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Vulnerability of water-food-environment nexus at coastal areas under climate change

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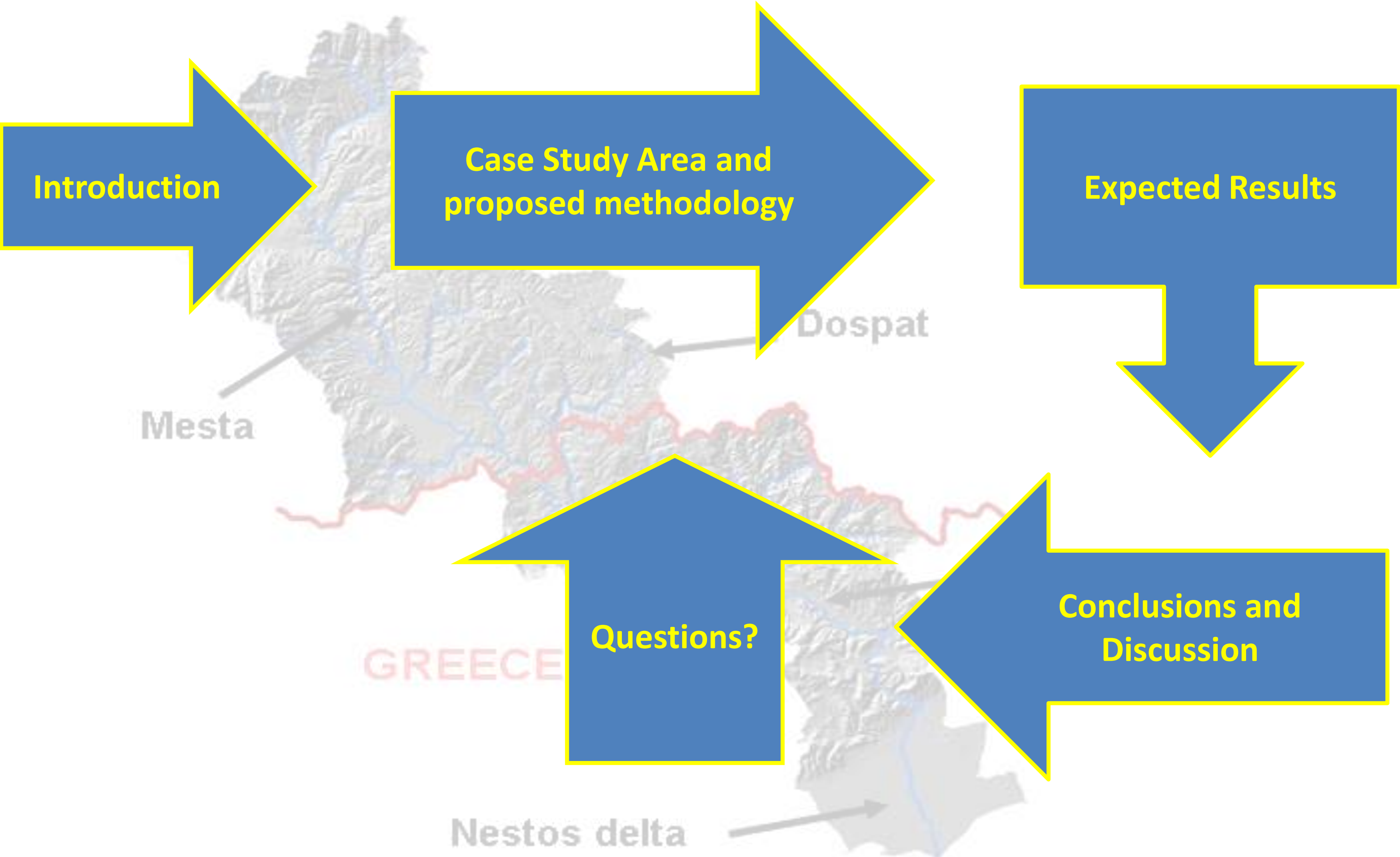
United Nations Educational Scientific and Cultural Organization

UNESCO Chair International Network of Water-Environment Centres for the Balkans

Aristotle University of Thessaloniki

Mykonos, 21 May 2019

Panorama of the presentation



Introduction

The **management of deltaic areas** requires a multidisciplinary approach since irrigated agriculture, fish farm industry, touristic activities and environmentally protected areas are conflicted water users.

Recent projections by both general circulation models (GCMs) and regional climate models (RCMs) show that **future climate** will be characterized by monthly net rainfall decrease during winter and potential evapotranspiration increase during summer due to global warming.

The Mediterranean region will be among the areas that will be most affected by CC. Thus, serious water issues arise, regarding sustainable water resources management and allocation of available water among competitive users.

Introduction

At the same time, the notable interdependencies between **water resources, energy production and provision of food, the so called "Nexus approach"** proposes a new concept on the Integrated Water Resources Management.

Moreover, the nexus approach "increases the understanding of the interdependencies across water, energy, food and other policies such as climate and biodiversity".

Consequently, **actions undertaken in one of the aforementioned sectors have imminent impacts to all others**.

Aim of the research

The research aims at **investigating the vulnerability of the water-food-environment nexus in the Mediterranean coastal zone under climate change conditions** by initiating:

a) the coupling of numerical models dedicated to the simulation of basins' rainfall-runoff, maritime hydrodynamics (coastal sea levels and currents) and physical characteristics of coastal waters, and
b) the integration of climate change projections derived from a regional climate model (RCPs 4.5 and 8.5) to the aforementioned models.

The produced river discharges and coastal waters' characteristics such as sea level elevations, flood volumes and seawater temperature/salinity, are evaluated based on the current hydrosystem water demands and the exposure of the nexus to climate change is quantified through a custom developed Decision Support & Management Model.

