# A dynamical downscaling case study for typhoons in SE Asia using a regional climate model

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# Abstract

This study explores the possibility to reconstruct the weather of SE Asia for the last decades using an atmospheric regional climate model, the Climate version of the Lokal Model (CLM). For this purpose global National Centers for Environmental Prediction - National Center for Atmospheric Research (NCEP-NCAR) reanalyses data were dynamically downscaled to 50 km and in a double-nesting approach to 16.5 km grid distance. To prevent the regional model from deviating to a great extent from the reanalyses for spacious weather phenomena, a spectral nudging technique was used which serves as a constraint exclusively for the large spatial scales of the regional simulation.

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 reanalyses are correctly identified and tracked; considerably deeper core pressure and higher wind speeds are simulated compared to the driving reanalyses. When the regional atmospheric model is run without spectral nudging, significant intra-ensemble variability occurs; also additional, non-observed typhoons form. Several sensitivity experiments were performed concerning varied grid distances, different initial starting dates of the simulations and changed spectral nudging parameters.

# 1. Introduction

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 (Bärring and von Storch (2004)).

In recent years, a dynamical downscaling strategy has been developed. It has been applied to the problem of determining a high-resolution hindcast of the weather of Western Europe for the last decades (Feser et al. (2001); Sotillo et al. (2005), Weisse et al. (2005)), and of seasons in SE Asia (Lee et al. (2004); Kang et al. (2005)). The idea is to force large-scale synoptic information provided by reanalyses, such as prepared by NCEP-NCAR (Kalnay et al. (1996)), upon a regional atmospheric model (RCM; von Storch et al. (2000); Miguez-Macho et al. (2004)). A similar approach has also been used for oceanographic simulations, see Wright et al. (2006). The RCM is not only run with information along the lateral and lower boundaries but also with a ”spectral nudging” (von Storch et al. (2000); Waldron et al. (1996)), which forces the simulated large-scale state in the interior of the domain of the RCM to be close to the analysed spacious weather phenomena. The rationale of doing so is that the large-scale state in the reanalyses 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 should represent correctly the given large-scale dynamics to enable a skillful representation of the regional scales. From the influence of regional detail a useful description of smaller scale dynamics should emerge.

The issue of the added value provided by RCMs is still contested. A dedicated analysis of the output of a spectral nudged RCM on different spatial scales has shown that the RCM performs better than the global reanalysis on medium scales (250-550 km), which are insufficiently resolved by the reanalysis (Feser (2006)). For large spatial scales ($>$ 700 km) an added value was detected for heterogeneous variables like near-surface temperature, whereas this was not the case for the more homogeneous sea level pressure. Winterfeldt (2007) examined NE Atlantic storms in the RCM data set. On a case-by-case basis, not all storms are reproduced well, but if statistics are considered, the reproduction is satisfactory without bias and variability similar to the observed one for coastal regions.

Hourly high-resolution wind and air pressure fields for the NE Atlantic have been used to assess changing ocean wave conditions (Soares et al. (2002); Gaslikova and Weisse (2006); Weisse and Plüss (2006)), coastal currents and storm surges (Weisse et al. (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). Recently Camargo et al. (2007) explored the feasibility of downscaling seasonal tropical cyclone activity in a global model with observed sea surface temperatures using a regional model. Their results show that the representation of the tropical cyclones was improved but they were not as intense as observed cyclones. The regional model did not reproduce the lower number of tropical cyclones in 1998 (Nakazawa (2001)) compared to 1994. We have begun to explore the performance of our method (using spectral nudging as a 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 very strong and large typhoon, namely Winnie in August 1997.

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

The storm Winnie formed inside of the eastern part of the regional model domain (Figure 1) at about 6 August 1997. The CLM simulations are initialized with NCEP-NCAR reanalyses (in the following just called ’NCEP’ for brevity reasons) at or shortly after 1 August 1997. The storm itself is described by NCEP reanalyses 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 too weak compared to the “best track data” (Japan Meteorological Agency (JMA), http://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/trackarchives.html) of 915 hPa and 51 m/s on 12 and 13 August 1997.

