Uncertainty Quantification of Ocean Driven Melting Under the Pine Island Ice Shelf, West Antarctica

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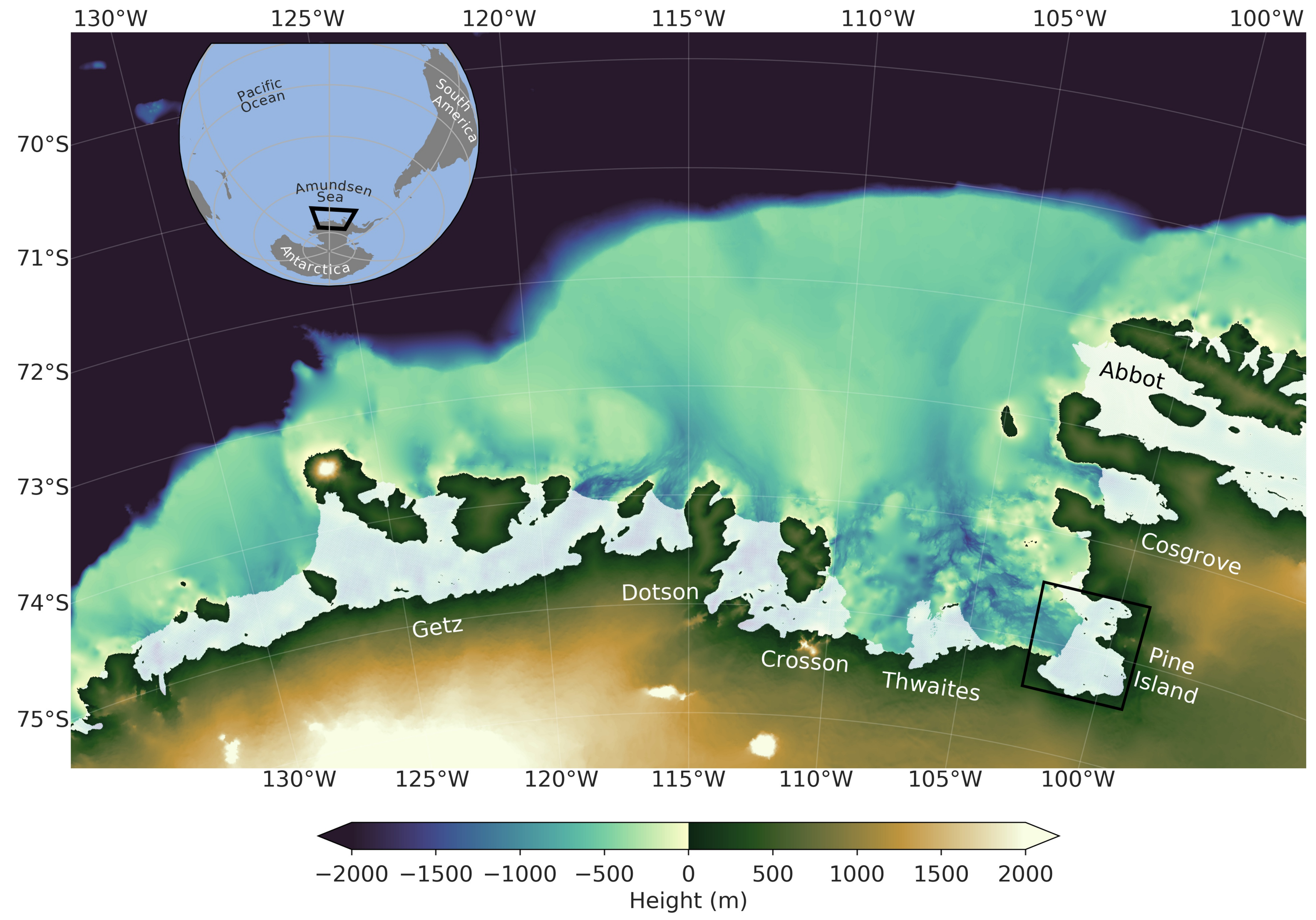
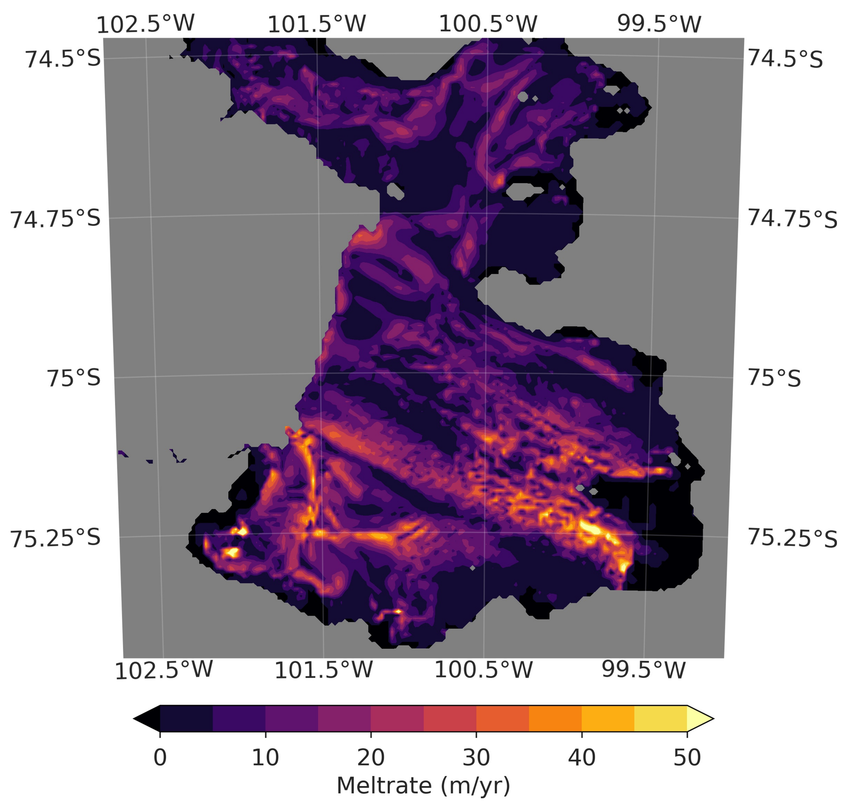
Motivation



