Mesoscale dynamics and orographic channeling of low-level flow through Nares Strait

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Abstract

model estimates of low-level winds and surface wind stress through Nares Strait, between Ellesmere Island and Greenland, during two years from August 2003 through July 2005. Analysis of the model results during these two periods also suggest that the intense, low-level, along-strait winds are strongly ageostrophic, and may be usefully estimated from pressure differences along the Strait.

1 Introduction

The ice and freshwater balance in the Arctic Ocean has importance for the maintenance of perennial Arctic pack ice, a critical element of the global climate system. Arctic ice and freshwater pass into the North Atlantic through Fram Strait into the Greenland Sea and through the Canadian Arctic Archipelago (CAA) into Baffin Bay. Kwok et al. (2004) and Vinje (2001) have studied the export of sea ice through Fram Strait, but little is known about the control on ice flux through Nares Strait (Fig. **??**), the main eastern channel of the CAA (Melling, 2000). Pack ice may drift southward year-round through Nares Strait, but often consolidates in winter behind an ice bridge near Smith Sound (Agnew, 1998). Consolidation can occur any time between November and April, and may occur in stages, with bridges forming consecutively in Robeson and Kennedy Channels and Smith Sound, and collapsing a few weeks later or persisting as late as mid-August. Evidently, the land-fast ice regime of Nares Strait is near marginal stability in the present climate, between the permanent mobility of pack ice in Fram Strait and the more persistently static conditions in the western CAA.

We hypothesize that local atmospheric forcing contributes to the intermittent instability of land-fast ice in Nares Strait. The purpose of this note is to provide direct support for this hypothesis, using model estimates of atmospheric forcing and satellite observations of ice motion. We focus here on periods in January-February and November-December 2004, which were chosen because of distinctive ice-motion events noted during ongoing continuous observation of Nares Strait.

2 Regional atmospheric model

Continuous, long-term in-situ measurements of atmospheric forcing are not currently available in the remote and logistically challenging Nares Strait region. A regional mesoscale atmospheric model is instead being used to simulate local meteorological conditions during 2003-2007, as part of an on-going oceanographic observational program (Münchow et al., 2005). The model used for these simulations is the Polar MM5 (Bromwich et al., 2001) version of the Pennsylvania State University/National Center for Atmospheric Research MM5, a non-hydrostatic, primitive-equation, terrain-following model with full moist physics. The Polar MM5 is optimized for the polar environment and has been used successfully to simulate meteorological conditions in both polar regions (e.g., Cassano et al., 2001; Guo et al., 2003). It is implemented here in a triply-nested configuration, with 54-km, 18-km, and 6-km grid resolutions in the outer, intermediate, and inner nests, respectively (Fig. **??**), and run in a daily 36-hr forecast mode. Initial and time-dependent outer boundary conditions are taken from the operational global National Center for Environmental Prediction AVN model, which can be expected to provide an accurate estimate of large-scale atmospheric conditions on these timescales. Hourly model fields from the simulations were concatenated into continuous time series, and analyzed at six grid locations in the channel (Fig. **??**). In the region of interest, radiational cooling and surface fluxes cause frequent development of a stable planetary boundary layer, in which wind direction and speed are strongly affected by the steep coastal orography. Mesoscale models nested in operational global atmospheric forecast models have previously been shown capable of reproducing observed low-level wind structure arising from the interaction of a stable lower atmospheric with coastal orography along the mid-latitude U.S. west coast (e.g., Perlin et al., 2004). It is presumed here that the regional model will reproduce similar effects in the Nares Strait region with similar accuracy. In-situ verification of model performance in other regions of the domain is in progress and will be reported on elsewhere.

3 Two-year climatology

In this section, a seasonal climatology is given, based on two years of simulations.

Monthly means and std dev (hourly output):

Figure 1:

Monthly mean 10-m winds are northerly with spatial maxima of 8-10 m/s for most of each of the two years. The exceptions occur during the summer: during August and September 2003, July and August 2004, and July 2005, the 10-m winds are generally 5 m/s or less throughout the domain, with no consistent directional pattern. The strong northerly monthly mean 10-m winds during the rest of the year have a characteristic spatial structure, with the strongest winds centered on the southern ends of Kennedy Channel and Smith Sound, where the narrow channels widen into larger basins (Fig. 1a). The corresponding monthly mean 10-m wind directions in the channel are oriented along the channel, but are westerly in the Lincoln Sea and northwesterly south of Smith Sound (Fig. 1b).