Management of transboundary WB

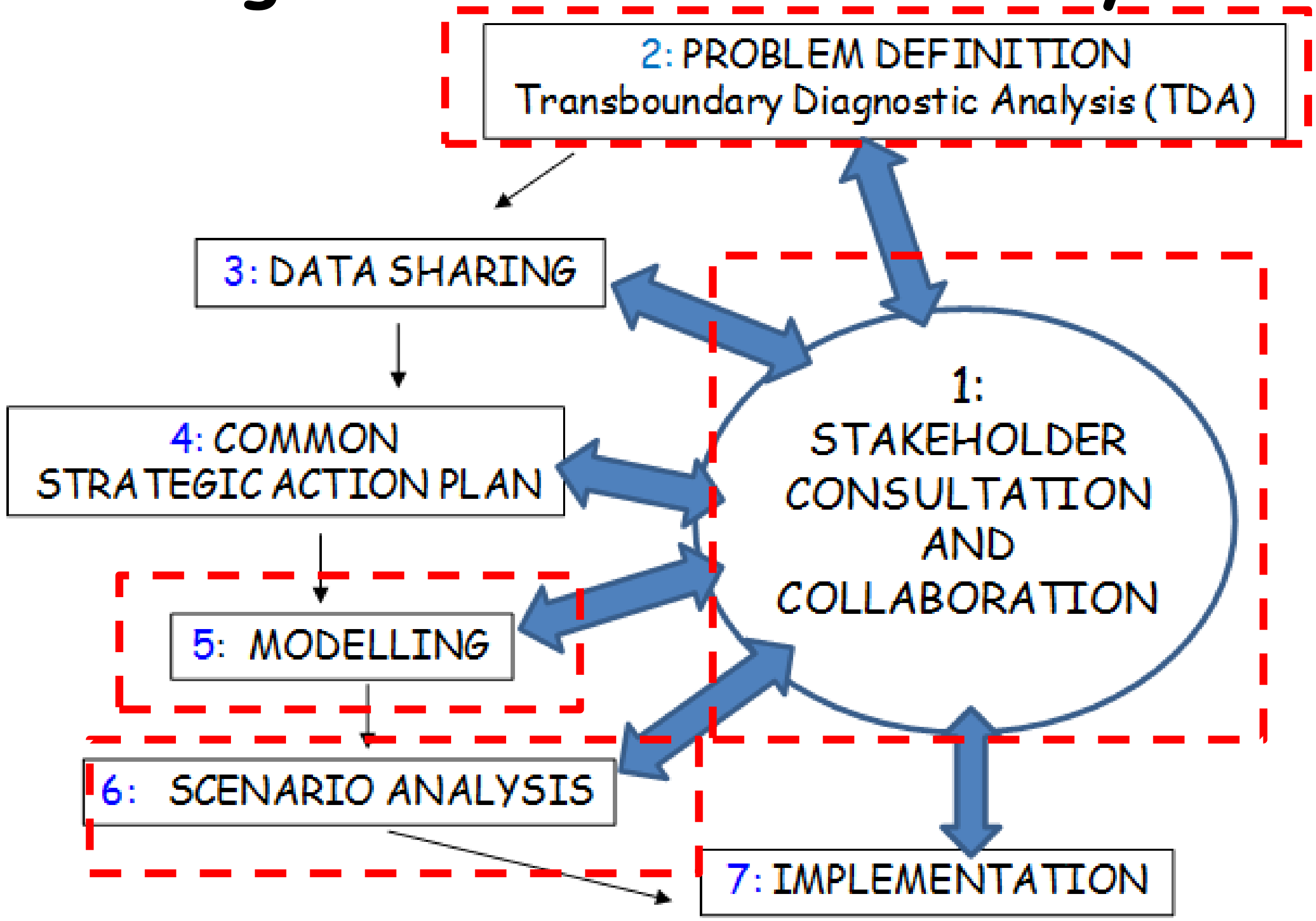
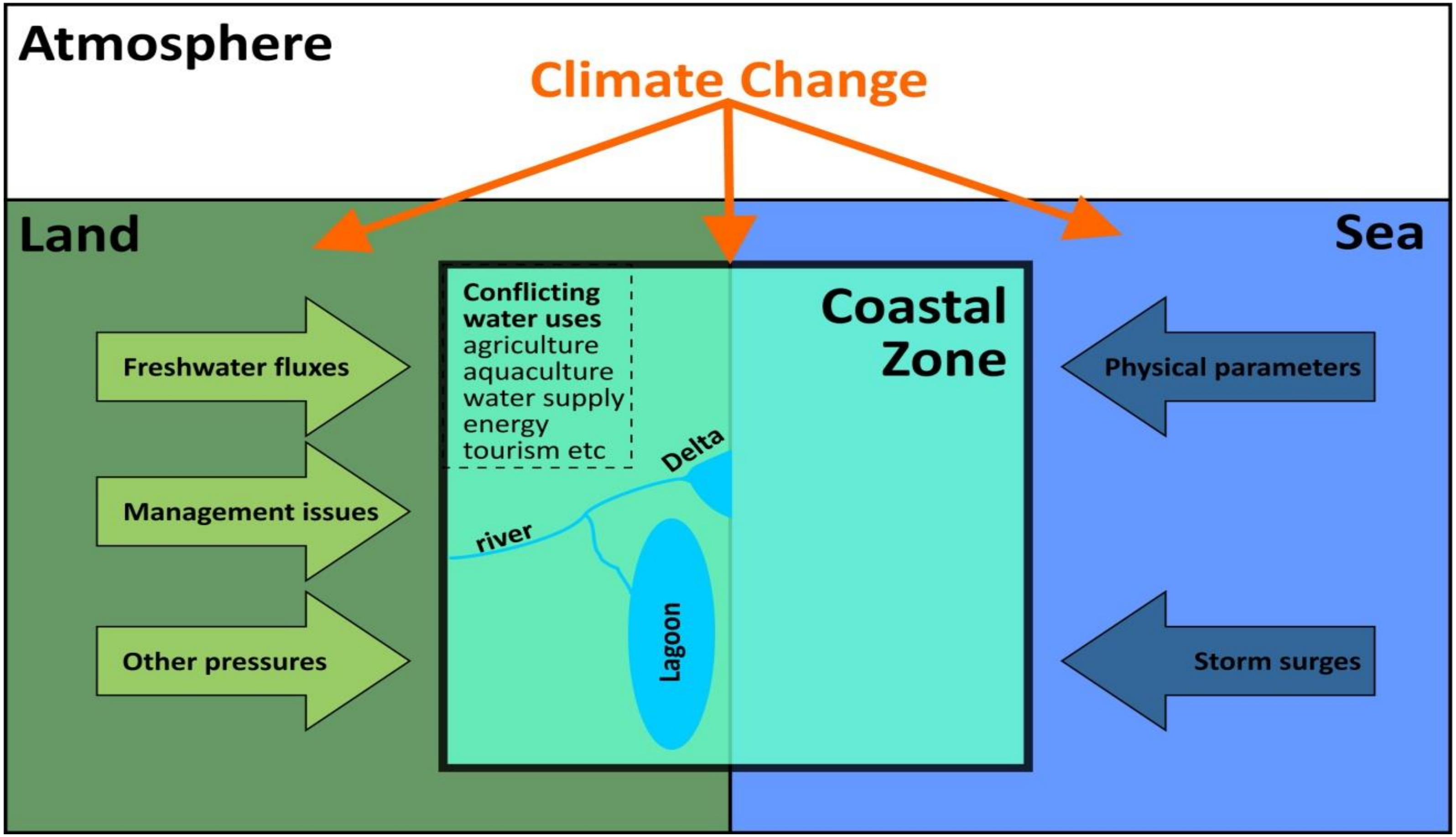


Figure 2: A conceptual model for effective management of transboundary water resources.

Πηγή: *Ganoulis, J., Skoulikaris, Ch. (2011). A Conceptual Model for Implementing Integrated Transboundary Water Resources Management (ITWRM). Journal of Hydrologic Environment, 7(1), 155-158*

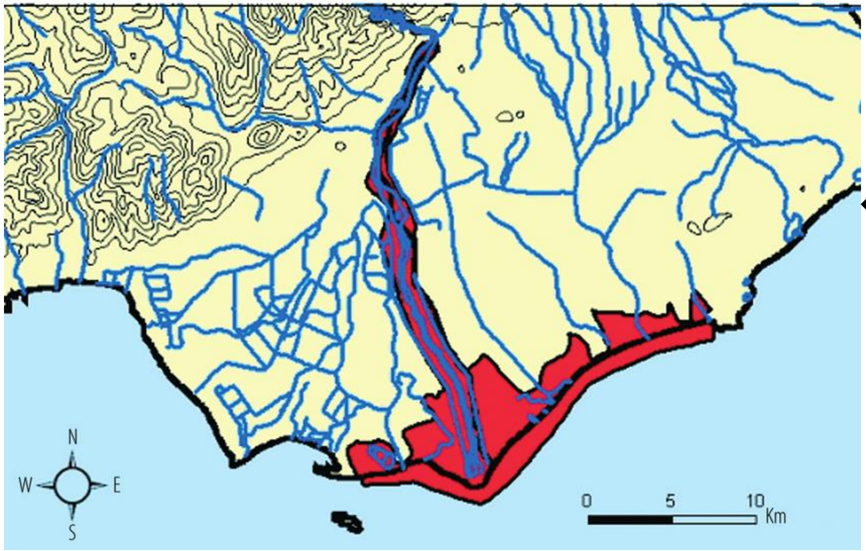
MATERIALS AND METHODS

For the achievement of the research aim, the integration of the three larger-scale modeling components is proposed:



Case study area

The Nestos River deltaic area is the area of interest:



- The river water is used for multiple purposes: power production (2 existing and one under design HPP), irrigation in the deltaic area, and environmental purposes.
- The regional economy is based mainly on agriculture, tourism and fishery.
- In environmental terms, the delta is a very important habitat that has been declared as Ramsar site (10593 ha), as Special Protection Area (10000 ha) as well as Specially Protected Mediterranean Area.

