A HIGH RESOLUTION AGCM STUDY OF THE EL NIÑO IMPACT ON THE NORTH ATLANTIC / EUROPEAN SECTOR

by

Ute Merkel · Mojib Latif

HAMBURG, August 2001
AUTHORS:

Ute Merkel
Mojib Latif

Max-Planck-Institut
für Meteorologie

MAX-PLANCK-INSTITUT
FÜR METEOROLOGIE
BUNDESSTRASSE 55
D - 20146 HAMBURG
GERMANY

Tel.: +49-(0)40-4 11 73-0
Telefax: +49-(0)40-4 11 73-298
E-Mail: <name> @ dkrz.de
A High Resolution AGCM Study of the El Niño Impact on the North Atlantic/European Sector

Ute Merkel and Mojib Latif
Max-Planck-Institut für Meteorologie, Hamburg, Germany

Hamburg, July 2001

submitted to Geophysical Research Letters

ISSN 0937-1060
Abstract

An atmospheric general circulation model (AGCM) sensitivity study has been performed with the ECHAM4 model forced by anomalous sea surface temperatures to investigate the role of the horizontal resolution (T42 versus T106) in determining the El Niño/Southern Oscillation (ENSO) response in the North Atlantic/European region. The higher resolution has been chosen in order to represent more realistically the transient eddy activity that is supposed to play a crucial role in the signal communication to regions remote from the tropical Pacific. In contrast to the T42 experiments, the T106 experiments reveal significant changes both in the mean of selected atmospheric variables (sea level pressure, temperature, precipitation) over Europe and in the transient and stationary wave activity. A cyclone tracking analysis reveals a southward shift of the North Atlantic low pressure systems in the winter season during El Niño events.
1 Introduction

Numerous studies - both observational and modelling - have been performed in order to address the relationship between tropical Pacific sea surface temperature (SST) anomalies related to the interannual El Niño/Southern Oscillation (ENSO) phenomenon and global atmospheric circulation changes (see Trenberth et al., [1998] for a review). While the ENSO impact is well established in some regions such as Indonesia, the response in the North Atlantic/European sector is less well understood. However, it has been concluded from observational studies [Fraedrich and Müller, 1992, Fraedrich, 1994] that a weak response may exist in some atmospheric quantities (sea level pressure, temperature, precipitation) during the winter season (DJF) of El Niño or La Niña events. Strong changes over Europe were reported by Dong et al., [2000] who investigated the El Niño/La Niña period of 1997-1999. Modelling studies (e.g. Ferranti et al., [1994], Bengtsson et al., [1996]) have been inconclusive so far with respect to the ENSO response simulated in the European sector. To our knowledge, none of these ensemble experiments has been performed at a higher resolution than T63. However, evidence arises from the analysis of different models [Déqué and Piedelievre, 1995, Stendel and Roeckner, 1998, Branković and Gregory, 2001] that the simulated upper-air fields as well as precipitation patterns in the North Atlantic/European sector benefit from increased horizontal resolution. We therefore hypothesize that increased resolution in AGCM experiments may help to understand the processes that lead to an ENSO response over the Atlantic/European sector. In this study high resolution experiments are conducted in order to get further insight into the establishment of the ENSO response over the Atlantic/European region.

