Particle Trajectory Modelling Applications

Michael Hart-Davis

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Utrecht University, Parcels Meeting
22.06.2022

Quick Introduction

Focus areas

- Ocean tide modelling and satellite altimetry
- Physical Oceanography, Particle Tracking, Ocean Modelling

Studies

Research Associate and PhD in Satellite Altimetry and Tide Modelling

At the Technical University of Munich (2019 -)

Masters in Physical Oceanography

At Nelson Mandela University (2018 – 2019)

Research Exchange (Masters Thesis)

At NERSC and University of Bergen (2018 - 2019) and
at Utrecht University (2018)

Contents

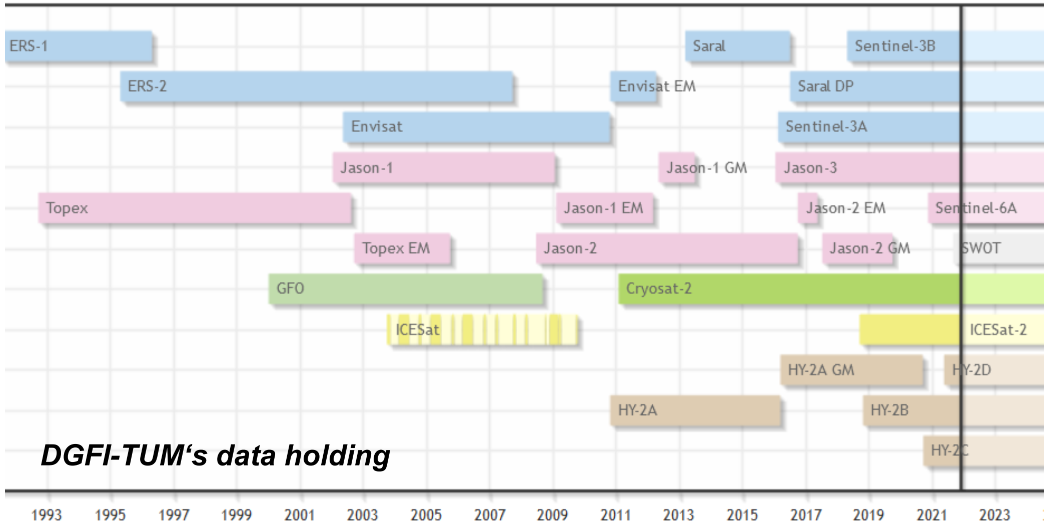
Satellite Altimetry at DGFI-TUM

- DGFI-TUM administrates complete **data holdings** of all altimeter missions since 1992 (radar and laser).

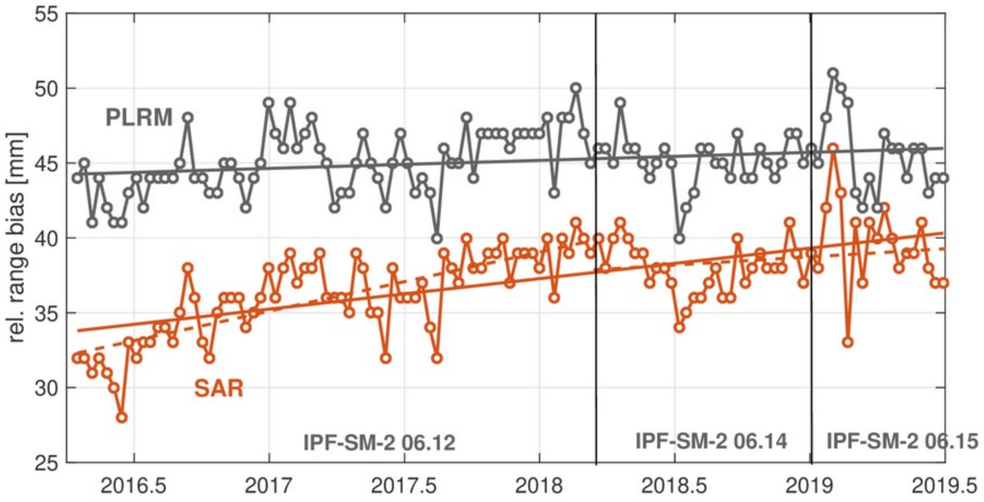
- DGFI-TUM maintains public altimeter data portals for satellite altimeter data and derived high-level products
  - **OpenADB: http://openadb.dgfi.tum.de**
  - DAHITI: http://dahiti.dgfi.tum.de

- DGFI-TUM developed a **global multi-mission crossover analysis** (MMXO) approach in order to ensure a harmonized dataset and an optimal combination of different altimeter missions.
  - ➢ one virtual long-term altimeter mission with optimal temporal and spatial resolution
  - ➢ calibration of single missions
  - ➢ identification and quantification of systematic errors in data and products

- **Scientific investigations** are (mostly) based on cross-calibrated multi-mission altimetry data



