UNIVERSITY OF TRIESTE

Ph.D PROGRAMME IN

”ENVIRONMENTAL AND INDUSTRIAL FLUID MECHANICS”

XXVII CYCLE

ACTIVITY REPORT
January 2012 -November 2014

MARCO REALE

CONTACT: REALE.MARCO82@GMAIL.COM
1. **Courses attended**

- **Courses of the Ph.D. Program (February 2012-July 2012)**
  
  - Fluid Mechanics (Prof. V. Armenio, University of Trieste)-final mark: 9/10
  
  - Advanced Mathematical Methods (Prof. P. Omari, dott. F. Obersnel, University of Trieste) -final mark: 7/10
  
  - Numerical Methods (Prof. A. Bellen, University of Trieste)-final mark: 10/10
  
  - Geophysical Fluid Dynamics (dott. S. Salon, OGS)-final mark: 10/10
  
  
  - Turbulence (Prof. V. Armenio, University of Trieste)

- **Additional courses attended (University of Trento; 18-22 June 2012)**

  - Geophysical fluid dynamics (prof. Dino Zardi, University of Trento)
  
  - Stratified flows (Prof. Stefano Lanzoni, University of Padova)
  
  - Mixing and stratification (Prof. Marco Toffolon, University of Trento)

- **First CLIM-RUN ”Summer school on climate services” (ICTP; Trieste - 15-19 October 2012)**

  - Climate change (F. Giorgi, ICTP)
  
  - Regional climate modeling (S. Somot, MeteoFrance)
  
  - Statistical downscaling (M. Frias, University of Cantabria)
  
  - Forest fire (C. Giannakopoulos, National observatory Athens)
  
  - Climate service (C. Goodess, University of East Anglia)
  
  - Stakeholder dynamics, methodologies for developing stakeholder interaction (D. Ghislain, University of Versailles)
  
  - Mediterranean impacts in coastal zone (S. Torresan, CMCC)
– Energy impact (R. Pasicko, Croatian Meteorological and Hydrological service)

• IMILAST (Intercomparison of Mid-Latitude Storm Diagnostics) Workshop-Organizer: Urs Neu, ProClim-Suisse-Weggis am See-Switzerland-15-17 May 2013

• ”Advanced School on Data Assimilation” (CMCC; Bologna-Italy, 24-28 June 2013)

– Introduction to data assimilation (Talagrand, École Normale Supérieure, France)
– Variational methods (Moore, UCD, USA)
– Ensemble methods (Sakov, NERSC, Norway)
– Reduced order methods (Brasseur, CNRS/LGGE, France)
– Non-Gaussian Data Assimilation and Model Learning (Lermusiaux, MIT, USA)
– Hybrid methods (Lorenc, Met Office, UK)
– Impact of Observations (De Mey, LEGOS, France)
– Monte Carlo methods (Vukicevic, HRD, AOML, NOAA, USA)
– Applications: Global ocean operational DA system (Dobricic, CMCC, Italy)
– Applications: Estimation of cloud microphysics model uncertainty (Vukicevic, NOAA, USA)
– Applications: Global reanalysis (Masina, CMCC, Italy)
– Presentation of operational oceanography products at the CMCC (Lecci, CMCC, Italy)
– Training Session

• ”2nd VALUE training school: Statistical and Dynamical Downscaling of Extreme Events” (ICTP, Trieste-Italy, 21-31 October 2013)

– Introduction: GCMs and end users needs (Coppola, Giorgi, Mariotti, ICTP, Italy)
– Regional Climate Models (RCMs) (Coppola, Giorgi, Mariotti, ICTP, Italy)
– Statistical downscaling: perfect prognosis (Gutiérrez, Santander Meteorology Group, CSIC-UC, Spain)
– Model Output Statistics (MOS) approaches (Maraun, GEOMAR, Germany)
– Validation methodology and Limitations (Maraun, GEOMAR, Germany)
– Theoretical foundation of extreme value distributions (Maraun, GEOMAR, Germany)
– Introduction to (weather and climate) extremes (Pfahl, ETH Zurich, Switzerland, Widmann, University of Birmingham)
– Statistical downscaling methods for extremes (Hertig, Augsburg University, Germany, Widmann, University of Birmingham)
– Downscaling extremes with RCMs (Soares, University of Lisbon, Portugal)
– Training sessions: hands-on-session with R / the statistical downscaling portal

• 2nd CLIM-RUN School: ”Building Two-way Communication: A Week of Climate Services”, Organizer(s): Erika Coppola, ICTP, Trieste, Paolo Ruti, ENEA, Italy - Trieste - Italy, 2-6 December 2013

– Presentation of CLIM-RUN Project (E. Coppola, ICTP)
– Climate information between planning and emergency: What are the needs for a municipality (A. Caparelli, City of Venice)
– How to build a plan for climate change action (A. Caparelli, City of Venice)
– Use of malaria seasonal forecast in health decision support system in Africa (A. Tompkins, ICTP)
– Developing climate services for the energy sector (M. Davis, Catalan Institute of Climate Sciences IC3)
– Visualization and communication of climate forecast information (M. Davis, Catalan Institute of Climate Sciences IC3)
– From seasonal to decadal up to climate change predictability (F. Kucharski, ICTP)

