Application for a DFG Research Grant

Research Unit „Earth Rotation and Global Dynamic Processes“

Project 10

Long-term ERP time series as indicators for global climate variability and climate change (ERP-CLIVAR)

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1. General information (Allgemeine Angaben)

Application for a Research Grant

New application

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1.2 Topic (Thema)

Long-term ERP time series as indicators for global climate variability and climate change

1.3 Code name (Kennwort)

ERP-CLIVAR

1.4 Scientific discipline and field of work (Fachgebiet und Arbeitsrichtung)

Meteorology:
- diagnosis of observed and simulated climate variability
- climate change

Oceanography:
- numerical modelling of transient dynamics in the global ocean
- long-term dynamics of the coupled atmosphere-ocean system
- angular momentum budget

Geodesy:
- Earth rotation and global geodynamics

1.5 Scheduled total duration (Voraussichtliche Gesamtdauer)

The project's intended total duration is six years (3+3). During the first three years work has foci on

- the identification, classification and understanding of observed and simulated relationships between Atmospheric Angular Momentum / LOD and large-scale atmospheric variability patterns as well as their underlying processes on interannual to decadal time scales. In particular, typical spatial patterns of atmosphere-ocean interaction induced by the atmospheric variability patterns are identified.
- the simulation of oceanic influences on the Earth Rotation Parameters as imposed by a given/observed forcing at the sea surface, and the estimation of the combined effects on the Earth Rotation Parameters.

While this work already aims at an integrating view of combined atmospheric and oceanic factors contributing to variations in the Earth Rotation, the second phase of this project will focus on the identification of joint modes of oceanic and atmospheric variability, and the effects of a future climate change. The specific influences of the joint atmosphere-ocean modes exerted on the Earth Rotation Parameters are identified, and thus the potential of observed Earth rotation parameters for an identification of climate variations and change is determined.

1.6 Application period (Antragszeitraum)

August 2005 to July 2008 (36 months)

1.7 First Proposal (Bei Neuanträgen)

Intended begin of funding: 01.08.2005

1.8 Summary (Zusammenfassung)

The project investigates the interrelation of climate variability / climate change and the variations in the Earth Rotation Parameters (ERPs) on interannual to decadal time scales. The extent is determined to which ERPs can be used as a climate indicator which is independent of measurements in the atmosphere and the ocean. Two approaches are combined to achieve this goal: On the one hand, the impact of dynamical processes in the atmosphere-ocean system on ERPs is analysed, taking into account the interdependence of the variability patterns in the two sub-systems. On the other hand, the ERP variations are projected on specific variations in the ocean-atmosphere system. Different patterns (like ENSO, NAO), their interrelation and underlying processes in atmosphere and ocean are investigated. While atmospheric contributions can be estimated from atmospheric reanalysis products the impact of the ocean cannot be deduced from three-dimensional observations. Thus, numerical global ocean models forced by atmospheric data are used. Coupled atmosphere-ocean models are employed for estimating the contribution of long term variations in the climate system to variations of the ERPs.

2. State of the Art and Preliminary Work

2.1 State of the Art (Stand der Forschung)

In the absence of external torques the Earth system including, e.g. atmosphere, ocean, and solid Earth can be regarded as a closed, angular momentum conserving system. Thus, any change of angular momentum in a fluid component of the Earth's system is related to an equivalent variation of angular momentum of the solid Earth and consequently to variations in the rotation of the solid Earth. The climate system (understood here as the atmosphere, the ocean and the land surface) produces variability in a range from subdaily variations up to interannual and decadal timescales. This variability means changes in the mass and momentum distributions of atmosphere, ocean and land surface, and these changes require an interaction with the solid Earth. As a consequence, they affect the solid Earth's rotation, expressed in the Earth Rotation Parameters (ERPs) like the Length-of-Day (LOD) and polar motion. While atmospheric contributions can be estimated from atmospheric reanalysis products provided by major weather prediction centres (ECMWF, NCEP) the impact of the ocean cannot be deduced from three-dimensional observations. Since oceanic in situ data are temporary and regional, i.e., restricted in time and space, and satellite data are essentially confined to the sea surface, numerical global ocean models provide an indispensable tool for estimations of the ocean's contribution to variations of the ERPs. In summary, several processes in the climate system should affect the ERPs, and there is indeed evidence that several climate variability phenomena can be identified in ERP variations. Interactions between the sub-systems have been considered in order to obtain a better understanding of the statistical relations between ERPs and climate system variability.

<u>Intraseasonal Variability</u>

In the recent past the scientific interest aimed at the physical explanation of the variability of different Earth Rotation Parameters (ERPs), especially LOD, and their connection to combined excitations by multiscale coupled atmosphere-ocean oscillations. Such excitations are present on timescales from intraseasonal to interannual and decadal. Daily LOD and atmospheric angular momentum (AAM) data were used for studies on the effects of atmospheric intraseasonal variations and ENSO (e.g. Marcus et al., 2001). Connections to large-scale atmospheric patterns (AO, NAO, PNA) and their intraseasonal variability, with respect to AAM in a frequency band between 15-30 days, are deduced to be mainly influenced by mountain torques (Lott et al., 2001; Lott et al., 2004a,b). On an intraseasonal timescale, the Madden-Julian Oscillation in the tropical atmosphere can be diagnosed in the ERP. There have been studies (e.g. Madden and Speth, 1995) linking variations in total atmospheric angular momentum with an approximate 50-day period to tropical intraseasonal oscillations with the same period. In the case of a complete inverse barometric response of the sea surface to atmospheric pressure changes Nastula and Salstein (1999) found significant oscillations in equatorial AAM functions across the frequency bands 25-75 and 75-125 days in prograde as well as retrograde directions, corresponding to counterclockwise and clockwise polar motion, respectively. Although some studies suggested the importance of ocean torques in intraseasonal AAM oscillations (see e.g. Madden, 1988; Gutzler and Ponte, 1990, Weickmann et al., 1997), a detailed asssessment of the relative importance of ocean (and land) torques is still lacking. Zatman and Bloxham (1997) emphasized a significant phase lag between AAM and LOD at low frequencies and most clearly at intraseasonal timescales. According to Ponte and Rosen (2001) the observed small phase lead of LOD relative to AAM cannot be explained by an ocean that rapidly transfers momentum between the atmosphere and the solid Earth. Thus, a simple barotropic approximation of ocean dynamics seems to be insufficient to explain atmosphere-ocean-solid Earth interactions.

Interannual Variability

Considering the half-century period from 1949 to 1998 observational data tell that the interannual variability of LOD series can be separated into three frequency bands: a quasi-biennial, a triennial-quadrennial and one at six-seven years (del Rio et al., 2000). While the atmosphere seems to excite the first two bands, no contribution to the six-seven year periodicity could be revealed from this study. Zheng et al. (2003) focus on interannual LOD and AAM variations caused by combined effects of multiscale atmospheric oscillations (e.g. ENSO), revealing that the effects of the 1982-83 and 1997-98 ENSO events on LOD were different. By means of reconstructed monthly sea surface temperatures Yan et al. (2002) estimated the impact of the migration of the western Pacific warm pool on interannual LOD variations during the period 1970-2000. In strong El Niño years (1975-1976, 1986-1987, 1997-1998) they found high correlation between computed warm pool excitation and LOD-AAM variations. Dickey et al. (1999) compared the rotational signature of the 1997-98 event in terms of the Earth-atmosphere angular momentum exchange to previous events. The analysis of AAM calculated from NCEP reanalysis data reveals a slow global coherent poleward propagation of angular momentum, originating in the equatorial regions, consistent with patterns found during earlier El Niños. Unlike the 1982-83 event, which had a dominant AAM maxima in the mid-latitudes, the 1997-98 event has more activity in the tropics. The above mentioned AAM structures penetrate into higher latitudes and are bimodal in nature with variations centred at low frequencies (~ 4.7 yr) and quasi-biennial (~2.4 yr) periods (Dickey et al., 1999). Interannual variability in LOD time series is often explained from ENSO and the stratospheric Quasi-Biennial Oscillation QBO (e.g. Gambis, 1992). The interannual time scale in the polar motion has been related to the North Atlantic Oscillation (NAO) by Chao and Zhou (1999). These relationships between climate system variability and the ERPs are not always stationary in a statistical (and physical) sense. Gambis (1992) refers to this problem with respect to the identification of ENSO-related influences on LOD. Applying the statistical concept of Wavelet Transformation, significant similar features between LOD and SOI series at low frequency could be identified. A similar result was achieved by Zhou et al. (2001) (LOD, AAM, ENSO) using observational data from 1970 to 1999. It has been demonstrated recently that the observed statistical relationship between ENSO and the NAO has been changing during the last century (Knippertz et al., 2003). Such long term changes in the relationship of different variability patterns in the climate system may affect the influence of a particular feature like ENSO on the ERP's.

