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Towards a homogeneous 50 year climatology of typhoons in SE Asia.

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Abstract

In recent years, a dynamical downscaling strategy has been developed and applied to the problem of determining characteristics and trends of storminess in the NE Atlantic. The technique operates with a regional atmospheric model, which is exposed to global re-analyses not only along the lateral boundaries but also to the large-scale state in the interior of the considered domain above a certain height ("spectral nudging"). The performance of this technique in dealing with SE Asian typhoons is now examined.

First case studies indicate that tropical storms which are described by the global NCEP reanalyses are correctly identified and tracked; considerably deeper core pressure and higher wind speeds are simulated compared to the driving NCEP re-analyses. When the regional atmospheric model is run without spectral nudging, significant intra-ensemble variability occurs; also additional, non-observed typhoons form.

1. Introduction: Regional weather reconstruction using regional models spectrally nudged to operational re-analyses

For assessing risks related to weather phenomena as well as for identification of anthropogenic signals in the weather record, long homogeneous time series are needed. In case of marine phenomena, the interest is mostly with wind statistics, in particular strong wind incidents, i.e., wind storms. Unfortunately, long homogeneous time series of wind speeds are hardly available because of the sensitivity of recording wind to local environmental change, changing instrumentation and observation practice (cf., Bärring and von Storch, 2004).

For the case of NE Atlantic storminess, a technique has been introduced which allows the “reconstruction” of the weather stream in that area with a high spatial and temporal resolution (Feser et al., 2001; Sotillo et al., 2005, Weisse et al., 2005). The idea is to force large-scale synoptic information provided by re-analyses, such as prepared by NCEP/NCAR, upon a regional atmospheric model (RCM; von Storch et al., 2000; Miguez-Macho et al., 2005). The RCM is not only run with information along the lateral and lower boundaries but also with a “nudging”, which forces the simulated large-scale state in the interior of the domain of the RCM to be close to the analysed large scale state. The rationale of doing so is that the large-scale state in the re-analyses is believed to be accurately described and homogeneous, while smaller scales may be less well described and subject to variations related to changing observational quality and distribution. In the spirit of dynamical downscaling (von Storch, 1995), the RCM is believed to derive from the correctly represented large scales and from the influence of regional detail a useful description of smaller scale dynamics.

The issue of the added value provided by RCMs is still contested, but a dedicated analysis of the output of an RCM on different spatial scales has shown that with spectral nudging the large scales are not better represented than by the driving analysis, but that the RCM performs better on medium scales, which are insufficiently resolved by the re-analysis (Feser, 2006). On a case-by-case basis, not all NE Atlantic storms are reproduced well, but if statistics are considered, the reproduction is satisfactory without a bias and variability similar to the observed one for coastal regions (Winterfeldt, pers. comm.)

For the NE Atlantic, wind and air pressure fields on a 50 km grid stored once an hour, have been used to assess changing ocean wave conditions (Soares et al., 2002; Gaslikova and Weisse, 2006; Weisse and Günther , 2006), coastal currents and well storm surges (Weisse and Plüß, 2005; Aspelien, 2006). The resulting data sets of ocean wave parameters and storm surge heights have been used in a number of impact studies related to offshore activities, ship construction, or coastal defence.

We suggest implementing a similar method to reconstruct tropical weather in SE Asia. Obviously, the key problem is the simulation of typhoons. Landman et al. (2005) have demonstrated that even with a relatively coarse resolution of 60 km, tropical storms are satisfactorily described by a regional atmospheric model (without large scale constraint). We have begun to explore the performance of our method (with large-scale constraint) in order to apply it to SE Asia. In the present contribution we describe our results, when we tried to reconstruct a rather strong and large storm, namely typhoon Winnie in August 1997.

2. Testing the approach with a typhoon: Winnie, August 1997

The storm Winnie formed in the eastern part of the regional model domain (Figure 1) at about 6 August; the CLM simulations are initialized with earlier conditions taken from NCEP re-analyses at or shortly after 1 August 1997. The storm itself is described by NCEP re-analyses with a minimum core pressure of 965 hPa and maximum surface wind speeds of 29 m/s on 17 August 1997 (Figure 2), which is to weak compared to the best track estimates of 915 hPa and 51 m/s on 12 and 13 August 1997 (Figure 5).

