing severe droughts, crop loss, and numerous forest and peat fires. The blocking high occurs as an overlay of a set of anticyclonic contributions on different time scales: (i) A regime change in ENSO towards La Niña modulates the quasi-stationary wave structure in the boreal summer hemisphere supporting the eastern European blocking. On climatology, La Niña summers are characterized by an increased blocking frequency over 30°-60°E and a double jet structure, which highlight the mean influence of La Niña on summer anticyclones over the Eurasian continent. The polar Arctic dipole mode is enhanced and shows a projection on the mean blocking high in summer 2010. (ii) Together with the quasi-stationary wave anomaly the transient eddies maintain the long-lasting blocking. (iii) Three different pathways of wave action are identified on the intermediate time scale (about 10-60 days). One pathway commences over the eastern North Pacific and includes the polar Arctic region; another one runs more southward and crossing the North Atlantic, continues to eastern Europe; a third pathway southeast of the blocking high describes the downstream development over South Asia.

Northeast China had its worst seasonal flooding for a decade in August 2010. Summer precipitation is influenced by the western North Pacific subtropical high (WPSH), and is often associated with southeasterly low-level winds, transporting moist air into China. The intra-seasonal variability of the WPSH is partly affected by quasi-stationary wave trains propagating eastwards from the continent along the westerly jets. Two wave trains are important: Silk-Road wave train and the polar wave train. This analysis examines the role of the two wave trains on extreme precipitation events. There is a strong link between the Silk-Road wave train and extreme precipitation; associated with a strong occasional impact of the polar wave train during mid-August. Both wave trains modulate the northward and westward shifts of the WPSH.

P2-6 Wehner: Rossby wave trains in reforecast data: climatology of object-based ensemble spread

Rossby wave trains in reforecast data: climatology of object-based ensemble spread

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The development of mid-latitude weather systems is intimately coupled to the evolution of Rossby waves. Upper-tropospheric Rossby wave trains (RWTs) have received considerable recent attention as precursors to severe weather events. It may be assumed that the long-lived, slowly-evolving envelope of RWTs exhibits more inherent predictability than the embedded, individual weather systems. To exploit this potential predictability for weather forecasts, however, our understanding of the characteristics of, and the processes contributing to uncertainties in RWT forecasts need to be improved.

This study examines RWTs in the unique Global Ensemble Reforecast Data Set. The spread of this 11-member ensemble is used to estimate the uncertainty of RWTs in medium-range forecasts over a 30-year period. RWTs are identified as “RWT-objects” based on the envelope of the meridional wind. The objects are characterized by three attributes: amplitude, location, and spatial extent. The standard deviation of these attributes is then used to describe the spread of the RWT-objects. A general climatology of ensemble spread will be presented. To the extent that the spread derived from this specific ensemble data set represents inherent atmospheric uncertainty, the climatology may serve as a benchmark to gauge the uncertainty of future RWT ensemble forecasts. Finally, the seasonal variability of ensemble spread and the dependence of ensemble spread on the stage of the RWT life cycle will be discussed.

P2-16 Karami: Climatological probability of stationary planetary wave propagation

Climatological probability of stationary planetary wave propagation

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A novel diagnostic tool (probability of favorable propagation condition for Rossby waves) to investigate the climatology of the impact of atmospheric background condition on stationary planetary wave propagation is introduced. 50 winters (1961-2010) of both northern and southern hemispheres based on NCEP/NCAR reanalysis data are analyzed to derive the probability of favorable propagation condition for Rossby waves (〖Pr〗_Ro (y,z)). Climatological mean of vertical component of refractive index of Rossby waves are calculated to show several problematic features of this traditional tool in climatology. Afterward, Rossby waves Membership Value Function (MVF) will be introduced. This quantity estimates the likelihood for stationary planetary waves to propagate from one region to another at any time, altitude and latitude in climatological sense. Higher values of 〖Pr〗_Ro (y,z) provides a window of opportunity for planetary waves to propagate at any latitude and height. Likewise, smaller values of 〖Pr〗_Ro (y,z) demonstrate the places where Rossby waves propagate away from these regions. We also show that 〖Pr〗_Ro (y,z) based on MVF may improve our understanding of atmospheric background conditions on stationary planetary wave propagation in a climatological sense. It is only on the light of 〖Pr〗_Ro (y,z) values that we can understand the impact of meridional wavenumbers on the wave propagation in the stratosphere in climatological sense. 〖Pr〗_Ro (y,z) reveals some important effects

P3-1 Harvey: Rossby waves on a slightly-smoothed PV front

Rossby waves on a slightly-smoothed PV front

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The isentropic gradient of potential vorticity (PV) at the tropopause is typically weaker in global numerical weather forecasts than in corresponding analyses. The average gradient declines with lead time and tends towards a steady value dependent on resolution. In this paper the consequence of this systematic model error on the propagation of Rossby waves is explored. The approach taken is to analyse Rossby waves on a slightly-smoothed PV front, or `step', in a simple single-layer model. The dispersion relation for linear Rossby waves on a PV front of infinitesimal width is well known; here an approximate correction resulting from smoothing such a setup is derived.

As the PV front is smoothed, the decrease in jet speed and the decrease in wave propagation speed cancel at first order. This applies to a wide class of single-layer flows with varying range of PV inversion operator. However, the decrease in jet speed dominates at second order so that Rossby wave speeds are lower on smoother PV fronts. Estimates are made for the propagation error associated with the difference in width of the tropopause zone between typical values from analyses and 5-day forecasts. The smoother tropopause in the forecast results in phase speeds that are too slow by around 1m/s, which over a 5-day period amounts to a phase error of 400km, and group speeds that are too slow by around 2m/s.

P3-2 Barton: Temporal Clustering of Regional-scale Extreme Precipitation Events in Southern Switzerland

Temporal Clustering of Regional-scale Extreme Precipitation Events in Southern Switzerland

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Temporal clustering of extreme precipitation events on sub-seasonal time scales is of crucial importance for the formation of large-scale flood events. Here, the temporal clustering of regional-scale extreme precipitation events in southern Switzerland is studied. These precipitation events are relevant for the flooding of lakes in southern Switzerland and northern Italy. This research determines whether temporal clustering is present and then identifies the dynamics that are responsible for the clustering.
An observation-based gridded precipitation data set of daily rainfall sums and ECMWF reanalysis data sets are used. We use a modified version of Ripleys K-function to characterize temporal clustering on sub-seasonal time-scales and to determine the statistical significance of the clustering. Significant clustering of regional-scale precipitation extremes is found on sub-seasonal time scales during the fall season.
Four high-impact clustering episodes are then selected and the dynamics responsible for the clustering are examined. During the four clustering episodes, all heavy precipitation events were associated with an upper-level breaking Rossby wave over Western Europe and in most cases strong diabatic processes upstream over the Atlantic played a role in the amplification of these breaking waves. Atmospheric blocking downstream over Eastern Europe supported this wave breaking during two of the clustering episodes. During one of the clustering periods, several events of extratropical transitions of tropical cyclones contributed to the formation of high-amplitude ridges over the Atlantic basin and downstream wave breaking. During another event, blocking over Alaska assisted the phase locking of the Rossby waves downstream over the Atlantic.

P3-3 Piaget: Dynamics of a local Alpine flooding event in October 2011: moisture source and large-scale circulation

Dynamics of a local Alpine flooding event in October 2011: moisture source and large-scale circulation

Nicolas Piaget[1], Paul Froidevaux[1], Paraskevi Giannakaki[2], Franziska Gierth[3], Olivia Martius[2], Michael Riemer[3], Gabriel Wolf[3] and Christian M. Grams[1]

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Alpine heavy precipitation events often affect small catchments, although the circulation pattern leading to the event extends over the entire North Atlantic. The various scale interactions involved are particularly challenging for the numerical weather prediction of such events. Unlike previous studies focusing on the southern Alps, here a comprehensive study of a heavy precipitation event in the northern Alps in October 2011 is presented with particular focus on the role of the large-scale circulation in the North Atlantic/European region. During the event exceptionally high amounts of total precipitable water occurred in and north of the Alps. This moisture was initially transported along the flanks of a blocking ridge over the North Atlantic. Subsequently, strong and persistent northerly flow established at the upstream flank of a trough over Europe and steered the moisture towards the northern Alps. Lagrangian diagnostics reveal that a large fraction of the moisture emerged from the West African coast where a subtropical upper-level cut-off low served as an important moisture collector. Wave activity flux diagnostics show that the ridge was initiated as part of a low-frequency, large-scale Rossby wave train while convergence of fast transients helped to amplify it locally in the North Atlantic. A novel diagnostic for advective potential vorticity tendencies sheds more light on this amplification and further emphasizes the role of the ridge in amplifying the trough over Europe. Operational forecasts misrepresented the amplitude and orientation of this trough.

For the first time, this study documents an important pathway for northern Alpine flooding, in which the interaction of synoptic-scale to large-scale weather systems and of long-range moisture transport from the Tropics are dominant. Moreover, the trapping of moisture in a subtropical cut-off near the West African coast is found to be a crucial precursor to the observed European high-impact weather.

