Subsea cable observing system design with regional models

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1. SMART cables

2. Bottom pressure anomaly

3. Observing system assessment

Deep Ocean Observing

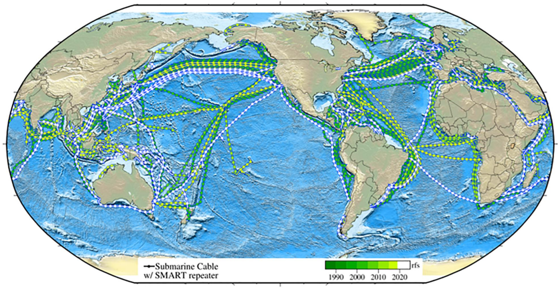
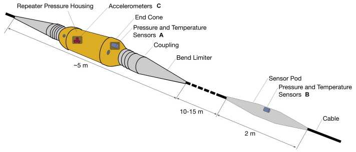


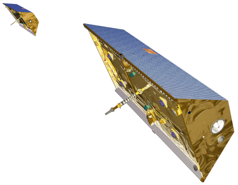
Figure 1: Proposed SMART sensor locations [Howe et al., 2019].

- Ocean observing system: *in situ* (buoys, moorings, ships) and remote (satellite)
- Deep ocean relatively unobserved/undersampled
- Proposed global network of scientific sensors "piggybacking" telecommunications cables on the ocean floor

SMART Cables



	SMART	GRACE
frequency	hourly	monthly
in situ	✓	✗
no aliasing	✓	✗



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Bottom pressure anomaly and wind

- Wind stress dominates seasonal bottom pressure changes relative to other atmospheric controls [Fukumori et al., 2015][Chen et al., 2023].
- During bottom pressure data assimilation, wind stress controls will receive the strongest adjustments
- In turn, constrain geostrophic transport

Adjoint Reconstruction

Consider the QoI of bottom pressure:

$$\mathcal{J}(t) = p_b$$

and it's monthly mean anomaly

$$\delta\mathcal{J}(t) = p_b - \overline{p_b}$$

Taylor series reconstruction using gradients w.r.t weekly forcing anomalies ϕ_i

$$\widetilde{\delta\mathcal{J}}(t) = \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial \mathcal{J}}{\partial \phi_i(\mathbf{x}, \Delta t)} \delta\phi_i(\mathbf{x}, t - \Delta t)$$

Q: Can we demonstrate the wind stress-bottom pressure connection at higher frequencies?

Adjoint Reconstruction

Consider the QoI of bottom pressure:

$$\mathcal{J}(t) = p_b$$

and it's ~~monthly~~ daily mean anomaly

$$\delta\mathcal{J}(t) = p_b - \overline{p_b}$$

Taylor series reconstruction using gradients w.r.t ~~weekly~~ hourly forcing anomalies ϕ_i

$$\widetilde{\delta\mathcal{J}}(t) = \sum_i \sum_{\mathbf{x}} \sum_{\Delta t} \frac{\partial \mathcal{J}}{\partial \phi_i(\mathbf{x}, \Delta t)} \delta\phi_i(\mathbf{x}, t - \Delta t)$$

Q: Can we demonstrate the wind stress-bottom pressure connection at higher frequencies?

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Observing System Simulated Experiments (OSSEs)

- Nature run
  - High resolution, high fidelity
  - Source of synthetic SMART data
  - Instrument, representation error
- Base/data assimilation model
  - Coarser, differing physics
  - Optimizable

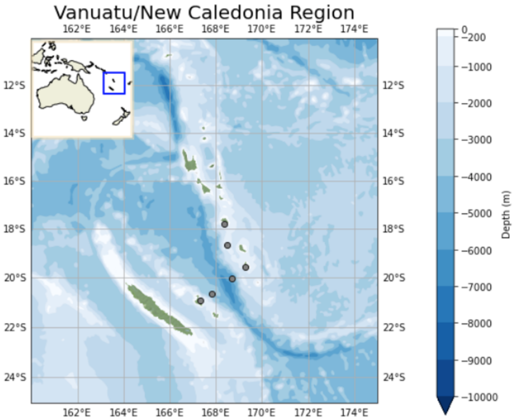


Figure 2: Regional of interest encompassing islands of Vanuatu and New Caledonia.

