SPECIAL PROJECT PROGRESS REPORT

Progress Reports should be 2 to 10 pages in length, depending on importance of the project. All the following mandatory information needs to be provided.

Reporting year	2011
Project Title:	REGCLIM - Optimal forcing perturbations for the atmosphere
Computer Project Account:	SPNOREGC
Principal Investigator(s):	Prof. Trond Iversen and Dr. Jørn Kristiansen.
Affiliation:	Norwegian Meteorological Institute (met.no)
Name of ECMWF scientist(s) collaborating to the project (if applicable)	Dr. Thomas Jung (until end 2010) [Colaboration also with Dr. Jan Barkmeijer, KNMI]
Start date of the project:	Continuation from start in 2003
Expected end date:	End 2011

Computer resources allocated/used for the current year and the previous one

(if applicable)

Please answer for all project resources

		Previous year		**Current year**	
		Allocated	Used	Allocated	Used
High Performance Computing Facility	(units)	600000	652958.48	600000	0
Data storage capacity	(Gbytes)	1000		1000	

Summary of project objectives

(10 lines max)

The focus is on the relations between external forcing perturbations and the atmospheric response as calculated in a state of the art global atmospheric model (ECMWF IFS). Based on well documented methods in the scientific literature, we calculate atmospheric forcing sensitivities and optimal forcing perturbations w.r.t. a predefined target response and optimization period (4 days). The focus is the Northern-Hemisphere during winter. We have followed up the recently published work (Iversen et al., 2008) with extended periods (1957-2002), more hemispherical flow patterns including their regional realizations and tests of the results to various parameter choices. In addition to complement the analysis of the hemispherical flow patterns, the regional patterns are employed in the study of polar meteorology and the sensitivity of the large-scale flow associated with the occurrence of polar lows. To complete the analysis of forcing perturbations and their associated responses we calculate forcing singular vectors used in non-linear ensemble forecasts.

Summary of problems encountered (if any)

(20 lines max)

The sensitivity suite is not supported any longer. Also, it is not straightforward to run FSVs with different spatial resolutions. Unclear, how FSV fits within cycles pre-EDA.

Summary of results of the current year (from July of previous year to June of current year)

This section should comprise 1 to 8 pages and can be replaced by a short summary plus an existing scientific report on the project

Introduction

At high latitudes, severe wind and intense precipitation are often associated with polar lows. Polar lows are short lived (typically less than 24h) mesoscale cyclones which are 100-1000 km in diameter. They occur with irregular intervals several times during each winter month and in particular when the background flow pattern forces cold air masses from the high Arctic over the ice-free ocean in the Nordic and Barents Seas.

Optimal relations between external forcing and the occurrence of regional atmospheric flow patterns in the Euro-Atlantic sector of the Arctic (47.5->85N; -57.5->67.5E), are estimated by employing the state of the art global atmospheric model at ECMWF (IFS) with T63 horizontal resolution and 60 vertical levels, and the diabatic tangent-linear adjoint technique (Iversen et al., 2008). The target patterns are regional realizations of, respectively, hemispheric patterns A and D from Corti et al. (1999). RC2 is associated with advection of cold air from land or ice surfaces over relatively warm water, favourable for polar low events, and vice versa for RC1. These patterns are targeted to the northern-most center of action of the North Atlantic Oscillation (NAO).Thus, we estimate the forcing sensitivities and optimal forcing sensitivity patterns (FSPs) associated with the onset – over 4 days – of RC1 and RC2. Calculations are made for 1125

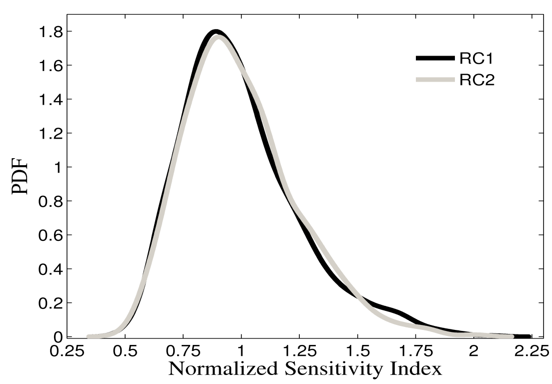

Figure 1: Estimated forcing sensitivity distributions w.r.t. two atmospheric regional flow patterns RC1 and RC2. The target patterns are regional realizations of, respectively, hemispheric patterns A and D from Corti et al. (1999).

approximately independent cases from the 45 winter seasons in the ERA-40 re-analysis data-set from ECMWF.