P3-4 Spensberger: Relating objectively detected jet axes, blocking and wave-breaking events

Relating objectively detected jet axes, blocking and wave-breaking events

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When detecting jets by a wind-speed threshold, information like the existence of several wind maxima is lost. We propose to identify jets based on their axes and present a new detection scheme for upper tropospheric jets which is based on a zero-wind-shear condition. We show that the new detection scheme reliably detects jet axes in instantaneous data from reanalysis data sets, as well as in weekly, or monthly averaged wind fields.

We demonstrate the dynamical implications of the detected jet axes using the synoptic evolution during the boreal winter 2013/14 as an example. This winter featured a stable high over the East Pacific, which led to anomalously cold conditions over eastern North America. Using published objective detection methods for Rossby wave breaking and dynamical blocks, we relate the detected jet axes to conceptual models describing the interplay between jet axis, wave breaking, and blocking. We show that the synoptic situation during the cold spell closely resembles the winter climatology, suggesting that only the persistence of this situation made it exceptional.

With the same tools, we furthermore discuss different dynamical interpretations of the NAO and the PNA, which are often thought to reflect variability of wave breaking and blocking. Our results support the Woollings et al high-latitude blocking interpretation of the NAO, whereas the relation between the PNA and blocking is less clear.

P3-5 Wolf: The representation of Rossby wave trains in reanalysis data and numerical weather forecasts

The representation of Rossby wave trains in reanalysis data and numerical weather forecasts

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Upper tropospheric Rossby wave trains have recently found some scientific interest, partly because of their suggested role in triggering high impact weather. However, the understanding of their dynamics is quite limited, which is somewhat surprising given their large spatial extent and occasional long lifetime. This motivated us to develop an algorithm for wave train tracking, allowing us to define wave train objects and to determine corresponding object-based errors. Also, it has recently been shown that the semigeostrophic nature of Rossby waves produces a tendency for single Rossby wave packets to fragment into several parts. Our wave train diagnostic explicitly accounts for this problem through the use of a suitable coordinate transformation.

We applied our novel method in order to compute an object-based wave train climatology for the ERA-Interim period. This provides us with statistical information about properties like duration, spatial extent, genesis regions and lysis regions.

We then used our diagnostic in order to investigate the skill of a numerical weather forecast model to predict the evolution of Rossby wave trains. It turns out that there is a systematic bias of the numerical model with a tendency to underpredict the size of a Rossby wave train. In addition, we investigated the dependence of the error on the stage of the Rossby wave train life cycle.

P3-6 Wirth: Implications of the semigeostrophic nature of Rossby waves for Rossby wave packet detection

Implications of the semigeostrophic nature of Rossby waves for Rossby wave packet detection

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Upper tropospheric Rossby wave packets have received increased attention recently. In most previous studies wave packets have been detected by computing the envelope of the meridional wind field using either complex demodulation or a Hilbert transform. The latter requires fewer choices to be made and appears, therefore, preferable. However, the Hilbert transform is fraught with a significant problem, namely a tendency which fragments a single wave packet into several parts. The problem arises because Rossby wave packets show substantial deviations from the almost-plane wave paradigm, a feature which is well represented by semigeostrophic dynamics. As a consequence, higher harmonics interfer with the reconstruction of the wave envelope leading to undesirable wiggles. A possible cure lies in additional smoothing, e.g.\ by means of a filter, or resorting to complex demodulation (which implies smoothing, too). Another possibility, which does not imply any smoothing, lies in applying the Hilbert transform in semigeostrophic coordinate space. It turns out beneficial to exclude planetary scale wave numbers from this transformation in order to avoid problems in cases when the wave packet travels on a low wave number quasi-stationary background flow.

P4-1 Quinting: A climatology of the linkage between the Madden-Julian Oscillation and midlatitude Rossby wave packets

A climatology of the linkage between the Madden-Julian Oscillation and midlatitude Rossby wave packets

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The Madden-Julian Oscillation (MJO) impacts the midlatitude flow on the synoptic- to planetary-scale.

This study focuses on the impact of the MJO on the characteristics of midlatitude synoptic-scale Rossby wave packets (RWPs) over a 30 year period. The propagation characteristics and the occurrence frequency of RWPs exhibit a significant variation with the life-cycle of the MJO. The RWP occurrence frequency increases globally, in particular over the storm track regions, when the MJO related convection is located over the Maritime Continent. The midlatitude RWP occurrence frequency is lowest at the end of the MJO life-cycle, i.e. when the MJO related convection decays east of the date line. The results indicate that planetary-scale circulation patterns which are linked to the MJO modify significantly the propagation characteristics of RWPs. When the MJO related convection is located over the Maritime Continent, a stronger jet over the Atlantic allows RWPs to propagate toward central Europe. At the end of an MJO life-cycle, a weaker North Atlantic jet allows RWPs to propagate into the subtropical east Atlantic. A systematic comparison between RWPs in a reanalysis dataset and RWPs in a reforecast dataset reveals that forecasts do not adequately represent the propagation characteristics and occurrence frequency of RWPs.

P4-2 Quinting: Rossby wave amplification through tropical cyclones: a composite potential vorticity perspective

Rossby wave amplification through tropical cyclones: a composite potential vorticity perspective

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Several recent studies have highlighted the importance of recurving tropical cyclones (TCs) in modifying the midlatitude flow and triggering Rossby waves. This study identifies processes that contribute to the development of a Rossby wave on the basis of potential vorticity composite maps for western North Pacific TCs with and without downstream development. A Helmholtz partition of the wind field enabled us to quantify the contribution of different upper-level circulation anomalies to the Rossby wave amplification. Negative potential vorticity advection through an upper-level divergent flow plays a major role in the downstream ridge amplification. Quasigeostrophic forcing diagnostics suggest that this upper-level divergent flow can be mainly attributed to convectively driven ascent within the TC and along the baroclinic zone. An upper-level anticyclonic circulation associated with the downstream ridge favors a phase locking between the TC and the upstream trough, and contributes strongest to the deepening of a downstream trough as part of the downstream development. The results of this climatological approach confirm findings of recent numerical experiments and case studies.

P4-3 Riemer: Cyclogenesis downstream of extratropical transition analyzed by Q-vector partitioning based on flow geometry

Cyclogenesis downstream of extratropical transition analyzed by Q-vector partitioning based on flow geometry

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Tropical cyclones that undergo extratropical transition (ET) may exert a significant impact on the mid-latitude circulation. Archetypical features of this impact are jet streak formation, amplification of the downstream ridge-trough couplet, and modification of downstream cyclogenesis. The evolution of the downstream cyclone plays an important role in the propagation of ET's impact into the further downstream region, where the medium-range forecast uncertainty is often increased significantly in association with ET events.

This study investigates the relative importance of the jet streak and the upper-level trough for downstream cyclone development by quantifying the respective contributions to mid-tropospheric vertical motion using the Q-vector partitioning introduced by Jusem and Atlas. Their framework partitions the Q-vector into contributions attributable to jets streaks and upper-level troughs and is here extended from quasi-geostrophic theory to Alternative Balance. The Q-vector under Alternative Balance involves the non-divergent wind, instead of the geostrophic wind, and therefore represents more accurately the balanced dynamics associated with vertical motion, in particular downstream of ET where the flow often exhibits significant curvature associated with the amplified trough.

An idealized ET scenario and three real cases, the cyclones downstream of Hanna (2008), Choi-wan (2008), and Jangmi (2009), are analysed. In all cases, the trough plays a prominent role in cyclone development. The jet streak plays a prominent, favourable role in the idealised scenario and downstream of Hanna. In contrast, the role of the jet streak downstream of Choi-wan is clearly of secondary importance. Interestingly, downstream of Jangmi the jet streak has a prominent but detrimental impact. It is concluded that amplified jet streaks associated with ET have the potential to be of significant importance of downstream cyclone development. The few cases considered in this study, however, point to a large case-to-case variability of the role of the jet streak.

P4-4 Rivière: The role of synoptic Rossby wave trains coming from the North Pacific in shaping the North Atlantic Oscillation

The role of synoptic Rossby wave trains coming from the North Pacific in shaping the North Atlantic Oscillation

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The boreal winters 2009-2010 and 2013-2014 are two contrasting winters during which the North Atlantic Oscillation (NAO) was mainly negative and positive respectively. Contrasting anomalies in the North Pacific were also present during the same periods with a straight zonal Pacific jet during the 2009-2010 winter and a strong deviation of the Pacific jet during the 2013-2014 winter. The role played by the North Pacific jet anomalies in triggering the two phases of the North Atlantic Oscillation (NAO) is investigated using a three-layer quasi-geostrophic model (QG) on the sphere and reanalysis datasets. Short-term simulations of the QG model are performed to identify the role played by the North Pacific large-scale jet in modifying the propagation of synoptic Rossby wave trains across North America and the type of breaking in the North Atlantic. In presence of a ridge anomaly in the northeastern Pacific, the Pacific jet exhibits a strong deviation which deflects the propagation of the synoptic wave trains in such a way that they mainly propagate equatorward in the Atlantic and break anticyclonically. On the contrary, in presence of a zonally-oriented Pacific jet, the wave-train propagation is more zonal, disturbances are more meridionally elongated, and cyclonic wave breaking is more frequent in the Atlantic than in the deviated jet case. The mechanism, which is based on the modification of synoptic Rossby wave trains by planetary-scale anomalies, provides a dynamical interpretation for the existence of hemispheric modes like the Northern annular mode. More specifically, it explains the relationship between the North Pacific and North Atlantic large-scale anomalies during the contrasting winters 2009-2010 and 2013-2014.

