

MODEl INItialisation by partially coupled spin-up (MODINI)

Schlussbericht zu Nr. 3.2

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Anlage 2
(zu Nr. 3.2 BNBest-BMBF 98)

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I. Kurze Darstellung

1. Aufgabenstellung

The objective of MODINI was “to develop a new method to initialize the ocean and sea ice components of a coupled climate model for subsequent decadal prediction of the climate system. The method is aimed to be simple and cost effective as well as flexible. The project will test the skill and the predictive potential with such initialization and can potentially become part of an operational system for decadal climate predictions.”

2. Voraussetzungen, unter denen das Vorhaben durchgeführt wurde

This report covers the part of the project that was based at the GEOMAR Helmholtz Zentrum für Ozeanforschung Kiel, an excellent research environment.

3. Planung und Ablauf des Vorhabens

The GEOMAR part of the project was planned and implemented by Prof. Dr. Richard Greatbatch in cooperation with Prof. Dr. Rüdiger Gerdes at the Alfred Wegener Institute (AWI) in Bremerhaven.

4. Wissenschaftlicher und technischer Stand, an den angeknüpft wurde

An important aspect of decadal climate prediction is the necessity of capturing and predicting internal modes of variability that evolve on decadal and longer times scales. Examples of such

variability are the Pacific Decadal Oscillation (PDO; e.g. Trenberth and Hurrell, 1994), the Atlantic Multidecadal Variability (e.g. Kushnir, 1994; Enfield et al., 1999; Dimu and Lohmann, 2007) and other shorter time scale, but still decadal modes of variability, in the North Atlantic climate system (e.g. Deser and Blackmon, 1993; Eden and Greatbatch, 2003). Indeed, the importance of internal variability sets decadal prediction apart from scenario calculations that try to look several hundred years into the future. For these calculations, estimates of boundary conditions like expected changes in the greenhouse gas concentration, land use and water management play a fundamental role. The changing boundary conditions can also be important on decadal time scales. However, decadal prediction is only useful when a substantial part of the natural variability can be captured. This requires initialization of a climate model with a realistic state description that contains information about the tendencies in heat and fresh water reservoirs to introduce the correct phase of natural oscillations into the climate model (Eden, Greatbatch and Lu (2002) provide an example). Indeed, all the early attempts at decadal climate prediction emphasise the importance of the initialisation of the ocean/ice system for determining the quality of the forecast (see e.g. Smith et al., 2007; Keenlyside et al., 2008)

5. Zusammenarbeit mit anderen Stellen

The project involved Prof. Dr. Rüdiger Gerdes at AWI in Bremerhaven.

II. Eingehende Darstellung

1. Verwendung der Zuwendung und erzielttes Ergebnis im Einzelnen, mit Gegenüberstellung der vorgegebenen Ziele

The idea behind MODINI is to create an initialization run by replacing the wind stress seen by the ocean component of a coupled climate/forecast model by the time series of the observed wind stress (anomalies) and then to use the resulting model state to initialize forecasts carried out using the free running coupled model. A necessary prerequisite is that these initialization runs reproduce the variability of the observed climate system. We have shown that the initialization runs have skill at reproducing ENSO events, the Pacific Decadal Oscillation, and part of the variability of the East Asian Summer Monsoon (EASM; Ding et al., 2014a) and the Southern Annular Mode (SAM; Ding et al., 2015). We have also used the initialization runs to interpret the changing relationship on interdecadal time scales between ENSO and each of the EASM and the SAM (Ding et al., 2014a, 2015). The success of MODINI rests on its ability to reproduce ENSO and the associated teleconnection patterns. This means that the initialization runs not only have skill in the ocean, but also in the atmosphere despite the fact that the only information about observations that is given to the model is the time series of observed wind stress that is used to drive the ocean component of the coupled model. The results reported above were carried out using the Kiel Climate Model (KCM; Park et al., 2009) but MODINI has also been implemented in the MPI-ESM by Malte Thoma at AWI with similar success (Thoma et

al., 2015a). We have also shown that MODINI has skill as an initialization for historical forecasts (i.e. hindcasts). Indeed, in Ding et al. (2013) we show that initialised with MODINI, the KCM has a skill at hindcasting the 1976/77 and 1998/99 climate shifts in the Pacific sector. Furthermore, the hindcast results obtained using the MPI-ESM model indicate that hindcasts initialized by MODINI have skill similar to that of the baseline1 and prototype MiKlip prediction systems over much of the globe over a wide range of lead times, with better performance over the Pacific sector, including skill in the Pacific sector for years 2-5 and 6-9 for which the baseline0, baseline1 and prototype systems exhibit no skill (Thoma et al., 2015b). Thoma et al. (2015b) also show that they are able to hindcast the global warming hiatus (Kosaka and Xie, 2013) when the MPI-ESM is initialized by MODINI, something the MiKlip system is not able to do. In Thoma et al. (2015b), we also make a forecast that is initialized using MODINI on January 1, 2015. The results successfully predict the large 2015 El Niño, that global mean surface air temperature will break a new record 2015 (also now substantiated), and also predict an end to the global warming hiatus.

