Influence of deep vortices on the ocean surface

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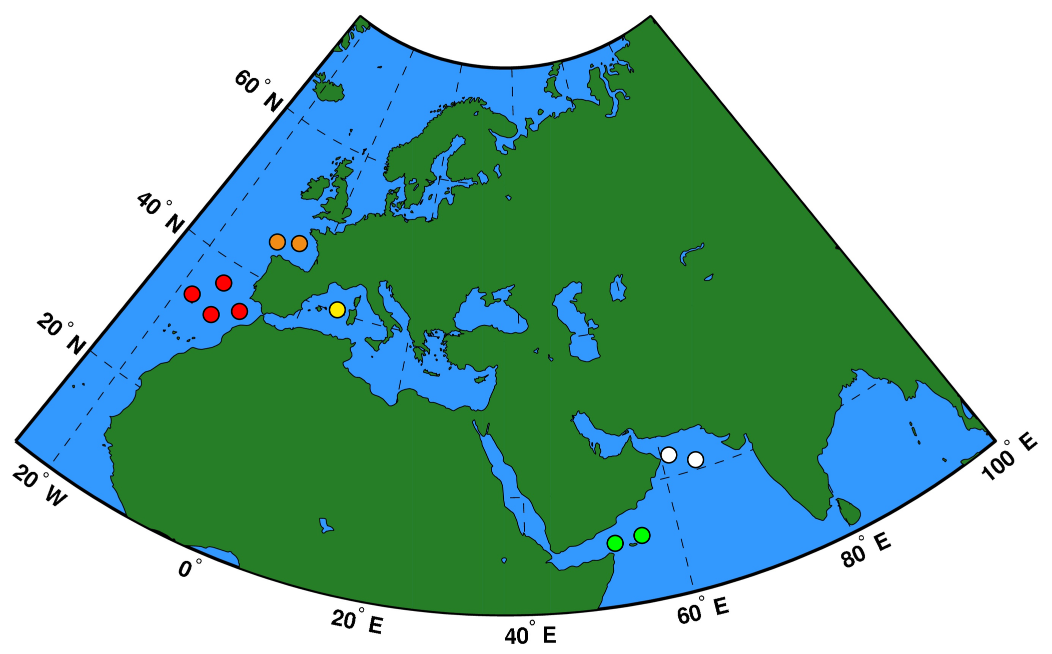
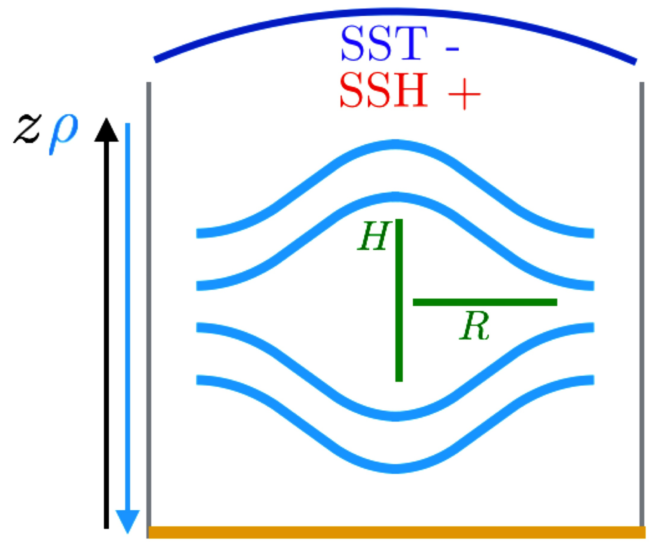
CONTEXT

Highly evaporative basins can exchange water with the open ocean through ejection of warm and salty currents at intrathermocline depths (up to 1000m). Currents interaction with the surrounding environment can cause instability, leading to the formation of mesoscale and submesoscale deep vortices.
The Persian Gulf, Red Sea and Mediterranean Sea are examples of evaporative basins and are sources of deep vortices (mostly anticyclones) for the Indian and Atlantic Ocean respectively.

DEEP ANTICYCLONES: distribution and overall characteristics



	Radius - R (km)	Thickness - H (m)	Depth - z_0 (m)	Rotation - q (m/s)
Leddies	25 - 50	300 - 1000	200 - 1000	0.2
Meddies	20 - 50	300 - 1000	700 - 1000	0.3 - 0.4
Peddies	20 - 30	100	250 - 400	0.3
Reddies	20 - 50	400 - 500	400 - 800	0.15
Swoddies	30 - 50	200	70 - 300	0.3



Isopycnal uplift in the upper oceanic layers: cold sea-surface temperature anomalies associated with positive sea-level anomalies are expected.