P4-5 Schneidereit: Subtropical influence on sudden stratospheric warming event of January 2009

Subtropical influence on sudden stratospheric warming event of January 2009

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In January 2009 a major sudden stratospheric warming (MSSW) event occurred with the strongest NAM anomaly ever observed at 10 hPa. Also stratospheric Eliassen-Palm flux convergence, zonal mean eddy heat fluxes of ultra-long waves at 100 hPa layer, and polar-night jet oscillations (PJO) were unusually strong in the mid-latitudes just before and after the onset of the MSSW. Beside internal interactions between the background flow and planetary waves and between planetary waves among themselves the subtropical tropospheric forcing of these enhanced heat fluxes is still an open question. This study investigates in more detail the dynamical reasons for the pronounced heat fluxes based on ERA-Interim re-analysis data. This is preparatory work for a future AGCM model study of stratospheric influence on poleward RWB and their impact on weather regimes.

Investigating the regional contributions of the eddy heat flux to the northern hemispheric zonal mean revealed a distinct spatial pattern with maxima in the Eastern Pacific/North America and the Eastern North Atlantic/Europe in that period. The first region is related with an almost persistent tropospheric blocking high (BH) over the Gulf of Alaska dominating the upper-level flow and the second region with a weaker BH over Northern Europe. The evolution of the BH over the Gulf of Alaska can be explained by a chain of tropospheric weather events linked to and maintained by subtropical and tropical influences: MJO (phase 7-8) and the developing cold phase of ENSO (La Niña), which are in coherence over the Eastern Pacific favor enhanced subtropical baroclinicity. In turn extratropical cyclone activity increases and shifts more poleward associated with an increase of the frequency of warm conveyor belts (WCB). These WCBs support enhanced poleward directed eddy heat fluxes in Eastern Pacific/North-American region. The Eastern North Atlantic/European positive heat flux anomaly is associated with a blocking high over Scandinavia. This BH is maintained by an eastward propagating Rossby wave train, emanating from the block over the Gulf of Alaska. Eddy feedback processes support this high pressure system. The evolution of these links is examined in its importance for the forcing of the MSSW 2009.

P4-6 Van Delden: Extreme south Foehn: its relation to large-scale flow

Extreme south Foehn: its relation to large-scale flow

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In this study a thirty-year record of meteorological measurements at Altdorf (Switzerland), north of the Alpine crest, serves to identify more than 1000 south foehn events. The 10% most extreme events (in terms of high wind speed) are identified as “extreme foehn events”. The synoptic-scale flow, accompanying foehn events, is investigated using the ERA-Interim reanalysis. Composites of the 500 hPa wind field during foehn events at Altdorf reveal that the Alps are consistently located under the exit region of a jetstreak (a local wind speed maximum in the jet). The composite jet flow during foehn is eastward and cyclonically curved over the Iberian Peninsula. The intensity of foehn in Altdorf is positively correlated with the intensity of the jetstreak. Extreme foehn events are also associated with a relatively large difference in sea-level pressure between the Italian side and the Swiss side of the Alps, with relatively high sea-level pressure south of the Alps. Furthermore, the right exit region of the jetstreak is located to the south of the Alps. This jet configuration seems instrumental in causing the aforementioned difference in sea-level pressure. Theoretically we expect a frontogenetically forced ageostrophic vertical circulation with a downward branch in the right jet exit region and an upward branch in the left jet exit region. This expectation is confirmed by the composite of the vertical velocity at 500 hPa for (extreme) foehn events. Large scale forced vertical motion during extreme foehn is consistently downward over the Po valley and consistently upward to the north of the Alps. Therefore, it appears that foehn is a manifestation of the surface branch of the frontogenetically forced ageostrophic circulation in the exit of a jetstreak. The Alpine crests and valleys serve to strengthen this flow.

Research Area B:

P1-8 Adler: The impact of boundary-layer processes on the pre-convective environment over the island of Corsica

The impact of boundary-layer processes on the pre-convective environment over the island of Corsica

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During the HyMeX field campaign, performed in late summer and autumn 2012 in the western Mediterranean Sea, the mobile observation platform KITcube was installed on the Corsican Island to investigate the spatial distribution and temporal evolution of water vapour over complex terrain. Humidity and its spatial variability are considered as decisive for the development of deep convection. The microwave radiometer measurements and radiosoundings, installed in the centre of the island and on the coast, are used to interpret the Integrated Water Vapour (IWV) data derived from the routine GPS network.

While the IWV data showed a similar behaviour at all sites during periods dominated by large scale events, distinctive spatial differences occurred on convective days with weak background winds. The strongest diurnal cycle was observed in the centre of the island (Corte) while the diurnal cycle was much weaker on coastal sites - especially on the western coast. Radiosounding data revealed that the spatial differences are mainly caused by thermally driven circulations, like slope and valley winds, as well as processes like topographic and advective venting.

P1-9 Martinez-Alvarado: Rossby-wave forecast errors: the influence of diabatic processes

Rossby-wave forecast errors: the influence of diabatic processes

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Rossby waves are key elements in the atmospheric circulation and manifest through a ridge/trough pattern in the tropopause region. Recent work has shown that both the amplitude of upper-level Rossby waves and the tropopause sharpness decrease with forecast lead time over several days in some operational weather forecast systems. In this contribution, the amplitude reduction of Rossby waves in forecast systems is investigated through a forecast error case study.

A companion paper by Madonna et al. shows, in this case study, that (i) the 320-K PV forecast error that develops over a five-day forecast is associated with errors in forecasts of warm conveyor belts and (ii) essentially the same error development can be found in different operational high-resolution and ensemble forecast systems. Exploiting this forecast error robustness across modelling systems, an investigation into the physical processes responsible for forecast error development was performed. This investigation was carried out through bespoke simulations with the Met Office Unified Model, enhanced with tracers of diabatic processes modifying potential temperature and PV. The process analysis consisted of a comparison between a sequence of short-range simulations, serving as a proxy to the realised flow, and a contemporaneous forecast.

The results show clear differences in the way potential temperature and PV are modified in warm conveyor belts between proxy and forecast. Further insight is obtained by comparing the effects of individual diabatic processes (e.g. radiation, convection) in the upper-level ridge development between the proxy and forecast. These results demonstrate that differences in potential temperature and PV modification in the proxy and forecast translate into very different atmospheric evolution paths, one close to reality and one far away from it. The results also highlight the uttermost importance of accuracy in the numerical representation of diabatic processes to enhance the accuracy and range of weather and climate forecasts.

P1-10 Rasp: High-resolution trajectory analysis of vertical motions in different weather situations

High-resolution trajectory analysis of vertical motions in different weather situations

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Vertical motions in the mid-latitude atmosphere occur on short time-scales (< 1 h), as a result of convective instabilities, as well as on synoptic time scales (~1 d) associated with warm conveyor belts (WCB). In this study the COSMO model at convection-permitting resolution is used together with a recently implemented online trajectory calculation module to analyze statistics of vertical motions associated with the processes mentioned above.

Three case studies were selected where different ascent characteristics are expected: one summer case (JUL), in which convective instabilities are released by frontal ascent, one winter case (JAN) of an Atlantic cyclone associated with a strong WCB and one autumn case (OCT), which contains both fast convective and slow slantwise ascent. It is found that statistics of cross-tropospheric (600 hPa) ascent times show distinct peaks depending on the synoptic situation. Convective trajectories (found in cases JUL and OCT) ascend in a few minutes while WCB-type ascent (cases OCT and JAN) occurs on time-scales of roughly one day.

Tracing of potential vorticity (PV) during the ascent shows a strong mid-tropospheric peak due to latent heat release, generating a negative PV anomaly in the tropopause region. These results confirm previous WCB studies and show this PV modification also for fast ascending convective trajectories. Results will also be presented, examining the fine-scale details of slantwise ascent, such as the possibility of embedded convection in WCBs.

P1-11 Schäfler: The mesoscale structure of WCBs during the T-NAWDEX-Falcon campaign

The mesoscale structure of WCBs during the T-NAWDEX-Falcon campaign

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The transport of water vapor in coherently ascending Warm Conveyor Belt (WCB) airstreams within extratropical cyclones governs large parts of diabatic processes in the mid-latitudes. These processes associated with latent heat release due to phase transitions of water, surface fluxes or radiative effects are highly relevant for the evolution and intensity of northern hemispheric mid-latitudes cyclones and the dynamics at the tropopause. Still, the representation of diabatic processes along WCBs is considered to be a limiting factor for the predictability of cyclones and downstream weather.