2 Model and Experiments

We use the ECHAM4/T106 (~1.1° × 1.1°) atmospheric general circulation model (AGCM) [Roeckner et al., 1996] with 19 vertical levels. In order to account for the internal variability of the atmosphere, the model is run in ensemble mode. Starting from different initial conditions, five members are conducted forced by the same anomalous SST pattern. The forcing pattern is derived from a regression analysis in which the global observed seasonal (DJF) SST anomalies are regressed onto the seasonal (DJF) Niño3 SST anomaly timeseries. The regression is based on the Reynolds SST dataset [Reynolds and Smith, 1994] and the period 1981-1998 which includes the strong El Niño events of 1982/83 and 1997/98. The resulting SST anomaly pattern (Fig.1) exhibits the typical El Niño shape with positive anomalies in the eastern equatorial Pacific and negative anomalies to the north and south of it. This regression pattern has been multiplied by a factor of 3 to mimic very strong El Niño events, and these scaled anomalies are used as a forcing for the ECHAM4 model. Since we impose a "canonical" SST anomaly
pattern, our study differs from those that have been performed by Dong et al. [2000] and Grötzner et al. [2000] who focussed onto the 1997/98 El Niño. Each realization has a duration of 120 days (Nov.-Feb.), but only the last 90 days (DJF) are analyzed. The results of this ensemble are compared to a similar control ensemble forced by climatological SST. In order to investigate the sensitivity of the results to the horizontal resolution, we performed analogous experiments with the ECHAM4 model run at T42 (∼ 2.8° × 2.8°) resolution.

3 Results

Mean Response

The seasonal ensemble mean response of sea level pressure (El Niño minus control experiment) is presented in Fig.2 for both resolutions. The significance of the response is assessed by applying a standard two-tailed Student’s t-test. In both cases, the Southern Oscillation signature is dominant in the Pacific region and significant negative anomalies are present over the North East Pacific and over parts of the United States. A considerable weakening of the meridional pressure gradient is simulated over the North Atlantic sector, implying a change in the North Atlantic Oscillation (NAO). However, only in the T106 experiment, the two centers of action over the North Atlantic extend eastward into Europe, and a statistically significant response over most parts of Central Europe is simulated only at this resolution (Fig. 2b). The extension of a significant response into Europe at T106 resolution is also present in other quantities such as the upper level zonal wind field (not shown). The latter exhibits a dipole-like structure with increased wind speeds spreading from Southern North America into South-Western Europe and reduced wind speeds further to the north.

Comparing the response of various atmospheric variables over Europe to the observational results of Fraedrich and Müller [1992] reveals a qualitatively similar and partly significant anomaly structure in the T106 simulation (Fig.3), whereas the T42 results (not shown) bear no resemblance to the Fraedrich and Müller [1992] composites over the European continent. Thus, our ensemble experiments with the T106 model indicate that European climate exhibits a significant response to strong El Niño events.

Stormtracks and Eddy Activity

In order to get more insight into the simulated mean response of the T106 experiment, a cyclone tracking analysis is performed by means of a detection tool developed at the University of Hamburg [Blender et al., 1997]. Fig.4 presents the
detected cyclone tracks of all T106 ensemble members during the DJF season. Especially over the central North Atlantic, higher cyclone density is simulated in the El Niño ensemble. This change corresponds to a southward shift of the North Atlantic storm track and is found to be significant at the 95% level within the region 30°N-45°N, 60°W-10°W, according to the non-parametric Mann-Whitney-Wilcoxon test. The storm track displacement is also evident in the bandpass-filtered (2.5-6 days) transient eddy variance of the 500hPa geopotential height field, which depicts the storm track activity on synoptic timescales (not shown). The analysis of the lower tropospheric Eady growth rate [Hoskins and Valdes, 1990], a measure of baroclinicity, further elucidates these changes. Those regions characterized by a decrease in storm track activity during El Niño conditions consistently exhibit a reduction in the Eady growth rate, which can mainly be attributed to a response in the vertical shear of the time mean wind.

From a nonlinear perspective, however, the mean flow itself is affected by changes in transient eddy activity. Therefore we analyze the large-scale response in terms of the barotropic energy conversions [Wallace and Lau, 1985] between the time mean zonal flow and the transient eddies. In both the bandpass-filtered (2.5-6 days) and lowpass-filtered (10-90 days) range the transient-eddy-mean-flow energy exchange is modified in the El Niño experiment. The climatological barotropic production of eddy kinetic energy over the North American continent is reduced, and may in part be related to a strengthening and a more downstream extension of the 200 hPa jetstream. However, since baroclinic production processes might also play a role, no simple causal relationship can be established. The relative role of these processes in determining the mean flow response is subject of current investigations.