– Dynamical and statistical downscaling models (C. Cacciamani, ARPA - Meteorological Service of Agricultural Development Agency - Emilia Romagna)

– Study cases developed by ARPA Simc for climate services (G. Villani, ARPA - Agricultural Development Agency - Emilia Romagna)


– Developing climate risk and adaptation services for coastal zone managers: the CLIM-RUN bottom-up approach (S. Torresan, CMCC - Euro Mediterranean Centre for Climate Change)

– Sea level rise risk assessment and mapping at the regional scale: the case study of the North Adriatic coast (V. Gallina, CMCC - Euro Mediterranean Centre for Climate Change)

– Application of the DEcision support SYstem for COastal climate change impact assessment (DESYCO) for the development of climate risk products in the coastal zone of the North Adriatic sea (S. Torresan, V. Gallina, E. Furlan, A. Sperotto, CMCC-Venice, University of Venice Ca’ Foscari)


• ”7th Workshop on Theory and Use of Regional Climate Modeling (RegCM)" Trieste 12-23 May 2014 - ICTP - Organizers: F. Giorgi (ICTP, Italy)- E. Coppola (ICTP, Italy)- X. Gao (CMA, China)- S. K. Dash (IIT Delhi, India)

– Update on RegCM4 developments and CORDEX (F. Giorgi, ICTP)

– The ICTP-CORDEX simulations. Overview of the CREMA ensemble result (Coppola, ICTP)

– An accurate and efficient numerical framework for the new RegCM dynamical core (Tumolo, ICTP)
– Identifying the sensitivity of precipitation of Anatolian Peninsula to Mediterranean Sea Surface Temperature using coupled regional climate model (Turuncoglu Istanbul Technical University, Turkey)

– The New Microphysics Cloud Scheme Implemented in RegCM4 (Nogherotto, ICTP)

– Climate Chemistry Simulation using RegCM4.5 (Shelaby, ICTP)

– The Med-Cordex perspective for regional earth system modeling (Ruti, ENEA)

– The MITgcm, a versatile ocean regional model: the Mediterranean Sea case (G.Sannino, ENEA)

– Testing RegCM 4.4 over Europe and a possible application of the Factor Separation method (Torma, ICTP)

– Planetary boundary layer schemes in RegCM: evaluation and impact on the climate change signal over Europe and Mediterranean region (I. Guettler, DHMZ)


– Estimates of Ambrosia artemisiifolia L. pollen emission and dispersion in Europe using RegCM (L. Liu, ICTP)

– Performances of RegCM4.4 over CORDEX-EA (phase 2) Region (X. Gao, CMA)

– CORDEX-East Asia (H.-S. Kang, KMA)

– The Southeast Asia Regional Climate Downscaling (SEACLID) / CORDEX Southeast Asia Project and Highlights of Sensitivity Experiments of RegCM4 for Different Physical Parameterizations (Tangang, IKLIM)

– CORDEX South Asia: Overview and performance of regional climate models (J. Sanjay, IITM)

– Evidence for Weakening of Indian summer monsoon and SA CORDEX results from RegCM (S.K. Dash, IIT Delhi)

– Interactions between Arabian dust emission and the Indian monsoon (F. Solmon, ICTP)

– Metrics for CORDEX: RegCM in context (W. Gutowski, Iowa State Un.)

– Dealing with a Regional Climate Model Ensemble 2 (M. Bukovsky, NCAR)

– Downscaling a perspective from Australia (B. Timbal, BOM)
- Publishing and Accessing CORDEX data via the Earth System Grid Federation - ESGF (G. Nikulin, SMHI)

- Projected climate change over West Africa: Intra-seasonal variability, Higher intensity precipitation events and Drought frequency and variability (B. Sylla, WASCAL)

- CORDEX South America: Overview of on going activities and evaluation of regional climate change scenarios for South America (S. Solman, CIMA)

- Interannual variability associated with ENSO: present and future climate projections of RegCM4 for South America-CORDEX domain (R. Porfirio da Rocha, USP)

- CORDEX activities in Mexico, Central America, and the Caribbean (T. Cavazos, CICESE)

- Seasonal and intraseasonal changes of African monsoon climates in 21st century CORDEX projections (L. Mariotti, ICTP)

- Projections of extreme rainfall events in RegCM4 CORDEX simulations for west Africa (I. Diallo, ICTP)

- Tropical cyclones in a regional climate change projection with RegCM4 over the CORDEX Central America (G. Tefera Diro, UQAM)

- Interannual variability of precipitation over the Central America CORDEX domain from a set of future projections from CMIP5 GCMs and RegCM4 simulations (R. Fuentes Franco, ICTP)

- Climate change impact on precipitation for the Amazon and La Plata basins (M. Llopart, USP)

- RegCM4.4rc Internal Variability What to expect (G. Giuliani, ICTP)

- Scale dependent impact of Climate Change in the Alpine Region: hydrological budget comparison between low, medium, high and very high resolution Regional Climate Model simulations (F. Raffaele, ICTP)

- Urban environment impact on climate (T. Halenka, Charles University)

