Inferring surface currents from wave observations in operation

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Albert Zulberti
+ Friends (incl. Matt Rayson, Paul Branson, Jeff Hansen, Nicole Jones, Rodrigo Garcia, Lachlan Astfalck)

UWA
PERTH · AUSTRALIA

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rps

TIDE
ARC Research Hub for
Transforming energy Infrastructure
through Digital Engineering

Project aim

ISSUE:

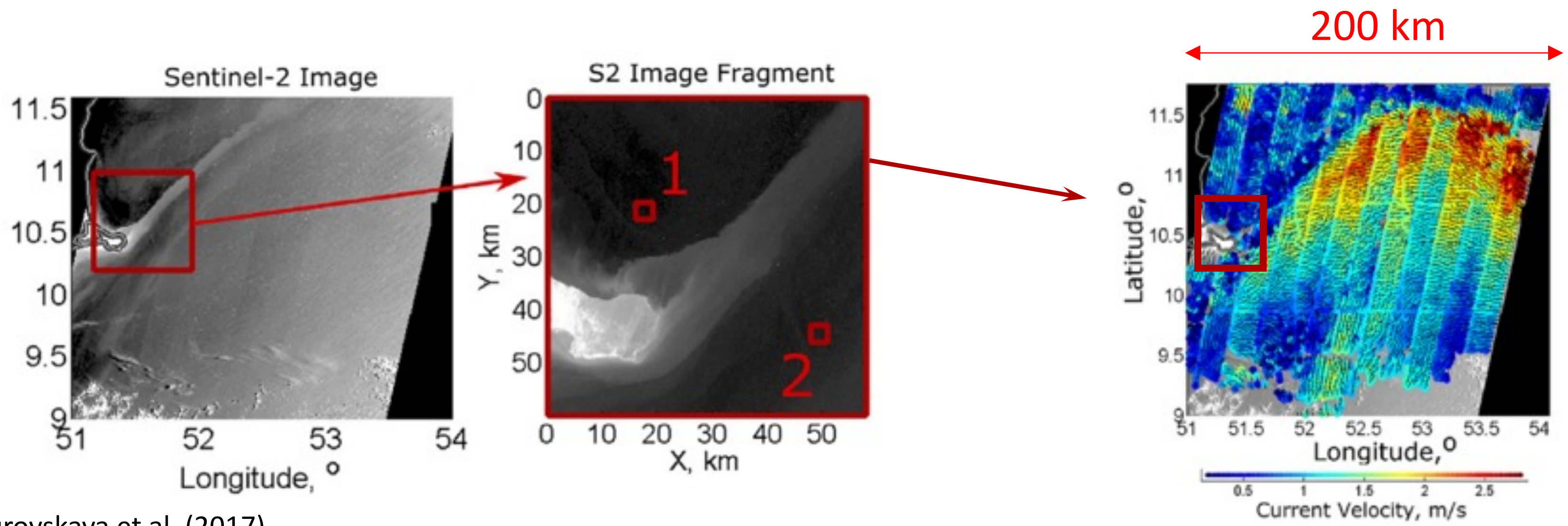
There are no tools for **rapid** quantification of ocean surface currents **at scale** that are viable to support **operational decision making**

OPPORTUNITY:

Methodological, technological and economic developments are always presenting new opportunities

– Even for old methods

AIM: **Progress** towards an **operational** tool for surface current estimation using **surface wave inversion**



Focus of this talk:

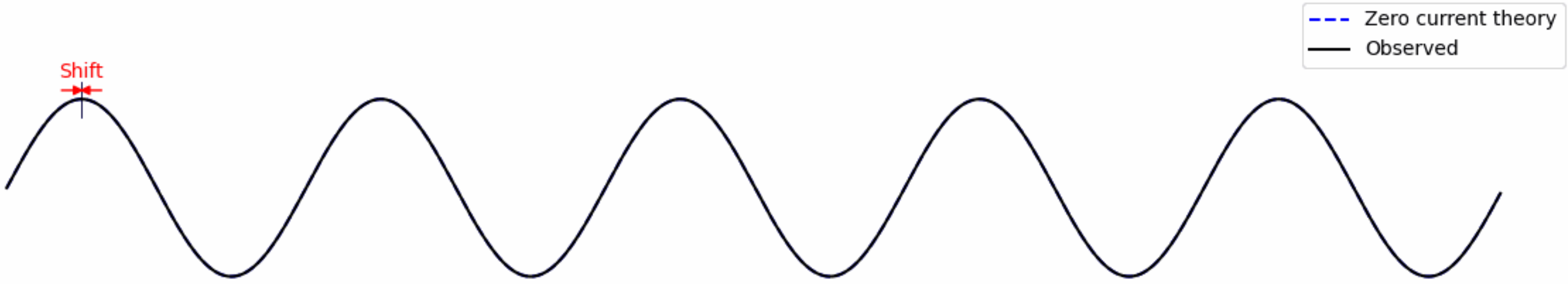
How should we manage this uncertainty in operation?