We use the CLM model (http://www.clm-community.eu), 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 Kain-Fritsch parameterization scheme has been selected. The model was chosen to run with a 0.5 degree grid which corresponds to about 50 km (see Figure 1). A sponge zone of 8 grid points is used. The spectral nudging is applied to the two horizontal wind 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 of approximately 2 hours at 100 hPa (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 approach 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 reanalysis is shown in Figure 2 - with a core pressure of about 970 hPa and 24 m/s maximum surface winds. In case of the spectrally nudged 50 km RCM simulation (Figure 3) also one typhoon is simulated, at the same location as in the NCEP reanalysis, but with a core pressure of 940 hPa and less and maximum wind speeds of 36 m/s.

The track of the typhoon Winnie is shown in Figure 4 for the best track data, 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. For the tracking a simple minimum pressure search was performed for the sea level pressure field. More sophisticated methods are available, e.g. Hodges et al. (1994) and Hodges et al. (1995). A comparison between both methods did not show any significant differences for this particular case study of typhoon Winnie (not shown).

The temporal development of the typhoon, in terms of core pressure and maximum surface wind speed is shown in Figure 5 for JMA best track data, for NCEP reanalyses, and for different configurations of spectral nudged 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 (see section 3). Obviously, the CLM simulation (grey solid line) creates significantly lower core pressure values and higher maximum surface wind speeds than NCEP (grey dashed line). 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 (grey dots), 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 29 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 for Taiwan and its surroundings are shown for NCEP (left column) and for the spectrally nudged RCM simulation (right column) initiated on 1 August 1997. A series of digital filters (with a footprint of 2x8+1) was constructed (Feser and von Storch (2005)) to approximately isolate different spatial ranges, namely large scales (diameters larger than about 625 km) and medium-scales (diameters between 180 km and 360 km). Results are shown for NCEP and spectrally nudged CLM on 17 August 1997, 0:00. For that purpose, NCEP was interpolated to the 50 km grid of CLM. To be able to distinguish between positive and negative values, negative values are also plotted as dashed isolines. Note that the filter response function only approximates an ideal response function with 1's for the retained scales and 0's for the suppressed scales. The actual response function deviates from the ideal form. Also the retained scales are somewhat dampened, and 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 Winnie's 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 (6 hPa in NCEP; 8 hPa in CLM), and an attenuation of the low pressure in a surrounding ring.

## 3. Sensitivity experiments

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 and Dethloff (2000); Weisse et al. (2000); Caya and Biner (2004)) and with the role of higher resolution and with changed spectral nudging parameters. 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 simulations 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 reanalyses. We interpret this behaviour 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.

Kobayashi and Sugi (2004) showed that increased grid resolution improves the simulation of the Asian monsoon and tropical cyclones occur more frequently and with higher intensities in a global model. Also a mesoscale model comparison (Nagata et al. (2001)) showed that horizontal resolution enhancement from 50 to 10 km has a great impact on intensity prediction of a typhoon while for this case study the track prediction was unaffected by the increased grid resolution. We ran the model, with spectral nudging as described above, also with higher resolution of 16.5 km using the ”double nesting approach” (Figure 1). The results of the 50 km run were used as input for the higher resolution run. The typhoon track in the high-resolution simulation is very similar to the track in the 50 km run (not shown). However, the core pressure is somewhat deeper, and the maximum surface winds slightly stronger (black dashed line in Figure 5). The storm develops slower in the beginning, but intensifies on 12 August quickly, comparable to the development in the best track data.

