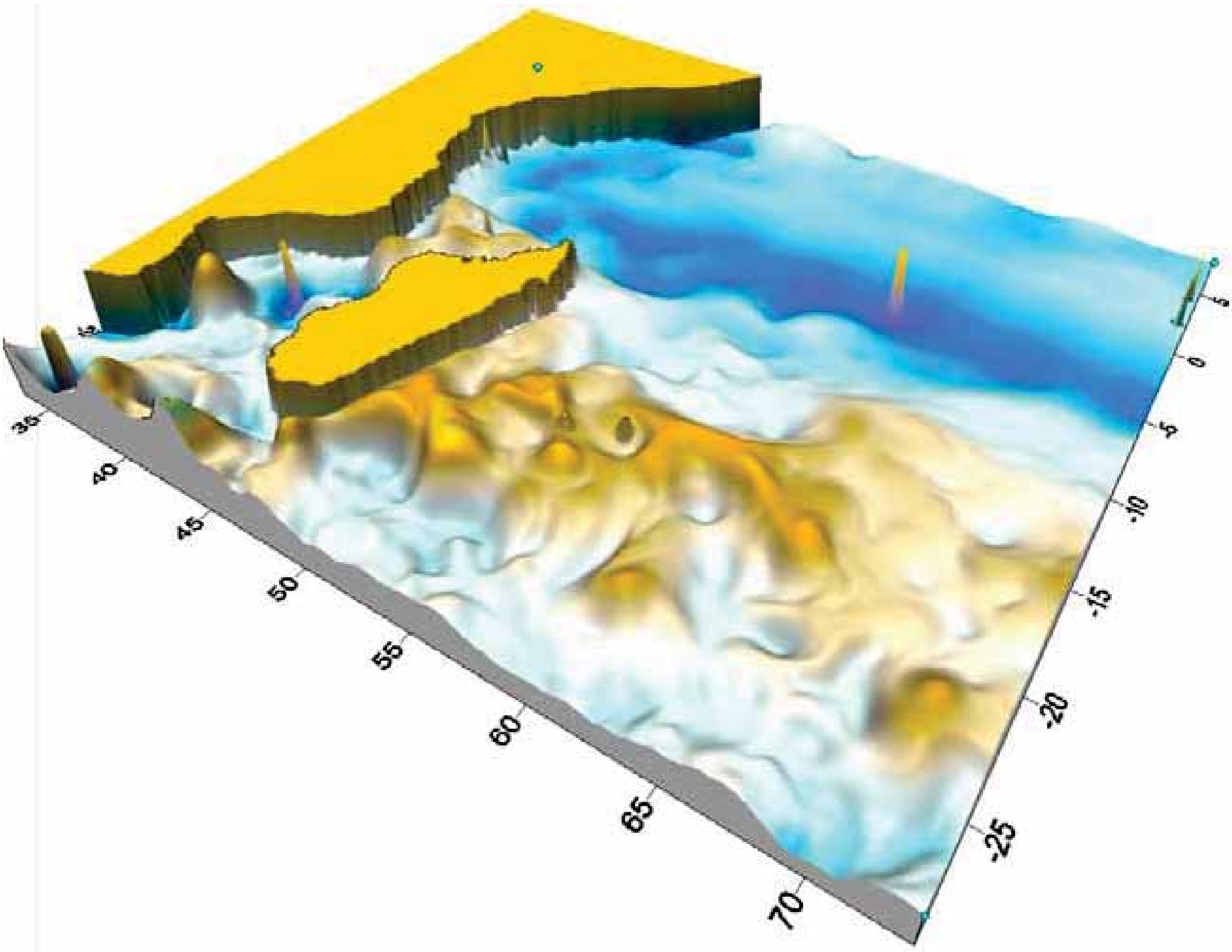
Atlas of Physical Oceanographic Parameters for the South Western Indian Ocean



based on 2002-2008 re-analysis | Arshad Rawat

Acknowledgement

This atlas was compiled within the framework of the AMESD project during a 2 months internship at Mercator Ocean. Special gratitude to the Mercator Ocean team for the collaboration and advice, particularly Silvana Buarque for her patience and dedication and Fabrice Hernandez for his advice. GLORYS re-analysis data was provided by Mercator. This work was fully supported by the AMESD project. I would also like to thank amongst others, Francois Carnus and Rezah Badal for their ongoing support, as well as the MOI and Mercator Ocean teams and any other people who collaborated to materialize this work.

Arshad Rawat, Toulouse, August 2010

Cover image: Mean June sea-surface height in the south-western Indian Ocean

Preface

The need for timely access to accurate and reliable information was stressed as one of the top priorities at the World Summit on Sustainable Development (WSSD) held in Johannesburg in August 2002. As a response to this urgency, the Africa Union and European Union launched the “African Monitoring of the Environment for a Sustainable Development” (AMESD) program. This continental-wide project is financed by the European Development Fund for the Regional Economic Communities in Africa and implemented by the African Union.

The main objectives of the project which will last for four years are : (i) to improve access by African users to existing basic Earth Observation data, (ii) to develop regional information services so as to improve decision making process by African institutions, (iii) to strengthen political and policy development frameworks such as Global Earth Observation (GEO) or Global Monitoring Environment and Security (GMES)-Africa and finally (iv) to develop human resources through the organization of trainings, staff exchange and fellowship programs.

The Mauritius Oceanography Institute (MOI) has been mandated with the implementation of the South West Indian Ocean (SWIO) component of this project. The latter has as overall objectives to help Indian Ocean Commission countries (i.e. Mauritius, Seychelles, Comoros, Madagascar and Reunion) and riparian countries of the Mozambique canal (i.e Kenya, Tanzania, Mozambique) to make better use of Ocean Observation data, from satellite and other sources, for the monitoring of their marine resources and the definition of their marine policies.

One of the services to be set up is the monitoring of physical oceanographic parameters and marine climatology. This would be built on two essential products, mainly the compilation of a referential database and the setting up of regular bulletin emission.

Data reception to put into operation the service would make use of several EumetCast satellite receiving stations which will be installed in the SWIO region. This atlas can be considered as a window on the database which is being compiled with the collaboration of Mercator Ocean and the use of their existing reanalysis database. The availability of forecast data from Mercator also led to the possibility of setting up an operational service as well.

Abbreviations

AMESD	African Monitoring of the Environment for a Sustainable Development
AVISO	Archiving, Validation and Interpretation of Satellite Oceanographic data
BUFR	Binary Universal Form for the Representation of meteorological data
EARS	Advanced Retransmission Service
EEZ	Exclusive Economic Zone
EKE	Eddy Kinetic Energy
EOF	Empirical Orthogonal Function
GLORYS	GLobal Ocean ReanalYsis and Simulations
GMMC	Group Mission Mercator Coriolis
IOC	Indian Ocean Commission
NEMO	Nucleus for European Modelling of the Ocean
NetCDF	Network Common Data Form
PSU	Practical Salinity Unit
SST	Sea Surface Temperature
SSH	Sea Surface Height
SSS	Sea Surface salinity
SWIO	South West Indian Ocean
THOAD	Transparent Handling of Operational and Additional Data
ORCA	Grid of the Ocean General Circulation Model OPA (Ocean PArallelized)
OSI SAF	Ocean and Sea Ice Satellite Application Facility

Contents

1 Introduction

1.1 The context

The general aim of this part of the IOC organization, leg of the AMESD project, is to set up a referential database in Physical Oceanography for the region. This would in turn facilitate the tracking of ocean parameters through the calculation of indicators (e.g. time series, anomalies, trends, etc.). Moreover, in order to have proper monitoring of climate change it is crucial to have a validated referential.

This referential will, in the first place, be derived from a period of around 7 years making use of GLORYS reanalysis from Mercator Ocean. With the Mercator Ocean collaboration, other interesting opportunities have appeared such as the validation of model data, mainly through observation campaigns and regional data compilation and the use of operational and reanalysis Mercator outputs as boundary conditions for finer regional modeling and maritime risk management.

This atlas can be considered as an overview illustrating the potential of information that can be can provided by the database and comes as a first version issued during the first year of the AMESD project. A final validated version is to be issued by the end of the project, after the availability of upcoming streams and versions of GLORYS. The database will gradually expand through incorporation of best analysis from the operational bulletins.

1.2 The region

The region of interest for the atlas is mainly the South Western Indian Ocean (SWIO) so as to include the EEZ delimitations of the IOC members as well as the riparian countries. Furthermore so as to have a good compromise between resolution and viewability, a window of 30°S to 5°N and 35°E to 75° E has been chosen for the charts as shown on Figure 1.2-1. However the constituted database covers the whole Indian Ocean: 40°S to 30°N and 20°E to 120°E.

1.3 The Datasets

For the setting up of the atlas/database, the GLORYS reanalysis (GLobal Ocean ReanalYsis and Simulations) dataset was used. Reanalysis aims to assimilate historical observational data spanning over an extended period of time using a single consistent assimilation model throughout. The GLORYS reanalysis is a project supported by the french Group Mission Mercator Coriolis (GMMC). The objective is to produce a series of realistic (i.e. close to the existing observations and consistent with the physical ocean) eddy resolving global ocean reanalysis.

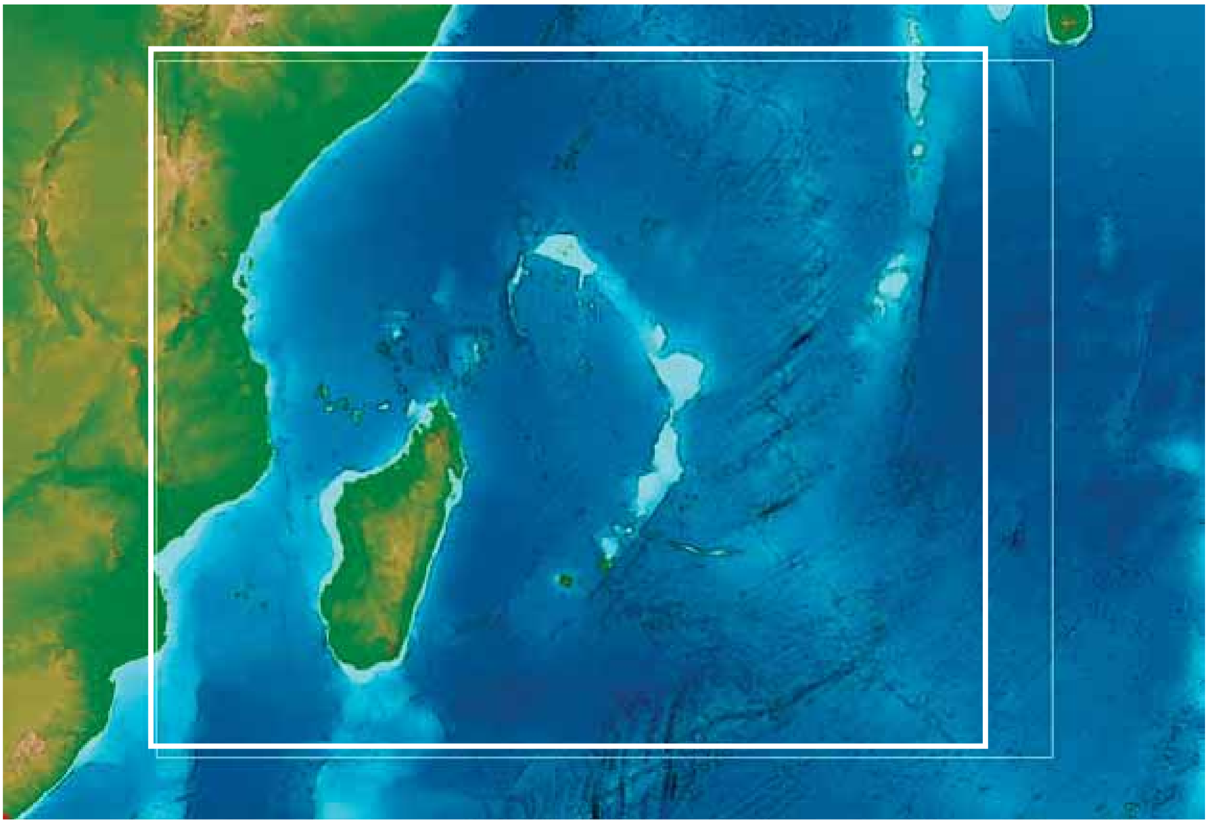


Figure 1.2-1. South West Indian Ocean and the chosen window for charts

1.4 The tools

Mercator Ocean has developed a toolbox called Transparent Handling of Operational and Additional Data (THOAD) [9] in order to automatically produce thematic bulletins. Inspired by the open sources developments, THOAD was build in KornShell for the transportability and its scripts shuts up others sources in any languages (e.g. Ferret, IDL, Fortran, etc.) .

The goal is to generalize solutions to specific problems like:

- to cope with complexity and cost of data manipulations;
- to experiment easily some applications of MERCATOR data;
- to promotes self-user training to MERCATOR products;
- to develop experimental diagnostics processing;
- to recover free data.

THOAD has been assigned to initiate the implementation of the oceanographic database. Most diagnostics used in this Atlas were made using THOAD.

2 GLORYS Features

The main advantage of using GLORYS is the completeness with respect to observations (satellite an in-situ data) and the performance of the interpolation method (assimilation) which provides a continuous spatial field that can be viewed as the “best estimate” of the ocean state. This product is especially important because oceanographic observations of salinity and temperature are quite scarce in this region. Also, parameters such as temperature and surface topography, which can be measured directly through satellite remote sensing, does not provide vertical information and does not have spatial continuity because of missing data between the orbit traces and cloud cover. However, it is important to note that the hydrodynamics of the reanalysis is inferred from the Sea Surface High (SSH) which is a satellite measurement.

2.1 Model Details

The ocean general circulation model used for GLORYS is based on ORCA025 NEMO OGCM configuration [1]. The assimilation method is based on a reduced order Kalman filter (SEEK formulation, [6]) adapted to eddy resolving global ocean model configuration [10]. The model configuration has 50 vertical levels (~1 m near the surface, 500 m at depth, 11 levels over the top 15m). All 50 levels are included in the database being compiled. The GLORYS modelling uses a leap year calendar and a TVD advection scheme which is enstrophy and energy conserving. The time step is 1440s.

Assimilation parameters include along-track SLA (from TOPEX/Poseidon, ERS-1, ERS-2, GFO, Envisat, and Jason-1), NCEP Real-time, global ½° sea surface temperature, and in situ T & S (Coriolis-REANALYSIS data set).

Parameters acquired for the database and atlas includes: all layer temperatures, salinities, the meridional and zonal current components as well as the mixed-layer depth and SSH. Other parameters such as the vertical velocity component, vertical eddy diffusivity, and detailed heat fluxes are also available from Mercator but have not been included in the atlas/database.

2.2 GLORYS Streams

Several streams are planned: stream 1 (2002-2008: GLORYS1), stream 2 (1993-2008: GLORYS2) and stream 3 (1958-2008: GLORYS3). Each stream can be produced several times (i.e. several versions), with different technical and scientific choices. The production of reanalysis is a work in progress and the quality and realism is intended to evolve over the different streams/versions. Currently only Version 1 of Stream 1 (GLORYS1V1) has been produced and is available on request from products@mercator-ocean.fr. Indicatively, GLORYS1V2 is to be available as from October 2010 and GLORYS2V1 as from December 2010.

2.3 Resolution

Thus, thanks to the model resolution, GLORYS1V1 can provide a daily gridded field with a resolution of about ¼° (27 km) in the Indian Ocean. As an example of the GLORYS spatio-temporal resolution, the Figure 2.2-1 shows the spatial distribution of the annual Sea Surface Temperature (SST) as the evolution of the daily SST averaged on the whole Indian Ocean.

Further details about this reanalysis can be found in [4].

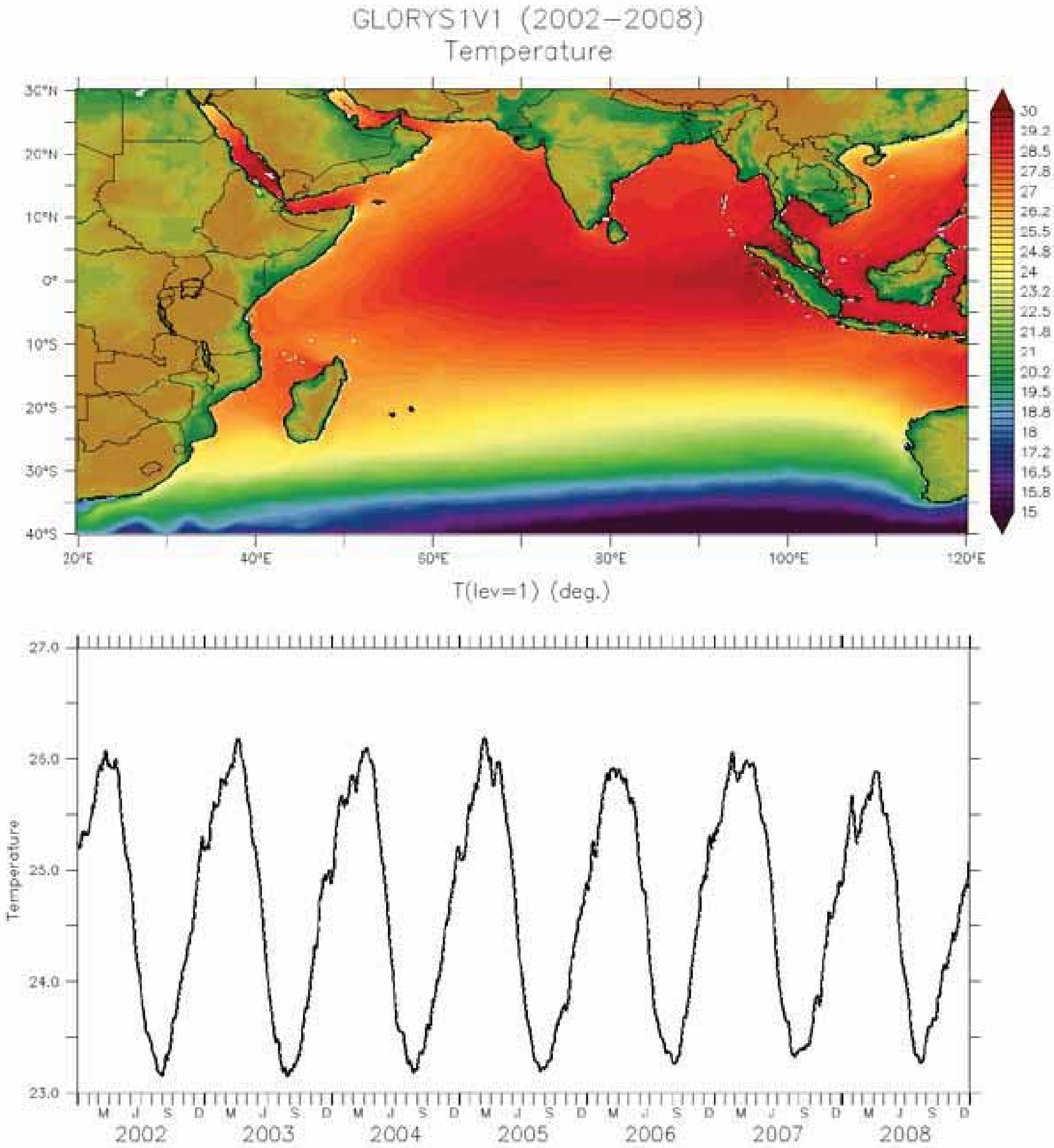


Figure 2.2-1 Spatial and temporal averages from GLORYS1V1: (top) annual mean of the SST and (bottom) evolution of the daily SST averaged on the whole Indien Ocean.