Numerous studies investigate the global interactions in the climate system without looking for their relationships to ERP variations. The global effects of the ENSO phenomenon in the climate system are well-known (with except to its effects in the North Atlantic sectors, see above), while the interaction between extratropical variability patterns in the atmosphere is less clear. Van Loon and Rogers (1978) identified a connection of the large-scale atmospheric patterns in the North Pacific and the North Atlantic, and this connection has been re-emphasised by Cerlini et al. (1999) in their consideration of the NAO and PNA variability patterns. Numerical models which are capable of reproducing the most important aspects of these variability patterns also show a coupling between atmospheric features over the different ocean basins (May and Bengtsson, 1998). Such a teleconnection can be variable on decadal time scales according to Raible et al. (2001). They noted that the connection between the Pacific and the Atlantic atmosphere is weaker in their model when the low frequency part of NAO variability is strong, and vice versa. Evidence for long-term variations of the observed NAO variability spectrum has been found in observational data based on measurements or based on proxy-data (Appenzeller et al., 1998). NAO and its hemispheric counterpart, the Arctic Oscillation AO, are mainly identified as tropospheric phenomena, but there is evidence from many studies that stratospheric variability influences them (e.g., Thompson et al., 2003). On the other hand, numerical models indicate that surface conditions like sea-ice cover cause changes in the sea level pressure field by a mechanism involving a change in low-level baroclinicity, thus perturbing the travelling baroclinic disturbances, which then bring the signal downstream to manifest a non-local Atlantic-wide response (Kvamsto et al., 2004).

Decadal Variability

Several studies analyse decadal variability of AAM and LOD (e.g. Rozelot and Nastula, 1992; Dickey et al., 2003). Rozelot and Nastula, for example, investigated the relationship between the LOD and the global Earth temperature for the time spanning from 1860 to 1984. Results show a good agreement between climatic and LOD anomalies, with a time lag of about 11 years. A possible explanation may consist in the memory of oceans. The authors conclude that periods of acceleration of the Earth’s rotation correspond to a global surface warming and vice-versa (Rozelot and Nastula, 1992). Dickey et al. (2003) identify the source of a decadal variability of 10 to 12 years in SST and AAM series in the equatorial and northern Pacific. These long-term fluctuations are also relevant for the research on impacts of environmental changes. Long-term time series of global climatic indices are, for example, related to fish stock (e.g. FAO, 2001; Mantua et al., 1997; Ravier and Fromentin, 2004). Klyashtorin et al. (1998) suggest that the detrended series of -LOD and global temperature change (dT, from approximately 1860 up to 1995) are very similar in shape and it can be revealed that -LOD runs several years ahead of the global temperature change, especially in its maxima. A shift of nearly six years produces almost a complete coincidence of the corresponding maxima of the early 1870s, late1830s, and middle of 1990s. The authors relate this long-term dynamics of both dT and -LOD, with a periodicy of roughly 60 years, to changes in the global atmospheric general circulation, classified e.g. by zonal or meridional types of circulation given by Lamb (1972) or Lambeck (1980).

The coupling of ocean and atmospheric variability has been considered in studies based on both observational data and on climate models. While the atmosphere-ocean coupling is rather well understood with respect to the ENSO phenomenon, it is still under discussion for the extratropical patterns. Evidence from GCM simulations suggests that the observed temporal development of the North Atlantic Oscillation can be reproduced on a decadal time scale when Sea Surface Temperatures are prescribed (Rodwell et al., 1999; Latif et al., 2000; Paeth et al., 2001, 2003). Friedrichs and Frankignoul (2003) find that tropical SST influences regularly produce a specific PNA response and a somewhat more irregular impact on the pressure distribution over the North Atlantic and Europe, mainly in late winter. The influence of North Atlantic SST forcing seems to be stronger in boreal autumn. Studies based on coupled atmosphere-ocean GCMs have found evidence for the ocean integrating atmospheric forcing in the North Atlantic (sea surface temperatures, ocean currents), but concluded that there was little evidence for strong coupled atmosphere-ocean modes (Selten et al., 1999; Christoph et al., 2000).

Model simulations directly related to ERPs

In addition to studies based on observational data and based on reanalysis data as consistent atmospheric data sets (cf. Egger et al., 2003) numerical climate models have been used in order to gain insight into the physical mechanisms connecting anomalies in ERPs and atmospheric, oceanic or coupled oscillations (e.g. Celaya et al., 1999; Rosen and Salstein, 2000; de Viron et al., 2002; Ponte et al., 2002; de Viron et al., 2004). Celaya et al. (1999) used output of a coupled climate system model to evaluate climatic excitation of polar motion on timescales from months to decades with a special view on the excitation of the 30-year Markowitz and the Chandler wobble. Model-predicted ocean currents and bottom pressure as well as the combined effects of barometric pressure and winds showed excitation power in the Chandler frequency band comparable to the observed one indicating a high degree of constructive interference between seafloor pressure and currents and between atmospheric pressure and winds. By means of 240 years of output from the coupled climate model HadCM2 of the Hadley centre Ponte et al. (2002) investigated the relation of oceanic angular momentum (OAM) low frequency signals to regional changes in currents, density, and sea level fields on seasonal to decadal timescales. They came to the conclusion that climate signals highlighted in OAM reflect variability in major ocean current systems like, for instance the Antarctic Circumpolar Current and the gyre circulation in the North Pacific. However, eustatic sea level variations due to mass fluxes as a consequence of, e.g., precipitation, runoff, and ice melting, could not be taken into account by means of the rigid lid model applied. With respect to the excitation source of the Markowitz wobble Celaya et al. (1999) and Ponte et al (2002) found only indications for a possible important role of climate oscillations. By analysing outputs of the models participating to the Coupled Model Intercomparison Project (CMIP-2) de Viron et al. (2002) examined the effect of increasing greenhouse gas concentrations in the atmosphere on the global atmospheric and oceanic circulation and corresponding changes in LOD. The authors concluded that the models globally agree to an increase of LOD of about 1 µs/year associated with an increase of mean zonal winds. De Viron et al. (2004) used a 100-year run of the Hadley Centre general circulation model to compute monthly values of the three components of atmospheric torque on the Earth and of the associated atmospheric angular momentum series. The authors also computed the LOD and polar motion by the use of both the torque and the angular momentum approaches. GCM data and NCEP reanalysis give comparable amplitudes of polar motion for both torque and angular momentum approach; however, with respect to long-term axial variations, related to LOD, results from GCM and NCEP reanalyses are physically inconsistent. De Viron et al. (2004) emphasize that atmospheric model results considered in this study strongly depend on observed mean sea surface temperatures. They recommend that long-term oceanic effects including dynamical interactions at the atmosphere-ocean boundary are taken into account.

