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Stefanie Wassermann, Christoph Kottmeier
Institut für Meteorologie und Klimaforschung, Universität Karlsruhe / Forschungszentrum Karlsruhe
Stefanie.Wassermann@imk.uka.de

Universität
Karlsruhe (TH)

Coupled vortices in Antarctic Wind Fields and Sea Ice Motion - Questions to solve with Cryosat data?

Introduction:

Weather forecasts and climatological studies for the Antarctic are based on observational data, numerical analyses (e.g. ECMWF) and infrared satellite products. The sparse availability of observational data in high southern latitudes makes numerical analyses less reliable. Infrared satellite images help to identify storms, but not each storm is characterized by an obvious cloud vortex, and infrared satellite images do not directly reflect surface conditions, which are most interesting for weather forecasts. Sea ice motion can be calculated from tracked SSM/I brightness temperature features (Drinkwater et al., 2001, Kwok et al., 1998), and implies information about wind forcing. Under conditions of free drift, surface winds provide momentum to sea ice motion, so cyclonic wind systems in atmospheric low pressure systems produce cyclonic patterns in the sea ice drift vector field. The intention of our work was to develop a method for detecting cyclones by ice motion patterns, and to evaluate the coincidence of sea ice motion for weather forecasting and cyclone statistically. Cryosat data on sea ice thickness may greatly facilitate studies like this since ice thickness may affect ice motion critically via control of internal stress in the ice cover.

Developing a method for automatic cyclone detection from SSM/I sea ice drift vectors

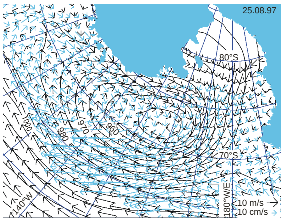


Fig. 1: Daily means of ECMWF wind vectors and isobars (black), and SSM/I sea ice drift vectors (blue). Positions of the displayed cyclone differ by about 10° longitude.

Data

SSM/I drift vectors (Kwok et al., 1998):
optimal interpolated from 37 GHz and 85 GHz channel and IPAB buoy drift data on a 100x100km polarstereographic grid (OI-data).

Reference data:
- ECMWF analyses a on 1.25°x1.25° grid
- buoy positions flagging high accuracies for ECMWF- and SSM/I data

1. Converting drift vectors to a scalar function for cyclone localisation algorithm after Murray and Simmonds (1991)

The Helmholtz theorem for a 2-dimimensional divergence free vector field leads to a Poisson equation for the streamfunction Ψ:

$$\nabla^2\Psi = \vec{k}\times\nabla\vec{v}$$

Krishnamourti and Bounoua (1996) provide two methods with different boundary conditions to solve this Poisson equation for surface wind fields. Both methods are applied to the drift vectors unmodified:

a) Overrelaxation method (RM) with Dirichlet and Neumann boundary conditions (mass flux conservation) (Fig. 1).

b) Fourier transform method (FTM) with periodic boundary conditions (Fig. 2)

2. Accentuation of cyclonic drift patterns by subtraction of regional means (SRM) before calculating the streamfunction

Mean zonal driftcomponents imply elliptic averaging areas with axis parallel to geographic grid, same dimension as synoptic cyclones and a constant number of grid points. Missing grid points at the edge of area covered by data are filled up with $|\vec{v}| = 0$.

Accuracy of streamfunction values is diminished

- at the borders of the area covered by zero-fill-up for SRM
- boundary conditions in the iteration procedure for calculation of streamfunction
- interpolation of drift components between data edge and edge of the rectangular iteration area (weighted means over a circular area, radius chosen as small as possible to reduce smoothing effects).

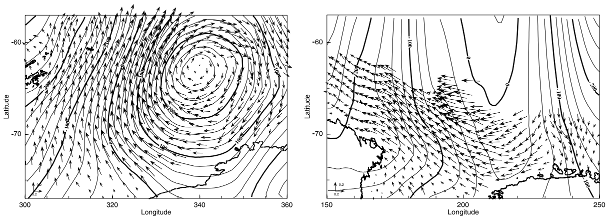


Fig. 1: Streamfunction by RM in 100 m²/s. Strong meridional streamline orientation corresponds well with drift vectors for Weddell sea area (left), but insufficiently for Ross sea (right).

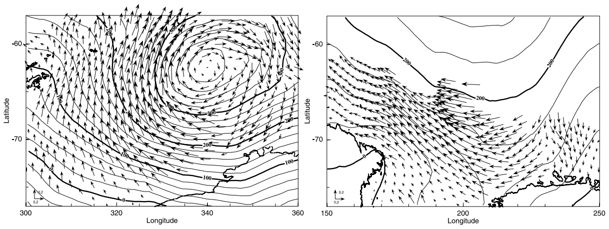


Fig. 2: Streamfunction by FTM in 100 m²/s. Strong zonal components of streamlines correspond sufficiently to drift vectors for both Weddell and Ross sea area.

