SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Potential sea-ice predictability with a high resolution Arctic sea ice-ocean model
Computer Project Account:	spdelosc
Start Year - End Year :	2015 - 2017
Principal Investigator(s)	Dr. Martin Losch
Affiliation/Address:	Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research Am Handelshafen 12 27570 Bremerhaven Germany
Other Researchers (Name/ Affiliation):	Dr. Mahdi Mohammadi-Aragh/AWI, now at Institut für Ostseeforschung Warnemünde (IOW)

The following should cover the entire project duration.

Summary of project objectives

The key objective was to investigate the potential predictability of linear kinematic features (LKF) that are commonly observed in Arctic sea ice. These LKFs emerge in high-resolution simulations sea ice models so that these models may be used to predict sea-ice conditions at these very short scales. Exploring the predictive skill of such a models was the second key objective. For these objectives we carried out ensemble simulations of a 4.5 km resolution sea ice-ocean model forced by atmospheric data of ECMWF's ensemble forecasts.

Summary of problems encountered

We did not encounter any serious technical problems. The only inconvenience was related to downloading the data from the tape archive. Because the AWI has a quite restrictive access policy it is not possible to access AWI computers from ECMWF computers and so the only method of tranfering data from the ECMWF servers to AWI was via sftp, which turned out to be difficult to script and instable in connection with migrated data. We then had to first copy the migrated data from the tape archive to a SCRATCH disk at ECMWF and then transfer it from there to our computers. That was a bit tedious, but not a serious issue.

Experience with the Special Project framework

I found the application procedure very simple to comprehend. Submitting progress reports was also alway easy. If we had any questions, the support staff was always very helpful and were able to answer all of our questions. The same is true for technical question about the computer system, data access and data transfer.

Summary of results

Motivation

One central aim of our project is to explore the intrinsic reproducibility of sea ice deformation forecasts, that is its potential predictability. Our study focuses on long and narrow geophysical features formed in high resolution deformation fields known as linear kinematic features (LKFs). Such structures are important since they emerge throughout the year in the Arctic pack ice and a large portion of sea ice deformation localizes along them (e.g. Kwok 2001).

Methods

For the spinup-simulations, we deployed the coupled sea ice-ocean ocean general circulation model MITgcm (source code and documentation at http://mitgcm.org) forced with the atmospheric fields of the ERA-Iterim-Reanalysis. The MITgcm is a portable open source code for sea ice-ocean (and atmosphere) simulations on massive parallel architectures that can be run with hybrid MPI and OpenMP (multi-threading) parallelization (Marshall et al. 1997, Hill et al. 2007, MITgcm-group 2015). We used the Hibler (1979)'s viscous-plastic (VP) rheology to simulate the sea ice dynamics. The recently implemented efficient method of blank tile listing helped to reduce CPU requirements. This method drops subdomains that are completely "dry" after domain decomposition. With this