Associated with these strong northerly monthly-mean 10-m along-channel winds is a large monthly mean along-channel gradient in sea-level pressure (SLP; Fig. 1c). The monthly mean SLP difference between the Lincoln Sea and northern Baffin Bay is typically 800-1000

Pa (8-10 mb). Roughly half of this drop occurs over the Nares Strait channel, from Robeson Channel to Smith Sound. In the Lincoln Sea and northern Baffin Bay, the 10-m winds are aligned approximately along isobars, and so are nearly geostrophic, except for surface frictional effects. The along-channel momentum balance of the orographically controlled flow within Nares Strait, however, is strongly ageostrophic, with flow down the pressure gradient from the Lincoln Sea to Smith Sound. Sea-level pressure contours are tilted across the channel, consistent with approximate geostrophy in the cross-channel momentum balance.

Annual means and EOFs, slp and u-v stress.

Figure 2:

Since the monthly mean SLP and 10-m wind fields have characteristic spatial patterns during most of the year, their variability can be efficiently described by EOFs. Nearly all the variance in the two-year time series of monthly mean SLP is described by the first two EOFs (Fig. 2). The leading SLP EOF

Lower-atmosphere stability; cross-sections. Extreme events. Precip?

4 dynamics

Pressure-diff vs. wind correlation; historical record. Reconstructed monthly mean time series for past 50 (?) years, with error estimate. Katabatic flow? Orographic channeling?

5 Ageostrophic winds and wind-pressure correlations

The model wind and wind stress during both the January-February and November-December 2004 periods discussed above are well correlated with the model sea-level pressure difference along Nares Strait between the Lincoln Sea and northern Baffin Bay, with correlations -0.96 and -0.92 during the first period and -0.88 and -0.84 during the second, respectively, and the signs consistent with flow from high to low pressure (Fig. **??**). This suggests that the low-level atmospheric jet and strong surface stresses arise from an ageostrophic response to orographic channeling of winds in the stable lower atmosphere, similar to that found in some midlatitude coastal marine regions (e.g.,Winant et al, 1987; Samelson and Lentz, 1994). During both periods, daily-averaged model sea-level pressure differences from north to south along the Strait reached values as large as 15 mb (Fig. **??**), and daily-averaged model wind stress reached values of 0.7-1.0 N m^{-2}.

These results suggest that, in the absence of in-situ meteorological observations, it may be possible to obtain a useful estimate of along-channel winds and stress in the Strait from measurements of sea-level pressure at or near the north and south ends of the Strait. A more complete analysis of this correlation and the associated dynamics is in progress and, along with a two-year model climatology of winds in the Strait, will be presented elsewhere. If successful, a method based on this correlation would allow reconstruction of wind and stress time series in Nares Strait from historical pressure records, and provide a method for estimating Nares Strait winds from robust and relatively low-cost surface meteorological observations.

6 Summary

Acknowledgments

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List of Figures

1 Jan 2005 mean 10-m wind speed and direction, and sea-level pressure. 10

2 10-m wind mean and EOFs from monthly means, Aug 2003 - Jul 2005. . . . 11

3 10-m wind EOF amplitudes from monthly means, Aug 2003 - Jul 2005. . . . 12

4 SLP Mean and EOFs from monthly means, Aug 2003 - Jul 2005. 13

5 SLP EOF amplitudes from monthly means, Aug 2003 - Jul 2005. 14

6 Stress Mean and EOFs from monthly means, Aug 2003 - Jul 2005. 15

7 Stress EOF amplitudes from monthly means, Aug 2003 - Jul 2005. 16

8 Normalized SLP EOF #1 and stress EOF #1 and #2 amplitudes from monthly means, Aug 2003 - Jul 2005. The SLP and stress EOF amplitudes have been scaled by the maximum values of the corresponding first EOFs. 17