We additionally analyzed the Plumb vector [Plumb, 1985], and it reveals a more zonal propagation of stationary wave activity in the North Atlantic sector compared to our control simulation.

4 Discussion and Summary

We found evidence for the hypothesis that increased horizontal resolution might be one step towards simulating a weak but significant impact of the El Niño phenomenon on the North Atlantic-European sector, as seen in observations [Fraedrich and Müller, 1992]. Increased horizontal resolution enables a more realistic representation of the orography and therefore a better simulation of the stationary waves and the synoptic scale transient eddies. In particular, a major improvement due to higher resolution is achieved for the zonally asymmetric components [Stendel and Roeckner, 1998]. An improved representation of the North Atlantic wintertime general circulation with increased horizontal resolution has also been found in sensitivity studies with the ARPEGE AGCM [Déqué and Piedelievre, 1995]. Since the eddy-mean flow interaction is considered to be crucial in determining mid-
latitude dynamical processes, the qualitative and at least partly significant reproduction of the observational results over the North Atlantic/European sector in the T106 experiment (in contrast to T42) may be attributed to the higher horizontal resolution.

We would like to emphasize that the simulated seasonal anomalies over Europe may only be interpreted as a "canonical" response pattern related to El Niño events. One has to take into account that the response in remote regions such as Europe might vary from event to event due to differences between El Niño events [Hamilton, 1988] and may be masked by the large internal variability of the atmosphere in midlatitudes. Large discrepancies, for instance, have been noticed between the observed DJF anomalies over Europe during the 1997/98 El Niño event and the Fraedrich and Müller [1992] composite picture. Furthermore, it still remains to be proven that the mean atmospheric response to La Niña events found by Fraedrich and Müller [1992] may be simulated in an analogous and successful manner.

The North Atlantic Oscillation is a major factor in determining European weather and climate anomalies. It plays an important role for the tracks of the rain-bearing North Atlantic cyclones, which follow a more northerly route during positive NAO extreme winters. Our model results suggest an El Niño-related weakening of the North Atlantic mean meridional pressure gradient and a southward shift of the North Atlantic stormtrack. The simulated response over Europe is consistent with a weakening of the NAO, with wetter conditions over central Europe and the western Mediterranean, and colder temperatures over Scandinavia [Hurrell and van Loon, 1997]. There may exist, however, a decadal modulation of the signal communication between the Pacific and the Atlantic sectors [Raible et al., 2001], so that the seasonal relationship between the tropics and the North Atlantic shown here should also be considered within a low-frequency context.

Acknowledgments

The authors are grateful to Drs. Scot Johnson and Noel Keenlyside on some helpful comments on an earlier version of the paper. This work was supported by the European Union’s DEMETER program.
References


Figure Captions

*Figure 1:* Regression of the global observed seasonal (DJF) SST anomalies onto the DJF Niño3 SST anomaly timeseries, scaled by a factor of 3. This pattern serves as anomalous SST forcing in the T42 and T106 experiments.

*Figure 2:* Seasonal (DJF) ensemble mean response of SLP [hPa]. Note the irregular contour spacing (0, ±1, 2, 3, 4, 5, 7, 10, 15 hPa). Shaded regions indicate significance at the 95% level according to a t-test. a) T42 experiment, b) T106 experiment.

*Figure 3:* Right panels: Seasonal (DJF) ensemble mean response in the T106 experiment of SLP [hPa] (top), air temperature at 850 hPa [K] (middle), precipitation [mm/month] (bottom). Shaded regions indicate significance on the 95% level according to a t-test. For comparison, the results of the composite study by Fraedrich and Müller [1992] are redrawn on the left.

