SPECIAL PROJECT FINAL REPORT

Project Title:	Impact of blocking and tropical-extratropical interactions on predictability in the Atlantic-European Sector
Computer Project Account:	spdeet
Start Year - End Year :	2012 - 2014
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Summary of project objectives

In the project we use medium range ensemble forecasts of the TIGGE ensemble to investigate the dynamical processes involved in the onset and the decay, the predictability and the impact of blocking.
The impact of extratropical transition (ET) events on the downstream midlatitude flow is quantified from a climatological perspective using ERA-Interim reanalyses. Eddy-kinetic-energy budgets and ensemble sensitivity analyses help to identify dynamical processes that are relevant to the midlatitude flow amplification through the ET of tropical cyclones. The relative role of initial perturbations and stochastic physics in the ECMWF EPS during ET events is analysed.
The linkage between the Madden-Julian Oscillation (MJO) and midlatitude synoptic-scale Rossby waves is investigated using ERA-Interim reanalyses. The high performance computing facilities provided by ECMWF were used to analyse the representation of the MJO in the global model ICON.

Summary of problems encountered

No problems encountered.

Experience with the Special Project framework

The experience with the Special Project framework was excellent.

Summary of results

1. **Impact of blocking on the predictability in the Atlantic-European sector**

   The onset and the decay period of an atmospheric blocking system is characterised by low predictability. As atmospheric blocking may cause high impact weather, there is a special interest in improving its predicitability and the understanding of the physical processes related to it.

   In our studies, we focus on the blocking high that led to a heat wave in Russia in summer 2010. We use TIGGE ensemble forecasts which consist of 93 members from three different EPS (ECMWF, NCEP and MetOffice). With the help of an EOF and Clustering methodology we can investigate the variability of the ensemble forecasts and extract the main development scenarios for comparison. To identify the blocked latitude for certain members, the blocking index by Tibladi and Molteni (1990) is calculated. The impact of the blocking high is shown by the temporal evolution of the 2m temperature averaged over a box around Moscow (35°-55°E and 50°-60°N) and by the distribution of the temperature field itself.

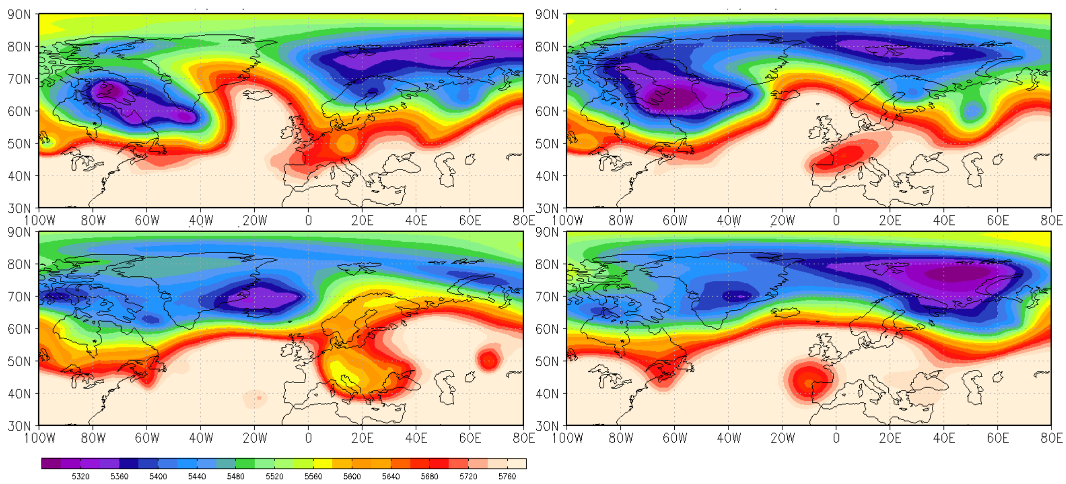

Fig 1. 500 hPa geopotential height [in gpm] at +96 hours (top) and at +168 hours (bottom). With blocking at 40°E (left) and without blocking (right).

For the onset period we used a forecast which was initialised on June 14, 2010 at 12 UTC. Two main scenarios were compared whereas we have one case showing the onset correctly and another one in which the block is not built up (Fig 1). Before the analysed onset of the blocking system, it can be observed that a poleward Rossby wave breaking event over the Atlantic develops differently. It seems that the onset is dependent on the shape, intensity and direction of the breaking wave. The impact of the blocking high can be clearly seen in the temperature at 2 m (Fig 2). Without blocking, the temperature fluctuates around 18°C during the investigated period, but with blocking the temperature clearly increases.