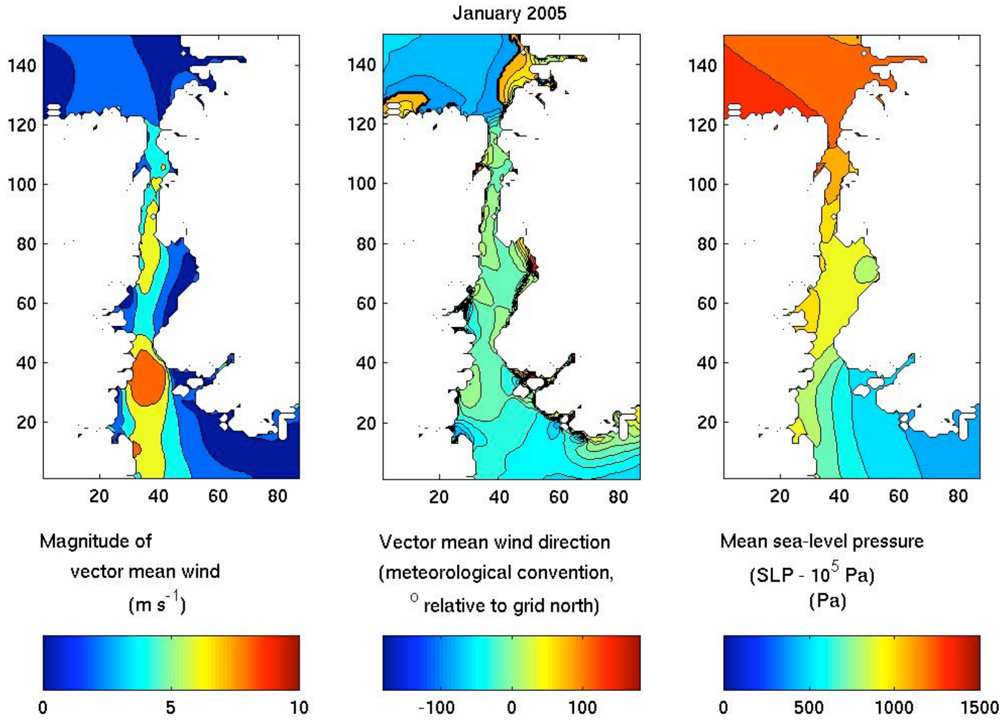

Figure 1: Jan 2005 mean 10-m wind speed and direction, and sea-level pressure.