- Modeling of Climate Indices for the Temperature Regimen in the Territory of Georgia by using RegCM4 (M. Elizbarashvili, Ivane Javakhishvili Tbilisi State University)

- Cloud-Aerosol Interaction in RegCM4: Indirect effects of aerosols over Africa (A. Zakey, Egyptian Meteorological Authority)

- Space- and Ground-Based Investigation of Atmospheric Aerosols and their Impact on Climate Over Egypt (A PEER NSF USAID NAS Project)
– Simulating the Characteristics of extreme rainfall events over Southern Africa using Regional Climate Models (B. J. Abiodun, University of Cape Town)

– A study of regional air pollution in spring using WRF/CMAQ model over Pearl River Delta, China (Q. Fan, Department of Atmospheric Science, Sun yat-sen University)

– Model validation of the Regional Climate Model (RegCM4.3) over the Loess Plateau, China (L. Wang, Macquarie University)

– Use of Regional Climate Model (RegCM3/4) in Mongolia (Gomboluudev Purevjav, Institute of Meteorology, Hydrology and Environment)

– Simulation of Indonesian Maritime Continent Rainfall using Regional Climate Model (Kadarsah, Indonesian Agency for Meteorological Climatological and Geophysical Agency (BMKG))

– Application of the ICTP Regional Climate Model 4.3 (RegCM4.3) to grain production in Nigeria (M. Adeniyi, University of Ibadan)

– Evaluation of dry/wet spells of the North American Monsoon with CORDEX (R. Cerezo Mota, Universidad Veracruzana)

– Assessment of RegCM4.3 over the CORDEX South America Domain: Sensitivity Analysis to Physical Parameterization Schemes (M. Reboita, Natural Resources Institute, Federal University of Itajubá)

– Surrogate Climate-Change Scenarios with a Regional Climate Model over South America (P. Reyes Fernandez, Center for Weather Forecasting and Climate Studies - CPTEC/INPE)

– Performance of RegCM4.3 over the India Region (S. Mishra IIT)

– Response of Atmospheric Circulations to Direct Radiative Forcing of Aerosols over Indian Subcontinent (S. Das, IIT, Delhi)

– Future Climatic and Hydrological changes over Upper Indus basin of Himalayan region Pakistan (A. Shaukat, Chin. Academy of Sciences)
• ”DPG Summer School on Physics of Ocean”, Organizers: Prof. Dr. Martin Visbeck (GEOMAR and Kiel University)-Prof. Dr. Wolfgang Roether (Bremen University)- 7-12 September, 2014, Physikzentrum Bad Honnef, Germany

- Introduction to Large-Scale Wind-Driven Circulation, Prof. David Marshall (Oxford University)
- Introduction to Large-Scale Density-Driven circulation, Prof. Dr. Wolfgang Roether (Bremen University)
- Introduction to Coastal Dynamics, Prof. Dr. Hans Burchard (IOW Warnemünde)
- Polar Oceanography, Prof. Dr. Ursula Schauer (AWI Bremerhaven)
- Tropical Oceanography, Prof. Dr. Peter Brandt (GEOMAR Kiel)
- Operational Oceanography, Dr. Bernd Brügge (BSH Hamburg)
- Biogeochemical Time Series, Dr. Joanna Waniek (IOW Warnemünde)
- Southern Ocean Circulation, Prof. Dr. Sabrina Speich (Brest University)
- Global Ocean Observing Systems, Prof. Dr. Martin Visbeck (GEOMAR Kiel)
- Ocean and Climate Dr. Magdalena Balmadesa (ECMWF Reading)
- Global and Regional Ocean Modelling, Prof. Dr. Arne Biastoch (GEOMAR Kiel)
- Internal gravity waves and ocean mixing, Prof. Dr. Dirk Olbers (AWI Bremerhaven)
- Mesoscale Ocean Dynamics, Prof. Dr. Carsten Eden (Hamburg University)
- Mixing and the tropical oceans, Dr. Marcus Dengler (GEOMAR Kiel)
- CO₂ in the Ocean, Prof. Dr. Reiner Schlitzer (AWI Bremerhaven)
- Ocean Biogeochemistry, Prof. Dr. Dieter Wolf-Gladrow (AWI Bremerhaven)
• "2nd TOSCA training school on Solar variability and climate response", Organizer(s): Thierry Dudok de Wit (University of Orleans, France), Ilaria Ermolli (INA F, Italy), Fred Kucharski (ICTP, Italy), Jean Lilensten (CNRS, Grenoble, France), Kleareti Tourpali (Aristotle Univ., Thessaloniki, Greece), Yoav Yair (School of Sustainability - Interdisciplinary Center Herzliya, Israel)- ICTP (Trieste, Italy), 13-17 October 2014

- Role of the sun in climate change: basic facts, societal impact (C. Muller, Belgian User Support and Operations Centre, Brussels, Belgium)

- Evidences of solar influence on climate: observations, models (D. Mitchell, Environmental Change Institute, University of Oxford, UK)

- Solar and space forcing (M. Haberreiter World Radiation Center Pmod, Davos, Switzerland)