3 The Atlas

The atlas is not exhaustive in this first version and is of a straight-forward nature. It is shown in this sample, just an overview of climatological monthly mean of main oceanic parameters.. Spatial resolutions for these parameters are about ¼° (27 km) on a quasi-regular grid projected geodetically, consistent with the GLORYS native grids.

3.1 Temperature

Monthly temperatures for the surface of the ocean (T0 or SST) are shown in annex A. The unit used is °C. Indicative temperature distribution for 550m and 1000m are displayed for January and July. The color palettes used are consistent only within each depth range. Indicative flow patterns are superimposed on the charts.

The monthly SST highlights two typical regions: the Western Equatorial Indian Ocean (WEIO, 5N:5S;35E:75E) and the south part of the SWIO (5S:30S;35E:75E).

The intra-annual variability within the WEIO is characterized by maximum values over the whole area (28°C<SST< 30°) during April-May and by a west-east bipolar pattern – relatively cold in the eastern part and relatively warm in the western part – during the Southern Summer DJF. Within the south part of the SWIO and for the cyclonic season from December to March, the high temperatures migrate from north to south.

3.2 Salinity

The Sea Surface Salinity (S0 or SSS) patterns are given in section B. The values are given in Practical Salinity Unit (PSU), and the range for the region is 30 to 36 PSU.

The semi-annual variability from January to June within the south part of the SWIO between 55E and 75E shows a north-south differential consistent with the zone of separation between the upper water mass Indian Equatorial Water (IEW) and South Indian Central Water (SICW).

3.3 Sea surface height

Monthly Sea Surface Heights (SSH) with respect to the GEOID are shown in section C. These are given in meters. It should be noted that the SSH is always positive in the region of study. The SSH is a good indicator of the large scale mean ocean circulation as can be seen by the superimposed flow patterns.

3.4 Current Patterns

The monthly current patterns at the surface of the ocean are shown on section D, and estimated from U and V data, respectively zonal and the meridian components. Directions of the flow are given by flow-lines and the magnitude is given by the color-map. The intensity of the current is calculated by $(U^2 + V^2)^{1/2}$.

3.5 The Mixed Layer

The mixed-layer is the layer between the ocean surface and a depth usually ranging between 25 and 200m, where the density is about the same as at the surface. The mixed-layer owes its existence to the mixing initiated by waves and turbulence caused by the wind stress on the sea surface. An effect of mixing is to make both properties of water, temperature and salinity, thus density, more uniform. The penetration of mixing to a certain depth (the mixed-layer depth) mostly depends on the stability of the sea water and on the incoming energy from the wind. The more stable is the surface water, the less mixing occurs, and the shallower is the mixed-layer.

The two criteria often used to determine the mixed layer depth (MLD) are temperature and sigma-theta (density) changes from a reference value (usually the surface measurement). The MLD displayed in this atlas is calculated according to the sigma-theta criterion which uses the depth at which a change from the surface sigma-theta of 0.125 has occurred.

The MLD is greater in winter than summer. During the summer increased solar heating of the surface water leads to more stable density stratification, reducing the penetration of wind-driven mixing. Because seawater is most dense just before it freezes, wintertime cooling over the ocean always reduces stable stratification, allowing a deeper penetration of wind-driven turbulence but also generating turbulence that can penetrate to great depths.

The patterns of the monthly MLD shows a semi-annual cycle consistent with the seasonal cycle. One notes a deep MLD in the south part of the SWIO from June to September.

4 Regional indicators

In order to lay the foundations for the future development of regional diagnoses, some analytical examples are present in this section. In addition to the diagnoses shown below we hope to develop (not shown) also those already validated by Mercator Ocean [3] and [7].

To facilitate the analysis of ocean parameters, the SWIO region could be divided into smaller regions. Region A for example enclosing the Mascarene Islands of Reunion, Mauritius and Rodrigues is defined by 23.5S to 17.5S and 53E to 56E. Cross-sections can also be chosen for Hovmuller diagrams. The 20°S latitude section has been chosen as it crosses Mauritius, Madagascar and the Mozambique Channel and represents a typical section of the SWIO.

The exercise can be quite easily reproduced for other areas such as the Mascarene Plateau or the Mozambique Channel.

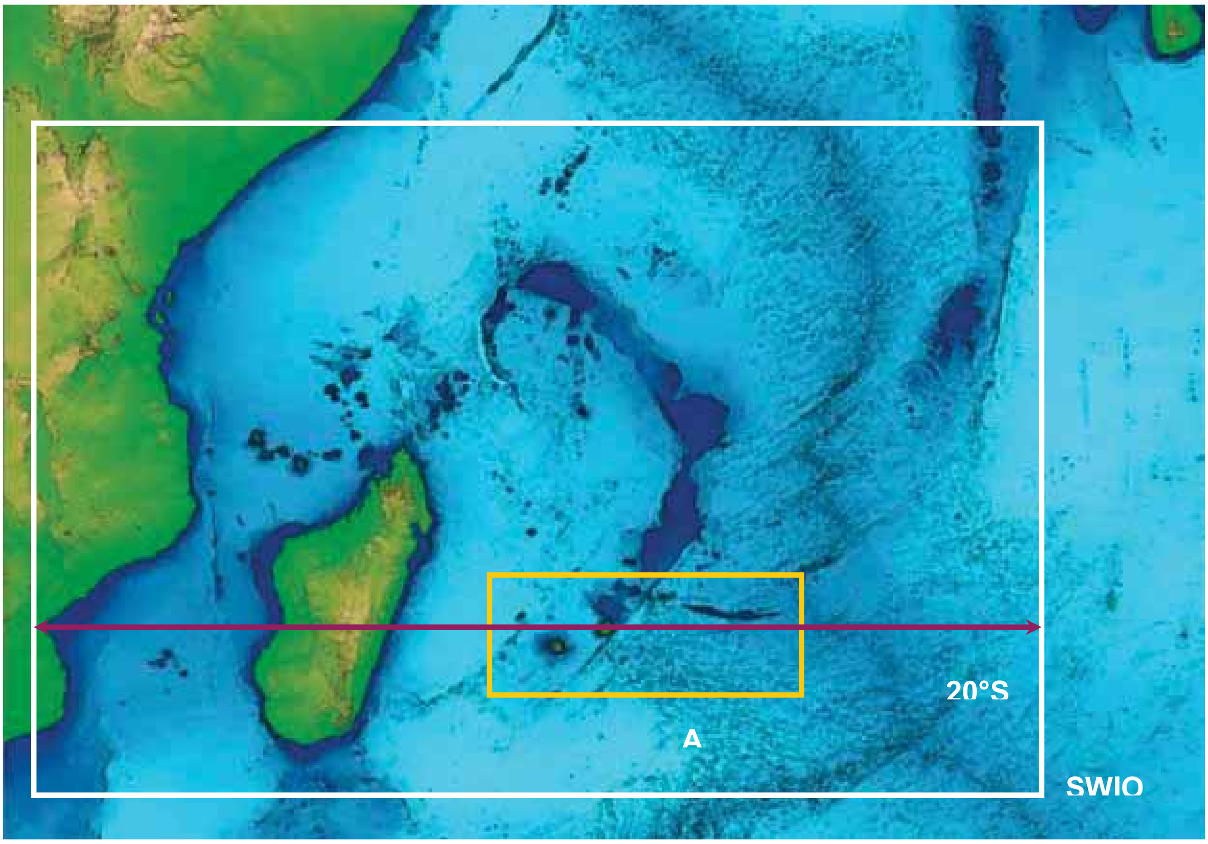


Figure 4.1-1 Topography of the Indian Ocean indicating the sub-regions and sections for analysis.

4.1 Sea Surface Temperature

The Figure 4.1-1 gives the evolution of the GLORYS1V1 daily SST along 20°S from 2002 to 2008. In the west side, the Mozambique Channel (MZC) show SST greater than 27°C almost five months a year, from December to April. In the east side, the minimum of the SST tends to increase and remain more confined between 65°E and 75°E from 2006.

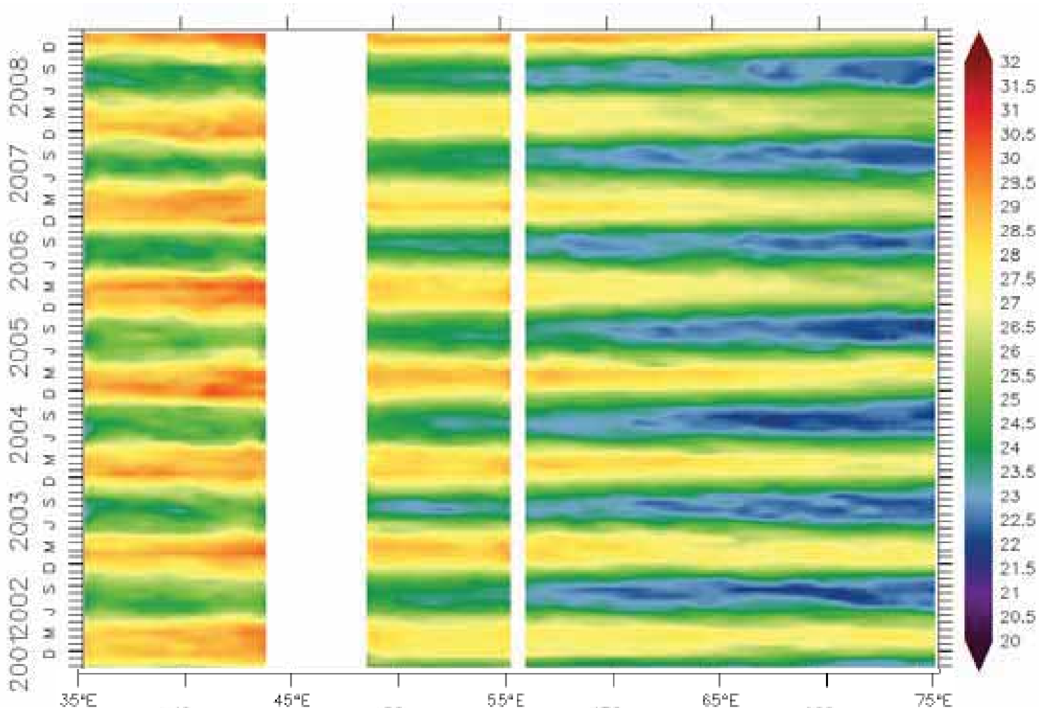


Figure 4.1-1 Space-time diagram showing the evolution of the SST along 20°S from 2002 to 2008.

Within the region A, the evolution of the climatological daily SST along a year is similar to the pattern observed along the period 2002-2008 for 20°S (Figure 4.1-2).

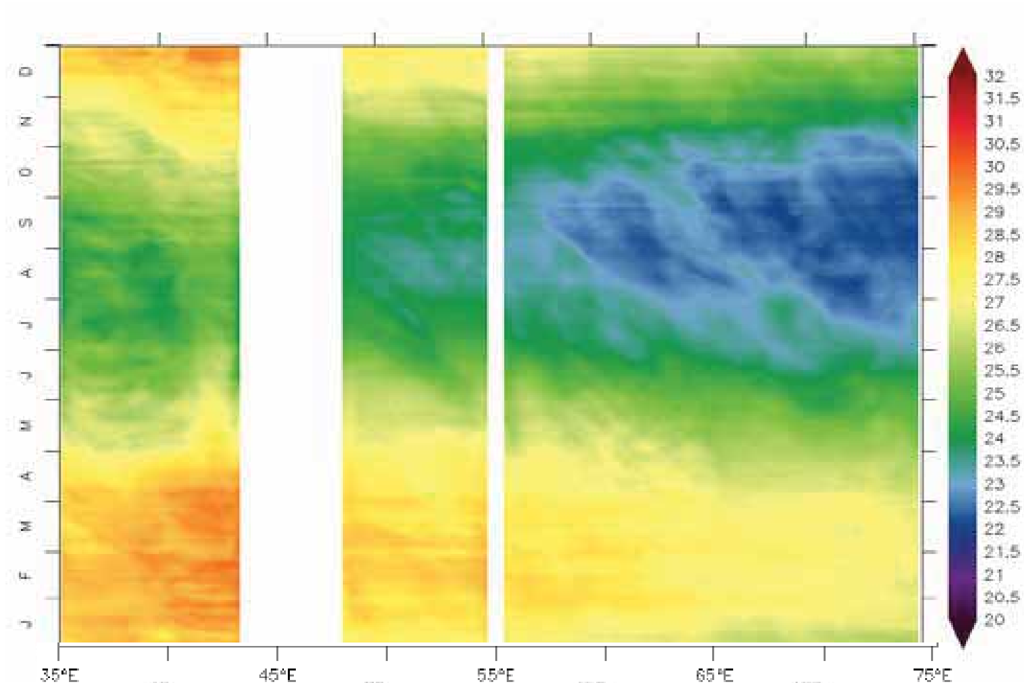


Figure 4.1-2 Space-time diagram showing the evolution of climatological (2002-2008) daily SST within the region A .

The inter-annual variability of the SST for the region A show that its maximum increases from 2002 to 2005 then falling to 2008 (Figure 4.1-3).

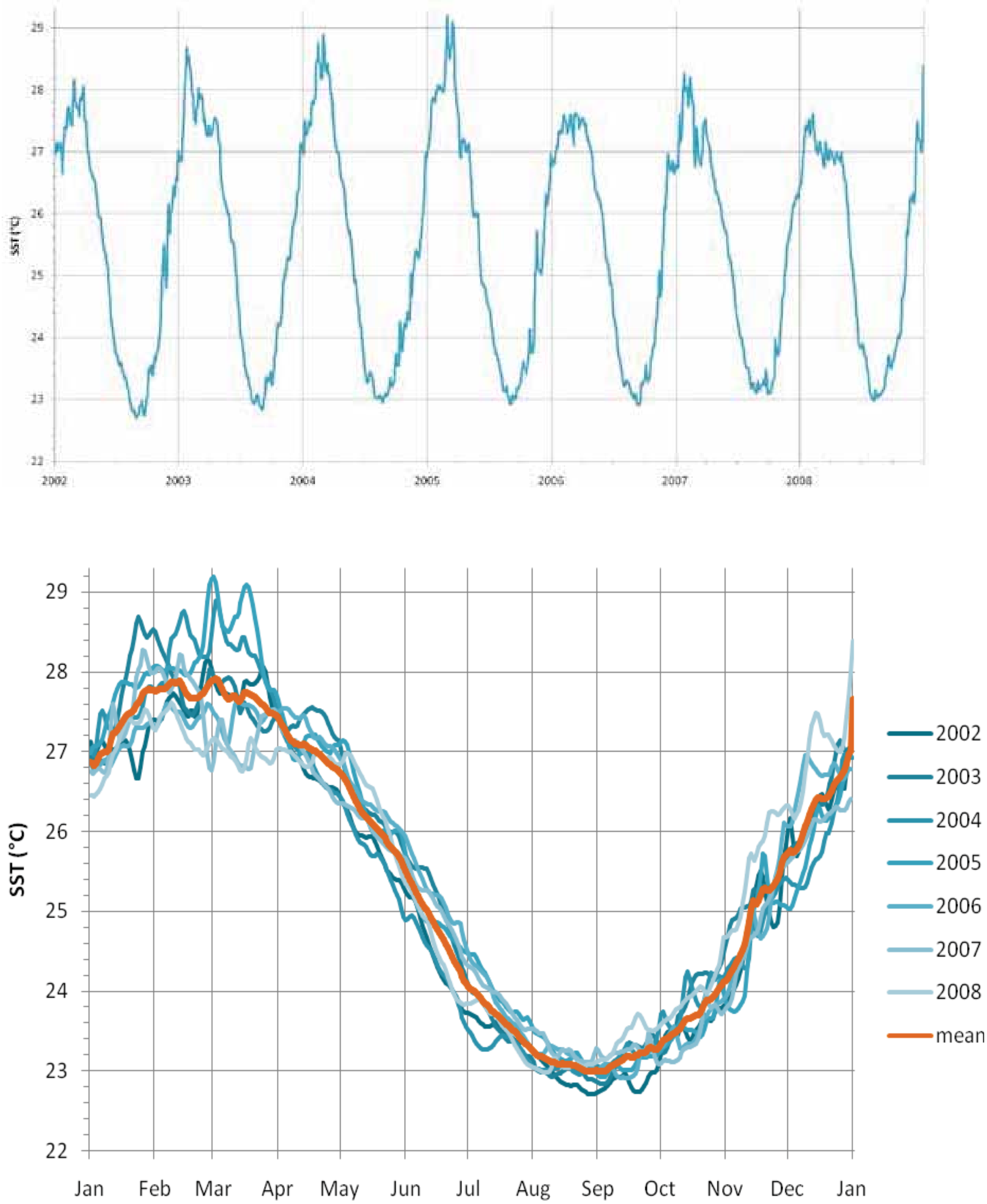


Figure 4.1-3 Evolution of monthly SST averaged within the region A. for the period 2002-2008 (top) and of the daily SST (in °C) from January to December for each year from 2002 to 2008 (bottom).

4.2 Eddy Kinetic Energy

Eddy Kinetic Energy (EKE) is the energy associated with the turbulent part of a fluid flow. Basically for oceanic circulations, EKE gives a quantification of the variability of the hydrodynamics and thus allows the study of mesoscale phenomena. For this kind of studies, it is typically computed, using the following formula:

EKE = ½ . [Variance (U) + variance (V)]

where U and V are meridian and zonal current components respectively.