Comparison results: FTM is preferable

- because zonal streamlines converge to dominantly zonal drift components and regions with small ice extension
- to avoid mass flux conservation as boundary condition
- to avoid the condition of minimum data extension of 40° latitude for RM

Comparing cyclone positions and intensities from SSM/I and ECMWF data

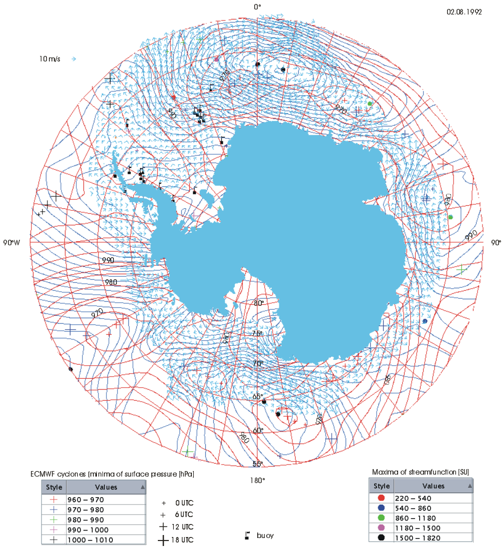
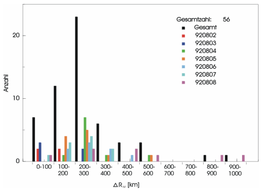


Fig. 4: Streamlines before SRM [1 SU = 100 m²/s] (blue), isobars [hPa] (red), SSM/I drift vectors[m/s] (blue), and cyclone positions calculated from ECMWF and SSM/I data (see legend).

After calculation of cyclone positions and intensities by the algorithm of Murray and Simmonds (1991) can be seen from Fig. 4 and Fig. 5:

- without SRM, number of cyclones from ECMWF data is underestimated
- overestimation of cyclone frequency by SRM streamfunction possibly related to ECMWF data inaccuracy
- ECMWF and SSM/I cyclone positions differ for both kinds of streamlines
- ice motion streamlines and ECMWF isobars differ explicitly
- north of sea ice edge positions and intensities of vortices are less reliable but reasonable
- assignment problems between ECMWF and SSM/I cyclone centres in Weddell sea region
- reasonable magnitude for maxima of streamfunction
- ECMWF and SSM/I cyclone intensities proportional with increasing factor



More than 70% of SRM streamfunction maxima are found closer than 300 km to the average daily position of the position of an assigned cyclone.
Excluding uncertainly assigned pairs of vortices and open cyclones improves these results insignificantly.

Fig. 6: Differences between positions of maxima of SRM streamfunction to means of 4 daily positions of assigned ECMWF cyclone, evaluated over 7 days (black). Assignment accomplished manually. Coloured bars show daily statistics (see legend).

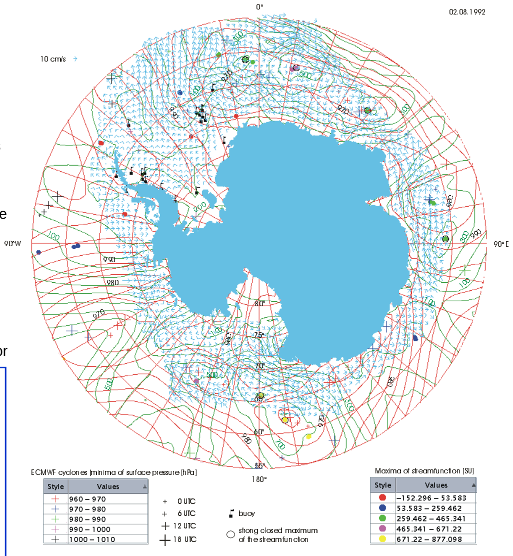


Fig. 5: SRM streamlines [1 SU = 100 m²/s] (green), isobars [hPa] (red), SSM/I drift vectors[m/s] (blue), and cyclone positions calculated from ECMWF- and SRM SSM/I data (see legend).

Conclusions: **The developed method for automatic detection of atmospheric cyclones by the means of their impact on sea ice dynamics works convenient for strong cyclones over sea ice. The fine-tuning of parameters for SRM, of boundary conditions for Poisson equation and parameters for cyclone localisation algorithm would improve accuracies, but is time consuming and seems to be limited by the inaccuracy of the ECMWF analyses and SSM/I based derivation of ice motion. Improved knowledge of the state of the sea ice, such as of ice thickness from Cryosat data and ice concentration would reduce uncertainty of wind/drift relationships significantly.**

References:

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