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Southern Ocean Eddies as Weather Makers

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Motivation

Eddies of scales of the order of 100 km are omnipresent in the global ocean, dominating the ocean's kinetic energy [1].

These **mesoscale eddies** typically feature **sea surface temperature (SST) anomalies** and hence represent non-stationary circular SST fronts.

SST fronts may impact the atmosphere [2]. Therefore, an impact of ocean eddies on the atmosphere is anticipated.

? Do **ocean eddies** systematically **affect** the overlying **atmosphere** due to their SST anomalies?

Data

Satellite data of the period 2002–2009:

- AVISO [3] sea level anomalies for eddy detection (1/3°, weekly);
- Atmospheric quantities (1/4°, weekly): wind (QuickScat [4]); cloud fraction (GlobColour [5]); liquid cloud water and rain (AMSR-E [4]).

Method

- **Detection of >600 000 snapshots of ocean eddies:** Eddy where vorticity is greater than strain [6][7];
- **Collocation** of detected eddies with **atmospheric** quantities;
- **Atmospheric anomalies (for Fig. 2, 3)**: difference of 'eddy impact area' (mean of circle of 2 eddy-radii) and 'background' (peripheral ring of 3 eddy-radii).

Mean composite maps of oceanic eddies and their atmospheric imprints

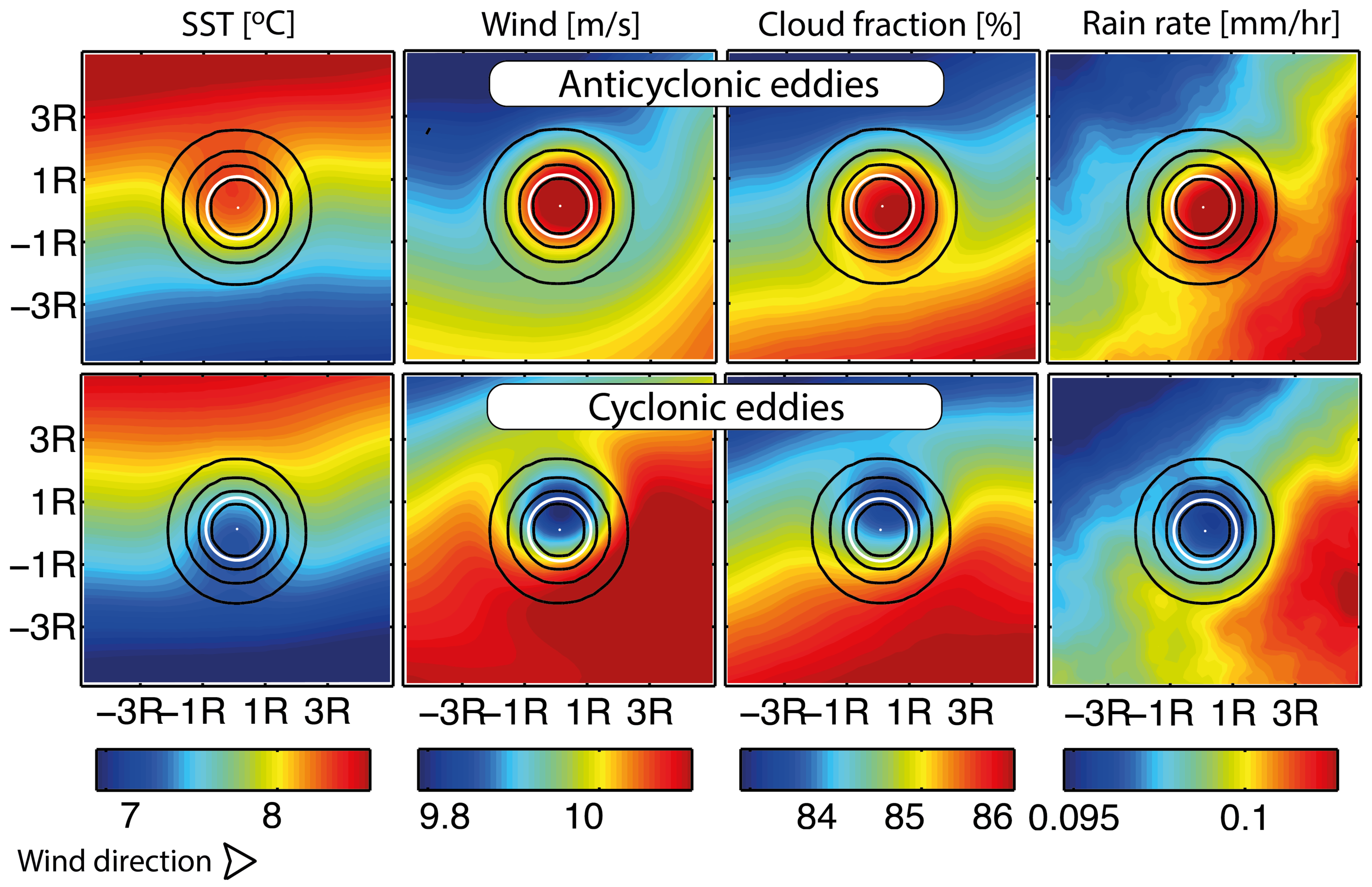

Figure 1: *Mean composite maps; x- and y-axes are given in radii (R) of eddies; the white circle marks the detected eddy-core and black contours sea level anomalies associated with the eddies; the eddies were scaled according to the individual eddy amplitude and radius, interpolated and rotated before calculating the mean composite so that the large-scale wind is from left to right.*

Correlation of SST anomalies of eddies and anomalies of liquid cloud water

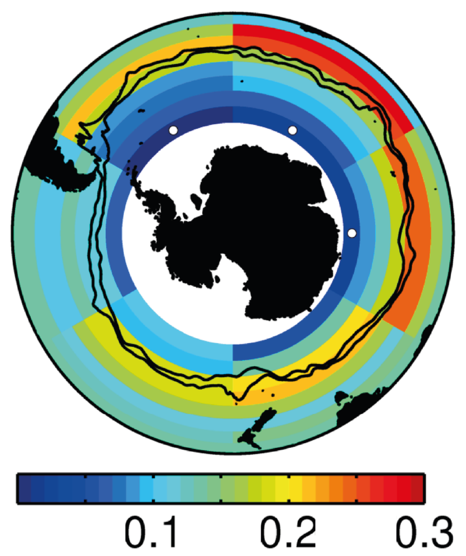

Figure 2: *60°x4° bins; white dots mark bins where correlations are not significant (p<0.01); black contours denote mean positions of the two major fronts of the Antarctic Circumpolar Current [8].*

Linear relationship of SST anomalies of eddies and liquid cloud water

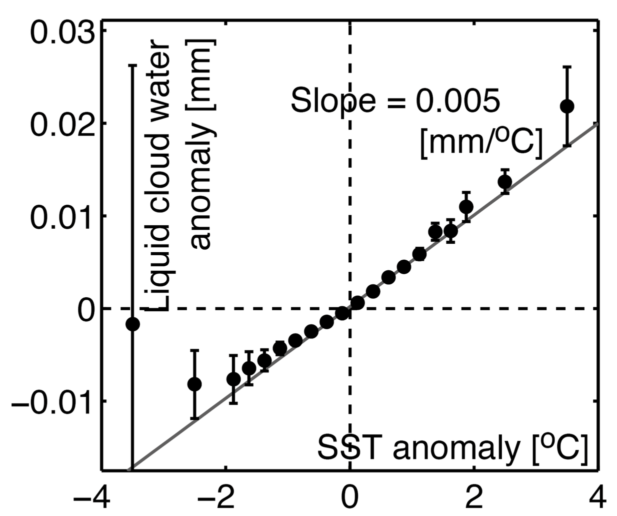

Figure 3: *Liquid cloud water anomalies binned according to SST anomalies; vertical bars show three standard errors of the mean. The least square fit to the unbinned data is shown as black line; other atmospheric quantities show a similar linear relationship (not shown).*