Figures from Yurovskaya et al. (2017)

Background:

Single wave in the presence of currents

Current direction ->



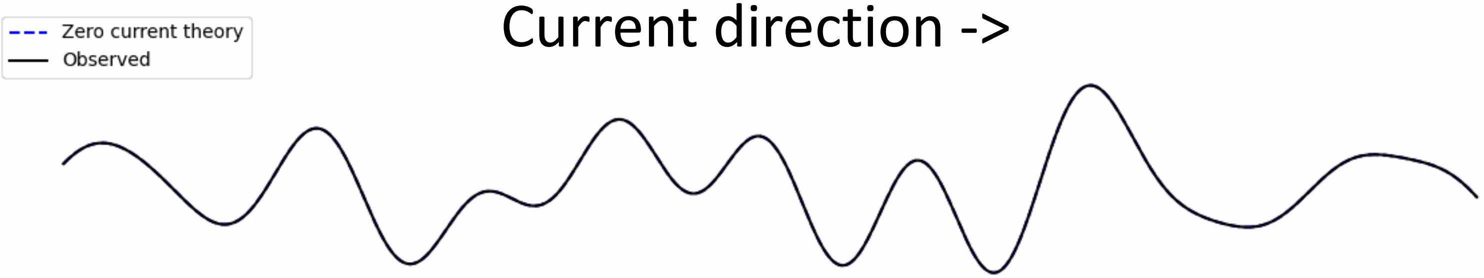
Current speed = Shift / Time

(Doppler shift)

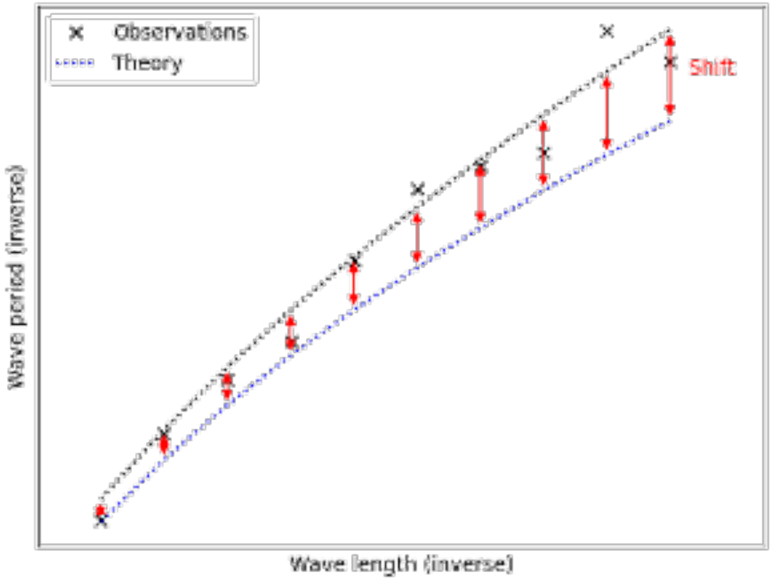
Background:

Wave spectrum in the presence of currents

Current direction ->

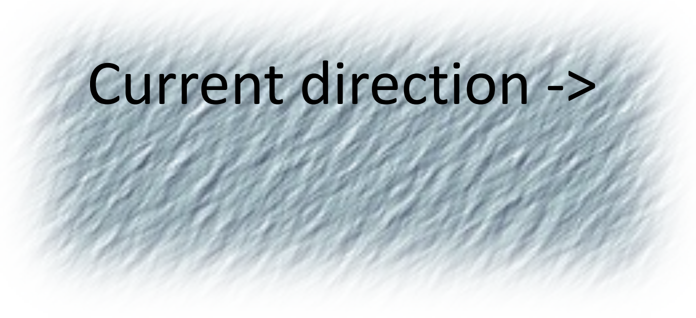


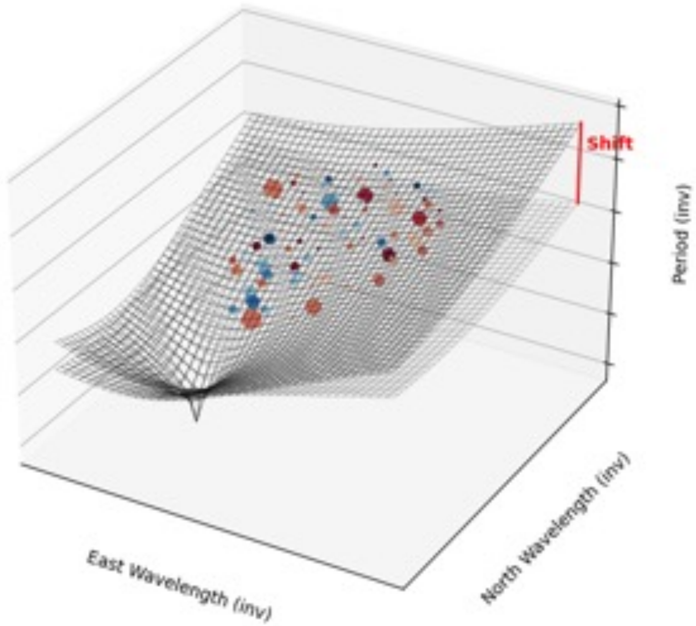
No single shift in physical space



Current speed =
Shift * Wavelength

In two dimensions





History: from fixed x-band radar to space-borne system

1904
Land-based microwave radar Invented

1941
First marine install U.S.S Semmes

1964/1965
Sea clutter for waves

1985
Surface currents from sea clutter

1983 Directional wave spectra from **sea clutter**

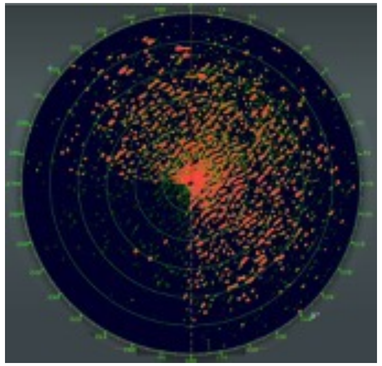
2001
Adaptation to coastal video

2003-2004
Video takes to the sky

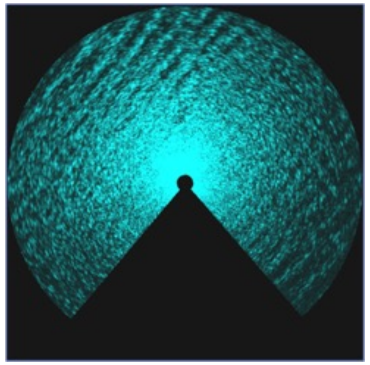
2007
Adaptation to Satellite
[2 frame]

2017
Adaptation to Public Satellite

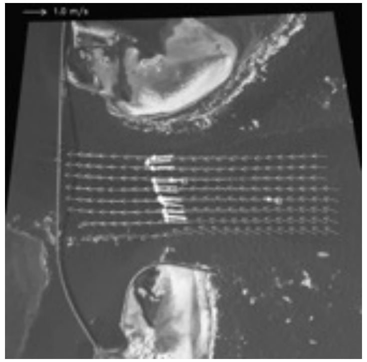
2023
UWA



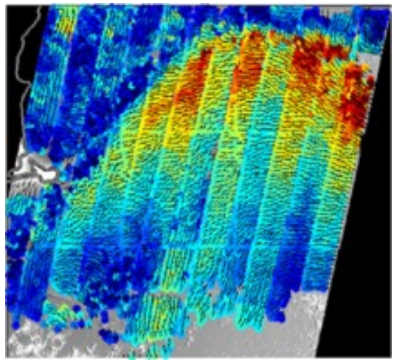
Source: Furono



Source: Miros AS



Source: Duggan and Piotrowski et al. 2003



Source: Yurovskaya et al. 2017

Better environmental satellites

Proliferation of drone tech

Proliferation of Machine learning

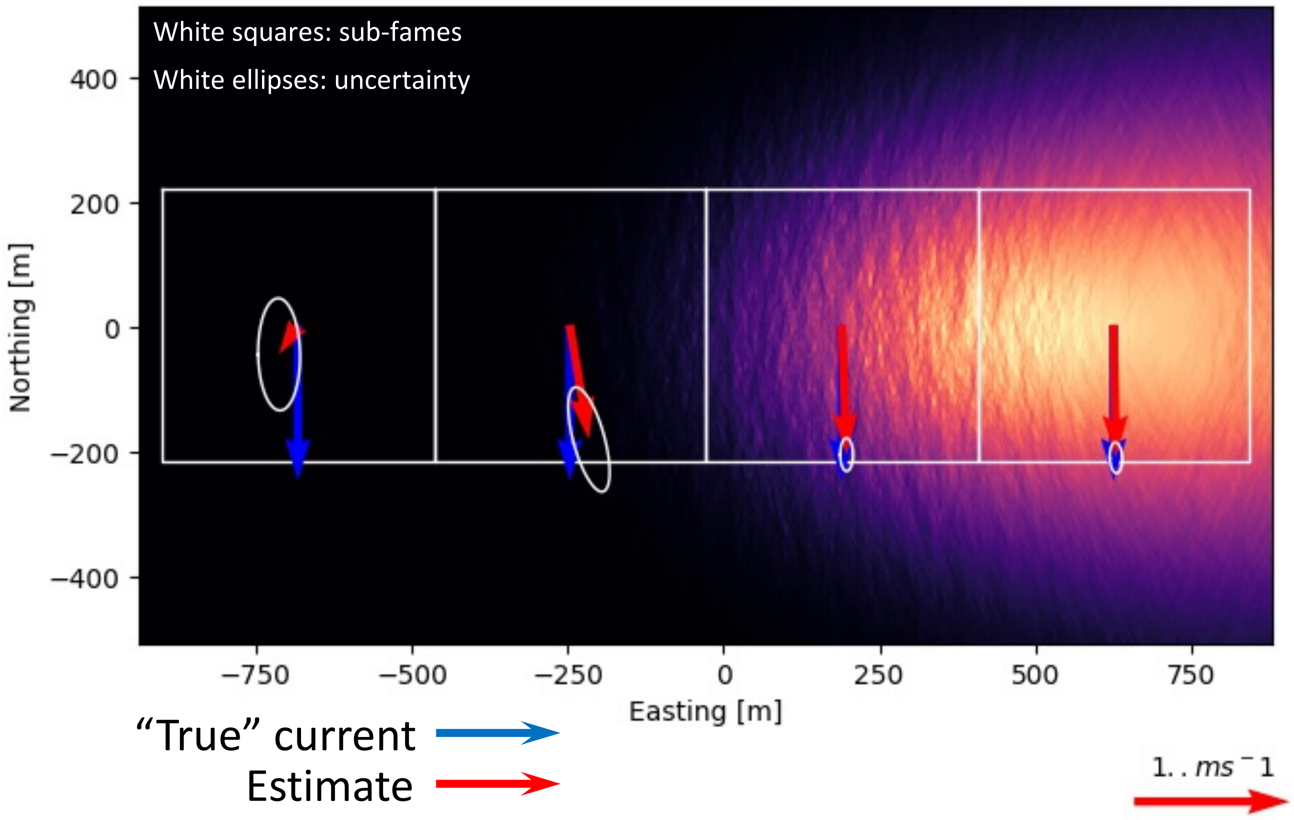
?