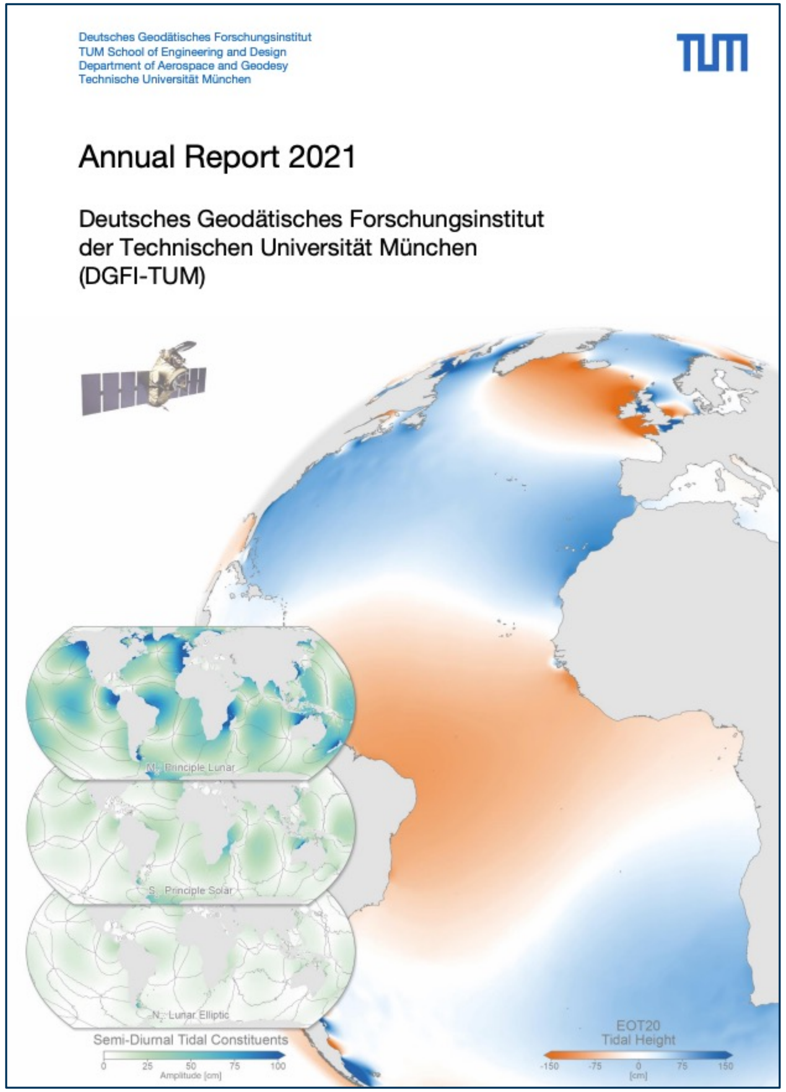
DGFI-TUM's data holding



Relative range bias of Sentinel-3 wrt. Jason-3

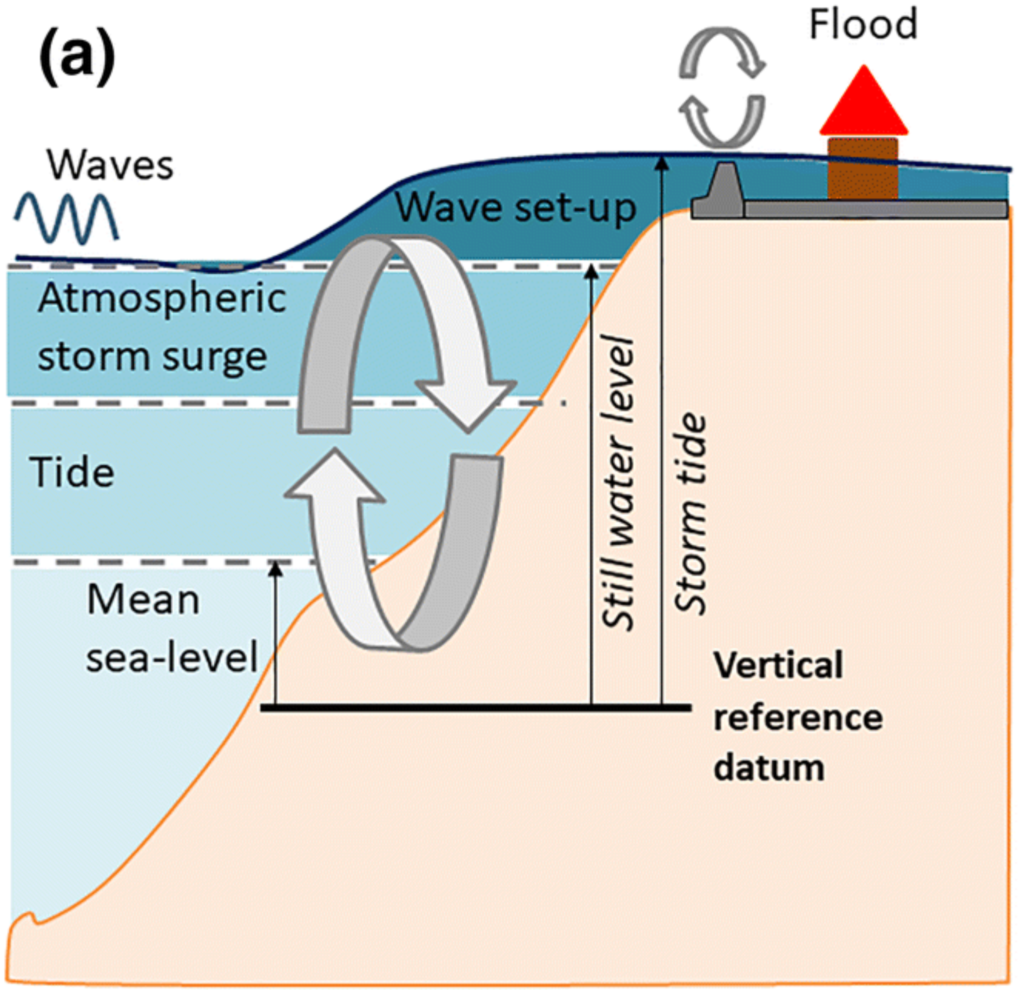
Satellite Altimetry Inland and Oceans

- Sea Level Change
- Sea State
- Empirical Ocean Tide Modeling
- Dynamic Ocean Topography and Geostrophic Surface Currents
- Water Levels of Inland Water Bodies
- Water Storage in Lakes and Reservoirs
- River Discharge
- For more information: Annual Report of 2021:
  https://mediatum.ub.tum.de/doc/1657456/1657456.pdf
  or visit https://www.dgfi.tum.de/