We use the CLM model (http://www.clm-community.eu/index.php?menuid=20), which is the climate version of the regional weather forecast model LM of the German Weather Service. The model runs with standard parameterizations for physical processes; for convection the parameterization suggested by Kain-Fritsch has been selected. The model was chosen to run with a 50 km grid (see Figure 1). A sponge zone of 10 grid points is used. The spectral nudging is applied to the two horizontal velocity components; below 850 hPa no nudging is used; beginning with 850 hPa a weak nudging (corresponding to an e-folding decay time of an introduced disturbance of 20 days) is adopted, which increases with height to an e-folding time at 100 hPa of approximately 2 hours (von Storch et al., 2000).

Embedded into the 50 km simulation region is a smaller region with a grid length of 16.5 km (Figure 1) Again a spectral nudging is employed, this time the constraint is taken from the 50 km grid simulation. The vertical structure of the nudging is the same as before, but the constrained spatial scales are now reduced to 215 km and longer – this scale is considered simulated reliably by the 50 km CLM.

The situation on 17 August 1997, 0:00 UTC, as described by the NCEP re-analysis is shown in Figure 2 – with a core pressure of about 970 hPa and 29 m/s maximum surface winds. In case of the spectrally nudged RCM simulation (Figure 3) also one typhoon is simulated, at the same location as in the NCEP re-analysis, but with a core pressure of 940 hPa and less and maximum wind speeds of 39 m/s.

The track of the typhoon Winnie is shown in Figure 4 for the "best track data" (http://agora.ex.nii.ac.jp/digital-typhoon/summary/wnp/s/199713.html.en), NCEP reanalysis, and for four simulations with spectrally nudged CLM and four unconstrained CLM simulations. The NCEP track deviates only in the earlier part of the development from the best track data; the spectrally nudged simulations all follow the best track data closely, even during the phase when NCEP deviates a bit.

The temporal development of the typhoon, in terms of core pressure and maximum surface wind speed is shown in Figure 5 for NCEP re-analyses, for best track data and for different configurations of CLM simulations. For the time being only the curve "CLM, 0.5 degrees" is of relevance; the other curves refer to results obtained with higher resolution and are discussed later.

Obviously, the CLM simulation (black line) creates significantly lower core pressure values and higher maximum surface wind speeds than NCEP. Minimum core pressure in NCEP is on 17 August about 965 hPa, whereas CLM generates at the same time about 930 hPa. In the best track data, however, the maximum intensity is reached earlier, on 12 and 13 August, with a core pressure of 915 hPa. A similar situation holds for wind speed, which is about 30 m/s in NCEP and 40 m/s in CLM about 3.5 days after a maximum of more than 50 m/s in the best track data.

In Figure 6 spatially filtered maps of air pressure are shown for NCEP and for the spectrally nudged simulation initiated on 1 August 1997. A series of digital filters (with a footprint of 2x10+1) was constructed (Feser and von Storch, 2005) to approximately isolate different spatial ranges, namely large scales (diameters larger than about 625 km; the overall mean is subtracted) and medium-scales (diameters between 180 km and 360 km). Results are shown for NCEP and spectrally nudged CLM on 17 August 2006. For that purpose, NCEP was interpolated to the 50 km grid of CLM; due to this interpolation, some wave structures were introduced in the medium filtered fields in the southern area with significant orography. Note that the filter response function approximates an ideal response function with 1's for the retained scales and 0's for the suppressed scales. Therefore, also the retained scales are somewhat dampened, a traces of the suppressed scales remain. The sum of the filtered components has less variability than the original field. The filter allows, however, a comparison of scale-contributions in different fields.

The large-scale filtered component is dominated by one isolated low pressure system with 20 hPa deviation from mean pressure and less for NCEP and less than 25 hPa in CLM (Figure 6). This circular low pressure system is modulated by medium-scale structures in both NCEP and CLM, with a further pressure deepening in the center (2 hPa in NCEP; 4 hPa in CLM), and an attenuation of the low pressure in a surrounding ring. The smallest scales mainly show small structures in the southeastern part of the model domain for the reanalyses.

3. Sensitivity simulations

A series of sensitivity experiments have been computed. They deal with the dependency of the simulation to different initial states (cf., Ji and Vernekar, 1997; Rinke et al., 2000; Weisse et al., 2000) and with the role of higher resolution.