During the second phase of PANDOWAE, DLR Oberpfaffenhofen and ETH Zurich could realize an airborne field experiment that aimed at Lagrangian measurements in WCB air masses. T-NAWDEX-Falcon (THORPEX-North Atlantic Waveguide and Downstream Impact Experiment) took place over Europe in October 2012. An overview on the nine research flights that were conducted in WCBs with the aim to study the representation of WCB structures and to quantify the transport of moisture and the net latent heating along the WCBs is given. In-situ and dropsonde observations of wind, temperature and humidity are used to characterize the representation of the thermodynamic structure during different stages of the WCBs. The Lagrangian connection between the performed flights and the observed data during different stages of the WCB is discussed.

P1-12 Steinfeld: Microphysical processes leading to PV modification in diabatic Rossby waves

Microphysical processes leading to PV modification in diabatic Rossby waves

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Diabatic Rossby waves (DRW) are cyclonic vortices, i.e.. positive potential vorticity (PV) anomalies, in the lower troposphere that are continuously reproduced through thermodynamic-dynamical processes. They propagate rapidly along zones with strong baroclinicity and sufficient moisture supply. The presence of cloud diabatic processes in the DRW leads to the non-conservation of PV and to the generation of PV below the level of maximum diabatic heating and to the dissipation above it.

Here the influence of microphysical processes, e.g. the latent heating associated with the formation of clouds, on the structure of PV anomalies and the importance of moist processes for cyclogenesis is studied. A detailed case study is undertaken for one DRW that occurred in January 2013 over the North Atlantic. The project is based on a special version of the ECMWF global model (IFS) which allows for output of the heating rates due to the individual microphysical processes. By applying a Lagrangian-based trajectory analysis, the relative importance of each microphysical process is evaluated along the path of air parcels undergoing PV modification.

The trajectories revealed that air streams entering the PV anomaly, thus the DRW, mainly approach at low-levels from south and in a descending flow from northwest. The main contributions to the PV generation in the present case are from condensation, convection, depositional growth of cloud ice and evaporation of rain. The major part of the air parcels leaving the DRW ascends due to the DRW mechanism. Thereby they pass the region of the strongest latent heat release. When the trajectories are located above the maximum diabatic heating, which is mainly caused by condensation they lose their high PV values similar to the PV modification concept of warm conveyor belts (WCB). For other trajectories staying close to the surface, the latent heating rate is negative due to evaporation of rain and melting of snow. The interaction between these two airstreams caused by the sedimentation of falling hydrometeors produces regions of heating and regions of cooling and therefore a strong gradient in the diabatic heating rate. The gradient of the diabatic heating rate as well as high values of absolute vorticity in the vicinity of the DRW determine the strength of the low-level PV modification.

P2-7 Crezee: Diabatic PV anomalies related to clouds and precipitation in an idealized extratropical cyclone

Diabatic PV anomalies related to clouds and precipitation in an idealized extratropical cyclone

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Extratropical cyclones have a large impact on the weather in the mid-latitudes through the accompanying strong winds and precipitation. The formation of clouds and precipitation and subsequent phase changes like freezing, melting, sublimation and evaporation lead to distinct diabatic potential vorticity (DPV) anomalies. Positive low-level DPV anomalies - which typically are formed along the fronts and close to the cyclone center - have been shown to interact with the upper-level PV anomalies thereby potentially enhancing storm intensification. We performed idealized moist baroclinic wave simulations with an accurate representation of the different cloud microphysical processes. Through calculating backward trajectories we are able to construct a PV budget for each individual anomaly. Thereby we quantify the contributions of, e.g., cloud condensation, depositional growth of snow and melting of snow to the individual anomalies and in turn to the near-surface circulation. Both the in-cloud microphysical processes as well as the below-cloud phase changes of hydrometeors are shown to contribute significantly to the formation of DPV-related near-surface winds, which underlines the importance of the microphysical scheme for an accurate prediction of (intense) wind structures in a mid-latitude cyclone.

P2-8 Hardy: Early Evolution of the 23–26 September 2012 UK Floods: Tropical Storm Nadine and Diabatic Heating

Early Evolution of the 23–26 September 2012 UK Floods: Tropical Storm Nadine and Diabatic Heating

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Major river flooding affected the UK in late September 2012 as a slow-moving extratropical cyclone brought over 100 mm of rain to a large swathe of northern England and north Wales, with local accumulations approaching 200 mm.

The cyclone first developed on 21–22 September following the interaction between an equatorward-moving PV streamer and Tropical Storm Nadine, near the Azores. A plume of tropical moisture was drawn poleward ahead of the PV streamer over a low-level baroclinic zone, allowing deep convection to develop. Cyclogenesis initiated within this moisture plume, northeast of Nadine. The cyclone subsequently deepened further over the UK on 23–26 September as it interacted with a second PV anomaly moving southeastward from Iceland.

Convection-permitting (4-km grid spacing) simulations using the Weather Research and Forecasting (WRF) model investigate the importance of convectively-driven latent heat release, within the tropical moisture plume, to the cyclone's early development. A full-physics, control simulation accurately resolves the cyclone's development northeast of Nadine. A sensitivity simulation, in which the effects of latent heating are removed, exhibits no such development. These results indicate that cyclogenesis is strongly sensitivity to latent heat release in the moisture plume, despite the presence of the upstream PV streamer. Additional simulations reveal that condensation heating dominates relative to other microphysical processes.

The cyclone exhibits diabatic Rossby wave (DRW) characteristics, with a region of strong low-level PV generation developing and moving northeastward along a lower tropospheric baroclinic zone in a region of rich tropical moisture. Despite these criteria being met, the presence of the upstream PV streamer before cyclogenesis precludes classification as a DRW.

Further simulations, with modified initial conditions, use PV inversion to investigate the respective roles of the upstream PV streamer, and the region of lower-tropospheric condensation heating within the moisture plume, to the cyclone's subsequent evolution.

P2-9 Joos: Microphysics and its influence on large and meso-scale flow features in an extra-tropical cyclone: Comparison of two IFS simulations

Microphysics and its influence on large and meso-scale flow features in an extra-tropical cyclone: Comparison of two IFS simulations

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The influence of microphysical processes on large- and meso- scale flow features in an extra-tropical cyclone are investigated with the ECMWF global model (IFS). A control simulation with the model version operational at ECMWF during 2014 and a simulation with new parametrizations of rain autoconversion/accretion, rain evaporation and snow riming are compared in detail. In order to investigate the impact of each microphysical process separately, the diabatic heating rate (DHR) for each microphysical process is output hourly from the simulations. The associated change in potential vorticity (PV) is then calculated for each microphysical process and compared for both simulations. Firstly, the influence on the upper-level ridge building and the downstream flow evolution is investigated. The changes in the microphysical parametrization lead to differences in the position and PV values of the warm conveyor belt outflow. Although these differences are relatively small at the beginning, they strongly amplify, leading to distinct differences in the upper level PV pattern five days after the initiation of the forecast. Secondly, the effect on the low level wind field is investigated. A day into the forecast, well defined differences in the flow of up to 10 m s-1 occur along the cold front. A detailed analysis shows that the differences in the microphysics lead to differences in the associated diabatic PV production. Especially the PV modification due to condensation of cloud liquid and the evaporation of rain vary between the two simulations leading to differences in the simulated low-level PV and consequently in the low-level wind field. These results highlight the importance for a correct representation of microphysical processes for meso- and large-scale flow features. Additionally they emphasize the need for detailed microphysical measurements in extra-tropical cyclones in order to better understand and constrain the microphysical processes in NWP models.

P2-10 Pfahl: The importance of diabatic heating for atmospheric blocking

The importance of diabatic heating for atmospheric blocking

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Atmospheric blocking is a key component of extratropical weather variability and can contribute to various types of extreme weather events. Recent studies suggested that changes in blocking frequencies due to Arctic amplification and sea ice loss may enhance extreme events, but no robust blocking trends have been found in observations, and the mechanisms potentially involved in such changes are still under discussion. Here we use a 21-year climatology of blocking from reanalysis data and a Lagrangian approach to quantify the diabatic heating along the trajectories that enter the blocking. We show that 46% of the air masses involved in Northern Hemisphere blocking are heated by more than 2 K (8.5 K in the median) in the 3 days prior to their arrival in the blocking anticyclone, and this number increases to 69% when considering a 7-day period. This reveals that, in addition to isentropic advection of air with low potential vorticity, cross-isentropic ascent from lower levels due to latent heating in clouds is of first-order importance for the formation and maintenance of blocking, a process that is not considered in current theories. Amplified latent heating in a warmer climate may modify the occurrence of blocking via this mechanism.

P2-11 Schäfler: Impact of the inflow moisture on the evolution of a Warm Conveyor Belt

Impact of the inflow moisture on the evolution of a Warm Conveyor Belt

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During a THORPEX-PARC (Pacific Asian Regional Campaign) aircraft mission that was conducted east of Japan on 19 September 2008 the humidity structure in the inflow of a Warm Conveyor Belt (WCB) was observed by a high resolution Differential Absorption Lidar. The comparison of observed humidity profiles with ECMWF analysis fields showed an overestimation of the low level moisture content. To investigate the sensitivity of the forecast of the cyclone, the associated WCB and the downstream weather evolution to the diagnosed uncertainty of the moisture fields, the water vapour profiles were assimilated into the European Centre for Medium Range Weather Forecasts (ECMWF) Integrated Forecasting System (IFS). In this way the inflow moisture humidity in the analysis could be corrected.