Climate Change data Description

2 representative RCPs scenarios for the 21st century in IPCC-AR5

•RCP4.5 describes a possible climate future that depends on “modest” estimations about greenhouse gas concentrations in coming years

•RCP8.5 poses a “worst case scenario”

•Datasets used as input in these simulations were retrieved from **Med-CORDEX** database dedicated to the Mediterranean

•Several subsets/domains include data derived by simulations combining various spatial resolutions (down to 10 km)

•Selected MED-44 and MED-10 domain cover the entire Mediterranean basin with spatial resolutions of 0.44° and 0.1 in a rotated-pole projected geographic system

•Three 35-yr periods are simulated: Reference period (1971-2005) / Short-term Future (2021-2055) / Long-term future (2061-2095)

•3 high-resolution Regional Climate Models (RCMs), **CMCC, CNRM and GUF**

Climate Change data Presentation

Table 1. MED-44 CORDEX domain geographic specifications

CORDEX Area	Name	Grid spacing, position of rotated North Pole (NP) and outermost cell centers in rotated coordinates (°)								
		Degrees (°)	NP lon	NP lat	N lon	N lat	West	East	South	North
Mediterranean	MED-44	0.44	198.0	39.25	98.00	63.00	-23.22	19.46	-21.34	5.

The original MED-44 data were further processed by the means of the Climate Data Operators tool set (https://code.mpimet.mpg.de/projects/cdo/), in order to match the requirements of the study's simulations

Table 2. Study domains geographic specification

Study Area	Name	Grid spacing and outermost cell centers in regular lon-lat coordinates (°)				
		Degrees (°)	West	East	South	North
Mediterranean	MED-Sea	0.1	-7.00	36.00	30.25	45.75
Nestos river coastal area	Nest-Sea	0.1	24.30	25.1	40.70	41.10
Nestos river basin	Nest-Hydro	0.1	23.30	25.00	40.80	42.20