The dependency to different initial states is examined by considering a series of four different simulations, which were initialized with analyses from different days at the begin of August 1997. When spectral nudging is invoked the different simulation differ very little (Figure 4), as was the case with NE Atlantic climate in Weisse et al. (2000) and Weisse and Feser (2003). The large-scale constraint obviously steers the track of the cyclone tightly. This is quite different in case of four simulations without spectral nudging. The tracks in three of four simulations deviate jointly quite a bit from the best track (Figure 4), whereas one follows the best track much better. When looking at the air pressure maps, one finds that Winnie is in all cases simulated, but that additional, unobserved typhoons were generated (Figure 7). In one case, a strong tropical storm is formed in the Bay of Bengal, which has no counterpart in any other simulation, satellite data, or in the best track data base or NCEP re-analyses. We interpret this behavior that the process of forming tropical storms is a strongly non-linear process involving chaotic dynamics. Thus slightly different initial conditions can lead to rather different developments in the interior of the simulation domain. Interestingly, Winnie is formed in all four cases.

We ran the model, with spectral nudging as described above, also with higher resolution. In one case, the model was run with a grid distance of 16.5 km in the entire (larger) domain; in this case the relatively coarse NCEP boundary conditions were directly taken as input for the 16.5 km model. This simulation yields clearly worse results than the 50 km resolution run; the track becomes very noisy (not shown) and both the core pressure and the maximum surface wind speeds (Figure 5) are worse simulated. The core pressure and the maximum surface winds become similar to the values in the driving NCEP re-analysis.

Another high-resolution run of 16.5 km grid size was computed using the “double nesting approach” (Figure 1). The results of th 50 km run were used as input for the higher resolution run. Results similar to the track in the 50 km run emerged. However, the core pressure is somewhat deeper, and the maximums surface winds slightly stronger. The storm develops slower in the beginning, but intensifies on 12 August quickly, comparable to the development in the best track data (Figure 5).

4. Conclusions

From our preliminary experiments we draw a number of tentative conclusions.

1) Some typhoons can be described at least partially realistically with the dynamical downscaling concept, using coarse-grid NCEP re-analyses and regional atmospheric models- which is consistent with the success reported by Landmann et al. (2005). In our case, Winnie from August 1997, the storm was caught and described by the re-analysis so that the RCM did not need to “invent” the storm. The storm was simulated in greater detail than in the NCEP description, also the core pressure was considerably deeper and the winds stronger.
Further experiments need to be made with less strong storms; first results indicate that sometimes such less energetic storms are not captured as well.

2) Our experiments indicate that lateral boundary control is insufficient to reconstruct the number and track of typhoons in a given synoptic situation. Of course, this depends on the size of the domain; in smaller domains the lateral control is more efficient (cf. Castro and Pielke, 2004). The inclusion of large-scale constraints, as for instance spectral nudging, is helpful in forming the storms along the right track.

3) Using a double-nesting approach has an effect on the simulation, which we believe may be a slight improvement compared to the 50 km simulation.

4) We want to stress that the reported results are of preliminary character; more experiments are needed. Also longer, seasonal as well as multi-year simulations are

needed to assess whether they return the right storm statistics (in frequency, location and intensity) conditional upon a number of large-scale factors, such as SST, vertical stability and the like.

5) A major problem for our analysis is the lack of a reliable, homogeneous data base for typhoons in SE Asia, which describe air pressure fields, wind speed fields and the like.

Figure 1 Simulation area – the large area is described by a 50 km grid, the smaller by a 16.5 km grid.

Figure 2 Description of Winnie on 17 August 1997 in the NCEP re-analysis.

Figure 3 Simulation of Winnie on 17 August 1997 on the 50 km grid with spectral nudging.

Figure 4 Tracks of Winnie as given by the best track data, by NCEP re-analyses, four simulations with CLM without spectral nudging and four with spectral nudging.

Figure 5 Core pressure and maximum surface wind speed as given by the best track estimates in the simulation of a 50 km grid, and two simulations with a 16.5 grid, either for the full area, without double nesting ("without DN") or with double nesting using the grids shown in Figure 1 ("with DN").

Figure 6 Spatially filtered air pressure field on 17 August 1997. Left: NCEP re-analysis after interpolation on 50 km grid; right: RCM simulation on 50 km grid. Top: large scales retained, (diameter ≥600 km), middle: medium scales retained (≤360 km; ≥180 km); bottom: small scales retained (≤ 180 km).

Figure 7 Two simulations with CLM on the 50 km grid without spectral nudging; state on 17 August 1997; the upper simulation was begun with initial conditions of 3rd August 1997; the lower with initial conditions of 7th August 1997.