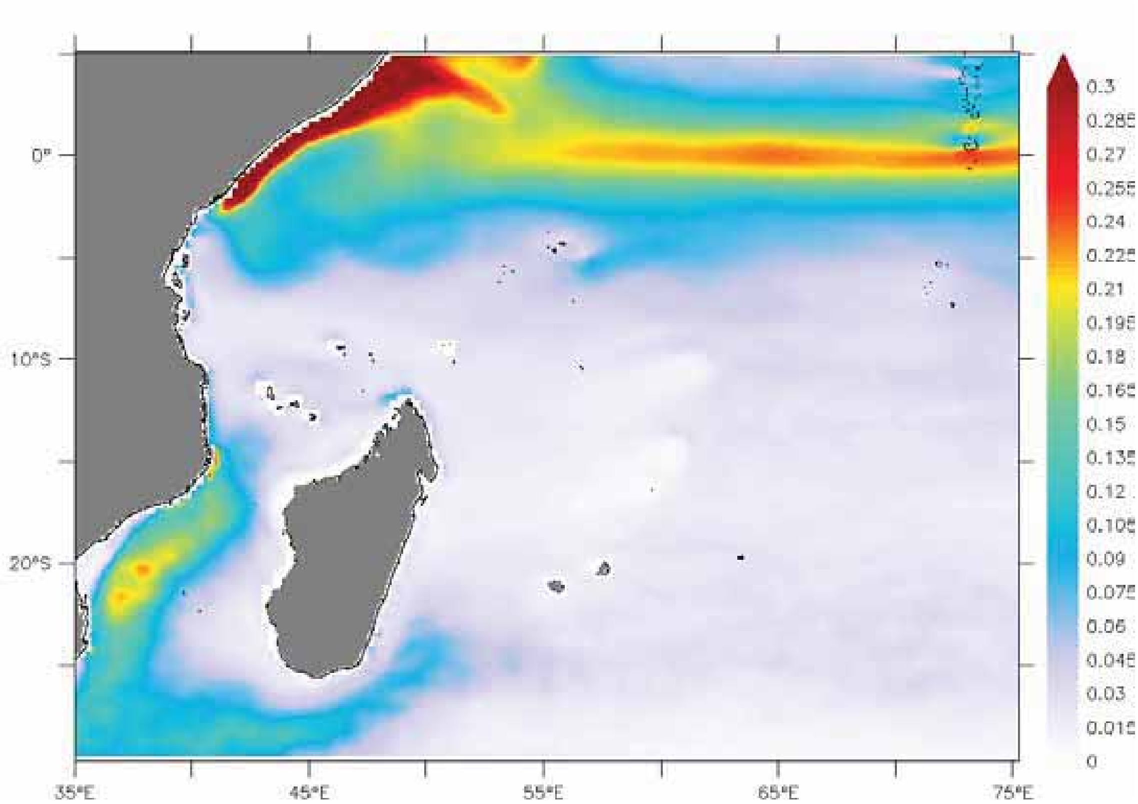


Figure 4.2-1 EKE calculated using daily data for the period 2002-2008.

Fig 4.2-1 shows the EKE calculated using daily data for the whole 2002-2008 period in m^2s^{-2}. Higher EKE means more variable flows in terms of both magnitude and direction and lower EKE means more stable flows.

It can be seen that the Mozambique Channel shows high variability as well as the circulation south-east of Madagascar. The Somali Current is very variable because of its seasonal reversal and its high magnitude. The equatorial jet is also very variable. However EKE is almost null over the Mascarene Plateau and around the Mascarene Islands, due to the low intensities of currents and their low variability.

4.3 Sea Surface Salinity

Figure 4.3-1 represents the variation of the salinity at the surface in region A for the period 2002-2008.

Figure 4.3-1 Evolution of the SSS in region A

Although some periodicity can be seen, such as the minimum occurring around March for most of the years, a general trend is apparent. However, this trend cannot be confirmed without a broader time-series. Spectral analysis would also better reveal the periodicity. Possible correlations of the extremes around 2007 with the Indian Ocean Dipole (IOD) could also be investigated.

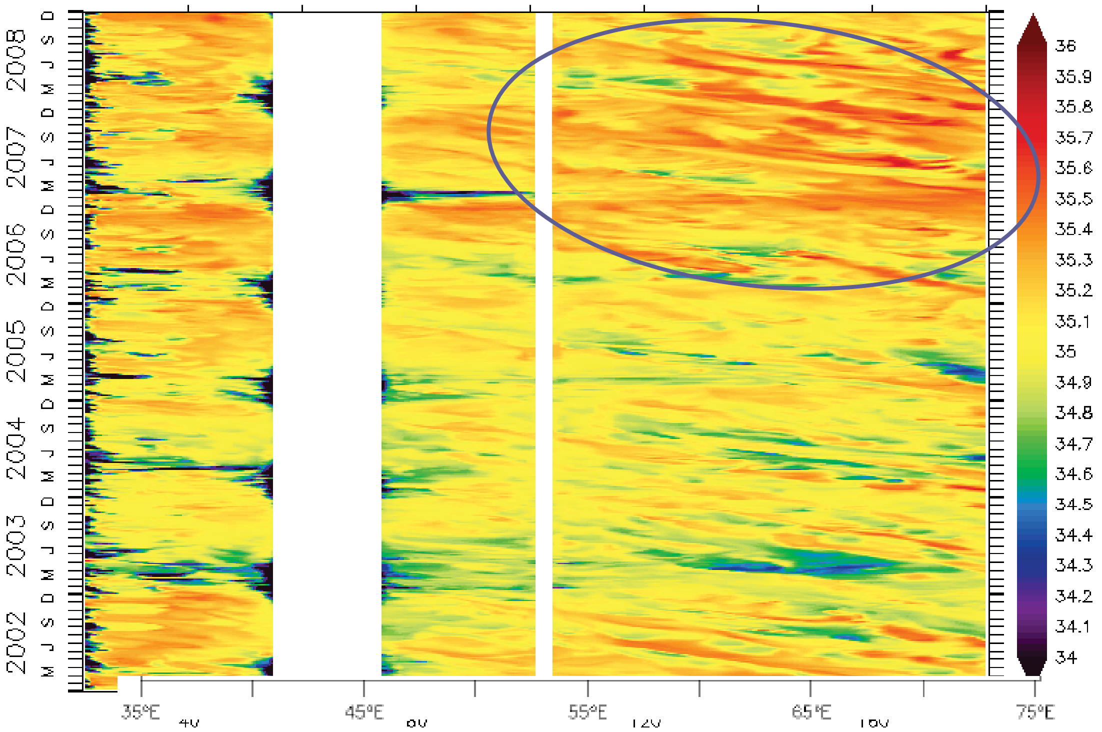


Figure 4.3-2 Variation of the SSS along 20°S

Figure 4.3-2 shows the variation along 20°S, displaying a nice seasonal variability in the Mozambique Channel and also possible IOD association mostly on the eastern side (gray circle).

4.4 SSH evolution

Figure 4.4-1 shows the variation of Sea Surface Height within region A.

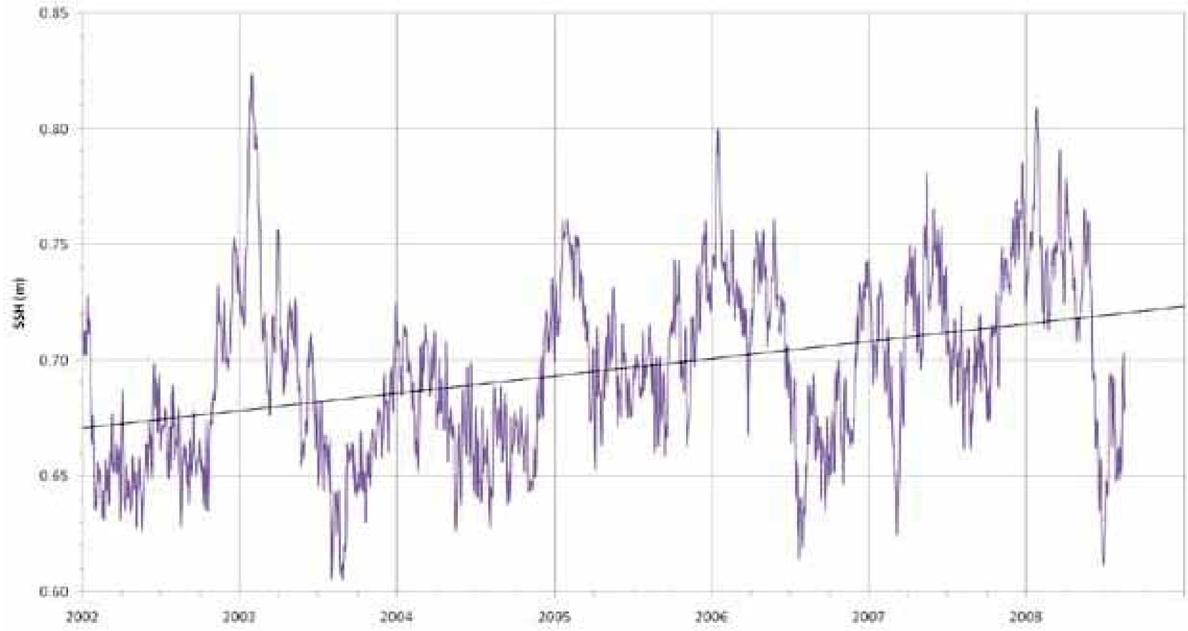


Figure 4.4-1 Variation of Sea Surface Height within Region A

It can be observed that although there seems to be some periodicity, unusual extremes are apparent, probably due to the IOD. A longer period span should allow better climatology. Otherwise, based on this period a net sea level rise of about 7.2 mm/year can be deduced.

Figure 4.4-2 shows the variation of Sea Surface Height along 20°S, displaying a nice seasonal variability in the Mozambique Channel but also possible IOD activity. Rossby waves are also very apparent.

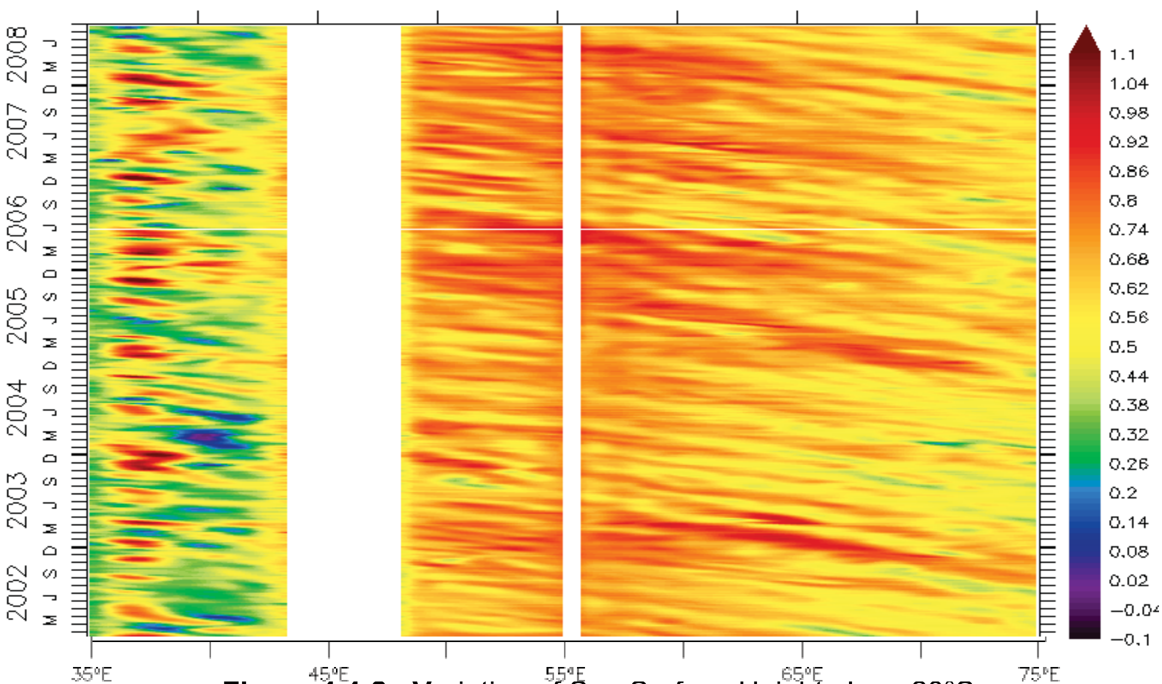


Figure 4.4-2 Variation of Sea Surface Height along 20°S

4.5 Variation of the Mixed Layer Depth

Figure 4.5-1 below shows the evolution of the MLD in region A.

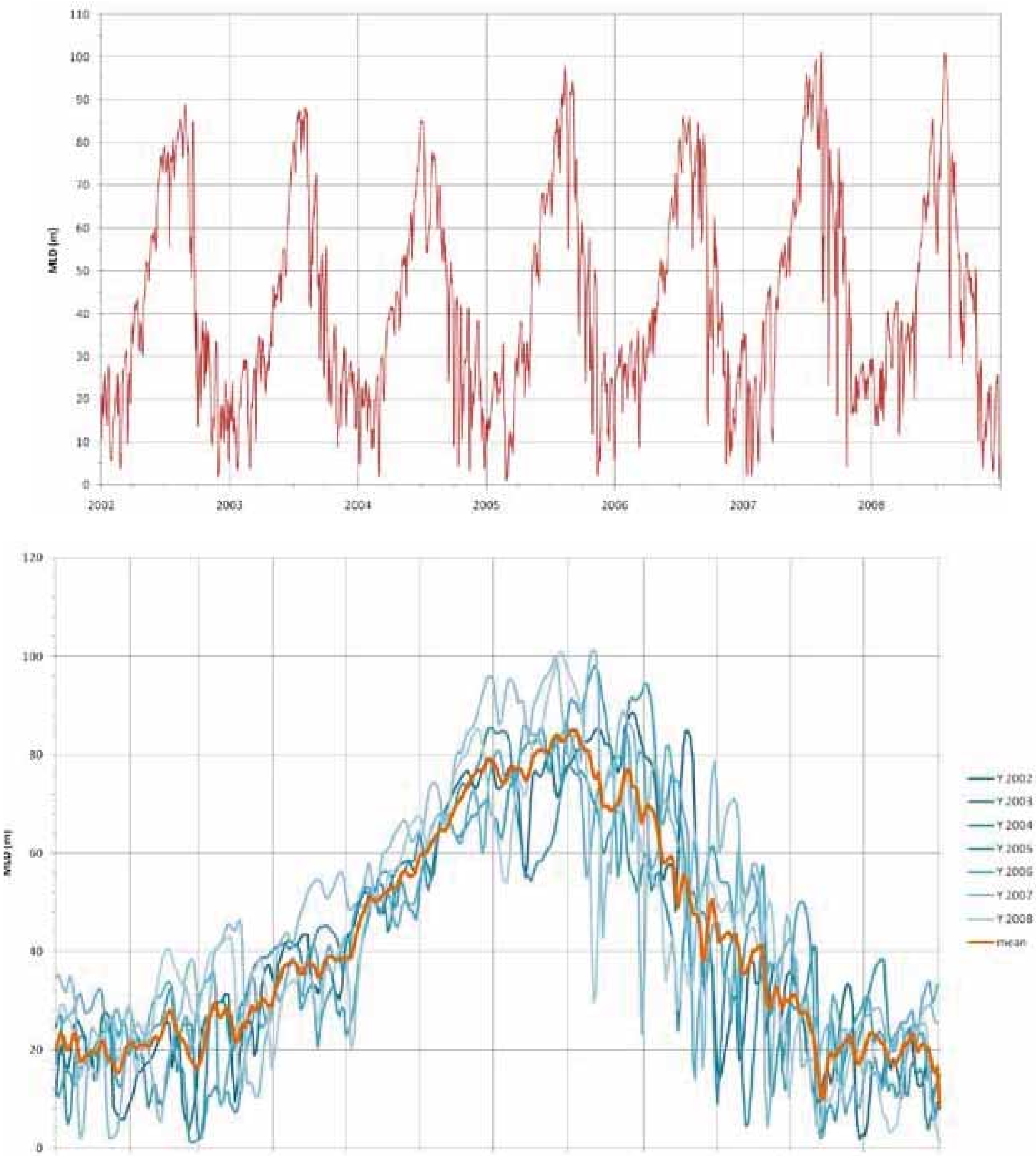


Figure 4.5-1 Evolution of the MLD averaged within the region A. for the period 2002-2008 (top) and from January to December for each year from 2002 to 2008 (bottom).

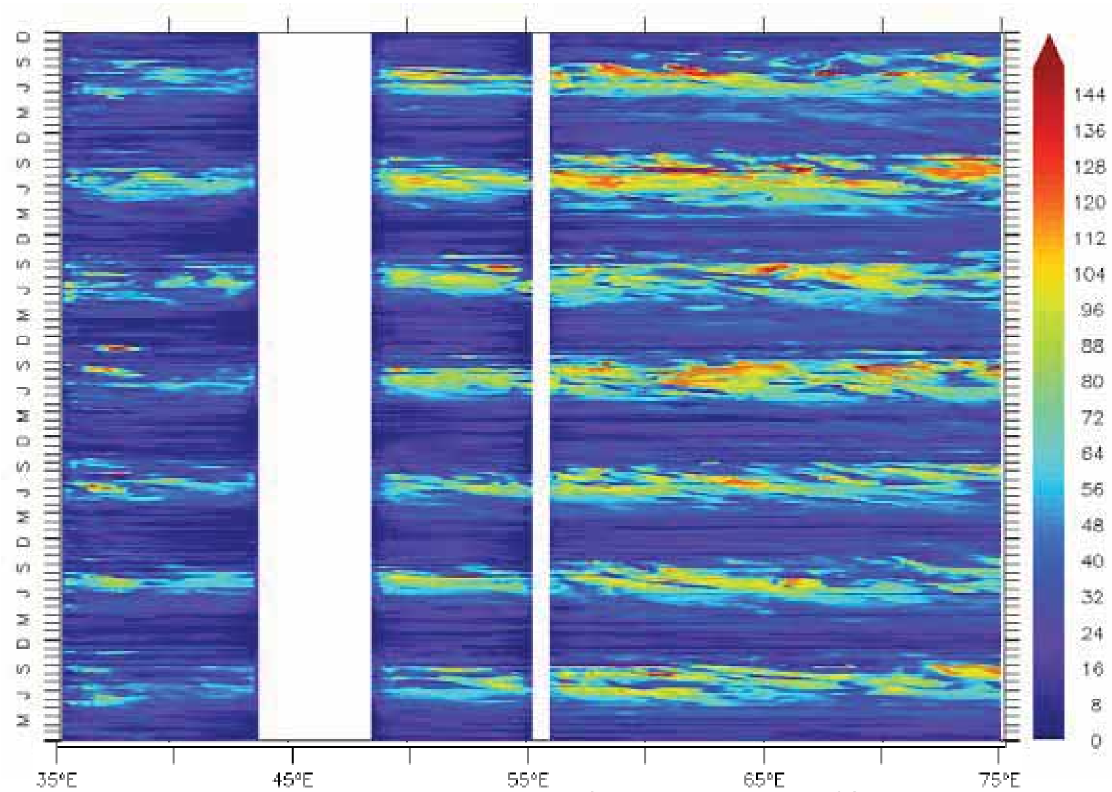


Figure 4.5-2 Variation of the MLD along 20°S

From these figures, a clear periodicity can be deduced for the MLD, thus climatological averaging based on this period would be straight-forward and unbiased

5 Intercomparison and Validation

Investigating the validity of the atlas/database can be done in several ways. Some global validation of the GLORYS reanalysis can be cited. For parameters such as SST and SSS, it would be interesting to compare with known existing databases such as Reynold, Levitus or OSTIA. Hydrodynamics can be compared with literature.