*Figure 4:* Cyclone tracks over the North Atlantic during DJF season from all ensemble members of a) the T106 control ensemble and b) the T106 El Niño ensemble. Shading indicates the smoothed changes in the total ensemble cyclone numbers.
Figure 1: Regression of the global observed seasonal (DJF) SST anomalies onto the DJF Niño3 SST anomaly timeseries, scaled by a factor of 3. This pattern serves as anomalous SST forcing in the T42 and T106 experiments.
Figure 2: Seasonal (DJF) ensemble mean response of SLP [hPa]. Note the irregular contour spacing (0,±1, 2, 3, 4, 5, 7, 10, 15 hPa). Shaded regions indicate significance at the 95% level according to a t-test. a) T42 experiment, b) T106 experiment.
Figure 3: Right panels: Seasonal (DJF) ensemble mean response in the T106 experiment of SLP [hPa] (top), air temperature at 850 hPa [K] (middle), precipitation [mm/month] (bottom). Shaded regions indicate significance on the 95% level according to a t-test. For comparison, the results of the composite study by Frädrich and Müller [1992] are redrawn on the left.
Figure 4: Cyclone tracks over the North Atlantic during DJF season from all ensemble members of a) the T106 control ensemble and b) the T106 El Niño ensemble. Shading indicates the smoothed changes in the total ensemble cyclone numbers.
Report 1-276
Please order the reference list from MPI for Meteorology, Hamburg

Report No. 277
September 1998
Interannual to Decadal Variability in the Tropical Atlantic
Dietmar Dommenget, Mojib Latif
* Journal of Climate, 1998 (submitted)

Report No. 278
October 1998
Application of a grid-scale lateral discharge model in the BALTEX region
Stefan Hagemann, Lydia Dümenil
* Nordic Hydrology, 30 (3), 209-230, 1999

Report No. 279
October 1998
Cyclostationary Circulation Estimation with a Global Ocean Assimilation System
Detlev Müller, Ralf Giering, Uwe Mikolajewicz, Ernst Maier-Reimer

Report No. 280
October 1998
A coarse grid three dimensional global inverse model of the atmospheric transport
1. Adjoint Model and Jacobian Matrix
   Thomas Kaminski, Martin Heimann, Ralf Giering
   * Journal of Geophysical Research, 1998 (submitted)
2. Inversion of the transport of CO₂ in the 1980s

Report No. 281
November 1998
Paleonutrient Data Analysis of the Glacial Atlantic using an Adjoint Ocean General Circulation Model
Arne M. E. Winguth, David Archer, Ernst Maier-Reimer, Uwe Mikolajewicz

Report No. 282
November 1998
The Effect of Environmental Conditions on Volcanic Plume Rise
Hans-F. Graf, Michael Herzog, Josef M. Oberhuber, Christiane Textor
* Journal of Geophysical Research, 1998 (submitted)

Report No. 283
December 1998
Model Simulations of the Changing Distribution of Ozone and its Radiative Forcing of Climate: Past, Present and Future
Geert-Jan Roelofs, Jos Lelieveld, Johann Feichter

Report No. 284
December 1998
Predicting the Number of Cloud Droplets in the ECHAM GCM
Ulrike Lohmann, Johann Feichter, Catherine C. Chuang, Joyce E. Penner
* Journal of Geophysical Research - Atmospheres, 1998 (accepted)

Report No. 285
December 1998
The Role of Ocean Dynamics for Low-Frequency Fluctuations of the NAO in a Coupled Ocean-Atmosphere GCM
Michael Christoph, Uwe Ulbrich, Josef M. Oberhuber, Erich Roeckner

Report No. 286
January 1999
Formation of nitrous acid: Parameterisation and comparison with observations
Gerhard Lammel