In another experiment, the regional model was again run with a grid distance of 16.5 km for the small model domain of Figure 1; but 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, it ’spirals’ around the main track). The core pressure and the maximum surface winds become similar to the values in the driving NCEP reanalysis (black solid line in Figure 5). Zhang et al. (2005) showed that typhoon Winnie featured an outer and inner eyewall. They were able to reproduce this double eyewall with the Mesoscale Model (MM5) at a resolution of 9 km. In our simulations we were not able to simulate two eyewalls and assume that our finest resolution of 16.5 km was still too coarse to resolve these mesoscale structures.

Also, the dependency to the spatial scales used for the spectral nudging was examined. Different simulations for both the CLM with 50 km and with 16.5 km grid distance were calculated. The spectral nudging was applied for scales larger than 2000 and 3000 km while the nudging coefficient was increased from 0.05 to 1.0. The results showed only small deviations from the runs with the more conservative spectral nudging configurations discussed before.

# 4. Summary and Conclusions

In this work we wanted to assess the feasibility to transfer a high-resolution hindcast approach which was successfully applied to Western Europe (Feser et al. (2001)) to SE Asia and the NW Pacific. Thereby the main new task for the regional model is the simulation of typhoons. A first case study was computed to evaluate the model's ability in generating typhoons inside the model domain (without introducing an artificial vortex) and in improving core pressure and near-surface wind speed compared to the driving reanalyses. The tracks, core pressure and wind speed developments of typhoon Winnie were extracted from reanalyses and regional model runs and compared to best track data. Sensitivity experiments were computed regarding higher grid resolutions and spectral nudging configurations as well as the dependency of the simulations to their initial states. From our typhoon simulation case study 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 reanalyses 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 reanalysis so that the RCM did not need to ”invent” the storm. But the tropical cyclone was generated completely inside of the regional model domain and did not just

pass through the lateral boundaries. 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 et al. (2005)). 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 in terms of core pressure development and near-surface wind speed; but the typhoon tracks were very similar which is in compliance with the results of Nagata et al. (2001).

4) We want to stress that the reported results concern just one case; before engaging in a multi-decadal retrospective simulation, we will examine more cases and specific storm-rich and storm-poor seasons in deatil, 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 data base for typhoons in SE Asia, which describes homogeneously air pressure fields, wind speed fields and other meteorological variables to evaluate the regional climate model simulations in more detail. Only recently, Zhang et al. (2007) presented a high-resolution tropical cyclone reanalysis for selected western Pacific typhoons of the year 2004 which has great potential for regional model validation efforts.

We think that the results of our case study are promising so that the next step will be to compare different typhoon seasons with many and few typhoons. Afterwards we will compute a multi-decadal hindcast for SE Asia resembling the approach just presented by Knutson et al. (2007) for Atlantic hurricanes. The regional atmospheric model data will serve as input for wave, sea level and storm surge models. These results should enable us to assess possible changes in the atmospheric and maritime climate for SE Asia during the last decades.