5.1 Comparison of SST

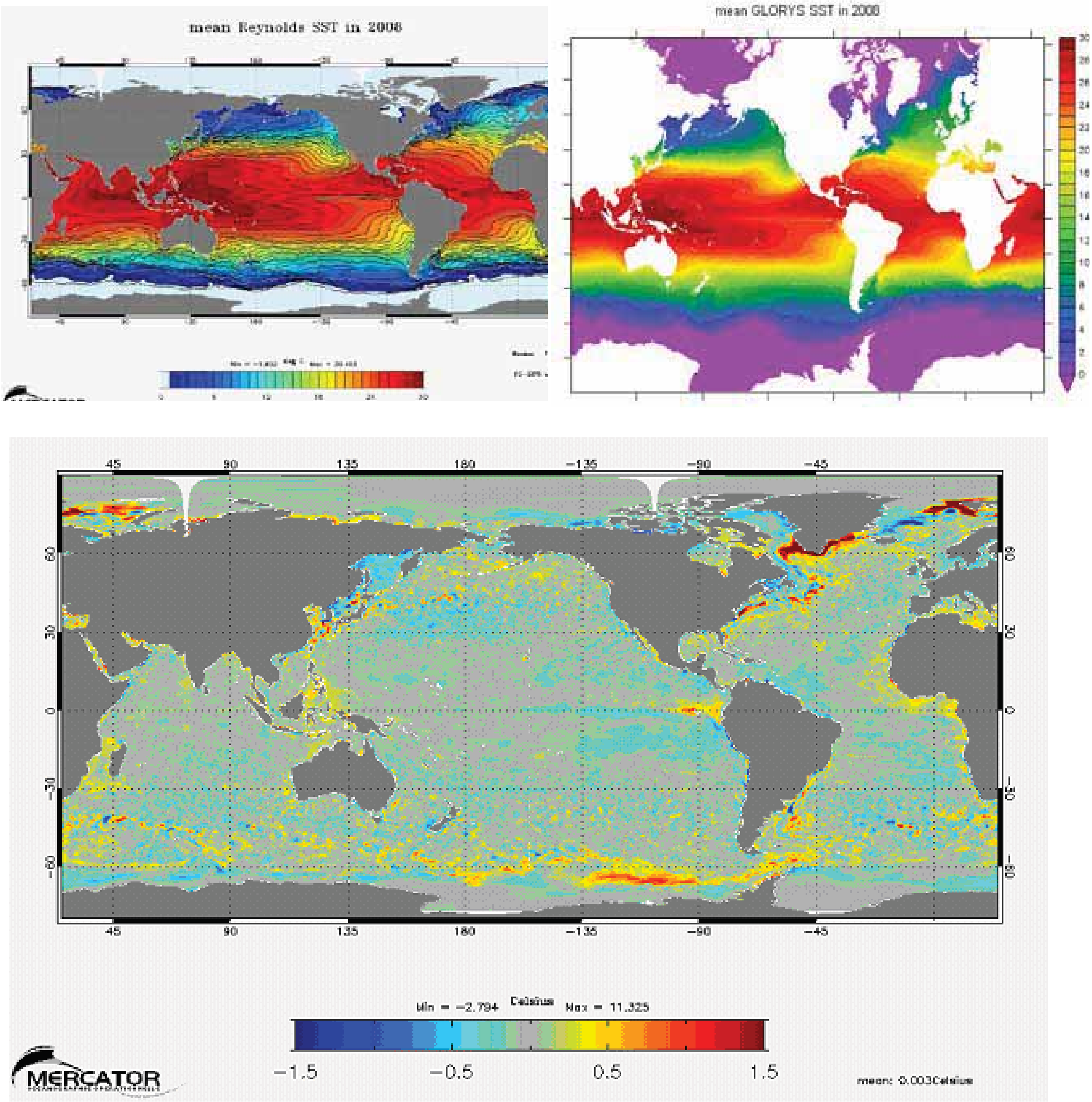


Figure 5.1-1 2008 mean Global SST according to Reynolds (top left) and GLORYS (top right) and the mean difference between (bottom)

A comparison with Reynolds in figure 5.1-1 above shows a maximum difference of less than 0.4°C for the mean SST in 2008 for the SWIO region. The average difference in close to zero in the region otherwise.

5.2 Comparison of Sea Surface Height

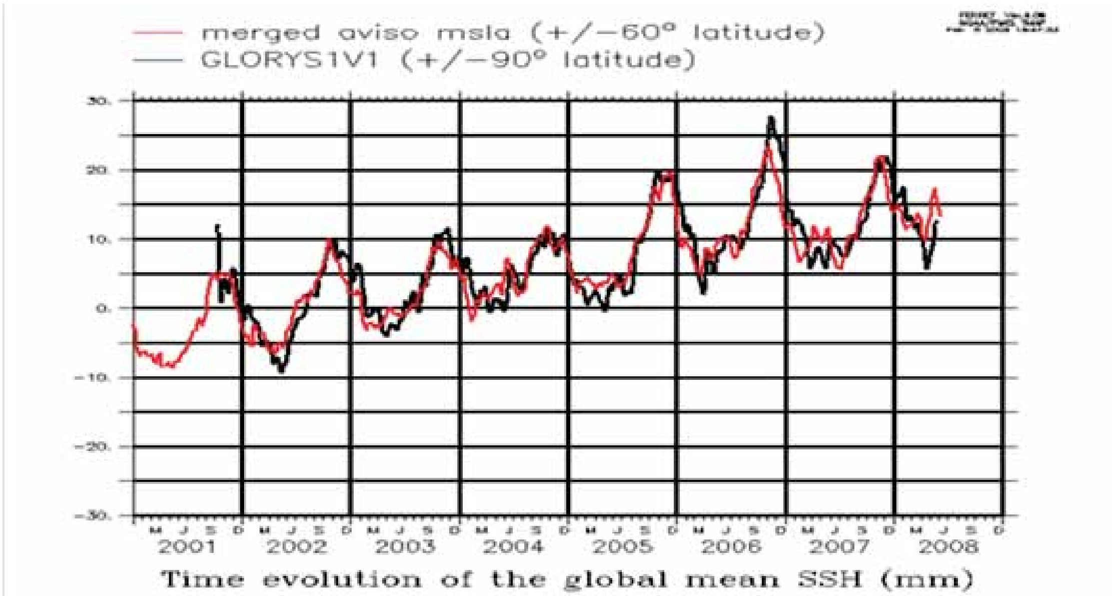


Figure 5.2-1 2001-2008 Global Sea Level comparison with AVISO MSLA

Figure 5.2-1 above compares the GLORYS1V1 mean sea level anomaly with the AVISO altimetry measurements showing very good correlation.

Figure 5.2-2 below shows the NOAA compiled 1993-2010 Sea Level Trends, which is in good accordance with the 7.2 mm/year deducted for region A in section 5.5.

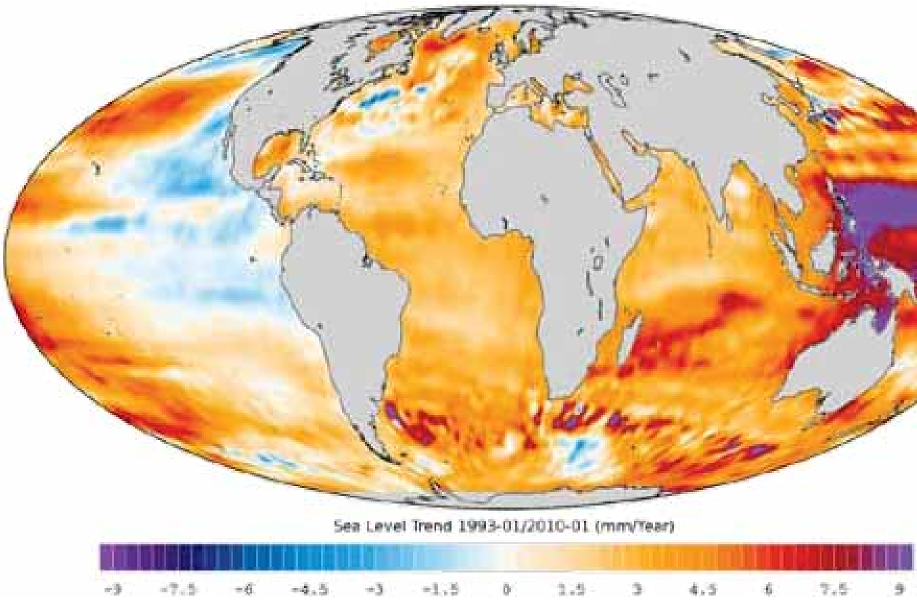


Figure 5.2-2 1993-2010 Sea Level Trend according to NOAA

5.3 Comparison of hydrodynamics within the literature.

Below are current patterns from 2 sets of literature: [8] and [2]

January June

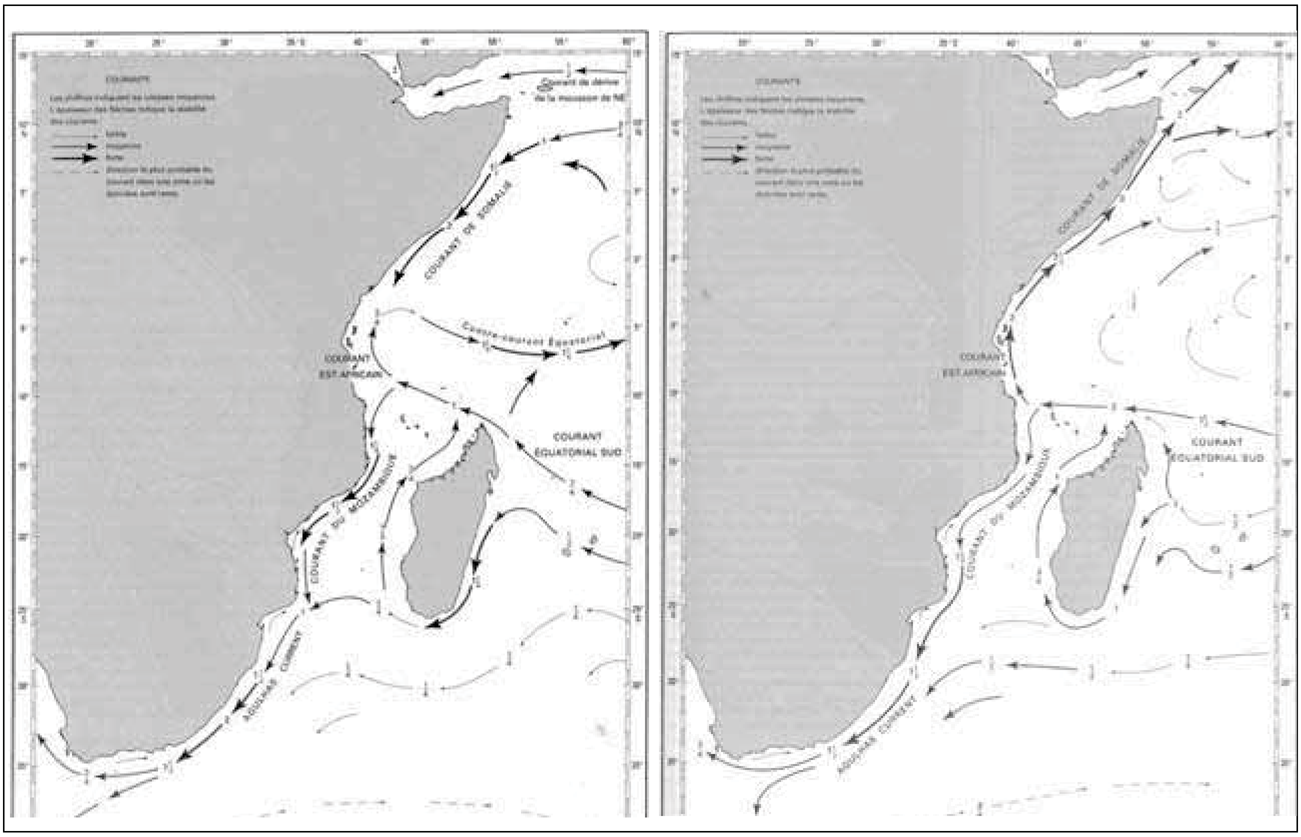


Figure 5.3-1 January and June circulation patterns in the western Indian Ocean from [8]

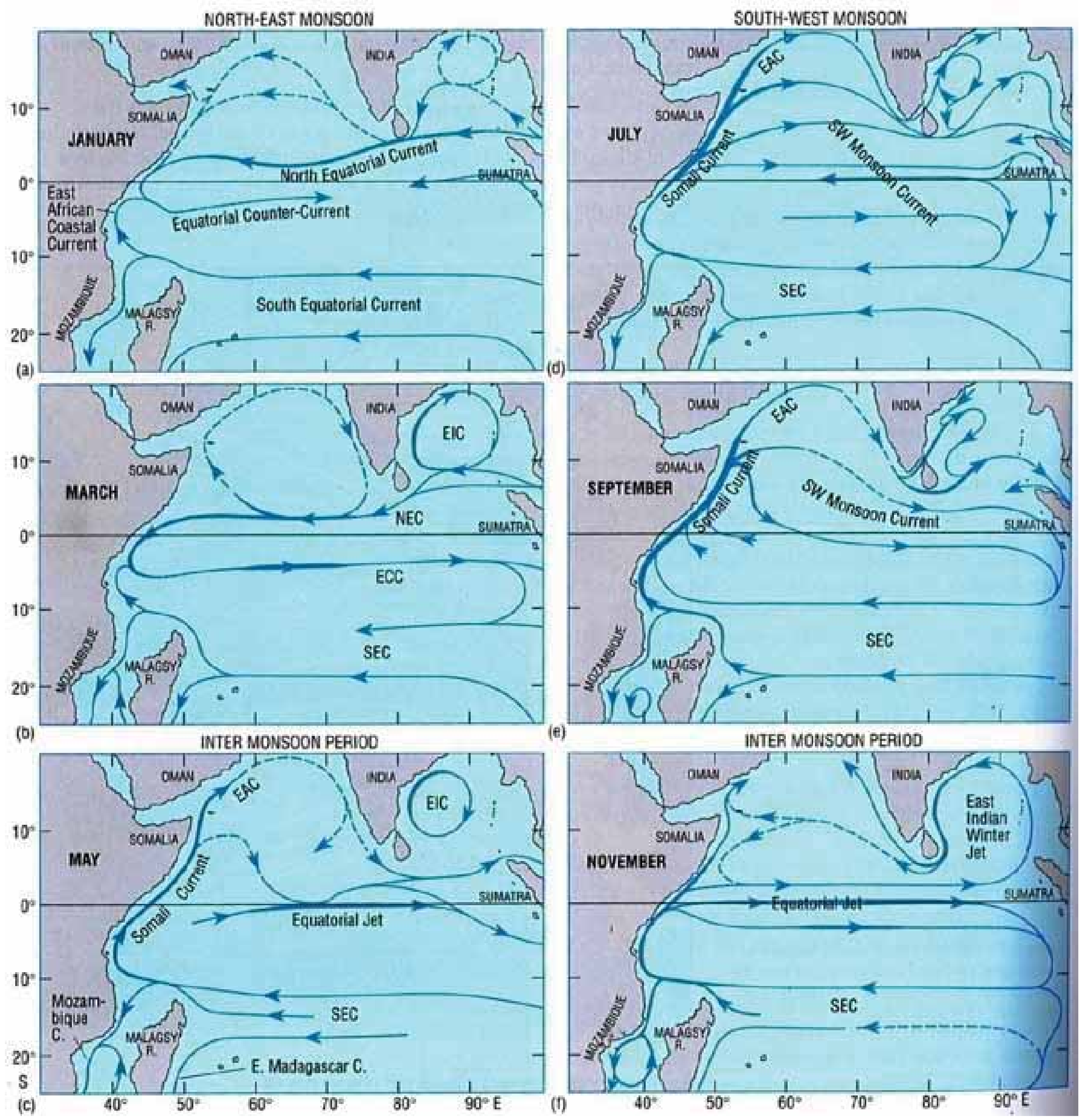
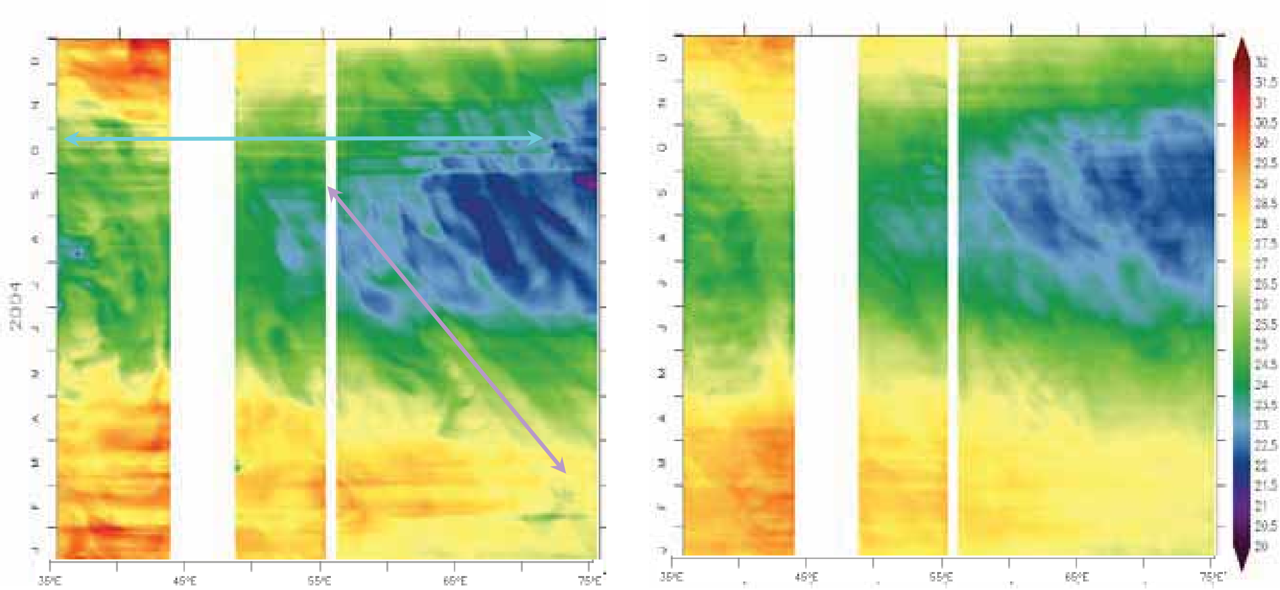


Figure 5.3-2 Circulation patterns in the Indian Ocean from [2]

Although being quite schematic, both compare favorably with the current patterns developed in this atlas.

