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# GHOSH v1.0.0: a novel Gauss-Hermite High-Order Sampling Hybrid filter for computationally efficient data assimilation in geosciences

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*Preprint under review for Geoscientific Model Development, open discussion at* https://gmd.copernicus.org/preprints/

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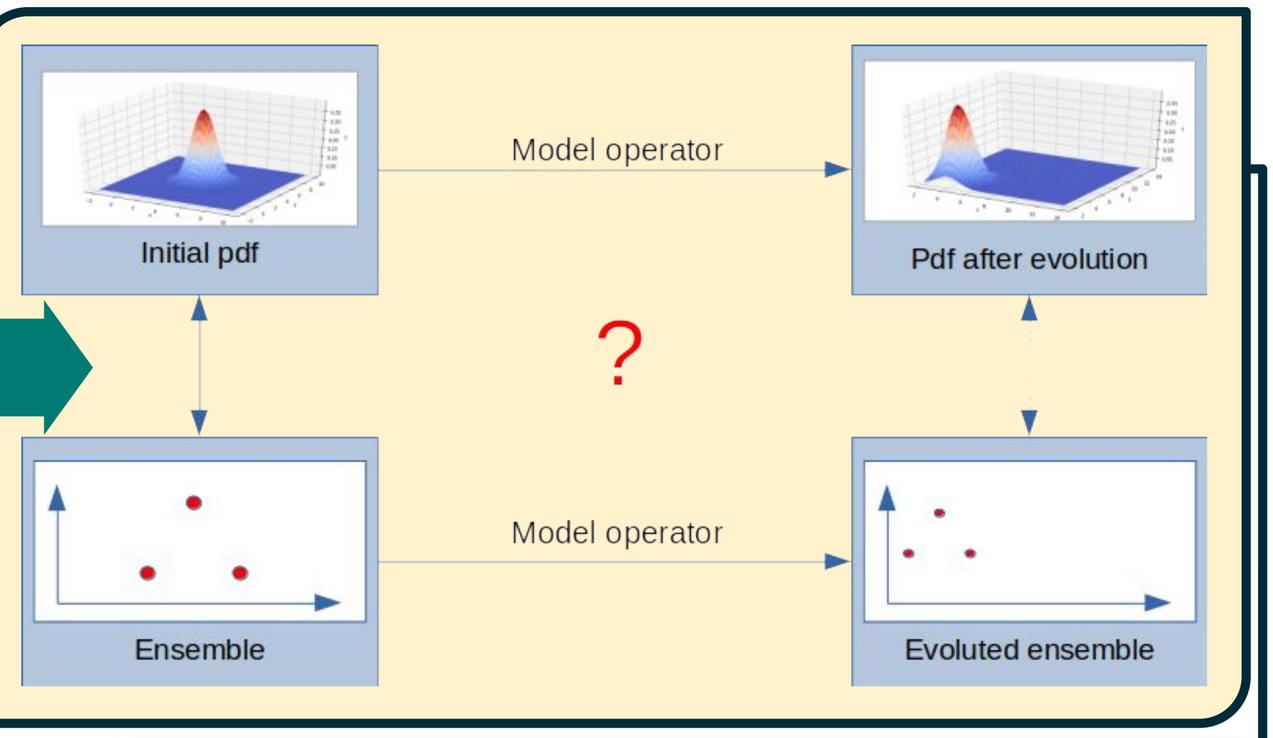
## The GHOSH sampling method

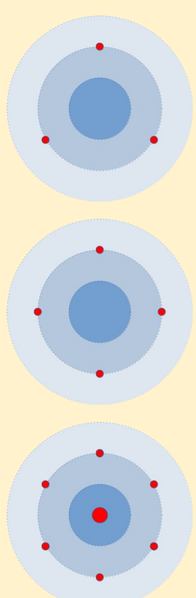
**Three facts you want to know about ensembles**:

1. An ensemble is a representation of the probability density function (pdf) of the uncertainty of the state of the system
2. Evolving the ensemble is not a good proxy of the evolution of the uncertainty pdf, i.e., **the diagram is not commutative**!
3. The ensemble mean after the evolution is affected by an error that can be reduced by increasing the **order** of the sampling method.