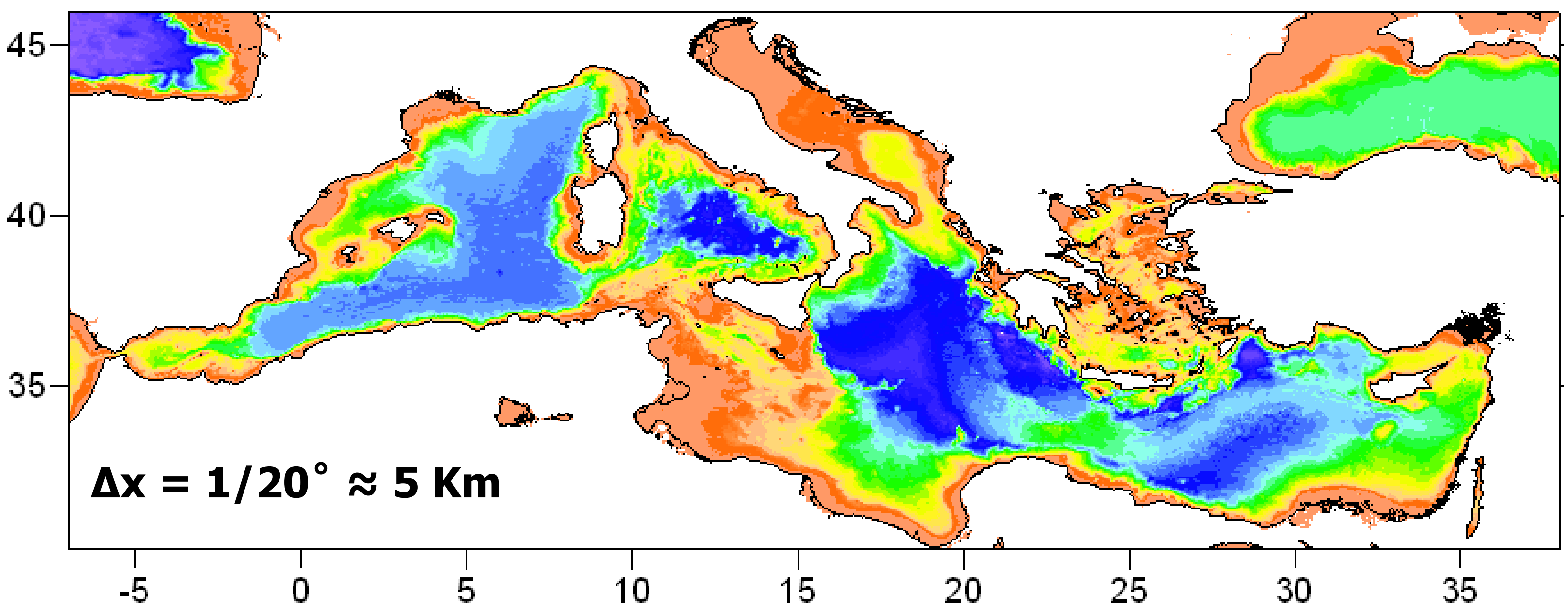
Climate data Validation

Historical climate data by all RCMs for the reference period

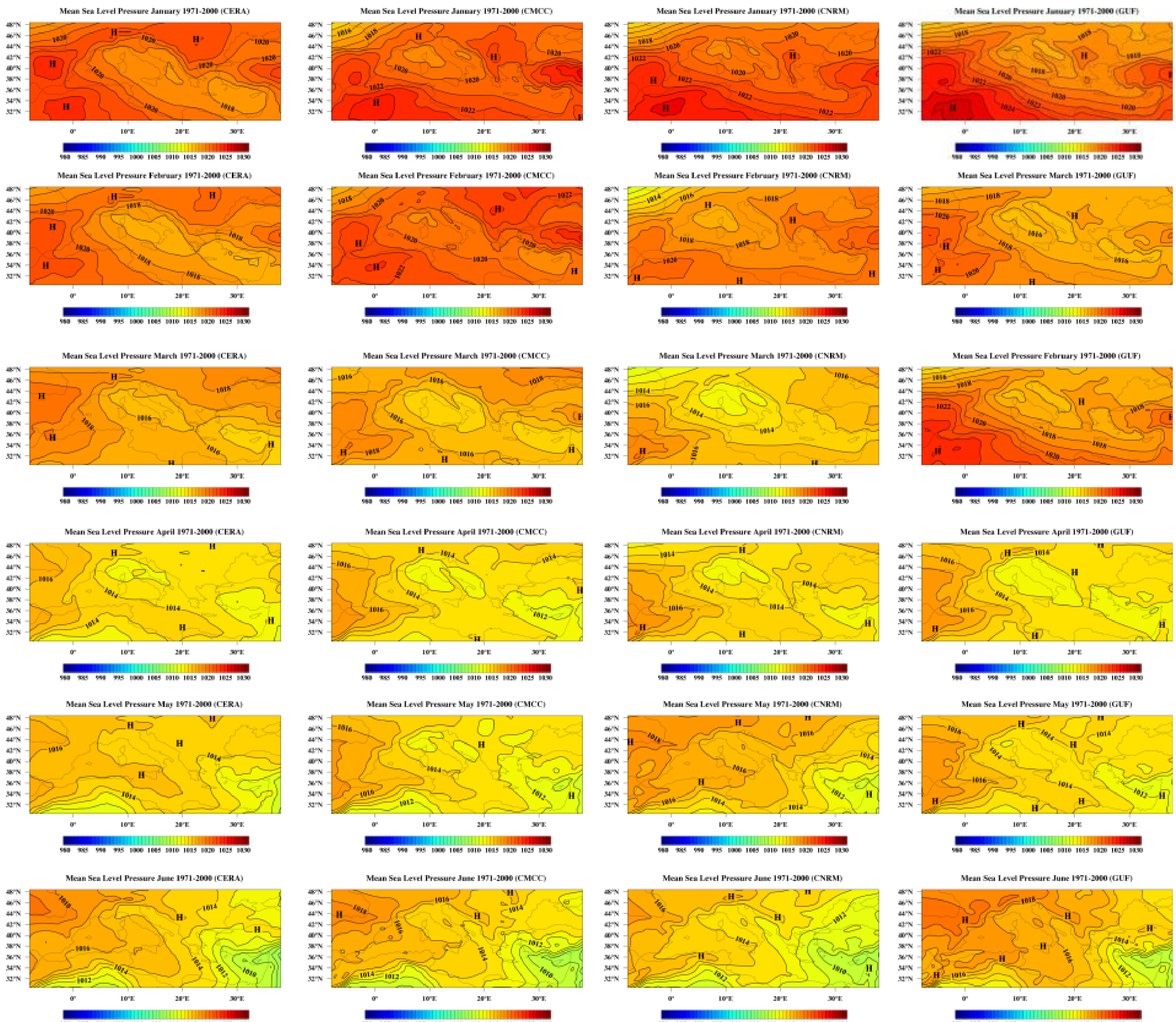
are validated against ECMWF reanalyses, based on assimilation system fields produced under CERA-20C, which consist of 10-member ensemble of coupled climate re-analyses of the 20th century from ECMWF (European Centre for Medium-Range Weather Forecasts) and aims to reconstruct the past weather and climate of the Earth system including the atmosphere, ocean, land, ocean waves, and sea ice; **Time-series: 1901-2010**

SCOPE: Run MeCSS Mediterranean Climate Storm Surge Model

With forcing SLP and Wind fields



Climate data Validation



SLP monthly patterns (Jan–June)

derived from CERA data (1st column)

VS.

Three models
CMCC
CNRM
GUF
(2nd, 3rd, 4th columns)

Climate data Validation

Spatial distribution of CERA data for wind speed (m/sec) on annual basis

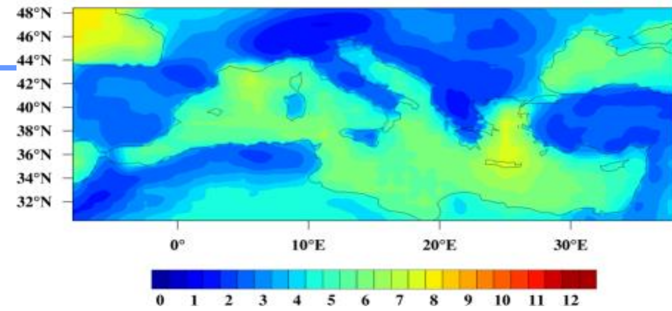
Spatial wind speed distribution of three examined models (left column)

+

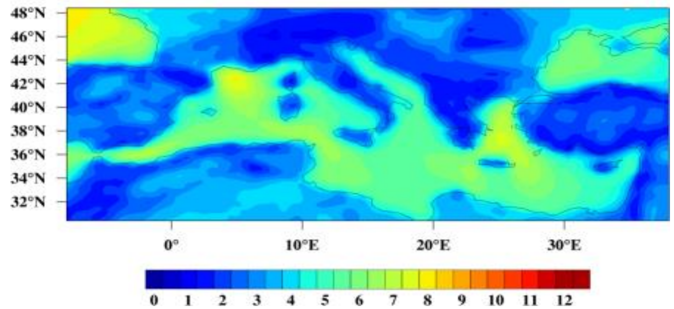
differences in comparison to CERA data (right column)

Statistically significant differences marked with grey points (**T-test** 0.05)

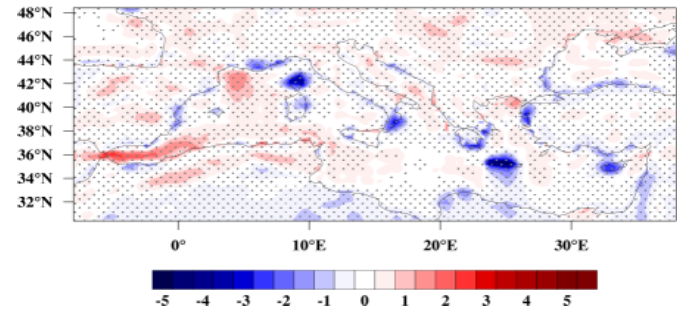
Wind Speed Year 1971-2000 (CERA)



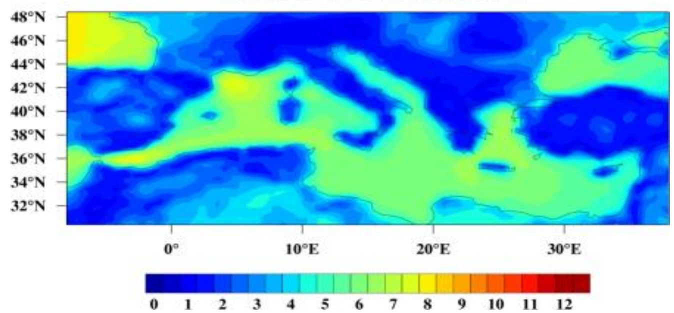
Wind Speed Year 1971-2000 (CMCC)



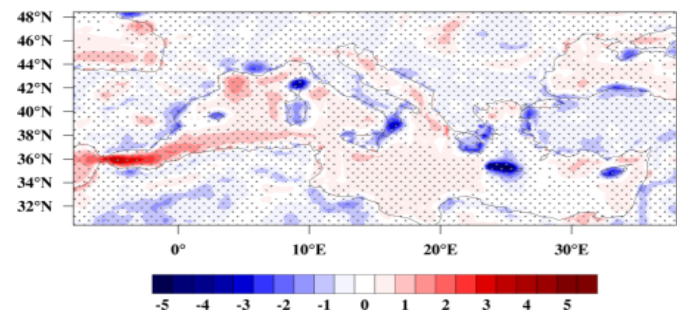
Differences (wind speed) Year 1971-2000 (CMCC - CERA)



