Jenkinson-Collison classifications as a method for analyzing GCM-scenario pressure fields, with respect to past and future climate change and European simulated mineral dust deposition.

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1. Purpose of the visit

The first goal of this visit is to construct the Jenkinson-Collison Weather Type Scheme, initially developed for the British Isles, with a grid centred above Belgium. The method was designed as an automatic version of Lamb's classification. Previous studies and applications are for example described in Trigo & Dacamara (2000), Post *et al.* (2002), Buishand & Brandsma (1996), Fowler & Kilsby (2002) and Buchanan *et al.* (2002). Normally, local meteorological station measurements are used to establish the relations between weather types and local surface characteristics, while daily gridded fields of SLP from NCEP/NCAR or ECMWF reanalysis data provide the pressure input for the JC-scheme. This research will use the ECMWF ERA40-reanalysis data as well as sea level pressure fields from the ECHAM5-AGCM model, developed at the Max-Planck Institute for Meteorology in Hamburg. It is the 5th-generation climate model, evolved from the model of the European Centre for Medium-Range Weather Forecasts (ECMWF). ECHAM5 solves prognostic equations for vorticity, divergence, surface pressure and temperature expressed in terms of spherical harmonics with a triangular truncation. Water vapour, cloud liquid water, cloud ice and trace components are transported with a flux form semi-Lagrangian transport scheme on a Gaussian grid. ECHAM5 contains a new microphysical cloud scheme with prognostic equations for cloud liquid water and ice. Cloud cover is predicted with a prognostic-statistical scheme solving equations for the distribution moments of total water. More detailed information on ECHAM5 can be found in Roeckner *et al.* (2003, 2004).

The 1961-2000 ERA40 period will be used to evaluate the ECHAM5 capabilities in simulating the sea level pressure fields. Afterwards, climatological trends based on the Jenkinson-Collison weather types will be calculated for the period 1860-2100, including a comparison between the A1B, B1 and A2 IPCC scenarios for the 2000-2100 time period. Furthermore, monthly mineral dust values will be correlated with mean monthly Jenkinson-Collison weather type occurrences. Finally, the relation of the JC circulation types with the NAO-index is investigated. The NAO index is either based on observed normalized pressure differences between Ponta Delgada and Iceland (Hurrel, 2003), or similarly on simulated normalized pressure differences between the respective ECHAM5 grid cells (Latif *et al.,* 2000). Following the above-mentioned, there are 4 main goals and therefore four main work packages a) grid sensitivity b) Evaluation of ECHAM5 to ERA40 for the 1961-2000 time period based on weather types c) Investigation of possible past and future climatic trends d) correlation of the weather types to the NAO-index and e) correlation to the modeled mineral dust concentration trends above Central Europe. Hereafter, the datasets and methods are described respectively in Chapter 2 and 3, followed by the main results for each of these work packages in Chapter 4. Chapters 5 and 6 describe possible future collaboration with the host institute and projected publications of these STSM research results.

2. Description of the datasets

a. Sea Level pressure datasets

The ECMWF - ERA40 SLP dataset was selected on a 2.5°x2.5° grid, for the larger European Atlantic Region (27.5°W-30°E, 85°N-15°N), centered above Belgium. The 6 hourly SLP values are averaged over a 24 hourly period resulting in daily mean sea level pressure fields for the period 1961-2000. The fields are also converted to seasonal and yearly means, which enables us to calculate different statistics and evaluate the ECHAM5 SLP fields. Global ECHAM5 SLP datasets are provided by the MPI for meteorology in Hamburg for 1860 to 2100 (Roeckner *et al.*, 2003, 2004). The last 100 year time span 2000-2100 encompasses 3 IPCC scenarios A1B, B2 and A2, each for which SLP fields are available. Pressure data for an area similar to the selected ECMWF-ERA40 region is extracted and re-gridded by conservative remapping to a 2.5° by 2.5° grid. The same preprocessing is done as for the ECMWF-ERA40 dataset, enabling a comparable evaluation.

