Observing system design using ensemble optimal interpolation: application to the tropical Indian Ocean mooring array

Objective
A series of Observing System Simulation Experiments (OSSEs) are performed using Ensemble Optimal Interpolation (EnOI) to design an improved mooring array for the tropical Indian Ocean. We apply a procedure to determine the optimal array of observations that minimizes the analysis/posterior error variance. We apply the system to the depth of the 20° isotherm (D20), representing interannual variability, and high-pass filtered mixed layer depth (MLD), representing intraseasonal variability.

Method
We consider fields from two different global ocean models with different resolution, surface fluxes and run for different periods. The details of these models are summarized in Table 1. EnOI produces gridded analyses \( \mathbf{w}' \), by solving

\[
\mathbf{w}' = \mathbf{w} + \mathbf{K} (\mathbf{d} - \mathbf{Hw})
\]

where \( \mathbf{w} \) is the gridded background field that is here defined as the temporal mean from a long model run; \( \mathbf{K} \) is the Kalman gain; \( \mathbf{d} \) is a vector of observations; \( \mathbf{H} \) interpolates from grid- to observation-space; \( \mathbf{R} = \epsilon' \mathbf{I} \) is the observation error covariance matrix, where \( \epsilon = 4 \) m is the assumed observation error; \( \mathbf{P} = \mathbf{A} \mathbf{I} - \mathbf{H} \mathbf{R} \mathbf{H}^{-1} \) quantifies the background error covariances, where \( \mathbf{I} \) is the ensemble size (here equivalent to the number of realizations from a long model run); \( \mathbf{A} = [\mathbf{w}_1, \mathbf{w}_2, ... , \mathbf{w}_n] \) is a matrix of anomalies; and \( \mathbf{w}' \) is the ith model anomaly from the background field/long-term mean. The theoretical analysis error covariance matrix \( \mathbf{P}^T \) resulting from (1) is given by

\[
\mathbf{P}^T = \mathbf{P} + \mathbf{K} \mathbf{R} \mathbf{K}^{-1}
\]

The prior and posterior error variances are given by the diagonals of \( \mathbf{P}^T \) and \( \mathbf{P} \), respectively; and an averaged background and expected analysis errors (EAE) are given by \( \sqrt{\text{trace} (\mathbf{P}^T)/n} \) and \( \sqrt{\text{trace} (\mathbf{P})/n} \), where \( n \) is the number of grid points.

We seek to define \( \mathbf{H} \), such that the EAE is minimized. In practice, we start with locations at every model grid point, we eliminate the location that, when withheld, gives the smallest EAE. We recursively repeat the procedure until the desired number of locations remain.

Results
The standard deviations of D20 and MLD are shown in Figure 1. Under the assumptions of (1-2), these fields can be regarded as prior error estimates.

The optimal observation locations for D20 and MLD are presented in Figure 2, for experiments using the ACOM2 and ACOM3 ensemble for two domains that extend within ±15º and ±25º of the equator. We note that while the details of the arrays differ, the general features are quite similar. For example, for D20, the optimal arrays tend to have many observations within 5º of the equator, and particularly to the east.

Conclusions
We find that in general, observations south of 8ºS and off the Indonesian coast are most important for resolving interannual variability; while observations within 5º of the equator; and particularly to the east, are important for resolving intraseasonal variability.

### Table 1 Details of model configurations

<table>
<thead>
<tr>
<th></th>
<th>ACOM2</th>
<th>ACOM3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resolution</td>
<td>2º, 0.5-1.5º, 25 levels</td>
<td>0.5º, 0.33º, 33 levels</td>
</tr>
<tr>
<td>Wind forcing</td>
<td>NCEP/NOAA</td>
<td>FSU</td>
</tr>
<tr>
<td>Shortwave heat flux</td>
<td>as above</td>
<td>OLR = NCEP</td>
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</tbody>
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