- Amundsen Sea ice shelves have some of the highest meltrates in Antarctica, e.g. (Adusumilli et al., 2020)
- This leads to ice shelf thinning, glacial mass loss, and sea level rise (Fürst et al., 2016; Gudmundsson et al., 2019)
- Warm waters access the deepest portions of the ice shelves and drive high meltrates (Jacobs et al., 2011)

Meltrate Estimate

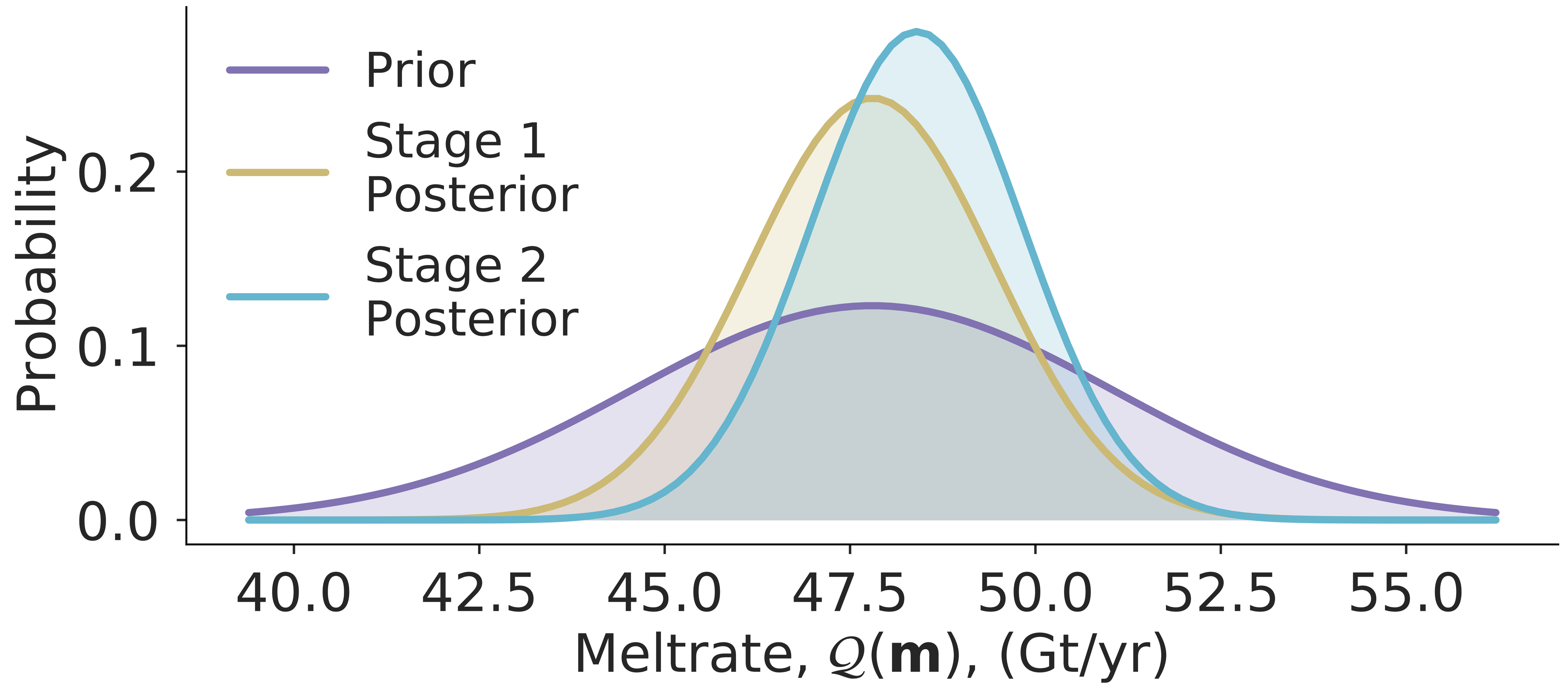


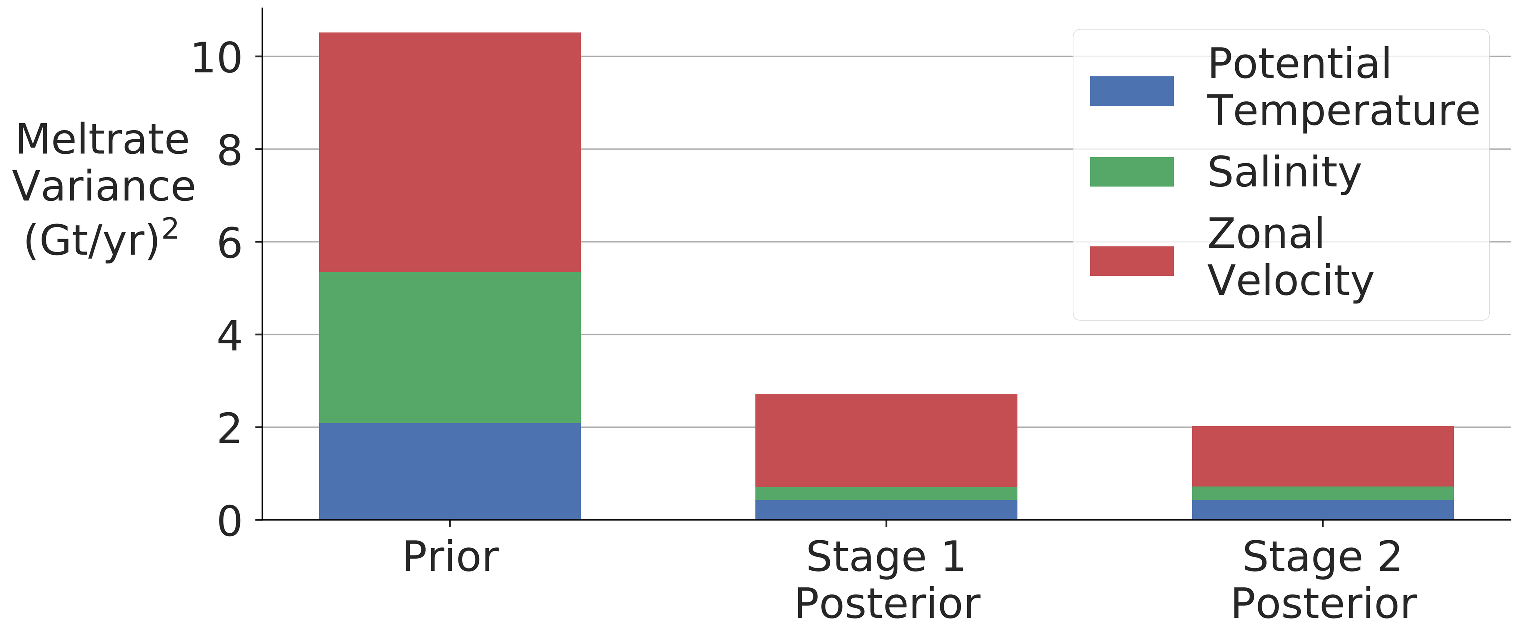
$$\mathcal{Q}(\mathbf{m}) = \frac{1}{t_f - t_0} \int_{t_0}^{t_f} \int_{\partial\Omega_{\text{ice}}} \mathcal{F}^S_{\text{ice}}(\mathbf{m}; \mathbf{x}, t)\, d\mathbf{x} dt$$

