Living Planet Fellowship

FINAL REPORT

Satellite **M**ode **W**aters **S**alinity, in synergy with Temperature and Sea Level, SMOWS

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1 EXECUTIVE SUMMARY

Mode waters (MWs) transport a large volume of heat, carbon and other properties across basins at seasonal to longer time-scales and thus play a major role in the modulation of the Earth climate. In the context of anthropogenic global warming, unlocking the understanding of the MWs transport and characteristics is critical. The SMOWS project aims at enhancing our knowledge of the role of surface salinity in the formation of MWs and of the processes behind the variability of surface salinity in formation areas. It will furthermore characterise the relationship between the surface and subsurface salinity signals along the MWs pathways. The SMOWS project leans on Sea Surface Salinity measured by the SMOS ESA Earth Explorer mission in synergy with ESA and non-ESA missions.
The work done supported by the LPF has enabled to characterise the surface signatures of mesoscale eddies in the Southern Ocean and shows the unprecedented use of satellite salinity data to describe the interaction of eddies with subsurface MW. Much still need to be understood about eddies in the Southern Ocean but this study offers great perspectives on using the most recent satellite borne SSS datasets. Better understanding the interaction of MW with the ocean surface is vital to better characterise their role in the Southern Ocean overturning circulation and thus the current global changes in our climate.

This work was supported by the ESA LPF and the Centre National d'Etudes Spatiales (CNES) through its SMOS TOSCA Project.

2 OBJECTIVES AND WORKPLAN

The SMOWS project is devoted to scientific exploitation of the Sea Surface Salinity measured by the SMOS ESA Earth Explorers mission in synergy with ESA and non-ESA missions. It promotes the development of new scientific results from observations focused on the mass, heat and salt (freshwater) oceanic budget and transport in the context of the interannual to longer time scale variability.
This project mainly falls in the Challenge O4 defined as a New Challenge of the Oceans of the Living Planet (Section 3 of the Call for Proposals 2018) as it unlocks knowledge of the Physical air–sea interaction processes on different spatiotemporal scales and their fundamental role in climate by investigating the formation of Mode Waters (MWs) and the export of their surface properties to the subsurface. Our work especially focuses on the role of salinity which has been overlooked in the existing literature because of a lack of observations and its role thought to be negligible.

The original plan was revised for the following reasons:

- A paper published early 2020 in the Journal of Physical Oceanography by Portela et al. addressed the main mechanisms driving the volume change of the interior water masses in the Southern Hemisphere oceans using both observations and modelling. Their study covered various MWs such as the Subantarctic Mode Waters (SAMW) in the South Pacific and South Indian Ocean basins, the Antarctic Intermediate Waters (AIW) and the Antarctic Winter Waters (AAWW). Authors observed changes in these waters and investigated possible mechanisms. After communicating with the authors, we decided to join forces and build on their work and explore in more detail mechanisms of diapycnal mixing.

- Recent results from observations (Laxenaire et al., 2019) and eddy-resolving models (Nishikawa et al., 2010; Xu et al., 2016) suggest that southern Atlantic mesoscale eddies contribute to the mode-water transport and subduction, on the same order of magnitude as that by the mean flow. (Herraiz-Borreguero and Rintoul, 2010) showed, from observations only, the impact of mesoscale features on the formation and on the characteristics of SAMW in the Tasman Sea. Recent improvements of the signal to noise ratio of SSS observations from satellite have given us the opportunity to use these datasets to investigate the signature of eddies over the Southern Ocean. We have thus led a study showing the signal in surface salinity and temperature of these eddies revealing unprecedented results such as the salinity patterns and their "longevity" compared to temperature which gets eroded quite fast. The study also hints for the eddies implication in vertical exchanges possibly responsible for the MWs diapycnal mixing observed by Portela et al. 2020.

In the light of these unforeseen findings during this first year of postdoctoral work under the Living Planet Fellowship, we have decided to not proceed at setting up the modelling framework in order to get the most out of the observational datasets (satellite and in situ). We therefore focused on the formation regions of the MWs as well as their interactions with surface waters after their subduction.

3 WORK PERFORMED

3.1 Scientific context

Eddies are coherent mesoscale features found nearly everywhere in the global ocean. Thousands of eddies are present at any given time in the ocean with lifespans that can reach several years (Chelton et al., 2011). Eddies can both be stationary (Pegliasco et al., 2020) or travel thousands of kilometres (Delcroix et al., 2019; Hasson et al., 2019). Advances in satellite altimetry since the 1990s has enabled the increasing details in our knowledge on transient oceanic features of O(10-100 km). Eddies are known for being responsible for disseminating hydrological properties as well as heat and chlorophyll across the surface of the global ocean over large distances but also at depth (McWilliams, 2008; Chaigneau et al., 2011; Laxenaire et al., 2019).