## 5. Acknowledgments

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# List of Figures

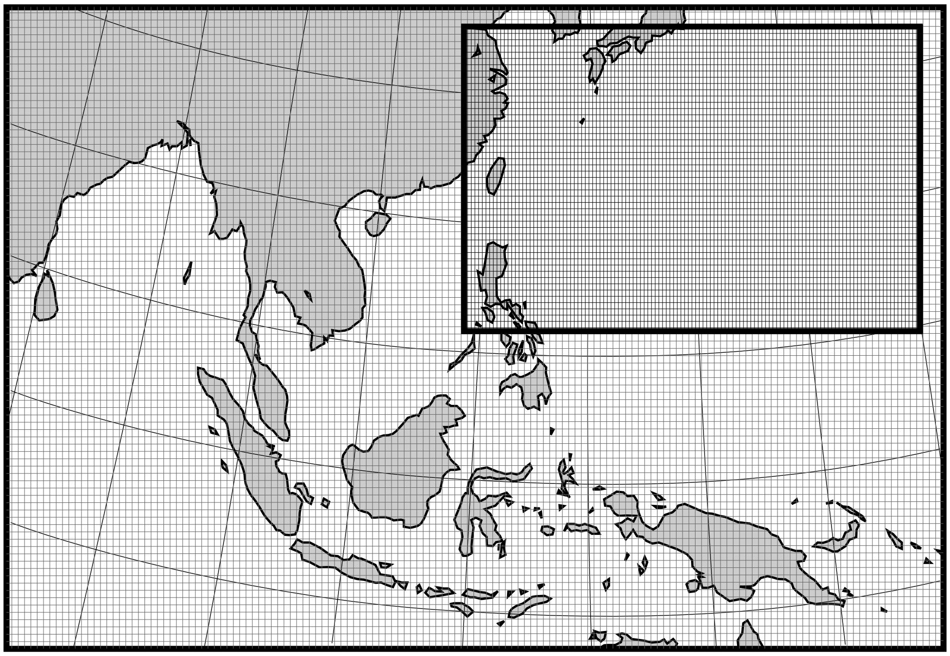

Figure 1: Simulation area - the large area is described by a 50 km grid, the smaller by a 16.5 km grid. The grid boxes are only schematically depicted and do not represent the real grid box sizes.

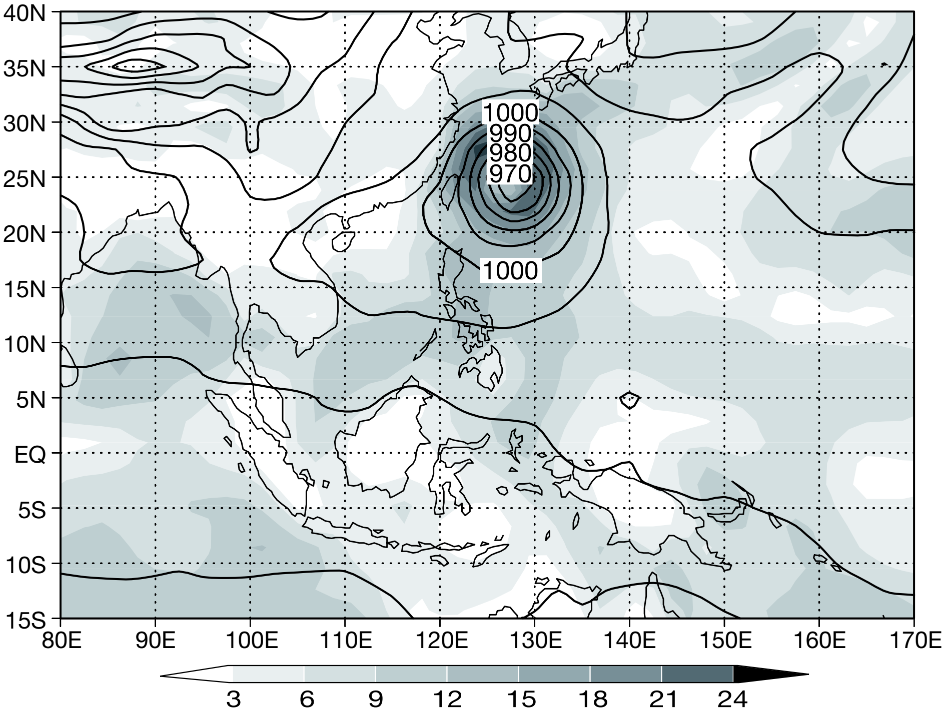

Figure 2: Description of Winnie on 17 August 1997, 0:00, in the NCEP-NCAR reanalysis. The Figure shows sea level pressure isobars (hPa) and shaded near-surface wind speed fields (m/s).