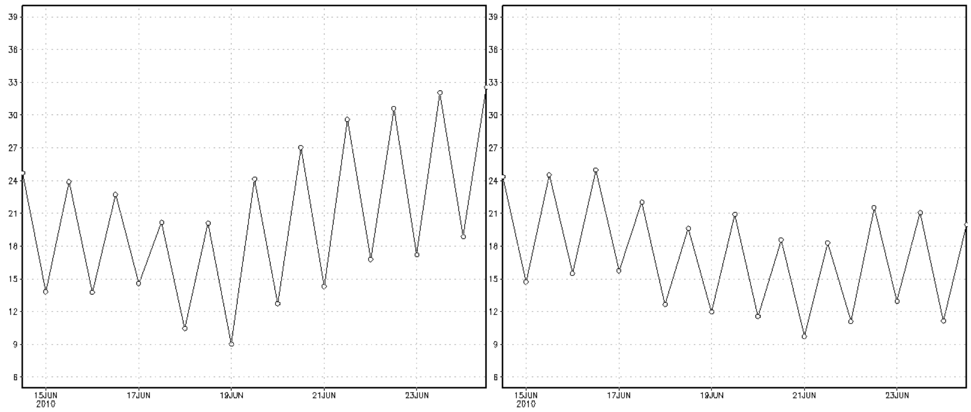

Fig 2. Time evoultion of the spatial average (35°-55°E and 50°-60°N) of the 2 m temperature (°C) with (left) and without (right) blocking onset.

In Addition, our studies indicate that the probability for the onset is dependent on the forecast initialisation time. For the TIGGE, ECMWF and the NCEP EPS the probability of forecasting the onset correctly increases as the initialisation time approaches the actual onset of the blocking (Fig 3). However, such behaviour is not found for the MetOffice EPS.

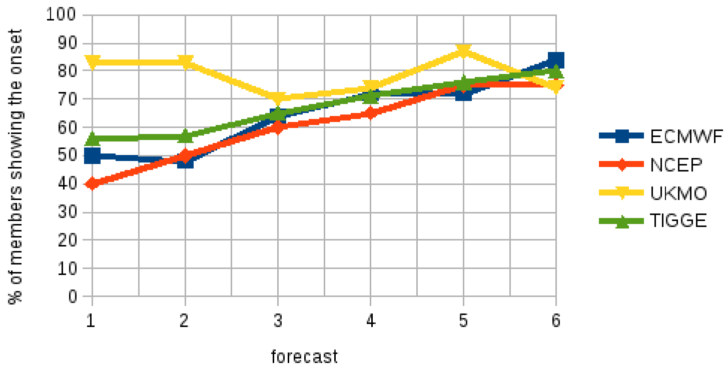

Fig 3. Probability for the onset for ECMWF, NCEP, TIGGE and MetOffice ensemble dependent on forecast initialisation time (1: 2010/06/13 00 UTC – 6: 2010/06/15 12 UTC, 12 hours interval).

To investigate the decay phase of the block, we used a forecast initialised on August 10, 2010 at 12 UTC. Some forecast members capture the decay whereas some others do not (*Fig 4*). For the case that the block still exists, higher temperature values can be found futher north in comparison to the case in which the decay is forecast correctly. The decay seems to be influenced by the dominance of a low pressure system which developed northeast of the blocking high (not shown).