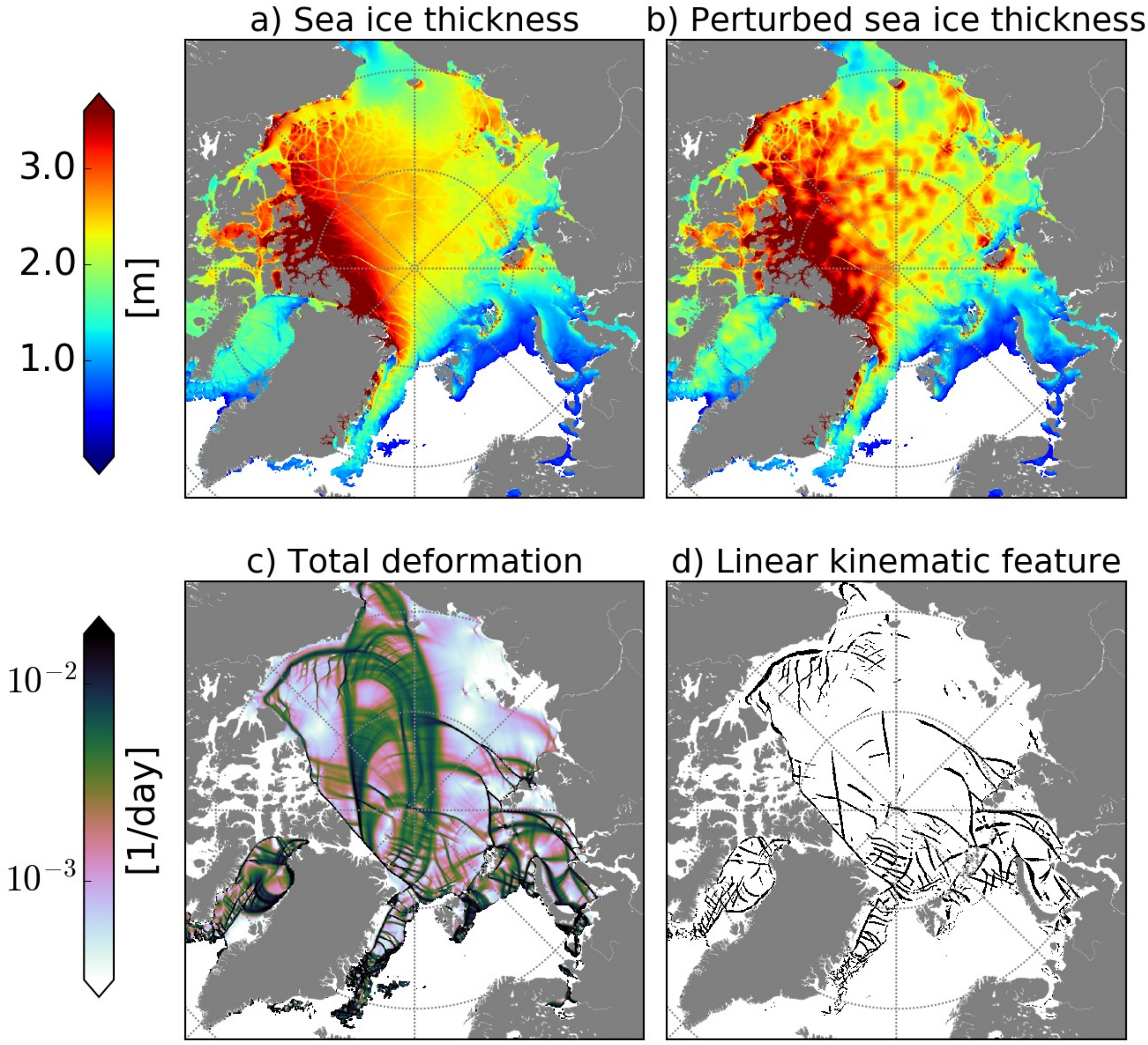

Figure 1. Sea ice thickness initial conditions (in m) on 1 February 2005 with a) atmospheric perturbations only (AtmU) and b) additional sea ice perturbations superimposed (AtmU+IcU). Also shown for AtmU: c) sea ice deformation (in 1/day) and (d) the binary map of Linear Kinematic Features (LKFs) associated with c). All results are based on six-hourly averaged fields.

method, we were able to reduce the number of grid cells and CPU requirements by approximately 30%. In the end, we used a configuration that required 624 CPUs.

We simulated the Arctic sea ice dynamics for eight years starting from the year 2002 until the year 2010. This configuration covers the entire Arctic Ocean and parts of the North Atlantic Ocean and the Bering Sea. This simulation with approximately 4.5 km horizontal resolution and with 1680*1536*50 = 129 Mio. computational cells and a time step of 240 sec is able to reproduce the quasi-linear structures that emerge in high resolution simulations (e.g. Wang and Wang, 2009, Hutter et al, 2018). The results of the numerical experiments provide a platform for developing new deformation comparison methods. Furthermore, the numerical result were used for preliminary visual comparison with radar images to find regions appropriate for more detailed investigations.