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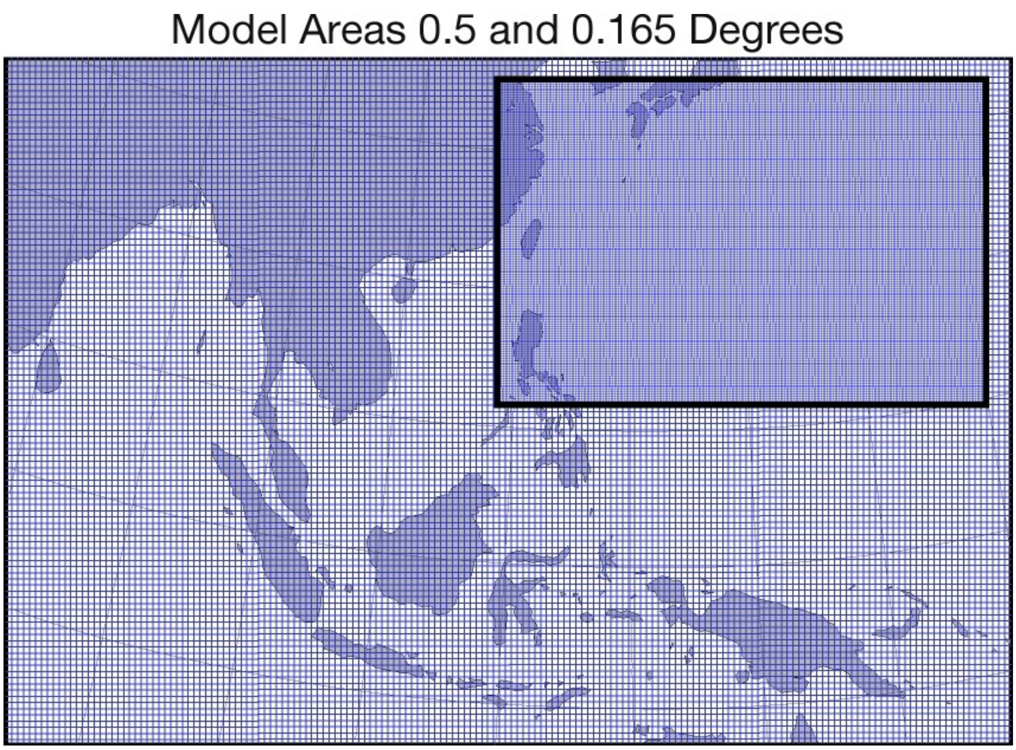

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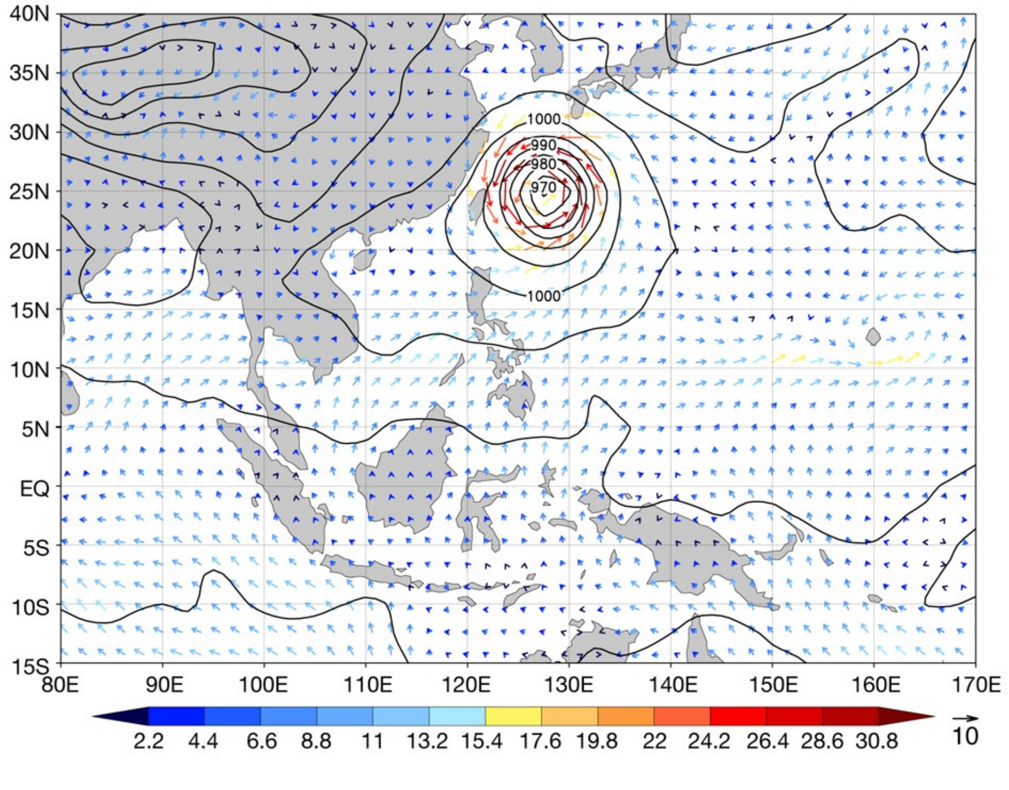