Ocean Tides

Tides in the context of studies on sea-level



- Estimates of sea-level from, for example, Satellite Altimetry are influenced by the tides.
- The cycle of the tides can result in over or under-estimated sea-level estimations if tides are not taken into account.
- Therefore, ocean tides need to be removed from the signals of satellite altimetry and tide gauges in order to get more accurate estimates of the sea-level changes.
- This has resulted in the development of the ocean tide models presented in the previous slide to produce ocean tidal corrections for satellite altimetry.

Difficulty in accurately understanding ocean tides

- Problems in estimating ocean tides frequently occur in the coastal region.

- This is caused by:

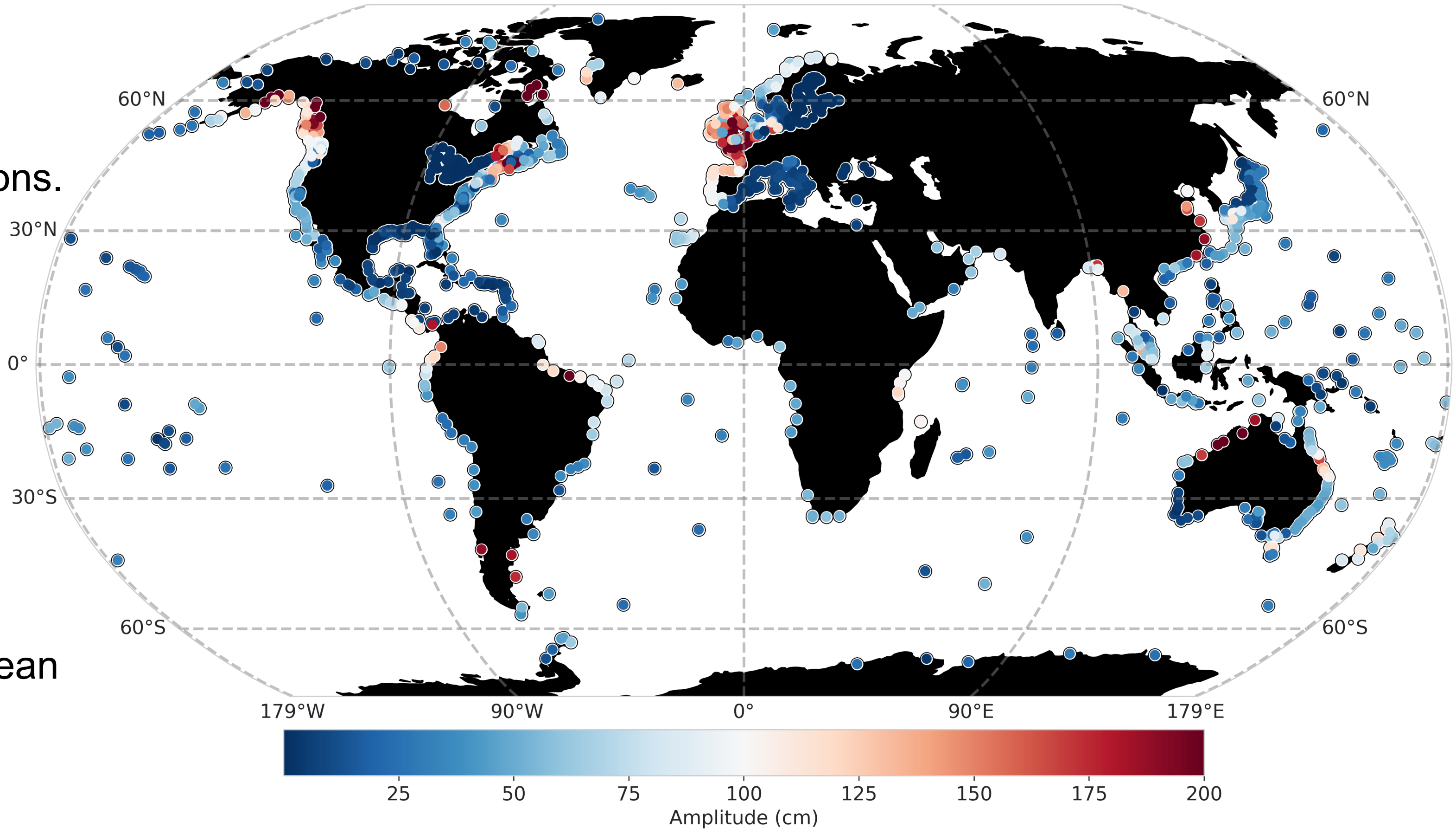
  - The lack of properly distributed observations.

  - Poorly understand bathymetry.