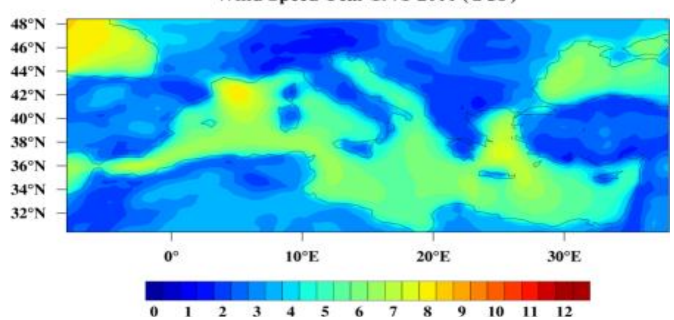
Wind Speed Year 1971-2000 (CNRM)



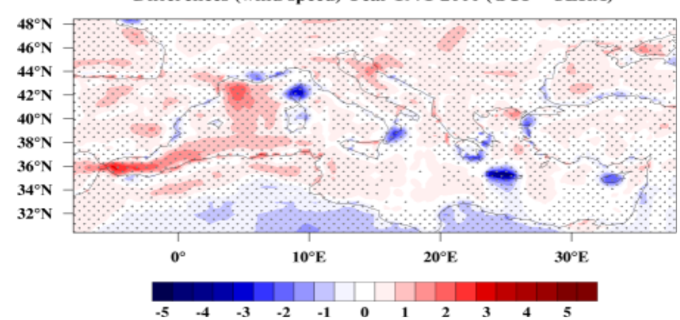
Differences (wind speed) Year 1971-2000 (CNRM - CERA)



Wind Speed Year 1971-2000 (GUF)



Differences (wind speed) Year 1971-2000 (GUF - CERA)



Maritime hydrodynamic models

Long-term climatic-type sea-state modelling

- Recent evolvement of **HiReSS/MeCSS** numerical model
- Simulation of storm surge in large enclosed water basins with diverse topography, varying bathymetry, complex coastlines, gulfs and semi-enclosed coastal areas
- 2-DH formulations of the depth-integrated Navier-Stokes equations
- Simulation of barotropic mode hydrodynamic circulation
- OUTPUT: Sea surface elevation/depression + Depth-integrated sea currents

due to meteorological forcing (weather conditions) + astronomical tides

Aims

- Reliable estimations of episodic (mean) sea level elevations and depth-averaged currents due to storm surge for three 35-yr periods

Methodology Model equations

Equations of motion conservation of momentum

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial y} - fV + g\frac{\partial z}{\partial x} + Z_x = -\frac{1}{\rho_o}\frac{\partial P_A}{\partial x} + E_h\left(\frac{\partial^2 U}{\partial x^2} + \frac{\partial^2 U}{\partial y^2}\right) + \frac{C_s}{\rho_o}\frac{W_x\sqrt{W_x^2 + W_y^2}}{(h+\zeta)} - C_b\frac{U\sqrt{U^2+V^2}}{\rho_o(h+\zeta)}$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial y} + fU + g\frac{\partial z}{\partial y} + Z_y = -\frac{1}{\rho_o}\frac{\partial P_A}{\partial y} + E_h\left(\frac{\partial^2 V}{\partial x^2} + \frac{\partial^2 V}{\partial y^2}\right) + \frac{C_s}{\rho_o}\frac{W_y\sqrt{W_x^2 + W_y^2}}{(h+\zeta)} - C_b\frac{V\sqrt{U^2+V^2}}{\rho_o(h+\zeta)}$$

- Spatiotemporal variation of the velocity field → **U and V**
- Coriolis Gravity Astronomical Tide effects
- Force due to pressure gradient
- Horizontal turbulence Diffusion by eddy viscosity
- Sea surface shear stress due to winds
- Bottom shear stress due bed friction

Continuity equation conservation of mass

$$\frac{\partial \zeta}{\partial t} + \frac{\partial}{\partial x}UH + \frac{\partial}{\partial y}VH = 0$$

Spatiotemporal variation of the sea surface **z** → **SSH**

Methodology Tide Parameterization

Newly formed equations in HiReSS

$$Z_x = -0.1g\frac{\partial\zeta}{\partial x} - 0.7g\frac{\partial\zeta_{tide}}{\partial x} \qquad Z_y = -0.1g\frac{\partial\zeta}{\partial y} - 0.7g\frac{\partial\zeta_{tide}}{\partial y}$$

Astronomical tide simulation Schwiderski (1980) STATIC MODEL

Tidal modes:

M2, S2, N2, K2, K1, O1, P1, Q1

Diurnal signal

$$\zeta = k_o \sin(2\varphi)\cos(\sigma t + x + \lambda)$$

Semi-diurnal signal

$$\zeta = k_o \sin^2(2\varphi)\cos(\sigma t + x + \lambda)$$

$$h_o = 279.69668 + 36000.768930485T_d + 3.03 * 10^{-4} {T_d}^2$$

$$s_o = 270.434358 + 481267.88314137T_d - 0.001133{T_d}^2 + 1.9 \cdot 10^{-6}{T_d}^3$$

$$T_d = (27392.500528 + 1.0000000356D)/36525$$

$$D = day + 365 \cdot (yr - 1975) + \mathrm{int}[(yr - 1973)/4]$$

Astronomical argument for M2 $x = 2 \cdot h_o - 2 \cdot s_o$

φ and λ: geographic longitude and latitude of each cell – mean distances of sun h_o and moon s_o

Accu-Waves

Methodology Special Features

Shear stresses on air-water interface and on the bottom

$$\tau = \rho_A C_D \, |W| \, W$$

W: wind velocity at 10m above MSL

$$C_D = (0.63 + 0.066W)/10^3$$

C_D: drag coefficient by Smith & Banke (1975)

$$C_b = \max\left\{ \left[\frac{1}{\kappa} \ln\left(\frac{H}{z_o} + 1 \right) \right]^{-2}, \ 0.0025 \right\}$$

C_b: bottom friction coefficient by Wang (2002)

Horizontal turbulent eddies modelled by a pseudo-LES model

Eddy viscosity concept of the Smagorinsky type

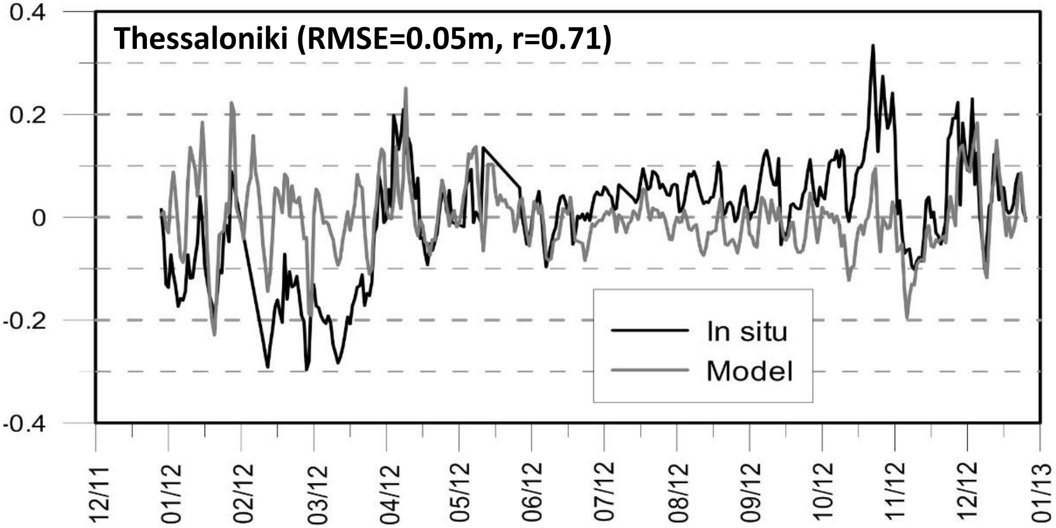
Coefficient C_S=0.1-0.2 by Rogallo & Moin (1984) for the E_h and v_t calculation

