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INTERACTIONS BETWEEN ANTARCTIC SEA ICE AND ATMOSPHERIC CIRCULATION ON WEEKLY TO SEASONAL TIME SCALES

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1. BACKGROUND AND MOTIVATION

Low frequency variability of the Southern Hemisphere atmospheric circulation is known to be concentrated over the southeast Pacific, largely as a result of ENSO forcing (Renwick and Revell 1999, Renwick 2002). ENSO modulation of the South Pacific circulation acts to further modulate sea ice across the southern Pacific and Atlantic sectors (Kwok and Comiso 2002, Renwick 2002, Yuan 2004). This work has been motivated by the hypothesis that sea ice variability may feed back upon the atmospheric circulation to further enhance and perhaps to geographically anchor low frequency variations of the circulation. On interannual time scales, the forcing appears to be from the atmosphere to the sea-ice, with little evidence as yet of a feedback in the other direction.

This poster presentation addresses shorter time-scale variability, through a preliminary study of weekly-scale atmospheric and Antarctic sea-ice fields. It seeks to identify the main patterns of coupled variation between atmosphere and sea ice, and to contrast observed patterns with those seen at seasonal time scales. It further seeks to identify whether sea ice variability influences the atmospheric circulation on synoptic time scales.

2. DATA & METHODS

2.1 *Sea Ice*

Daily sea ice concentrations derived from SSMR and SSM/I, using the bootstrap algorithm (Cavalieri et al. 2002), were obtained through the National Snow and Ice Data Center (NSIDC) in Boulder, CO. Twenty four years of record were obtained, from November 1978 to December 2002. The data are available on a polar projection with a grid spacing of approximately 25km.

Prior to July 1987, the data were available every two days rather than daily. The “missing” days were filled in by linear interpolation. Following this, any other one-day gaps were filled by linear interpolation. The daily sea ice concentrations were then processed into pentad (5-day) means and averaged onto a ~150km resolution polar stereographic grid. In leap years, one pentad was extended to six days duration, to allow for the extra day at the end of February, and to maintain a common set of 73 pentads for each year of the data series. The resulting data set is convenient for analysis of weekly and longer-term variability.

2.2 *Atmospheric Circulation*

Once-daily height fields at 1200UTC were taken from the NCEP/NCAR reanalysis (Kistler et al 2000) at 500hPa and 1000hPa. Fields were projected onto a southern polar stereographic grid and averaged into pentads to match the sea ice data, over the same period of record (Nov 1978 to Dec 2002).

2.3 *Methods*

The data analysis made use of a series of empirical orthogonal function (EOF, Wilks 1995) and cluster analyses of the sea ice concentration time series, after removal of a smoothed annual cycle. The annual cycle of sea ice is described briefly below.

A series of maximum covariance analyses (MCA, Bretherton et al. 1992) were carried out between atmospheric circulation and sea ice concentration anomaly fields, at a range of time lags. MCA was applied for specified pentad windows, corresponding to “seasons” in the mean growth and decay life cycle of the sea ice concentration. Interannual variability was removed by subtracting the seasonal mean for each year from each set of fields, to concentrate on synoptic time scales.

3. ANNUAL CYCLE OF SEA ICE

Sea ice concentration fields were analyzed as departures from a smooth climatology derived from pentad means. The climatology was calculated as the long-term

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mean concentration for each of the 73 pentads, then smoothed point-by-point with a 1-2-1 filter applied five times.

The smoothed pentad data capture the seasonal cycle of ice growth and decay, as shown below. The minimum total ice concentration/extent occurs at pentad 10, centered on 17 February, and the ice maximum occurs at pentad 53, centered on 20 September. The transition seasons are centered around early June and early December (Fig. 1).

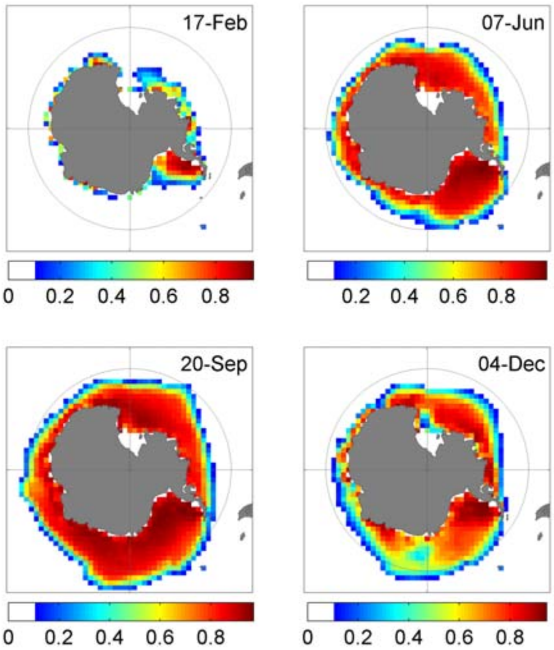

Figure 1: Average sea ice concentration for times of minimum extent (top left), rapid growth (top right), maximum extent (bottom left) and rapid decay (bottom right)

4. SYNOPTIC SCALE COUPLED VARIABILITY

A series of time-lagged MCA trials were carried out, using 500hPa (or 1000hPa) height anomalies and pentad-mean sea ice concentration anomalies, for different 9-pentad (45 day) time windows covering the full year. A relatively narrow time window was chosen, since mean sea ice conditions change quite rapidly with season. Daily height fields were lagged relative to the start time of each sea ice pentad, then averaged into pentad means, to achieve a daily increment in time lag.