Observational uncertainty

- Here quantifies how well data conforms to the adopted model (2D Doppler shift)
- Here applies to U & V, plus their covariance
- Should be **quantified** when estimates are made

What do we do with it?

Example: Observational uncertainty quantification – four current estimates from one set of 'images'



Case study: remote sensed currents for floate trajectory estimates?

We have:

Point estimates of surface currents with **uncertainty**

Handling?

Require:

Trajectory estimates with **uncertainty**

Question: while we develop better instruments, could we be making **better informed decisions** through more **robust quantification and propagation of uncertainty**?

Handling observational uncertainty

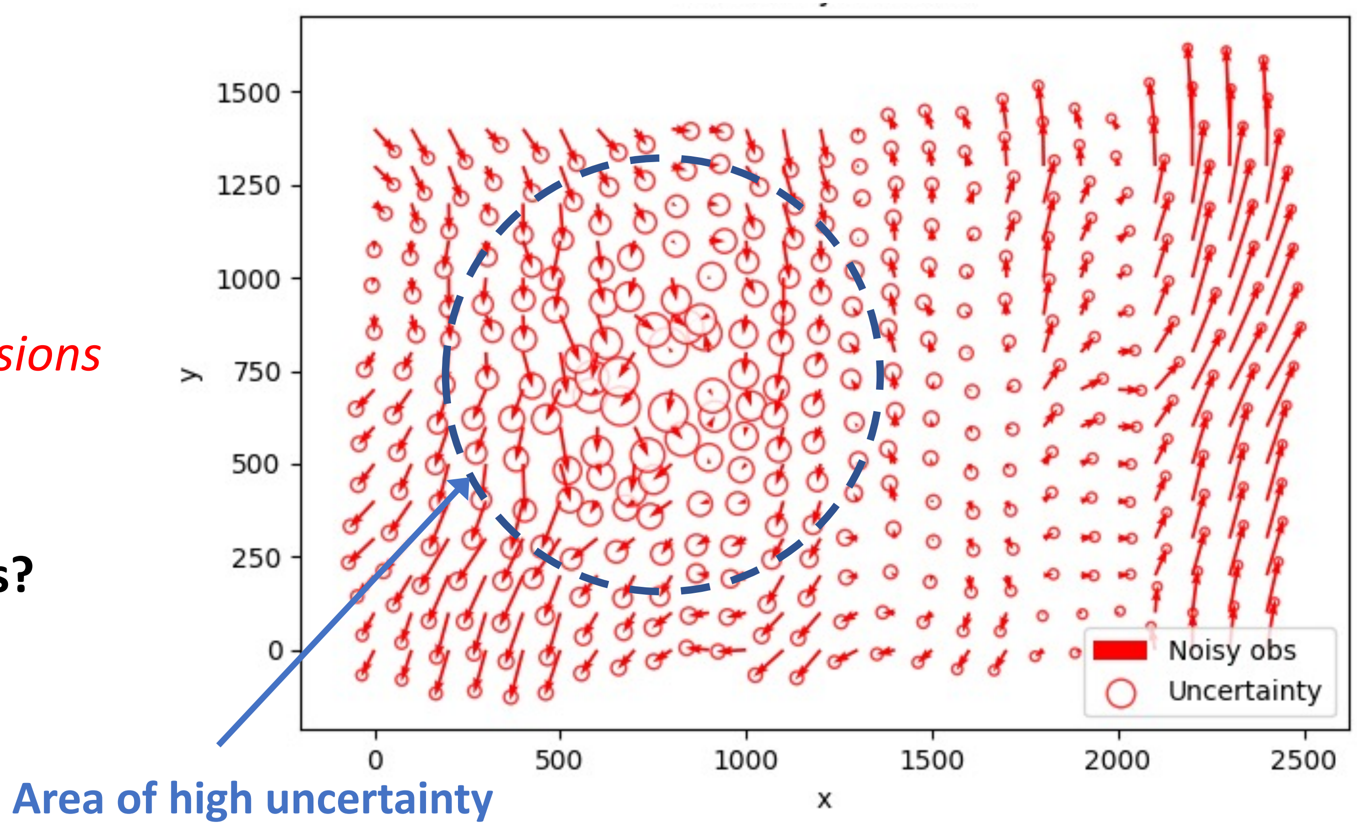
- QC / Rejection? *-> Don't make a decision*
- Skill? *-> Put a disclaimer on our decisions*
- Propagate it! *-> Make more informed decisions*

Propagate to where?