A sampling has **order** *h* if the ensemble mean is exact after evolving the pdf with any polynomial model operator of order not bigger than *h*




**Sampling and order examples**



3 ensemble members:
2nd order sampling
*This is the most used sampling in square root / deterministic filters*

4 ensemble members:
3rd order sampling

7 weighted ensemble members:
5th order sampling

**Improved precision**

*is obtained by*

**rising order**

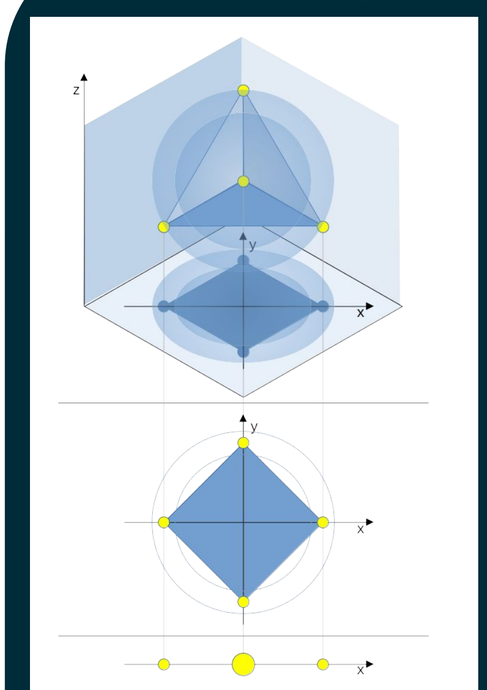
*which requires*

**more members**

*but implies*

**higher computational cost**

**A new *SOLUTION***



4 members in 3D
(2nd order approximation)

*that project in*

4 members in 2D
(3rd order approximation)

*that project in*

3 weighted members in 1D
(5th order approximation)