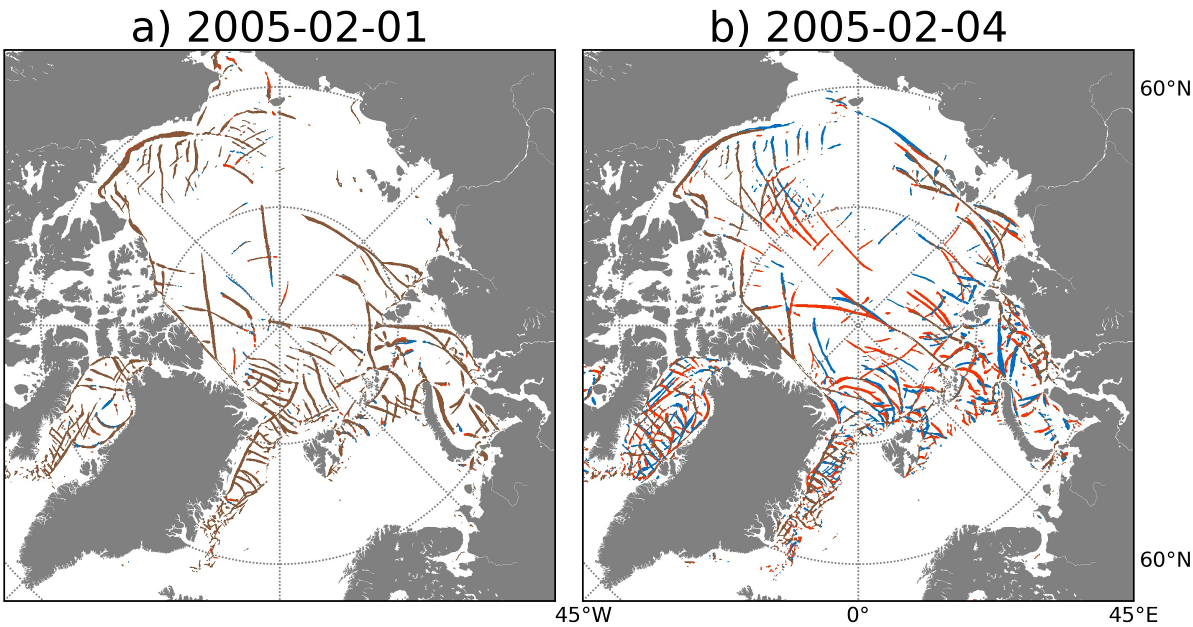

Figure 2. Predictions of Linear Kinematic Features (LKFs) at leads times of a) 1 day and b) 4 days for two randomly chosen ensemble members with atmospheric perturbations only (AtmU). Both forecasts have been initialized on 1 February 2005 at 0 UTC. The LKFs of the two forecasts are marked in red and blue. Where they overlap they are gray, hence gray LKFs indicate agreement between the two forecasts in terms of the predicted location of the LKFs; in contrast, red (first member) and blue (second member) LKFs indicate mismatch between the two forecasts. For 1-day (4-day) forecasts the correlation between the LKFs amounts to 0.9 (0.5); for the Modified Hausdorff Distance (MHD) values of 5.6 km (16.4 km) are obtained.

Results

First, we performed several ensemble prediction scenarios to explore the sensitivity of the potential predictability of LKFs to sea ice thickness initialisation and to uncertainties of the atmospheric forcing forecasts (Buizza et al. 2007). A second step was devoted to developing a fast and applicable detecting method. We explored complex and modern object detecting algorithms, but our experience shows that they are expensive and hence impractical. We found that the final binary maps of LKFs are sensitive to details of, that is the choice of parameters in, the detection algorithm. Thus, it was also necessary to analyse these effects on potential predictability. Finally, we decided to measure the spatial reproducibility of the sea ice deformation and the LKFs using different metrics including spatial correlation and Modified Hausdorff Distance (MHD).

Our results show that, on the 10-day-time scale, the model has lower predictive skill for LKFs and deformation than for sea-ice thickness and concentration. In addition, the atmospheric forcing uncertainties largely determine LKFs predictability. Furthermore, the potential predictability skills varies geographically such that the prediction skill of the pan-Arctic deformation fields can be largely different from the skill of a regional potential prediction.

To analyse the sensitivity of potential predictability to the seasonal anomalies and to the ensemble size of the prediction system, we performed several ensemble forecasts for two seasons including six months and twelve starting dates. The size of the ensembles varied between 15 to 50 members.