b. NAO – indices

The annual index of the NAO is based on the difference of normalized sea level pressure (SLP) between Ponta Delgada (37.7°N, 25.7°W), Azores and Stykkisholmur (65°N, 22.8°W) / Akureyri (65.7°N, 18.1°W), Iceland since 1865. The SLP anomalies at each station are normalized by division of each annual mean pressure by the long-term mean (1865-1984) standard deviation (Hurrel, 2003). Seasonal NAO indices (DJF, MAM, JJA, SON) are calculated similarly, normalized by division of each seasonal mean pressure by the long-term mean (1865-1984) standard deviation. All above-mentioned datasets are available on http://www.cgd.ucar.edu/cas/jhurrell/indices.html.
The modeled annual and seasonal NAO index was calculated following the method of Hurrel (2003). The nearest grid cell to both Ponta Delgada and Stykkisholmur are selected and normalized pressure differences are calculated between 1860 and 2100, with the A1B scenario as input for the last century. The model response is then compared to the observational NAO index for the whole period. Using the Jenkinson-Collison weather type groups, correlations are calculated between weather type groups and seasonal and annual NAO indices, as well for observations as for simulated values. Afterwards, a comparison is done between both modeled and observed correlations.

c. Simulated Mineral Dust concentration

The microphysical aerosol module HAM, integrated in the ECHAM5 AGCM, depends on the ECHAM5 wind speed and hydrological parameters to calculate the emissions of mineral dust. The dust aerosol spectrum is represented by two log-normal distributed distributions (modes), whereby the modes of the aerosols are composed either of compounds with no or a very low water solvability, denoted as insoluble mode (I) or by a mixture of both insoluble and soluble compounds, which are denoted as soluble (S). Freshly emitted dust is assumed insoluble and due to coagulation, thermo- dynamical processes and cloud processing, the internal mixing mode of the mineral dust can be changed. A full description of the dust schemes used and their evaluation results is beyond the scope of this report and can be found in Tegen *et al.* (2002) and Stier *et al.* (2005). The deposition module calculates dry deposition, wet deposition and sedimentation for each mode of the mineral dust fraction. Dry deposition is calculated as the product of the surface layer concentration and the dry deposition velocity, sedimentation velocities are based on the Stokes velocity and wet deposition is depending on the fraction of scavenged tracers that are calculated from the in-cloud content utilizing the precipitation formation rate of the ECHAM5 cloud scheme. Scavenging ratios for wet deposition are different for stratiform and convective clouds (Tegen *et al.,* 2002). Unfortunately, the mineral dust data is only available as monthly means for the whole time period. Comparing daily mineral dust concentrations with daily derived weather types was not possible. Instead, monthly values are correlated to averaged monthly occurrences of Jenkinson-Collison weather types for each directional weather type group.

3. Methods

The Jenkinson-Collison circulation pattern for a given day is described using the locations of the centers high and low pressure that determine the direction of the geostrophic flow. It uses coarsely gridded pressure data on a 16-point moveable grid, and is therefore easily applicable in any area with available data. This method allows 27 different classification weather types to be defined. These types are characterized through the use of a set of indices associated to the direction and vorticity of geostrophic flow. The indices used were the following: southerly flow (SF), westerly flow (WF), total flow (F), southerly shear vorticity (ZS), westerly shear vorticity (ZW) and total shear vorticity (Z). These indices were computed using sea level pressure (SLP) values obtained for the 16 grid points. The weather types are defined by comparing values of FF (strength of flow) and Z:

- Direction of flow is given by $\tan^{-1}$ (W/S), 180° being added if W is positive. The appropriate wind direction is computed using an eight-point compass, allowing 45° per sector.
- If |Z|<FF, flow is essentially straight and considered to be of a pure directional type (eight different possibilities according to the compass directions).
- If |Z|>2FF, the pattern is considered to be of a pure cyclonic type if Z>0, or of a pure anticyclonic type if Z<0.
- If FF<|Z|<2FF, flow is considered to be of a hybrid type and is therefore characterized by both direction and circulation (16 different types).