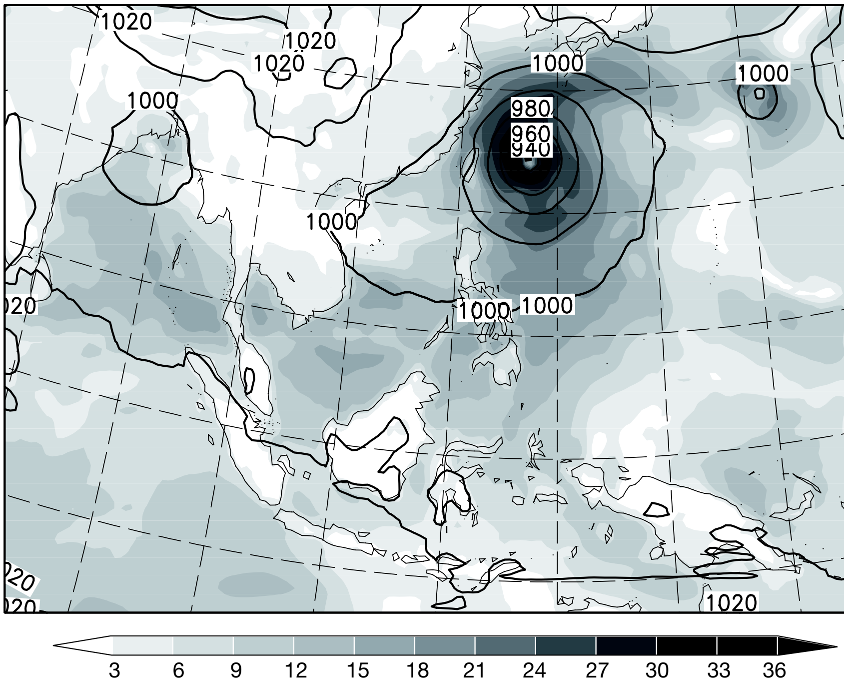

Figure 3: Simulation of Winnie on 17 August 1997, 0:00, on the 50 km grid with spectral nudging. The Figure shows sea level pressure isobars (hPa) and shaded near-surface wind speed fields (m/s).

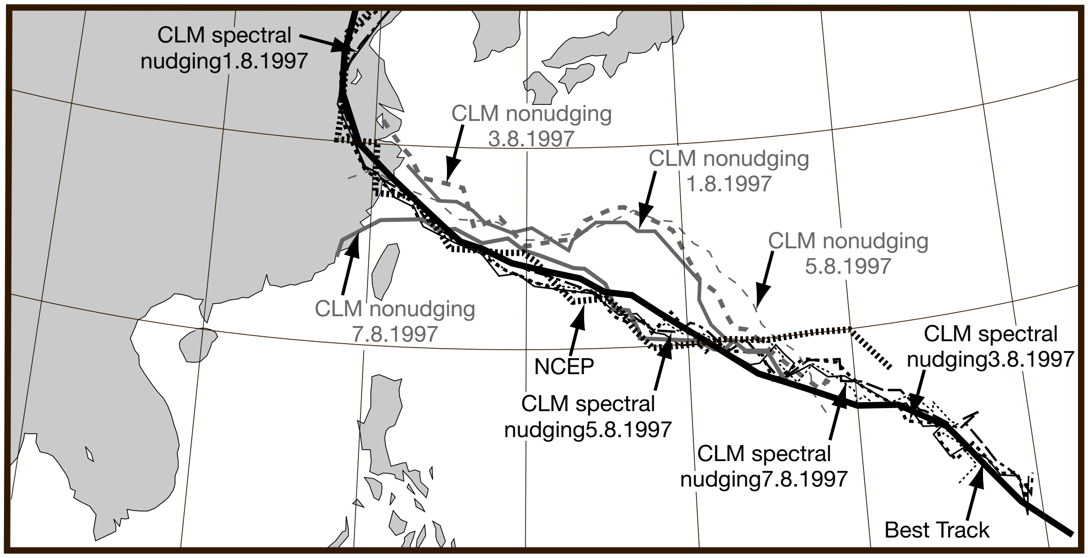

Figure 4: Tracks of Winnie as given by the JMA best track data (thick black solid line), by NCEP-NCAR reanalyses (thick black dashed line), four simulations with CLM without spectral nudging (thin grey solid and dashed lines) and four with spectral nudging (thin black solid and dashed lines). The only difference between the individual CLM ensemble members with or without spectral nudging is their starting date at or shortly after August 1, 1997.