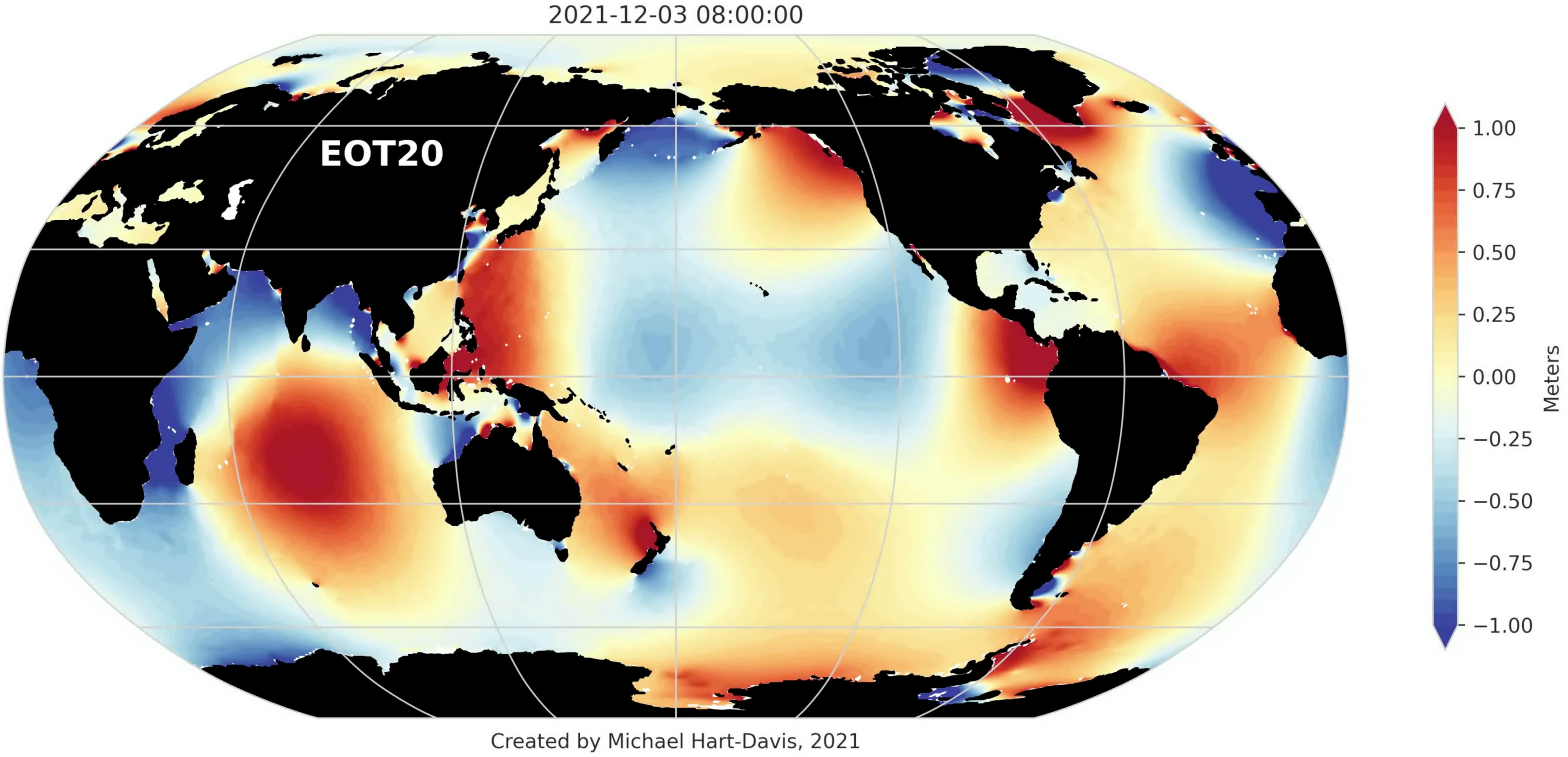
  - Radar returns of satellite altimetry more strongly affected in the coastal region.

  - Requires very high computational load to more accurately estimate all the tidal constituents needed to resolve the full ocean tide.