Results are show for 500hPa heights, as they illustrate more clearly the atmospheric wave structures associated with sea ice anomaly patterns. However, results using 1000hPa fields were qualitatively similar to those shown here.

Relationships were strongest during the sea ice growth seasons, through to the time of maximum sea ice extent. MCA results suggest the atmosphere leads the sea ice field as the ice is growing, and especially around the time of maximum extent. The optimal lag was two days during the growth period (pentads 28-36) and six days during the time of maximum extent (pentads 49-57, Fig. 2).

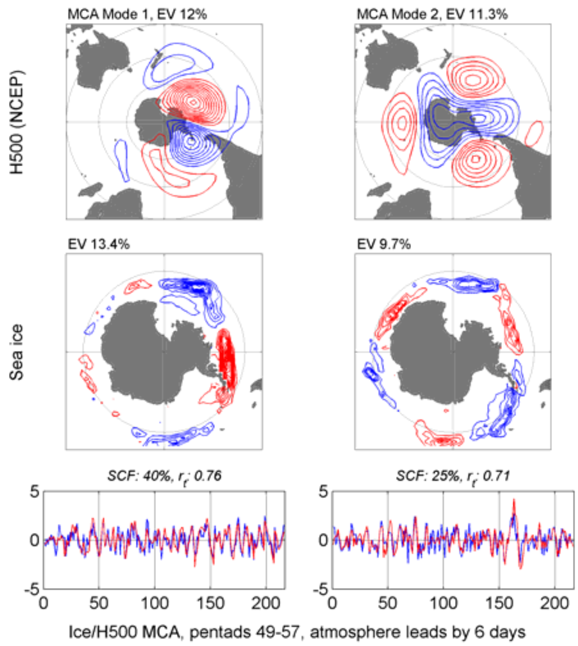

Figure 2: Lagged MCA between pentad mean 500hPa height anomalies (top row) and sea ice concentration anomalies (middle row), for the time of maximum extent, pentads 49-57 (late August to mid-October), with interannual variability removed. The height fields lead the sea ice fields by 6 days. Amplitude time series are shown in the bottom row (blue for height, red for sea ice). In all contour plots, red contours represent positive anomalies and blue contours represent negative anomalies. The zero contour is suppressed.

As shown in Fig. 2, atmospheric and sea ice variations often display a zonal wave number three pattern, maximizing over the southern Pacific, partly related to tropical forcing and partly to the Southern Annular Mode (SAM, Thompson and Wallace 2000). The amplitude of the leading coupled pattern maximizes over the Pacific and across the Antarctic Peninsula, while the second pattern is more evenly distributed in amplitude around the hemisphere When interannual variability is included (not shown), the SAM signature becomes more prominent.

The leading sea ice anomaly pattern shown above closely resembles both the leading mean pattern from a cluster analysis of sea ice concentration anomalies (not shown), and the leading EOF of sea ice concentration anomalies for pentads 49-57 (not shown).

5. DISCUSSION

From daily (or two-daily) SSMR-SSM/I-estimated Antarctic sea ice concentrations on a 25 km grid, a pentad-mean sea ice concentration data series and associated climatology has been developed, at a spatial resolution convenient for analyzing synoptic-scale variability.

The climatology of sea ice concentration shows a minimum extent in mid-February, a maximum in mid-September, and seasons of maximum growth or decay centered in early June and December, respectively.

During ice growth and ice maximum seasons, from May through mid-October, weekly-scale variability is dominated by the atmosphere leading (forcing) the sea ice field, by between two and six days. The leading patterns of coupled variability exhibit a zonal wave three pattern, maximizing over the southern Pacific. Cluster analysis and principal components show similar patterns to those captured by MCA.

Such patterns appear to contribute to the dipole of sea-ice variability across the Antarctic Peninsula (e.g. Yuan and Martinson 2001) and appear partly forced from the tropics, via Rossby wave propagation, but also partly from internal variability.

There are both similarities and differences between weekly and monthly-seasonal relationships (Renwick 2002). Tropical forcing becomes more prominent as the time scale lengthens. In all cases, forcing time scales appear short (days to ~one week).

6. ACKNOWLEDGEMENTS

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