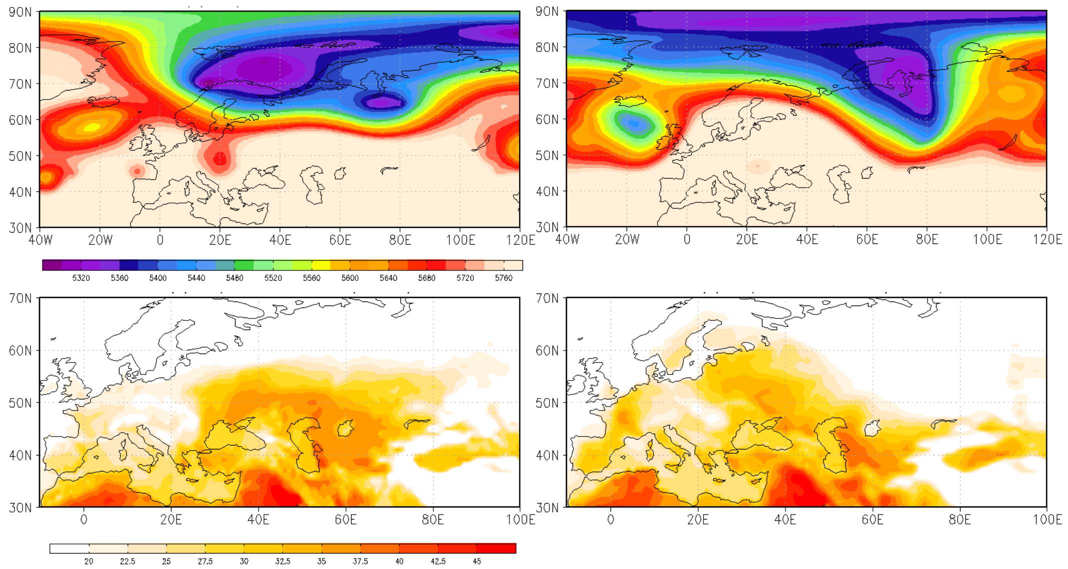

Fig 4. 500 hPa geopotential height (in gpm) (top) and 2 m temperature (°C) (bottom) at +240 hours. Case with decay of the blocking system (left) and a second case still showing the blocking ridge (right) during the analysed decay period.

2. The interaction of tropical cyclones with the midlatitude flow

Predicting the extratropical transition (ET) of tropical cyclones (TCs) poses a considerable challenge for numerical weather forecast systems as the interaction between the TC and the midlatitude flow covers a large range of scales from the convective inner-core of a TC to the synoptic- to planetary-scale Rossby waves. Reduced predictability may be associated with the direct impact of an ET event, if the ex-TC is predicted to reach a continent as an extratropical storm. Arguably the larger impact on predictability, however, occurs due to the excitation of a Rossby wave packet that can initiate explosive development downstream of the ET system itself. This may initiate extratropical cyclogenesis in the eastern ocean basin, or modify existent flow patterns enhancing the risk of severe precipitation events. Due to its influence on the downstream flow an ET event can lead to significantly reduced predictability over an entire ocean basin.

2.1. Impact of tropical cyclones on Rossby wave packets: a climatological perspective

In order to investigate the impact of TCs on Rossby waves from a climatological point of view we identified synoptic scale Rossby wave packets (RWPs) in the ERA-interim data set. The identification of RWPs is based on a Hilbert transform filtering technique that was first applied to atmospheric data by Zimin et al. (2003). By applying the filtering technique on the meridional wind at 250 hPa we were able to extract the envelope of synoptic-scale RWPs.

In the period June to November 1980–2010, 280 TCs recurved and interacted with the midlatitudes over the western North Pacific. We found a statistically significant increase in RWP amplitude and occurrence frequency downstream of these recurving TCs. The RWP occurrence frequency exceeds the climatological mean by up to 20% between the western North Pacific and central North America from two days prior to five days after extratropical transition (
Fig 5a). There is a statistically significant increase in RWP amplitude of about 2 m/s over the central North Pacific (
Fig 5b).

South Indian Ocean TCs have a statistically significant impact on RWP occurrence frequency and amplitude, too (not shown). The RWP occurrence frequency exceeds the climatological mean by up to 15% between 60°E and 180° from two to seven days after recurvature. Over the same region, the RWP amplitude is enhanced significantly by up to 2 m/s. The results for both basins, the western North Pacific and the South Indian Ocean, show that RWPs which are associated with recurving TCs are stronger than those which are associated with midlatitude synoptic systems. The amplitude and occurrence frequency of RWPs downstream of North Atlantic recurving TCs do not differ from the general variability.