5.4 Reanalysis performance

The quality of the reanalysis is influenced by several factors, including availability and coverage of observed parameters. Satellite observations has the largest surface coverage, but relies on cycle times and weather conditions. They are also limited to surface parameters. Still, the best observation data for reanalysis include satellite SST and SLA. As these are assimilated, temporal discontinuities tend to appear.



2004 | 2002-2008 averaged

Figure 5.4-1 Evolution of SST along 20°S for 2004 and 2002-2008 averaged

Fig 8.3a shows the variation of SST for the year 2004 along the latitude 20°S. Striations which are perfectly horizontal can be seen throughout the plot, which correspond to discontinuities associated with assimilation (assimilation jumps). These striations tend to be periodic and span across the whole dataset. However, these jumps are quite low compared to the general variations patterns and are greatly reduced through climatology averaging as seen on figure 8.3b. The presence of Rossby waves can be noted through diagonal patterns.

An exhaustive analysis of the performance of GLORYS and its validation can be found in [4] and [5].

6 Conclusion and perspectives

In this Atlas, the main features of the GLORYS1V1 reanalysis (2002-2008) developed by Mercator Ocean have been presented for the SWIO. Within a few months it has been possible to have an overview of main features concerning several parameters: SST,SSS, SSH, CMD and current.

It can be said that GLORYS1V1 on its own is fairly sufficient to be used as a regional climatology, even though a larger span would improve the validity. Thus, the setting up of the database would now allow the computation of anomalies and trends for the issuing of bulletins.

Unfortunately, the two month study was quite a short time to study all possibilities in agreement with regional applications desired. However, these could be done for the next version of the atlas.

Some possible improvements to take into account for the next phase of the study are listed below.

- **Upcoming versions of GLORYS**

With the upcoming advent of GLORYS1V2 and GLORYS2, the climatology study would definitely be improved in terms of reanalysis performance, assimilation and span of the study period (1992-2009 for GLORYS2)

- **Integration of biological model for nutrients and chlorophyll concentration**

Much research and development is also being done at Mercator for the integration of Biological parameters, namely the *PISCES* model [*]. Parameters such as Chlorophyll concentration and the *nitracline* are being derived. Biological modeling is to go into operational phase by the end of 2010 and is to be included into reanalyzes as from GLORYS1V2. The biological model parameters could be interesting add-ons for future versions of the atlas.

- **EOF Analysis**

The method of empirical orthogonal function (EOF) analysis is a statistical analysis method performed through the decomposition of a dataset in terms of orthogonal basis functions which are determined from the data. In the case of the whole Indian Ocean region, this could prove to be a major improvement, particularly to study the structure of the variability within a dataset.

References

[1] Barnier B, Madec G, Penduff T, Molines JM, Tréguier AM, Le Sommer J, Beckmann A, Biastoch A, Böning C, Dengg J, Derval C, Durand E, Gulev S, Rémy E, Talandier C, Theetten S, Maltrud ME, McClean J, De Cuevas B, **2006**: Impact of partial steps and momentum advection schemes in a global ocean circulation model at eddy-permitting resolution, Ocean Dyn., doi:10.1007/s10236-006-0082-1.

[2] Brown, E., Colling A., Park D., Phillips J., Rothery D. and Wright J., **2002**: Ocean Circulation, The Open University.

[3] Crosnier L, M Drevillon, S Ramos Buarque, J-M Lellouche, E Chassignet, A Srinivasan, O M Smedstad, S Rattan and A Wallcraft, 2009: Intercomparison of environmental Ocean indicators: a complementary step toward scientific expertise and decision making, Mercator Ocean, Quarterly Newsletter N°33, pp 11-17.

[4] Ferry, Nicolas, **2008**: GLORYS-1 Reference Manual For Stream 1 (2002-2007), Mercator Ocean internal documentation.

[5] Ferry, N., L. Parent, G. Garric, B. Barnier, N. C. Jourdain and the Mercator Ocean team, **2010**: Mercator Global Eddy Permitting Ocean Reanalysis GLORYS1V1: Description and Results, *Mercator-Ocean Quarterly Newsletter N° 36*.

[6] Pham, D. T., J. Verron and M.C. Roubaud, 1998: A singular evolutive extended Kalman filter for data assimilation in oceanography, Journal of Marine Systems, 16, 323-340.

[7] Ramos Buarque, S., L. Crosnier, V. Landes, F. Soulat and M. Drévillon, **2008**: L4 Sea Surface Temperature Applicationsat Mercator Ocean. Proceedings of the 9th Science Team Meeting (G9) of the Global Ocean Data Assimilation Experiment High Resolution Sea Surface Temperature Pilot Project (GHRSST-PP), Perros-Guirec, France, 9-13 June.

[8] Instruction nautique L3—INA, 2008: Océan Indien (partie Nord-Ouest) : du Sri Lanka au Pakistan, SHOM (http://www.shom.fr/)

[9] Ramos Buarque, S., 2006: Tranparent Handling of Operational and Additional Data (THOAD) Manual, Mercator Ocean internal documentation.

[10] Tranchant, B., C.E. Testut, L. Renault, N. Ferry, F. Birol, and P. Brasseur. 2008. Expected impact of the future SMOS and Aquarius Ocean surface salinity missions in the Mercator Océan operational systems: New perspectives to monitor ocean circulation. Remote Sensing of the Environment 112:1,476–1,487.

A Sea Surface Temperatures with current patterns

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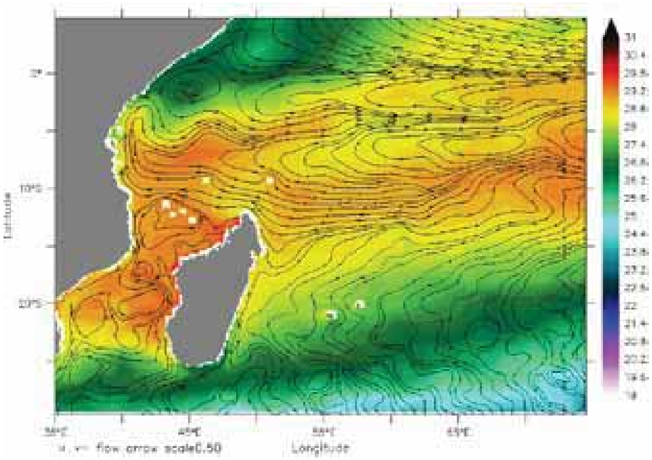

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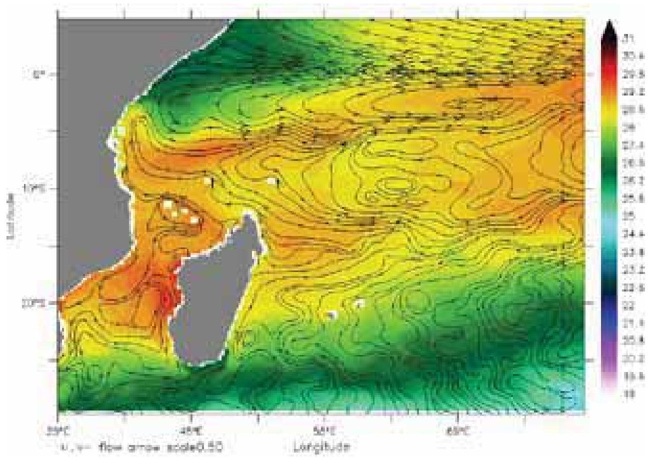

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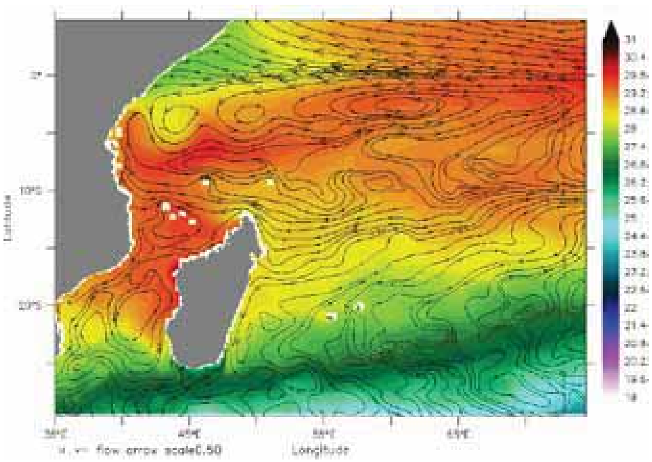

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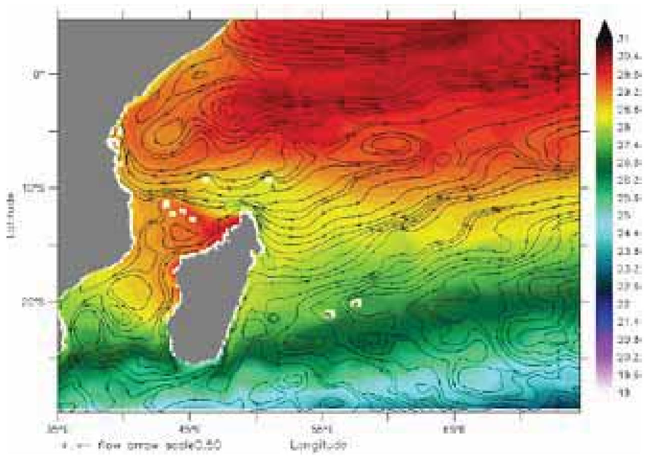

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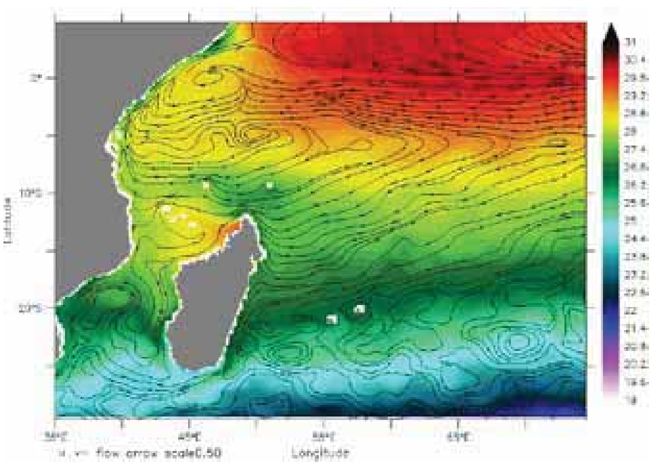

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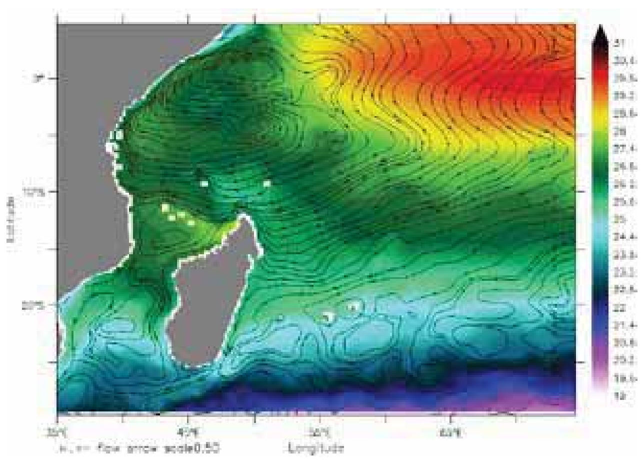

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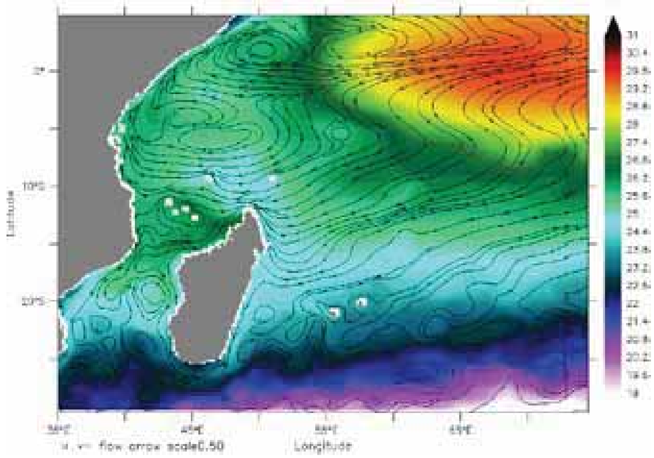

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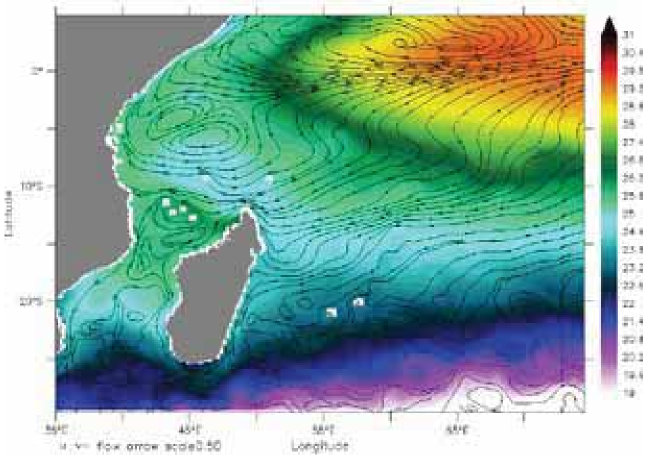

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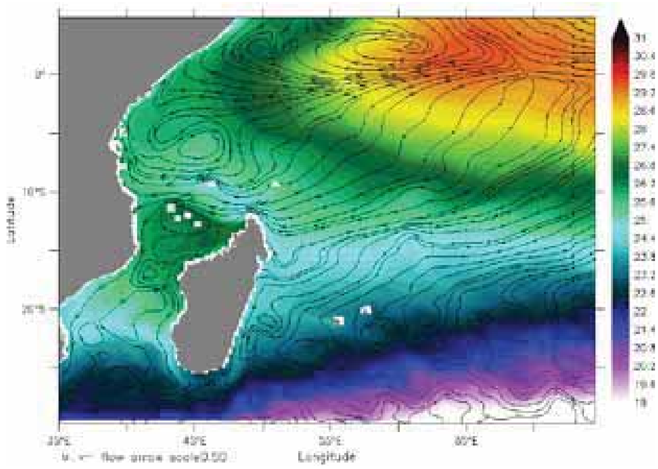

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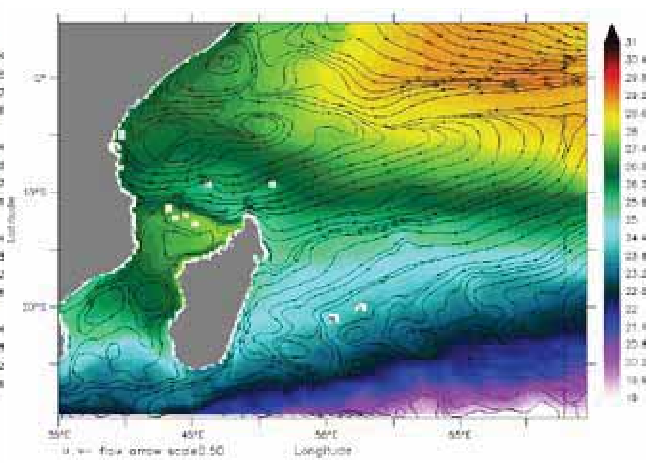

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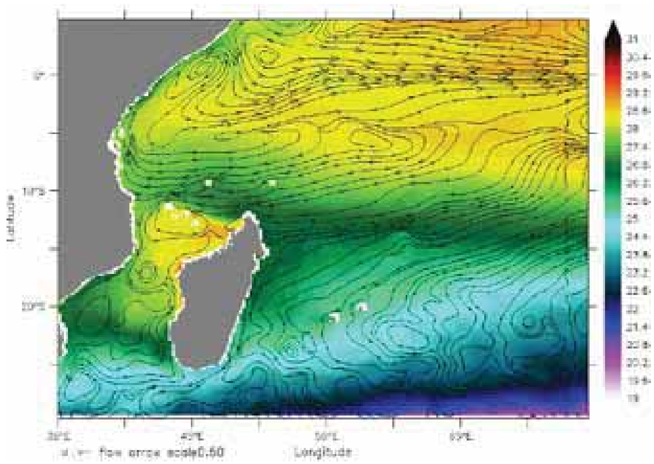

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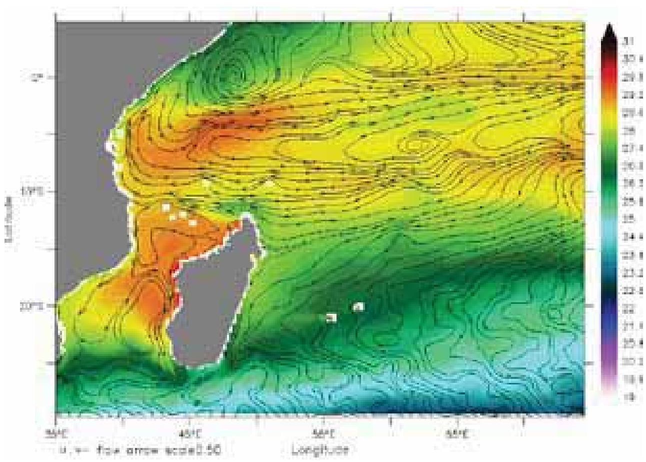

6.1 Temperatures at 500m

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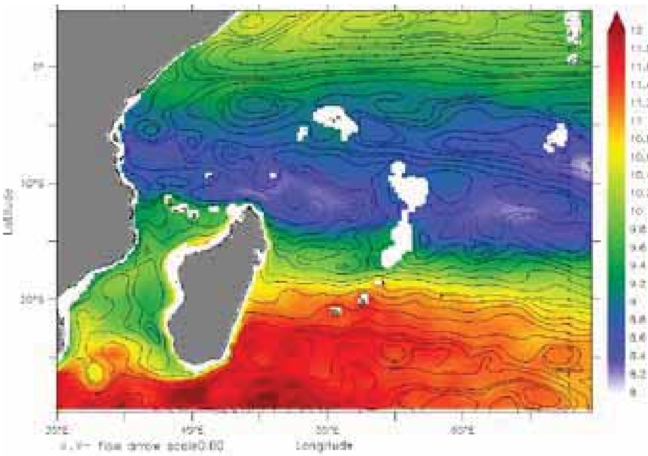