Two ECMWF model runs are compared which are initialized from the operational observations and the analysis with additionally assimilated high resolution lidar water vapour observations. The reduced transport of moisture into the WCB affected the latent heat release along the WCB as well as the PV production at lower levels which subsequently caused a lower WCB outflow height and a reduced tropopause height. This led to a weaker ridge building and reduced jet stream wind speeds downstream. Comparisons with the operational analysis show that the better representation of the initial humidity field in the inflow region leads to an improvement of the forecast. Although the impact on the developing surface cyclone was small, improvements of the PV structure as well as of the kinetic energy could be identified.

P3-7 Binder: The role of warm conveyor belts for explosive cyclone intensification

The role of warm conveyor belts for explosive cyclone intensification

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Warm conveyor belts (WCBs) are strongly ascending, cloud and precipitation producing airstreams in extratropical cyclones. The intense diabatic heating within the ascending air leads to a modification of potential vorticity (PV), with the production of a positive PV anomaly in the lower troposphere and a negative PV anomaly in the upper troposphere. The low PV values in the WCB outflow can interact with the extratropical waveguide and thereby significantly influence the downstream flow. The low-level positive PV anomaly, in turn, can interact with the associated cyclone. However, only little is known about where - relative to cyclone center - WCB-related diabatic PV-production occurs and whether these positive PV anomalies contribute to cyclone intensification.

In this study the relationship between cyclone and WCB intensity is investigated using climatological considerations and case studies based on the ERA-Interim reanalysis data. Special focus is placed on explosively intensifying cyclones.

Results show some correlation between WCB strength and the deepening of the associated cyclone, but there is a large scatter. For the explosively intensifying cyclones two categories are distinguished, one with strong WCBs (C1) and one with weak WCBs (C2). Composites show large differences between both categories: The C1 cyclones are warm, moist and associated with strong diabatic PV production within the cyclone centre, while the C2 cyclones are cold and mainly characterised by dry dynamics. An analysis of the location of WCB ascent in category C1 shows that during the strongest intensification the major part of the WCB ascent (and diabatic PV production) occurs close to the cyclone centre, while before and afterwards the ascent occurs preferentially along the cold or slightly less frequently the warm front, far away from the cyclone centre. This points to an important role of WCB-related PV production within the cyclone centre for the explosive intensification of these cyclones.

P3-8 Boettcher: Sensitivity experiments of a diabatic Rossby-Wave with the COSMO model

Sensitivity experiments of a diabatic Rossby-Wave with the COSMO model

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Diabatic Rossby waves (DRWs) are low-tropospheric positive potential vorticity (PV) anomalies that are continuously regenerated through moist-diabatic processes, leading to a rapid propagation along a zone with increased baroclinicity. It has been shown that in some cases DRWs are important precursors for rapid cyclone development.

A DRW that occurred in December 2005 over the North Atlantic and intensified explosively after its propagation phase has been simulated and investigated with the regional COSMO model. To verify the DRW mechanism and its sensitivity due to changes in the environmental conditions of the propagating DRW, artificial sensitivity experiments have been conducted. Modifications of humidity, latent heat release, ocean evaporation and sea surface temperature were mainly carried out in predefined boxes along the DRW track for limited time periods.

While latent heat release and moisture removal lead to a weakening or dissipation of the DRW, the local suppression of the surface evaporation and the modification of the SST did hardly disturb the propagating DRW. However, the various low-level PV intensities and track positions of the DRWs resulting from the modifications led to different scenarios for the subsequent intensification, pointing to the important role of the phasing of the low- and upper-level PV disturbances.

P3-9 Čampa: PV towers and evaporative moisture sources of their diabatically produced parts

PV towers and evaporative moisture sources of their diabatically produced parts

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The development of extratropical cyclones can be seen as an interplay of three positive potential vorticity (PV) anomalies: an upper-level stratospheric intrusion, low-tropospheric diabatically produced PV, and a warm anomaly at the surface acting as a surrogate PV anomaly. In the mature stage they become vertically aligned and form a “PV tower” associated with strong cyclonic circulation. Several studies showed that the diabatic part of the tower is a very important ingredient of extremely strong cyclones.

This project investigated contributions of different PV anomalies to PV towers in cyclones in the Northern Hemisphere in a climatological sense. It has been found that the portions of PV towers vary for cyclones of different intensities, and also in different regions and seasons. The diabatically produced low-level anomaly is the strongest in the western parts of the oceans, while the stratospheric PV anomaly is more important in the eastern ocean basins.

The study also investigated the evaporative sources of moisture that was involved in PV production through condensation in these cyclones using Lagrangian backward trajectories.

The main contribution from surface evaporation to the specific humidity of the trajectories is collected 12-72 hours prior to the time of PV production. The cyclones in the eastern part of the oceans collect their moisture over a much larger area than those in the western parts. The uptake region for weaker cyclones with less PV in the centre is typically more localized with reduced uptake values compared to intense cyclones. However, in a qualitative sense uptakes and other variables along single trajectories do not vary much between cyclones of different intensity in different regions.

P3-10 Grams: Quantification of the impact of T-PARC Typhoon Jangmi (2008) on the midlatitude flow

Quantification of the impact of T-PARC Typhoon Jangmi (2008) on the midlatitude flow

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Extratropical transition (ET) of a tropical cyclone (TC) can modify the midlatitude flow and impact the weather and predictability in downstream regions. This study uses a combination of model and observational data to investigate the interaction of T-PARC Typhoon Jangmi with the midlatitude circulation in September 2008. The contribution of ET to the midlatitude flow modification is quantified with a novel PV surgery technique.

The joint interaction of the TC circulation with the midlatitude baroclinic zone and of the TC outflow with the upper-level jet results in substantial diabatically enhanced vertical transport of lower-tropospheric air that arrives tropopause level with low PV values and is further isentropically advected to the jet. This key physical process explains the ridgebuilding and the evolution of the jet streak to the Northeast of Jangmi, with upper-level PV being reduced by 6 PVU and the midlatitude jet enhanced by at least 25 m/s.

Subsequently Jangmi decayed missing a region favourable for reintensification ahead of a midlatitude trough. Relocation experiments reveal a critical bifurcation point for the track of Jangmi in the midlatitude background flow. The relative position to this bifurcation point exhibits two contrasting scenarios. Firstly, decay of Jangmi accompanied by a broad ridge over the Pacific. Secondly, extratropical reintensification accompanied by a pronounced Rossby wave train and downstream cyclogenesis.

The observed behaviour gives a simple explanation for the reduced predictability of the track and of the downstream midlatitude flow during ET and corroborates the crucial role of ET for the downstream midlatitude flow evolution.

P3-11 Grams Quantifying the midlatitude impact of extratropical transition: From case studies to a composite view

Quantifying the midlatitude impact of extratropical transition: From case studies to a composite view

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A tropical cyclone (TC) undergoing extratropical transition (ET) may interact with the extratropical flow such that a jet streak forms and an upper-level ridge amplifies. Moreover, the TC–extratropical flow interaction can amplify a Rossby wave train that disperses far downstream. Therefore, ET may cause high-impact weather in the vicinity of the ET-system and in downstream regions such as North America or Europe.
In this study we unite the case study approach with composite analysis to elucidate the general characteristics of ET and to quantify the impact of ET on the midlatitude flow evolution. Recurving western North Pacific (WNP) TCs are composited based upon the strength of the TC–extratropical flow interaction. Then the TC is removed from the composite fields using PV surgery. These modified composite fields serve as initial conditions for a simulation of the midlatitude flow evolution in the absence of ET. Comparing this “no TC” simulation against a “control” simulation allows for a quantification of the impact of ET.
Lagrangian and Eulerian analyses of the simulations corroborate previous findings that a general characteristic of ET is downstream ridge amplification and jet streak intensification via diabatic PV reduction and isentropic transport of low-PV air by warm conveyor belt-like outflow of the ET-system. Furthermore, in the presence of ET, the initial amplification of the flow pattern disperses downstream, resulting in a second even stronger ridge over the eastern North Pacific and western North America. Thus, ET over the WNP significantly influences the flow pattern downstream over North America.

P3-12 Lentink: A comparison of the structural developments of Typhoon Sinlaku (2008) and Typhoon Choi-Wan (2009) during their extratropical transitions: a modeling study

A comparison of the structural developments of Typhoon Sinlaku (2008) and Typhoon Choi-Wan (2009) during their extratropical transitions: a modeling study

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The structural changes of tropical cyclones (TCs) during extratropical transition (ET) have been investigated in several studies. Many studies used coarse resolution model data, and general processes involved in the evolution are known. Still, a lot of uncertainty can be found while forecasting ET. In this study, high resolution simulations of two different ET cases are performed, in order to get a better understanding of the interaction between the transitioning storm and the midlatitude flow. In the first place we want to examine the processes involved during ET in more detail. Secondly, we want to compare two distinct ETs and analyze the differences and similarities between the two cases.
Sinlaku (2008) was a relatively weak TC and underwent a non-characteristic ET. It re-intensified as a tropical cyclone in the course of the first ET phase before transitioning into a weak extratropical system. Choi-Wan (2009) was much stronger when it started ET. It interacted with an existing extratropical cyclone at the end of the transition and underwent rapid re-intensification.
The non-hydrostatic regional forecast model COSMO (COnsortium for Small-scale Modeling) with an horizontal resolution of 2.8 km was used to obtain simulations of both storms. The structural changes during different phases of ET will be shown, as well as the interaction with the midlatitude jet.