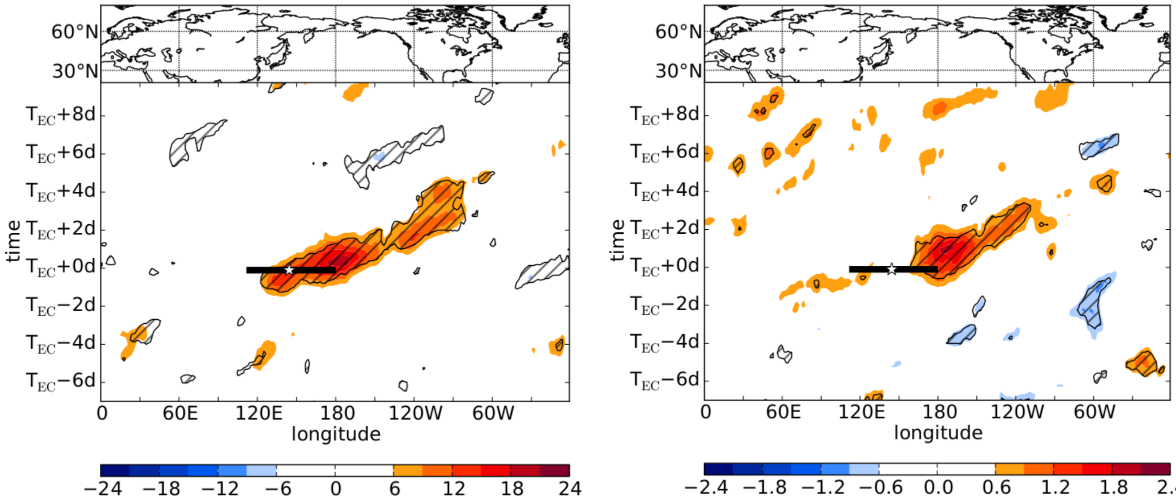

Fig 5. ET relative composites of (a) RWP occurrence frequency anomaly (shaded in %) and (b) RWP amplitude anomaly (shaded in m/s) relative to June to November climatology for western North Pacific TCs. Values that are statistically significant at 95% confidence level are hatched. Black horizontal bar marks the range of longitudes of TCs at the time of ET. White star marks the mean longitude of all TCs. From Quinting and Jones (2015).

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

The impact of a transitioning tropical cyclone on the amplification of the downstream midlatitude flow can also be considered from an eddy kinetic energy perspective. Thereby, the TC may act as additional source of eddy kinetic energy, aiding the amplification of the downstream wave train in the framework of the downstream baroclinic development paradigm (Orlanski & Sheldon, 1995).

In a first part of our study, we investigated the eddy kinetic energy (Ke) budget of several forecast scenarios for the ET of Hurricane Hanna and Typhoon Choi-Wan, respectively. The forecast scenarios were derived from the operational ECMWF EPS via an EOF- and Fuzzy clustering approach (Harr et al., 2008). Analysis of the Ke-Budget in the various scenarios allowed to identify the processes that caused the scenarios to be different. The study was reliant on the operational ECMWF EPS archive, as vertical velocity is not available e.g. in TIGGE. For Choi-Wan, four different scenarios were extracted from the forecast, and the differences in the scenarios could be traced back to the interaction of the Typhoon with a midlatitude frontal wave and the phasing between the TC and an upstream midlatitude trough. The strongest downstream dispersion of Ke was found if Choi-Wan moved ahead of the trough and merged with the frontal wave, while downstream dispersion was hindered when the TC moved into a midlatitude ridge, instead ahead of the trough.

For Hurricane Hanna, two development scenarios were found. Their differences resulted from the duration of baroclinic conversion within the transitioning cyclone. Only if the ascent of warm and descend of cold air masses within the TC (generation of Ke) continues until Hanna moved ahead of a weak short wave trough in the midlatitudes, Hanna aided the amplification of the downstream midlatitude wave train. This part of the work is published in Keller et al. (2014).

These findings could be further confirmed by testing the sensitivity of the amplification of the downstream wave train to the Ke Budget (ensemble sensitivity analysis, Torn & Hakim, 2008) for the two forecasts under consideration. This approach also allowed for investigating the relative role of the transitioning TC and the upstream midlatitudes.

The amplification of the downstream midlatitude wave train (our forecast metric) is determined to be the upper 5% of the Ke maximum that is found at the rear flank of the downstream trough about 2-3 days after the TC impinged on the midlatitude flow. We then determine the sensitivity of this forecast metric to the several quantities in the Ke budget up to 48 h earlier.

For Choi-Wan, the amplification of the downstream wave train is sensitive to the baroclinic conversion within Choi-Wan, the frontal wave and within the baroclinic zone, as it is sensitive to downstream dispersion and advection of Ke (Fig 6a-d). No clear sensitivity is found to the Ke budget in upstream regions on the forecast time shown here. Another 24hrs earlier (not shown), some sensitivity is linked to the trough, Choi-Wan is interacting with, but is overall weaker that the sensitivity to the storm. Thus, the amplification of the downstream wave train during the ET of Typhoon Choi-Wan is sensitive to the position of the storm (dipole structure around TC), with stronger amplification in case Choi-Wan is at more northeastern position, the baroclinic conversion along the baroclinic zone and within the frontal wave and the Ke fluxes from these toward downstream regions.

For Hurricane Hanna (not shown), the dependence of the amplification of the downstream RWT to the duration of baroclinic conversion could be confirmed. Furthermore, the amplification was also sensitive to Ke generation in an extratropical cyclone that developed upstream of Hanna.

A publication summarizing these results is currently in preparation.