Eddies have a critical role in the Southern Ocean, a key region for the global circulation and climate modulation. The eddy-induced mixing balances the horizontal northward Ekman transport as well as the vertical Ekman pumping. Eddies indeed account for the majority of oceanic poleward heat transport across the Antarctic Circumpolar Current (ACC; (de Szoeke and Levine, 1981; Lee et al., 2007; Rintoul and da Silva, 2019). They also interact with subsurface water masses that form in the vicinity of the ACC fronts such as the Subantarctic Mode Waters (SAMWs). Eddies play a major role during the SAMWs subduction (Karsten and Marshall, 2002; Sallée et al., 2008b; Naveira Garabato et al., 2011). Recent results from observations (Laxenaire et al., 2019) and eddy-resolving models (Nishikawa et al., 2010; Xu et al., 2016) suggest that southern Atlantic mesoscale eddies contribute to the mode-water transport and subduction, at the same order of magnitude as the contribution by the mean flow. Eddies also interact with the SAWMs once isolated from the mixed layer. Eddy mixing is indeed essential for the modification of the water mass properties after subduction (Joyce et al., 1998; Gebbie, 2007; Sallée et al., 2010).

In high mesoscale activity areas, such as downstream from the Kerguelen Plateau (Fig. 1), eddy mixing erodes the near-surface stratification and precondition the ocean mixed-layer for deep winter convection (Sallée et al. 2008). SAMWs are formed in the deep winter mixed layers located just north of the Subantarctic Front (SAF). SAMWs export large volumes of oxygen, heat, nutrients and salinity at depths isolated from the atmosphere. They ventilate the interior of the upper ocean as they spread northward towards the subtropical gyres (Hanawa and D.Talley, 2001). Understanding the interaction of eddies with SAMWs is crucial to investigate and model the role of the Southern Ocean in a changing climate.

While many studies have focused on sea level height as well as temperature as primary tools to observe and study eddies, only a few have investigated their signature in the salinity fields. Salinity is however not only a key tracer of ocean dynamics and air-sea interactions but also a driver of the ocean circulation by its effect on density. The lack of salinity observations at the adequate scale has refrained its use in the investigation of mesoscale eddies, especially in the Southern Ocean. The Argo international program has provided since the mid-2000s global observations of salinity over the 2000 first meters, with a resolution of about 300km by 300km every 10 days. Using these datasets, the vertical structures of eddies has been described as composites across the Southern Ocean (Frenger et al., 2015). The surface signature, above the Argo shallowest measurement usually between 5m and 10m depth, could however not be studied from the lack of observations at the time the study was performed.

Sea surface salinity (SSS) has been observed from space since 2010 with an unprecedented resolution of about 50km by 50km weekly thanks to the European and American L-Band microwave radiometer missions: Soil Moisture Ocean Salinity (SMOS, Reul et al., 2020) and Soil Moisture Active Passive (SMAP, Piepmeier et al., 2017). This unprecedented spatio-temporal coverage of the quasi-global ocean has led to several studies on the salinity signature of mesoscale features in warm waters where the signal to noise ratio is the highest: tropical instability waves (Lee et al., 2014; Yin et al., 2014; Olivier et al., 2020), annual-period planetary waves in the Indian Ocean (Menezes et al., 2014), eddies in the vicinity of major river mouths (Fournier et al., 2017b, 2017a; Fournier and Lee, 2021), mesoscale eddies in the Atlantic and Indian Ocean (Melnichenko et al., 2017, 2021), in the Gulf of Mexico (Brokaw et al., 2020), in the Arabian Sea (Trott et al., 2019) and 10°N westward propagating eddies over O(1000km) in the Pacific Ocean (Delcroix et al., 2019; Hasson et al., 2019).

Recent advances in the data processing have enabled scientists to investigate satellite surface salinity in colder waters such as the Arctic Ocean (e.g. Supply et al., 2020; Tarasenko et al., 2021) and now in the Southern Ocean.