Computational Domain type

Ortho-regular staggered Cartesian grid of the Arakawa-C type for the finite difference method

Results Validation of HiReSS

Short-term forecast evaluations for real-time data

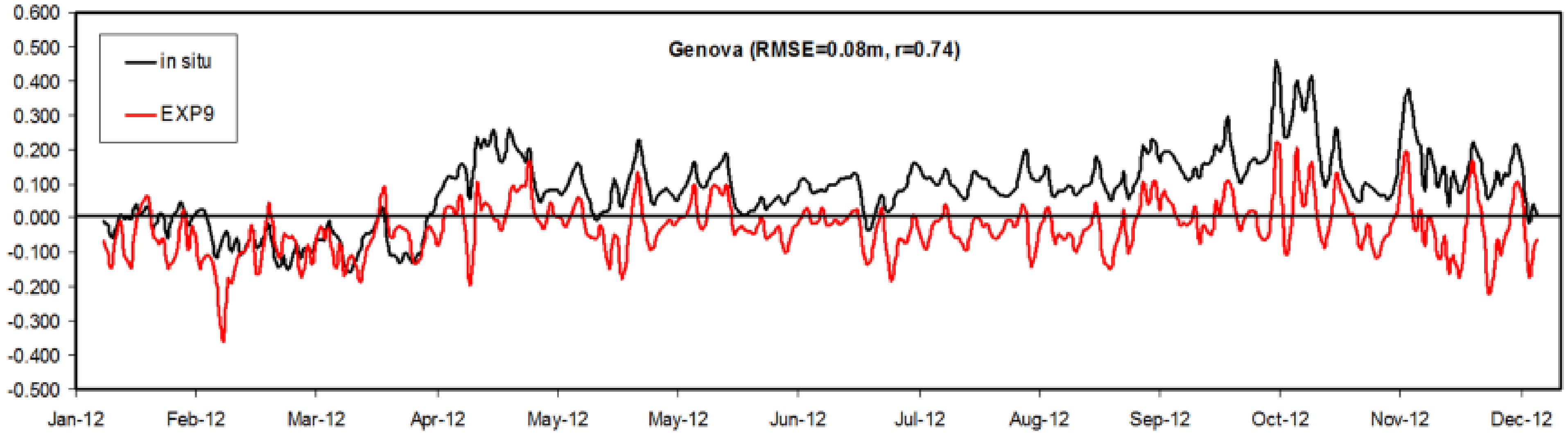


Comparisons of HiReSS hindcasting model results against in situ observations of **real-time SSH** (m) by tide gauges during 2012

Thessaloniki and Genova ports

RMSE: root-mean-square error

r: Pearson correlation



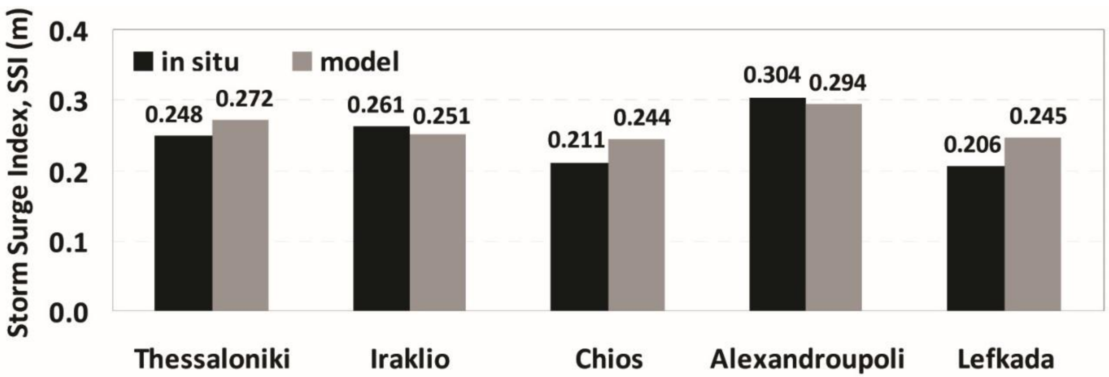
Results Validation of MeCSS

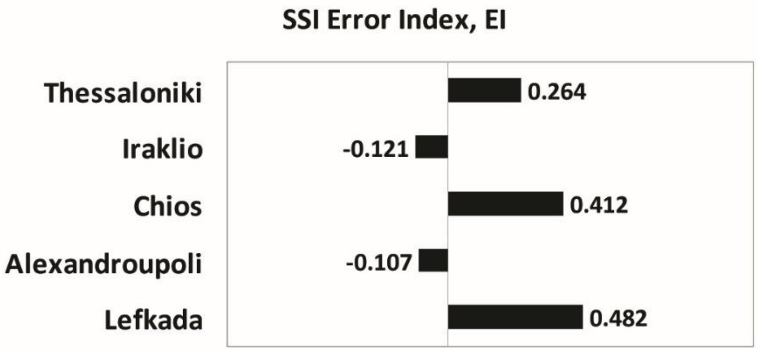
Long-term hindcast evaluations for climatic-type data

Past evaluations in Mediterranean, Aegean and Ionian Seas (**MeCSS model**)

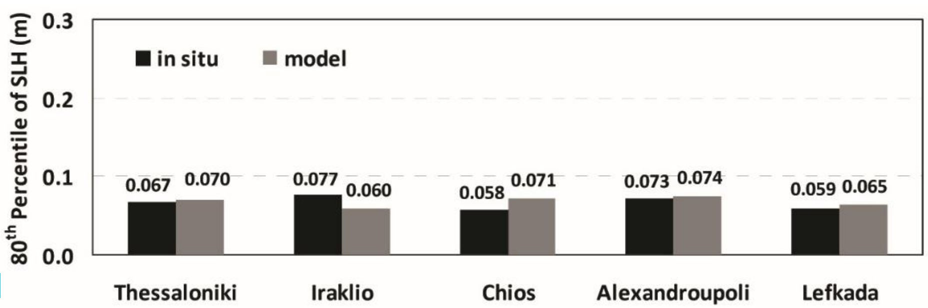
Comparisons in situ vs. **model based** on **SSI (m)** and **Error Index**