- Impact of solar irradiance variability and signal propagation (K. Tourpali, Aristotelean University of Thessaloniki, Greece)

- Impact of particles on atmosphere (physical effects / ionization) (I. Usoskin, University of Oulu, Finland)

- The complex relationship between Galactic Cosmic Rays, the Global Electrical Circuit and Cloud Microphysics (E. Tanskanen, Finnish Meteorological Institute, Helsinki, Finland)

• Seminars attended within the Ph.d Programme

- Modeling and Simulation of Pulsatile Flow in Cerebral Aneurysms (Julia Mikhal, University of Twente, NL, 3 April 2012)

- Computational modeling of complex flows (Prof. Bernard J. Geurts, University of Twente, NL, 5 April 2012)

- Inhomogeneous incompressible fluids with bounded density and non-Lipschitz velocity (prof. Marius Paicu, Université de Bordeaux 1, France, 24 April 2012)

- Wave Equations with nonregular Coefficients (Prof. Ferruccio Colombini, Università di Pisa, 29 May 2012)

- On nonhomogeneous incompressible fluids with discontinuous density (Prof. Raphal Danchin, Université Paris-Est Marne-la-Vallée, 29 May 2012)
– Ercoftac (European research community on Flow, Turbulence and combustion) autumn festival (ICTP, Trieste, 25 October 2012)
– Large-eddy simulation of particle-laden flow-recovering small scales (Prof. Bernard J. Geurts, University of Twente, NL, 17 April 2013)
– Predictability and prediction of Monsoon in the present and future climate (Prof. Yagadish Shukla, George Mason University, 18 June 2013)
– The science of ocean predictions and its application to the Mediterranean Sea (Prof. Nadia Pinardi, Universitá di Bologna, 15 January 2014)

• Seminars delivered

– Trends in mean air temperature over northern Italy as inferred from ensembles simulations (together with I. Balog; First CLIM-RUN Summer school on climate services -ICTP; Trieste - 15-19 October 2012)
– Towards a modeling approach for the mechanics of BiOS (Adriatic-Ionian Bimodal Oscillating System) (OGS, Borgo Grotta Gigante, 15 January 2013)
– A process study of baroclinic dynamics of Adriatic-Ionian System (ICTP, Trieste, 10 January 2014)

• Seminars attended at OGS-ICTP

– A study of the Tiber River dynamics and coastal primary production with satellite data, circulation and primary production models (dott. C. Pizzi, ISAC-CNR, 9 July 2013)
– Nonlinear Dynamics Of The Black Sea Ecosystem and Its Response To Anthropogenic and Climate Variations (Ekin Akoglu, ICTP-OGS, 1 October 2013)
– NODC - Better science through better data management (Elena Partescano, Alberto Brosich, Marina Lipizer, OGS, 25 February 2014)
– Submesoscale dynamics, coherent turbulence, and scalable lateral mixing in the ocean (G. Badin, University of Hamburg, 19 March 2014)
– Technical aspects of the Biogeochemical Flux Model (BFM) (E.Gutierrez, CMCC, 7 May 2014)

– Pacific Climate Variability: Dynamical Processes Affecting the Ocean-Atmosphere System Along the U.S. West Coast (A.Miller, SIO, 4 June 2014)

– Modelling BIOS? Why not! (R.Mosetti, OGS, 6 June 2014)

– Air-sea Interaction in the South Atlantic Convergence Zone (Marcelo Barreiro, Udelar, 1 October 2014)

• Teaching activity

  – ”Waves in the Ocean and Atmosphere”-Lecture given in the framework of Geophysical Fluid Dynamics lectures (teacher: dr Stefano Salon, OGS), addressed to students of the ph.d programme in Earth Sciences and Fluid Mechanics—University of Trieste-July, 2th 2014

• Research Interests

  – Modeling of variability of ocean circulation in the Ionian in response to external forcings and internal mechanisms
  
  – Links between Cyclones and Extreme events in the Mediterranean region
  
  – Climate changes assessment and impacts in the Mediterranean Region

• Others activities

  – Article reviewer for ”International Journal of Climatology”

  – Certificate for ”Corso formazione lavoratori sulla salute e sicurezza nei luoghi di lavoro per studenti universitari, percorso rischio basso, settore ”istruzione” -Università degli Studi di Trieste (art. 37 del D.Lgs. 81/2008) obtained on 9 March 2014

  – Member of ”IMILAST (Intercomparison of mid-latitude storm diagnostics)” International Project-Coordinator: dr. Urs Neu-Proclim Suisse-Research Line: Mediterranean Cyclones

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1 in the framework of Circ project EU project-http://www.circeproject.eu
2 http://onlinelibrary.wiley.com/journal/10.1002/(ISSN)1097-0088
3 http://www.proclim.ch/imilast/index.html
– Member of SMI (Società Meteorologica Italiana)
– Member of AGI (Associazione Geofisica Italiana)
– Member of AGU (American Geophysical Association)
– Member of SISC (Società italiana di Scienze del clima)

. Incoming activities

– ”Developer School for HPC applications in Earth Sciences”-ICTP-Trieste 10-12 November, 2014

. Publications


12


Ph.d project : Baroclinic Dynamics of Adriatic-Ionian System

Supervisor : Dr. Alessandro Crise - OGS (http://www.ogs.trieste.it)
Co-Supervisor : Dr. Riccardo Farneti - ICTP (http://www.ictp.it)
Tutor : Dr. Filippo Giorgi - ICTP (http://www.ictp.it)

1 Background

The contribution of internal oceanic processes (baroclinic sources and column stretching due to vertical movements of interfaces) in modifying the upper layer vorticity of the oceans is often neglected in favor of the wind effect despite these effects can be as important as, or even more important than the wind stress, in semi enclosed and stratified basins like the Mediterranean [2].