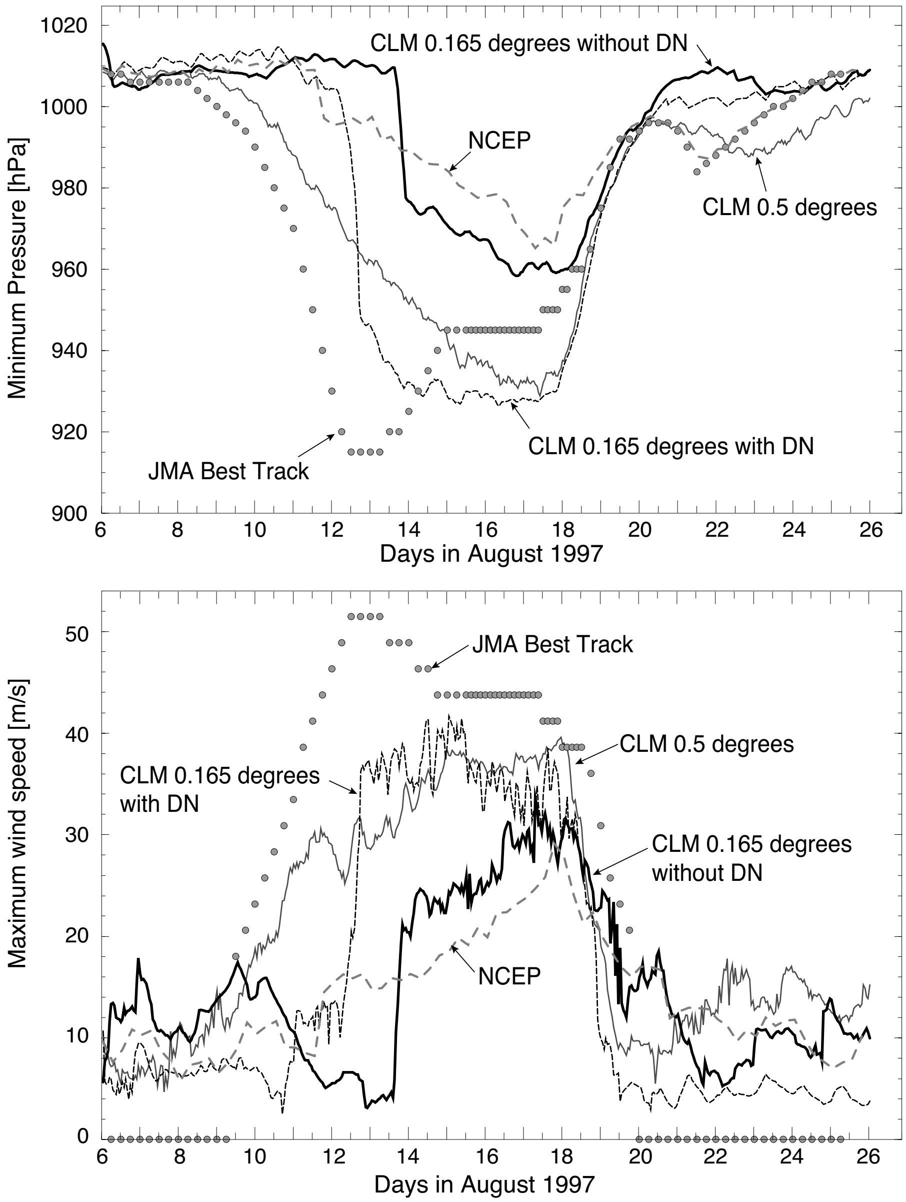

Figure 5: Core pressure (hPa) and maximum surface wind speed (m/s) as given by the JMA best track estimates, in the NCEP-NCAR reanalyses, in the CLM simulation with a 50 km grid, and two CLM simulations with a 16.5 km grid, either for the full area, without double nesting (”without DN”) or with double nesting using the grids shown in Figure 1 (”with DN”).

