The coupled biogeochemical model SHYFEM-BFM for scenario analysis in the regulated Venice Lagoon system

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The high-resolution finite element coupled model SHYFEM-BFM and Hg simulating water transport, diffusion, and radiative transfer, biogeochemical cycles and pollution in the Venice Lagoon is applied to simulate water circulation, sea level, salinity, water temperature and productivity, contamination.

Model projections for two climate scenarios (RCP 8.5 and RCP 4.5) to the end of the century using projected downscaled atmospheric forcing and boundary conditions from a regional climate model COSMO_CLM and the regional ocean coupled physical-biogeochemical model NEMO+OGSTM-BFM.

Simulations of human regulation, closure of inlets to protect the city from flood events.

Projected changes in the lagoon's thermohaline and hydrodynamics are expected to impact the lagoon's ecology, from individuals to communities, habitat distribution patterns, lagoon ecosystems, and ecosystem services.

Effects on biogeochemistry, contamination and clam farming
The Venice Lagoon Sentinel-2 processed in natural color on 28th February 2019. (Photo: ESA)

Total surface of 550 km$^2$, made up of islands (44 km$^2$), wetlands ("barene") and tidal flats ("velme")

average depth 1m; deep channels allow navigation (65 km$^2$).

11 tributaries: average freshwater discharge $\approx 3 \times 10^6$ m$^3$ day$^{-1}$

3 inlets: $\approx 3.85 \times 10^8$ m$^3$ day$^{-1}$ water exchanged through the inlets $\approx 1/3$ of the total volume in a tidal cycle
Evolving environment and pressures
Some questions \(\rightarrow\) Management responses

How climate changes and human uses affect the lagoon trophic state, contamination levels, state of the ecosystems and their services? \(\rightarrow\) regulation, adaptation, mitigation

How changes in land use affect the Lagoon water quality? \(\rightarrow\) Maximim Load, regulation

How the water regulations affect the lagoon trophic state from the lower to the highest levels? \(\rightarrow\) adaptation

How are contaminated sediments moving/contaminating the lagoon ecosystem? \(\rightarrow\) regulation

Which are the effects on the lagoon Ecosystem Services, such as fishery production? \(\rightarrow\) regulation, adaptation, mitigation
SHYFEM

3D hydrodynamic model
Coupled with several modules: biogeochemistry, ecology, sediment transport, pollution.

High resolution: 6686 nodes
Triangular elements
7 vertical levels

Open sea boundaries

River inputs of water and substances
And point sources

Atmospheric forcing and inputs of water and substances

Coupled models

**HYDRODINAMIC**
- Shallow water Hydrodynamic Finite Element Model

**BOUNDARY**
- River
- Tide

**FORCING**
- Wind
- Irradiance

**BOUNDARY**

**BFM**
- Biogeochemical flux model

**SHYFEM**
- Shallow water Hydrodynamic Finite Element Model

https://bfm-community.github.io/www.bfm-community.eu/
Coupled models, mercury POLLUTION


Rosati et al., Mercury cycling in contaminated coastal environments: modeling the benthic-pelagic coupling and microbial Hg resistance in the Venice Lagoonin prep.
Coupled models, POLLUTION, bioaccumulation

Wind Irradiance

FORCING

HYDRODINAMIC

BOUNDARY

RIVER

BOUNDARY TIDE

SHYFEM

- Shallow water Hydrodynamic Finite Element Model

HYDRODINAMIC

3D

BFM

Biogeochemical flux model

MERCURY

Hg, MeHg

Coupled models, POLLUTION, bioaccumulation
[1] high resolution regional climate model

[2a] statistical model of nutrient input

[2b] statistical model of sea-lagoon boundaries

[3] biogeochemical model of the lagoon of Venice

[4a] Food web model of the lagoon

[4b] clam aquaculture

Rain

T, solar radiation, humidity

Wind, pressure


SCENARIO SIMULATIONS: levels, temperature and salinity up to 2100, RCP 8.5 RCP 4.5

WATERSHED
River discharge, temperature

ATMOSPHERIC FORCING
(Regional downscaled model
(Bucchignani et al., 2016, Zollo et al. 2016).
Atmospheric conditions (wind, rain, pressure, solar radiation): hourly

URBAN
Local urban and seawage inputs of water

SEA
Water levels (Zanchettin et al., 2020)
temperature, salinity: hourly
(Reale et al., 2022)
SCENARIO SIMULATIONS: levels, temperature and salinity up to 2100, RCP 8.5 RCP 4.5

WATERSHED
River discharge, temperature

METEOROLOGY
(Regional downscaled model (Bucchignani et al., 2016, Zollo et al. 2016).
Atmospheric conditions (wind, rain, pressure, solar radiation): hourly