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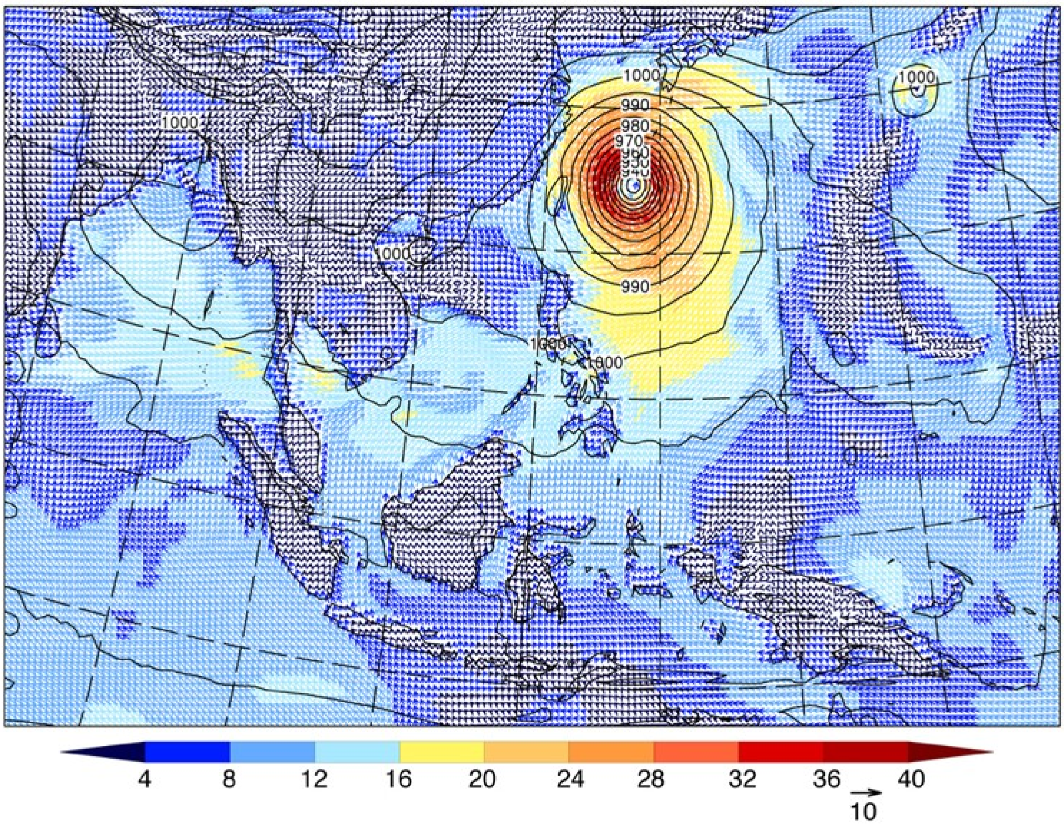