Threshold values of Z and FF are used to define whether a day is allocated as unclassified or not. Values of Z and FF don't show any clustering or grouping, which is in line with the findings of Goodess (2000). Therefore, the implementation of another more useful cut-off point for the central European region is not appropriate and hence a value of 6 was retained (Jones *et al.*, 1993).

The analysis results in 26 +1 different weather types. Because of the fact that a typing scheme is constructed to result in circulation types each with a characteristic synoptic pattern and surface flow and because the aim of this paper is to investigate if Jenkinson-Collison weather types are able to explain past, present and future trends in mineral dust loading above Central Europe, the 27 types are classified according to their directional characteristics, which results in 8 directional types (e.g. N(d) = N, CN, AN) 2 pure vorticity types A and C and the unclassified U type, so 11 types in total. This method described above will be used to allocate weather types to each day for the ECMWF-ERA40 1961-2000 and the ECHAM5 1860-2100 periods. For each day SLP pattern maps are visualized and will be made available online in the near future.

4. Results and evaluation

a. Grid sensitivity of the Jenkinson-Collison Scheme

First, a sensitivity test is done using various number of grid points and different grid configurations. Originally, the grid was set up consisting of 9 grid points with a 10° resolution in zonal and a 5° resolution in meridional directions (Dessouky & Jenkinson, 1977). One could expect that grid size and resolution play an important role in the allocation of weather types, moreover in the number of unclassified days. The latter should be minimized for the investigated period. Eight sensitivity runs are set up, differing in number of grid points (9, 16, 32) and grid resolution (2.5°, 5° and 10°). A sensitivity run with a 10° resolution on a 32 point grid is neglected because the area described by such a configuration highly exceeds the region of interest. The grid spatial scale needs to be related to the typical scale of synoptic weather systems. This explains the overall bad results of the 2.5° runs. R9_2.5° doesn't even capture any weather system, and classifies each day as pure anticyclonic, which explains the non-existence of unclassified days. The number of unclassified days decreases with a decreasing grid resolution, with an optimal grid configuration consisting of 16 grid points on a 10° grid resolution. While differences between the 5° and 10° grid resolution for 16 grid points are small and previous studies (Trigo & Dacamara, 2000; Post *et al.,* 2002; Buishand & Brandsma, 1996; Fowler, H.J. & Kilsby, C.G., 2002 and Buchanan *et al.*, 2002) used the R16_5 grid concept, this study applies the R16_5 grid, enabling the opportunity to compare the results to former studies.