- **Directly into decision making tools?**
- **Model of the regional flow field?**

***DISCLAIMER: I'm not a decision maker*

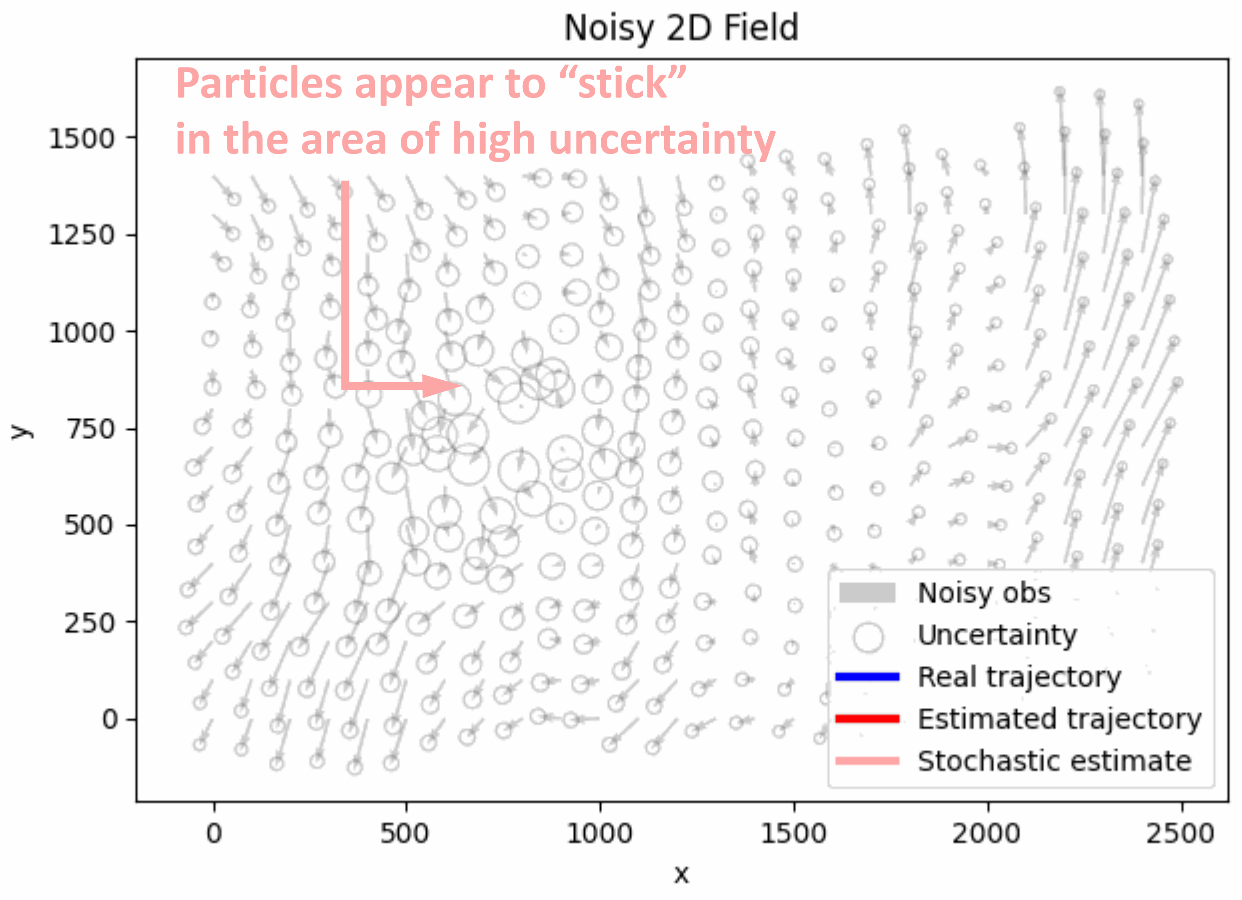
Simulation: Noisy velocity field with uncertainty



Uncertainty propagation (cont.)

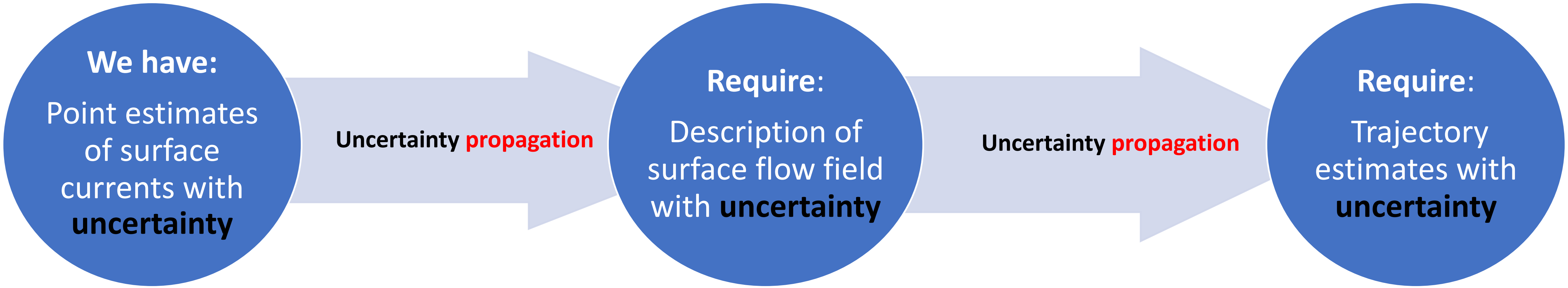
METHOD 1: Observational uncertainty propagated directly into a decision-making tool

- Poor model of reality
  - Almost certainly not to recover "truth"
- Method ignores covariance of "true" flow
- Method ignores covariance of errors



ABOVE: Time history of object trajectory

Case study: remote sensed currents for floate trajectory estimates?