In conclusion, additional research effort is necessary for the understanding of the physical processes leading to the statistical relations between ERPs and the variability patterns of the climate system. In particular, the interaction between different atmospheric-oceanic oscillations, as ENSO or NAO, and their relevance for the variability of ERP's on different timescales is not fully understood. Open questions regarding the interactions of the variability patterns in the atmosphere-ocean system should be addressed using ERP time series as independent data.

References

Appenzeller, C., T.F. Stocker, and M. Anklin, 1998: North Atlantic Oscillation dynamics recorded in Greenland ice cores. Science, 282:446-449.

Celaya, M., J. Wahr, and F. O. Bryan, 1999: Climate driven polar motion. J. Geophys. Res., 104, 12 813-12 829.

Cerlini P.B., S. Corti and S. Tibaldi, 1999: An intercomparison between low-frequency variability indices. Tellus, 51, 773-789.

Chao, B.F. and Y.H. Zhou, 1999: Meteorological excitation of interannual polar motion by the North Atlantic Oscillation. Journal of Geodynamics 27 (1), 61-73.

Christoph, M.; Ulbrich, U., Oberhuber, J.M., Roeckner, E., 2000: The role of ocean dynamics for low-frequency fluctuations of the NAO in a coupled Ocean-Atmosphere GCM. J. Climate, 13, 2536 - 2549.

de Viron, O., V. Dehant, H. Gooses, Michel Cricifix and Participating CMIP Modeling Groups, 2002: Effect of global warming on the length-of-day, Geoph. Res. Lett., 29(7), 1146, doi:10.1029/2001GL013672.

de Viron, O., Salstein, D., Bizouard, C. and L. Fernandez, 2004: Low-frequency excitation of length of day and polar motion by the atmosphere. Journal of Geophysical Research-Solid Earth 109 (B3), Art. No. B03408.

del Rio, R.A., Gambis, D. and D.A. Salstein, 2000: Interannual signals in length of day and atmospheric angular momentum. Annales Geophysicae - Atmospheres Hydrosheres and Space Sciences, 18 (3), 347-364.

Dickey, J.O., P. Gegout and S.L. Marcus, 1999: Earth-atmosphere angular momentum exchange and ENSO: The rotational signature of the 1887-98 event. Geophys. Res. Lett., 26 (16), 2477-2480.

Dickey, J.O., S.L. Marcus and O. de Viron, 2003: Coherent interannual and decadal variations in the atmosphere-ocean system. Geophys. Res. Lett., 30 (11), 1573.

Egger, J., K.P. Hoinka, K. Weickmann and Huei-Ping Huang, 2003: Angular momentum budgets based on NCEP and ECMWF reanalysis data: an intercomparison. Mon. Wea. Rev., 131, 2577-2585.

FAO, 2001: Climate Change and Long-Term Fluctuations of Commercial Catches - The Possibility of Forecasting. Food and Agriculture Organization of the United Nations: FISHERIES TECHNICAL PAPER 410, Ed. Prof. Leonid B. Klyashtorin, Federal Institute for Fisheries and Oceanography Moscow, Rome.

Friederichs P, Frankignoul C, 2003: Potential seasonal predictability of the observed Euro-Atlantic atmospheric variability using SST forced ECHAM4-T42 simulations. Q.J.Royal Meteorol. Soc., 129, 2879-2896.

Gambis, D., 1992: Wavelet transform analysis of the length of the day and the El-Nino southern oscillation variations at intraseasonal and interannual time scales annales. Annales Geophysicae-Atmospheres hydrospheres and space sciences, 10 (6), 429-437.

Gutzler, D.S., and R:M. Ponte, 1990: Exchange of momentum among atmosphere, ocean, and solid Earth associated with the Madden-Julian oscillation, J. Geophys. Res., 95, 18,679-18,686.
Klyashtorin, L., A. Nikolaev and R. Klige, 1998: Variation of global climate indices and Earth rotation velocity. In: Book of Abstracts GLOBEC First Open Science Meeting, Paris, 17-20 March 1998. 55p.
Knippertz, P., U. Ulbrich, F. Marques, and J. Corte-Real, 2003: Decadal changes in the link between El Nino and springtime North Atlantic oscillation and European-North African rainfall. Int. J. Climatology, 23, 1293-1311.
Kvamsto NG, Skeie P, Stephenson DB, 2004: Impact of labrador sea-ice extent on the North Atlantic oscillation. Int. J. Climatol., 24, 603-612.
Lamb, H.H., 1972: Climate, present, past and future. London, Methuen and Co. 613p.
Lambeck, K., 1980: The Earth Variable Rotation. Cambridge Univ. Press.
Latif M, Arpe K, Roeckner E, 2000: Oceanic control of decadal North Atlantic sea level pressure variability in winter. Geophys. Res. Lett., 27, 727-730.
Lott, F., A.W. Robertson and M. Ghil, 2001: Mountain torques and atmospheric oscillations. Geophys. Res. Lett., 28 (7), 1207-1210.
Lott, F., A.W. Robertson and M. Ghil, 2004: Mountain torques and Northern Hemisphere low-frequency variability. Part I: Hemispheric aspects. J. Atmos. Sci., 61 (11), 1259-1271.
Lott, F., A.W. Robertson and M. Ghil, 2004: Mountain torques and Northern Hemisphere low-frequency variability. Part II: Regional aspects. J. Atmos. Sci., 61 (11), 1272-1283.
Madden, R.A., 1988: Large intraseasonal variations in wind stress over the tropical Pacific, J. Geophys. Res., 93, 5333-5340.
Madden, R.A. and P. Speth, 1995: Estimates of atmospheric angular momentum, friction, and mountain torques during 1987-1988. J. Atmos. Sci., 52, 3681-3694.
Mantua, N.J., S.R. Hare, Y. Zhang, J.M. Wallace and R.C. Francis, 1997: A Pacific interdecadal climate oscillation with impacts on salmon production. Bulletin of the AMS, 78, 1069-1079.
Marcus, S.L., J.O. Dickey and O. de Viron, 2001: Links between intraseasonal (extended MJO) and ENSO timescales: Insights via geodetic and atmospheric analysis. Geophys. Res. Lett., 28 (18), 3465-3468.
May W. and Bengtsson L., 1998: The Signature of ENSO in the Northern Hemisphere Midlatitude Seasonal Mean Flow and High-Frequency Intraseasonal Variability. Meteorology and Atmospheric Physics, 69, 81-100.
Nastula, J., and D. Salstein, 1999: Regional atmospheric angular momentum contributions to polar motion excitation, J. Geophys. Res, 104(B4), 7347-7358.
Paeth H, Friederichs P, Hense A, 2001: Covariability and interaction of North Atlantic sea surface temperature and North Atlantic Oscillation in ECHAM3 greenhouse-gas scenario simulations. Met. Z., 10, 295-306.
Paeth H, Latif M, Hense A, 2003: Global SST influence on twentieth century NAO variability, Climate Dynamics, 21, 63-75.
Ponte, R.M., and R.D. Rosen, 2001: Atmospheric torques on land and ocean and implications for Earth's angular momentum budget, J. Geophys. Res., 106, 11,793-11,799.
Ponte, R.M., J. Rajamony, and J.M. Gregory, 2002: Ocean angular momentum signals in a climate model and implications for Earth rotation, Climate Dynamics, 19, 181-190.
Raible, C, U. Luksch, K. Fraedrich, and R. Voss, 2001: North Atlantic decadal regimes in a coupled GCM simulation. submitted to Climate Dynamics.
Ravier, C. and J.M. Fromentin, 2004: Are the long-term fluctuations in Atlantic bluefin tuna (Thunnus thynnus) population related to environmental changes? Fisheries Oceanography, 13 (3), 145-160.
Rodwell MJ, Rowell DP, Folland CK, 1999: Oceanic forcing of the wintertime North Atlantic