- $\mathcal{F}^S_{\text{ice}}$: meltrate field
- $\mathbf{m}$: Uncertain open boundary temperature, salinity, and velocity fields
- $\mathcal{Q}(\mathbf{m})$: spatially integrated, temporally averaged meltrate

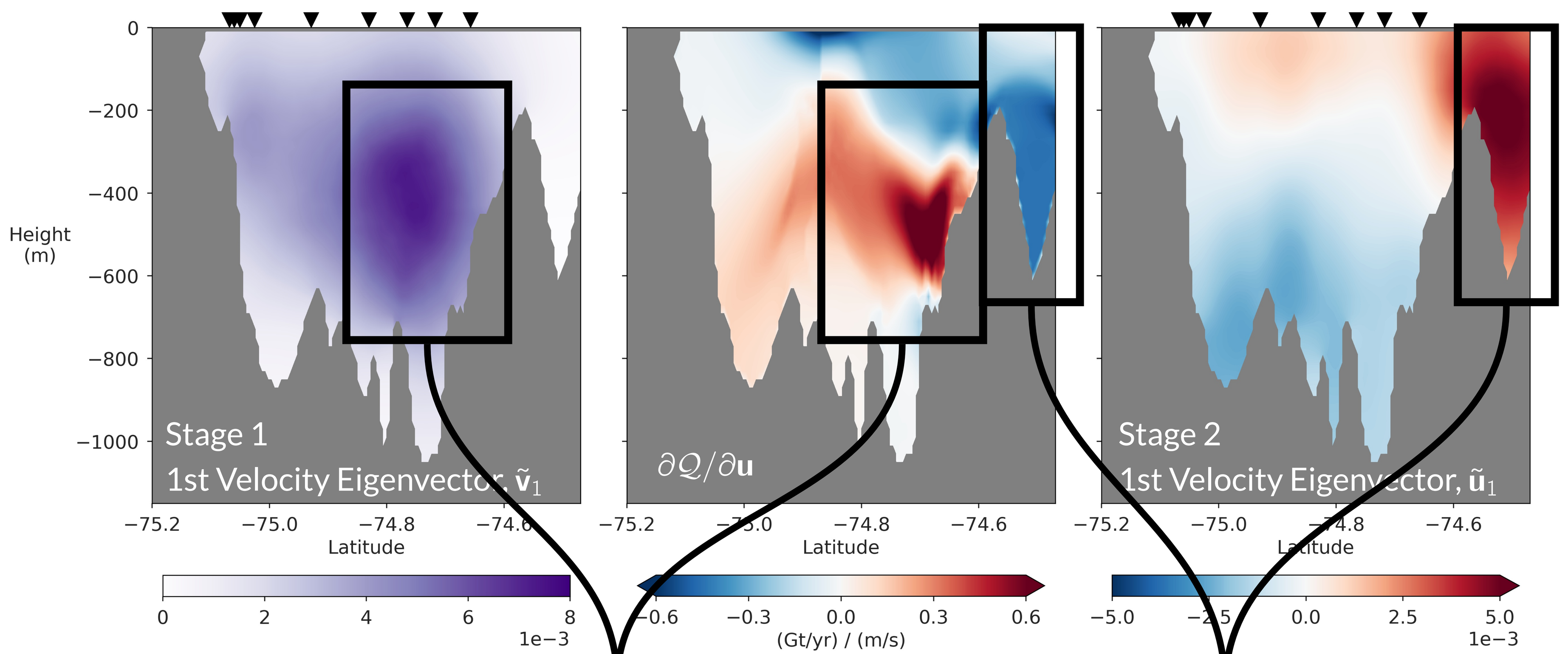
What are the uncertainties, stemming from the open boundary conditions?