Mechanism of the impact of mesoscale oceanic eddies on the atmosphere

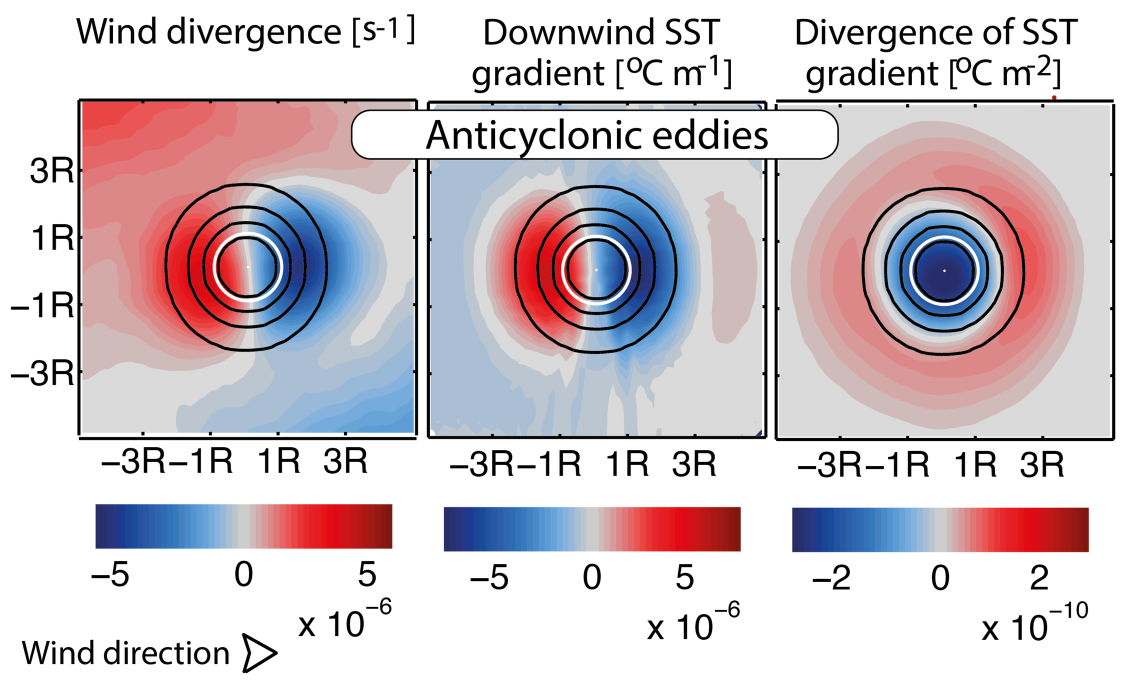

Figure 4: *Mean composite of the wind divergence (left), downwind SST gradient (middle) and divergence of the SST gradient (right); the latter reflects the expected pattern of the sea level pressure anomaly related to an SST anomaly [9]; otherwise as Fig. 1; the picture is similar but of opposite sign for cyclonic eddies (not shown). The* ***resemblance*** *of the* ***wind divergence*** *and the* ***downwind SST gradient*** *favors the* ***downwind momentum mixing*** *mechanism as explanation in contrast to the pressure adjustment mechanism [10].*

Results

! **Ocean eddies affect** the **atmosphere** locally [11] (Fig. 1-3):

5% change of wind, 3% of cloud fraction, 6% of liquid cloud water and 8% of rain rate and probability per 1°C of SST anomaly.

! **Mechanism: stability change** of the atmospheric boundary layer (Fig. 4, 5).