MOTIVATION

Most of the oceanic vortices are coherent and highly energetic structures. They trap water masses from their origination areas and carry them for long distances ($O(10^3 km)$) across the ocean, significantly contributing to the three-dimensional distribution of active and passive tracers (e.g., heat and salt). Vortex detection is thus an important task in order to have a complete description of the global ocean.
Surface-intensified cyclones and anticyclones often have a clear signature at the sea-surface and they can be studied using satellite data, providing a global scale and synoptic information. [Chelton et al., 2011, Frenger et al., 2013].
Deep vortices also play a role in advection of active and passive tracers, but can be much harder to detect. We thus investigate their influence on the sea-surface in terms of sea-level anomaly. This will help evaluating the impact of the future SWOT satellite mission [Fu et al., 2009] on the derivation of the three-dimensional ocean dynamics from surface observations.
SWOT will provide high-resolution altimetric products capable of catching motions up to submesoscale with a precision measurement around 2 cm on a global scale.

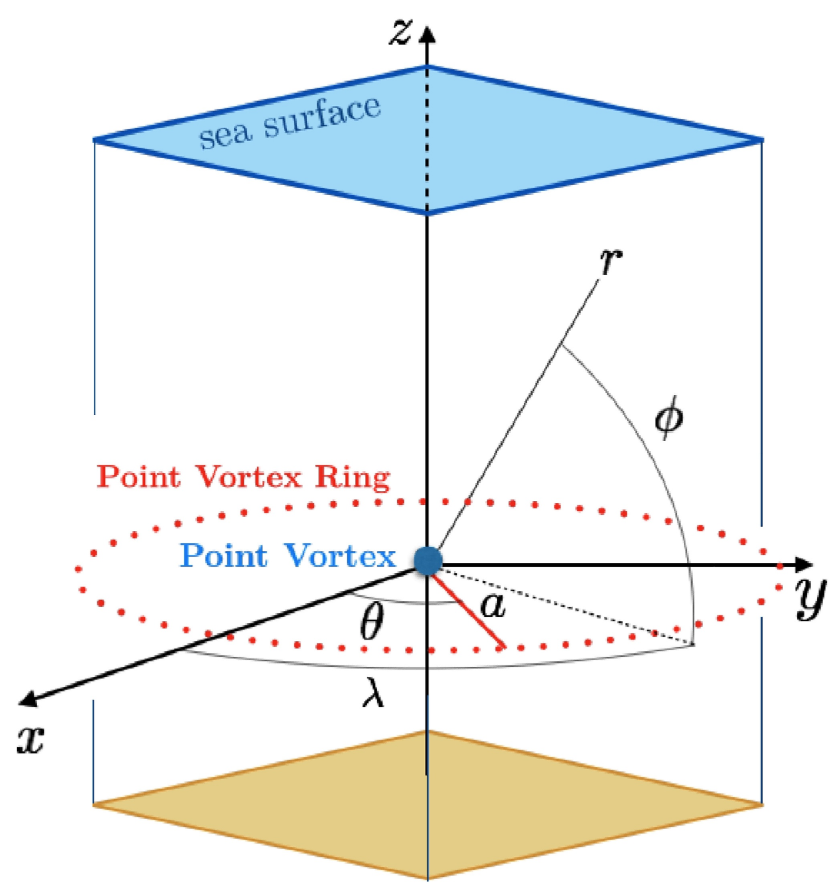
APPROACH

Deep anticyclones of a-priori known structure are introduced in an idealized ocean at rest. Their impact on the sea-surface is evaluated in terms of sea-level anomaly (SLA). The study is carried out by means of analytical models in the quasi-geostrophic framework as well as quasi-geostrophic (QG) and primitive-equation (PE) numerical models.