Oscillation and European climate. Nature, 398, 320-323.
Rosen, R.D. and DA Salstein, 2000: Multidecadal signals in the interannual variability of atmospheric angular momentum. Clim. Dyn., 16 (9), 693-700.
Rozelot, J.P. and J. Nastula, 1992: On the Earth global temperature related to its rotational fluctuations. Comptes rendus de l'Academie des Sciences Serie II, 315 (6), 667-672.
Selten FM, Haarsma RJ, Opsteegh JD, 1999: On the mechanism of North Atlantic decadal variability. Journal of Climate, 12, 1956-1973.
Thompson DWJ, Lee S, and Baldwin MP, 2003: Atmospheric processes governing the Northern Hemisphere annular mode /North Atlantic Oscillation. In: The North Atlantic Oscillation, climate significance and environmental impact. J. Hurrell et al. (eds.), American Geophysical Union, Washington, 279 pp.
van Loon, H., and Rogers, J.C., 1978: The seesaw in winter temperatures between Greenland and Northern Europe, Part I, general description. Mon. Wea. Rev., 106, 296-310.
Weickmann, K.M., G.N. Kiladis, and P.D. Sardeshmukh, 1997: The dynamics of intraseasonal atmospheric angular momentum oscillations, J. Atmos. Sci., 54, 1445-1461.
Yan, X.-H., Y. Zhou, J. Pan, D. Zheng, M. Fang, X. Liao, M.-X. He, W. Liu, and X. Ding, 2002: Pacific Warm Pool Excitation, Earth Rotation and El Nino Southern Oscillations, Geophys. Res. Lett., 19(21):15,685-15,690.
Zatman, S., and J. Bloxham, 1997: The phase difference between length of day and atmospheric angular momentum at subannual frequencies and the possible role of core-mantle coupling, Geophys. Res. Lett., 24. 1799-1802.
Zheng, D.W., Ding, X.L., Zhou, Y.H. and Y.Q. Chen, 2003: Earth rotation and ENSO events: combined excitation of interannual LOD variations by multiscale atmospheric oscillations. Global and Planetary Change, 36 (1-2), 89-97.
Zhou, Y.H., Zheng, D.W. and X.H. Liao, 2001: Wavelet analysis of interannual LOD, AAM, and ENSO: 1997-98 El Nino and 1998-99 La Niña signals. Journal of Geodesy, 75 (2-3), 164-168.

2.2 Preliminary work, Progress report (Eigene Vorarbeiten)

Preliminary work consists of studies devoted to ocean modelling connected to ERP variations, and studies devoted to the atmospheric variability and ocean-atmosphere coupling. First, the ocean model is addressed:

The main **oceanic** data sets to be analysed within this proposal are produced by model simulations with the Ocean Model for Circulation and Tides (OMCT). This conceptionally new kind of global ocean model, which is also applied in this research project for coupled atmosphere-hydrosphere simulations, was developed during the DFG research projects "Drehimpulsbilanzierung" ("Angular momentum budget", funded by the DFG under grant Br 675/8-2) and "Erdrotationsvektor" ("The Earth's rotation vector", funded by the DFG under grant He 1916/4-1) by adjusting the originally climatological Hamburg Ocean Primitive Equation Model (HOPE) (Wolff et al., 1996) to the weather time-scale and coupling with an ephemeral tidal model. After sufficient computing facilities had become available, it was possible to examine – as a main object of these projects - the validity of the conventional separation of circulation and tides in global models, especially with respect to the associated influences upon Earth's rotation. Implemented is a prognostic thermodynamic sea-ice model (Hibler, 1979) that predicts ice-thickness, -compactness and –drift. Higher order effects such as nonlinearities are accounted for as well as the secondary potential due to loading and self-attraction (LSA) of the water masses. Since, the fluctuating thickness of the water column due to steric effects is, in general, not spatially uniform but heterogeneous, a slightly extended steric correction is applied in the actual OMCT version, which additionally takes into account local effects (Thomas, 2002). Considering the dominant diurnal and semidiurnal tides in a global general circulation model required a significant increase of the time-resolution. In the present configuration, the model uses a time-step of 30 minutes, a horizontal resolution of 1.875° and 13 layers in the vertical.

In contrast to the traditional partial tide approach, the OMCT takes into account effects from the complete lunisolar tidal potential computed from the ephemerides of the tide-generating bodies. To guarantee precise ephemerides over long periods (Hellmich, 2003) ephemerides are calculated by the analytical algorithm VSOP87 (Variations Seculaires des Orbites Planetaires) developed by Bretagnon and Francou (1988) reaching accuracies of computed positions below one arc minute which is sufficient in view of a grid resolution of 1.875°.

To estimate the quality of the tidal oscillation system produced by the ephemeris approach applied in OMCT, harmonic coefficients of main partial tides were extracted and contrasted to the ST103 data set of observed pelagic tidal coefficients according to LeProvost (1995). Although modelled tidal amplitudes are frequently about 10-20% lower than observed, phase differences are always below the level of significance, i.e., smaller than the time step applied (cf., Thomas, 2002). Despite comparatively coarse resolution in time and space the ephemeris approach implemented in OMCT meets the quality of Seiler's (1991) free barotropic partial tidal model using a time step of 90 seconds and a horizontal resolution of 1 degree in latitude and longitude (Thomas and Sündermann, 1999). The new concept of a free combined model of ephemeral tides and circulation realised in OMCT allows to estimate the importance of nonlinear interactions between partial tides as well as between tides and general circulation and, finally, the corresponding contributions to oceanic angular momentum. According to Thomas et al. (2001), nonlinear interactions between tides and circulation and secondary effects arising from loading and self-attraction are responsible for about 8% of total oceanic excitation of polar motion on subseasonal to decadal timescales. The simultaneous consideration of ephemeral tides in an OGCM will allow to separate the linear trend caused by tidal friction from angular momentum time series and consequently to identify the expected climate induced linear trends, e.g., as a consequence of global warming.

To simulate the ocean's general, i.e., thermohaline, wind-, and pressure-driven circulation, the OMCT is driven by time varying wind stress fields, atmospheric pressure anomalies at the sea-surface as well as heat and freshwater fluxes. From the hydrographic variables temperature, salinity, density, ice-distribution, and sea-surface height, the model generates three-dimensional distributions of currents and mass with a time resolution of half an hour. Mass and current distributions are used for routine calculations of bottom pressure and integral quantities such as angular momentum, the components of the tensor of inertia, and the ocean's impact on the coordinates of the centre of mass. Finally, from simulated time series of oceanic angular momentum (OAM) effective angular momentum functions, χ, and ocean induced variations in length-of-day and polar motion are calculated (e.g. Thomas and Sündermann, 1998; Thomas and Sündermann, 2000; Thomas et al., 2001).

From several long-term simulations with different forcing fields from the climate models ECHAM3 and ECHAM4 (DKRZ, 1992) and NCEP reanalyses it turned out that the simultaneous treatment of general circulation and tides including the mentioned secondary effects, even for the world ocean, is both technically feasible (e.g., with respect to computational expense) and meaningful or even necessary from a scientific point of view, because nonlinearities between circulation and tides as well as the secondary potential proved to be significant (Thomas and Sündermann, 2000; Thomas et al., 2001). Within the limits of the chosen space- and time-resolution, atmospheric forcing in connection with the tides allowed for a simulation of the oceanic field of motion, well reflecting the dynamics governing the world ocean on subdaily to interannual timescales. As an example for interannual variations, in Figure 1 anomalies in sea surface temperatures associated with the El Niño Southern Oscillation in December 1982 are depicted as simulated by OMCT driven with ECHAM3 forcing fields. Obviously, the OMCT reproduces typical positive temperature anomalies in the equatorial western Pacific up to about 4°C as well as anomalously low temperatures in higher latitudes.