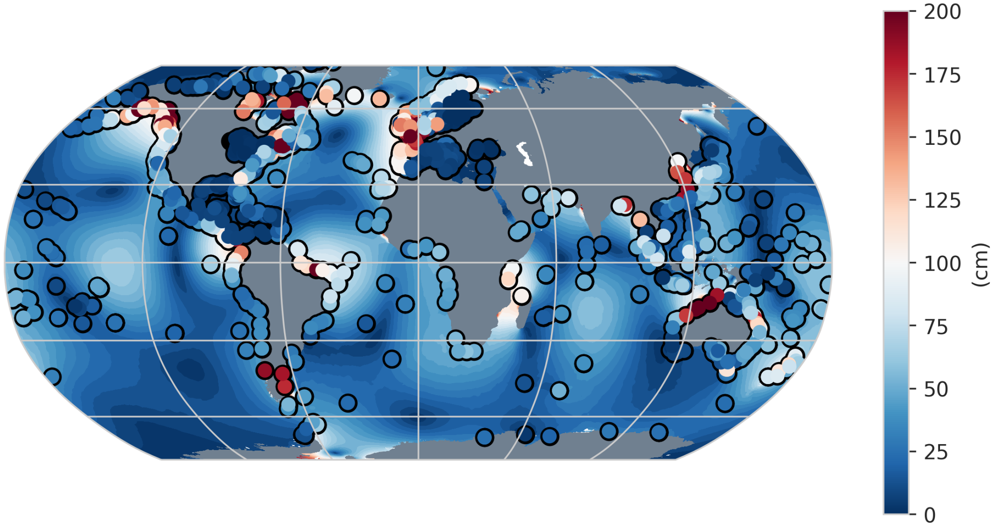
  - Sea Ice

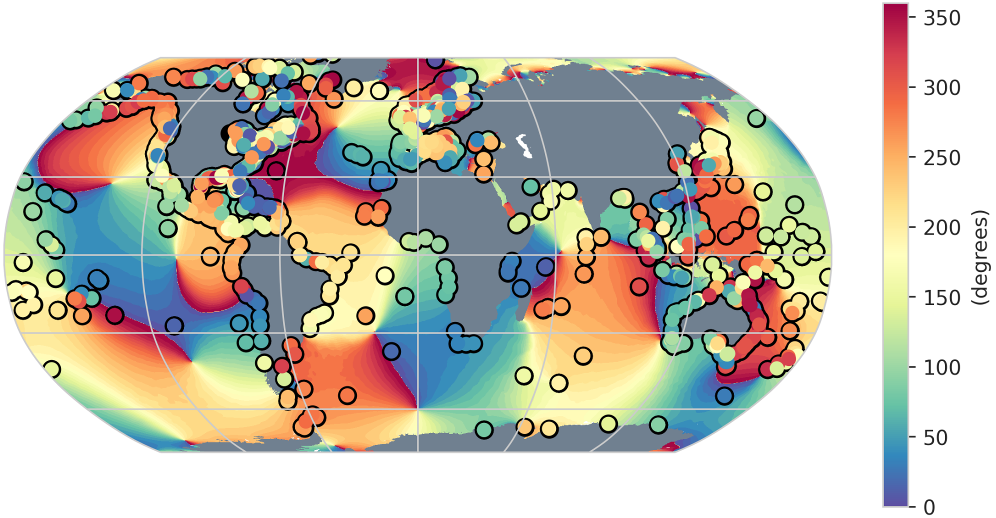


Ocean Tides – A Global Empirical Ocean Tide Model



TICON-3





TICON-3:

The TIdal CONstants (TICON) dataset was first published in Piccioni et al (2019). The dataset has served the community well as it was used for the validation of global ocean tide models in several studies (e.g. Hart-Davis et al 2021; Sulzbach et al 2021).

- An update is in process of being made public, based on the updated GESLA-3.
- 3679 Tide Gauges
- 1.1 billion observations
- Above 66N/S – 70 tide gauges
- TICON-3, M. Hart-Davis, D. Dettmering, F.Seitz (2022) Pangaea.

Global Tide Gauge Analysis

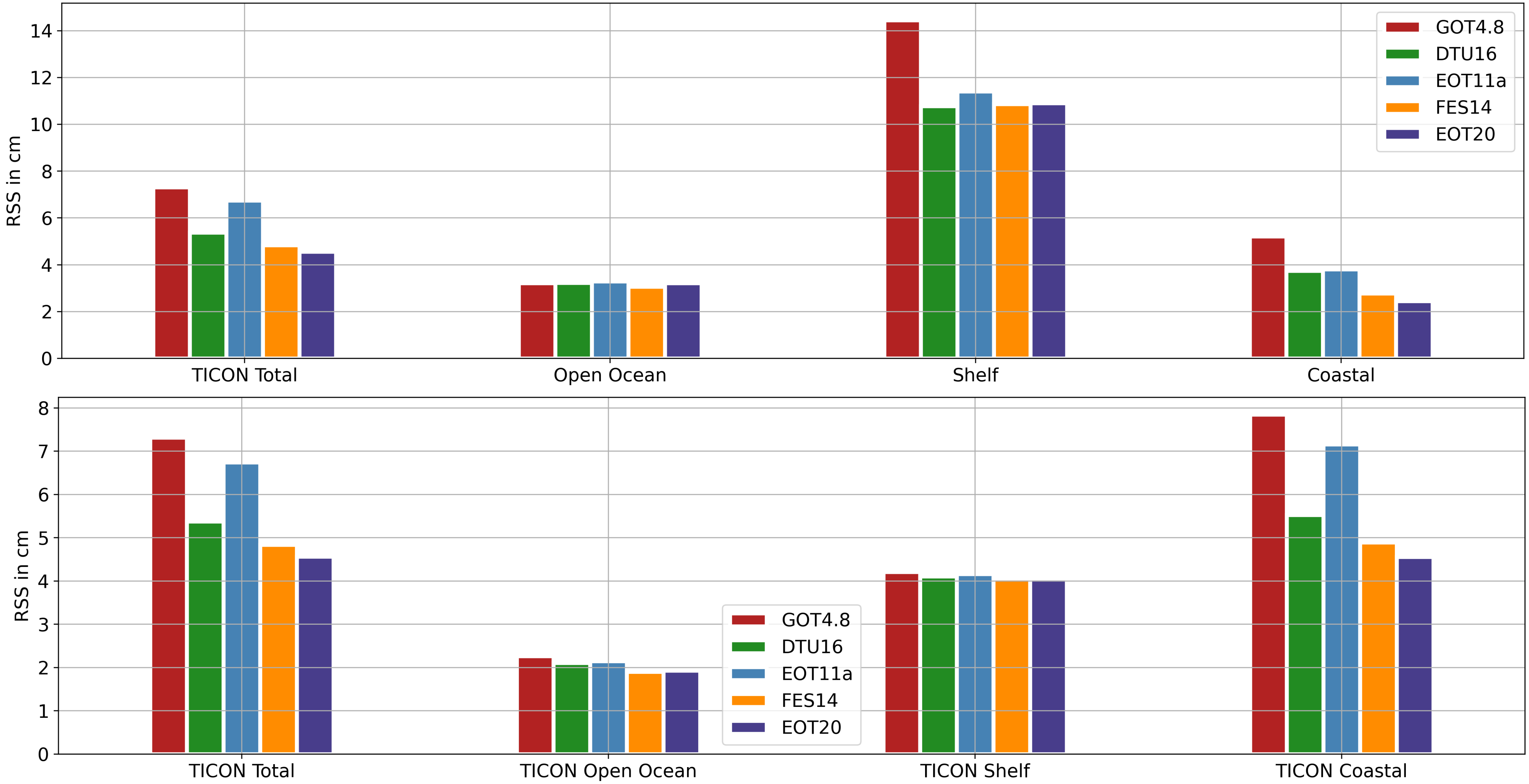


Figure. The Root Square Sum (RSS) for the eight major tidal constituents from the five tide models in the different regions.