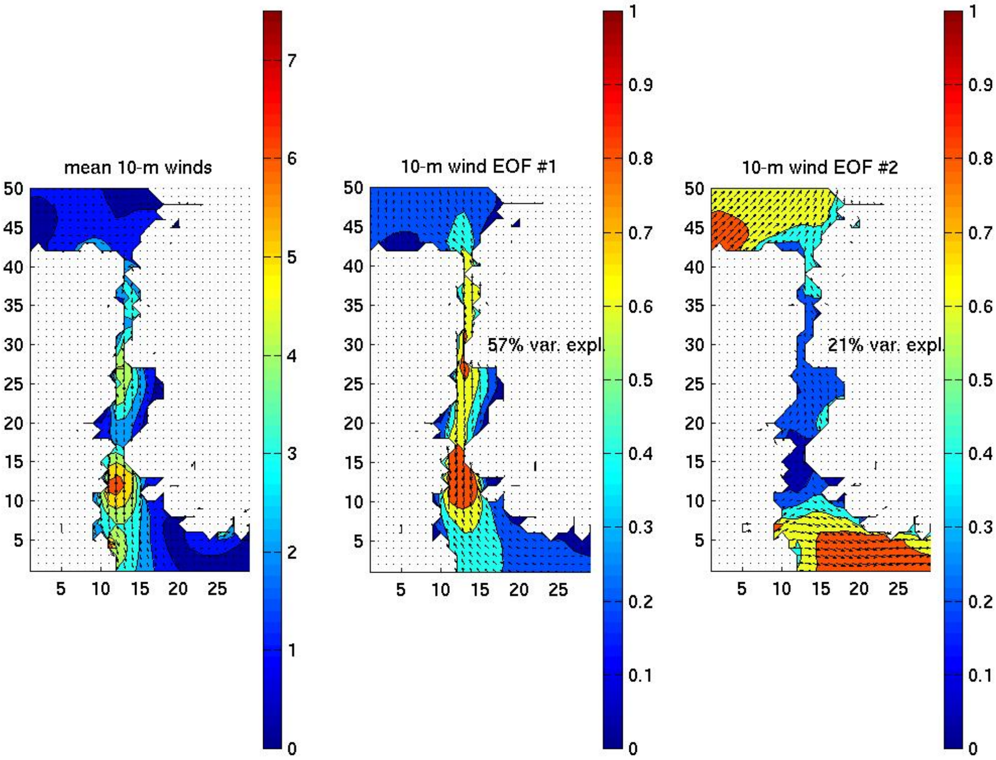

Figure 2: 10-m wind mean and EOFs from monthly means, Aug 2003 - Jul 2005.

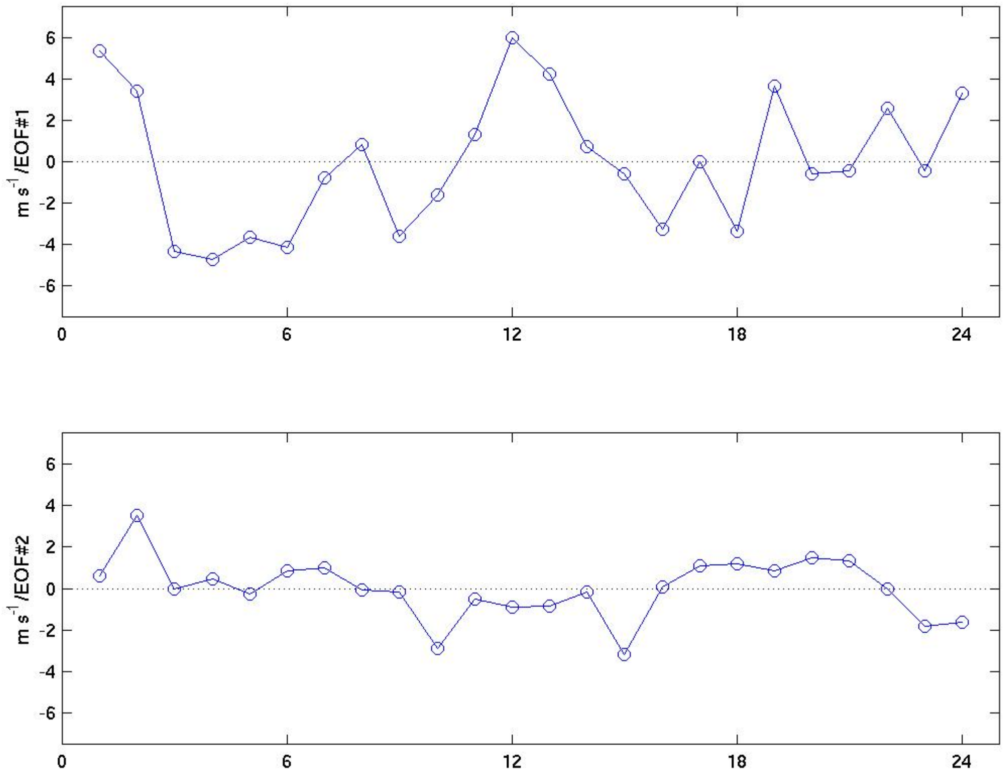

Figure 3: 10-m wind EOF amplitudes from monthly means, Aug 2003 - Jul 2005.