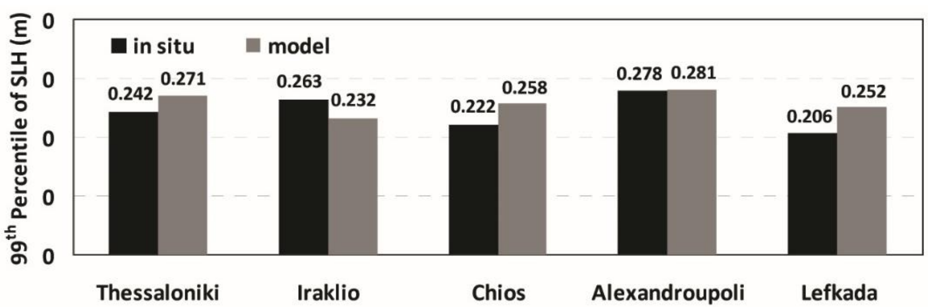
Control Run – Past



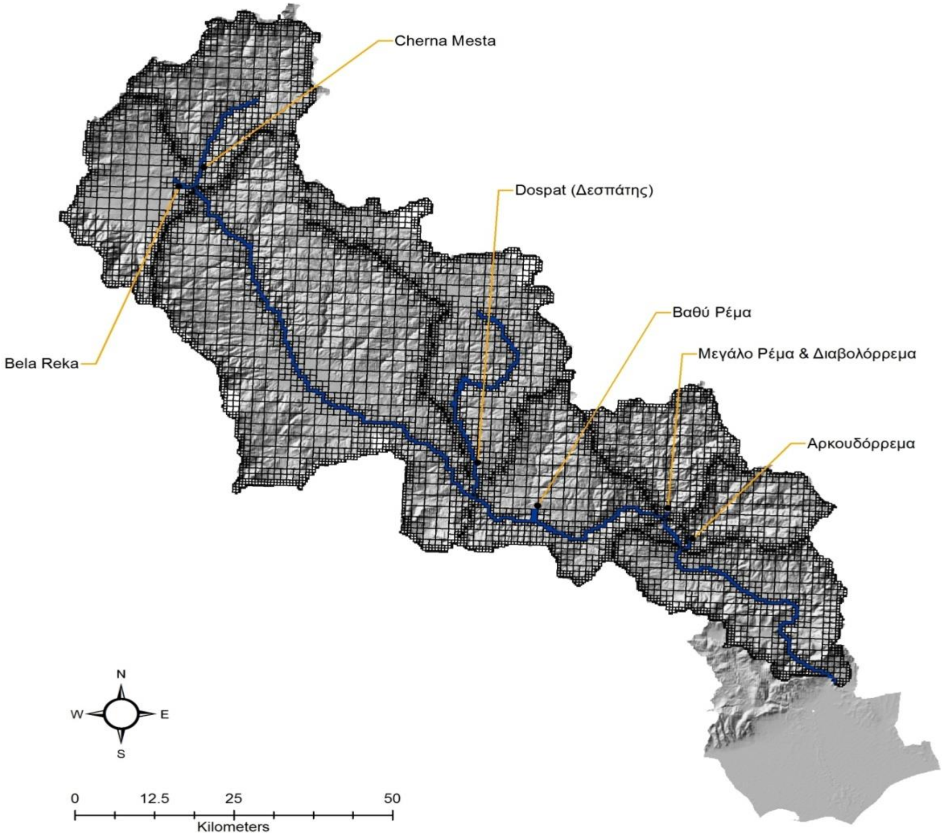


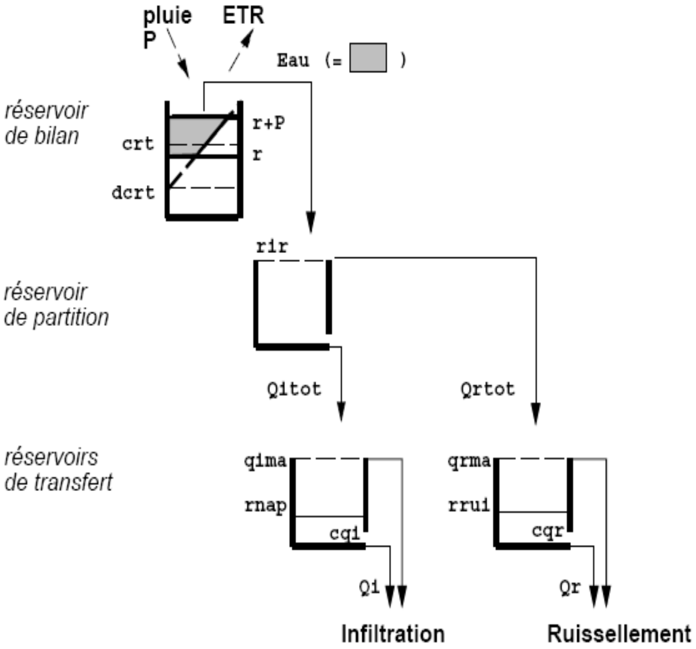
Comparisons in situ vs. **model based** on **80^{th}** and **99^{th} Percentiles of SSH (m)**





Hydrological modeling



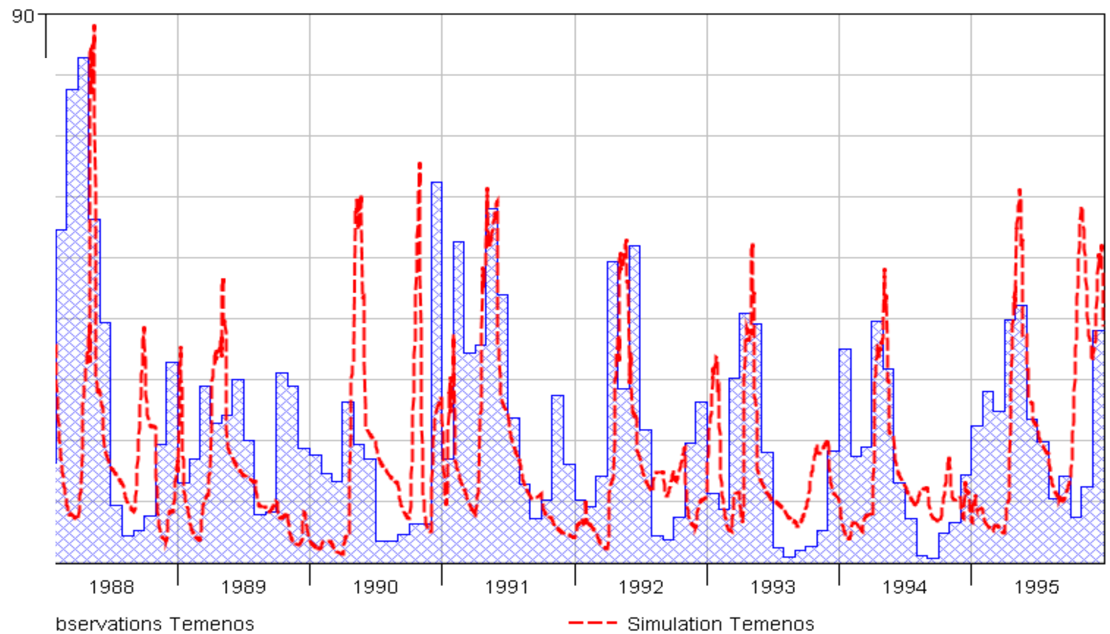


The freshwater volumes that are concentrated in the case study's river basin and thereafter discharged into the sea will be simulated with the MODSUR hydrological model. It is a spatially distributed model, hence is based on a densely spaced grid and uses a progressive quadtree structure with varying cell sizes.