P4-7 Čampa: Moisture transport between Atlantic and Mediterranean regions leading to extreme precipitation and flooding event

Moisture transport between Atlantic and Mediterranean regions leading to extreme precipitation and flooding event

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Extreme weather events such as severe cyclogenesis with heavy precipitation and flash-flooding regularly affect the Mediterranean region. The orography surrounding the basin further enhances the formation of heavy rain.

In October and November 2012, during the HyMeX (HYdrological cycle in the Mediterranean EXperiment) special observation period, a series of three Mediterranean cyclones reached the Gulf of Genoa and the Adriatic area bringing large amounts of moisture in this region. They caused extreme precipitation with peaks of up to 400 mm/24 h and severe flooding events with considerable damage and casualties. This study focuses on transport of moisture involved in heavy precipitation.

A Lagrangian trajectory analysis has shown large amounts of moist air arriving from 2 sources in the Atlantic, one associated with an atmospheric river along the western African coast and the other associated with a cyclone entering the Mediterranean from the Atlantic and later a large scale trough situated over western and central Europe. For one of the events occurring shortly after a strong mistral event, the Mediterranean was identified as the most important source. The most extreme precipitation occurred after the interaction of the moist air with the Alps and the Apennines. Data collected during Hymex (buoys, pressurized balloons, radiosondes and rain gauges) help to characterize the involved air masses.

Furthermore, the transport of moisture, which evaporated from the Mediterranean, is investigated on the climatological basis. The results show that Mediterranean evaporation is especially important for precipitation in the northern Africa, however the moisture reaches all over Europe and near east.

P4-8 Corsmeier: Humidity Transport Pathways and High Precipitation Events within Mediterranean Cyclones – A HyMeX case study

Humidity Transport Pathways and High Precipitation Events within Mediterranean Cyclones – A HyMeX case study

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Synoptic-scale weather systems are responsible for the main part of the three-dimensional water transport in the mid latitudes. The water transport within and into the Mediterranean region is of high importance, because it can play a crucial role in producing high precipitation events (HPE) with subsequent damage and loss of lives.

This case study examines characteristic but different humidity transport pathways linked to low pressure systems over the western Mediterranean during HyMeX IOPs 8 and 19 using Lagrangian trajectories as described by Wernli and Davies (1997). In both cases, very high amount of precipitation was observed, widespread about 100 mm, locally up to 250 mm within 24 hours, but the moisture uptake areas of the air incorporated in the lows and the respective moist air pathways were very different. The trajectory analysis shows considerably more details with respect to diabatic process understanding than classical Eulerian weather charts do. The changing regions of humidity origin were localized, their areal extent, the speed of ascent of the air masses, the phase transformations along the path and subsequent precipitation were calculated and compared with observations. It gets obvious, that between large scale and longtime slow ascent (lifting) and small scale, short time rapid ascent (convection) a large variety of vertical motion exists. It was distinguished between convective and advective moisture transport and intermediate hybrid types of vertical motion and the resulting effects on precipitation pattern. While the convective transport and locally restricted forced lifting was most important during IOP 8 downstream a slow moving cut-off low over Spain, the moist air was slowly and persistently rising along a large scale trough during IOP 19. Embedded convection is seen as an important process for HPE because of the different processes amplifying lifting on different scales.

P4-9 Grams: The Central European floods in June 2013: the role of "preconditioning" and warm conveyor belts

The Central European floods in June 2013: the role of "preconditioning" and warm conveyor belts

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In June 2013 Central Europe was hit by a century flood affecting the Danube and Elbe catchments after a 4-day period of heavy precipitation and causing severe human and economic loss. In this study model analysis and observational data are investigated to reveal the key atmospheric processes that caused the heavy precipitation event. The period preceding the flood was characterised by a weather regime associated with cool and unusual wet conditions resulting from repeated Rossby wave breaking (RWB) in Europe at the downstream side of an Atlantic blocking ridge and the upstream side of a Scandinavian blocking ridge. The RWB events lead to unusually high accumulated rainfall amounts in many parts of Europe in the two weeks prior to the event. During the event a single RWB established a reversed baroclinicity in the low to mid troposphere in Central Europe with cool air trapped over the Alps and warmer air to the North. The upper-level cut-off resulting from the RWB instigated three consecutive cyclones in eastern Europe that unusually tracked westward during the days of heavy precipitation. Continuous large-scale slantwise ascent in warm conveyor belts (WCBs) associated with these cyclones is found as the key process that caused the 4-day heavy precipitation period. Fed by moisture sources from continental evapotranspiration, these WCBs unusually ascended equatorward along the southward sloping moist isentropes. Although such equatorward ascending WCBs are climatologically rare events in Europe, they have great potential for causing high impact weather.

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P4-10 Röhner: Model study of a Mediterranean heavy precipitation event during the HyMeX campaign

Model study of a Mediterranean heavy precipitation event during the HyMeX campaign

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High impact weather events in the western Mediterranean basin can provoke locally high precipitation rates which cause floods and landslips. These events mostly occur from September to November. In autumn 2012 the international field campaign HyMeX (Hydrological cycle in Mediterranean Experiment) took place in the western Mediterranean. It provides a wide dataset to study heavy precipitation events. At 28 September 2012, a very prominent mesoscale convective system - causing huge damage and several casualties - affected the Spanish Mediterranean coast.
To asses the importance of diabatic processes on amount and distribution of precipitation over the Spanish landmass and over the Mediterranean Sea, we performed a high resolution run of the German COSMO (Consortium of small scale modeling) model (grid size of 2.8km) for this HyMeX case. The simulation was validated with HyMeX data, gained by raingauges, surface stations and radar systems. To investigate the interaction between moist processes and large-scale dynamics, lower and upper tropospheric atmospheric environments were studied. A horizontal wind convergence and the Spanish orography led to the initiation and development of heavy precipitation for this HyMeX case.
To investigate the predictability of the heavy precipitation event, an ensemble analysis was performed with COSMO (grid size of 7km). With a synoptic-scale ensemble, an ensemble with perturbations in physical parameters, as well as with an ensemble considering both kinds of uncertainties, the relative roles of different spacial scales in limiting the predictability of the heavy precipitation are investigated. For two of the ensembles, the recently developed stochastic cumulus convection scheme Plant-Craig was deployed. With this method, we want to show that the natural variability of convective clouds can be reproduced in a numerical weather prediction model, which might lead to an improved forecast of heavy precipitation events.

P4-11 Weijenborg: Coherent PV anomalies associated with (extreme) deep moist convective cells

Coherent PV anomalies associated with (extreme) deep moist convective cells

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The WEX-MOP project aims at a next generation ensemble prediction system for the mesoscale. One goal of WEX-MOP is to quantify the role of conserved quantities during extreme convective weather. Conserved variables might offer new insight in the predictability of those events. An important conserved quantity is potential vorticity (PV), a fundamental property of the atmospheric flow on synoptic and planetary scales. However, investigations thereof on the atmospheric mesoscale are relatively new. PV has a close relation to rotation and balance, which is important in storm dynamics. Here we characterise the evolution of storm cells in terms of PV to provide new insights into storm dynamics.

Tracking of storm cells has been frequently performed using radar and/or satellite data. It received less attention using model data. We present storm cell tracks for 6 cases of severe convection in 2011, 2012 and 2013 simulated using the non-hydrostatic COSMO-DE weather model. The cases are selected with a different synoptic background, i.e. different background shear and CAPE. For each of the cases vertical velocity maxima are tracked. Composites of the typical evolution of a storm cell are made.

There is a relatively large variability between the characteristics of individual cells. However, the PV dipole associated with the storm updraft is clearly visible in the composites. When we cluster on the strength of CAPE, the differences between the composites with large and small CAPE values are small. However, clustering on other intensity measures like PV, vertical velocity or precipitation rates gives, for intense cells, composites with a supercell structure i.e., a relatively strong rotating updraft. The results show that PV, unlike CAPE, might be a good predictor for intense convective cells, and motivates the use of PV on smaller scales.

Research Area C:

P1-13 Berner: Increasing the skill of probabilistic forecasts: Understanding performance improvements from model-error representations

Increasing the skill of probabilistic forecasts: Understanding performance improvements from model-error representations

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Four model-error schemes for probabilistic forecasts over the Contiguous United States with the WRF-ARW meso-scale ensemble system are evaluated in regard to performance. Including a model-error representation leads to significant increases in forecast skill near the surface as measured by the Brier score. Combining multiple model-error schemes results in the best-performing ensemble systems, indicating that current model error is still too complex to be represented by a single scheme alone.

To understand the reasons for the improved performance, it is examined whether model-error representations increase skill merely by increasing the reliability and reducing the bias- which also could be achieved by postprocessing - or if they have additional benefits.