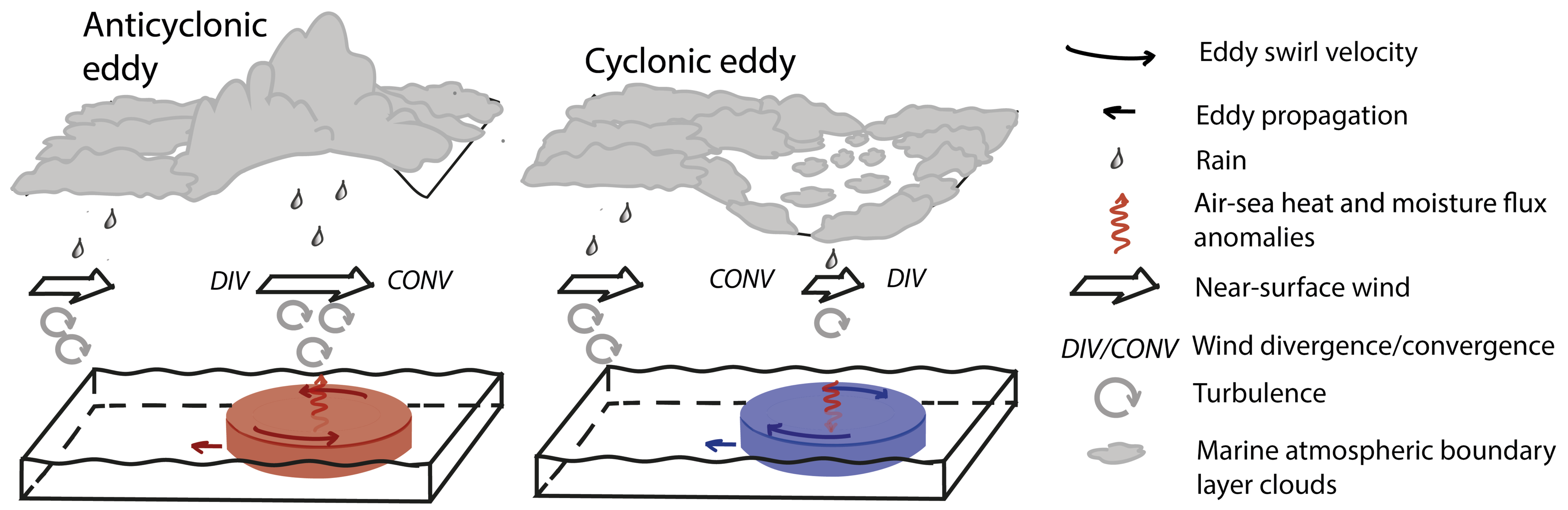

Figure 5: ***Schematic to summarize the impact of oceanic eddies on the lower atmosphere****; the situation is depicted for a Southern hemispheric warm-core anticyclone (left) and a cold-core cyclone (right), indicated with red versus blue colors; wind blowing across the narrow SST gradients affiliated with the SST anomalies of eddies results in an air-sea disequilibrium and corresponding adjustments of heat and moisture fluxes, leading to a change of the marine atmospheric boundary layer stability and thickness; the associated modifications of the boundary layer turbulence and associated vertical momentum as well as moisture transports may evoke a response of wind, cloud properties and rain.*

Outlook

Analysis of a newly developed **coupled atmosphere-ocean regional model** (COSMO-ROMS [12][13], Fig. 6), **objectives** are e.g.:

? Can the model system reproduce the observational findings?

? Impact of the ocean mesoscale variability on the atmospheric mean/variance?

? Effect of the atmospheric feedback on the ocean (e.g. eddy dissipation)?