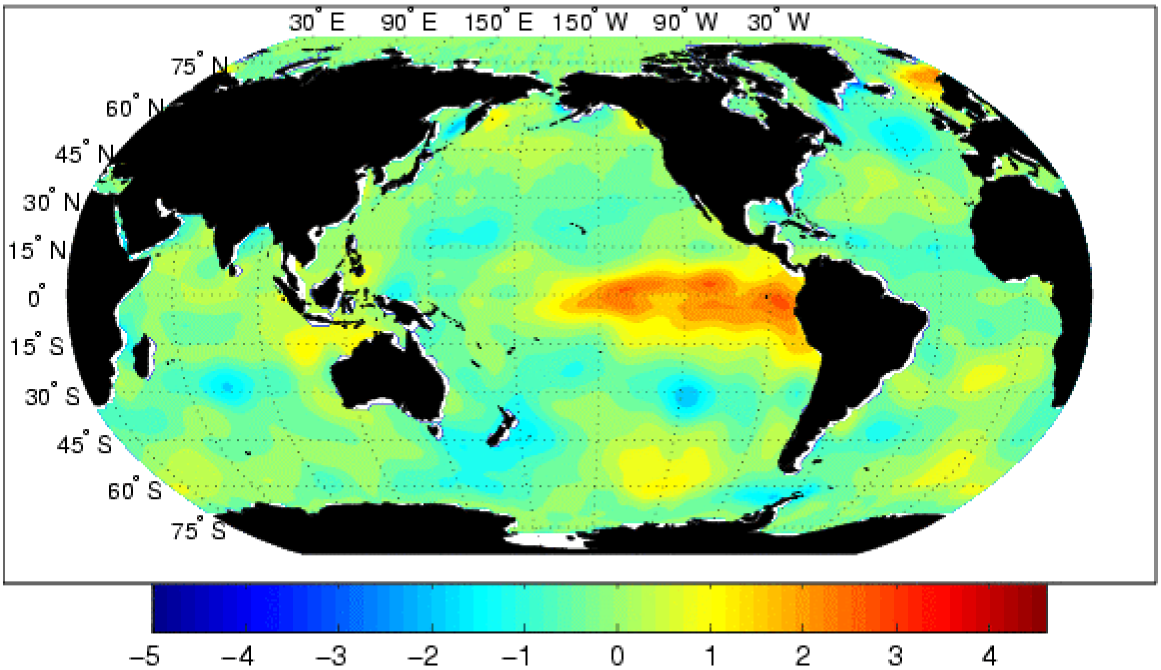

Fig. 1: Anomalies of sea surface temperatures in December 1982 resulting from OMCT simulations driven with atmospheric forcing fields from ECHAM3 climate simulations.

The simultaneous consideration of the main components of motion of the world ocean, including nonlinear interactions, sea-ice and second-order effects from loading and self-attraction, for the first time yielded a description of instantaneous dynamics in the ocean. Thus, a coupled simulation of the tidal, wind-induced and thermohaline fields of mass and motion can be considered as an important step towards an operational modeling of the oceanic state, which on the global scale was so far performed for the atmosphere, but was impossible for the ocean. The OMCT has already proved successful in many interdisciplinary applications. By means of OMCT simulations Wünsch et al. (2001), for instance, estimated the impact of high frequency circulation induced mass redistributions on the gravity missions CHAMP, GRACE, and GOCE. Seitz et al. (2004) used output from ECHAM and OMCT to force the gyroscopic Dynamic Model for Earth Rotation and Gravity (DyMEG) and concluded that stochastic signals in climate dynamics caused by weather and oceanic mass redistributions are a sufficient source to maintain the Earth's free wobble by resonant interaction. Output from above mentioned OMCT simulations forced with ECHAM3, ECHAM4 climate data, and NCEP reanalyses are to be used for analyses within this proposal.

Work regarding the **atmospheric** variability patterns has been performed both on the mechanisms of variability, on pattern interactions and on climate change aspects as well as on impacts related to the climate variability patterns. The atmospheric variability of the coupled

atmosphere-ocean GCM ECHAM4/OPYC3 and of a version of this atmospheric model coupled to a mixed layer ocean were investigated (Christoph et al., 2000). It was found that the coupled model is capable of producing a realistic North Atlantic Oscillation both in terms of the pattern and the spectral variability, while the version without a full ocean underestimates variability by about 15%. The study also looked into the existence and the importance of coupled atmosphere ocean modes. In the coupled model the atmospheric variability over the North Atlantic influences the ocean in several specific ways, for example in driving the zonal ocean currents with a lag of 2-4 years east of Newfoundland, and with a lag of 1-3 years in the subtropical east Atlantic. Meridional current anomalies associated with the anomalous horizontal circulation were also observed, but had a slightly longer lag of 4-5 years.
The relationship of the North Atlantic variability and the ENSO phenomenon was investigated by Knippertz et al. (2003). This study identified three different phases of the observed teleconnection during the last century. During the initial 25 years (1900-1925) and during a later period (1962-87) running 25 year correlations of El Niño and the spring NAO-index were weakly positive (r=0.3), while between 1931 and 1956 a phase of negative correlations occurred (r=-0.5). These phases were associated with a change of the Atlantic pressure anomaly pattern associated with ENSO. This pattern had a dipole-like structure during the central time period but a quadrupole structure during the earlier and the later one. Recent work (Ulbrich et al., 2004) shows that the ECHAM4/OPYC3 GCM is capable of reproducing the ENSO-NAO relations for boreal winters. First evaluations suggest that a mechanism involving the PNA pattern and the mid-latitude eddies is important in understanding the connection. The relation of mid latitude eddies, the conditions for their growth and of the large-scale variability patterns has also been investigated looking into climate change scenario simulations. Ulbrich and Christoph (1999) found a north-eastward shift of the NAO associated with increasing greenhouse gas forcing which was closely related to the eastward extension of eddy activity in the middle troposphere and the Atlantic and Europe. Knippertz et al. (2000) confirmed that an effect was also visible in surface cyclone activity, and that one of the factors leading to the changes in the simulation was the increasing baroclinicity in the upper troposphere upstream of this region.

One drawback of commonly used indices like the NAO or the Pacific-North American PNA pattern is their purely statistical origin, based on normalized pressure and temperature deviations in fixed regions. It is well known that an arithmetic mean and its deviations are no solution in a nonlinear system. Furthermore, diagnosis of the global interaction in the atmosphere-ocean system needs some single, dynamical based index, which can be calculated at every point of the atmosphere. In order to overcome these disadvantages a newly designed Dynamic State Index (DSI) based on the Energy-Vorticity-Theory of fluid mechanics is introduced (Névir and Blender 1993, Névir 1998). Whereas the NAO index or the Southern Oscillation Index (SOI) can only be defined as normalized pressure deviations in preferred regions, the DSI is a local measure of the deviations from an exact nonlinear solution of the primitive equations. This nonlinear solution is a generalization of the well known geostrophic equilibrium. This energy-vorticity equilibrium (DSI=0) describes the stationary state of the atmosphere without friction and diabatic forcing. The important deviations of this equilibrium which cause the variability of the atmosphere, i.e. all non-stationary and diabatic forcing processes can be diagnosed by the DSI (Brand 2002, Névir and Brand 2002, 2003). There is a single climate index for the whole atmosphere, based on the first principles of energy, potential vorticity and entropy conservation. This diagnostic method can be also traced back to the particle relabelling symmetry of the Lagrangian description of fluid mechanics (Névir 2004). Preliminary results show (Fig.2) that the DSI is very sensitive for indicating not only the interannual variations of the El Niño / La Niña events, but can also detect the important decadal variations of the ENSO phenomenon. The pacific climate shift around 1975 can clearly be seen, which confirms the regime shift of the Pacific Decadal Oscillation.