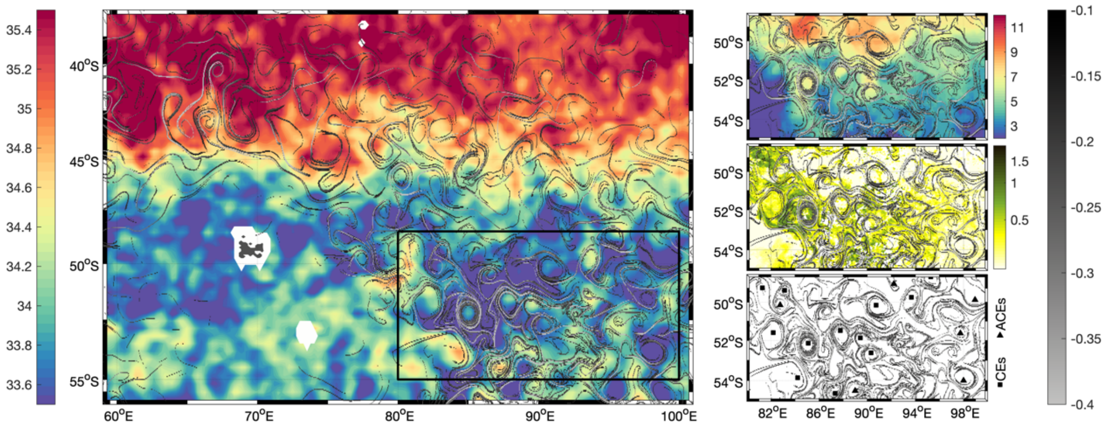

Figure 1. (a) Sea Surface Salinity in the Kerguelen Plateau Region for the 15th of December 2011. The black box denotes a subset of particular interest. (b) Sea Surface Temperature (°C), (c) chlorophyl-a (mg.m-3, log10 scale) and (d) detection of anti-cyclonic eddies (ACEs) and cyclonic eddies (CEs) in the subset area. All Panels feature the finite size Lyapunov exponents (gray scale), highlighting the convergence of currents.

SSS in the Southern Ocean presents strong gradients and many intense anomalies which were previously interpreted as noise in the observations. The eddies are indeed fast-moving features that cannot be properly captured by in situ measurement such as Argo floats on the basin scale and therefore differences between in situ and satellite SSS are not accounted for. However, the consistency between SSS and the Finite Size Lyapunov Exponents (FSLE) reveals the capability of satellite SSS to capture mesoscale variability. Sea Surface Temperature (SST) and chlorophyl-a also show some consistency which will be discussed hereafter.

This study aims at describing the SSS signatures of mesoscale eddies in the Southern Ocean. The observational datasets and methods are described in Section 2. Results are presented in Section 3 followed by a discussion (Section 4) on the signature of the eddies possible interaction with subsurface water masses.

3.2 Methods

This study is based on a series of observational datasets mainly satellite measurements. Maps of eddies, SSS, SST and the SAF position as well as Chl-a and FLSE used in this study are briefly described hereafter.

The mesoscales eddies are characterised in position, amplitude and size using a methodology based on (Mason et al., 2014) and optimised by Collecte Localisation Satellite (CLS, Pegliasco et al. submitted). Eddies are tracked during their existence using overlapping contours. The dataset produces a daily position for each tracked eddy from its first detection to last. The eddy detection and thus eddy tracking algorithms are based on absolute dynamic topography to better represent the ocean dynamics in the more energetic areas and close to coasts and islands. The horizontal resolution of the product thus depends on the one of its input absolute dynamic topography which is 0.25° in both directions. The mesoscale eddy trajectory atlas used here is research product, produced by SSALTO/DUACS and distributed by AVISO+ with support from CNES, in collaboration with IMEDEA and made available by Aviso+ from 1993 to 2019. In the present study, only the eddies with a lifespan between 30 and 1000 days, an amplitude between 0.1 and 1 m and an equivalent diameter between 30 and 100 km are kept. This selection enables the study of the most robust eddies, that are in the detection range of our SSS and SST datasets.

In order to compute anomalies of SSS and SST associated with eddies, a daily climatology was produced for each product. As the largest eddies we are interested in have a diameter of O(100km), each product is smoothed using a moving spatio-temporal Gaussian filter with 2 sigma of about 200km in both longitude and latitude and two weeks in the temporal dimension. SSS maps are interpolated in time to provide daily solutions. The SSS and SST daily climatologies are finally produced by averaging for each calendar day the smoothed 2010-2018 datasets. Anomaly fields are subsequently computed by subtracting every map with its associated daily climatology. In order to discard the effect of rain as much as possible on our SSS datasets, whenever needed, the median will be chosen over the mean.

These anomalies are then collocated with the daily eddies' positions provided by the atlas, to either produce a central anomaly or to study finer details and produce composites.
In order to compute the central anomaly, the SSS and SST anomalies collocated (closest neighbour to eddy's center) with each occurrence in time of each eddy is first saved. The central anomaly for each eddy is then computed as the median of the anomalies during the eddy's lifespan. To stay away as much as possible from formation and disaggregation processes, the first and last 10 days were discarded when computing the median anomaly for each eddy.

The composite calculation is three-step process. (1) At each occurrence in time of each eddy, a tile of 4 times by 4 times the eddy's diameter, centred on the closest position to the eddy's centre is extracted. (2) This tile is then interpolated on 50x50 km^2 grid. This step takes care of the variations in time of the eddy's size but does also permit the creation of composites of different eddies. (3) A composite is created for each eddy by computing the median of each of his tiles. As for the central anomaly, the first and last 10 days were discarded.