The Ionian Sea plays an important role in the main thermohaline cell of the Eastern Mediterranean (EMed) conveyor belt. Dense and oxygenated waters, mainly of Adriatic origin (ADW), spread into the Ionian bottom layer, whilst the intermediate layer is influenced by salty and warm waters coming from the Levantine and Aegean basins (LIW, Levantine Intermediate Water). Furthermore through the Sicily Strait, the relatively fresh water of Atlantic origin (Modified Atlantic Water, MAW) enters the Ionian, propagates toward the Levantine basin and, occasionally, bifurcates northward [1] [2]. Therefore the Ionian circulation plays an important role in the redistribution of the different water masses to adjacent seas [2].

A reversal of Ionian circulation had been observed by the middle of 1997 and consisted of a complete reversal of the Ionian upper layer circulation from anticyclonic to cyclonic [1] and has been associated with the relaxation of EMT (Eastern Mediterranean Transient). In fact before 1997, deep water formed in Aegean Sea (CSOW) occupied mainly the eastern and northeastern flanks of the Ionian and its concentration decreased moving westward resulting in a bottom pressure gradient directed towards the center of the basin, which sustained a stationary cyclonic shear in the bottom layer and the anticyclonic one in the upper thermocline layer [1]. After 1997, CSOW reaching the northwestern Ionian was mixed with the ADW (less dense than CSOW) in the central abyssal portion of the basin setting up a bottom pressure gradient directed from the center of the basin toward the coast, sustaining a stationary anticyclonic shear in the bottom layer and the cyclonic one in the upper thermocline layer [1].
Nevertheless studies have documented that the Ionian upper layer basin wide circulation undergoes reversals on decadal scales (see for more details [2]) affecting, for example, the amount of nutrients imported into the Adriatic from Ionian [3], biodiversity pattern [3], salinity and temperature of water in Levantine Basin [4]. Comparing the rate of change of the vorticity and the source of vorticity due to the wind stress it has been suggested [2] that variations in the Ionian circulation can be effectively driven by internal oceanic processes, which can outweigh wind stress [2]. These processes have been suggested to be the result of a feedback mechanism between the redistribution of water masses in the Ionian and the thermohaline properties of deep waters formed in the Southern Adriatic [2]. Associated with the Ionian cyclonic or anticyclonic circulation, the alternate advection into the Adriatic of saltier water from the Aegean/Levantine basin or fresher water of Atlantic origin modifies the thermohaline properties of the Adriatic. These modifications are hypothesized to induce redistribution of water masses in the Ionian capable of sustaining the reversals of the upper-layer circulation [2].

This feedback mechanics has been called BiOS (Adriatic Ionian Bimodal Oscillating System, Figure 1,[2] ) according to:

- Adriatic-Ionian system behaves as a bimodal oscillating system
- when anticyclonic circulation are present in Ionian, MAW are deflected in the Adriatic leading to production of ADW of lowering density which spread in the Ionian producing a deepening of isopycnal surface and stretching of water column resulting in a reversion from anticyclonic to cyclonic.
- when cyclonic circulation are present in Ionian salty LIW enters in the Adriatic leading the production of ADW of increasing density which produce a shallowing of isopycnal surface and so a reversion from cyclonic to anticyclonic.

2 Objectives

The aim of this study is to assess the relative impact of the external forcing acting on Adriatic-Ionian Seas system by evaluating their effects on vorticity and energy budget. A series of experiments have been set with the following protocol:

- to set up an idealized model for Adriatic-Ionian-Levantine system
- to progressively refine the physics and the forcings of the model in order to rank the relevant mechanisms acting on the variability observed in the Ionian circulation
Figure 1: Schematic representation of the Adriatic Ionian bimodal oscillating system (BiOS) : (a) anticyclonic mode and (b) cyclonic mode [2]. For water mass acronyms please see the text

- to define which is the contribution of the remote forcing (wind) to the Ionian circulation

2.1 Numerical model

The dynamics of system has been simulated through a model based on primitive equation (e.g.) MITGCM (MIT General Circulation Model 4). MITGCM has a number of interesting aspects:

- it can be used to study both atmospheric and oceanic phenomena
- it can be used to study both small-scale and large scale processes
- finite volume techniques which allows the treatment of irregular geometries
- it is developed to perform efficiently on a wide variety of computational platforms