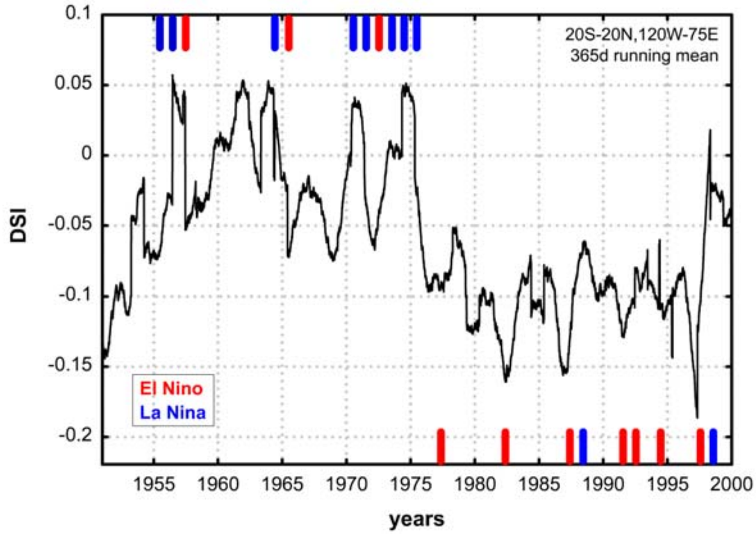

Fig. 2: Time series of the DSI over the central Pacific region: 1950-2000

References:

Brand, S., 2002: Ein dynamischer Wetter- und Klima-Zustandsindex auf der Grundlage der Energie-Wirbel-Theorie. Diploma thesis, Freie Universität Berlin, 161 pp

Bretagnon, P., and G. Francou, 1988: Planetary theories in rectangular and spherical variables. VSOP87 solutions, Astronomy and Astrophysics 202, 309-315.

Christoph, M.; Ulbrich, U., Oberhuber, J.M., Roeckner, E., 2000: The role of ocean dynamics for low-frequency fluctuations of the NAO in a coupled Ocean-Atmosphere GCM. J. Climate, 13, 2536 - 2549.

Deutsches Klimarechenzentrum (DKRZ) Modellbetreuungsgruppe, 1992: The ECHAM3 atmospheric general circulation model, Tech. Rep. No. 6, ISSN 0940-9237, 184 pp., Deutsches Klimarechenzentrum, Hamburg, Germany.

Greatbach, R.J., 1994: A note on the representation of steric sea level in models that conserve volume rather than mass, J. Geophys. Res., 99, 12,767-12,771.

Hagemann, S., 1998: Entwicklung einer Parametrisierung des lateralen Abflusses für Landflächen auf der globalen Skala, Examensarbeit Nr. 52, Max-Planck-Institut für Meteorologie, Hamburg.

Hellmich, A.-M., 2003, Ein rechenökonomisches Modul für ephemeridische Gezeiten-simulationen, Diplomarbeit am Inst. f. Planet. Geod., Techn. Univ. Dresden, 131 S..

Hibler III, W.D., 1979: A dynamic thermodynamic sea ice model, J. Phys. Oceanogr., 9, 815-846.

Kalnay, E., M. Kanamitsu, R. Kistler, W. Collins, D. Deaven, L. Gandin, M. Iredell, S. Saha, G. White, J. Woollen, Y. Zhu, M. Chelliah, W. Ebisuzaki, W. Higgins, J. Janowiak, K.C. Mo, C. Ropelewski, J. Wang, A. Leetmaa, R. Reynolds, R. Jenne, and D. Joseph, 1996: The NCEP/NCAR 40-year reanalysis project, Bull. Am. Meteorol. Soc., 77, (3), 437-471.

Knippertz, P., U. Ulbrich and P. Speth, 2000: Changing cyclones and surface wind speeds over the North-Atlantic and Europe in a transient GHG experiment. Climate Research, 15, 109-122.

Knippertz, P., U. Ulbrich, F. Marques and J. Corte-Real, 2003: Decadal changes in the link El Niño, NAO and European/North African rainfall. Int. J. Climatology, 23, 1293 - 1311.

Le Provost, C., 1995: A new sea truth data set for tides, ftp://meolipc.img.fr/pub/ST103, LEGI/IMC, BP 53X, 38041, Grenoble Cedex.

Névir, P. and R. Blender, 1993: Nambu representation of incompressible hydrodynamics using helicity and enstropy. J. Physics A 26, L1189-L1193.

Névir, P., 2004: Ertel´s Vorticity theorems, the Particle Relabelling symmetry and the Energy-Vorticity-Theory of fluid mechanics. Met. Zeitschrift 13, No. 6, in press.

Névir, P., 1998: Die Nambu-Felddarstellungen der Hydro-Thermodynamik und ihre Bedeutung für die dynamische Meteorologie. Master thesis, Freie Universität Berlin.

Névir, P. and S. Brand, 2003: Ein dynamischer Wetter- und Klima-Zustandsindex. Terra Nostra, 6. Deutsche Klimatagung, Schriften der Alfred-Wegener-Stiftung 6, 311-314.

Névir, P. and S. Brand, 2002: Wenn Energie und Wirbelgrößen sich verbinden – Ein dynamischer Wetter- und Klima-Zustandsindex In: Der belebte Planet, Sonderheft der Berliner Geowissenschaftlichen Abhandlungen zum Jahr der Geowissenschaften. 118-125

Seiler, U., 1991: Periodic changes of the angular momentum budget due to the tides of the world ocean, J. Geophys. Res., 96, 10287-10300.

Seitz, F., J. Stuck, and M. Thomas, 2004: Consistent atmospheric and oceanic excitation of the Earth’s free polar motion, Geophys. J. Int., 157, 25-35.

Thomas, M., 2002: Ozeanisch induzierte Erdrotationsschwankungen – Ergebnisse eines Simultanmodells für Zirkulation und Gezeiten im Weltozean, Dissertation am Fachbereich Geowissenschaften der Universität Hamburg, 128 S..

Thomas, M., und J. Sündermann, 1998: Zur simultanen Modellierung von allgemeiner Zirkulation und Gezeiten im Weltozean und Auswirkungen auf bestimmte Erdrotationsparameter, in: W. Freeden (ed.), Progress in Geodetic Science, Shaker Verlag, 144-151.

Thomas, M., and J. Sündermann, 1999: Tides and tidal torques of the world ocean since the last glacial maximum, J. Geophys. Res., 104, 3159-3183.

Thomas, M., and J. Sündermann, 2000: Numerical simulations of ocean induced variations of Earth´s rotation, in: M. Soffel and N. Capitaine (Eds.), Motion of celestial bodies, Astrometry and astronomical reference frames, pp. 167-169, ISBN 2-901057-42-X.

Thomas, M., J. Sündermann, and E. Maier-Reimer, 2001: Consideration of ocean tides in an OGCM and impacts on subseasonal to decadal polar motion excitation, Geophys. Res. Lett., 28, 12, 2457-2460.

Ulbrich, U., M. Christoph , J.G. Pinto and J. Corte-Real, 1999: Dependence of Winter Precipitation over Portugal on NAO and Baroclinic Wave Activity. Int. J. Climatol., 19, 379-390.

Ulbrich, U., and M. Christoph, 1999: A Shift of the NAO and Increasing Storm Track Activity over Europe due to Anthropogenic Greenhouse Gas Forcing. Climate Dynamics, 15, 551-559.

Ulbrich, U.; Christoph, M.; Knippertz, P., 2004: Observed and Simulated Links between ENSO and European Climate. 1st International CLIVAR Science Conference, Baltimore, USA, DP-30.