Take home messages on Tidal Research

Development

EOT20 builds on the previous EOT global models by incorporating ALES retracked data, the FES2014 tide model as a reference model and an improved coastal representation

Validation

The model was validated using tide gauges and sea level variance analysis with the results being compared to other global tide atlases.

Results

EOT20 demonstrates a clear improvement in the coastal region compared to other global ocean tide models.

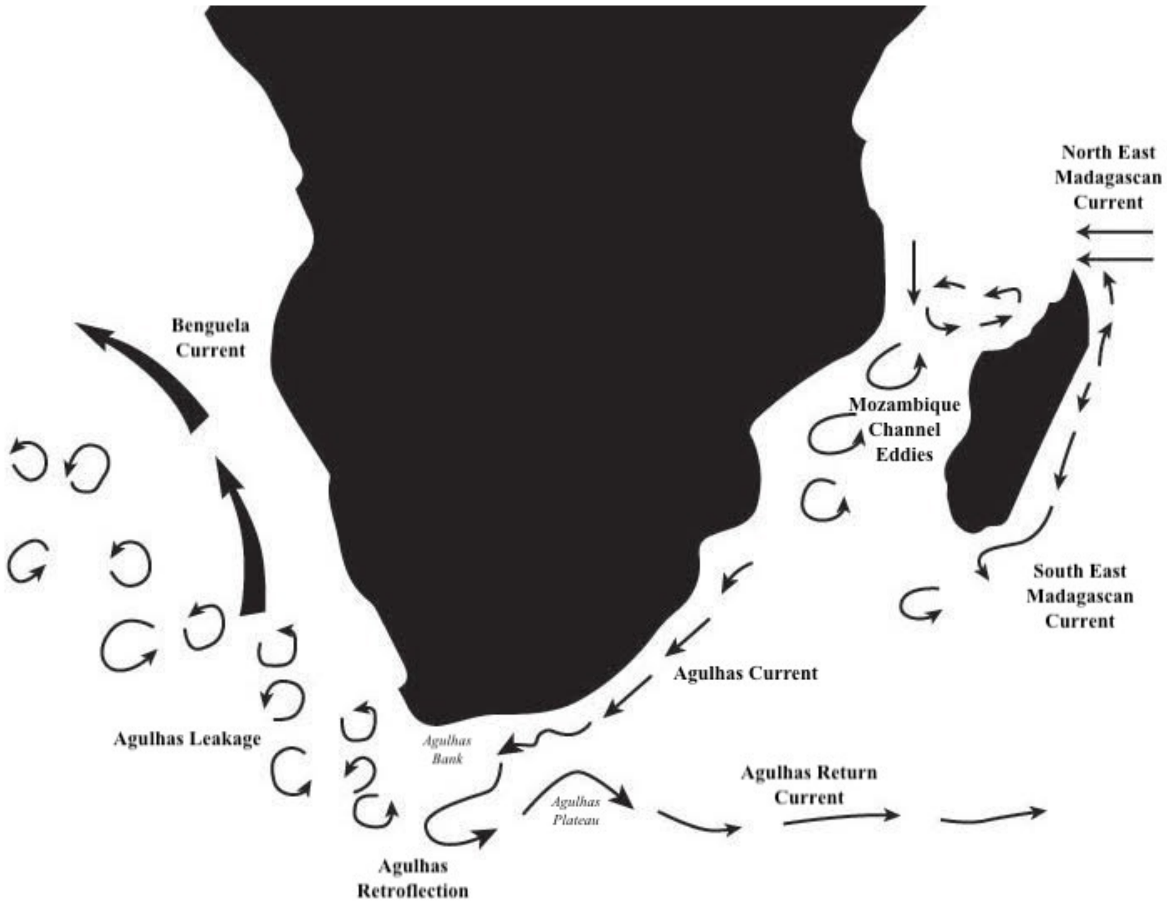
Future Work

The inclusion of additional altimetry missions to allow for the expansion into the polar regions and the improvement of altimetry data to optimise tide estimations.

Hart-Davis, M.G., Dettmering, D., Sulzbach, R., Thomas, M., Schwatke, C. and Seitz, F. 2021. Regional Evaluation of Minor Tidal Constituents for Improved Estimation of Ocean Tides. Remote Sens., 13, 3310. https://doi.org/10.3390/rs13163310.

Hart-Davis, M. G., Piccioni, G., Dettmering, D., Schwatke, C., Passaro, M., and Seitz, F. 2021. EOT20: a global ocean tide model from multi-mission satellite altimetry, *Earth Syst. Sci. Data,* 13, 3869–3884, https://doi.org/10.5194/essd-13-3869-2021.