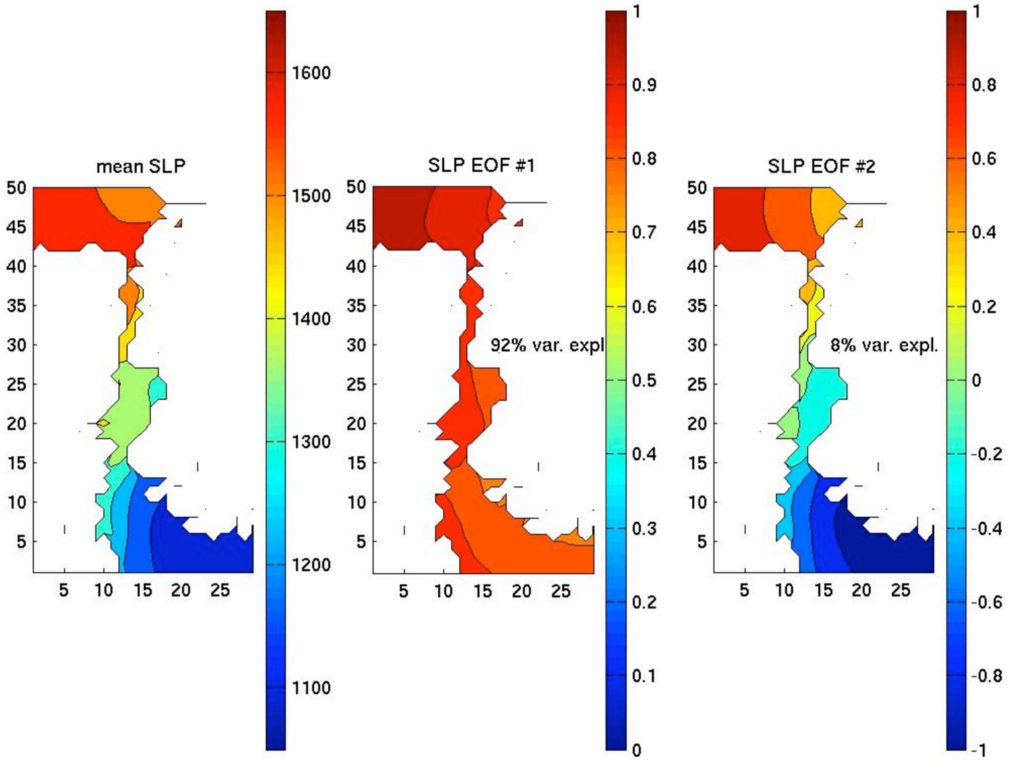

Figure 4: SLP Mean and EOFs from monthly means, Aug 2003 - Jul 2005.

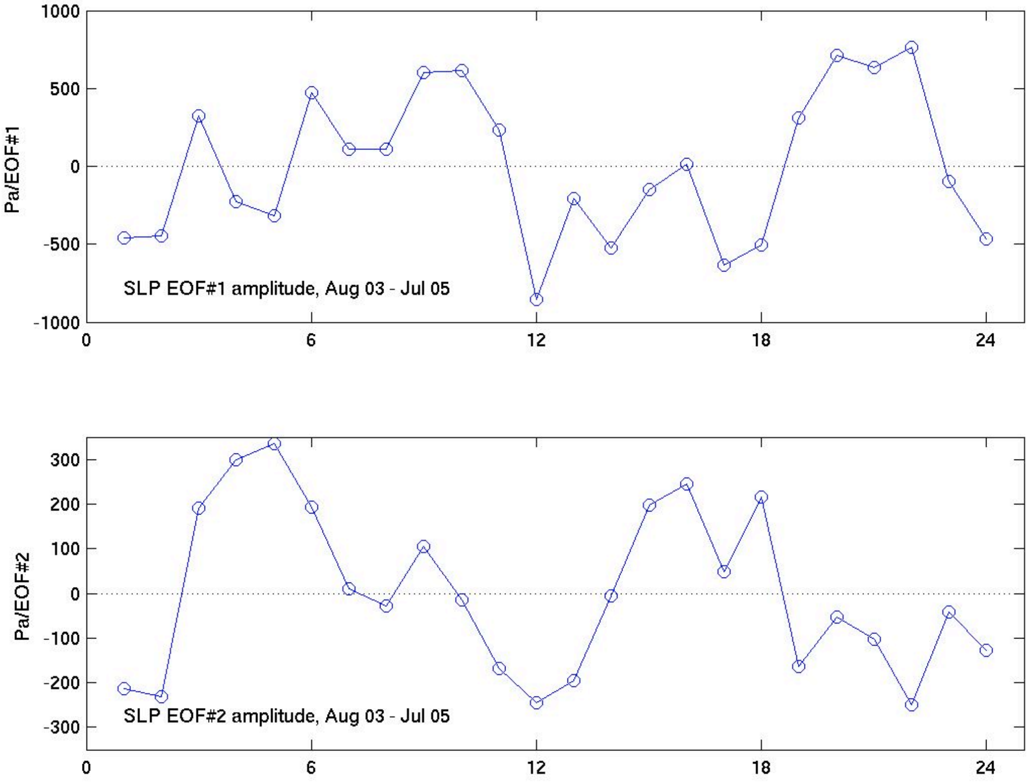

Figure 5: SLP EOF amplitudes from monthly means, Aug 2003 - Jul 2005.