**Improved precision**

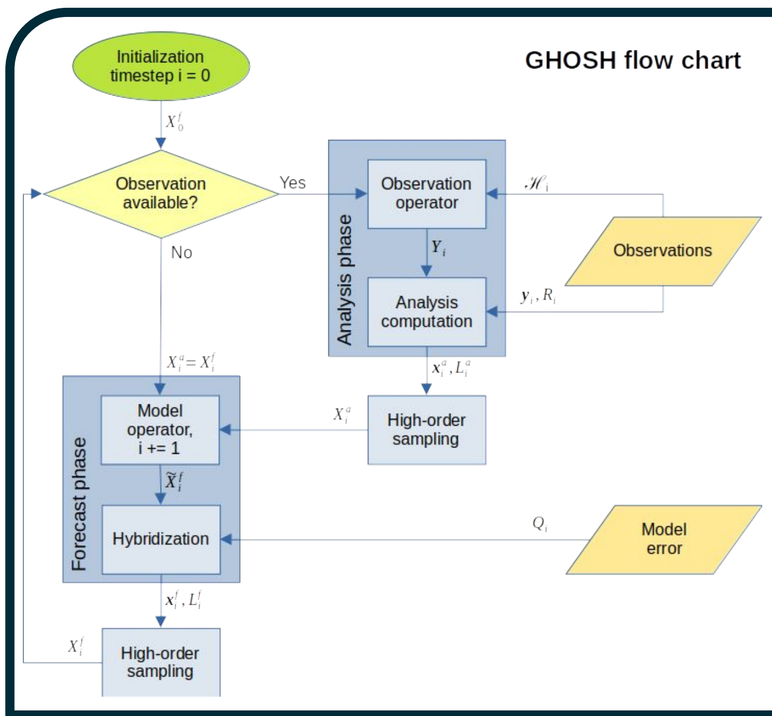
*by*

**rising order in the most relevant PCA components**

**NO more members**

**NO higher computational cost**

GHOSH flow chart



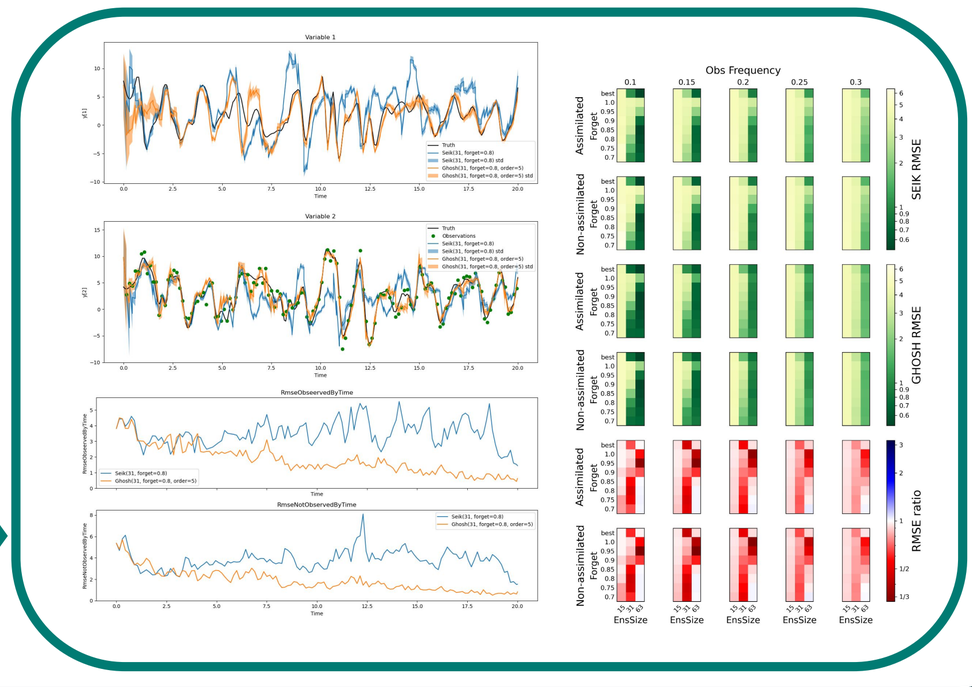

## The GHOSH filter

**Features**:

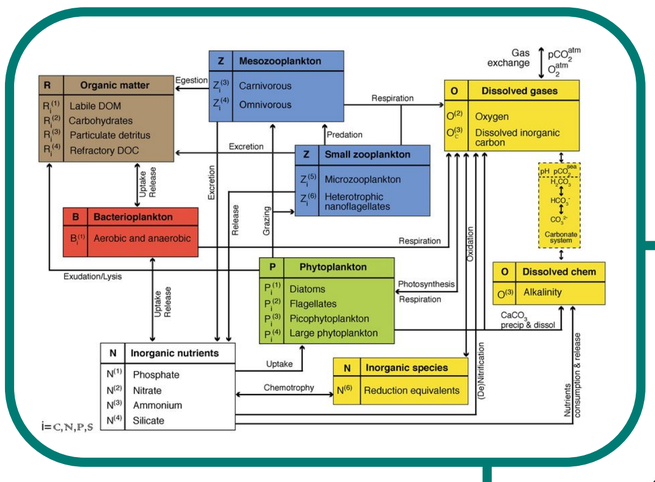
- Two **high-order** resamplings
- Weighted ensemble
- Hybrid covariance
- Improved analysis equations
- **Same computational cost** as a common square root filter (e.g., SEIK, ETKF)

**Twin experiment** (**GHOSH** vs **SEIK**):

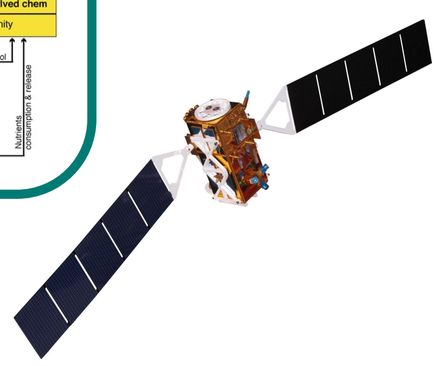
- Lorenz96 model (56000 tests)
- **GHOSH** up to **3 times better** than **SEIK**
- **GHOSH** improves stability

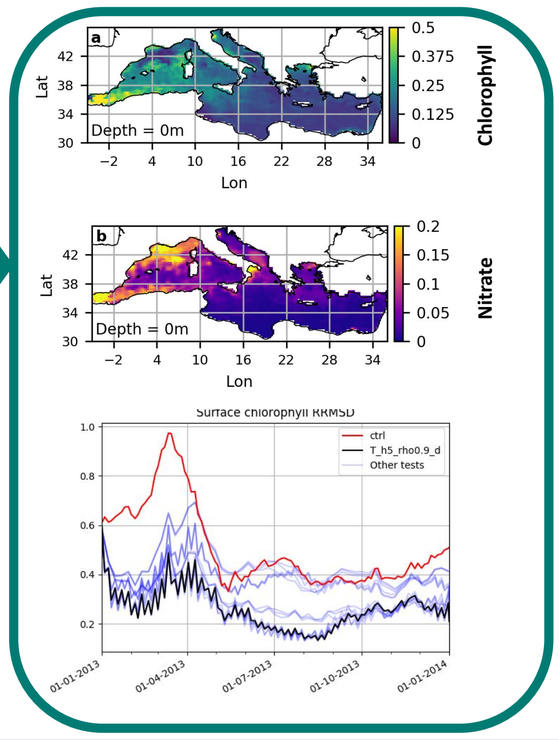



## 3D application in the Mediterranean Sea: Copernicus Marine Service transport-biogeochemical coupled model




**OGSTM-BFM model**
**+**
**Satellite chlorophyll observations**






## RESULTS

**GHOSH parallel realistic implementation:**

- Feasible
- Improves RMSD
- Does not degrade non-assimilated variables
- Over 18 tests, the order resulted highly correlated with improvements in assimilation skill
- Same computational cost as other ensemble method