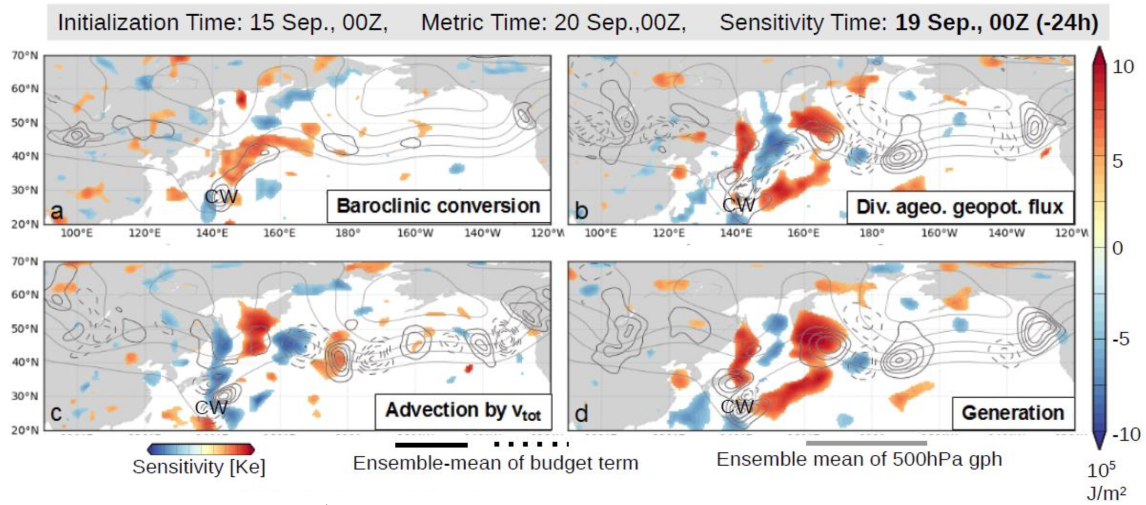

Fig 6. Sensitivity (shaded, in 10^5 J/m^2) of the amplification of the downstream trough after the ET of Typhoon Choi-Wan to Ke budget terms 24 hrs earlier. a) baroclinic conversion, b) dispersive Ke flux, c) advective Ke flux and d) generation of Ke Ensemble mean of Ke budget terms indicated by black contours, ensemble mean of 500 hPa geopotential height in grey contours.

2.3. Impact of ET of tropical cyclones on poleward Rossby wave breaking

During the ET of a TC, diabatic processes within the remnant TC may cause the amplification of an existing ridge and of the midlatitude jet (Jones et al., 2003). This deflection of the midlatitude flow may result in a diffluent flow configuration at upper levels (Riemer et al., 2008). In a diffluent flow, poleward anticyclonic Rossby wave breaking (P2 RWB) is observed frequently (Gabriel and Peters, 2008).

By using ECMWF EPS forecasts that exhibited a relatively large spread it was possible to identify forecast scenarios with and without ET (Fig 7). We applied an EOF analysis and a Fuzzy clustering to classify the different scenarios and to find representative members for each scenario (Harr et al., 2008; Keller et al., 2011). We investigated the ET of four hurricanes (Jeanne 2004, Ophelia 2005, Noel 2007 and Tomas 2010).

The generation of an anticyclonic vortex in the upper troposphere downstream of the storm seems to be crucial for P2 RWB events (McIntyre and Palmer, 1985). An additional poleward cyclonic RWB (P1) may develop as a consequence of a local influence of the storm. Another possibility for the former TC to influence RWB is to weaken a trough and thus preventing the formation of an equatorward anticyclonic RWB (LC1).