Since the coarse horizontal resolution employed here is not able to adequately resolve the polar lows, we employ ***a stability criterion*** frequently used by forecasters to evaluate the large-scale conditions favourable for polar low development; this is: $\boldsymbol{SST\text{-}T_{500hPa}>43K}$ (Noer and Ovhed, 2003).

Forcing sensitivities

Figure 1 shows the estimated distributions of the forcing sensitivities with respect to RC1 (black) and RC2 (grey). The sensitivities have been normalized by their respective mean values. The two distributions are similar with about the same peak and standard deviation. The distributions are non-gaussian and asymmetric with tails extending towards high values. The frequency of rare events is thus low but considerably higher for strong sensitivity than for weak; i.e. the atmosphere is sensitive only very intermittently during periods of a few days. This is consistent with Iversen et al. (2008) who used the hemispherical COWL pattern as target. RC1 is the regional sector-realization of COWL.

During the rare events of high sensitivity to forcing perturbations, the atmosphere is most likely to be in a position where small external perturbations may alter its subsequent phase space trajectory. We therefore focus on the 5% most sensitive dates and estimate the associated optimal forcing perturbations on which external perturbations need to project positively (Palmer, 1999; I08). We employ the adjont and tangent-linear model of the ECMWF-IFS and the corresponding responses are evolved by running the model with full physics complexity.

Large scale flow patterns conditioning polar lows

Figure 2 shows Z_{500hPa} composites of the evolved response patterns (perturbed minus unperturbed integration) w.r.t. RC1 (left) and RC2 (right) after 4 days for the 5% most sensitive days. The optimal forcing structures systematically alter the daily large-scale atmospheric flow conditions within the target domain. However, the response is not restricted to the target domain only and the evolved response patterns resemble the positive (RC1) and negative (RC2) phase of the NAO. The amplitudes of anomalies agree closely with other studies of the daily flow pattern associated with marine cold air outbreaks (Kolstad et al., 2009).

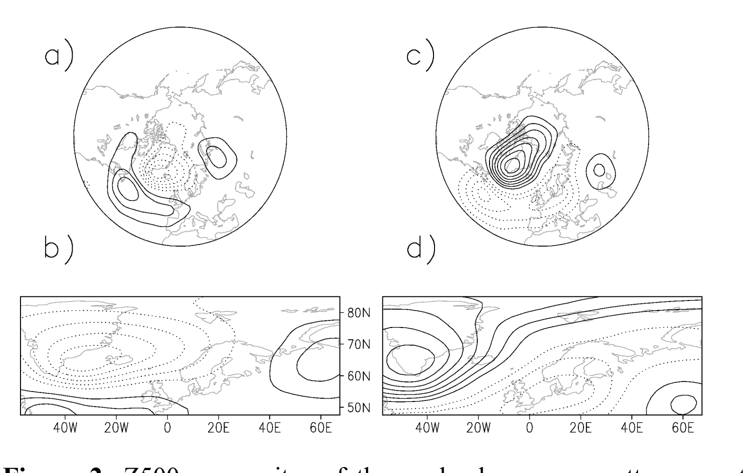

Figure 2: Z500 composites of the evolved response patterns w.r.t. RC1 (left) and RC2 (right). The bottom panels show the flow within the target domain. Negative (positive) contours are dotted (solid) and the contour interval is 30m (the 0-contour is omitted).

Figure 3 shows for each grid point the fraction of dates when the stability criterion is fulfilled after 4 days for perturbed and unperturbed (control) forecasts for the 5% most sensitive dates. Clearly the evolved RC1 and RC2 responses are associated with large-scale flow patterns that are unfavourable respectively favourable for polar low development. The spatial distribution of frequency of occurrence of polar low events in the Nordic Seas is consistent with previous climatology studies (e.g. Bracegirdle and Gray, 2008).