4mitgcm.org
Table 1: Model configuration of $S800_{IT}$ and $S800_{RT}$

<table>
<thead>
<tr>
<th>Model settings</th>
<th>$S800_{IT}$</th>
<th>$S800_{RT}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathymetry</td>
<td>Idealized</td>
<td>Real</td>
</tr>
<tr>
<td>Type of grid</td>
<td>Spherical</td>
<td>Spherical</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>$0.25^\circ$</td>
<td>$0.125^\circ$</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>$5(20m) + 10(50m) + 4(100m) + 5(200m)$</td>
<td>$5(20m) + 10(50m) + 4(100m) + 5(200m) + 8(250m)$</td>
</tr>
<tr>
<td>Configuration</td>
<td>Hydrostatic</td>
<td>Hydrostatic</td>
</tr>
<tr>
<td>Timesteps</td>
<td>1200s</td>
<td>1200s</td>
</tr>
<tr>
<td>Length of simulation</td>
<td>864000000s</td>
<td>864000000s</td>
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<tr>
<td>Surface parametrization</td>
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<td>Rigid Lid</td>
</tr>
<tr>
<td>Convection parametrization</td>
<td>Convective adjustment</td>
<td>Convective Adjustment</td>
</tr>
<tr>
<td>Advection</td>
<td>$3^{rd}$ Order Advective scheme</td>
<td>$3^{rd}$ Order Advective scheme</td>
</tr>
<tr>
<td>Forcing</td>
<td>heat fluxes over Southern Adriatic</td>
<td>heat flux over Southern Adriatic</td>
</tr>
<tr>
<td>Horizontal eddy viscosity</td>
<td>$400 \frac{m^2}{s}$</td>
<td>$100 \frac{m^2}{s}$</td>
</tr>
</tbody>
</table>

3 Experiments designs

The experiments in this study can be divided in two groups:

- Closed boundaries + no wind
- Open boundaries + wind

3.1 Closed Boundaries + no wind

A first set of experiments has been runned to study the baroclinic dynamics of Adriatic-Ionian system in a closed system configuration:

- No wind
- No lateral mass fluxes (MAW and LIW)
- Idealized/Real bathymetry (Figure 2)
- Heat fluxes located over the Southern Adriatic in order to simulate deep water formation process which takes place in this area in winter

The general settings and initial conditions employed for two representative experiments ($S800_{IT}$ for the idealized bathymetry and $S800_{RT}$ for the real bathymetry) are reported in Table 1 and Table 2. The most obvious differences between the two experiments together with the bathymetry and horizontal eddy viscosity values is the vertical and horizontal resolution of the computational domain that is higher in the case of $S800_{RT}$.
Table 2: Initial conditions of $S_{800IT}$ and $S_{800RT}$

<table>
<thead>
<tr>
<th>Initial conditions</th>
<th>$S_{800IT}$</th>
<th>$S_{800RT}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity field</td>
<td>Null</td>
<td>Null</td>
</tr>
</tbody>
</table>

Figure 2: Idealized (a) and Real (b) bathymetry of Adriatic-Ionian system
3.2 Open Boundaries + Wind

A second set of 6 experiments (indicated by EXPnum where num is the number of simulation) has been runned to study the baroclinic dynamics of Adriatic-Ionian system in a open system configuration in order to study its response to different external forcings (including wind stress) in the last two decades. The main characteristics of the first experiment (EXP1) are reported in Table 3 (not exhaustive list). Despite $S800RT$ shares the same horizontal/vertical resolution with EXP1, the latter is mainly characterized by:

- A wider computational domain (shown in Figure 3)
- Lateral mass fluxes at Western/Eastern boundaries
- Temperature/Salinity at Western/Eastern boundaries
- Wind forcing

The variability over a long period for Temperature and Salinity on the Western Boundary (corresponding to Sicily Strait) is assumed to be nil. The data from Medar-MedAtlas for Temperature and Salinity BC on the Eastern Boundary have been chosen to reproduce the characteristics of Aegean waters during EMT period. Float data have been chosen for the second part of simulation because they represent the most recent data available for this area (so they should be far from the influence of EMT) despite the spatial and temporal coverage are not high. A preliminary run (not included in this set of experiments) with these BC and no wind has shown a permanent anticyclonic pattern over the Ionian and no variability. Float data didn’t show a strong difference in term of value with respect Medar-MedAtlas and, on the contrary, they showed in the case of salinity higher values.
<table>
<thead>
<tr>
<th>Settings</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Bathymetry</td>
<td>—Exp</td>
</tr>
<tr>
<td>Type of grid</td>
<td>—Real</td>
</tr>
<tr>
<td>Horizontal resolution</td>
<td>—0.125°</td>
</tr>
<tr>
<td>Vertical resolution</td>
<td>—5(20m) + 10(50m) + 4(100m) + 5(200m) + 8(250m)</td>
</tr>
<tr>
<td>Configuration</td>
<td>—Hydrostatic</td>
</tr>
<tr>
<td>Timesteps</td>
<td>—1000s</td>
</tr>
<tr>
<td>Length of simulation</td>
<td>—300 months</td>
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<tr>
<td>Surface parametrization</td>
<td>—Free Surface</td>
</tr>
<tr>
<td>Convection parametrization</td>
<td>—Convective adjustment</td>
</tr>
<tr>
<td>Advection</td>
<td>—3rd Order Advective scheme</td>
</tr>
<tr>
<td>Initial Conditions</td>
<td>—TS from Medar MedAtlas, U=V=0</td>
</tr>
<tr>
<td>Boundary conditions for Wind</td>
<td>—zero for the period 1987-1995 / ReGCM4 climatology for the period 1996-2012</td>
</tr>
<tr>
<td>Boundary conditions for U-V</td>
<td>—MyOcean b</td>
</tr>
<tr>
<td>Heat flux</td>
<td>—Strong loss heat in January over South Adriatic/the heat loss is gained by the entire basin during the rest of year</td>
</tr>
<tr>
<td>Lateral Sides</td>
<td>—No slip</td>
</tr>
<tr>
<td>Bottom</td>
<td>—Quadratic Coefficient (0.003)</td>
</tr>
<tr>
<td>Horizontal eddy viscosity</td>
<td>—100 m²</td>
</tr>
<tr>
<td>Vertical eddy viscosity</td>
<td>—10⁻³ m²</td>
</tr>
</tbody>
</table>