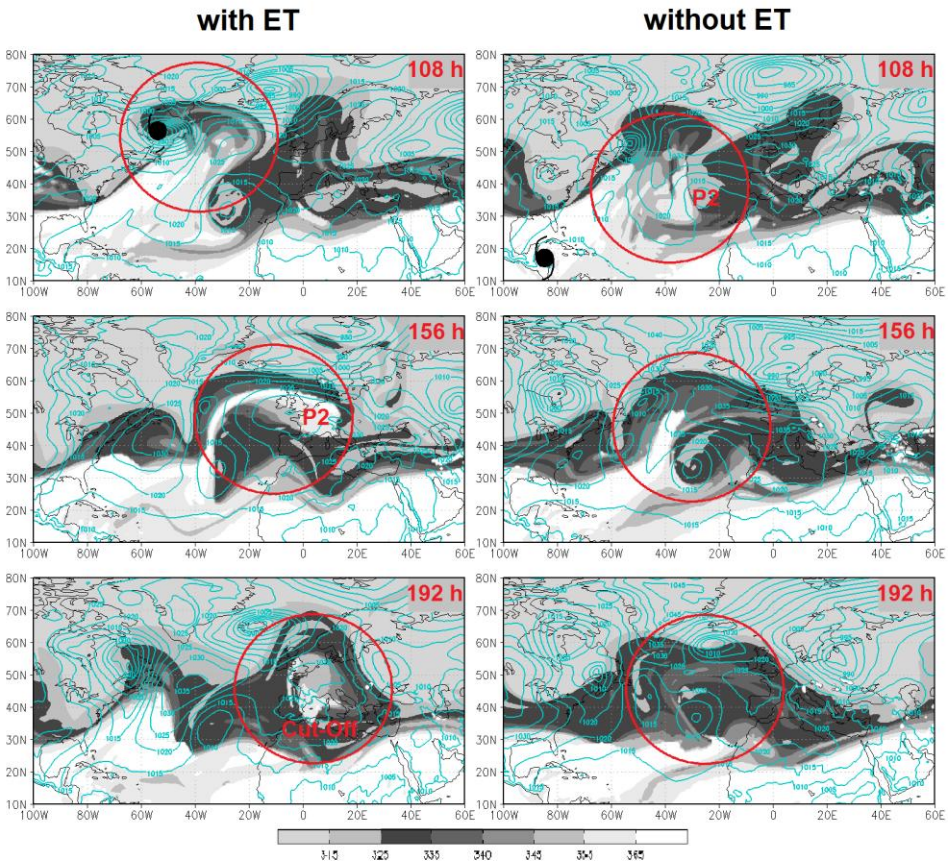

Fig 7. Potential temperature at 2 PVU (shaded in K) and mean sea level pressure (blue contours in hPa) at +108 hours (top), +156 hours (middle) and +192 hours (bottom) for forecast scenarios with (left) the ET of Noel (2007) and without (right) the ET.

2.4. Data denial for extratropical transition

An important source of uncertainty associated with ET is due to the fact that these types of phenomena are poorly observed given the insufficient and inhomogeneous data coverage over the ocean where the majority of TCs undergo ET. Introducing additional targeted observations in the vicinity of ET events or in sensitive regions associated with TCs approaching the midlatitudes should bring a notable forecast improvement.

The data denial experiments were conducted with the ECMWF Integrated Forecasting System (IFS) which was implemented in May 2011. The 12 hour window 4D-Var Assimilation system at the resolution T255 was used whilst the observation departures (difference between observations and model) and the model trajectory were computed at T799. Three types of experiment were carried out for eight ET events. In the first (SVout), data was denied in sensitive regions determined by the leading extratropical singular vector (SV), i.e. SV1, optimized at day 2 over Europe. The second experiment (ETout) is characterized by observations denied at each analysis time on boxes centered on the TC. The boxes have about the same size as the SV areas. The third experiment is the control experiment (Ctrl) equivalent to the operational configuration in which all observations are assimilated.

The experiments reveal the following results

- In the ET stage of a TC, the SV based sensitive regions for forecast degradation over Europe are strongly associated with the ex-TCs
- In the presence of a TC over the Atlantic which approaches the midlatitudes additional observations around the TC are much more beneficial for the forecast over Europe than additional observations in extratropical sensitive regions
- After a TC underwent ET the extratropical SVs are closely connected to the ET system

3. The interaction of the MJO with the midlatitude flow

3.1. The impact of the MJO on Rossby wave packets: a climatological perspective

We investigated the relation between the MJO and midlatitude Rossby wave packets (RWPs) from a climatological point of view by identifying synoptic-scale RWPs in the ERA-Interim data set. The identification is based on a Hilbert transform filtering of the meridional wind at 250 hPa along streamlines of the background flow (Zimin et al., 2006). We identified the RWPs for the period DJF 1980-2009 in six hourly time intervals for the MJO phases 1 to 8 (Wheeler and Hendon, 2004).

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 (Fig 8a). 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 (Fig 8b). 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.