Multi-Stage Uncertainty Quantification





The Informed Regions of the Velocity Field



$$\frac{\lambda_1}{\lambda_1 + 1}(\tilde{\mathbf{v}}_1^T \mathbf{q})^2$$
Stage 1 Info Gain

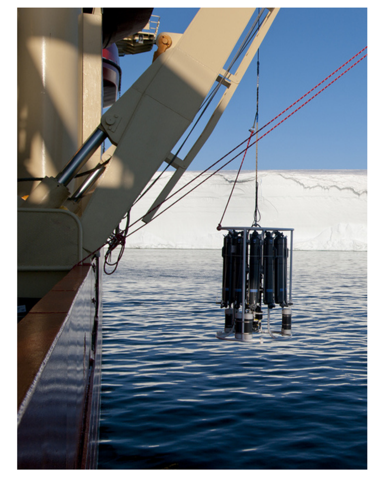
$$\frac{\mu_1}{\mu_1 + 1}(\tilde{\mathbf{u}}_1^T \mathbf{q})^2$$
Stage 2 Info Gain

Main Results

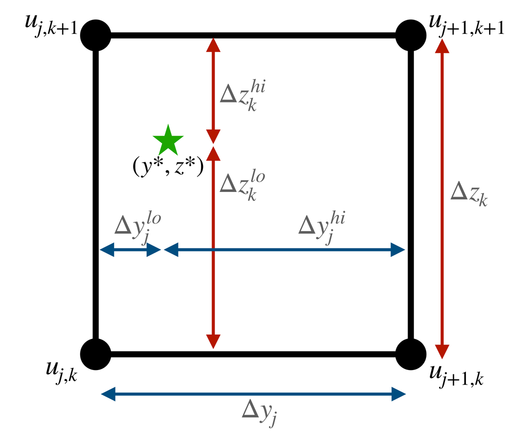
- Optimal Interpolation constrains open boundary conditions near CTD/LADCP measurements
- Unobserved region informed via model dynamics during physics informed inference
- Standard deviation in meltrate reduced by 90% relative to prior 3.2 Gt/yr

Bayesian Inference for Open Boundary Conditions

Stage 1: Optimal Interpolation, info gain from:

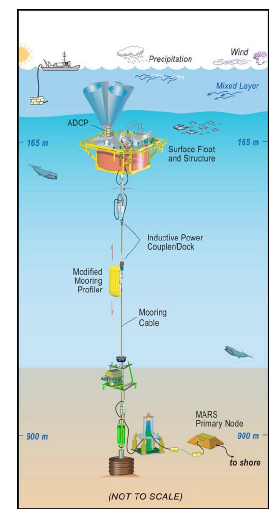


CTD/LADCP observations at open boundary

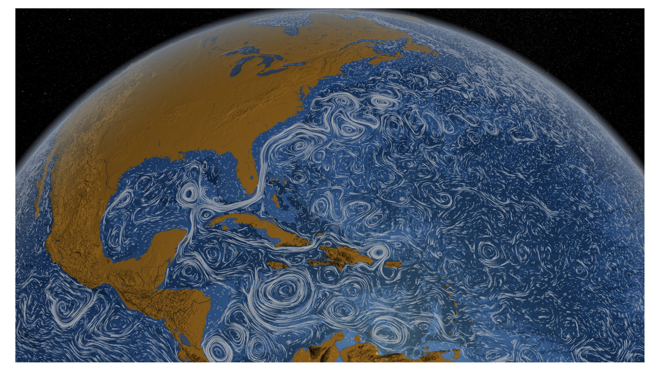


Interpolation Operator (no dynamics)

Stage 2: Physics Informed Inference, info gain from:



Mooring observations closer to ice shelf



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Meltrate Uncertainty Propagation

Using adjoint model, compute sensitivity of meltrate to open boundaries,

$$\mathbf{q} := \frac{\partial \mathcal{Q}}{\partial \mathbf{m}^T}$$

Map eigenvalue decomposition of posterior covariance onto meltrate via sensitivity,

$$\mathbf{q}^T \Gamma_{\text{post}} \mathbf{q} \simeq$$

$$\underbrace{\mathbf{q}^T \Gamma_{\text{prior}} \mathbf{q}}_{\text{Prior Uncertainty}} - \underbrace{\sum_{i=1}^{r} \frac{\lambda_i}{\lambda_i + 1}(\tilde{\mathbf{v}}_i^T \mathbf{q})^2}_{\text{Stage 1 Info Gain}} - \underbrace{\sum_{i=1}^{l} \frac{\mu_i}{\mu_i + 1}(\tilde{\mathbf{u}}_i^T \mathbf{q})^2}_{\text{Stage 2 Info Gain}}$$

References

(Adusumilli et al., 2020) doi: 10.1038/s41561-020-0616-z
(Fürst et al., 2016) doi: 10.1038/nclimate2912
(Gudmundsson et al., 2019) doi: 10.1029/2019GL085027
(Jacobs et al., 2011) doi: 10.1038/ngeo1188