Report No. 287
February 1999
Natürliche Senken und Quellen des atmosphärischen Kohlendioxids: Stand des Wissens und Optionen des Handelns
Martin Heimann, Christine Weber, Jan C. Duinker, Arne Körtzinger, Ludger Mintrop, Nina Buchmann, Ernst-Detlef Schulze, Michaela Hein, Alberte Bondeau, Wolfgang Cramer, Marcus Lindner, Gerd Esser

Report No. 288
March 1999
Large-eddy simulation of a nocturnal stratocumulus-topped marine atmospheric boundary layer: An uncertainty analysis
Andreas Chlond, Andreas Wolkau
Boundary-Layer Meteorology, 95,31-55, 2000

Report No. 289
March 1999
Derivation of global GCM boundary conditions from 1 km land use satellite data
Stefan Hagemann, Michael Botzel, Lydia Dümenil, Bennert Machenhauer
A nonlinear impulse response model of the coupled carbon cycle-ocean-atmosphere climate system
Georg Hooss, Reinhard Voss, Klaus Hasselmann, Ernst Maier-Reimer, Fortunat Joos

Rapid algorithms for plane-parallel radiative transfer calculations
Vassili Prigarin

Oceanic Control of Decadal North Atlantic Sea Level Pressure Variability in Winter
Mojib Latif, Klaus Arpe, Erich Roeckner
* Geophysical Research Letters, 1999 (submitted)

A process-based, climate-sensitive model to derive methane emissions from natural wetlands:
Application to 5 wetland sites, sensitivity to model parameters and climate
Bernadette P. Walter, Martin Heimann
* Global Biogeochemical Cycles, 1999 (submitted)

Possible Changes of δ18O in Precipitation Caused by a Meltwater Event in the North Atlantic
Martin Werner, Uwe Mikolajewicz, Georg Hoffmann, Martin Heimann
* Journal of Geophysical Research - Atmospheres, 105, D8, 10161-10167, 2000

Borehole versus Isotope Temperatures on Greenland: Seasonality Does Matter
Martin Werner, Uwe Mikolajewicz, Martin Heimann, Georg Hoffmann
* Geophysical Research Letters, 27, 5, 723-726, 2000

Numerical Modelling of Regional Scale Transport and Photochemistry directly together with Meteorological Processes
Bärbel Langmann
* Atmospheric Environment, 34, 3585-3598, 2000

The impact of two different land-surface coupling techniques in a single column version of the ECHAM4 atmospheric model
Jan-Peter Schulz, Lydia Dümenil, Jan Polcher
* Journal of Applied Meteorology, 40, 642-663, 2001

Long-term climate changes due to increased CO2 concentration in the coupled atmosphere-ocean general circulation model ECHAM3/LSG
Reinhard Voss, Uwe Mikolajewicz
* Climate Dynamics, 17, 45-60, 2001

Tropical Stabilisation of the Thermohaline Circulation in a Greenhouse Warming Simulation
Mojib Latif, Erich Roeckner
* Journal of Climate, 1999 (submitted)

Impact of Global Warming on the Asian Winter Monsoon in a Coupled GCM
Zeng-Zhen Hu, Lennart Bengtsson, Klaus Arpe
* Journal of Geophysical Research-Atmosphere, 105, D4, 4607-4624, 2000

Impacts of Deforestation and Afforestation in the Mediterranean Region as Simulated by the MPI Atmospheric GCM
Lydia Dümenil Gates, Stefan Ließ