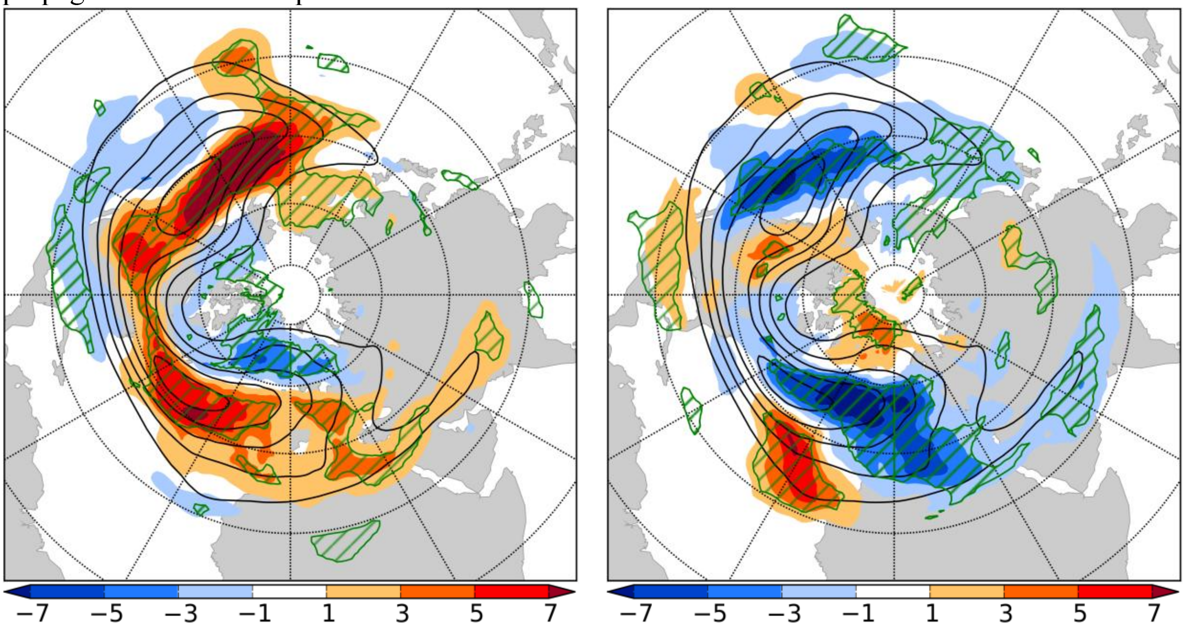

Fig 8. DJF climatology of RWP occurrence frequency (black contours, interval 5%) and anomaly of RWP occurrence frequency (shading, %) for MJO RMM phases (a) 5 and (b) 8 relative to DJF climatology. Values that are statistically significant at the 99% confidence level are hatched.

3. Representation of MJO in ICON and linkage to predictability in midlatitudes

High-performance computing facilities at ECMWF were used to investigate the representation of the Madden-Julian Oscillation in the new German global model ICON, and to investigate the relation between forecast performance in tropical and extratropical regions. The numerical experiments have been conducted in 2014, using the allocated resources of this project, but analysis of the results is still in progress. Thus, this provides only a preliminary overview on the results.

We focus on a major MJO event in spring 2012 to reveal characteristics of ICON in forecasting various phases of the MJO event. ICON was run at 20km global horizontal resolution with 90 vertical levels for 10 days, and was initialized from ECMWF operation analysis every second day from February 14 till March 19.

By comparing precipitation from the ICON runs to observational data (TRMM-Dataset), and the ECMWF and NCEP (EPS control forecasts, obtained from TIGGE, Fig 9, right), it becomes obvious that ICON shows a quite good performance in capturing the development of the precipitation events associated with the MJO event and their eastward propagation, once the MJO was already present in the analysis. However, eastward propagation tends to slow down/stop once the convection reaches and crosses the Maritime Continent (not shown). When the convective activity is not present in the analysis, some of the forecasts develop an MJO-like precipitation field, but some do not (not shown). For the upper level wind field, indicating the divergence above the convective areas, ICON is found

to match quite well with the fields described in ERA-INTERIM, even when precipitation fields do not match perfectly. This indicates that the large scale circulation seems to be captured quite well.
We will continue analysing these experiments by a more thorough assessment of the representation of MJO in the model run. By investigating forecast quality in the tropics and midlatitudes, we aim on identifying the impact of poor representation MJO forecasts in the tropics and their effect on midlatitude predictability. Furthermore, some experiments may be conducted in which representation of convection is modified to investigate the impact on midlatitudes.

