Statistical inversion of surface tracers to predict fine-scale near-surface ocean currents

Rick de Kreij[1], Andrew Zammit-Mangion[2], Matt Rayson[1], Nicole Jones[1], and Andrew Zulberti[1]

1. School of Earth and Oceans, and the Oceans Institute, The University of Western Australia, Perth, Australia **(rick.dekreij@research.uwa.edu.au)**
2. School of Mathematics and Applied Statistics, University of Wollongong, Wollongong, Australia

1. Submesoscale sea surface currents

- Vital for climate, marine ecosystems, and transporting nutrients
- Direct in situ measurements are sparse in space or time, missing submesoscale dynamics
- **Goal**: predict surface currents from remotely-sensed tracers, like sea surface temperature (SST), via a physics-informed, uncertainty-aware statistical model

2. Indirect remote sensing method

Gaussian process (GP) prediction of surface currents using the tracer transport equation:

$$\underbrace{\frac{\partial T}{\partial t}}_{\text{temp. change in time}} = -\underbrace{\boldsymbol{v}\cdot\nabla T}_{\text{advection}} + \underbrace{S}_{\text{vertical heat flux}}$$

Given the observed SST, we want to estimate $\boldsymbol{v} = (u, v)'$ and S.

We discretise on a grid and write the tracer transport eq. as a linear system:

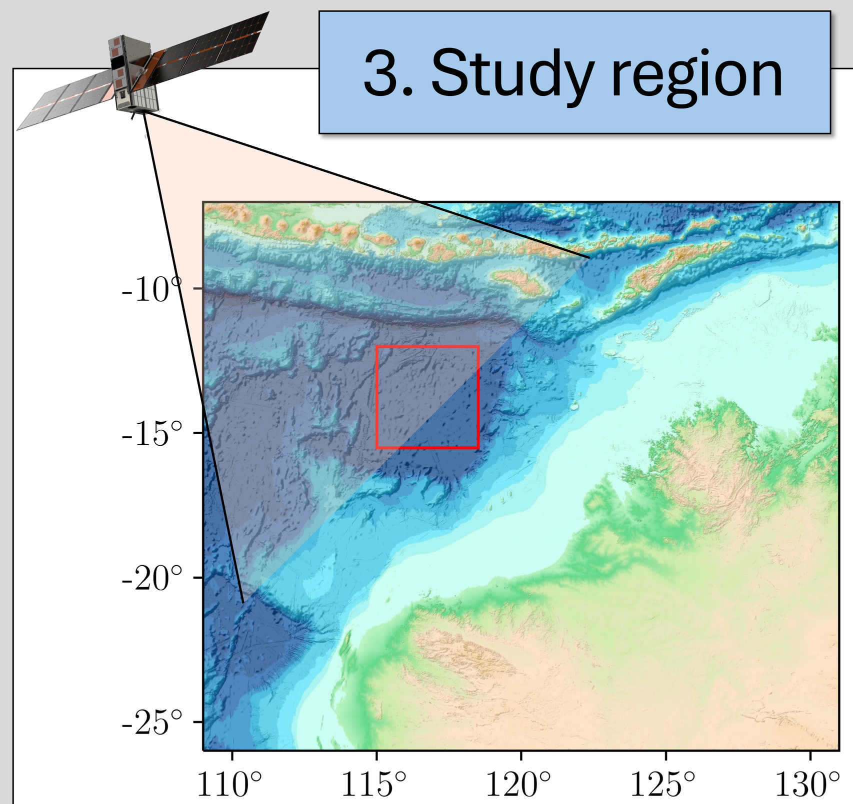
$$\mathbf{z} = \mathbf{A}\mathbf{x}$$

$$\underbrace{\begin{pmatrix} \left.\frac{\partial T}{\partial t}\right|_1 \\ \vdots \\ \left.\frac{\partial T}{\partial t}\right|_N \end{pmatrix} = \begin{bmatrix} -\left.\frac{\partial T}{\partial x}\right|_1 & & & -\left.\frac{\partial T}{\partial y}\right|_1 & & & 1 & & \\ & \ddots & & & \ddots & & & \ddots & \\ & & -\left.\frac{\partial T}{\partial x}\right|_N & & & -\left.\frac{\partial T}{\partial y}\right|_N & & & 1 \end{bmatrix}}_{\text{observed}} \underbrace{\begin{pmatrix} u_0 \\ \vdots \\ u_N \\ v_0 \\ \vdots \\ v_N \\ S_0 \\ \vdots \\ S_N \end{pmatrix}}_{\text{model parameters}}$$

- We model u, v, and S as GPs with covariance functions whose parameters are estimated from the observed SST.

Using GP regression, we find the predictive distribution of the surface currents.