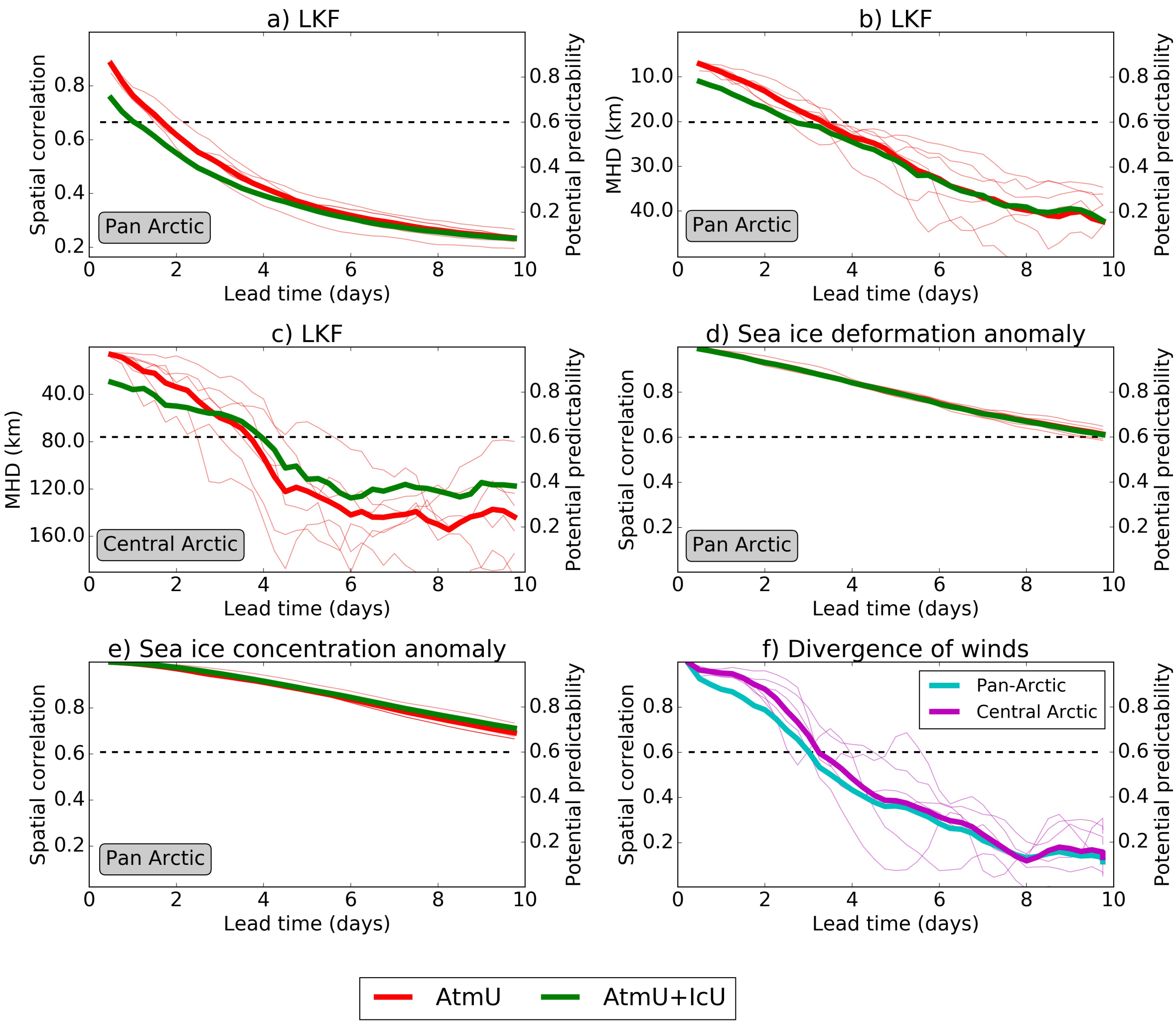

Figure 3. a) Spatial correlation coefficient (left axis) and potential predictability (right axis) for LKFs of pan-Arctic sea ice as a function of forecast lead time for the ensemble experiment with atmospheric uncertainty only (AtmU, red curve) and the one with atmospheric and initial sea ice uncertainty combined (AtmU+IcU, green curve). b) as in a), but for Modified Hausdorff Distance (MHD in km) and corresponding potential predictability. c) as in b), but for sea ice in the central Arctic only (80–90∘N, 120oE–240oE) d) as in a), but for sea ice deformation anomalies. e) as in a), but for sea ice concentration anomalies. f) as in a), but for the divergence of near-surface winds with atmospheric forcing only and for the whole Arctic (blue) as well as the central Arctic (purple). The dashed gray lines mark a common threshold of useful potential predictability for deterministic metrics. Results are based on all 6 cases (initial times) and 15 ensemble members. The thin curves represent the ensemble means for each individual case.