b. Evaluation of ECHAM5 SLP fields using ECMWF - ERA40 data

Frequencies of weather types are calculated using both ECMWF-ERA40 and ECHAM5 pressure fields as input for the period 1961-2000. Overall, ECHAM5 fields result in lower number of unclassified days, both yearly and seasonal, which could suggest that ECHAM5 pressure patterns have more pronounced synoptic characteristics. The yearly mean frequencies for east directional groups NE(d) and E(d) are lower for ECHAM weather types, and slightly higher for the SE(d) direction. Contrary, SW(d) and W(d) are lower for ECMWF-ERA40 data compared to ECHAM5. From a seasonal point of view, the largest differences occur during the summer season JJA, with a negative relative difference of 3.8% and 4.7% between ECHAM5 and ERA40 for the JJA NE(d) and E(d) directional groups respectively and a positive relative difference of 0.7%, 4% and 14% for the JJA S(d), SE(d) and E(d) respectively. Differences during spring (MAM) show a similar difference trend as in summer. Contrarily, larger differences for the pure (anti)cyclonical types occur in winter, with a higher mean frequency of cyclonical days (C) and a lower mean frequency of anticyclonic days (A) for ECHAM5 data. Based on these facts one could state that ECHAM5 overall succeeds fairly well in capturing the mean quantities of Jenkinson-Collison weather types over the whole period, except for eastern and western directional groups. The discrepancies depend on spring and summer weather type occurrences of eastern and western types that are significantly higher and lower for the ECHAM5 – ERA40 comparison, respectively. This statement is also supported by the mean number of Jenkinson-Collison types for each month over the whole observational period. Except for the pure anti(cyclonical) types, discrepancies between the mean number of days for each type and month are largest for late spring and summer. Simulated weather types broadly reproduce the observed weather types quantities for the October-November-December-January-February-March (ONDJFM) period. Non-negligible differences for the April-May-June-July-August-September (AMJJAS) period are found, where ECHAM5 overestimates (underestimates) the number of westerlies (easterlies). Because of these differences, further research is focused on the ONDJFM period. This is also consistent with the aim of correlating ECHAM NAO indices with observed NAO-indices, since the winter season shows the strongest interdecadal variability and the strongest influence of the NAO on surface climate (Osborn *et al.*, 1999).

Mean sea level pressures are calculated for the period 1961-1980, 1981-2000 and 1961-2000, for the ONDJFM period, only. Generally, the SLP shows similar patterns for ECHAM5 and ERA40, although values differ regionally. ECHAM5 overestimates pressure patterns over the Sahara region and northern parts of Scandinavia, with pressure differences up to respectively 3 and 4.5 hPa, whereas winter pressure patterns are underestimated from Central Europe to the Northwest region of Ireland, with differences up to 2 hPa.

Furthermore, an ECHAM5 – ERA40 evaluation can be done displaying weather type trends for the 1961-2000 period, again for the selected ONDJFM period. For the pure (anti)cyclonic and the 8 directional weather type groups, linear trends are plotted. Two other groups are defined, combining the three western directional groups SW(d), W(d) and NW(d) and the three eastern directional groups SE(d), S(d) and NE(d) into an All-West and All-East group, respectively. For each year the number of days per type is accumulated and all observed years are used to construct the related weather type time series. Overall, the model simulates the observed trends reasonably well for all directional weather type groups. Contrarily, ECHAM5 fails to reproduce the trends for the anticyclonic types and the All-West and All-East weather type groups. Discrepancies between the ECHAM5 and ERA40 trend for the latter are fully explained by the difference in the directional West group W(d) (directional East group E(d)), whereas there is a good agreement for the NW(d) and SW(d) (NE(d) and SE(d)) groups. While ECHAM5 is predicting a constant trend in westerlies, ERA40 shows an increase of 20 extra allocated W(d) days over a 40 year period. For the anticyclonic group, both trends are similar whereby the difference is only caused by the number of anticyclonic weather types.