Van Flandern and Plukkinen, 1998: Low-precision formulae for planetary positions, The Astrophysical Journal-Supplement Series, 41, 3, Willmann-Bell, Inc.

Wolff, J.O., E. Maier-Reimer, and S. Legutke, 1996: The Hamburg Ocean Primitive Equation Model HOPE, Technical Report No. 13, DKRZ, Hamburg, 103pp.

Wünsch, J., M. Thomas, and T. Gruber, 2001: Simulation of oceanic bottom pressure for gravity space missions, Geophys. J. Int., 147, 428-434.

3. Goals and Work Schedule (Ziele und Arbeitsprogramm)

3.1 Goals (Ziele)

The project investigates the interrelation of climatic variability / climate change and the variations in the ERP on interannual to decadal time scales in order to determine to which extent length of day and polar motion can be used as climate indicators which are independent of measurements in the atmosphere and the ocean. The project combines two approaches to achieve this goal: On the one hand, the impact of dynamical processes in the atmosphere-ocean system (frequently expressed by means of climate index series) on Earth rotation parameters is analysed. This approach looks at the combined effects of atmospheric and oceanic variability patterns on the ERP, taking into account that they are interdependent. On the other hand, the use of ERP variations as an indicator for specific variations in the ocean-atmosphere system is explored.

General and specific questions to be addressed in this context are, for example:

a) interannual time scale

- What are the characteristic ERP signatures associated with typical dynamical features in the atmosphere-ocean system (e.g., ENSO, NAO)? What are the transfer functions and amplitude-phase relations between climate dynamics and resulting observed rotational variations?
- To which extent can phases and amplitudes of dynamical features in the atmosphere-ocean system be deduced from ERP time series? In how far can dynamical features in the atmosphere directly be assigned to ERP variations?
- What are the underlying physical processes and forces responsible for angular momentum exchange between atmosphere/ocean and solid Earth? What are the resulting time-dependent distributions of torques acting on the solid Earth?
- Why are ENSO events different in their effect on the ERP variations? Is this related to the different relations of tropical SST anomalies in the Pacific and mid-latitude atmospheric circulation patterns (like the North Atlantic / Arctic Oscillation) or is it related to different anomalies in the oceans?
- In how far is the intensity and pattern of eddy activity in the atmosphere (storm tracks, cyclones and their momentum transports) related to the ERP variations? Is there evidence for an effect of these eddies on the oceans that could be relevant for ERP variations?
- Are intraseasonal variations in the atmospheric circulation patterns a key for understanding of different atmosphere-ocean interaction and thus a different response in the ERP?
- Is the Dynamic State Index (DSI) correlated with the ERP (in particular with LOD), and are the different ENSO characteristics found from this parameter related to the different ENSO effects on the ERP?

b) decadal time scale

- Which particular atmospheric patterns and processes have a particularly strong influence on the decadal variations in the ERP? Is there a correlation of LOD with the Pacific Decadal Oscillation (PDO), which has a similar anomaly pattern as the interannual ENSO phenomenon?

- Is the recently found decadal variation in observed ENSO-NAO relations related to the decadal ERP variations, for example through an effect on the total Atmospheric Angular Momentum or through the atmosphere-ocean interactions?
- Is it possible to understand the decadal variations in the LOD from the decadal variations in the DSI?
- What is the influence of transient global warming in the atmosphere and oceans on the ERP? Should a global change signal in the ERP be expected from the simulated changes in the atmosphere, or must a compensation be expected from the changes in the ocean (including the atmosphere-ocean interaction)?

c) time lags

- Can sequences of anomalies in the atmosphere and the ocean be identified which lead to a particularly strong change in the ERP on the time scales considered?
- Is there evidence for a physically consistent mechanism that could explain the apparent predictability of fish catch from variations in the length of day? Is it possible to use the time lag between LOD and global temperature anomalies in order to predict climate trends or fish population?

3.2 Work schedule (Arbeitsprogramm)

3.2.1 Year 0-1.5:

In the initial phase of the first three year period of the project it is planned to consider the interrelations between Earth Rotation Parameters on the one hand and atmospheric, oceanic and surface processes on the other hand according to observations. As a consequence of the lack of global three-dimensional oceanic observations as well as of the dominant role of the atmosphere in exciting length-of-day variations on sub-seasonal to interannual time scales, the state of knowledge of interrelations between atmospheric dynamics and ERP variations on the one hand and ocean dynamics and ERP variations on the other hand is on a different level. Thus, the meteorological and oceanographic working group initially have to concentrate on slightly different approaches. According to the objectives specified in chapter 3.1 the working plans of the groups at the Institute for Meteorology and at the Institute of Planetary Geodesy are as follows:

For the **atmospheric part** work starts from the preliminary assumption that the ocean effects are of a secondary order in producing ERP variations. This should be more valid for the LOD variations. The LOD variations are related to anomalies in large scale atmospheric patterns (e.g., AO and NAO, PNA and PDO) and their underlying processes (spatial anomalies of storm tracks / cyclones, the DSI) on the time scales considered. Typical spatial patterns of surface parameters relevant for atmosphere-ocean interaction are determined, taking into account the individual atmospheric patterns, their combinations and temporal sequences.
Different ENSO anomalies are compared and classified in terms of their effects on the LOD. The different classes of ENSO-LOD relations are examined with respect to specific anomalies in the atmosphere (e.g., ENSO-NAO relations, DSI anomalies, storm tracks, vertically integrated momentum transports, stratospheric anomalies), and at the surface (e.g., drag, SLP anomalies, SST anomalies). The latter are chosen according to their potential influence on the oceans and its effects on the ERPs.

Available observational time series for the atmosphere and the surface are:

SST: Kaplan SST reconstruction 1856-now, COADS 1800-1997

SLP: Trenberth's Northern Hemisphere monthly Sea Level Pressure 1899-now,
COADS (sea only) 1800-1997, Kaplan reconstruction (sea only) 1854-1992.
Reanalysis data (ERA40 1957-2002, NCEP reanalysis 1958-1998/now),

DSI time series from NCEP reanalysis (1950-2000)

The results for observational time series are intercompared to results from GCM simulations forced with observed SSTs (see uncoupled runs a-c listed farther below).

The **oceanographic investigations** initially focus on the identification of characteristic signals of Earth's rotation parameters, i.e., variations in length-of-day and polar motion, due to climate relevant dynamical processes in the atmosphere-ocean system. To identify oceanic signals geodetic angular momentum functions initially have to be reduced by atmospheric angular momentum contributions calculated from the dynamical states of the atmosphere that had been used to force the ocean models. Since the identification of underlying oceanic processes responsible for rotational variations can only be derived from at least two-dimensional distributions of angular momentum and torques, analyses require availability of time-space dependent dynamical state parameters. This is available in output from the following model combinations produced in preliminary research projects ("Angular momentum budget", "The Earth's rotation vector") and in the partner project "The Earth's rotation and the ocean's circulation" (proposal of this research unit):

<u>Uncoupled simulations</u>

a) OMCT forced with observational data:
NCEP (1948-2002), ERA40 reanalyses (1956-2002)

b) LSG forced with ERA40 (1956-2002);

c) OMCT forced with data from atmospheric models runs with prescribed observational SSTs
ECHAM3 (1949-1994), ECHAM4 (1902-1994);

<u>Dynamical coupled simulations</u>

d) ECHAM5/MPI-OM forced with solar variability, volcanic aerosol, and greenhouse gases (planned for 2005 by the MPI for Meteorology, E. Roeckner, pers. comm.)

e) ECHAM5/MPI-OM (multi-century control run and 1890-2100 scenario A1b).

3.2.2 Year 1.5-3:

Atmospheric Angular Momentum changes and drags (surface drag, gravity wave drag, and mountain torque) are determined for the specific atmospheric circulation patterns and their combinations as identified in the first project phase. This leads to an identification of atmospheric/oceanic forces and physical mechanisms responsible for stated ERP signatures by means of, e.g., time-space analysis of torque distributions acting on the solid Earth.