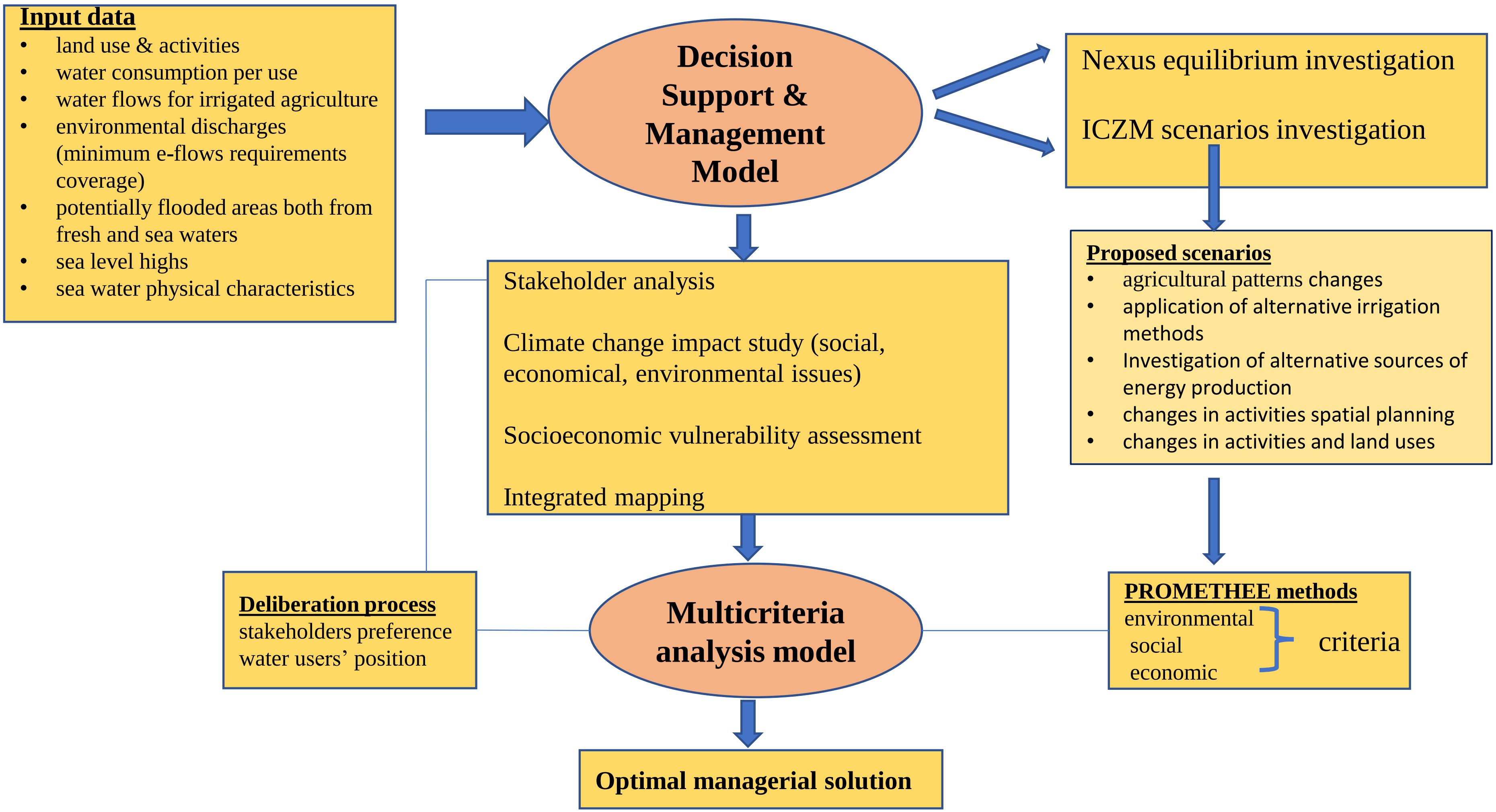
Results of model validation

Input data
- Topography
- Land use
- Precipitation
- Temperature
- ETP

Output:
- Surface flow at each river cell



Decision support and management model



Stakeholder mapping

National Park of East Macedonia-Thrace

- Nestos Delta Management Body Vistonidas- Ismarida and Thassos (F.D.)
- private legal entity, non-profit organization
- established by CMD of Ministries of Environment, Agriculture and Development
- includes the protected areas of wetlands: Delta Nestos, Vistonida-Ismarida lakes and the wider region (total area 930,000 acres)

↓

Purpose: Protection of the rare flora and fauna habitats

Stakeholder mapping

Administrative authorities		
Authority	**General Directorate**	**Directorate**
Decentralized Administration of Macedonia and Thrace	General Directorate of Spatial and Environmental Policy	• Department of Environment and Spatial Planning • Water Directorate
	General Directorate of Forestry and Rural Affairs	• Forest Directorate • Directorate of Rural Affairs
Periphery of East Macedonia and Thrace	General Directorate of Development Planning, Environment & Infrastructure	• Directorate of Environment and Spatial Planning • Technical Engineering Directorate
	General Directorate of Regional Agricultural Economics & Veterinary	• Directorate of Rural Economy • Land Directorate • Agricultural Economics & Veterinary Directorate of Regional Unities
	General Directorate of Development	Industry, Energy & Natural Resources Directorate Development Directorate
	Independent Civil Protection Directorate	
Municipalities	Municipality of Nestos	
	Municipality of Xanthi	

Stakeholder mapping

Related stakeholders of the study area have been reported

Rural authorities	
Authority	**Description**
Geotechnical Chamber of Greece	public service aiming to expand and promote scientific knowledge in the fields of agriculture, livestock farming, forestry, fishing and the management of mineral and water resources in an attempt to
Local Land	
Agricultura	
Rural Asso	
Agronomic	

Fishery authorities	
Authority	**Description**
Institute for Fisheries Research	• belongs to the Greek Agricultural Organization DIMITRA • supervised by the Ministry of Rural Development and Food • based in Nea Peramos, Kavala operating since 1995 • research activities in the field of fishery, aquatic environment (coastal, transitional and inland waters), exploitation of fishery products and aquaculture
Agricultural Fishery Cooperative of Lagoons	• public body operating since 1950, in the Keramoti Lagoons • free fish farming and development • Products: sea bass, bream, blue crab, calf, fish roe

Stakeholder mapping

Related stakeholders of the study area have been reported

Environmental associations	
Association	**Description**
Hellenic Ornithological Society	Environmental nonprofit organiza the protection of wild birds and t habitats
Greenpeace	International nonprofit organizat highlighting environmental probl promoting effective solutions for and peaceful future
Arktouros	Nonprofit environmental organization dealing with the protection of wildlife and the natural environment
WFF Greece	Global environmental organization, active in more than 100 countries
Greek Biotope/Wetland Centre	Generates knowledge, provides information, raises public awareness of the need for wise use of resources

Other related authorities	
Authority	**Description**
Chamber of Commerce	Responsible for the tourist activities within the delta
Public Power Corporation	Responsible for the reservoir management within the study for power generation purposes

Expected outcomes

Scientific Benefits

Main benefits include:

a) the development and testing of novel tools for coupling climate, eco-hydrology and seawater intrusion models for sustainable water resources management in coastal areas;

b) the introduction of novel applications for the concurrent modelling of hydrologic parameters and coastal ocean dynamics (circulation and sea level) under climate change scenarios;

c) the development of an Integrated Coastal Zone Management (ICZM) tool for the evaluation of aqua-farming under CC applied to selected sites;

Expected outcomes

Societal, environmental, and economic benefits

a) achieve sustainable development;
b) meet the real needs of local inhabitants of coastal zones especially those suffering from scarcity of water and climate change;
c) improve the environmental context by the added value of water resources management and control;
d) increase water availability through seawater intrusion control and artificial recharge (including water reuse);
e) render the water resources professionals (managers, planners and engineers) in targeted areas of the Mediterranean Sea's coastal zone as immediate beneficiaries.

Acknowledgement

This research forms part of the MEDAQCLIM project: Integrated Quantitative Assessment of Climate Change Impacts on Mediterranean Coastal Water Resources and Socio-Economic Vulnerability Mapping, which is financed by National Action Plan: "European R&D Cooperation - Grant Act of Greek partners successfully participating in Joint Calls for Proposals of the European Networks ERA-NETS" and of the "Competitiveness, Entrepreneurship & Innovation" Program.

Ευχαριστώ!