3.3 Data

The SMOS mission is at the centre of our study as it is the first-time satellite SSS is used to investigate the SSS anomalies associated with mesoscale eddies in the Southern Ocean. Shortly after its launch in November 2009 as the second European Space Agency (ESA) Earth Explorer (Kerr et al., 2010), SMOS has permitted the unprecedented space-born observation of SSS from space. In this study, we use a level-3 SMOS product developed by the CATDS CEC-LOCEAN known as debiased v4 (Boutin et al., 2020). This product is corrected from systematic observed biases using an improved methodology from its previous versions (Boutin et al., 2018). In particular, a specific temperature dependent correction has been implemented for high latitudes regions to mitigate the systematic differences observed with previous versions with respect to in situ SSS (Thouvenin-Masson et al., 2020).
V4 SSS maps are available from 01/2010 to 09/2019, using a combination of ascending and descending orbits. Data are provided every 4 days but are temporally smoothed using a slipping Gaussian kernel with a half maximum width of 9 days. An analogous situation is true for the spatial resolution. It is delivered on a 25x25km^2 grid, based on neighbors average within 30km is applied when the native resolution of the instrument is close to 45x45km^2. The SMOS Pilot-Mission Exploitation Platform (www.salinity-pimep.org) Match up report gives a 0.32 root mean square for the difference between Argo floats and the SMOS V4 SSS. One must however keep in mind that, as stated earlier, the Argo floats cannot capture mesoscale (and smaller) features and therefore this number cannot only account for the measurement error.

The L3_DEBIAS_LOCEAN_v4 Sea Surface Salinity maps have been produced by LOCEAN/IPSL (UMR CNRS/SU/IRD/MNHN) laboratory and ACRI-st company that participate to the Ocean Salinity Expertise Center (CEC-OS) of Centre Aval de Traitement des Donnees SMOS (CATDS). This product is distributed by the Ocean Salinity Expertise Center (CEC-OS) of the CNES-IFREMER Centre Aval de Traitemenent des Donnees SMOS (CATDS), at IFREMER, Plouzane (France).

SST is also key in the study of the Southern Ocean mesoscale eddies and is observed by a myriad of instruments. In order to stay consistent with the SSS dataset just described, the Remote Sensing of the Environment (REMSS) microwave (MW) optimally interpolated SST product has been selected. This product is based on a series of MW satellite sensors: TMI, AMSR-E, AMSR-2, WindSat and GMI. The optimal interpolation scheme is described in(Reynolds and Smith, 1994). Correlation scales of 3 days and 100 km are used in determining the weights used in their methodology. Data is available daily on a 25x25km^2 grid resolution from 06/2002 to present.

The Sub-Antarctic Front (SAF) mean, and time-varying positions are central to this study. They have been derived from a combination of gridded altimetric sea level anomalies and a climatology of mean sea level constructed from historical data and Argo T / S profiles based on the (Sallée et al., 2008a) method. The major improvement of this product with respect to the previous ones is the capability to reproduce meanders in the front. This research dataset is developed and delivered by the Centre for Topographic studies of the Ocean and Hydrosphere (CTOH). The dataset is available from 1993 till 2018 with a weekly temporal resolution.

The Finite-Size Lyapunov Exponents (FSLE) are shown for visual comparison with the eddy detection methodology presented above. FSLEs highlight the coherent Largangian structures and thus not only resolve mesoscale eddies but also finer scale structures such as sub-mesoscale fronts. These features are however, beyond the scope of the present study. The FSLEs are based on altimetry-derived surface currents and are produced and distributed by Aviso+. The data is available daily from 1994 till present with a 0.04° horizontal resolution (see (d'Ovidio et al., 2004) for greater details on the FSLE method).

Just as for FSLE, Chlorophyll-a data is used for extra visual support, to underscore the physical coherence of all products described above, when it comes to characterising eddies. The dataset presented in this paper is generated by the Ocean Colour component of the European Space Agency Climate Change Initiative project. The version 4 of this product is a combination of different spaceborne sensors and is available every 8 days at a 4km nominal horizontal resolution at the equator (detailed information on esa-oceancolour-cci.org).

3.4 Results

Over 6 000 eddies are examined throughout their life in the Southern Ocean between 2010 and 2019. Most eddies are found in proximity of the Antarctic Circumpolar Current (ACC). They are generated within hotspots driven by topography such as the Kerguelen Plateau, Canterbury Plateau or Drake Passage (Fig. 2, grayscale). The hotspots are thoroughly described in the literature (Sallée et al., 2011 & Frenger et al., 2015). The eddies median life span is of 2 months and the 95th percentile is 6.5 months. 77 eddies are detected for periods longer than a year. One must note that only eddies with life spans between 30 and 1000 days were kept for this study (refer to Section II). The eddies lifespan is represented by the size of dots on Fig. 2, the larger the longer and vice versa.