ANALYTICAL MODELS

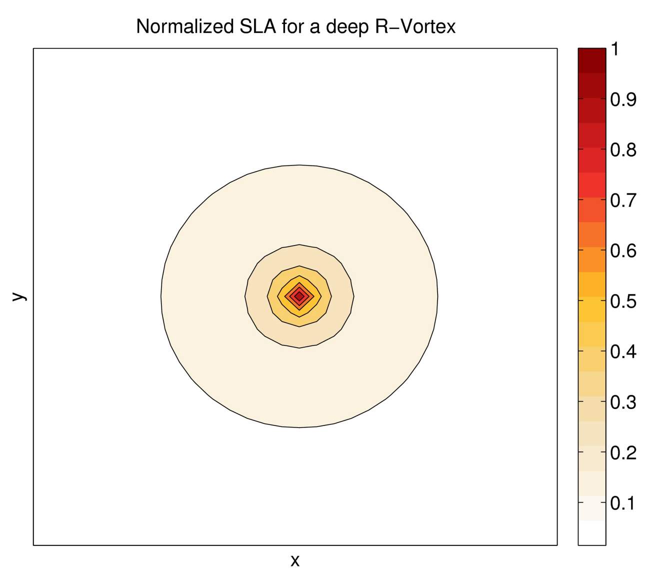
Steady Case

Deep isolated anticyclones of known potential vorticity q (R-vortices, [Morel and McWilliams, 1997]) are studied by means of point vortex theory. The associated surface stream function, which is proportional to sea-surface elevation in the QG framework, is obtained through potential vorticity inversion. Analytical solutions to this problem are possible in an ocean at rest and with uniform stratification. The resulting SLA is positive and monopolar (steady signature). The dependence on the vortex parameters is also derived.