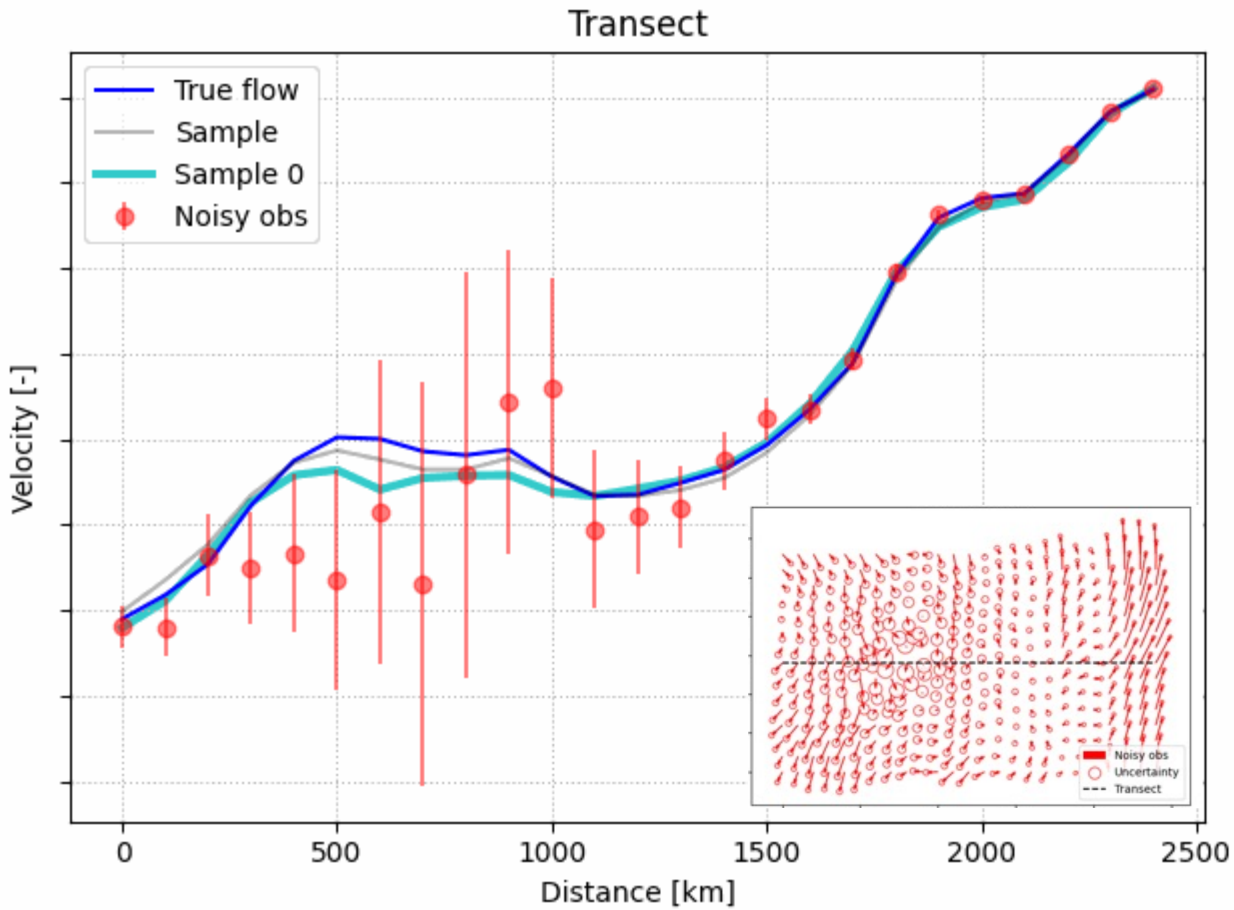


Question: while we develop better instruments, could we be making **better informed decisions** through more **robust quantification and propagation of uncertainty**?

Uncertainty propagation (cont.)

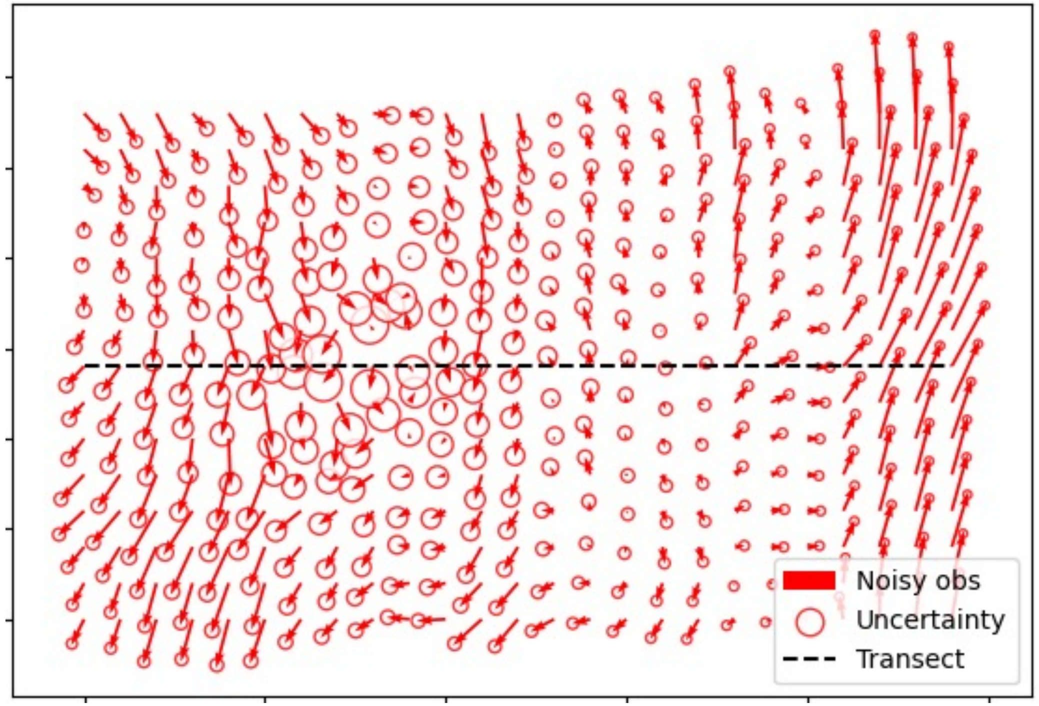
METHOD 2: Observational uncertainty propagated
via stochastic flow model