The median SSS anomalies found at the centre of eddies (hereafter central SSS anomaly) detected in the Southern Ocean show great differences depending on the rotation direction (Fig. 2ab).
On top of the rotation direction, the climatological position of the SAF (black solid line in Fig. 2) with respect to the eddies generation location also roughly delimits a change in sign of the central SSS anomalies. South of the SAF, the vast majority of anticyclonic eddies have negative central anomalies reaching -0.2 and cyclonic eddies have positive central anomalies reaching 0.2. The opposite is true north of the SAF.

The central SST anomalies show both similarity and great differences with the central SSS anomalies. Central SST anomalies polarity depending on the rotation direction is strong but no latitudinal delimitation (depending on the SAF position or not) can be observed (Fig. 2cd). The vast majority of anticyclonic eddies display a positive central SST anomaly often exceeding 1°C and cyclonic eddies a negative anomaly exceeding -1°C.

A particular sort of long-lived eddies is standing out as large dots on Fig. 2 in both SSS and SST anomalies around the island of Tasmania (around 145°E). These are associated with the Tasman leakage of the East Australian Current (van Sebille et al., 2012; Pilo et al., 2015) and are beyond the scope of this study.

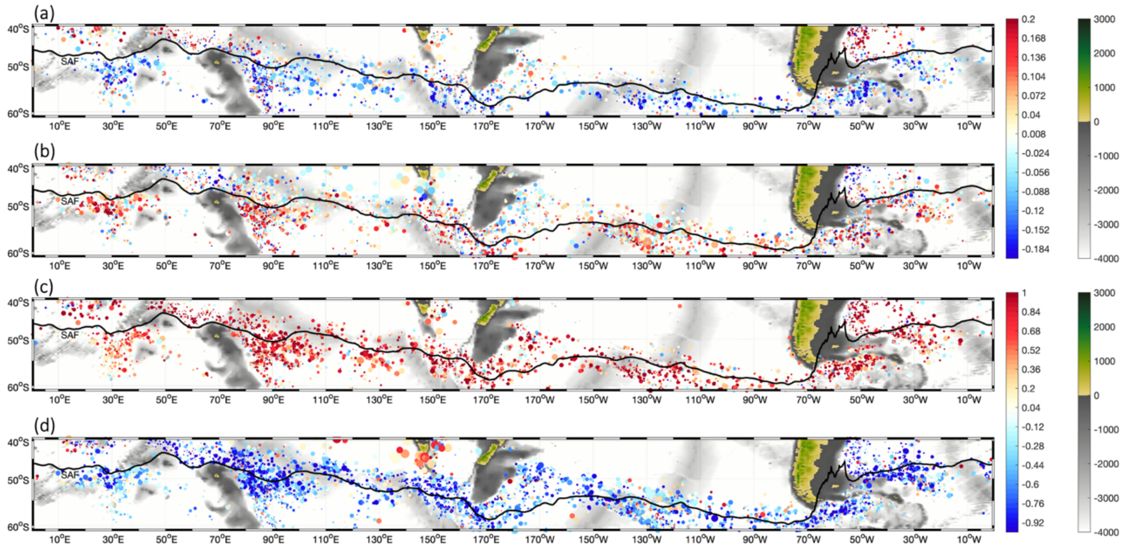

Figure 2. SSS central anomalies (unitless, colors) of anticyclonic eddies (a) and cyclonic eddies (b). SST anomalies (ºC, colors) of anticyclonic eddies (c) and cyclonic eddies (d). The eddies position indicates their first detection location and the size the overall detected lifespan. The largest dots represent lifespans of up to 1000 days and the smallest down to 30 days. The Sub-Antarctic Front (SAF) climatological location is denoted by the solid black line.

The latitudinal differences in central SSS and SST anomalies and their relation to the SAF position is worth investigating when considering both as different tracers of the ocean dynamics.

Composites were computed as described in the Method Section. Moreover, the time-varying and meander permitting SAF dataset enabled the selection of eddies depending on their latitudinal position with respect to the SAF during their entire life span. Eddies that crossed the SAF from north to south or the reverse were discarded.

A more complex pictures appears when looking at the composites (Fig.3). South of the SAF, both cyclonic and anti-cyclonic present strong cores of anomalies in SSS and SST. The opposite sign depending on the rotation direction is consistent with the central anomalies depicted in Fig. 2. Differences arise north of the SAF. In SST, the signal is analogous to the one found south of the SAF, and thus with central anomalies. In SSS, cyclonic eddies reveal a double anomaly with a positive anomaly to the east and negative to the west of its core. Anticyclonic eddies bare an intricate pattern of anomalies, weakly positive.