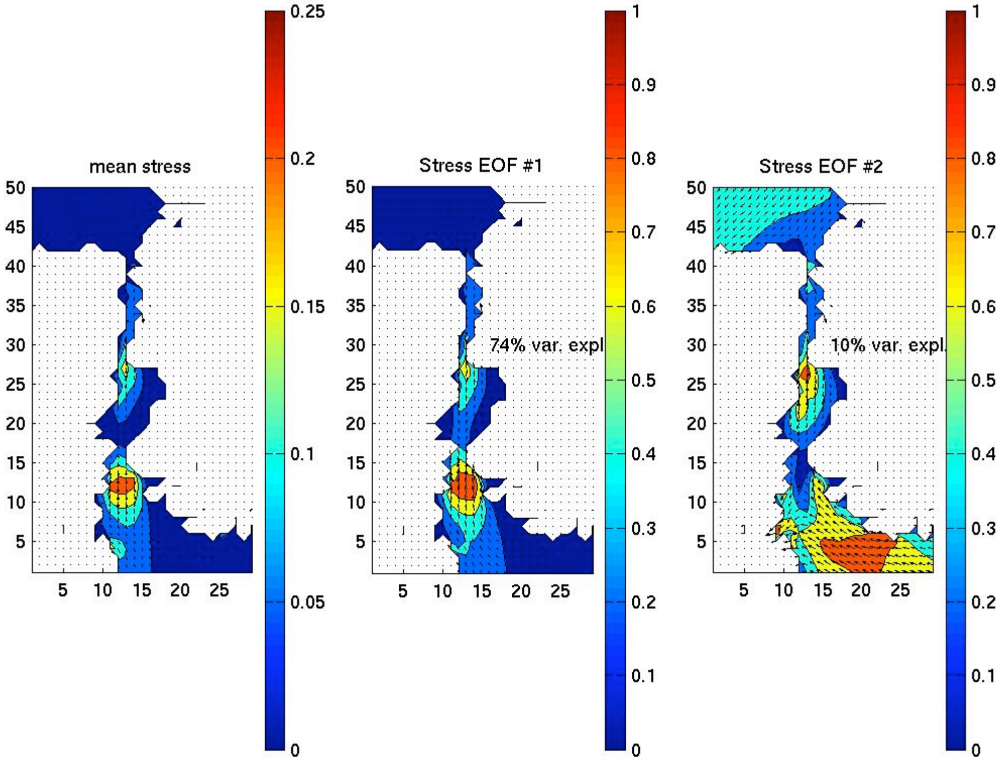

Figure 6: Stress Mean and EOFs from monthly means, Aug 2003 - Jul 2005.