Optimal forcing perturbations

A shift in the frequency of occurrence of the positive (RC1) and the negative (RC2) phase of the NAO is prone to be triggered if the external forcing projects positively onto either of the optimal

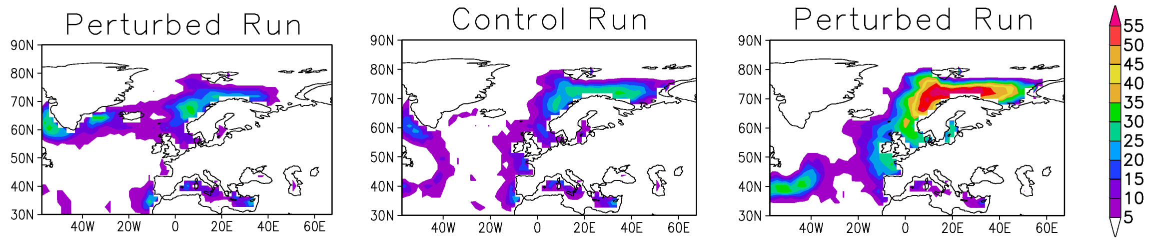

Figure 3: Percentage of dates fulfilling thec stability criterion (SST-T_{500hPa}>43K) of Noer and Ovhed (2003) after 4 days. Perturbed forecasts are for the 5% most sensitive dates w.r.t. RC1 (left) and RC2 (right). The unperturbed forecasts are for reference (middle).

forcing structures w.r.t. RC1 or RC2. Due to linearity, the two FSPs are estimated to be similar but with reversed sign, see Fig. 4. Hence, Fig. 5 shows only the FSPs w.r.t. RC2 averaged over the 5% most sensitive dates. On a given day, the mean forcing pattern is not optimal but includes important local perturbations associated with the flow of the day.