Compared to the standard methods used by MiKlip for initialization (baseline0, baseline1 and prototype), it is only in Year 1 that initialisation by MODINI gives a poorer performance and then, only in the Atlantic sector (Thoma et al., 2015b). To remedy this, we have implemented a technique whereby NAO-related heat flux anomalies are added to the heat flux seen by the ocean component of the KCM, following the idea of Eden and Jung (2001). Run in this way, KCM shows skill at reproducing interannual SST variability in the North Atlantic but shows poor performance when comparing the model Atlantic Multidecadal Variability (AMV) with the observed AMV. One reason for this failure is the subpolar North Atlantic cold bias in the KCM (a common feature of coupled climate models, including MPI-ESM), an issue addressed in Drews et al. (2015). However, using a Canonical Correlation Analysis (CCA), applied to the model Atlantic Meridional Overturning Circulation (AMOC) and observed SST, shows that our modelling system actually does have skill at reproducing the observed AMV (the CCA effectively corrects the model SST for the bias) and the model AMOC variability can, in turn, be used to forecast the AMV into the future (Klöwer et al., 2014).

2. Die wichtigsten Positionen des zahlenmäßigen Nachweises

- Personnel: 171.913,12 € (in particular, Martin Claus)
- Inland travel: 2.187,95 € (e.g., to attend MiKlip Seminars and Module Meetings)
- Foreign travel: 3.835,03 € (e.g. EGU in Vienna)

3. Notwendigkeit und Angemessenheit der geleisteten Arbeit

The work that has been carried out is entirely consistent with the original proposal and makes an important contribution to MiKlip through (i) the illustration of the utility of a very simple way to initialize a coupled atmosphere/ocean/sea-ice model for decadal predictions and (ii)

demonstrating that there is useful predictability in the Pacific sector (including the associated atmospheric teleconnections from the equatorial Pacific) on time scales out to decadal. Regarding (ii), we demonstrated skill in the Pacific sector, and the global mean surface air temperature, that was not present in the MiKlip system in phase 1.

4. Voraussichtlicher Nutzen, insbesondere Verwertbarkeit des Ergebnisses im Sinne des fortgeschriebenen Verwertungsplans

The results are important for the next phase of MiKlip, demonstrating the potential for predictive skill in the Pacific sector out to decadal time scales.

5. Während der Durchführung des Vorhabens dem ZE bekannt gewordener Fortschritt auf dem Gebiet des Vorhabens bei anderen Stellen

Probably the best operational seasonal prediction system today is the one being run by UK Met Office. A feature of their system is the care they take over initialization in the equatorial region, as exemplified by the work on Bell et al. (2004). These authors introduce the “pressure correction method”, a technique for adjusting the initialized state of a coupled forecast model to ensure it is dynamically consistent in the equatorial zone. The equatorial zone is special because this is the one place where the Coriolis force due to the Earth’s rotation goes to zero, geostrophic balance breaks and the zonal pressure gradient in the ocean is largely balanced by the zonal wind stress. The “pressure correction method” is an integral part of the Met Office forecast system and has recently been improved upon as described in an article by Waters et al. that is submitted to the Quarterly Journal of the Royal Meteorological Society. Using the time series of observed wind stress to initialize the forecast model, as in MODINI, already ensures that the correct balance is achieved between the zonal pressure gradient in the ocean component of the forecast model and the zonal wind stress used for initialization, an advantage over initializing the ocean and atmosphere components separately.

6. Erfolgte oder geplante Veröffentlichungen des Ergebnisses nach Nr. 11.

The following publications have so far resulted from this work with at least one more in preparation:

Ding, H., R. J. Greatbatch, M. Latif, W. Park, and R. Gerdes, 2013: Hindcast of the 1976/77 and 1998/99 Climate Shifts in the Pacific., *J. Clim.*, 26, 7650–7661, doi:10.1175/JCLI-D-12-00626.1.

Ding, H., R.J. Greatbatch, W. Park, M. Latif, V. Semenov, V. and X. Sun, 2014: The variability of the East Asian Summer Monsoon and its relationship to ENSO in a partially coupled climate model., *Clim. Dyn.*, 42, 367-379, doi:10.1007/s00382-012-1642-3.

- Ding, H., R.J. Greatbatch and G. Gollan, 2015: Tropical impact on the interannual variability and long-term trend of the Southern Annular Mode during austral summer from 1960/1961 to 2001/2002., *Clim. Dyn.*, 44 (7-8), 2215-2228, doi:10.1007/s00382-014-2299-x.
- Drews, A., R.J. Greatbatch, H Ding, M. Latif and W. Park., 2015: The use of a flow field correction technique for alleviating the North Atlantic cold bias with application to the Kiel Climate Model., *Ocean Dynamics*, 65, 1079-1093. doi: 10.1007/s10236-015-0853-7
- Klöwer, M., Latif, M., Ding, H., Greatbatch, R. J. and Park, W. (2014) Atlantic meridional overturning circulation and the prediction of North Atlantic sea surface temperature, *Earth and Planetary Science Letters*, 406, 1-6. doi: 10.1016/j.epsl.2014.09.001.
- Thoma, M., R. Gerdes, R.J. Greatbatch and H. Ding, 2015a: Partially coupled spin-up of the MPI-ESM: implementation and first results., *Geosci. Model Dev. Discuss.*, 8, 51-68, doi:10.5194/gmd-8-51-2015.
- Thoma, M., R.J. Greatbatch, C. Kadow and R. Gerdes, 2015b: Decadal hindcasts initialised using observed surface wind stress: Evaluation and Prediction out to 2024, *Geophys. Res. Lett.*, 42 (15), 6454-6461. doi: 10.1002/2015GL064833.