Simulations with a atmospheric GCM forced with observed SSTs and with variable solar, volcanic, greenhouse gases, and aerosol forcing (ECHAM5, see run d above) are further considered in order to identify in how far the model reproduces the observed patterns and their combinations/sequences, also looking into parameters like DSI, storm tracks etc.. Finally, a multi-century control run of the coupled atmosphere-ocean model ECHAM5/OM1 at T63 resolution is investigated in the same manner. Here the question is if such situations and if the decadal variations are reproduced in this model, while of course no temporal coincidence with observations can be expected.

Coupled model runs with ECOCTH are prepared: implementation of the torque module developed in partner project “The Earth’s rotation and the ocean’s circulation” into the global coupled atmosphere-hydrosphere model ECOCTH; a simulation with ECOCTH with transient greenhouse gas forcing (CO_2, SO_4) and variable solar radiation from observations and forecasts will be performed within this project for the period 1890-2100. Thus, the influence of transient climate forcing conditions can be identified by comparison with the run produced in the project “Model of the Earth System”.

3.2.3 ERP data

The interrelation of angular momentum changes in the atmosphere-ocean system and variations of Earth rotation parameters, i.e., length-of-day and polar motion, and corresponding causative physical processes are considered by analyses of various ERP data sets of different quality and resolution:

Geodetic observed angular momentum and corresponding excitation functions are deduced from the time series EOP C01 and EOP C04 provided by the Product Centres of the International Earth Rotation and Reference Systems Service. EOP C01 covers the time interval from 1962 to now for polar motion and length-of-day; EOP C01 provides variations in length-of-day for the period 1900-2000 and polar motion for the period 1846-2000. Additionally, the new optical astrometric solutions OA04 and OA04a covering the periods 1899.7-1992.0 for polar motion and 1956.0-1992 for UT1 (J. Vondrak, 2004, pers. commun.) are provided by courtesy of the Astronomical Institute Prague.

3.2.4 Working plan for the second phase

Based on the meteorological and geodetic/oceanographic investigations in the first phase, the project focuses on joint effects of atmosphere and ocean on the ERP parameters. Variability in coupled atmosphere-ocean runs and observed variability is focussed on an identification of joint modes of oceanic and atmospheric variability. In particular, runs with the ECOCTH model system are used in order to make use of the improved assessment of the atmosphere-hydrosphere coupling effects with respect to the ERP they provide. These studies are the basis for investigations of projected future climate change and its expected signature in ERP parameters.

3.3 Experiments with humans (Untersuchungen an Menschen)

- not applicable -

3.4 Experiments with animals (Tierversuche)

- not applicable -

3.5 Experiments with recombinant DNA (Gentechnologische Experimente)

- not applicable -

5.2 Cooperation with other scientists (Zusammenarbeit mit anderen Wissenschaftlern)

Within the ongoing project "Model of the Earth System" the OMCT is dynamically coupled with the atmospheric general circulation model ECHAM5 and a hydrological discharge model (Hagemann, 1998). In contrast to other coupled models main advantages of this coupled atmosphere-hydrosphere model (ECOCTH) lie, for instance, in a consistent consideration of mass transports in the hydrological cycle, a regard of the pressure-driven circulation by allowing for deviations from a pure inverse barometric response of the sea surface, and in the consideration of impacts due to loading and self-attraction. In the second project phase a ECOCTH model run with transient greenhouse gas forcing and variable solar radiation is planned for investigations of projected future climate change and corresponding signatures in Earth rotation parameters.
Model output from coupled atmosphere-hydrosphere runs with ECOCTH during the second project phase will be made available for simulations with the gyroscopic model DyMEG at the Deutsches Geodätisches Forschungsinstitut, Munich. Model runs performed at the MPI in Hamburg are available due to their general availability for German Climate Research or through cooperation with Dr. E. Roeckner.

Close cooperation is essential with the following sub-projects of the DFG research group "Earth rotation and global dynamic processes":

- P1: Data resulting from analyses of atmospheric and oceanic angular momentum and torques will be provided to the Earth rotation information system to be elaborated within this sub-project.
- P2: Collaborations with the sub-project "The Earth's rotation and the ocean's circulation" particularly concern the exchange of output from model simulations with LSG and OMCT, discussions with respect to the torque module, and statistical analyses.
- P4: To separate climate induced rotational variations from decadal and subdecadal contributions of the Earth's interior, i.e., core and mantle, regular discussions and, where appropriate, data exchange with this sub-project is intended.
- P8: The data are provided to this sub-project for evaluation. Assistance in obtaining and interpreting further atmospheric data is also provided for this project which focuses on sub-daily ERP variations.

A close cooperation is also foreseen with scientists experienced in the geodetic, atmospheric, and oceanic data, in particular
Prof. Dr. Andreas Hense, University of Bonn
Prof. Dr. Peter Speth, University of Cologne
Prof. Dr. Detlef Stammer, Institute for Oceanography, University of Hamburg, Germany
Dr. Jochen Stuck, Geoforschungszentrum Potsdam, Germany
Dr. Florian Seitz, Deutsches Geodätisches Forschungsinstitut, Munich, Germany

5.3 Foreign contacts and cooperations (_Arbeiten im Ausland und Kooperation mit ausländischen Partnern)

The working groups are integrated in international research efforts regarding Climate Variability and Climatic change coordinated through the WMO CLIVAR initiative. In particular the planned work shall be carried out in cooperation with the following scientists working on atmospheric and oceanic variability

Prof. Dr. Brian Hoskins, Dr. David B. Stephenson, University of Reading, England
Prof. Dr. Claude Frankignoul, LODYC, Paris, France
Prof. Dr. Heinz Wanner, Universität Bern und NCCR Schweiz, Switzerland
Prof. Dr. Joao Corte-Real, University of Évora, Portugal
Prof. Dr. Kunihiko Kodera, Meteorological Research Institute, Japan
Dr. Roland A. Madden, c/o NCAR, Boulder, USA
Dr. Jim Hurrell, NCAR, Boulder, USA

Investigations with respect to atmospheric and oceanic torques as well as angular momentum will particularly benefit from regular discussions with
Dr. Olivier de Viron, Royal Observatory of Belgium,
Dr. Rui Ponte, Atmospheric and Environmental Research, Inc., Lexington, USA,
Dr. Richard Gross, Jet Propulsion Laboratory, Pasadena, JPL, USA,
Prof. Dr. Aleksander Brzezinski, Space Research Centre of the Polish Academy of Sciences, Warszawa, Poland,
Dr. Jolanta Nastula, Space Research Centre of the Polish Academy of Sciences, Warszawa, Poland.

5.4 Scientific equipment available (Apparative Ausstattung)

Institute for Meteorology, Free University of Berlin:
At the Institute for Meteorology and the university's computing centre ZEDAT the technical resources needed for the planned work (personal computers, data storage, printing equipment etc) are available. In addition, high speed computing facilities available at DKRZ will be used.

Institute of Planetary Geodesy:
At the Lohrmann Observatory of the Institute of Planetary Geodesy six UNIX Workstations (Sun Sparc) as well as several Personal Computers are available for data analyses. The intended OMCT simulations will be performed on the NEC SX-6 parallel supercomputer of the Deutsche Klimarechenzentrum (DKRZ) Hamburg, Germany. Simulations with the Hydrological Discharge Model will be done on the supercomputer SGI Origin2000 of the Zentrums für Hochleistungsrechnen at the Technical University Dresden, Germany. The access to these computer systems is assured, calculating capacity will be allocated art no charge. In addition, a workstation cluster of the electronic data processing center of the Technical University Dresden is available for data post-processing.