ASSIMILATION OF WATER QUALITY DATA IN A 3D ECOSYSTEM MODEL OF THE LAGOON OF VENICE

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Aim: “Best estimate” of the nutrient and phyto fields using Data Assimilation for the lagoon of Venice
Knowledge of the state of the system is important for a sustainable management of the lagoon: water quality target, …

• Data assimilation consists of three parts:
  1. a model → TDM model
  2. a set of observations → MELa1 monitoring
  3. a DA scheme → ESSE - error subspace statistical estimation

• Several tests on the model error formulation

• Results: insight about ecosystem dynamics and estimation of the nutrient and phyto fields
Dejak, Pastres, Solidoro et al. (1987-present)

TDM - Trophic Diffusive Model

3D coupled model

\[
\frac{\partial C_i}{\partial t} = w_{si} \frac{\partial C_i}{\partial z} + \nabla K \nabla C_i + F(C, T, I, \ldots)
\]

Dejak, Pastres, Solidoro et al. (1987-present)

domain and boundaries

7000 cells of 300x300x1 m³

DRAINAGE BASIN

Nutrient loads

Zoo \rightarrow Phyto \rightarrow Oxy

Detritus \[ C \; P \; N \]

NO₃⁻ \; PO₄³⁻ \; NH₄⁺

Nutrients

Exhange through lagoon inlets

AIR

Light intensity

Air deposition

N, P

Air

Water temperature

ADRIATIC SEA

Exhange through lagoon inlets

LIDO INLET
Main findings:

Model simulations show that:

- nitrogen cycle in the system is mainly driven by external input in the system
- exchanges with Adriatic Sea represents an important ‘purification’ process
- exists a spatial variability of productivity (northern basin more rich than southern one) due to presence of rivers
Data for the year 2001 – MELa1

MELa1-Monitoring of the Ecosystem of the Lagoon
(1st example of monitoring of the whole lagoon from 2001 to 2003)

12 Monthly sampling campaigns in 2001

Network of 30 fixed sampling points:
- 2 outside of the inlets
- 8 in channel
- 20 in shallow water area

20 water quality parameters:
- temp, salinity
- DIN (NH4+NO3)
- DIP
- CHLa
...

Sponsored by Consorzio Venezia Nuova
Magistrato alle Acque Venezia
Main findings of MELa1:

- Strong Nutrient and Chlorophyll a gradients from the inner part toward lagoon inlets. And from northern basin toward southern one

- Trophic index from Principal Component Analysis of water quality parameters

- The index is fairly well explained by multiple regression with Salinity (a proxy of the fresh water discharge) and Residence Time (a proxy of exchanges)

The lagoon is strongly affected by input and exchanges.

Fig. 7. Score of each stations in the first components.
Data Assimilation scheme

\[ dC = F(C, t) \cdot dt \]

\[ \text{model} \]

\[ \text{observation} \]

\[ \text{Obs}_k = H \cdot C_k + \nu_k \]

MERGING SCHEME

Filter scheme:

\[ C(+)_k = C(-)_k + K \cdot (\text{Obs}_k - H \cdot C(-)_k) \]

where the gain matrix is

\[ K = P \cdot H^T \cdot \left( H \cdot P \cdot H^T + R \right)^{-1} \]

estimation of P forecast error covariance?

NEW estimation of the state of the system C(+) using Error Subspace Statistical Estimation Scheme (Lermusiaux, 1999)
ESSE (Error Subspace Statistical Estimation) Scheme

Assimilation events: for month 1 to 12

Test on the formulation of:
- model error
- error of initial condition ICs
- error on boundary condition BCs
Testing several stochastic boundary settings: ensemble of BCs is set $\rightarrow$ std of the forecast

\[ dC_i = F(C,t) \cdot dt + d\eta_i, \]
\[ C_i\big|_{x=\text{inlet}} = C + \varepsilon_i, \]
\[ C_i\big|_{x=\text{river}} = \Phi_C \cdot f_R + \nu_i \]
\[ \varepsilon, \nu \in N(0, \text{var}_B) \]
\[ \eta \in N(0, \text{var}_M) \]

BC\textsubscript{inlet} time evolution from observations

BC\textsubscript{river} from monthly estimation ($\Phi_C$) and random function of daily rainfall ($f_R$)

Looking for misfit obs-mod(dots) $<>$ model error forecast (maps)

\[ \eta, \varepsilon, \nu \hspace{1cm} \varepsilon, \nu \text{ time correlated} \hspace{1cm} \eta \text{ not spatial correlated} \hspace{1cm} \eta \text{ spatial correlated} \]

\begin{align*}
\text{var}_{B} &= 0.3 \\
\text{var}_{M} &= 0.05 \\
\text{var}_{M} &= 0.05 \\
\text{var}_{M} &= 0.05
\end{align*}

best choice
Results of ESSE:

1. Eigenvectors of the covariance decomposition (most energetic modes in the system)

2. New estimates of nutrient and phyto fields

3. Evolution of the uncertainty of the estimation
1. Results of ESSE: First Eigenvectors (most energetic dynamics in the system)

**DIN**

- **March**:
  - 1st eigenvector: ~80% of uncertainty explained by 5 first eigenvectors
  - External input from northern rivers

- **April**:
  - 2nd eigenvector: Central rivers & internal dynamics in the northernmost part of lagoon

- **May**:
  - 3rd eigenvector: Other sources

- **June**:
  - ~99% by 20-25 Eigenvectors
2. Results of ESSE: NEW estimation of the FIELDS

*a priori* field (and observation)  
*a posteriori* field (and observation)

**DIN**  
*april*

**PHY**  
*july*
2. Relevance of the results:
WATER QUALITY TARGET FOR THE LAGOON (Italian legislation)

Percentage of time of the year during which the lagoon is above the limit for DIN WQT=0.35mg/l
3. Relevance of the results: Comparison between *a priori* error and *a posteriori* error covariance can help in designing the network of sampling stations.

**A priori error**

**A post error**

Mean of the relative reduction of forecast error

- Strong reduction in northern part but some marginal areas (and southern basin) and areas close to inlets still have quite high uncertainty.

- \[ \text{mod}_\text{err} \text{ reduction} \]

- \[ \text{err}_{\text{mod}} = 60 \text{B setting} \]

- \[ \text{err}_{\text{obs}} = 0.025 \text{obs} \ast 10\% \]
Conclusions

Lagoon of Venice is a laboratory for testing DA methods (model & data available)

Data Assimilation via ESSE allows to get:
- new estimations of nutrient & phytopl. fields
- information on dynamics
- information on the effectiveness of the monitoring network design
Many Thanks
for your attention