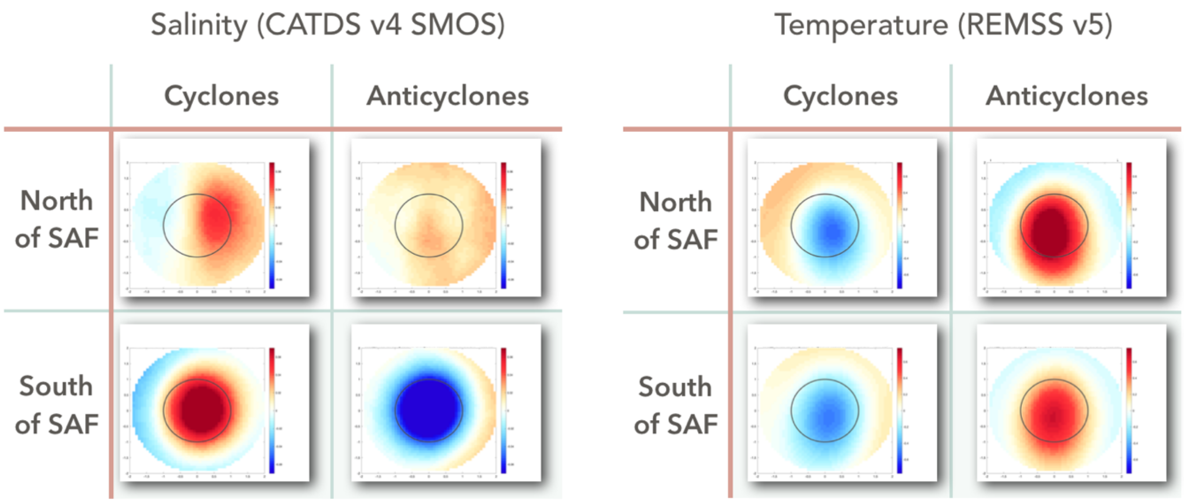

Figure 3. Composites of eddies signatures in SSS and SST (ºC) for cyclonic and anti-cyclonic eddies, north of the sub-antarctica front (SAF) and south of the SAF.

Previous studies on tracers associated with mesoscale activity has been dividing the tracers spatial signal into 2 main patterns: monopoles and dipoles (e.g. Frenger et al., 2015, 2018; Delcroix et al., 2019). The monopoles denote a single anomaly centred on the eddy centre of rotation and the dipoles denotes a double anomaly of opposite signs. The dipole does not necessarily have its centre aligned with the one of the eddies' rotation.
SSS anomaly composite for the cyclonic eddies north of the SAF do indeed show the strong presence of both 2 types of signal when other composites do not (Fig. 3). This difference can be attributed to different physical mechanisms such as for instance trapping fluid, steering gradient or vertical exchanges. These possible mechanisms are discussed in the following section.

4 CONCLUSIONS AND RECOMMENDATIONS

Understanding the role of mesoscale eddies in the Southern Ocean is crucial for the full comprehension of its subtle climate balance and thus the global climate. In particular, their interactions with water masses horizontally and vertically essential has been proven to be essential.

The SSS and SST anomalies spatial patterns observed in meso-scale eddies can be associated with physical mechanisms described in the literature. The patterns and their unprecedented association give the present study an even greater insight of processes at stake.
Firstly, the monopole pattern can result from fluid trapping. When an eddy crosses a sharp gradient and when its rotation speed is greater than its propagation speed, it becomes a coherent body under solid body rotation that has the potential to transport water and its features across long distances (Oh and Zhur, 2000 and Chelton et al., 2011). The monopole pattern can also be the result of a modification of vertical processes. A change in the vertical stratification by the presence of an eddy can produce a tracer anomaly, enhancing or reducing the efficiency of mixing. The cyclonic

eddies have a tendency to upwell or enhance the mixing of sub-surface waters when the anti-cyclonic eddies downwell or reduce the mixing of sub-surface waters.
A dipole pattern on the other hand can be generated by the stirring of the tracer field along the edge of the rotating eddy (Chelton et al., 2011). The eddy's propagation does also create a dipole-like spatial pattern as the leading edge tend to reduce the field gradient for the trailing edge. This creates an asymmetric signal, stronger at the leading edge and weaker at the trailing edge, resulting in a bipolar anomaly.

Monopoles are computed following Frenger et al. (2015) as the radial average of the composites generating a circular symmetry around the eddy's centre. The dipolar patterns emerge when subtracting from the original composite anomaly the monopole signal. The monopolar component accounts for over 90% of the anomaly for all composites except for the north of SAF cyclonic eddy SSS composite (Figure 4). Therefore, this study focuses on what can be learned on monopole patterns only. The study of bipolar anomalies is moreover limited due to the difficulty aligning the maxima/minima. The dipolar patterns shown in this paper can only underestimate the reality. Several methods based on the literature have been adapted to this dataset without giving coherent results. Further investigations are needed to infer conclusions.