Removing the bias results overall in the largest skill improvement. Forecasts with model-error schemes continue to have better skill than without, indicating that their benefit goes beyond bias-reduction.

Decomposing the Brier score into its components, we find that in addition to the spread-sensitive reliability, the resolution component is significantly improved. This indicates that the benefits of including a model-error representation go beyond increasing reliability. This is further substantiated when all forecasts are calibrated to have similar spread.The calibrated ensembles with model-error schemes consistently outperform the calibrated control ensemble.

Including a model-error representation remains beneficial even if the ensemble systems are calibrated and/or debiased. This suggests that the merits of model-error representations go beyond increasing spread and removing the mean error and can account for certain aspects of structural model uncertainty.

P1-14 Brundke: Stochastic perturbations to represent effects of subgrid-scale orography on convective initiation

Stochastic perturbations to represent effects of subgrid-scale orography on convective initiation

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The forecast of high-impact weather in situations with weak large-scale forcing still poses problems, since convection is often triggered too late in numerical weather prediction models. A reason for this seems to be missing small-scale variability in the atmospheric boundary layer. Several physical processes are relevant in the development of this variability, e.g. the effects of orography.

In this study, we focus on the mechanical effect of subgrid-scale orography (SSO) on the flow. The study is conducted within the framework of an existing stochastic boundary layer perturbations scheme. Two high-resolution SSO data sets (30 arcsecond and 1 arcsecond) are applied to derive the parameters describing SSO within the COSMO-DE model (2.8 km horizontal resolution). They are used to formulate stochastic perturbations representing the variability caused by SSO. We assume that convection is initiated earlier and hence more precipitation is observed in mountainous areas. The impact of the perturbations is quantified in comparison with unperturbed reference COSMO-DE simulations and observations for several quantities and quality measures.

P1-15 Harnisch: Potential of SEVIRI satellite observations for convective-scale ensemble data assimilation

Potential of SEVIRI satellite observations for convective-scale ensemble data assimilation

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The limited predictability of convective systems requires the assimilation of frequent and spatially dense observations in convective-scale data assimilation systems. Measurements from geostationary satellites are therefore a potentially powerful data set. So far, mainly variational methods have been used to assimilate radiances, while using radiances in ensemble data assimilation is still in its infancy. Clear-sky infrared channels are used successfully in several modelling systems, but assimilating cloud-affected data poses significant challenges.

To facilitate the direct assimilation of MSG SEVIRI observations in the experimental km-scale ensemble data assimilation (KENDA) system of Deutscher Wetterdienst (DWD), a variety of problems need to be addressed. These are, among others, accurate and fast forward operators, an effective treatment of clear-sky and cloudy areas and the correction of systematic differences between observations and model equivalents. A new fast forward operator for visible and near-infrared reflectance observations is currently in development. The operator relies on a look-up table based method that is sufficiently accurate and orders of magnitude faster than conventional radiative transfer solvers for the visible spectrum.

KENDA assimilation experiments are performed with visible and infrared SEVIRI channels.
First results show, that assimilating visible reflectance information can improve the cloud fields and also the humidity analysis. To successfully assimilate infrared brightness temperatures, apparent biases, which are cloud-dependent, need to be corrected. The largest impact of the infrared data is again connected to the water vapor and cloud fields.

P2-12 Kyouda: Predictability of wintertime East-Asian weather regimes in medium-range forecasts

Predictability of wintertime East-Asian weather regimes in medium-range forecasts

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A weather regime is a persistent and/or recurrent large-scale atmospheric flow circulation pattern which is associated with specific weather conditions on a regional scale. Accurate simulations of weather regimes are important in weather and climate predictability. The classification of East-Asian (20-60˚N, 100-170˚E) weather regimes in winter (November-March) are conducted using the ERA-Interim data. The winter (W), Western Pacific (WP), high (H), low (L), and deep west trough (DWT) flow-patterns are detected as weather regimes. The predictability of the flow-patterns is investigated in the periods 2006/07-2013/14 and 1985/86-2013/14 using The International Grand Global Ensemble (TIGGE) and NOAA's Global Ensemble Forecasting System (GEFS) reforecast datasets, respectively. In the TIGGE data, we focus on five of the leading operational Numerical Weather Prediction (NWP) centres: CMC, ECMWF, JMA, NCEP, and UKMO. The NOAA's reforecast data have been produced with a fixed NWP system, whereas the TIGGE data have been produced with a various series of each NWP system. Comparison of probability matrices for regime transitions reveals that the NWP systems have the same preferred circuit (routed from/to L through W or WP, H, and DWT) but show some differences in expected flow-pattern frequency by the Markov chain of regime transitions. These results suggest that NWP skill for wintertime East Asia depends on weather regimes. In addition, comparison of NWP forecast scores shows that the skills of the forecasts initiated in H are lower than the averaged skill regardless of forecasted flow-patterns, and the skills to predict WP or L, especially transition from L or WP to WP, are higher.

P2-13 Maranan: Object-Based Verification of Tropical Precipitation Forecasts During the YOTC-Period

Object-Based Verification of Tropical Precipitation Forecasts During the YOTC-Period

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This study focuses on the development of forecast errors in the ECWMF Integrated Forecast System by investigating the representation of tropical convection during the YOTC period. Operational 5¬-day forecast runs are verified against precipitation estimates of the Tropical Rainfall Measuring Mission (TRMM) using two kinds of verification methods, an object-based and an field based approach. These approaches were applied on different regions in the Tropics (Maritime Continent, Africa, Central Pacific) to account for the diverse precipitation regimes.

The analyses suggest that the growth of the overall forecast error is due to an increasing bias towards higher domain-averaged precipitation amounts relative to the observations over lead time in all investigation areas. Object-based examinations show an increase in size of the convective systems over lead time while their intensity remain rather constant, indicating that the evolution of the forecast error is mostly controlled by the former. A significant diurnal cycle in displacement and intensity error is identified and can be attributed to a wrong representation of the diurnal cycle of convection where rainfall peaks about 3 – 4.5 hours too early in the model. This is the case for convection both over land and ocean. Furthermore, in all investigation areas the intensity error is largest during the first 24 hours and exhibits a sharp drop afterwards which hints on the existence of a spin-up problem.

P2-14 Saffin: The Attribution of Potential Vorticity Sources in a Numerical Weather Prediction Model

The Attribution of Potential Vorticity Sources in a Numerical Weather Prediction Model

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Numerical models of the atmosphere can be considered as the combination of a dynamical core, which solves the adiabatic and frictionless primitive equations, combined with modifications from parametrised physical processes. In terms of potential vorticity (PV), the dynamical core handles PV advection and the parametrisations modify PV along a trajectory. This allows us to partition PV into a set of tracers and assess the effects of each parametrisation scheme. These PV tracers are implemented in the Met Office's Unified Model (MetUM). Errors in parametrisation schemes will lead to forecast errors. By using PV tracers the cumulative model error could be linked to physical processes. However, quantification reveals that the full model PV cannot be fully described by conservative advection plus the modifications from parametrised physical processes. It is shown that inconsistency between tracer advection of PV and the dynamical core, which does not explicitly conserve PV, can cause errors of comparable magnitude to the physical process PV tracers. Analysis using trajectories shows that this inconsistency is mostly attributable to the dynamical core not conserving PV, with the effect of implicit diffusion on tracer advection having a slower timescale. This allows us to consider a PV tracer for the modification of PV by the dynamical core. The inclusion of this dynamical PV tracer reduces the error in the PV budget by an order of magnitude and is shown to have systematic effects on the tropopause PV structure. The implication of this work is that the consistency of a dynamical core, in terms of PV, can be assessed in non-idealised situations and that systematic model errors due to the dynamical core can be compared with those from parametrisation schemes using PV tracers. Results will be shown using simulations of case studies from the DIAMET project.

P2-15 Klocke: Predictability of the Typhoon Haiyan with the new weather forecasting model ICON

Predictability of the Typhoon Haiyan with the new weather forecasting model ICON

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Typhoon Haiyan made landfall on 8. November 2013 in the Phillipines with devastating effects. Storm warnings played a crucial role. The purpose of our work is to investigate how a new weather forecasting model (the German ICON model) is representing this typhoon in terms of initial condition and model physics. To investigate predictability the ICON model is initialized with 26 members of the ECMWF ensemble data assimilation (EDA) system at 32km resolution and 40 members of the ICON EDA system at 40km resolution. To investigate the dependence of model error on the physics we apply different physics packages (a TKE closure versus the DUALM-EDMF boundary layer cloud approach). Physical tendencies are analyzed to understand the interaction of transport at the extreme physics of a typhoon. Additionally, we run the ICON model at 40km, 20km and 10km globally and nested to 5km and 2.5km to investigate how simulations at low resolutions with convection parameterization can compete with convection resolving simulations. Generally, the ICON model is able to represent the track as well as the minimum pressure with reasonable accuracy.

P3-13 Keller: Predicting the MJO at various resolutions with the new global model ICON

Predicting the MJO at various resolutions with the new global model ICON

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The capability of the new ICOsaheadral Non-hydrostatic global model ICON in representing the MJO is investigated. ICON is a joint development of German National Meteorological Service (DWD) and Max-Planck Institute for Meteorology (MPI-M). Its modelling framework allows for numerical weather prediction and climate simulations across a broad range of scales, down to a convective permitting resolution. Regional grid refinement and two way nesting enables us to consider particular regions, e.g. areas of active tropical convection with an increased resolution.