Base model-nature run comparison

	base model	nature run
Horiontal grid spacing [degrees]	1/6	1/48
Vertical levels	50	90
Surface level thickness [meters]	10	1
Atmospheric forcing	6-hourly ECMWF analysis 0.14-degree grid bulk formulae/relative wind	6-hourly ERA-interim analysis 0.7-degree grid bulk formulae
Atmospheric load	No	Yes
Tides	No	Yes
Barotropic time-stepping	Adams-Bashforth	Crank-Nicolson
Time step [seconds]	120s	25s

Table 1: Comparison of regional model to nature run [Gallmeier et al., 2023].

Synthetic data: vertical representation

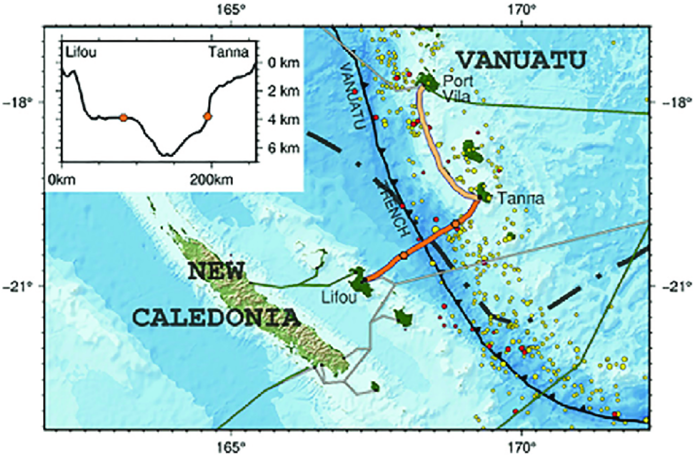


Figure 3: Proposed SMART cable connecting Vanuatu and New Caledonia, a SMART repeater situated on either side of the New Hebrides Trench.[Howe et al., 2019]

Synthetic data: horizontal representation

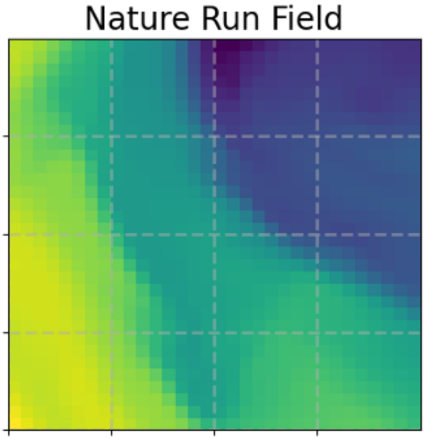
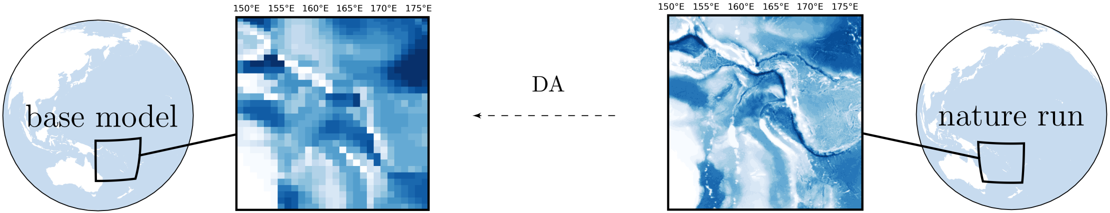
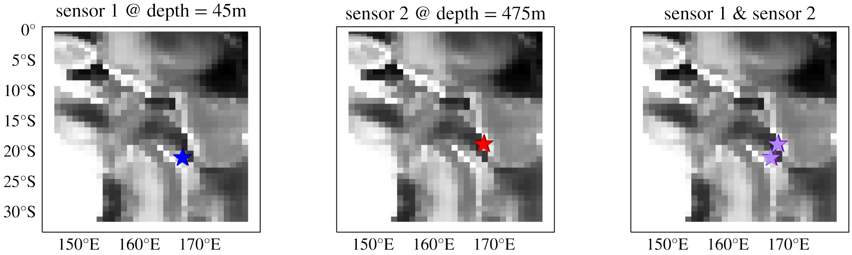