The first order SSS and SST horizontal gradients are analogous in the Southern Ocean. Lower salinities and temperatures are found south of the SAF and higher salinities and temperatures are found north of the SAF. The latitudinal gradients follow to the first order the SAF layout. This observation rules out the predominant role of water trapping in the monopolar patterns characterized for SSS and SST. The role of trapping was already diminished by discarding eddies whose position suggested a possible interaction with the SAF.
Consequently, most of the SSS and SST monopolar anomalies presented in this study must be caused by vertical processes. This can give precious indications on the interaction of the Southern Ocean eddies with sub-surface water masses.

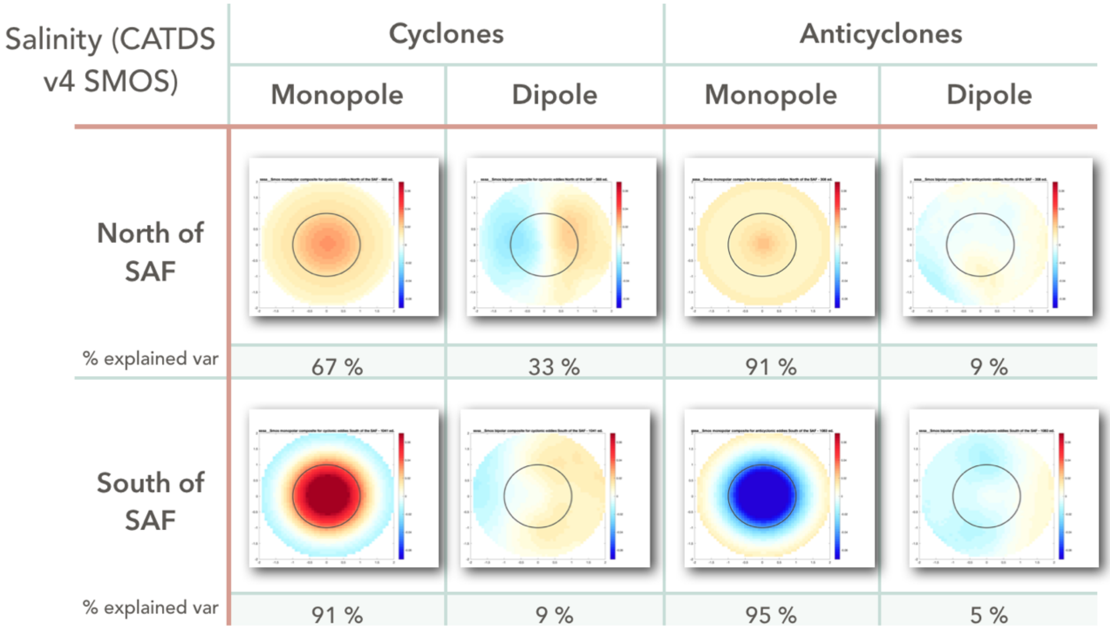

Figure 4. Composites of cyclonic and anticyclonic eddies signatures in SSS north and south of the SAF divided into their monopole and dipole components.

The Southern Ocean vertical distribution of salinity and temperature is quite different. According to (Whitworth and Nowlin, 1987) and following studies, the SAF position is defined by the abrupt sinking of the Antarctic Intermediate Waters (AAIW) salinity minimum. North of the SAF, sub-surface waters (AAIW) with salinities < 34.5 lie at depth below the surface waters with salinities > 35. The average depth of the AAIW salinity minimum across the Southern Ocean is around 800-1000 meters (Hanawa and D.Talley, 2001). This vertical configuration leads to a strong negative gradient of salinity.
South of the SAF, the Circumpolar Deep Waters (CDW) shoal bringing salinities > 34.6 just below (at 1000 meters depth) fresher surface waters (Santoso and England, 2004). The salinity vertical gradient south of the SAF is positive and thus opposite to the one north of the SAF.
This change of vertical gradient across the SAF is not found in temperature, where warmer waters generally sit on top of colder waters as our region of interest lies far from the Antarctic coast.

As described earlier, the anti-cyclonic eddies reduce mixing. The disposition of gradients would lead to a negative SSS anomaly and positive SST anomaly to the south of the SAF. North of the SAF, the anti-cyclonic eddies would generate both a positive anomaly in SSS and SST. This is consistent with our monopolar composites of anomalies associated with anti-cyclonic eddies.
In an analogous manner, as cyclonic eddies enhance mixing, a positive SSS anomaly and negative SST anomaly ought to be observed to the south of the SAF. Negative anomalies in SSS and SST should be generated north of the SAF. Once again this is coherent with what is presented in this paper. Although the cyclonic eddies north of

the SAF is not in agreement with this paradigm. We can only hypothesise on why this is the case. As this particular class of eddies show a strong dipolar signal, its monopolar signal might be eroded.

Much still need to be understood about eddies in the Southern Ocean but this study offers great perspectives on using the most recent satellite borne SSS datasets. The study of the interaction of eddies with subsurface waters is vital to characterise better their role in the Southern Ocean overturning circulation and thus the global redistribution of heat and carbon, especially as Hogg et al. (2015) 's study shows an increase in their intensity since the 1990s.