URBAN
Local urban and sewage inputs of water

SEA
Water levels (Zanchettin et al., 2020)
temperature, salinity: hourly
(Solidoro et al., 2021, Reale et al. 2022)
In-situ data

~ 65 variables for a total of over 30 million measurements (2000-2020). Some of the variables:

- river flow rates
- sea level
- current speed (ADCP)
- solar radiation
- atmospheric pressure
- air temperature
- rain
- air humidity
- wind direction and speed
- water temperature
- salinity
- dissolved oxygen
- alkalinity
- pH and redox potential
- turbidity
- dissolved nitrogen
- silicates
- dissolved phosphorus
- dissolved and particulate organic carbon
- chlorophyll-a
WATER RESIDENCE TIMES

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WRT 2019
Average 9 days

WRT 2050 RCP 4.5
Average 10 days

WRT 2100 RCP 4.5
Average 10 days
WATER RESIDENCE TIMES

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WRT 2019
Average 9 days

WRT 2050 RCP 8.5
Average 12 days

WRT 2100 RCP 8.5
Average 15 days
SEA LEVEL RISE, MONTHLY MEANS

2019

no MOSE closures
SEA LEVEL RISE, MONTHLY MEANS

2050

2050 : Sea surface height

no MOSE closures
SEA LEVEL RISE, MONTHLY MEANS

2100 : Sea surface height

no MOSE closures
WARMING, MONTHLY MEANS

RCP 8.5

RCP 4.5
TEMPERATURE ANOMALY, MONTHLY MEANS

2050

2100
RCP 8.5 with MOSE closures

- **mean** (2002-2019) (red line)
- **90th percentile of the climatology (years 2002-2019)** (blue line)
- **model projection far future** (2100) (black line)

**MHW** (Hobday et al., 2016, 2018)

MHW are defined as prolonged episodes with temperatures that reach critical levels (>4 over 90° perc > 4 cons. days)

MHW are already reached in most of the stations in the mid-future scenario, and are present for almost the 30% of time
Anomalies
2050

Chlorophyll DECREASES!!!

Due to Increase in respiration = less productive

However, different assumption can be made regarding the boundary inuptes from the watershed
MOSE CLOSURES

ANOMALY
CLOSE-NOCLOSE
2100
RCP 8.5

DISSOLVED OXIGEN
MOSE CLOSURES

ANOMALY
CLOSE-NOCLOSE
2100
RCP 8.5

Chlorophyll
Coupled mercury models, POLLUTION


Rosati et al., Mercury cycling in contaminated coastal environments: modeling the benthic-pelagic coupling and microbial Hg resistance in the Venice Lagoonin prep.
MeHg

Decrease in 2050
→ Related to a reduction of sediment resuspension

Increase in 2100
→ Related too increase in summer temperatures
Bioaccumulation model

Graph showing changes in mercury concentration in sediment over time.

Map indicating areas of high mercury concentration (A, B, C).

Photos of a shell and a map of a geographic area.
SHYFEM model shows:

• general increase in the frequency and magnitude of extreme conditions in future scenarios, site specific response to CC is high! (temperature, salinity, water levels, water residence times, pH, chlorophyll, oxygen)
• not linear effects, nor uniformly distributed, spatially, but shaped by the combined acting forcing conditions
• increasing intensity and duration of marine heatwaves, with MHW4 occurring almost for the 30% of the days in the RCP 8.5 scenario 2100
• adoption of the downscaled and high-resolution approach allows to address the expected changes at local scales
• crucial to support risk assessment to ecosystems and ecosystem services
Acknowledgmente

Questions?
Climate change simulation scenarios
RCP 4.5 RCP 8.5 2050 2100

Global climate model
CMCC-CM
atmosphere-ocean general circulation model

Italy, 0.0715 ° Subregional mode
COSMO-CLM
Atmosphere boundary

MOSE closures

Observations Adriatic Sea boundary

MFS 16 NEMO
Italy: 0.0625 °
Mediterranean Sea model
Adriatic sea boundaries

Reference simulations
2005 2008 2019

Observations
Atmosphere boundary

Venice Lagoon, 30 m, 2 km
SHYFEM_CLIM model

WATER REGULATION
The comparison of the distribution of the % of times and lagoon surface where the WRT value reaches the thresholds values, in days for the 3 years of reference (black lines), mid-future (blue lines), far-future (red lines) for the two scenarios RCP 8.5, with closures.
Effects on biogeochemistry, analysis in progress

- Temporal shifts in phytoplankton blooms and grazing, anticipated to early spring
- Increase of detritus processes
- Decrease in chlorophyll concentration