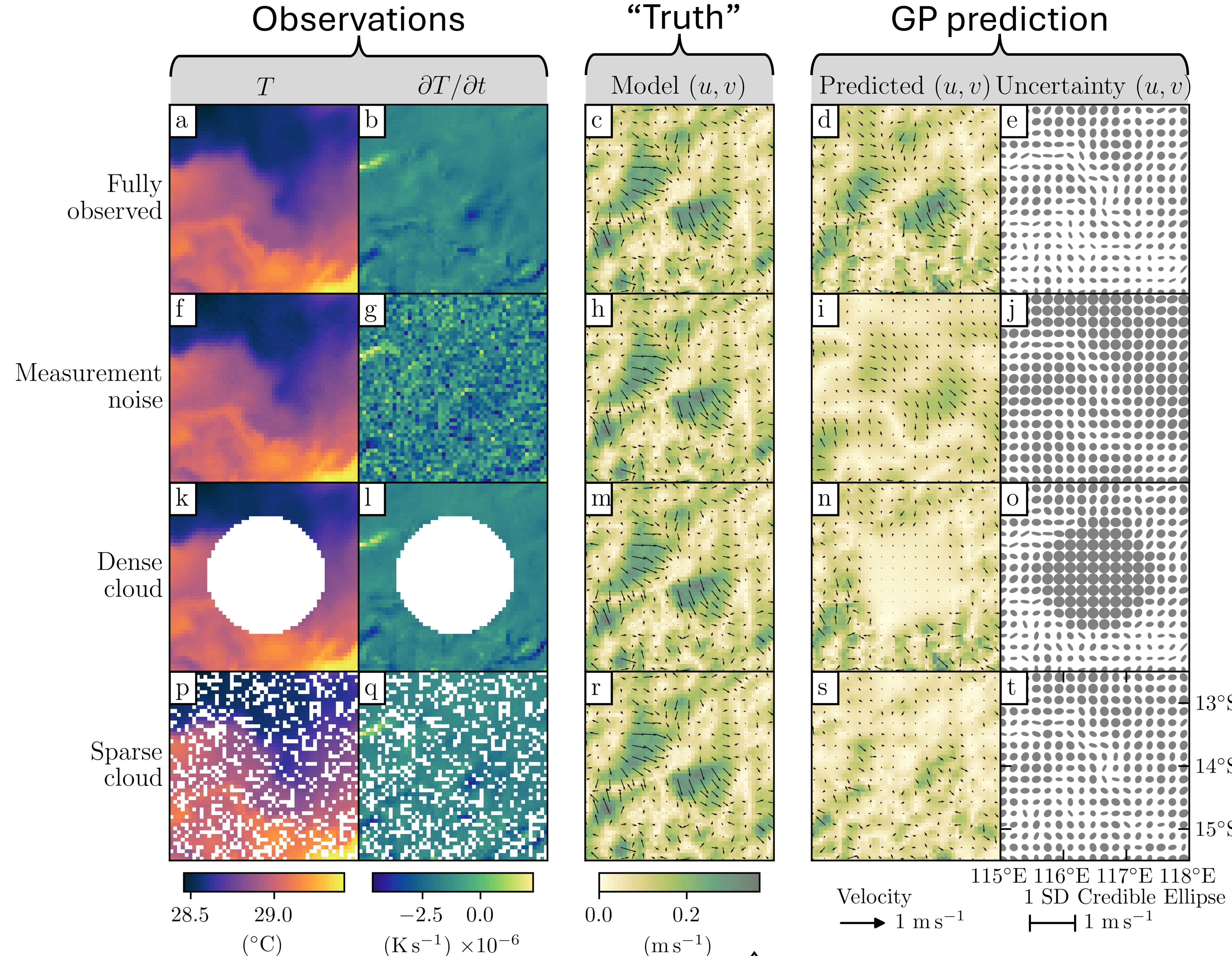
3. Study region



- Abyssal region in eastern Indian Ocean
- Average depth of 5.7 km
- Domain of 3° by 3°
- Grid of 50 by 50 points, resolution of 7 km

Fig 1. Study region indicated in red

4. Apply to numerical observations



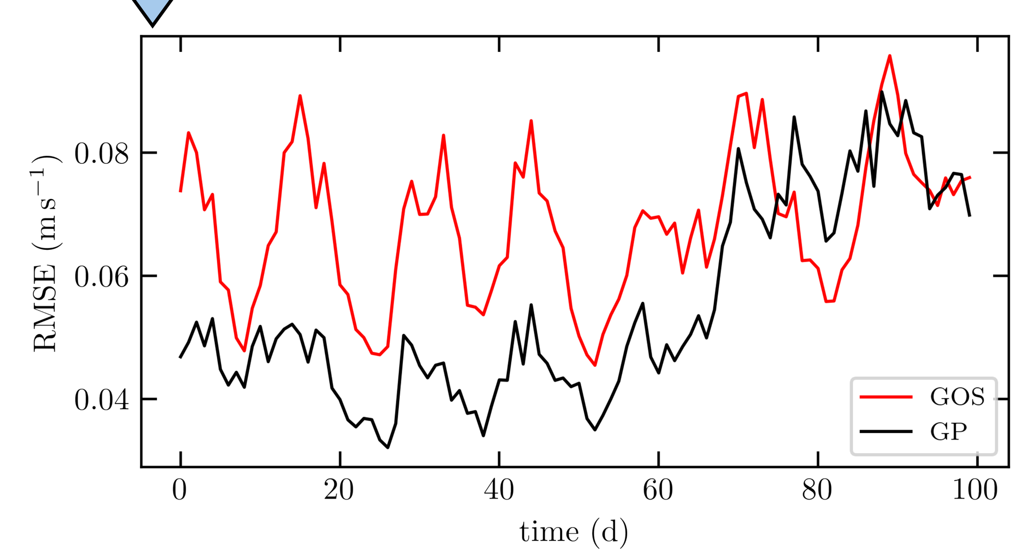
Validation using numerical model: SUNTANS (Rayson et al., 2021)

- Simulate noise and cloud cover on the SST
- Velocity prediction: mean and uncertainty
- Compare to the "true" currents of the numerical model