c. Climatic trends in Jenkinson-Collison Weather Types

The chosen set of ECHAM5 simulations covered not only the ERA40 period, but also climate change experiments with observed atmospheric greenhouse and aerosol concentrations since 1860 and climate change scenario experiments based on different assumptions on future greenhouse gas and aerosol concentrations. The scenarios A1B, B1, and A2 are used in this study and provide data until 2100. Following the IPCC report 2001, scenario A1B describes the future with a fast economic growth, a world population that peaks in the mid-century and declines afterwards and new and more efficient technologies. The 'B' in A1B denotes the sub-scenario where all energy sources are balanced, i.e. in which a community not to heavily relies on one energy source, only. The scenario B1 is described by a similar population curve as A1B, but with an emphasis on global solutions to economic, social and environmental sustainability, including improved equity. The last scenario A2 differs herein that population continues growing through the century with a regionally developing economic growth and fragmented technological changes (Climate Change 2001: Synthesis Report, Summary for policymakers). For each weather type group and scenario, the mean number of occurrences is calculated for the 2001-2100 period. Trends are calculated for the 8 directional and 2 pure (anti)cyclonic weather type group between 2001-2100 and the differences between the various scenarios A1B, B1 and A2. Within each directional weather type group, trends for scenarios A1B, B1 and A2 are similar over the whole period. Year-to-year variability is different, as one could expect due to the use of different socio-economical developments. Small discrepancies can be found for the pure (anti)cyclonical group, with a similar linear trend curve for the A1B and B1 anticyclonical group compared to a larger increase for the A2 anticyclonical group. Similar results, but reversed, are found for the cyclonical group. The linear trend for the A1B and B1 curve are similar, though with a different intercept, whereas the trend is decreasingly stronger for the A2 cyclonic linear trend curve. Because long-term differences between the various scenario trends based on weather types are small, this study will continue its focus on the scenario A1B, only. Trends can be seen over the whole 240 year period, expanding from 1860 till 2100, selecting ONDJFM months, only. Linear trends for directional groups N(d), NE(d), SE(d), S(d), SW(d) and NW(d) show a steady trend over the whole time period. A small negative trend can be seen for the E(d) as well as for the pure cyclonic type C. This decrease is compensated by a minor increase in A(d) and a larger increase of W(d), resulting in an absolute mean increase of almost 73 extra days of westerly flow W(d) over central Europe during the months ONDJFM. Again, a great year-to-year variability can be seen for all directional groups.

d. Correlation between JC-types and NAO

The most prominent mode of atmospheric variability over the North Atlantic Ocean affecting the climate of North America, Europe and parts of Africa is the North Atlantic Oscillation (NAO) (Latif *et al.*, 2000 and references therein). Since the 1960's, a contemporaneous trend towards a positive phase of the oscillation has been observed in winter. Much research has been done on the influence of alternatively positive or negative NAO shifts on a variety of climatological parameters as temperature precipitation, cloud cover variations etc. Hurrel (1996) related the last 40 years shift towards a positive NAO index with a trend in increasing Northern Hemisphere land temperatures. This shift towards a positive phase implies low pressure anomalies in the region of the Icelandic low and anomalous high pressure in the Azores high region (Trigo *et al.*, 2002). Although the Jenkinson-Collison grid scheme doesn't capture the whole Azores – Icelandic area, anomalies in pressure patterns should also be reflected in Jenkinson-Collison weather type changes. A shift towards a positive winter NAO-index implies an enhancement of the meridional Atlantic pressure gradient, contributing to an increase in winter westerlies. To analyze whether Jenkinson-Collison weather types reflect past, present and future trends in the NAO-index, the computed NAO-index based on ECHAM5 simulated sea level pressure fields is compared to the observed NAO index for the period 1865 to 2000. Further research on annual and seasonal NAO correlation with directional Jenkinson-Collison Weather Types is planned and results will be presented in the near future (Chapter 6).

e. Correlation between JC-types and modeled mineral dust concentrations

Mineral dust emissions show an increase of about 10% towards the end of the integration period near 2100 (Stier *et al.*, 2005) as compared to present values. As the mineral dust emission scheme depending on ECHAM5 wind speed and hydrological parameters assumes constant preferential source areas and vegetation cover (Tegen *et al.*, 2002, 2004), this is likely to be a lower estimate. Whether this climatological trend is also found in dust depositions over the central European region between 1860 and 2100 during the period ONDJFM is evaluated by visualizing 40-year period mean mineral dust concentrations (1861-2000, 1961-2000, 2061-2100) and the absolute deposition differences between these three periods. In combination with these mineral dust plots, identical time averages are plotted for ECHAM5 SLP patterns. In addition, year-to-year, decade-to-decade and climatological (all period means) mineral dust deposition concentrations are correlated with the derived weather types. Thereby, source areas and particular wind directions for high mineral dust depositions are investigated for various time scales. Because late spring and early summer emissions from the Sahara are likewise assumed to be contributors the overall mineral dust deposition over Central Europe, the same will be done for the AMJJAS period. This work is still in progress and will be completed in the near future.