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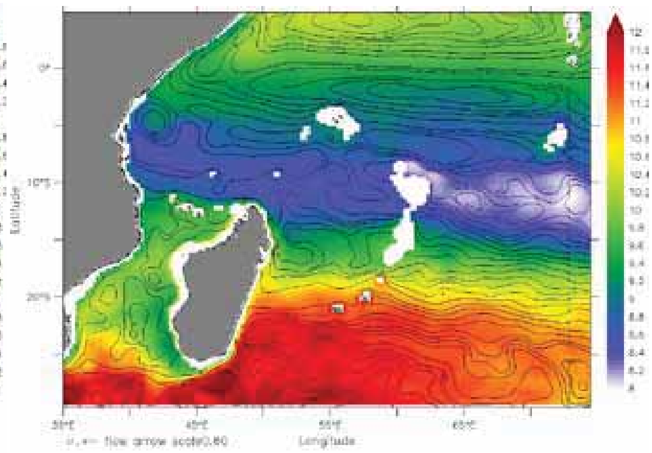

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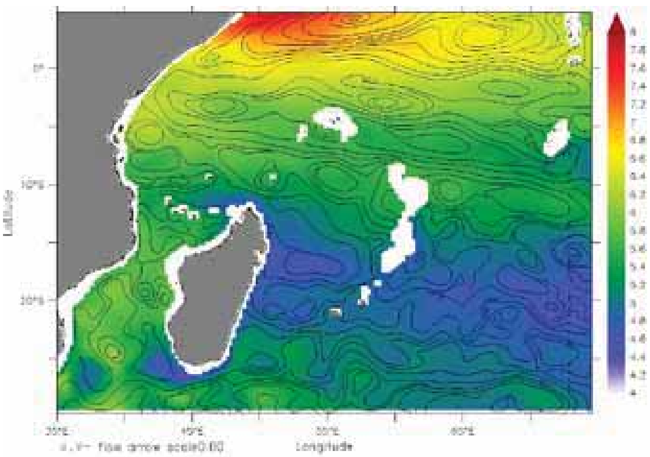

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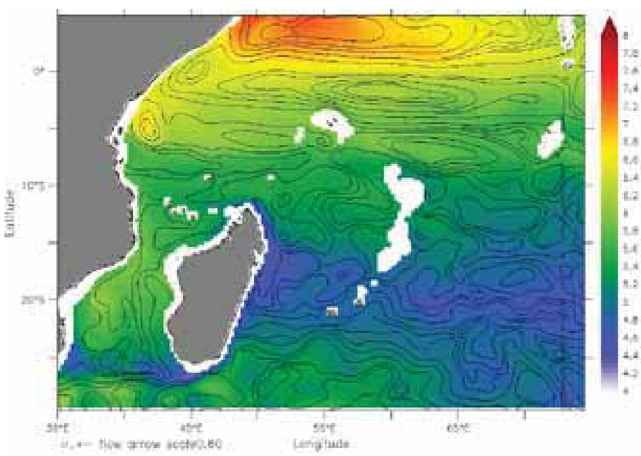

B Monthly distribution of salinity at the surface

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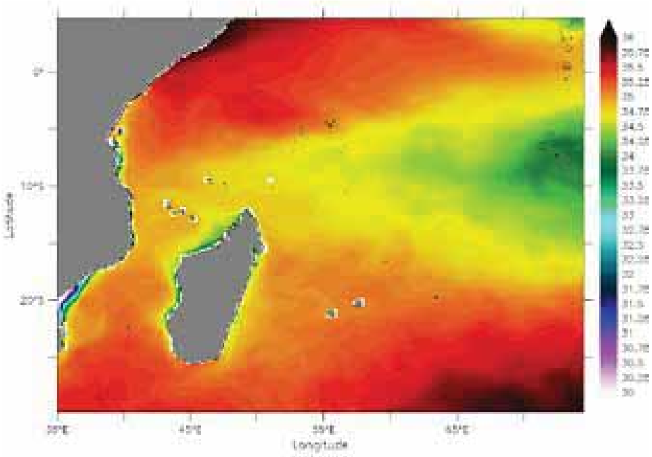

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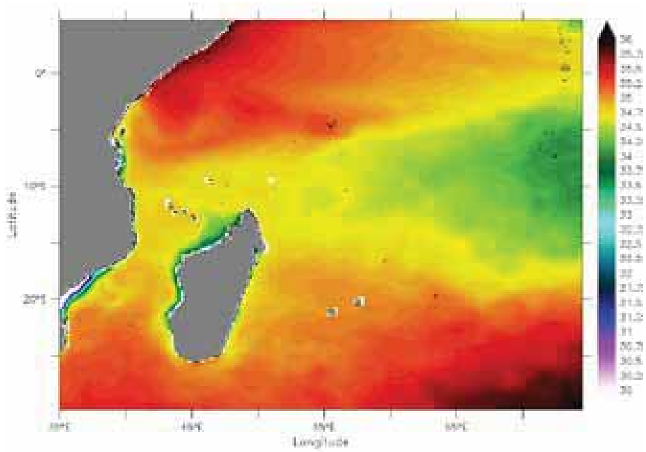

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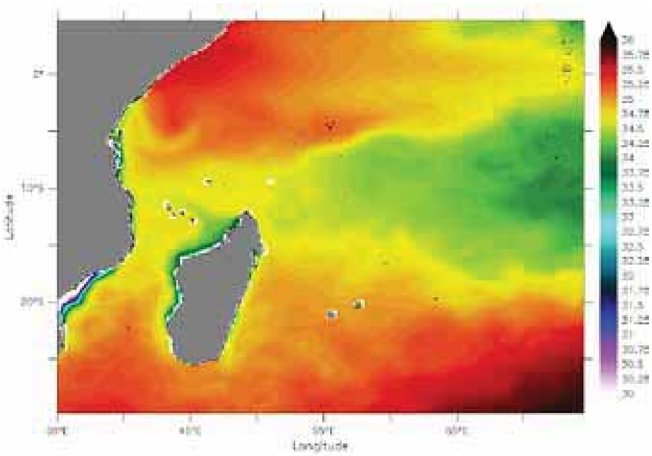

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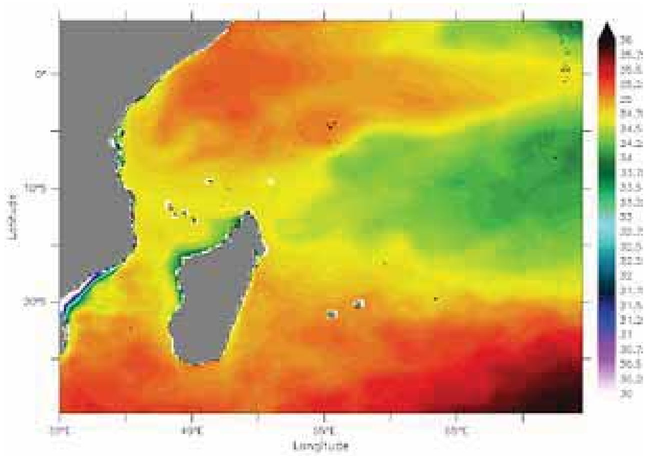

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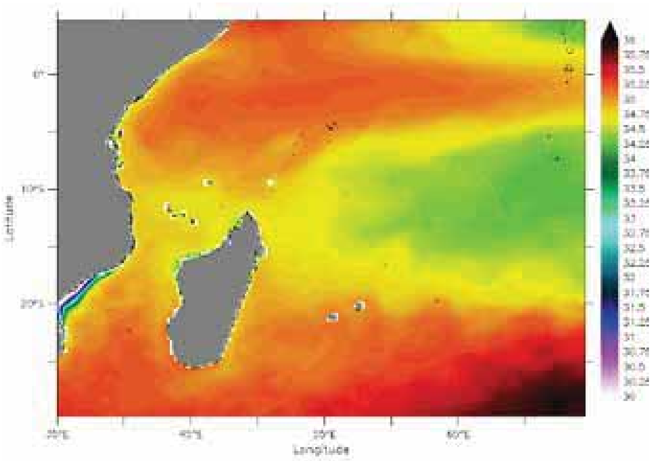

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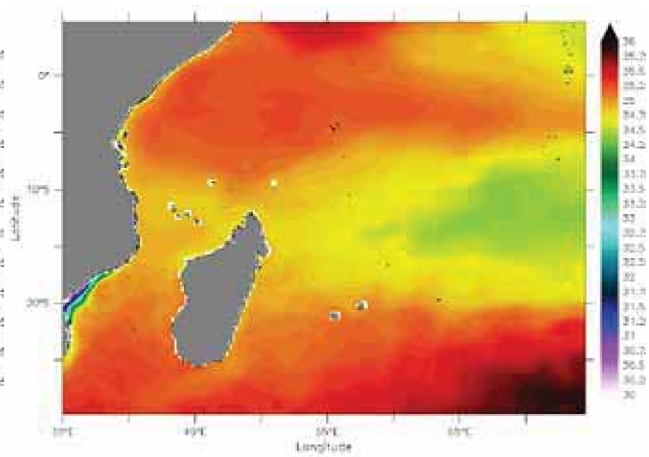

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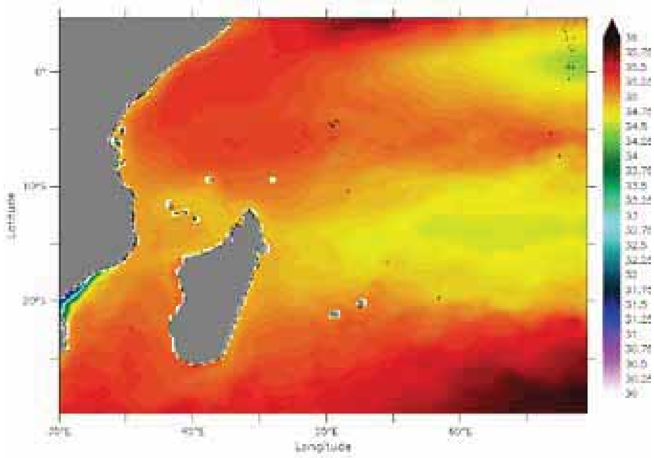

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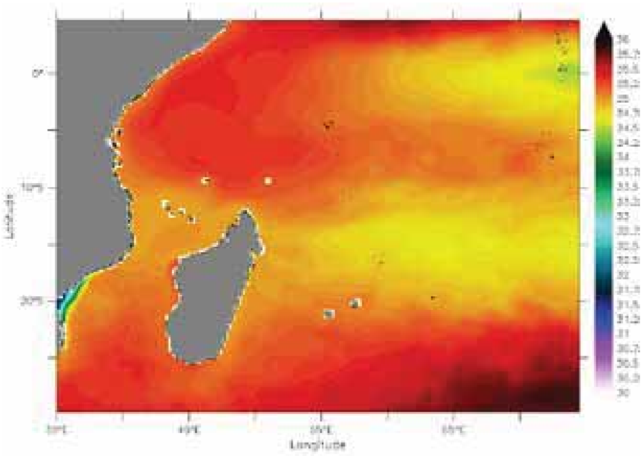

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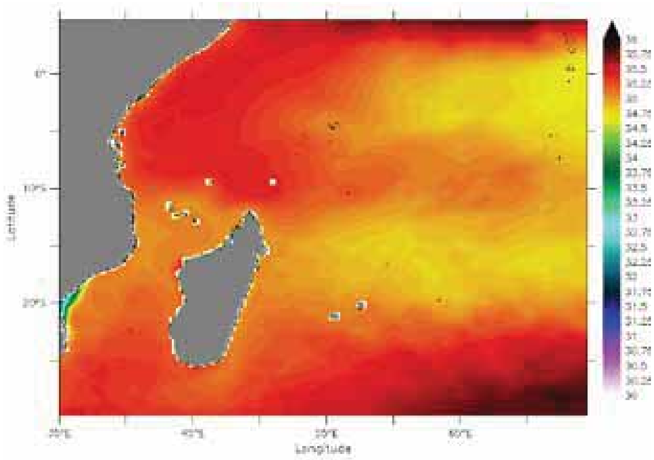

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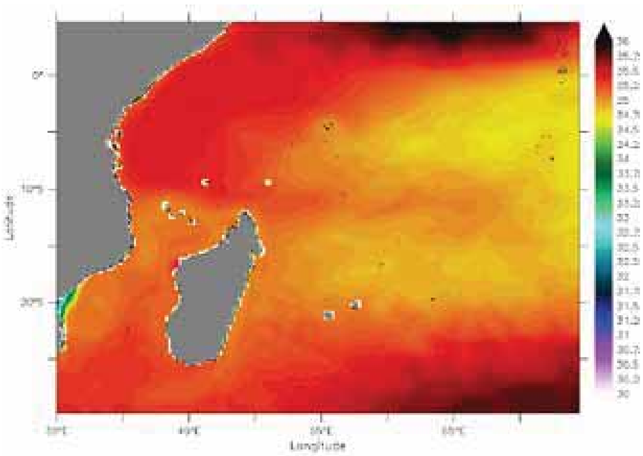

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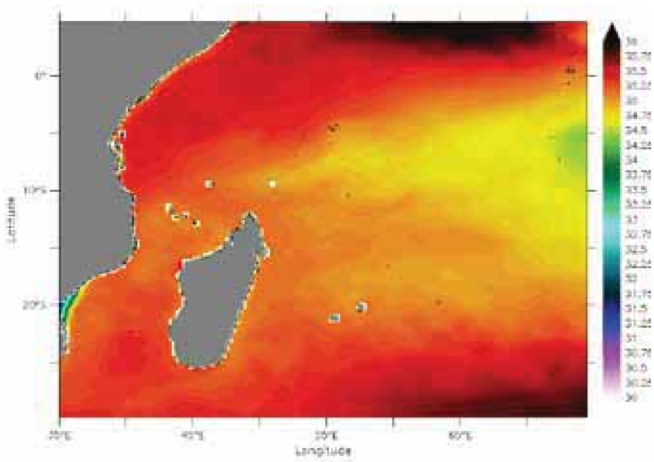

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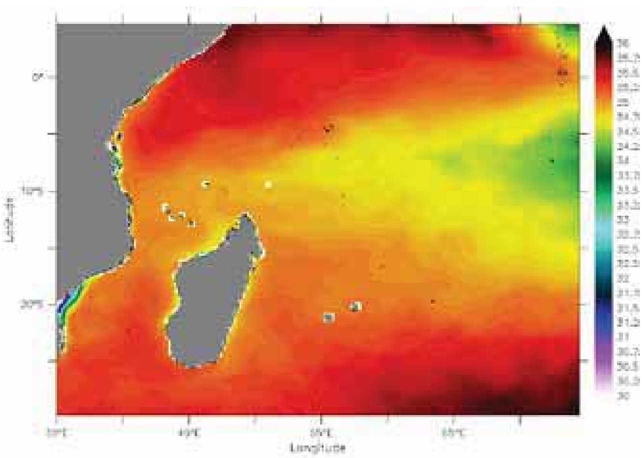

C Monthly Distribution of SSH with current patterns

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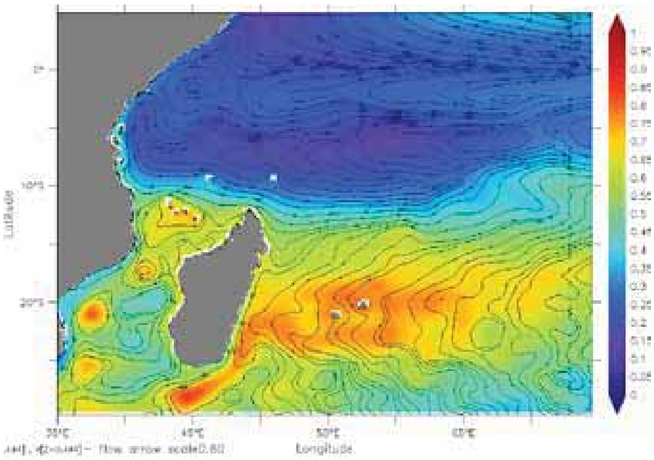

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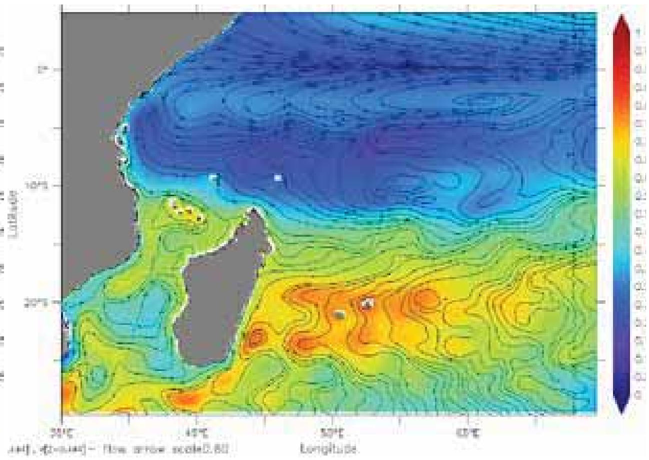

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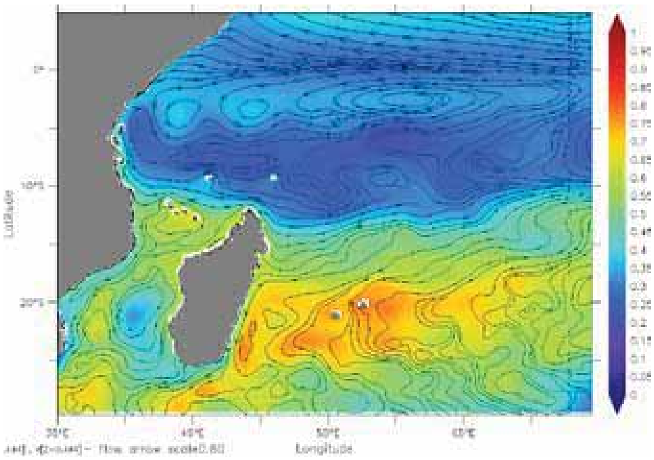