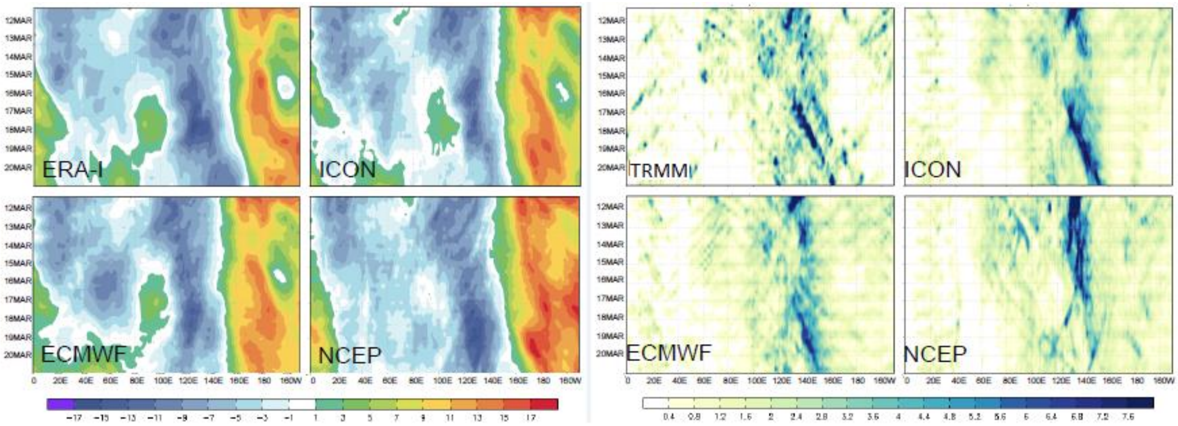

Fig 9. Hovmöller Diagram (10°S-10°N) for 200 hPa zonal wind (left) and total precipitation (right) in TRMM/ERA-I, and forecasts from ICON 20km, ECMWF EPS control and NCEP EPS control. All forecasts initialized on 11 March 2012 around the onset of the major 2012 MJO event.

4. Verification of tropical precipitation forecasts via object oriented verification methods

We evaluated the performance of the ECMWF-IFS in the representation of tropical convection by comparing precipitation forecasts with TRMM rainfall measurements in the YOTC period. We used two object-oriented techniques which provide information on various properties of precipitation objects (Keil and Craig, 2009; Davis et al., 2006).
An assessment of the representation of convective systems at low latitudes in the ECMWF-IFS was conducted over the Maritime continent for the summer months of the YOTC-period. Following a slight drop after the first forecast day, the mean precipitation steadily increases over the course of the remaining lead time (Fig 10a). While the former is presumably caused by a spin-down issue, the latter might be the consequence of a structural change of the convective systems. Since the intensity is underestimated it is suggested that the increase of precipitation is rather due to the increase in size of precipitation objects (Fig 10b). Similar results were found for the central Pacific and Africa.

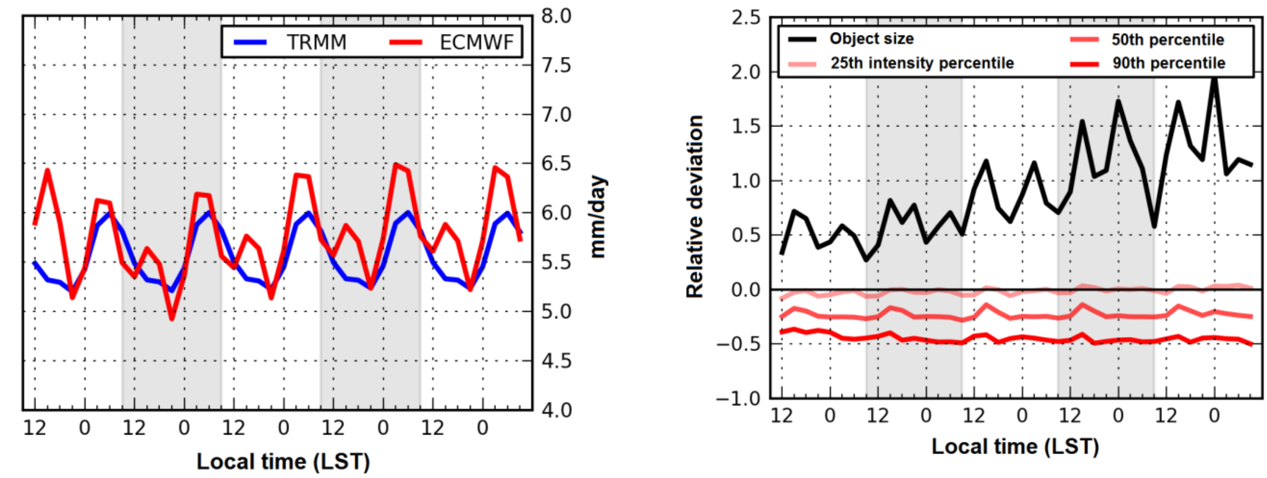

Fig 10. (a) Mean precipitation over the Maritime continent for TRMM observations and ECMWF forecasts. (b) Bias of object size, 25th-, 50th- and 90th intensity percentile as a function of forecast lead time over the Maritime continent.

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Future plans

There are no immediate plans for a continuation of this ECMWF special project.

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