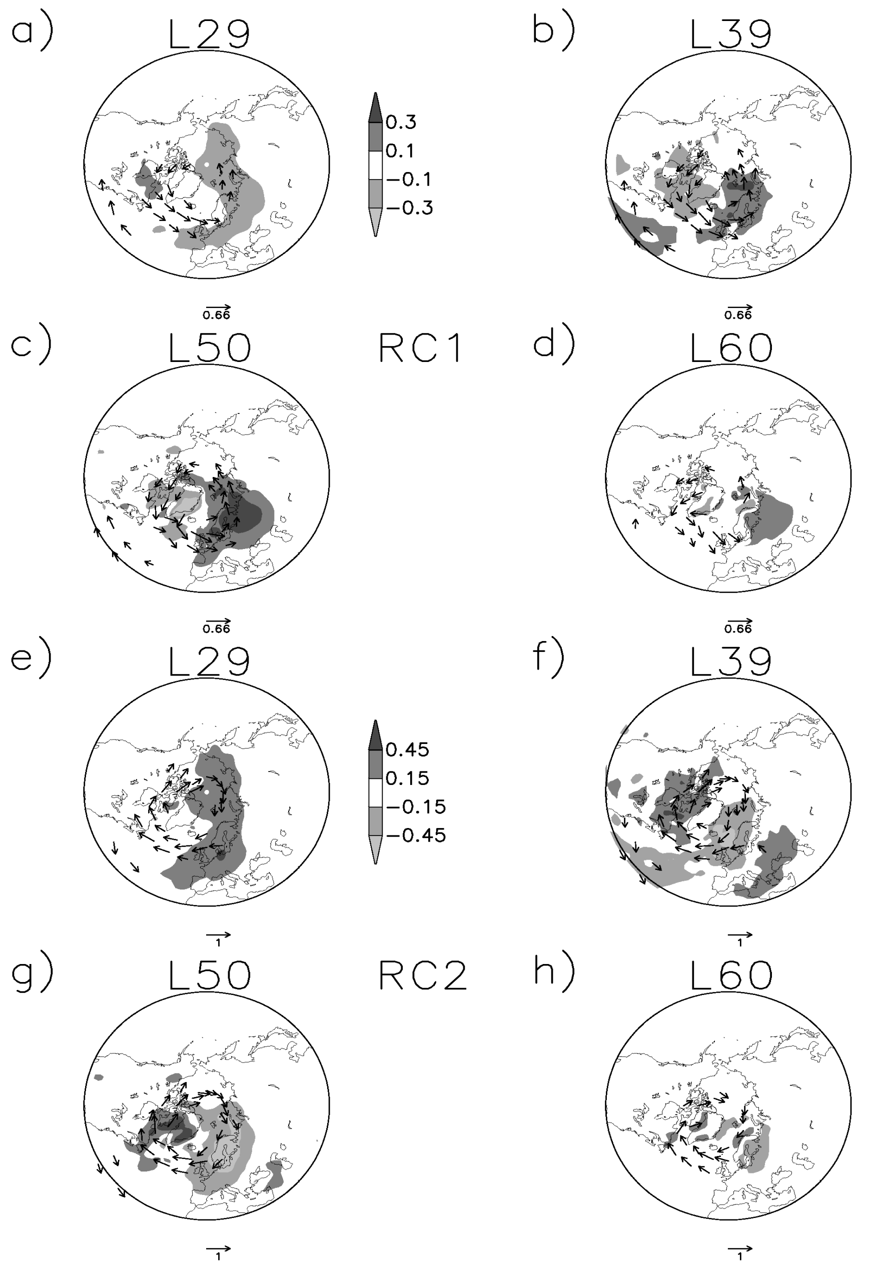

Figure 4: Optimal forcing structures w.r.t. (a-d) RC1 and (e-h) RC2 at model levels 29 (177 hPa), 39 (500 hPa), 50 (884 hPa) and 60 (surface). The temperature perturbations (K/day) are shaded and the wind perturbations are shown as arrows. The perturbations are averaged over the 5% most sensitive dates. For RC1 (RC2) wind speeds below 0.25 (0.40) m/s/day are omitted.

The strongest temperature perturbations are found in the lower half of the troposphere. Close to the surface the perturbations are generally weak but for there is influence from areas along the coast of Northern-Norway (Fig. 4). In the lower half of the troposphere the strong negative temperature perturbations are co-located with strong northerly wind perturbations and v. v. This supports that the temperature and momentum perturbations are equally important for the growth of the response. However, there are significant feedbacks. Note that the perturbations associated with RC2 (NAO-) are larger than those associated with RC1 (NAO+).

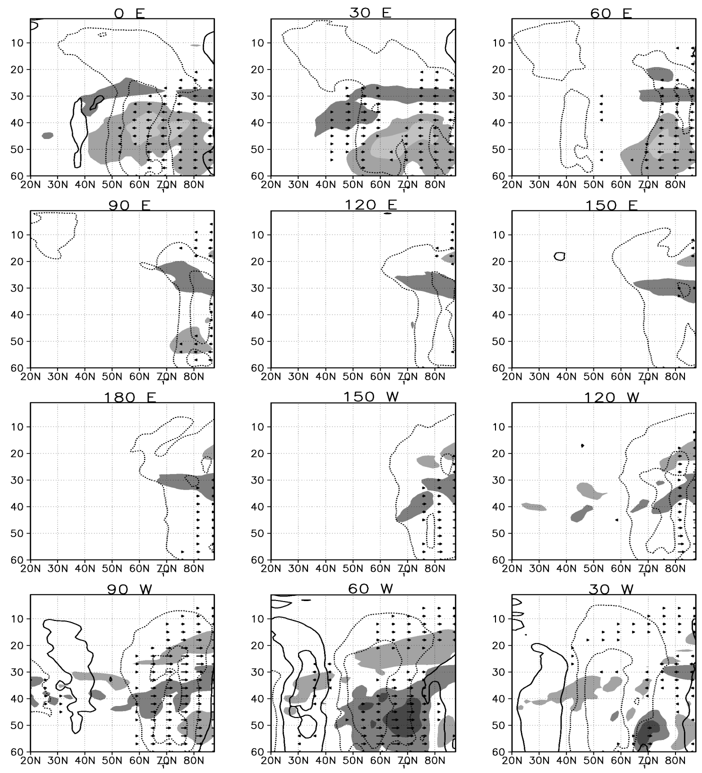

Figure 5: Same as Fig. 4 but meridional-vertical cross sections. The zonal wind component are contoured at -0.45, -0.15, 0.15 and 0.45 m/s/day (solid lines are positive) and the meridional winds are shown as arrows. For both components values in the range -0.15 to +0.15 m/s/day are omitted. The shading intervals for temperature are the same as in Fig. 4.