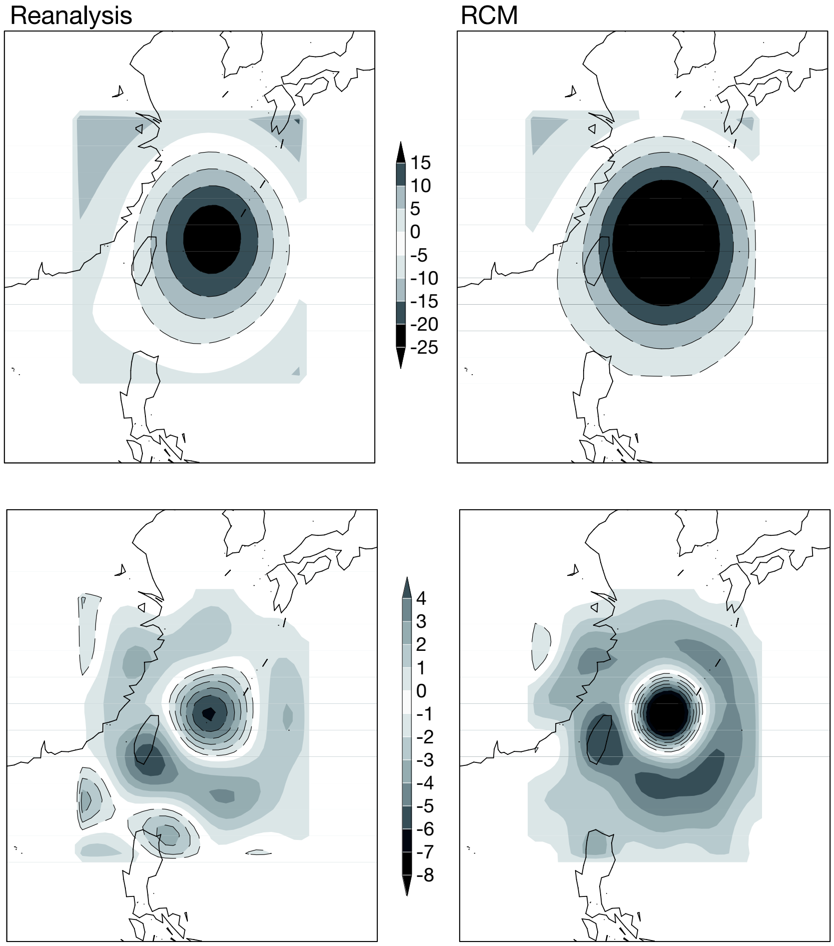

Figure 6: Spatially filtered air pressure fields on 17 August 1997, 0:00. Left: NCEP-NCAR reanalysis after interpolation on 50 km grid; right: RCM simulation on 50 km grid. Top: large scales retained, (diameter $\geq$ 600 km), bottom: medium scales retained ($\geq$ 180 km and $\leq$ 360 km). Negative values are also plotted as dashed isolines.