Figure 4: Representing a nature run observation (single pixel) in a coarser model (grey squares) requires we carry some notion of representation uncertainty.

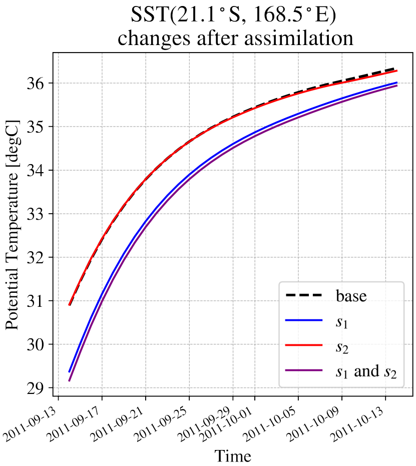
Observing System Simulated Experiments (OSSEs)

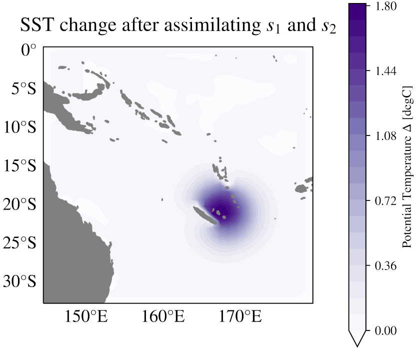


Example OSSE: Two temperature sensors



Example OSSE: Two temperature sensors





OSSE result: Skill score comparison

Compare DA with NR fields with simple mean-squared difference

$$\mathrm{MSD}(x,y) = \frac{1}{n}\sum_{i=1}^{N}\left[(x_i - \langle x\rangle) - (y_i - \langle y\rangle)\right]^2$$

Normalized MSD relative to reference experiment is then

$$\mathrm{MSD}_{\mathrm{NORM}} = \frac{\mathrm{MSD}_{\mathrm{TRIAL}}}{\mathrm{MSD}_{\mathrm{REF}}}$$

and a skill score is assigned:

$$\mathcal{S} = 1 - \mathrm{MSD}_{\mathrm{NORM}}.$$

For our example, we compute MSD of SST

$$\mathrm{MSD}_{\mathrm{NORM}} = \frac{\mathrm{MSD}(\mathrm{SST}_{\mathrm{TRIAL}}, \mathrm{SST}_{\mathrm{NR}})}{\mathrm{MSD}(\mathrm{SST}_{\mathrm{REF}}, \mathrm{SST}_{\mathrm{NR}})}$$

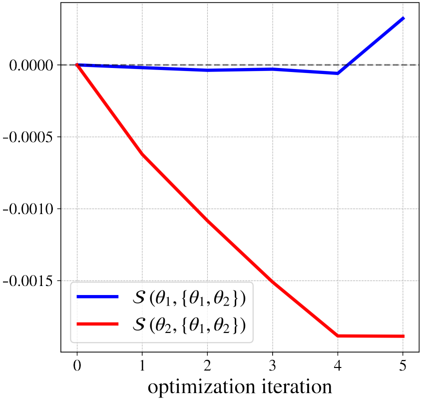


Figure 6: Regional of interest encompassing islands of Vanuatu and New Caledonia.

Uncertainty Quantification

- Endow parameters with notion of (e.g. Gaussian) uncertainty
- Curvature of misfit cost function provides data-informed directions
- Project QoI sensitivities onto data-informed subspace
- Compute dynamic proxy potential, i.e. QoI uncertainty reduction in the face of new data [Loose and Heimbach, 2021]

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