Table 3: Main features of Exp 1
with respect the climatologies known for this area: so a correction for Temperature and Salinity data have been adopted. These corrections have been identified as STRONG (1 C and -0.25 psu) and MILD (0.5 C and -0.15 psu). The STRONG correction have been adopted for the EXP1-3 and EXP5, the MILD correction for EXP4.

The main differences between EXP2 − 5 and EXP1 are reported in the following list (EXP6 will be described later):

- EXP2 is equal to EXP1 despite there is no wind along the simulation
- EXP3 is equal to EXP1 despite wind is also present in the first part of simulation
- EXP4 is equal to EXP3 despite the increase of temperature and the decrease of salinity at Eastern Boundary is more contained with respect EXP3 (0.5 C and -0.15 psu with respect 1 C and -0.25 psu in EXP3)
- EXP5 is equal to EXP3 despite the increase of temperature and the decrease of salinity at Eastern Boundary is linear over a period of 3 years and not abrupt as in EXP3

Figure 4, a shows the climatology of wind field in January as reproduced by RegCm4 and used to force the model in our experiments while Figure 4, b reports the annual mean wind stress curl. This last figure shows clearly that the southern Adriatic is interested by strong cyclonic input by the wind while the Ionian Sea by a negative vorticity input.
Figure 4: Snapshots of wind field in January as reproduced by RegCM4 (a) and annual wind stress curl computed by MITGCM (b)
Figure 5: Hovmueller diagram of Z3 density in the case of $S800_{IT}$ (a) and $S800_{RT}$ (b)

4 Results

The results discussed in this section will include:

- Vorticity analysis
- Descriptive analysis
- Energetics
4.1 Vorticity analysis

The density of the vertical component of relative vorticity which is defined as:

\[ \frac{1}{\Delta V_{\text{domain}}} \int \int \int_{V} \zeta dxdydz \]

has been computed in the Ionian Sea for both set of experiments.

In the case of closed configuration Figure 5 and Figure 6 show clearly that deep water formation processes taking place in the Adriatic always induce an anticyclonic circulation in the upper layer of Ionian sea and cyclonic circulation in the bottom layer. Definitely the Ionian basin behaves as bi-layer system as predicted by [2] and [3]. A more detailed analysis of vorticity balance (not shown here) has shown that in both experiments the main terms of the balance are represented by diffusion and stretching terms.
Figure 7 reports the temporal evolution of the same quantity for all the experiments in the open configuration: in both STRONG/MILD correction and abrupt/gradual change in correspondence of temperature/salinity boundary conditions change on the Eastern Boundary a reversal from anticyclonic to cyclonic circulation takes place in the Ionian. The intensity of cyclonic signal in the Ionian is weaker in the case of MILD correction. After the transition from anticyclonic to cyclonic circulation no further reversal has been observed. A further analysis has been carried out to identify the importance of wind in our system during the EMT conditions: Z3 has been compared between EXP1 (no wind forcing in the first part of simulation) and EXP5 (wind forcing in the first part of simulation). The difference between the two time series is always about 10%-20%. So wind is able to reinforce the circulation but the anticyclonic pattern is mainly due to lateral flux of CSOW [1]. Still the mean anticyclonic contribution of wind to Ionian Sea cannot be related to the reversal of circulation observed in our simulations.

4.2 Descriptive analysis

The behavior of CSOW during the EMT conditions has been visualized through a tracer released in the Kithira strait and it is shown in Figure 8. At the beginning the CSOW occupied the eastern flank of the Ionian basin and then they move northward-westward filling progressively the Ionian bottom. The resulting circulation is cyclonic [1]. It is worthwhile mentioning that the tracer released in the
Adriatic Sea is not found in this part of simulation in the Ionian bottom.

The corresponding situation in the upper layer is shown in Figure 9. During the EMT situation the Ionian Sea (a) is occupied by a strong positive anomaly [1] in the sea surface elevation corresponding to an anticyclonic pattern. An negative value is observed along the eastern flanck. In correspondance of linear change (b) in temperature and salinity a weaking of anticyclonic circulation is observed and cyclonic pattern appears(b). At the end of this linear change inTemperature and Salinity (c) a strong negative anomaly (cyclonic circulation) in the sea surface elevation occupied the Ionian Sea and a positive anomaly is observed along the eastern flanck.