Dynamical and Cloud-Radiation Feedbacks in El Niño and Greenhouse Warming
Fei-Fei Jin, Zeng-Zhen Hu, Mojib Latif, Lennart Bengtsson, Erich Roeckner
* Geophysical Research Letter, 28, 8, 1539-1542, 2001
<table>
<thead>
<tr>
<th>Report No.</th>
<th>Date</th>
<th>Title</th>
<th>Authors</th>
<th>Journal</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>303</td>
<td>December 1999</td>
<td>The leading variability mode of the coupled troposphere-stratosphere winter circulation in different climate regimes</td>
<td>Judith Perlwitz, Hans-F. Graf, Reinhard Voss</td>
<td>Geophysical Research, 105, 6915-6926</td>
<td>2000</td>
</tr>
<tr>
<td>306</td>
<td>June 2000</td>
<td>On the Interpretation of Climate Change in the Tropical Pacific</td>
<td>Mojib Latif</td>
<td>Journal of Climate, 2000 (submitted)</td>
<td></td>
</tr>
<tr>
<td>307</td>
<td>June 2000</td>
<td>Observed historical discharge data from major rivers for climate model validation</td>
<td>Lydia Dümenil Gates, Stefan Hagemann, Claudia Golz</td>
<td></td>
<td></td>
</tr>
<tr>
<td>309</td>
<td>August 2000</td>
<td>A Cautionary Note on the Interpretation of EOFs</td>
<td>Dietmar Dommenget, Mojib Latif</td>
<td>Journal of Climate, 2000 (submitted)</td>
<td></td>
</tr>
<tr>
<td>311</td>
<td>October 2000</td>
<td>The impact of a downslope water-transport parameterization in a global ocean general circulation model</td>
<td>Stephanie Legutke, Ernst Maier-Reimer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>313</td>
<td>December 2000</td>
<td>Secular trends in daily precipitation characteristics: greenhouse gas simulation with a coupled AOGCM</td>
<td>Vladimir Semenov, Lennart Bengtsson</td>
<td></td>
<td></td>
</tr>
<tr>
<td>314</td>
<td>December 2000</td>
<td>Estimation of the error due to operator splitting for micro-physical-multiphase chemical systems in meso-scale air quality models</td>
<td>Frank Müller</td>
<td>Atmospheric Environment, 2000 (submitted)</td>
<td></td>
</tr>
<tr>
<td>315</td>
<td>January 2001</td>
<td>Sensitivity of global climate to the detrimental impact of smoke on rain clouds</td>
<td>Hans-F. Graf, Daniel Rosenfeld, Frank J. Nober</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Report No.</td>
<td>Title</td>
<td>Authors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------------------------------------------</td>
<td>--------------------------------------------------------------------------------------------------</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>316</td>
<td>Lake Parameterization for Climate Models</td>
<td>Ben-Jei Tsuang, Chia-Ying Tu, Klaus Arpe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>318</td>
<td>On North Pacific Climate Variability</td>
<td>Mojib Latif</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>319</td>
<td>The Madden-Julian Oscillation in the ECHAM4 / OPYC3 CGCM</td>
<td>Stefan Liess, Lennart Bengtsson, Klaus Arpe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>321</td>
<td>Impact of the Vertical Resolution on the Transport of Passive Tracers in the ECHAM4 Model</td>
<td>Christine Land, Johann Feichter, Robert Sausen</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>322</td>
<td>Summer Session 2000 Beyond Kyoto: Achieving Sustainable Development</td>
<td>Edited by Hartmut Graßl and Jacques Léonardi</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>323</td>
<td>An atlas of surface fluxes based on the ECMWF Re-Analysis-a climatological dataset to force global ocean general circulation models</td>
<td>Frank Röske</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>324</td>
<td>Long-range transport and multimedia partitioning of semivolatile organic compounds: A case study on two modern agrochemicals</td>
<td>Gerhard Lammel, Johann Feichter, Adrian Leip</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>325</td>
<td>A High Resolution AGCM Study of the El Niño Impact on the North Atlantic / European Sector</td>
<td>Ute Merkel, Mojib Latif</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Reprinted in Journal of Climate, 2001 (submitted)

* Reprinted in Climate Dynamics, 2001 (submitted)

* Reprinted in Paleoceanography, 2001 (submitted)

* Reprinted in Tellus, 2001 (submitted)


* Reprinted in Geophysical Research Letters, 2001 (submitted)