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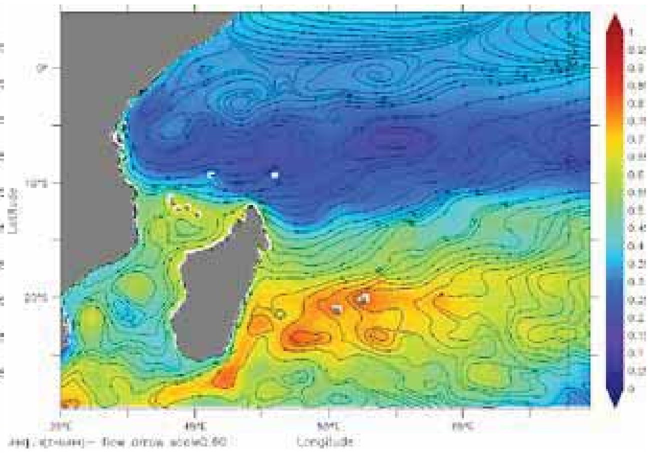

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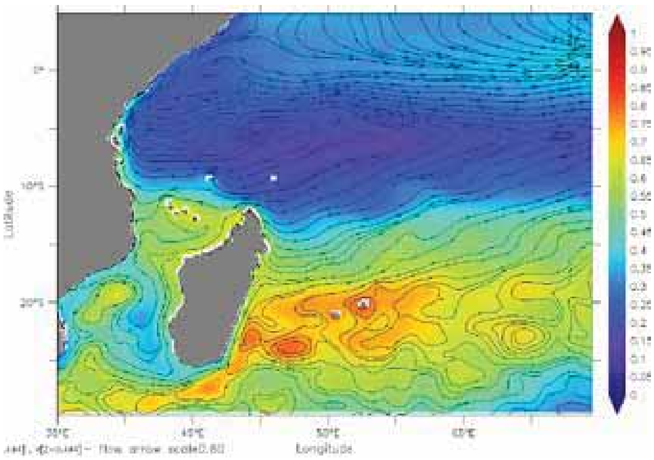

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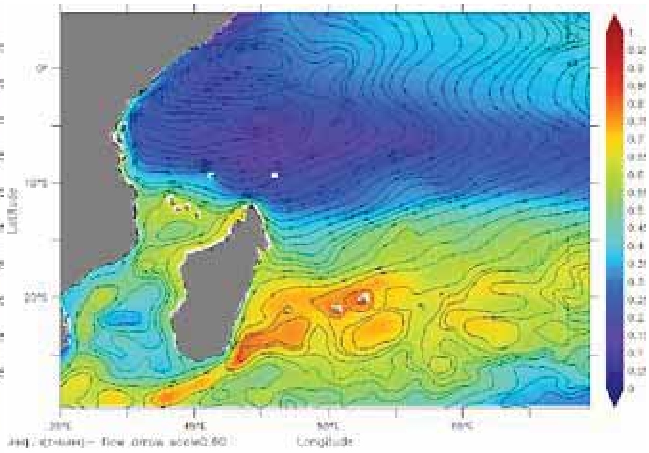

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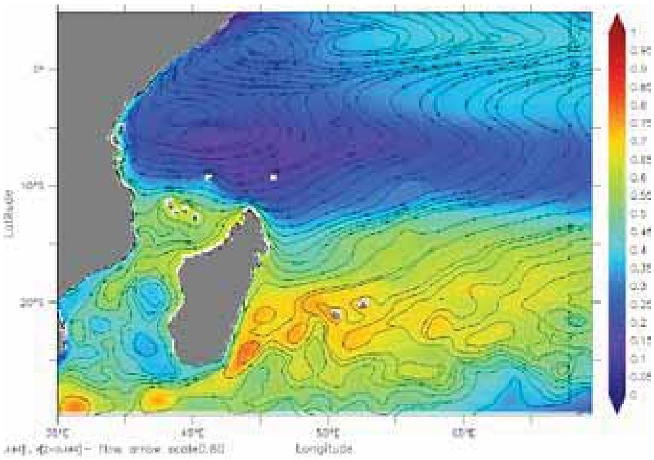

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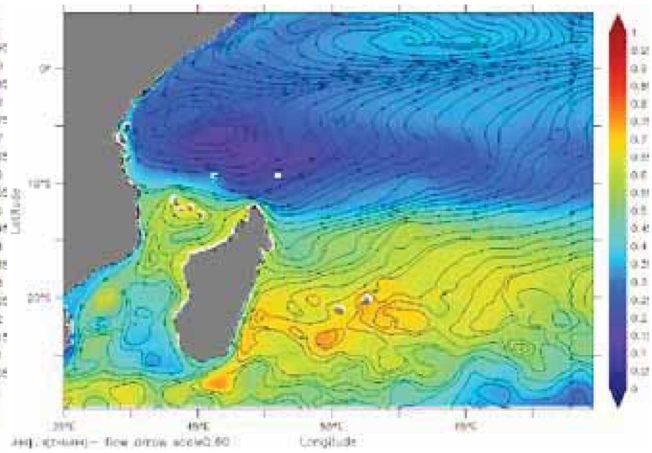

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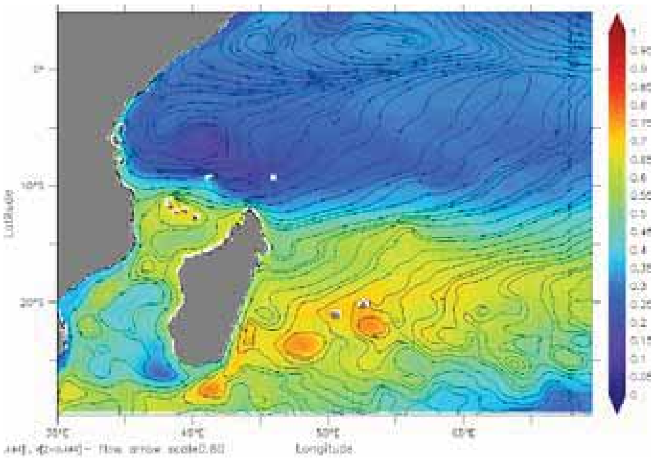

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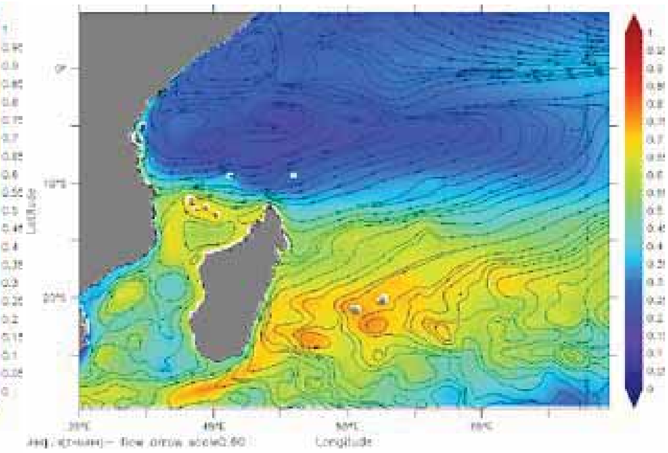

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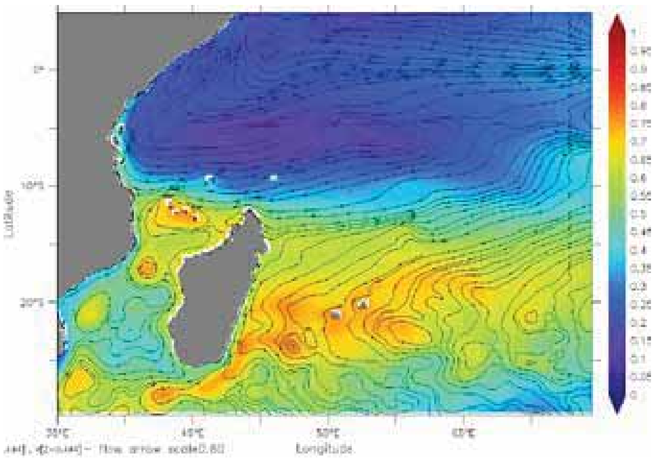

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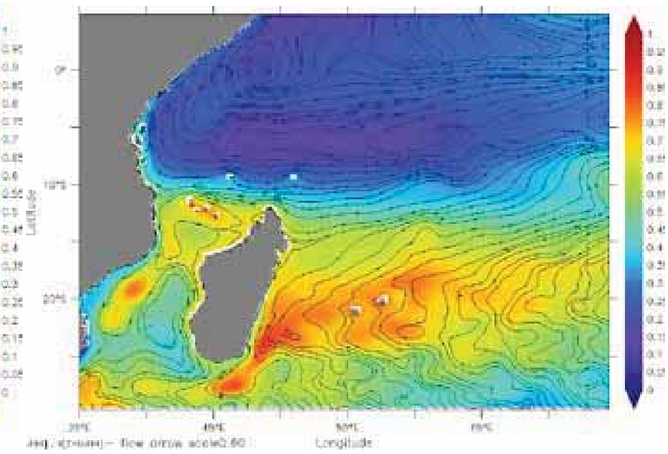

D Typical Surface Current Patterns and intensities

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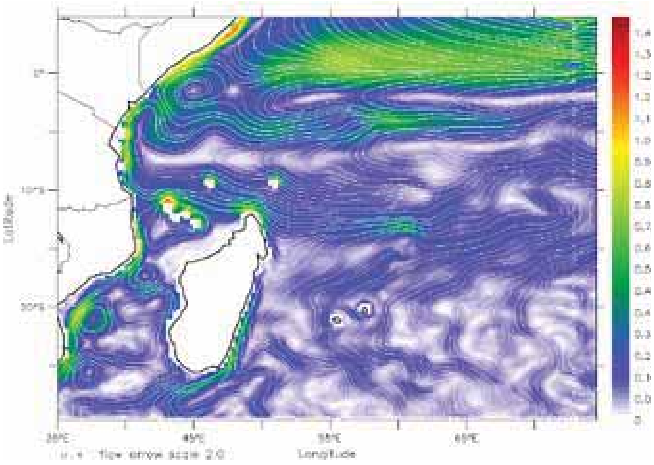

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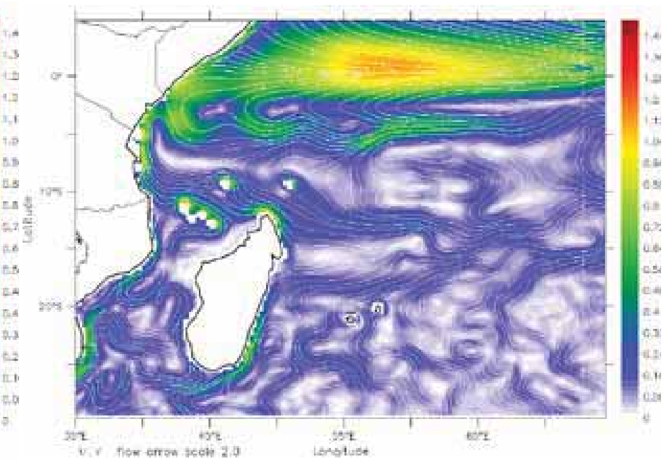

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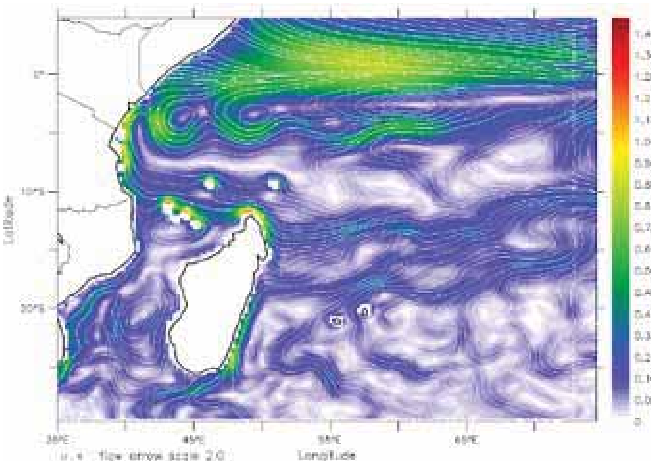

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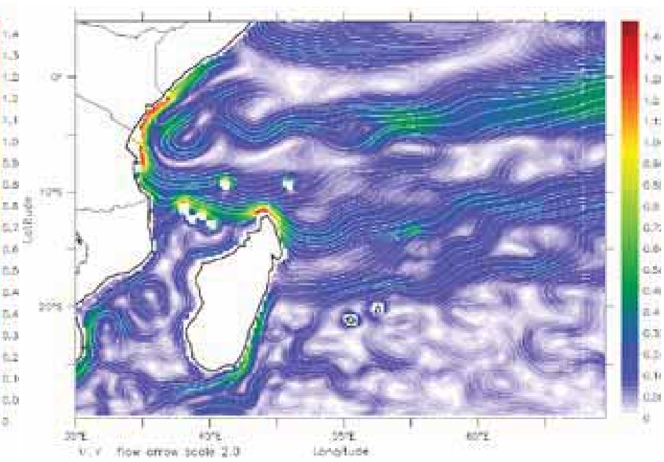

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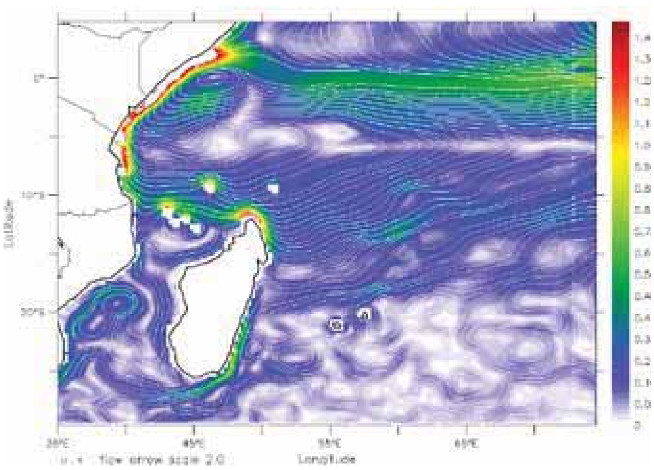

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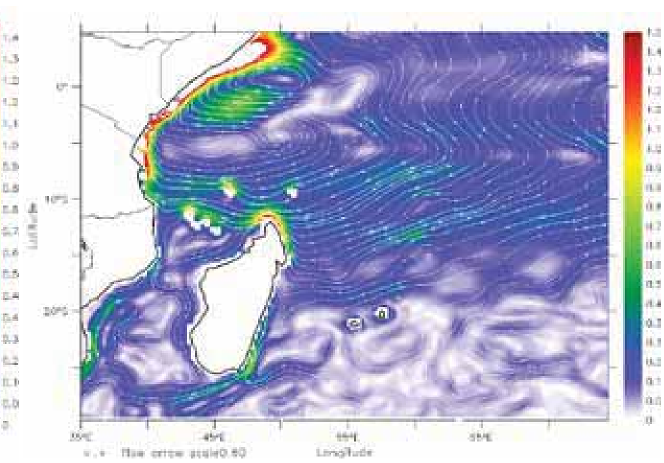

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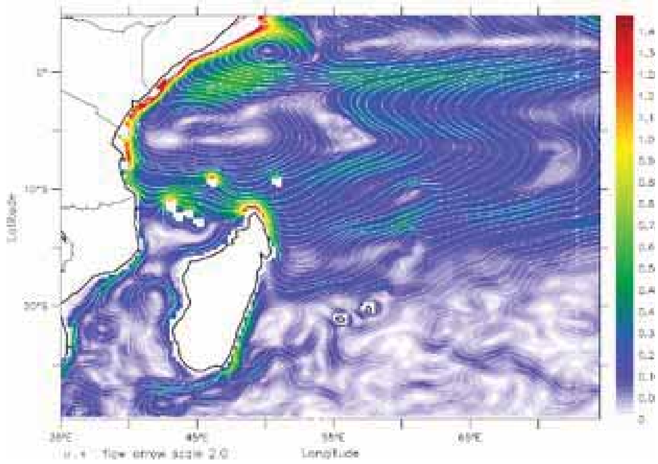

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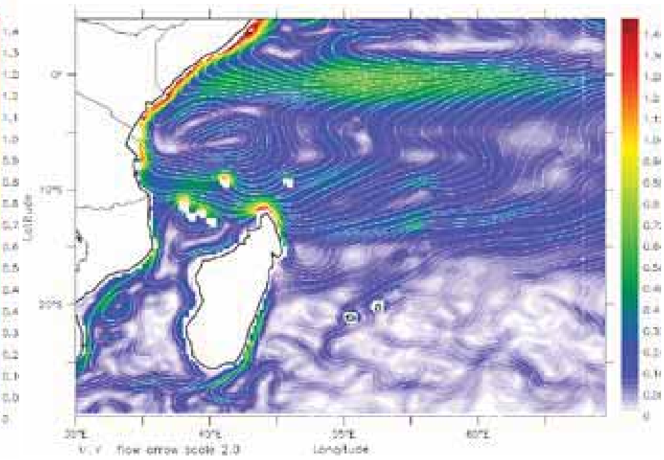

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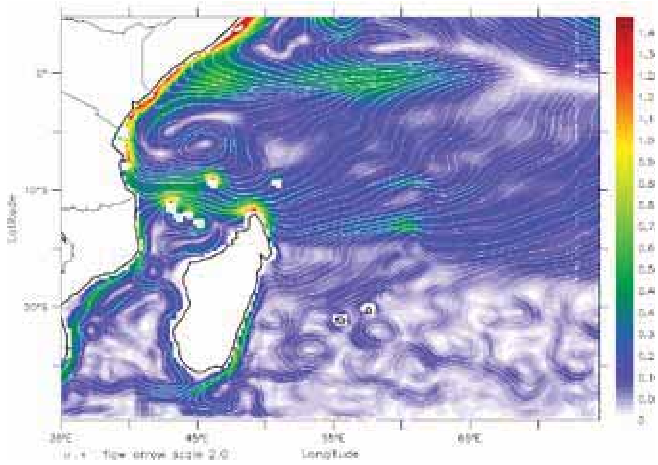

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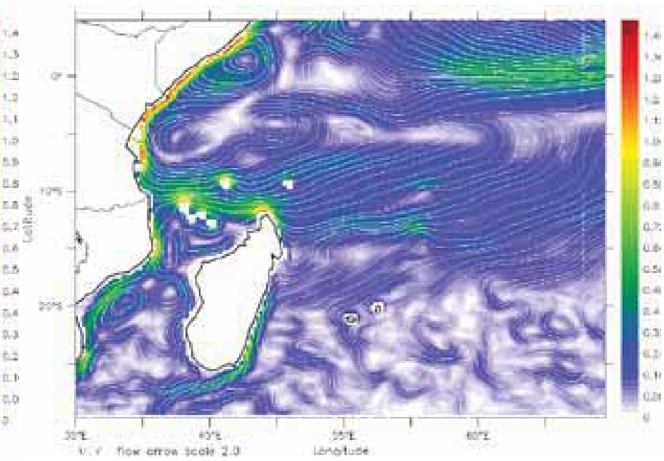