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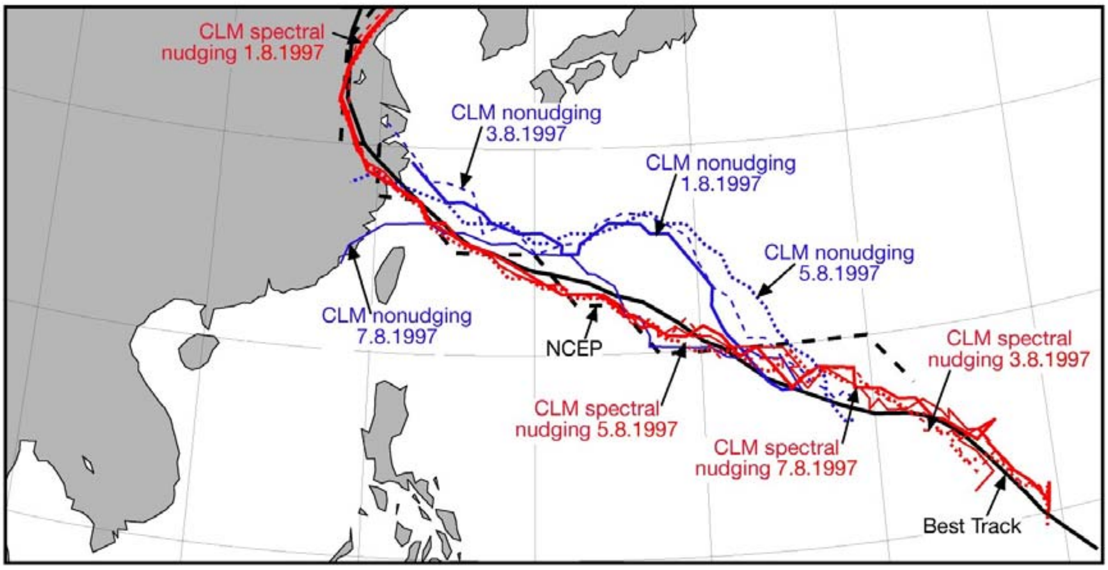

Figure 4

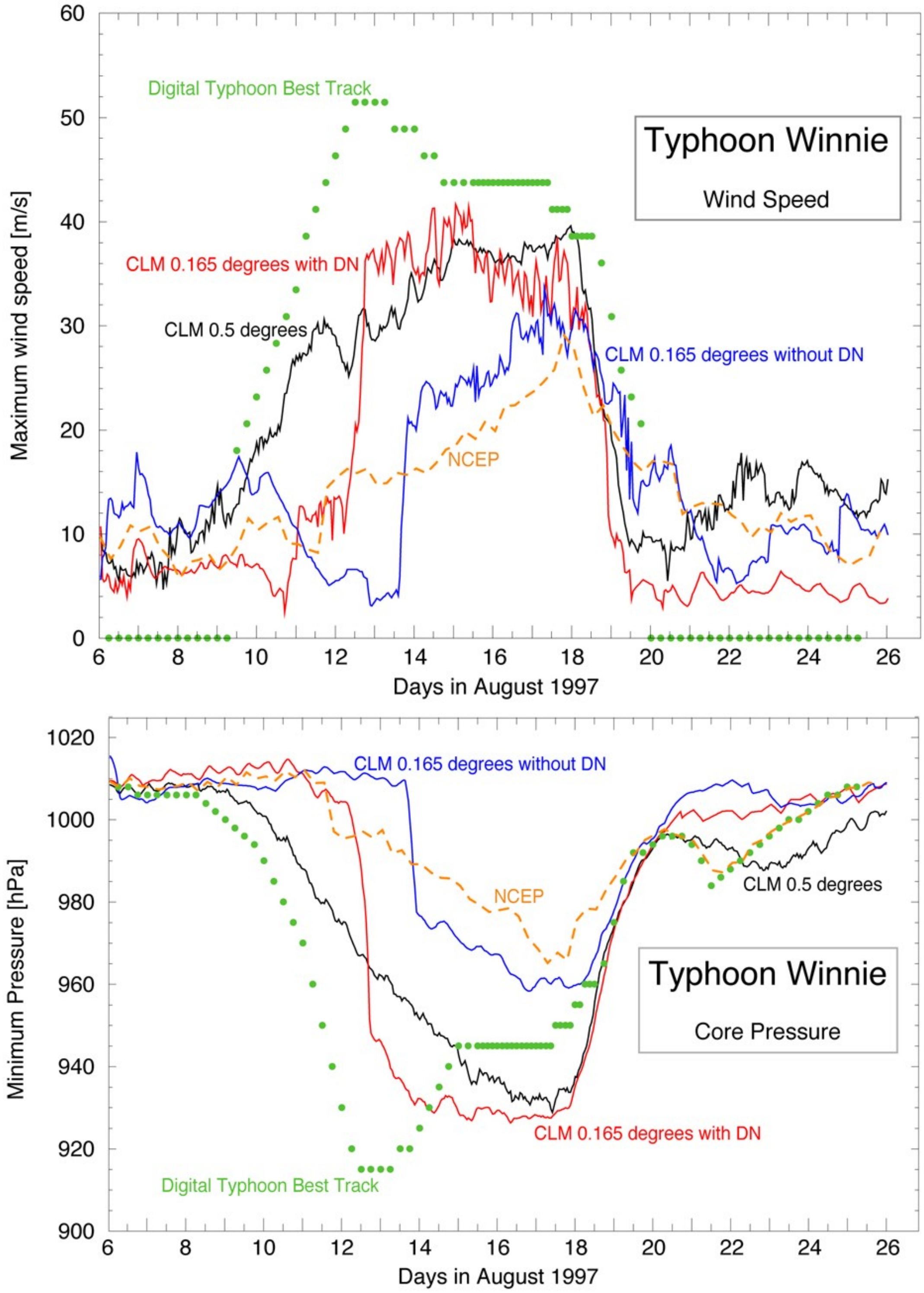
Typhoon Winnie
Wind Speed
Digital Typhoon Best Track
CLM 0.165 degrees with DN
CLM 0.5 degrees
CLM 0.165 degrees without DN
NCEP
Maximum wind speed [m/s]
Days in August 1997
Typhoon Winnie
Core Pressure
CLM 0.165 degrees without DN
NCEP
CLM 0.5 degrees
CLM 0.165 degrees with DN
Digital Typhoon Best Track
Minimum Pressure [hPa]
Days in August 1997