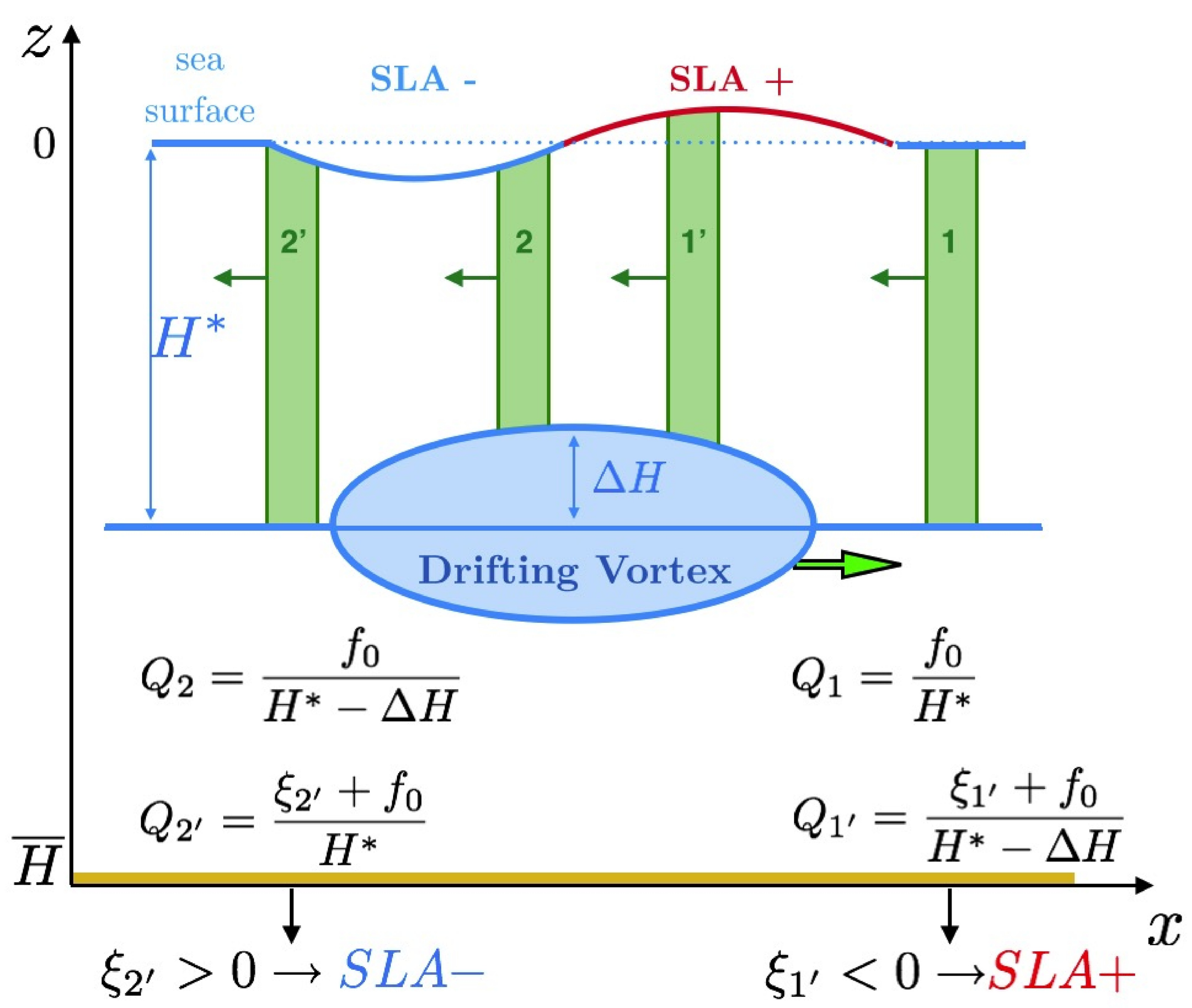
Surface Stream Function

$$\psi|_{z=0} \simeq \frac{qR^2H}{z_0^3}$$



Dynamic Case

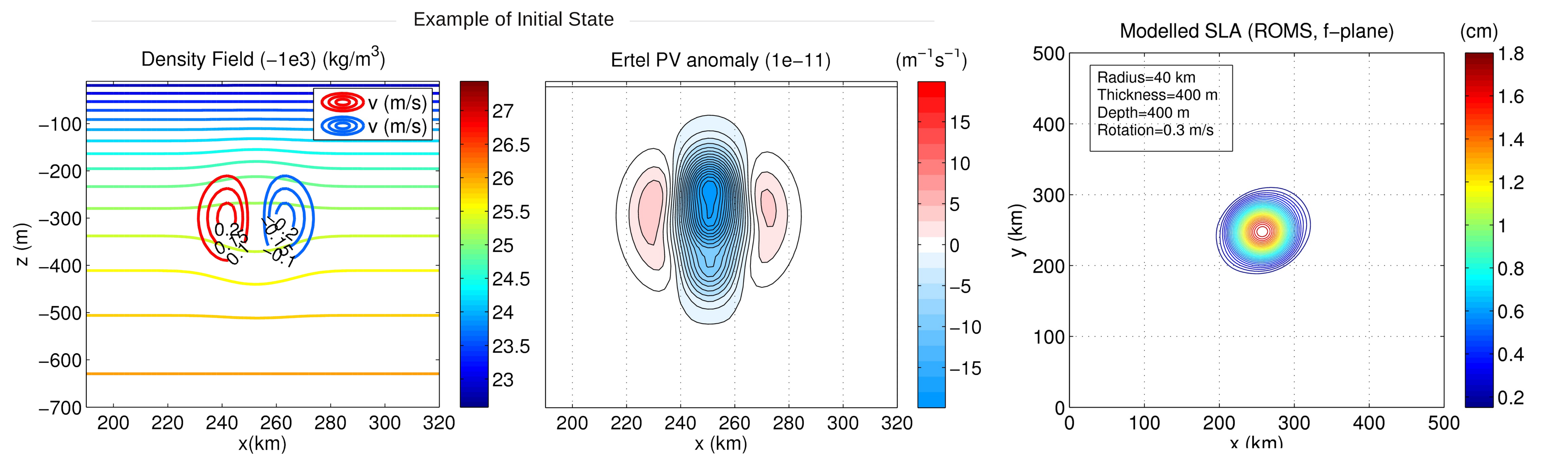
The SLA generated by a deep anticyclone in motion is qualitatively predicted in a two-layer ocean. If the vortex has no initial steady signature, it will generate a dipolar SLA, the positive pole being colocated with the leading half of the vortex. This mechanism, provided conservation of potential vorticity Q, results from the compression and release of water columns in the upper layer.