- True flow is a process with structure in space and time
- **Learn** the flow structure from data [machine learning]
- Weight observations by uncertainty [red bars]
- Update best estimate ***AND*** belief in the uncertainty [black lines]

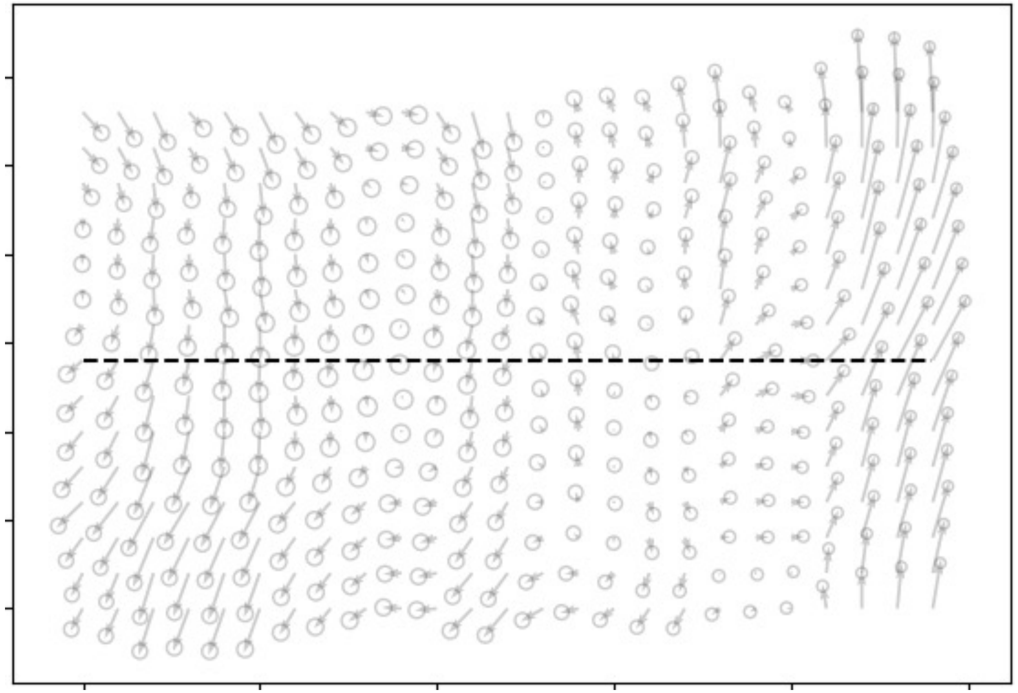


Uncertainty propagation (cont.)