We found that an ensemble prediction system forced by one atmospheric forcing realisation, the potential predictability increases when the initial condition of sea ice and ocean are perturbed in a physically consistent way. The potential predictability is smaller when only sea ice thickness is perturbed, but largest uncertainty is introduced with the atmospheric forcing uncertainty. From our sensitivity analysis to sea ice thickness initialisation, we concluded that perturbations with very short correlation lengths can lead to very noisy LKF fields thus rendering the simulation results useless.

Comparing different metrics showed that spatial correlation is a powerful metric for comparing the similarity of deformation fields. However, it fails to show high correlation of two similar LKF structures when one of them is spatially shifted even only with a short distance. The MHD metric can improve the results, but its result can also be misleading if LKF density is artificially changed due to spurious initial perturbations.
We used a high-resolution sea ice-ocean model forced by an ensemble weather prediction system. Our analyses and simulations indicate that LKFs are less predictable than other sea ice parameters such as sea ice concentration anomalies, especially beyond the first two days of the forecast. From the outcome of our investigation it is possible to conclude that atmospheric uncertainty is more important in generating sea ice forecast error than initial sea ice uncertainty, especially for medium-range (3–10 day) predictions. Figure 1 to 3 show example results published in Mohammadi-Aragh et al. (2018).

Fracture zones and leads represent challenges for numerical sea-ice models that generally rely on a quasi-continuity assumption and some form of viscous-plastic (VP) rheology. At coarse resolution, the solutions of velocity field and sea ice state are smooth and with very little detail. In contrast, at high resolution, numerical sea-ice models introduce sharp discontinuities in the ice movement that makes the comparison between model simulations and observations complex. Thus, we developed a verification method using a neighbourhood approach and spatial verification metrics for detailed comparisons of deformation and LKFs observed in satellite radar images and the sea ice simulations. We found that our numerical model generates large scale continuous LKFs. In contrast, the detected LKFs from the observational data source are affected by both small and large scale sea ice movement. Furthermore, from the deterministic spatial verification that has been carried out, it is possible to conclude that the numerical model generates fewer LKFs, that is, the LKF density is lower. In addition, our sea ice model has higher skill, whenever the density of the numerical LKFs increases. The findings suggest that our approach is useful for sensitivity analyses used to identify the missing physical processes in the atmosphere/ocean/sea-ice models.

The results have been presented in the Polar predictability workshop 2016 at Lamont-Doherry Earth Observatory, at the Polar Prediction Workshop in Bremerhaven, 2017 and in a manuscript published in Scientific reports. A manuscript detailing the different detection methods is in preparation.

References

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List of publications/reports from the project with complete references

Mohammadi-Aragh, M. , Losch, M. , Goessling, H. F. and Hutter, N. (2016). Predictability of Arctic sea-ice linear kinematic features in high-resolution ensemble simulations, Poster at the Polar predictability workshop, Palisades, New York, USA, 4 May 2016 - 6 May 2016, hdl:10013/epic.47969

Mohammadi Aragh, M. , Losch, M. , Goessling, H. , Hutter, N. and Jung, T. (2017). Predictability of Deformation Features in Arctic Sea Ice , Poster at the Polar Prediction Workshop, Bremerhaven, 27 March 2017 - 30 March 2017, hdl:10013/epic.50670

Mohammadi-Aragh, M, Goessling, H. F., Losch, M., Hutter, N., and Jung, T. (2018). Predictability of Arctic sea ice on weather time scales. Scientific Reports, 8, 6514, doi: 10.1002/2017JC013119

One manuscript in preparation: Mohammadi-Aragh et al.

Future plans

There are no imminent plans to continue this project. Similar project proposals with a similar model and model configuration have been submitted last year and been rejected. We are considering a revision re-submission.