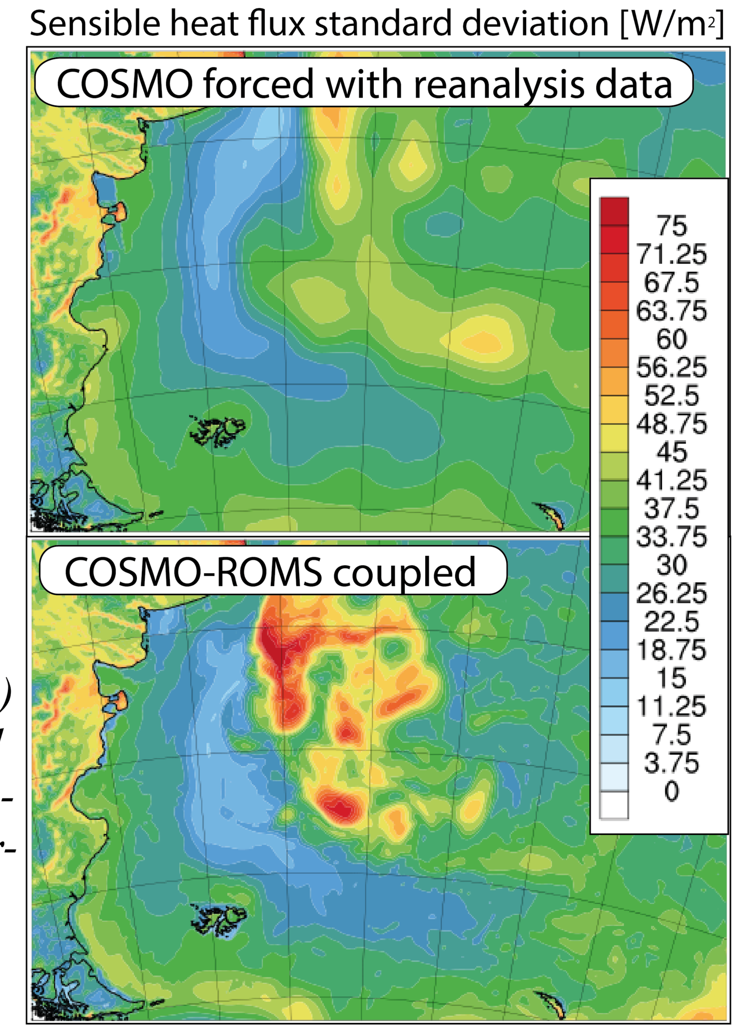

Figure 6: *COSMO forced with reanalysis data (ERA-Interim) lacking mesoscale variability (top); COSMO-ROMS coupled simulation where mesoscale variability is resolved; the variability of heat fluxes (and other quantities, not shown) is clearly increased (shown for winter 2004, preliminary results).* ***Domain & resolution****: South Atlantic, 0.1°/6-hourly output;* ***Simulation period****: 2 winters (June-August 2004/2005).*

References: [1] Ferrari, R. & Wunsch, C. (2009). Ocean circulation kinetic energy: reservoirs, sources, and sinks. *Annu. Rev. Fluid Mech.*, 41:253–282; [2] Small, R. J. et al. (2008). Air-sea interaction over ocean fronts and eddies. *Dynam. Atmos. Ocean,* 45: 274-319; [3] Available at http://www.aviso.oceanobs.com (v3.0.0.0); [4] Available at http://www.remss.com; [5] Available at http://www.globcolour.info; [6] Okubo, A. (1970). Horizontal dispersion of floatable particles in the vicinity of velocity singularities such as convergences. *Deep-Sea Res.*, 17:445-454; [7] Weiss, J. (1991). The dynamics of enstrophy transfer in two-dimensional hydrodynamics. *Phys. Nonlinear Phenom.*, 48:273-294; [8] Sallée, J.-B. et al. (2008). Response of the Antarctic Circumpolar Current to atmospheric variability. *J. Climate,* 21:3020-3039; [9] Minobe, S. et al. (2008). Influence of the Gulf Stream on the troposphere. *Nature,* 452:206-209; [10] Chelton, D. B. et al. (2004). Satellite measurements reveal persistent small-scale features in ocean winds. *Science,* 303:978-983; [11] Frenger, I. et al. Southern Ocean eddies affect local weather. In review for *Nature Geosci.*, March 2013; [12] Steppeler, J. et al. (2003). Meso-gamma scale forecasts using the nonhydrostatic model LM. *Meteor. Atmos. Phys.*, 82:75–96; [13] Shchepetkin, A. F. & McWilliams J. C. (2005). The regional oceanic modeling system (ROMS): a split-explicit, free-surface, topography-following-coordinate oceanic model. *Ocean Model.*, 9:347-404.