5. Future collaborations with host institution

In the near future, results will be extended and sharpened. Data access to the MPI for Biogeochemistry server computer in Jena is still guaranteed to fulfill this task. Furthermore, contact is set up with Dorothea Banse, a Ph D student working at the MPI in Hamburg, performing research on storm track frequencies based on the ECHAM5 simulations. Possible confirmation of this study's results by the independent work of D. Banse is evaluated. Support on mineral dust processes and deposition is given by Dr. Ina Tegen, employed at the Institute for Tropospheric Research in Leipzig.

A second, (continued) phase of this research project could involve a downscaling approach of the ECHAM5 data. The ECHAM5 scenarios could serve as initial and boundary conditions for the non-hydrostatic mesoscale model ARPS (Advanced Regional Prediction Model). Suited ARPS simulations will produce local surface meteorological characteristics which can be compared to local meteorological station measurements. Again, circulation patterns can be derived and connections can be set with these derived local surface weather elements. This second part could be performed in my home institute, the Catholic University of Leuven (Belgium) in the framework of my PhD and of the COST 733 action.

6. Projected publications/congress attendances

Although Jenkinson-Collison weather types are already derived for the British Isles on a continuous base, this was until now not done with the grid centered above Belgium. This objective is now reached and in the near future, online daily Jenkinson Collison weather types will be calculated online and presented on the authors personal research webpage (http://perswww.kuleuven.be/matthias_demuzere - under construction).

Secondly, an abstract is submitted and accepted for the EGU 2006 conference in Vienna on 2-7 April. The abstract is entitled "Trend analysis of circulation types and their influence on the present and future mineral dust cycle over Central Europe" Demuzere, M., Werner, M. and Van Lipzig, N., scheduled for the session “Anthropogenic climate changes: forcing, modeling, detection and impact (CL012)”, which is convened by Dr. Li, L. and Dr. Roeckner, E. The latter is one of the senior scientists responsible for the ECHAM5 simulations at the MPI for Meteorology in Hamburg. Furthermore, an article will be written, summarizing all the results achieved during the STSM in Jena. In addition, results will be presented on the special COST733 website as written in the Progress Report of the Technical Committee.

7. Confirmation by the host institute of the successful execution of the mission

“I hereby state that the analyses and results presented in this report have been the focus of Matthias Demuzere’s work during his COST STSM stay at the Max-Planck-Institute for Biogeochemistry, Jena (November 2005 – February 2006). M. Demuzere has proven to be a mature Ph.D. candidate who has worked in a very responsible and self-determined approach on the selected topics. His scientific results on the capability of the ECHAM5 GCM in simulating weather types over Europe in agreement with available ERA40 observational data are highly valuable for the evaluation of one of the leading climate models used for the upcoming next IPCC Assessment Report. Overall, I rate M. Demuzere’s achieved scientific work as very good – it was a real pleasure to supervise him during his stay in Jena.” – M. Werner, MPI-BGC Jena, 2006.

8. Comments

First of all, I would like to thank the COST733 chair Dr. Ernst Dittmann and the whole Management Committee for the chance they gave me to collaborate with the Max Planck Institute for Biogeochemistry in Jena. Of course I would like to acknowledge Dr. Martin Heimann of the MPI for his agreement of this STSM, and last, but definitely not least, Dr. Martin Werner, who supervised me during this research and gave some constructive comments on how to use various techniques and ECHAM5-HAM datasets. I hope that these findings will help in the search for a harmonized general numerical method for assessing, comparing and classifying typical weather situation in Europe. I do believe that these results support the use of weather types in verification of past, present and future general circulation modeled data, in climatological research and air quality/environmental variables. Of course this research is limited to one type of classification, but these results can give perspective to future comparative studies.

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