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6 PUBLICATIONS

6.1 Papers:

Hasson, A. , C. Pegliasco, J. Boutin and R. Morrow, R. Sabia, Sea Surface Salinity anomalies associated with Southern Ocean meso-scale eddies: an unprecedented observation from satellites, to be submitted to Frontiers in Marine Science

Olivier, L., Reverdin, G., **Hasson, A.** & Boutin, J. (2020). Tropical instability waves in the atlantic ocean: Investigating the relative role of sea surface salinity and temperature from 2010 to 2018. Journal of Geophysical Research: Oceans, 125, e2020JC016641. https://doi.org/10.1029/2020JC016641.

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Reul, N., Boutin, J., Turiel, A., Tenerelli, J., Vergely, J., Arias, M., **Hasson A**., et al. (2020). Sea Surface Salinity estimates from Spaceborne L-band radiometers:an overview of the first 9 years of observation (2010-2018). Remote Sensing of Environment Vol. 242,111769

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doi.org/10.3389/fmars.2019.00243

6.2 Presentations

Hasson, A., Pegliasco, C., Boutin, J. & Morrow, R., Colder and smaller : 10 years of observations of surface salinity by SMOS, Aquarius and SMAP to study mesoscale eddies in the Southern Ocean, EGU 2020-21449 , 2020 EGU General Assembly, Wien, Ostria
A. Hasson, C. Pegliasco, J. Boutin and R. Morrow, Satellite Salinity for the characterization of Southern Ocean Eddies and their interaction with Mode Waters (Poster), 2020 Ocean Sciences Meeting, San Diego, USA

Boutin, **Hasson** et al. , 'More than 10 years of Sea Surface Salinity monitoring from space', EO4water conference 2020, (presentation visible on https://youtu.be/ABOlTKudERA)

Hasson & Boutin: 'Sea Surface Salinity a tracer of Ocean and Atmosphere anomalies during ENSO events', ESA LVP 2019, 'SMOS – an ESA Earth Explorer satellite: From technology demonstrator to operational applications' special session

Boutin, **Hasson** et al., Overview of the CCI+SSS PROJECT, ESA LVP 2019
Boutin, **Hasson** et al., Overview of the CCI+SSS PROJECT, CCI colocation meeting, 2019

J. Boutin, N. Reul, R. Catany, J. Koehler, J.L. Vergely, **A. Hasson**, C. Thouvenin-Masson and S. Guimbard, Overview of the CCI+SSS project (Talk), 2019 EGU General Assembly, Wien, Autriche
Hasson, A., Boutin, J. & Morrow, R., Satellite Salinity for the characterization of Mode Waters at the interannual timescale, 2019 Living Planet Symposium, Milan, Italy
J. Boutin, N. Rodriguez-Fernandez, E. Anterrieu, F. Cabot, **A. Hasson**, Y. Kerr, N. Kolodziejczyk, L. Olivier, N. Reul, G. Reverdin, B. Rougé, A. Supply, B. Tranchant, J. Vialard. Unprecedent High Resolution Sea Surface Salinity from space: Achievements using SMOS and SMAP and way forward (SMOS-HR), Ocean Obs 19, Honolulu, Hawaii
A. Hasson, C. Pegliasco, J. Boutin and R. Morrow, The CCI product catches skillfully the mesoscale SSS in the Southern Ocean (Invited Talk), Salinity Science Seminar (FOR1740 + CCI+SSS group meeting), 2019 Hamburg, Germany

6.3 Misc.

ESA Advanced Ocean Synergy Training Course 2019 - OTC 2019 Chania Greece 04 to 08 November 2019

Full day lecture and practical sessions on satellite salinity
Full week support for group projects

Co-convener at International conferences

H. Bellenger, K. Drushka, A. Hasson, B. Ward, Physical processes of Air-Sea Interaction and their representation in models, **2020 EGU General Assembly,** Online
N. Vinogradova Shiffer, A. Hasson, S. Fournier, K. Drushka, Ocean Salinity in Support of Scientific and Environmental Demands, **2020 Ocean Sciences Meeting**, San Diego, USA
H. Bellenger, K. Drushka, A. Hasson, B. Ward, Physical processes of Air-Sea Interaction and their representation, **2019 EGU General Assembly**, Wien, Autriche

Double page on satellite oceanography in a prestigious outreach book made for the CNRS 80th anniversary. (Arnaud, N., 2019. L'atlas des nouveaux mondes: territoires d'exploration et de découverte, Cherche-midi. ed.)

Newsletter Météo et Climat - French Meteorological Society (A. Hasson, Boutin J. ,2019. La salinité vue depuis l'espace : 9 années d'observations SMOS du phénomène El Niño)