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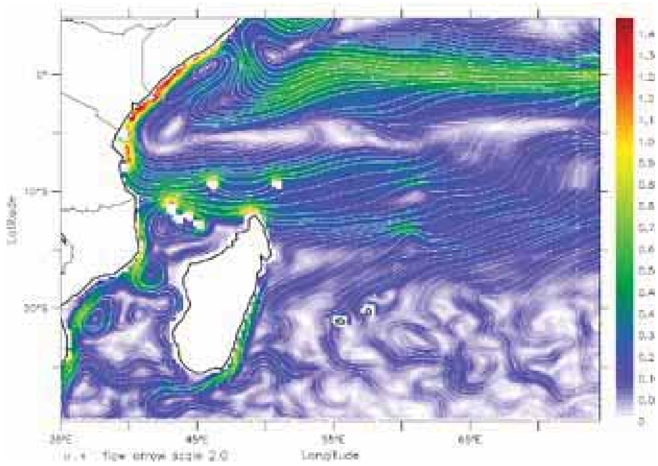

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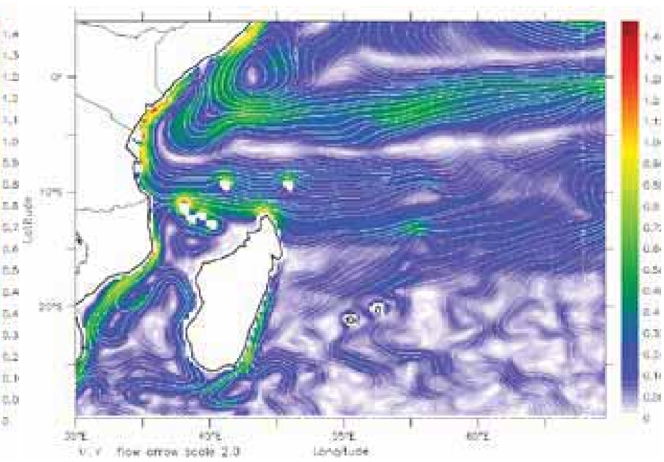

E Typical Thickness of the Temperature Mixed Layer

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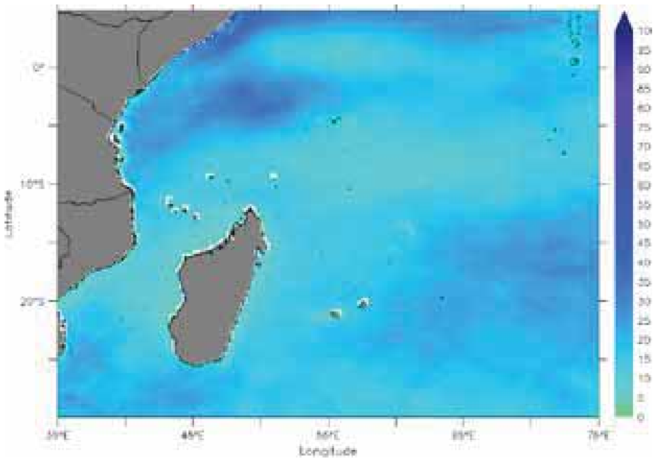

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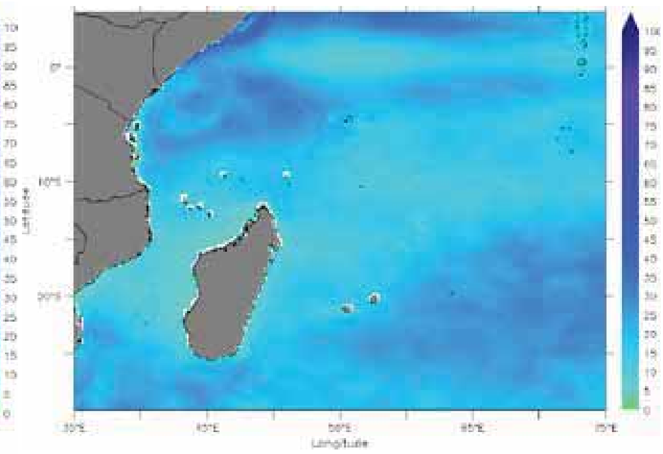

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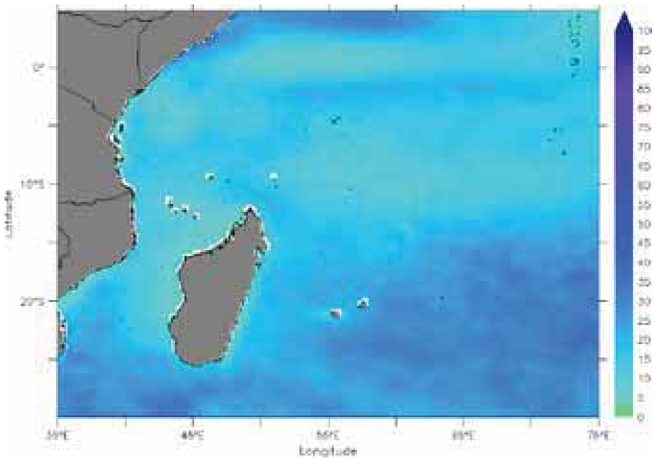

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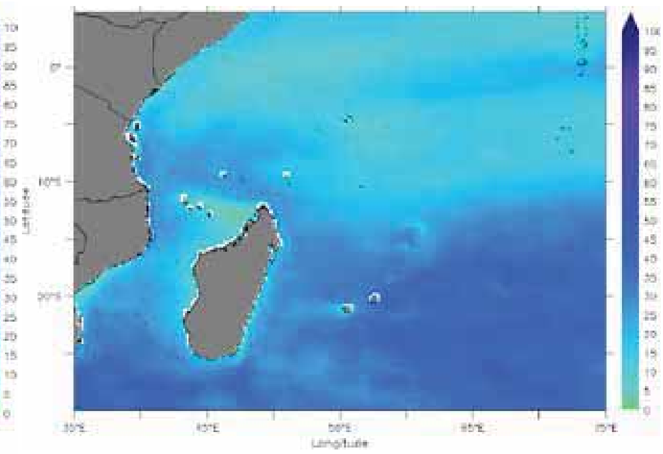

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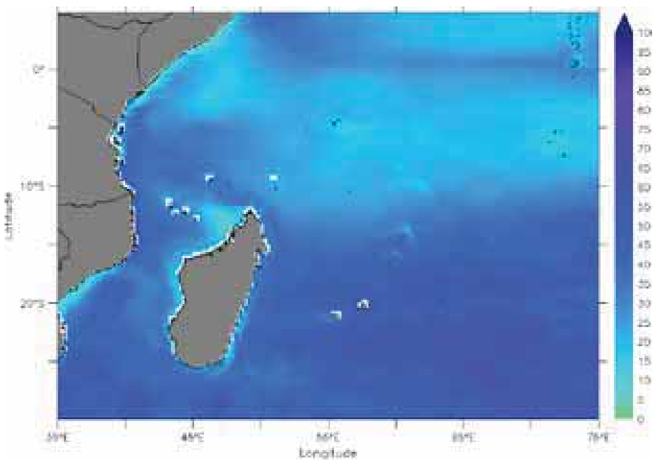

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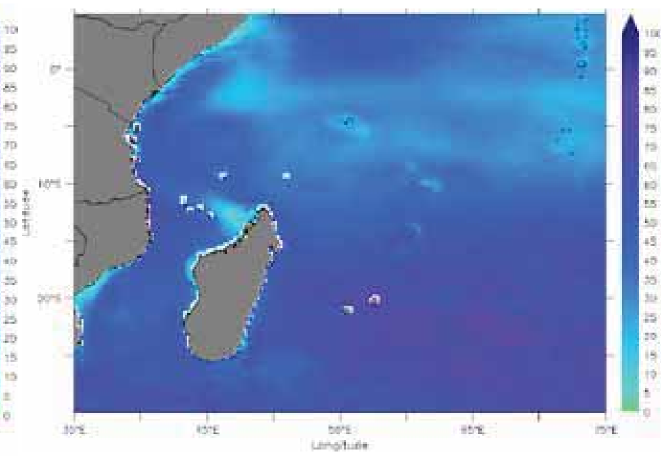

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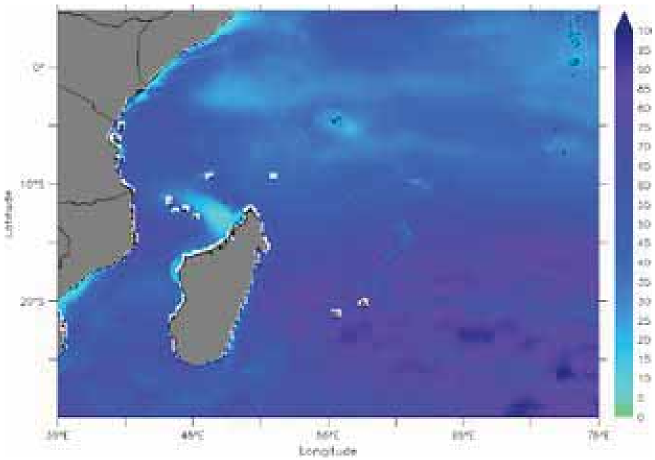

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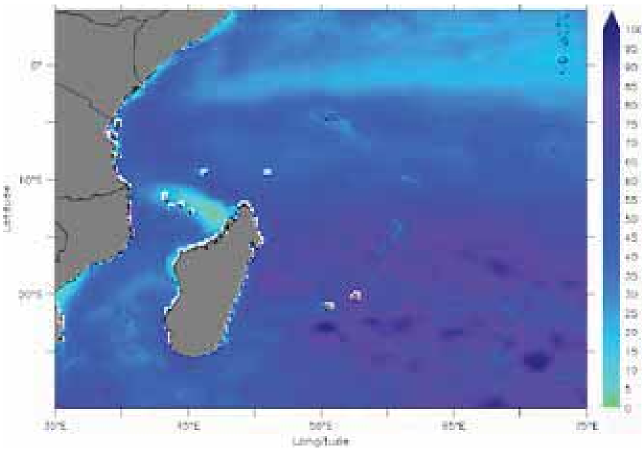

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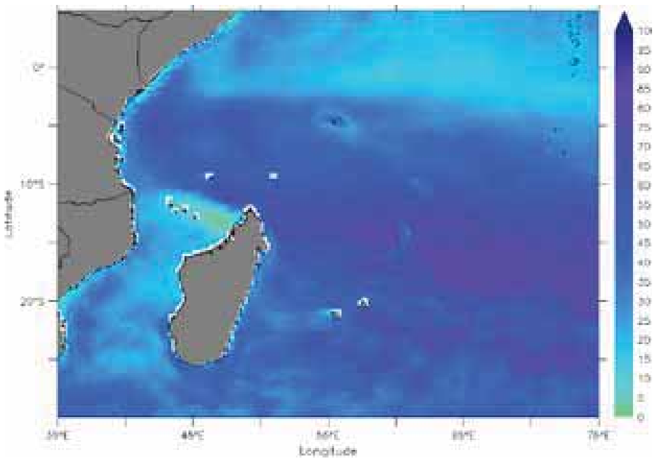

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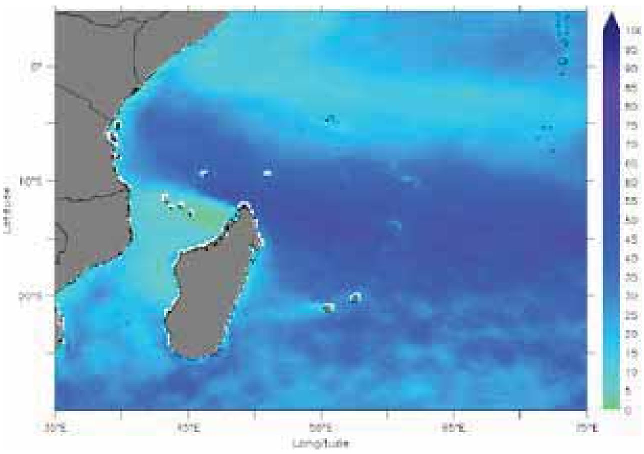

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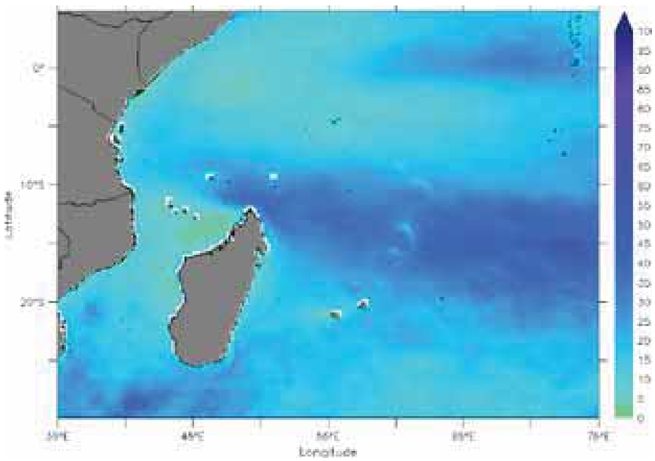

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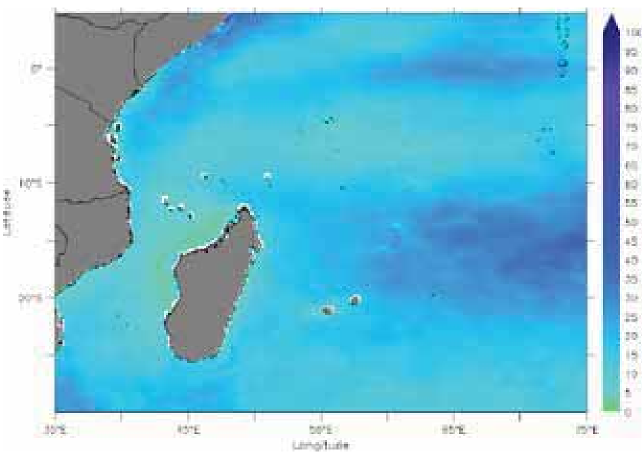

F Annex I Detailed Parameters

6.2.1 SSH, SSHm, SLA, MDT and ADT

Altimetric data basically gives the Sea Surface Height (SSH). By removing the temporal Mean SSH (SSHm), the Sea Level Anomalies (SLA), also called the Sea Surface Height Anomaly (SSHA). can be obtained.

$$SLA = SSH - SSHm \quad \text{(A1)}$$

The SSH is a good indicator of the large scale mean ocean circulation, and the SLA of the mesoscale features. SLA data can be used to track cold-core, warm-core eddies and meanders (Morrow et al., 2004). As models do not recreate perfectly the mesoscale activity, assimilating these SLA data generally improves the model simulation.

The Mean Dynamic Topography (MDT) is the Mean SSH adjusted with the Geoid

$$MDT = SSHm - Geoid \quad \text{(A2)}$$

The Absolute Dynamic Topography (ADT) is the sum of the SLA and MDT

$$ADT = SLA + MDT \quad \text{(A3)}$$

6.2.2 U and V

From altimetric data, another important quantity can be extracted: the Geostrophic current U, calculated from the gradient of SSH. We can also extract the anomaly of current velocity from the gradient of SLA. The geostrophic current is given by the following equation:

$$f.U=-g.dh/dy \quad \text{(A4)}$$

where f is the coriolis term, g the gravity, dh the SSH (or SLA) gradient, and dy the distance gradient. Along the altimeter tracks, the projection of the Geostrophic current orthogonal to the tracks can thus be obtained. At crossover points between two tracks, there are two projections and can thus the two components of the Geostrophic current can be determined (Morrow et al., 1994).

U and V can also be obtained through modeling using the 2D Shallow-Water equations or by resolving more general Navier-Stokes equations for 3D.

G Annex II The Mixed-Layer

The ocean mixed-layer is the layer between the ocean surface and a depth usually ranging between 25 and 200m, where the density is about the same as at the surface. The mixed-layer owes its existence to the mixing initiated by waves and turbulence caused by the wind stress on the sea surface. An effect of mixing is to make both properties of water, temperature and salinity, thus density, more uniform. The penetration of mixing to a certain depth (the mixed-layer depth) mostly depends on the stability of the sea water and on the incoming energy from the wind. The more stable is the surface water, the less mixing occurs, and the shallower is the mixed-layer. Sea water stability in the near-surface is determined by the atmospheric fluxes through the ocean surface (wind stress, heat and fresh water exchange). A typical unstable configuration is when water is denser (“heavier”) at the surface than below. The mixing that ensues, for example with some impulse from waves or turbulence, renders the density more uniform and deepens the mixed-layer. In certain conditions occurring only in a few areas of the high-latitude seas (e.g. Labrador Sea in North Atlantic, Weddell Sea in the Antarctic waters), instability is so strong that denser surface water literally sinks and mixes over large depths reaching more than 1000m.

The temperature criterion used in Levitus (1982) defines the mixed layer as the depth at which the temperature change from the surface temperature is 0.5 degree Celsius. The sigma-theta (density) criterion used in Levitus (1982) uses the depth at which a change from the surface sigma-theta of 0.125 has occurred. Neither criterion implies that active mixing is occurring to the mixed layer depth at all times but rather a measure of the depth to which mixing occurs over the course of a few weeks.

In many situations, the mixed-layer can be identified with the layer of mixed temperature, when the salinity does not vary much with increasing depth in general. However, this becomes untrue as soon as for instance fresh water is exchanged between the ocean and the air above (evaporation or rain), which may create large salinity contrast.

The mixed-layer is the oceanic surface zone that responds the most quickly and directly to atmospheric fluxes, and it is through the mixed-layer that such influence is transmitted to the whole ocean in the long term. Conversely, the mixed-layer is the part of the ocean through which the ocean influences directly the atmosphere. Many important processes occur within the mixed-layer, whether physical (e.g. direct wind-forcing of the ocean circulation), chemical (e.g. dissolution of incoming CO_2 from the atmosphere), or biological (e.g. phytoplankton production).

Abstract

The south west of the Indian Ocean is home to some interesting characteristics which despite not being well known are evolving in the context of a changing climate. Therefore proper monitoring needs for to be done in order to qualify and quantify these changes. However, the scarcity of a proper climatological database of relevant parameters in this particular region of the Indian Ocean delayed the setting up a proper monitoring system.

In this context, the AMESD project is piloting both the constitution of a climatological database and the setting up of an operational monitoring bulletin for specific parameters in the south-western Indian Ocean.

This atlas can be considered as a window on the database which is being compiled with the collaboration of Mercator Ocean and the use of its GLORYS reanalysis database.