METHOD 2: Observational uncertainty propagated
via stochastic flow model



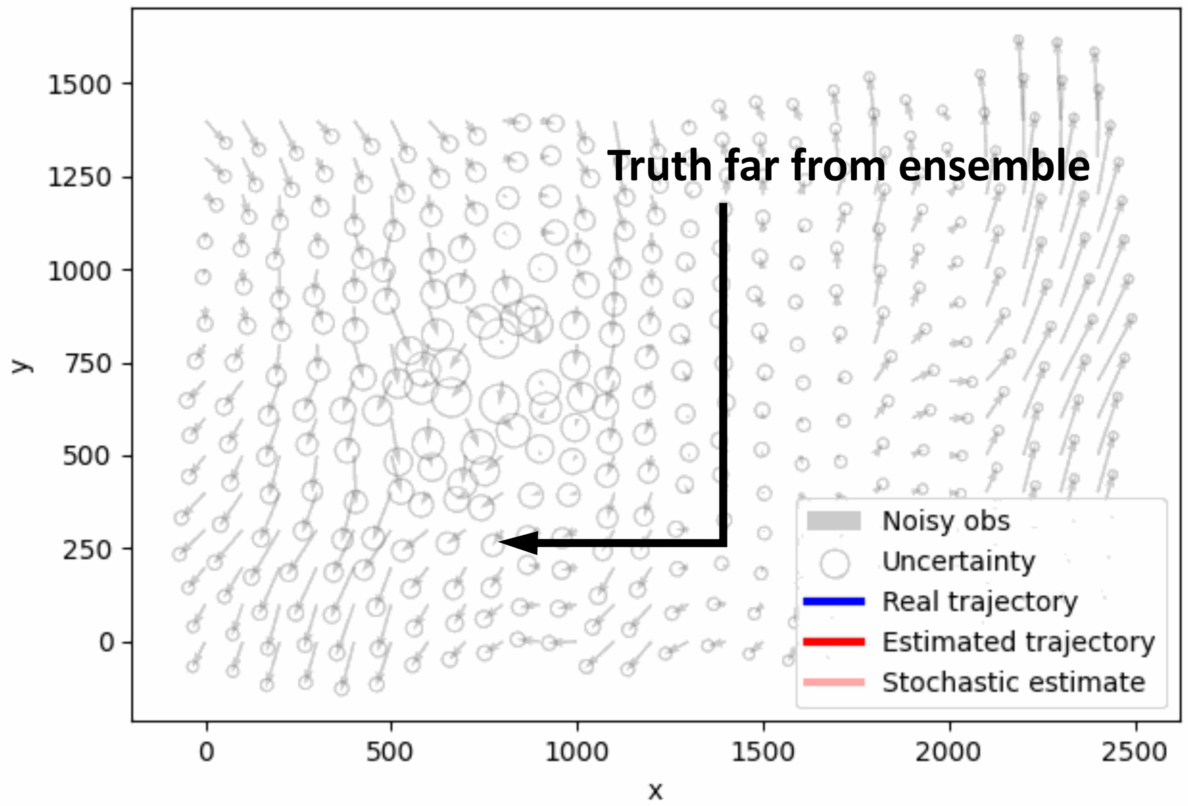
Machine learning



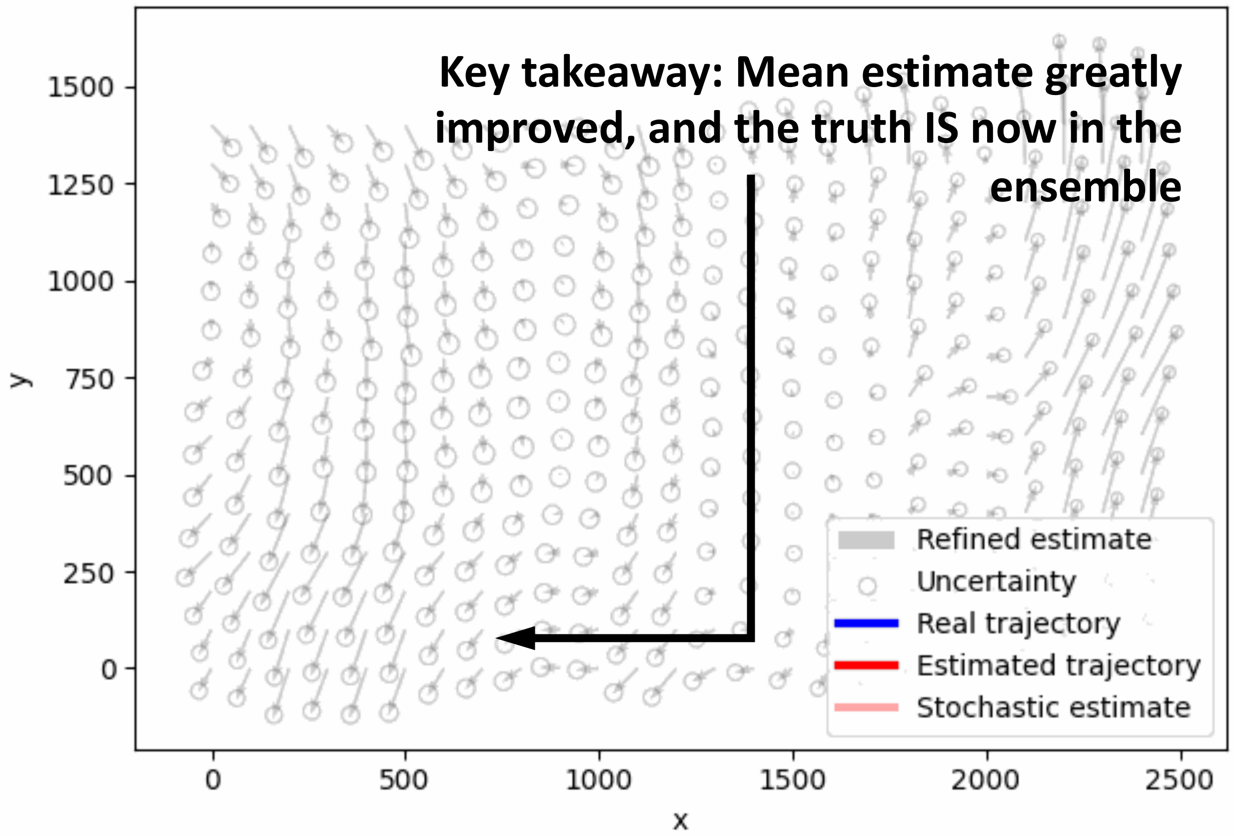
Update best estimate ***AND*** belief in the uncertainty

Side by side: method 1 & 2:

Method 1: Direct propagation



Method 2: Propagation via machine learning of flow



Roll-out: method & hardware

Study objective: Robust **uncertainty quantification + propagation** for wave-based current estimates at **multiple scales**

METHOD DEVELOPMENT

View ~200 km;
Res ~1 km;

View ~1-2 km;
Res ~200m - 1 km;

View ~100-400 m;
Res ~100-400 m;

HARDWARE DEVELOPMENT

Study objective: Development of an **affordable** **low-altitude** aerial system

- Prototype developed
- Major field trials intended for Q1/Q2 2026

Summary

Despite age of wave-inversion methods, there are no **operational** systems to support **decision making**

Modern machine learning methods + opening of hardware market present opportunities to improve

-> *The first X-band radars could barely detect boats*

Handling of **uncertainty** key for **decision making****, and a will be major focus of this work

Low altitude prototype developed, major field trial scheduled for 2026