To assess the ability of ICON in developing tropical circulations and especially the MJO, 5-year climate simulations with monthly updated SST and SI are conducted at 80, 40 and 20km horizontal resolution. An evaluation of the resulting of climatological distributions for precipitation and OLR, as well as an investigation of the tropical circulations in wavenumber-frequency spectra reveal the capability of ICON in developing MJO and other tropical waves to various degrees. The impact of the resolution used and other aspects of the model setup will be addressed in this presentation. We will also compare our results with simulations from other global models.

The performance of ICON in predicting a particular MJO event through its life cycle is demonstrated by conducting 10-day NWP forecasts with 20km resolution that are initialized prior and during the major MJO event in Feb/Mar 2012. While the model encounters some difficulties when the active convection crosses the Maritime Continent, the large scale circulation features, like horizontal wind at various levels are captured well, especially once the MJO was already active at initialization time. An outlook will be given on the potential benefit of local grid refinement.

P3-14 Keller: Characteristics of TIGGE in representing forecast variability associated with extratropical transition

Characteristics of TIGGE in representing forecast variability associated with extratropical transition

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The characteristics of the extratropical transition (ET) of tropical cyclones and its impact on the midlatitude flow are examined in the THORPEX Interactive Grand Global Ensemble (TIGGE) multimodel ensemble prediction system (EPS). Ten ensemble forecasts initialized prior to ET for five tropical cyclones in 2008 are investigated using an empirical orthogonal function analysis and fuzzy clustering methodology. Each forecast contains 231 members from eight different global EPS. The EPS contributing to TIGGE differ in their spread and their contributions to the different scenarios. Some of the individual EPS are generally confined to only a few scenarios, whereas others contribute regularly to almost all. TIGGE contains more development scenarios than European Centre for Medium Range Weather Forecast (ECMWF) EPS but the full range of development scenarios is only found with the ECMWF included in the multimodel EPS. By comparing the development scenarios with the corresponding analysis it can be shown that in some of the cases the multimodel approach is necessary to get the analysed development included in the ensemble forecast.

P3-15 Meng: Ensemble sensitivity analyses on the high-impact extreme rainfall event in Beijing on 21 July 2012

Ensemble sensitivity analyses on the high-impact extreme rainfall event in Beijing on 21 July 2012

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On 21 July 2012, a record-breaking extreme rainfall event happened in Beijing, China. The maximum 24-h rainfall between 00Z 21 July to 00Z 22 July reached 460 mm. The heavy rainfall caused severe flooding and debris flow, which killed 79 people in Beijing area. Observational studies showed that this heavy rainfall event was likely caused by a low-level vortex and an MCS triggered by the vortex. Interestingly, almost all operational or research models predicted a rainfall with a time lag of 6-h late and a much less magnitude. In this work, the performance of TIGGIE operational ensemble forecasts were examined. They were also used to explore the main factors that may have contributed to the disatrous heavy rainfall.

The performance of ensemble forecast produced by NCEP, ECMWF and CMA were compared. Results showed that the NCEP ensemble forecast did a better job for this event. Some members even captured the extremly high rainfall at a quite small timing and magnitude error. Results also showed that the forecast performance was not very consistent among different lead times. A forecast made 3-days ahead was more accurate than that with a shorter lead time.

ECMWF ensemble forecast, which has 60 members thus is useful for sensitivity analyses, was used to perform time-lag correlation analyses between the 24-h rainfall and various features at the initial time. Results showed that the depth of the westerly trough and the associated low-level cyclonic vortex was the dominant factors for the occurance of the extremely high rainfall event.

P4-12 Keil: Impact of different sources of uncertainty in convective-scale EPS

Impact of different sources of uncertainty in convective-scale EPS

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The effective representation of the sources of uncertainty in convective-scale EPSs is a crucial but largely open issue. A common approach to account for initial condition (IC) uncertainty in high-resolution EPSs is based on dynamical downscaling of an ensemble of coarser-resolution driving (global) model forecasts. The downscaling approach is attractive due to its relative simplicity and practicality of implementation (and is used in COSMO-DE-EPS at Deutscher Wetterdienst). However, the downscaling approach cannot comprehensively address IC uncertainties at the scales represented by the high-resolution EPSs.

One novel approach to account for IC uncertainty in convective-scale EPSs offers thecombination with ensemble data assimilation methods. The novel kilometer-scale ensemble data assimilation (KENDA) system for the COSMO model is based on a Local Ensemble Transform Kalman Filter and provides, in principal, an analysis ensemble that can be used to initialise convection-permitting ensemble forecasts.Error sources in the model formulation inevitably result in a systematic underestimation of variances cycled in ensemble data assimilation. Inflation methods and stochastic physics represent different techniques to enhance ensemble variance and improve forecast quality.

Results gained with operational COSMO-DE-EPS forecasts and experimental ensemble forecasts based on KENDA-COSMO address these issues and highlight the role of different realizations of uncertainty.

P4-13 Khodayar: HPE environment in comparison to the seasonal mean conditions in the WMED

HPE environment in comparison to the seasonal mean conditions in the WMED

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Among all severe convective weather situations, fall season heavy rainfall represents the most threatening phenomenon in the western Mediterranean region. Devastating flash floods occur every year somewhere in eastern Spain, southern France, Italy, or North Africa, being responsible for a great proportion of the fatalities, property losses, and destruction of infrastructure caused by natural hazards. Investigations in the area have shown that most of the heavy rainfall events in this region can be attributed to mesoscale convective systems.
The main goal of this investigation is to understand and identify the atmospheric conditions that favor the initiation and development of such systems. Insight of the involved processes and conditions will improve their predictability and help preventing some of the fatal consequences related with the occurrence of these weather phenomena. The HyMeX (Hydrological cycle in the Mediterranean eXperiment) provides a unique framework to investigate this issue.
Making use of high-resolution seasonal simulations with the COSMO-CLM model the mean atmospheric conditions of the fall season, September, October and November, are investigated in different western Mediterranean regions such as eastern Spain, Southern France, northern Africa and Italy. The precipitation distribution, its daily cycle, and probability distribution function are evaluated to ascertain the similarities and differences between the regions of interest, as well as the spatial distribution of extreme events. Additionally, the regional differences of the boundary layer and mid-tropospheric conditions, atmospheric stability and inhibition, and low-level triggering are presented.
Selected high impact weather HyMeX episodes are analysed with special focus on the atmospheric pre-conditions leading to the extreme weather situations. These pre-conditions are then compared to the mean seasonal conditions to identify and point out possible anomalies in the atmospheric conditions which could favor the initiation and intensification of extreme precipitation weather events. This study gives an overview of the main low-level characteristics of the environment of HPE just before the onset of the precipitation system, during the event, and just after dissipation. Common mesoscale features have been identified which drive the HPE events, such as high values of IWV and CAPE over the sea, as well as fast low-level winds. The atmospheric water vapour is shown to play a key role in the initiation and intensification of intense precipitation events. The topography of the area concentrates high humidity values over land favouring HPE.

P4-14 Weissmann: Ensemble-based estimates of observation impact

Ensemble-based estimates of observation impact

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Knowledge on the contribution of various observations and observing systems is crucial for the refinement of observing networks and data assimilation systems. This poster presents a novel approach for estimating observation impact in ensemble-based data assimilation and forecasting systems and its application to the experimental, convective-scale ensemble system of Deutscher Wetterdienst. Instead of the subsequent analysis, it uses subsequent observations for verification that are considerably more independent from the forecast. Furthermore, a peculiar property in the probability distribution of observation impact is used to define a measure for the accuracy of the impact assessment. Applying this method to a three-day test period shows that a well-defined observation impact value can be assigned to most observation groups.

P4-15 Yamaguchi: Global distribution of the skill of tropical cyclone activity forecasts on short- to medium-range time scales

Global distribution of the skill of tropical cyclone activity forecasts on short- to medium-range time scales

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Operational global medium-range ensemble forecasts of tropical cyclone (TC) genesis and the subsequent track (TC activity) are systematically evaluated to understand the skill of the state-of-the art ensembles in forecasting TC activity as well as the relative benefits of a multi-center grand ensemble with respect to a single-model ensemble. The global ECMWF, JMA, NCEP, and UKMO ensembles are evaluated from 2010 to 2013 in seven TC basins over the world. The verification metric is the Brier Skill Score (BSS), which is calculated within a 3-day time window over a forecast length of two weeks to examine the skill from short- to medium-range time scales.

These operational global medium-range ensembles are capable of providing guidance on TC activity forecasts that extends into week 2. Multi-center grand ensembles (MGGEs) tend to have larger BSSs than the best single-model ensemble, which is the ECMWF ensemble in most verification time windows and most TC basins. The relative benefit of the MCGEs is relatively large in the North Indian Ocean and TC basins in the Southern Hemisphere where the BSS of the single-model ensemble is relatively small. The BSS metric and the reliability are found to be sensitive to the choice of threshold wind values that are used to define the model TCs.