III. Kurzgefasster Erfolgskontrollbericht (wird nicht veröffentlicht)

1. Beitrag des Ergebnisses zu den förderpolitischen Zielen

MODINI war ein Beitrag zum Modul A (Initialisierung) von MiKlip, einem Programm, das auf die Entwicklung dekadischer Vorhersagesysteme abzielt, die perspektivisch vom Deutschen Wetterdienst betrieben werden sollen. MODINI hat gezeigt, dass im Pazifischen Sektor Vorhersagepotential existiert, das bislang nicht im in Phase 1 entwickelten MiKlip-System vorhanden war. Ferner hat MODINI den Nutzen eines einfachen Initialisierungsschemas für dekadische Vorhersagen demonstriert.

2. Wissenschaftlich-technisches Ergebnis des Vorhabens, erreichte Nebenergebnisse und gesammelte wesentliche Erfahrungen

Der ursprüngliche Plan beinhaltete nicht, dass Vorhersagbarkeit im Pazifischen Sektor untersucht werden soll. Dennoch haben die historischen Vorhersagesimulationen, die mit MODINI initialisiert wurden, genau dies gezeigt.

3. Fortschreibung des Verwertungsplans

- Erfindungen/Schutzrechtsanmeldungen und erteilte Schutzrechte, die vom ZE oder von am Vorhaben Beteiligten gemacht oder in Anspruch genommen wurden, sowie deren standortbezogene Verwertung (Lizenzen u. a.) und erkennbare weitere Verwertungsmöglichkeiten,

Nicht anwendbar.

- Wirtschaftliche Erfolgsaussichten nach Projektende (mit Zeithorizont) - z. B. auch funktionale/wirtschaftliche Vorteile gegenüber Konkurrenzlösungen, Nutzen für verschiedene Anwendergruppen/-industrien am Standort Deutschland, Umsetzungs- und Transferstrategien (Angaben, soweit die Art des Vorhabens dies zulässt),

Die Ergebnisse von MODINI fließen direkt in das MiKlip-Projekt ein, das darauf abzielt, ein dekadisches Vorhersagesystem zu entwickeln, welches von potentiell wirtschaftlichen Nutzen für die Bundesrepublik Deutschland und für weitere Staaten ist.

- Wissenschaftliche und/oder technische Erfolgsaussichten nach Projektende (mit Zeithorizont) - u. a. wie die ge-planten Ergebnisse in anderer Weise (z. B. für öffentliche Aufgaben, Datenbanken, Netzwerke, Transferstellen etc.) genutzt werden können. Dabei ist auch eine etwaige Zusammenarbeit mit anderen Einrichtungen, Firmen, Netzwerken, Forschungsstellen u. a. einzubeziehen,

Die Ergebnisse von MODINI fließen direkt in die zweite Phase von MiKlip ein und bilden darin die Basis des neuen Projektes ATMOS/MODINI.

- Wissenschaftliche und wirtschaftliche Anschlussfähigkeit für eine mögliche notwendige nächste Phase bzw. die nächsten innovatorischen Schritte zur erfolgreichen Umsetzung der FE-Ergebnisse,

MODINI wird in der zweiten Phase von MiKlip als Teil des neuen Projektes ATMOS/MODINI fortgeführt.

4. Arbeiten, die zu keiner Lösung geführt haben

Die Nutzung des beobachteten Wärmeflusses, der während der Initialisierungsphase zusätzlich zu den beobachteten Windstressanomalien zum Antrieb der Ozeane dienen soll, bleibt Gegenstand von Untersuchungen. Diese Arbeit wird derzeit weiter verfolgt. Sie stellt eine wichtige Motivation für die Entwicklung einer Zirkulationskorrektur-Technik (Dews et al., 2015) dar, die die in praktisch allen Atmosphären-Ozean-Meereis-Modellen vorherrschende nordatlantische Kälteanomalie verringert.

5. Präsentationsmöglichkeiten für mögliche Nutzer

Die Ergebnisse von MODINI wurden auf dem jährlichen MiKlip-Statusseminar, auf den regelmäßig (mindestens jährlich) stattfindenden Modul-A-Projekttreffen, auf internationalen Konferenzen (wie der EGU-Generalversammlung in Wien) und im Rahmen von zahlreichen Seminaren und Präsentationen in internationalen Meetings vorgetragen.

6. Einhaltung der Kosten- und Zeitplanung

Das Projekt wurde in Übereinstimmung mit der ursprünglichen Zeit- und Kostenplanung durchgeführt.

References (other than those arising from the project):

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