NUMERICAL MODELS

Steady Case

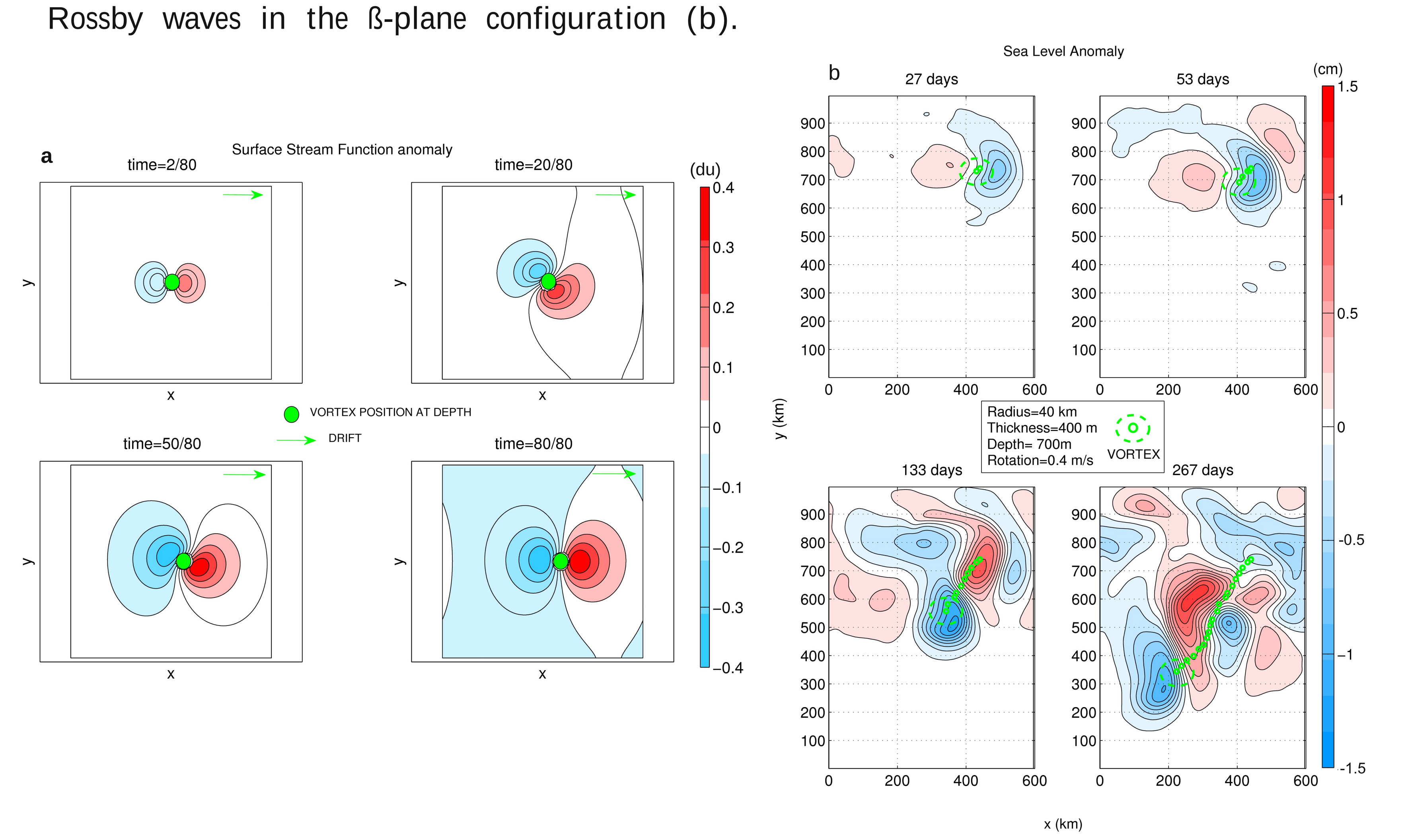
Using a PE model [Shchepetkin and McWilliams, 2005] we evaluate the SLA generated by deep anticyclones in a f-plane configuration. The resulting SLA is positive and it maintains a monopolar structure. The dependence on the vortex parameters is derived from simulations.



$$SLA \propto \frac{qRH}{z_0^3}$$

Dynamic Case

In a QG (a, [Dritschel and Perrot]) and a PE (b, [Shchepetkin and McWilliams, 2005]) context, deep anticyclones are let to drift by means of an advection current and of planetary ß-effect, respectively. The resulting SLA, if SLA(t=0)=0, is dipolar in both cases, with generation of Rossby waves in the ß-plane configuration (b).



CONCLUSIONS AND PERSPECTIVES

Deep anticyclones can generate monopolar and dipolar sea-level anomalies in a steady and dynamic case, respectively. The results of the dynamic case show that anticyclones with no initial signature can eventually develop one as a result of their displacement. The modelled SLA is compatible with future SWOT measurements if mesoscale structures are taken into account. In a future analysis, the SLA generated by deep anticyclones will be studied in a realistic context. In particular, the outputs of a high-resolution realistic model [Barbosa Aguiar et al., 2013] will be used to investigate the surface signature of Meddies, which are deep anticyclones generated by water exchanges between the Mediterranean Sea and the Atlantic Ocean.

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