Figure5

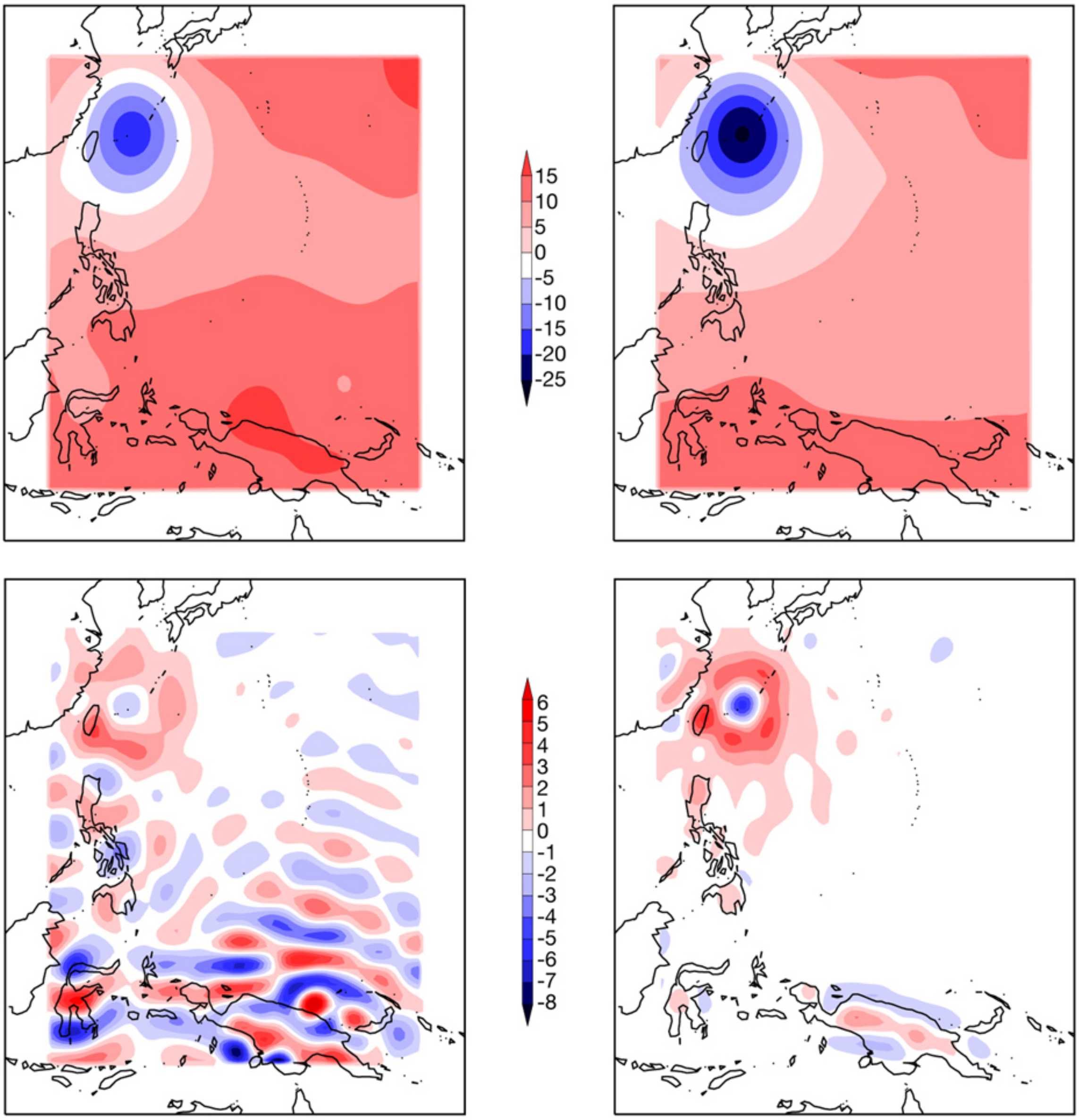

Figure 6

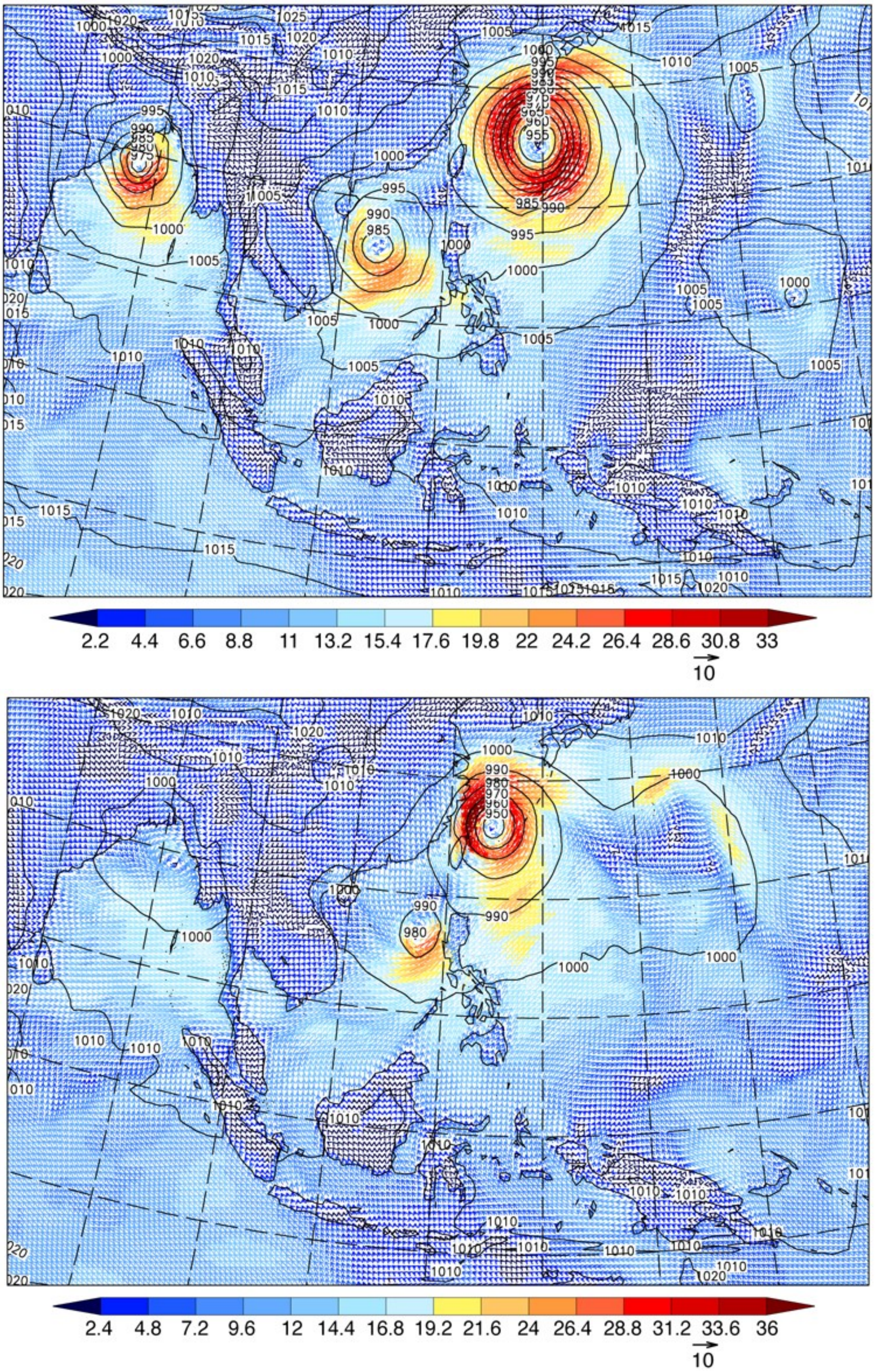
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Figure 7