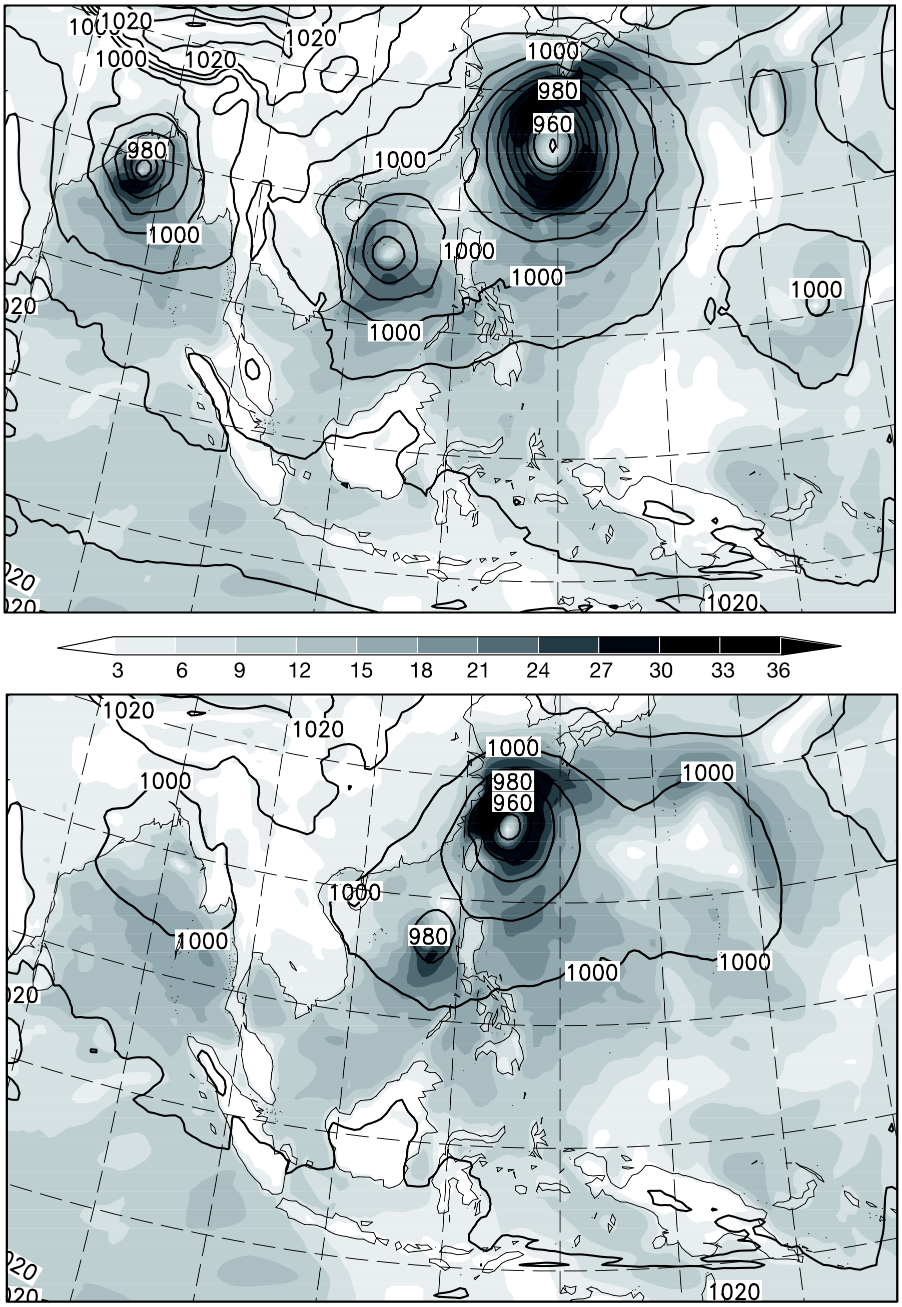

Figure 7: Two simulations with CLM on the 50 km grid without spectral nudging; state on 17 August 1997, 0:00; the upper simulation was begun with initial conditions of 3rd August 1997; the lower with initial conditions of 7th August 1997. The Figure shows sea level pressure isobars (hPa) and shaded near-surface wind speed fields (m/s).