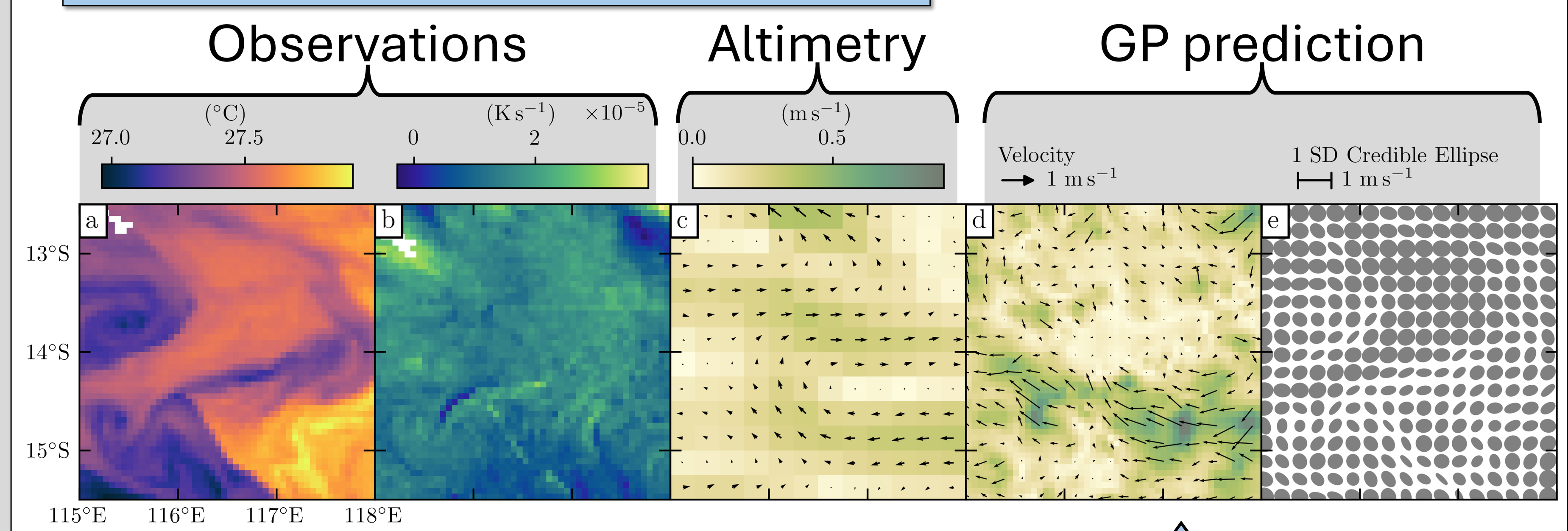
Fig 2. Simulation experiments: using the observations we predict the velocity which we can compare to the "truth"

- Accurate prediction down to 7 km resolution, especially with high SST gradients
- Handles measurement error
- Effective under cloud cover, with increased prediction uncertainty in the obscured areas
- Outperforms the Global Optimal Solution (GOS) of Chen et al. (2008)

Fig 3. Evolution of the GP model performance compared to the GOS, showing the RMSE in time