The momentum perturbations are also strong outside the target domain with an almost uniform vertical structure from the surface into the stratosphere. The perturbations of the zonal wind are found at all longitudes and have an annular shape centred around Greenland. The perturbations follow the circulation of the evolved response (Fig. 2) around its central anomaly.

Conclusions

We have shown that polar lows in the Euro-Atlantic sector of the Arctic are considerably more favourable during low NAO (RC2) than during high NAO (RC1). Hence, we have estimated the associated forcing sensitivities and optimal forcing perturbations for these two flow situations.

Both the optimal forcing perturbations and the associated response after 4 days extend beyond the limits of the target domain defining RC1 and RC2. We intend to investigate in more detail the dynamical processes associated with the optimal forcing structures. The forcing sensitivity patterns (FSPs) can be useful for discussing the relative role of internal atmospheric dynamics and interactions with the ocean. Nonlinear developments of Forcing Singular Vectors (FSVs) should be a valuable supplement to such an analysis.

References

Bracegirdle, T.J., and S. Grey, 2008: An objective climatology of the dynamical forcing of polar lows in the Nordic Seas. Int. J. Climatol. 28, 1903-1919.

Corti, S., F. Molteni and T.N. Palmer, 1999: Signature of recent climate change in frequencies of natural atmospheric circulation regimes. Nature, 398, 799-802.

Iversen, T., J. Kristiansen, T. Jung and J. Barkmeijer, 2008: Optimal atmospheric forcing perturbations for the cold-ocean warm-land pattern. Tellus, 60A, 528-546.

Kolstad, E.W., T.J. Bracegirdle and I.A. Seierstad, 2009: Marine cold-air outbreaks in the North Atlantic: temporal distribution and associations with large-scale atmospheric circulation. Clim. Dyn, 33, 187-197.

Noer, G. and M. Ovhed, 2003: Forecasting of Polar Lows in the Norwegian and the Barents Sea. Proceedings of the 9th meeting of EGS Polar Lows Working Group, Cambridge, UK. Available: http://www.unitrier.de/index.php?id=28161#c60628.

List of publications/reports from the project with complete references

1) Iversen, T., Barkmeijer, J., and Palmer. T.N., 2003: Optimal forcing perturbations for the atmosphere. RegClim Phase III-General Technical Report, 7, 107-135.
2) Iversen, T., Kristiansen, J., Jung, T., and J. Barkmeijer, 2006: Optimal Forcing Sensitivity patterns for changes in northern hemispheric flows in the atmosphere, RegClim Phase III-General Technical Report, 9, 21-49.
3) Iversen, T., Kristiansen, J., Jung, T., and J. Barkmeijer, 2008: Optimal atmospheric forcing perturbations for the cold-ocean warm-land pattern, *Tellus,* **60A***,* 528–546. doi:10.1111/j.1600-0870.2008.00310.x

Summary of plans for the continuation of the project

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A publication of this work is underway for soon submission. This may require some additional experiments. Having implemented the method for FSV calculations using diabatic TL and adjoint in cycle 36r1, we focus on FSVs in order to extend the study of predictability and sensitivity related to large-scale flow conditions favourable and unfavourable for the occurrence of polar lows in the Nordic Seas. These calculations work with an EPS-version before EDA was introduced. Further, the FSV calculations should be performed on a higher spatial resolution than the current T42L62. The choice of perturbation amplitudes (wrt variable) also requires attention. The feasibility of employing FSVs to represent actual forcing of the atmosphere or model inaccuracies will be further investigated. This topics are common to GLAMEPS - Grand Limited Area Model Ensemble Prediction System, i.e. SPNOGEPS.