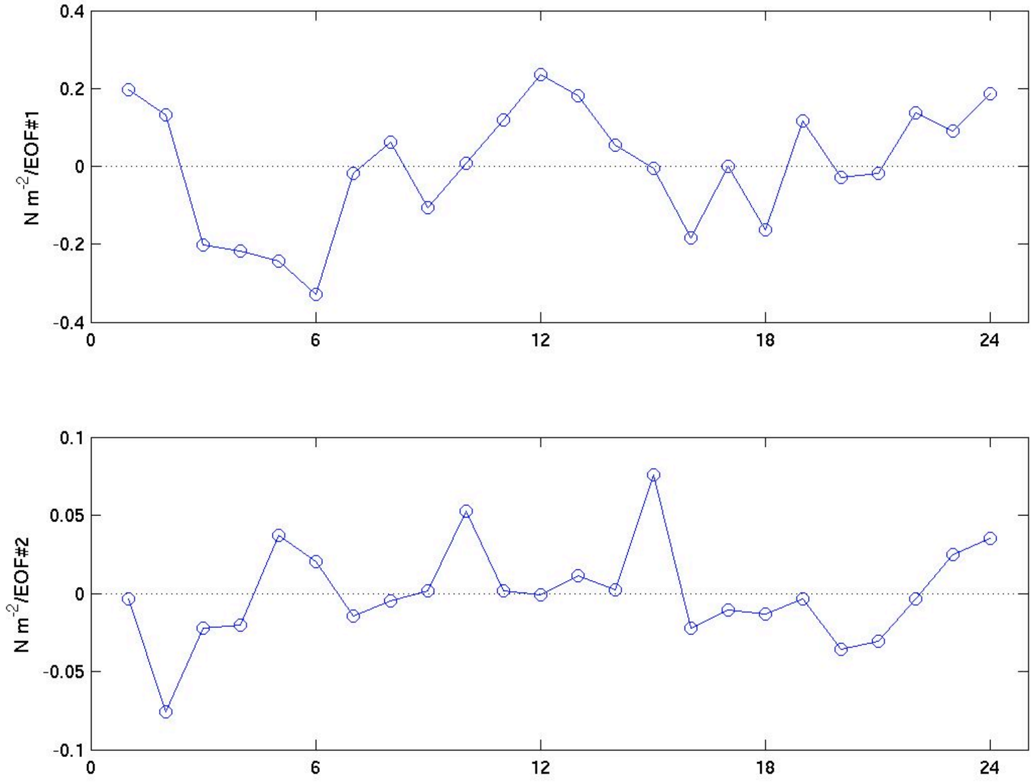

Figure 7: Stress EOF amplitudes from monthly means, Aug 2003 - Jul 2005.

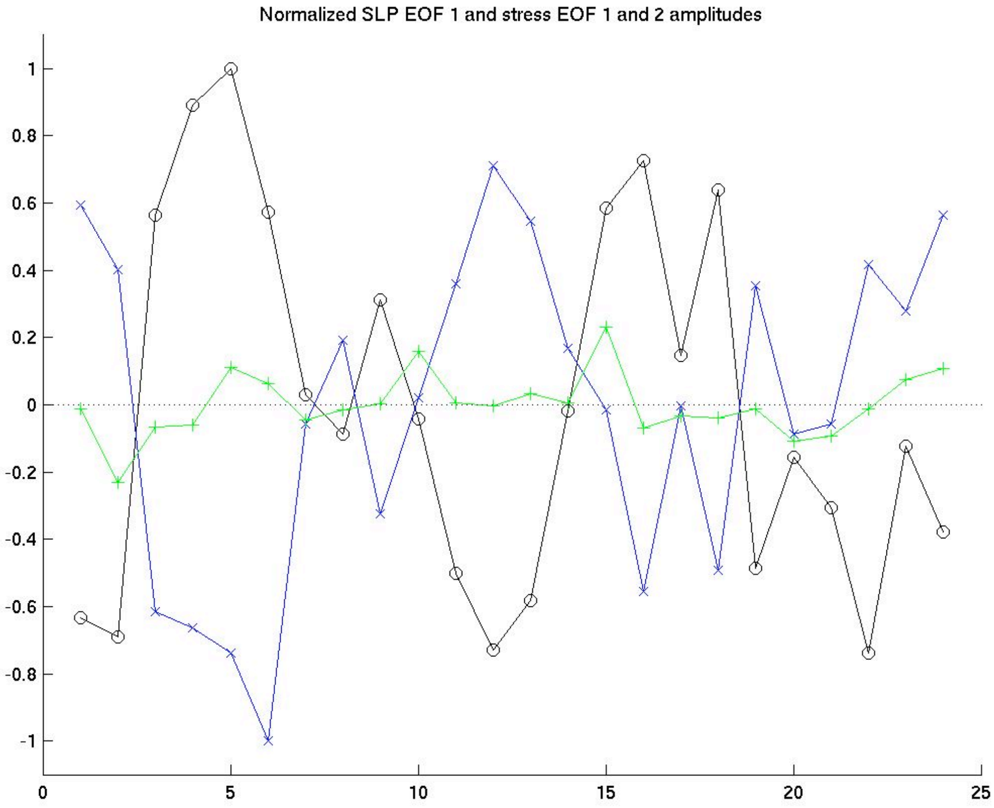

Figure 8: Normalized SLP EOF #1 and stress EOF #1 and #2 amplitudes from monthly means, Aug 2003 - Jul 2005. The SLP and stress EOF amplitudes have been scaled by the maximum values of the corresponding first EOFs.