Finally a longer simulation called EXP6 has been done. The BC for the Temperature and Salinity in this experiment follows this scheme: EMT-linear change in Temperature and Salinity-STRONG-linear change in Temperature and Salinity-EMT. The resulting changes in the vorticity are the following: anticyclonic circulation-weakining of anticyclonic circulation-cyclonic circulation-weakining of cyclonic circulation-anticyclonic circulation. The effects of the change in the circulation affects the salinity of Southern Adriatic (Figure 10) which is characterized by a negative trend during anticyclonic pattern in the Ionian due to the advection of MAW [2], a positive trend during cyclonic pattern due to advection of LIW [2] and a negative trend at the end of the experiment during the new anticyclonic pattern.
Figure 8: Spatial distribution between 3500m and 4000m of a tracer released in the Kithira strait in four different snapshots of EXP1. The Tracer has been released during the first time step of the simulation.
Figure 9: Sea Surface Elevation (in m) + Streamline of velocity fields at 20 m in three different snapshots in EXP5
4.3 Energetics

A final analysis of energetics of the system has been carried out. The following quantities have been computed for each experiment:

- Density of Kinetic Energy (KE):
  \[ \int \int \int_V KEdxdydz \]

- Density of Quasi-Geostrophic Available Potential Energy (\( APE_{QG} \), according to [9]):
  \[ \int \int \int_V APE_{QG}dxdydz = -g \int \int \int_V \frac{[\rho - \bar{\rho}(z)]^2}{2\rho_z} dxdydz \]

  with \( g \) gravity, \( \rho \) potential density in a point of the grid, \( \bar{\rho} \) the reference state defined by the horizontal averaging of the density field and \( \rho_z \) the local gradient of potential density.

- Wind power stress [6] has been defined as
  \[ W = \int \int \tau u dA \]

  where \( \tau \) is the wind stress and \( u \) is the velocity fields. The scalar product of these two quantities is integrated over the entire surface.
• Buoyancy Flux due to heat fluxes (the haline component due to evaporation and precipitation is zero in our models) is given by [8]

\[ B = -g \alpha \frac{Q_o}{\rho c_p} \]

with \( \alpha \) thermal expansion coefficient, \( Q_o \) is heat flux over the surface, \( \rho \) potential density and \( c_p \) is the specific heat for the sea water.

All these quantities have been integrated over the surface/volume of Adriatic-Ionian Sea and are shown in Figure 11, Figure 12, Figure 13, Figure 14. The estimation of APE and Kinetics energy agree in order of magnitude with some estimations provided by R. Mosetti (personal communication) by using a quasigeostrophic analytical model. The transition from anticyclonic/cyclonic is characterized by a strong variation in the APE (up to an order of magnitude) (Figure 11). From a mechanical point of view the anticyclonic pattern corresponds to a minimum in the potential energy so it is the most stable state for Ionian circulation. In all the experiments wind power is greater during the first part of simulation due to a substantial agreement in terms of sign between curl wind sign and Ionian circulation (in both cases anticyclonic). Then the wind power decreases as consequence of change in circulation in the Ionian (Figure 13). The Buoyancy flux is constant along the simulations. The values estimated of W and Buoyancy flux corresponds in term of order of magnitude with those computed by [8]. As shown in Figure 11 the reversal observed is strictly correlated with variation of APE. We are currently completing this analysis producing some estimations of input of energy from the boundaries.
Figure 11: Integral of KE in the Adriatic-Ionian Sea

Figure 12: Integral of APE in the Adriatic-Ionian Sea
Figure 13: Integral of Wind power over the Adriatic Ionian system

Figure 14: Integral of Buoyancy flux over the Adriatic Ionian System
5 Final conclusions

This study has put in evidence:

- **Closed boundaries + no wind configuration:**
  - In a closed system the effect of convection in the Southern Adriatic is to induce an anticyclonic circulation in the Ionian Sea
  - Ionian Sea behaves as a bi-layer system with opposite sign in the vorticity as predicted in [1] [2]
  - The level zero for vorticity is located between 1500 m and 2000 m as expected by [1] [2]
  - Vortex stretching and diffusive terms are the prevailing terms in the vorticity balance

- **Open boundaries configurations + wind**
  - Thermohaline fluxes from the Eastern Boundary are able to induce a cyclonic circulation in the Ionian by providing a substantial input of APE
  - Wind forcing is able to reinforce/weakens the Ionian circulation but it’s not able to reverse the circulation itself
  - Bathymetry plays an important role in maintaining a permanent anticyclonic pattern in the Southern Ionian
  - The transition between anticyclonic and cyclonic circulation is tightly connected with the time rate of change of thermohaline characteristics of Eastern Boundary
  - In general Eastern Boundary effects are more energetics than thermohaline processes taking place in the Southern Adriatic
References


[9] Huang R., Available potential energy in the world’s ocean , Journal of Marine Sciences, 63 , 141-158, 2005