5. Apply to satellite observations



Observed satellite SST of Himawari-9

Compare to Copernicus L4 altimetry-derived currents

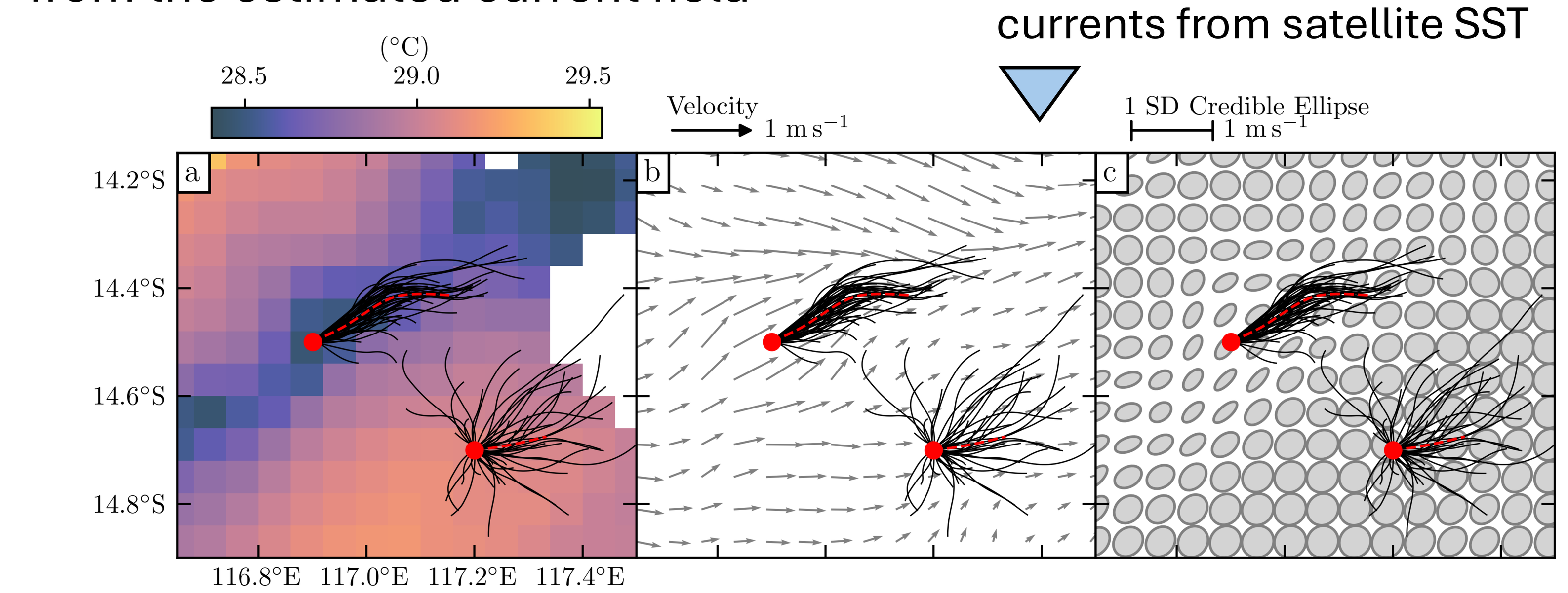
- Overlap in large-scale features
- GP prediction resolves down to submesoscale
- GP prediction of total current while altimetry covers only the geostrophic component

Fig 4. GP prediction of satellite observed SST compared to altimetry-derived currents

6. Propagate uncertainty

- Simulate possible particle trajectories from the estimated current field

Fig 5. Particle trajectories simulated over 24h using distribution of GP-predicted currents from satellite SST



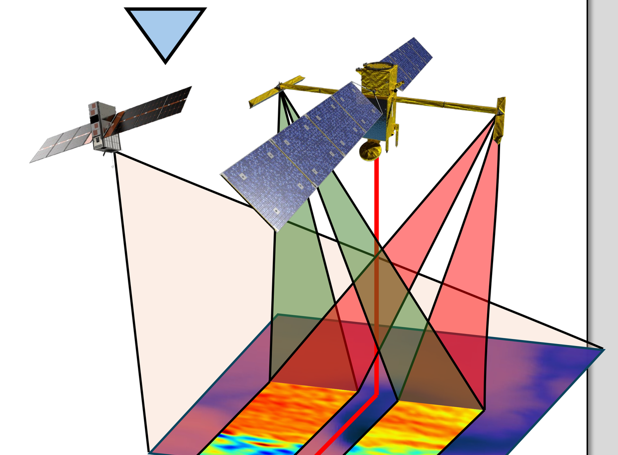
7. Conclusion

- Solved the 2D tracer equation using a physically informed statistical approach
- Accurate predictions even with weak SST gradients
- Handles measurement error and cloudy SST: no explicit pre-filtering needed

Future work

- Include time
- Include sea surface height (SSH)

Fig 6. Fusion of SSH and SST observations to predict currents



Acknowledgement

All authors were supported by the Australian Research Council (ARC) Industrial Transformation Research Hub for Transforming energy Infrastructure through Digital Engineering (IH200100009), and ARC Discovery Project (DP210102745). AZ was also supported by ARC Linkage Project, LP210200613.

References

Chen, W., Mied, R. P., and Shen, C. Y. (2008). Near-surface ocean velocity from infrared images: Global Optimal Solution to an inverse model. Journal of Geophysical Research, 113(C10):C10003.

Rayson, M. D., Jones, N. L., Ivey, G. N., and Gong, Y. (2021). A seasonal harmonic model for internal tide amplitude prediction. Journal of Geophysical Research: Oceans, 126(10):e2021JC017570.

Vote