Developing ocean particle tracking tools for cross-disciplinary oceanic research with applications in the Agulhas Current region



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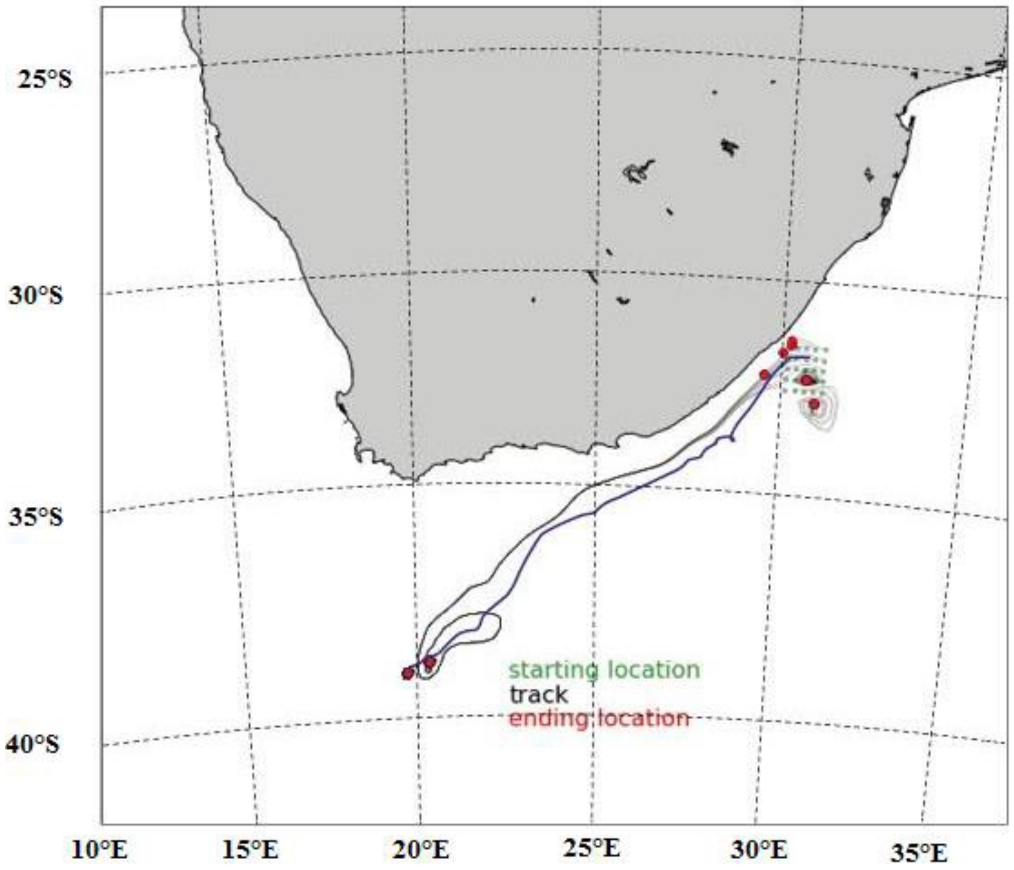
Our Particle Tracking History

2016 – TracPy implementation with GlobCurrent



February 2017

– Moved to OceanParcels (pre v0.9)

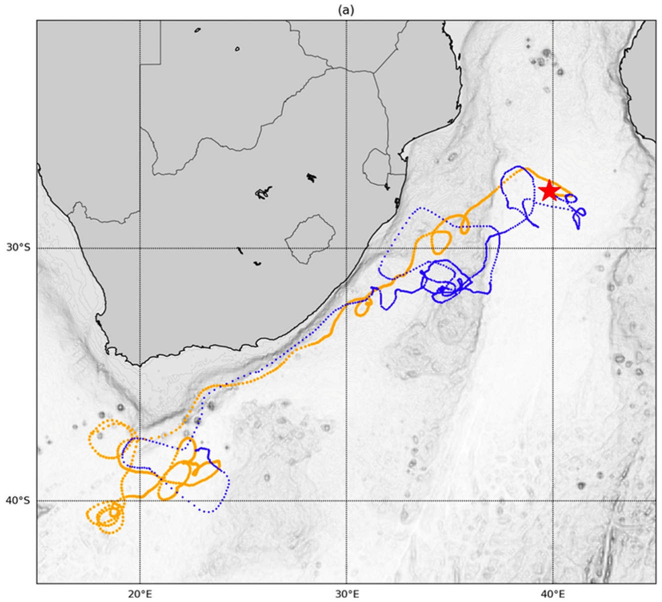
Michael Hart-Davis <mhartd@gmail.com> Tue, May 16, 2017, 12:34 PM

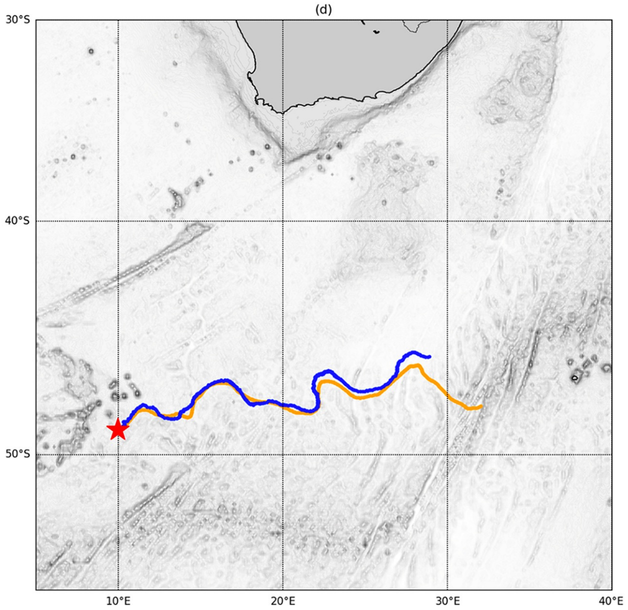
to E.vanSebille

Submitted Aug 2017, Accepted March 2018:

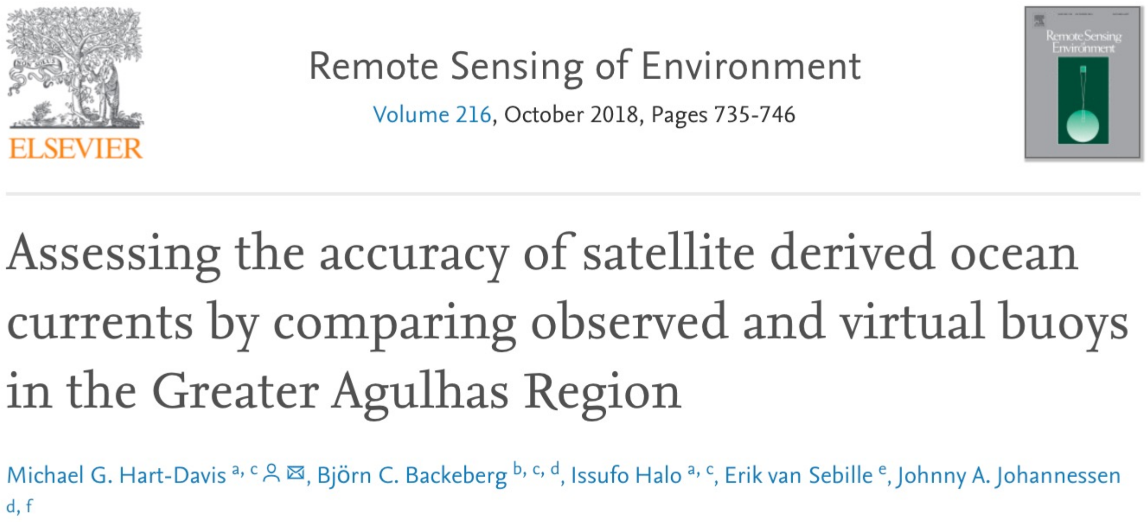
Assessing the accuracy of satellite derived ocean currents by comparing observed and virtual buoys in the Greater Agulhas Region

Michael G. Hart-Davis[a,c,*], Björn C. Backeberg[b,c,d], Issufo Halo[a,c], Erik van Sebille[e], Johnny A. Johannessen[d,f]





GlobCurrent Validation



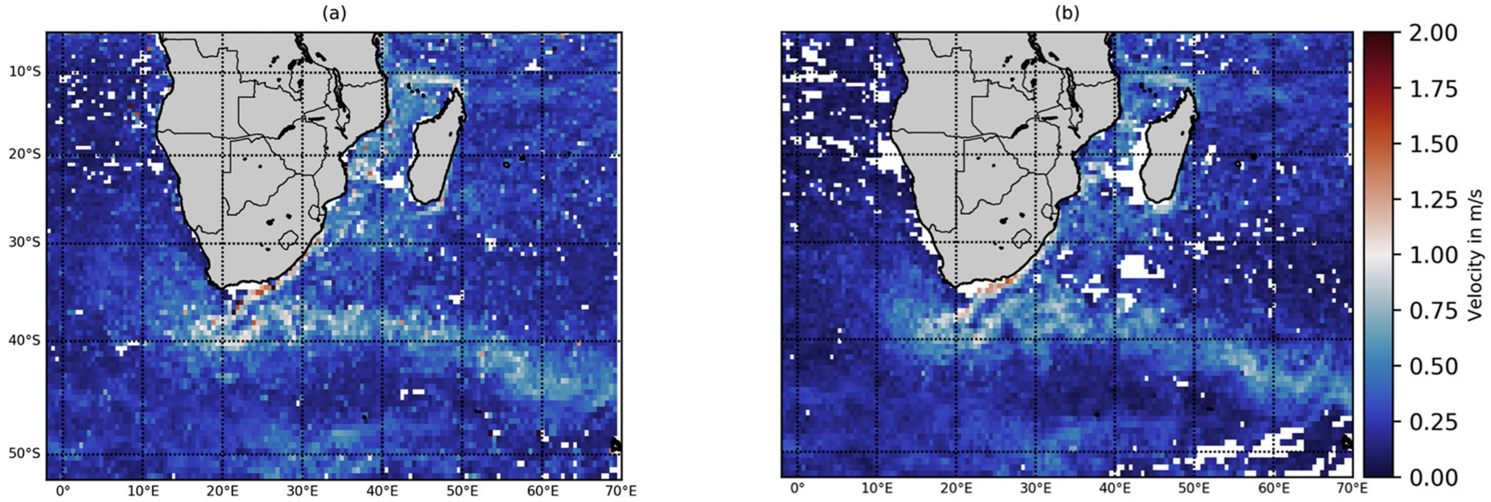
ELSEVIER

Remote Sensing of Environment

Volume 216, October 2018, Pages 735-746

Assessing the accuracy of satellite derived ocean currents by comparing observed and virtual buoys in the Greater Agulhas Region

Michael G. Hart-Davis [a, c], Björn C. Backeberg [b, c, d], Issufo Halo [a, c], Erik van Sebille [e], Johnny A. Johannessen [d, f]



- We assessed the accuracy of a combined geostrophic and Ekman current product (GlobCurrent) that estimates ocean currents at 15m depth, by coupling it to a synthetic particle tracking tool and comparing the virtual trajectories to those of surface drifting buoys drogued at 15m in the Greater Agulhas Current Region.

- The results suggested an overall underestimation of the GlobCurrent product in the Agulhas Current. A later study by Cancet et al (2019) in East Australian Current found a similar underestimation.

- The mean difference between all the simulated and observed velocities reveals that the GlobCurrent-based current field underestimated the ocean velocity by 27% throughout the entire domain.

GlobCurrent Validation – Application in search and rescue

Published in Remote Sensing of Environment: Hart-Davis et al 2018 - https://doi.org/10.1016/j.rse.2018.03.040

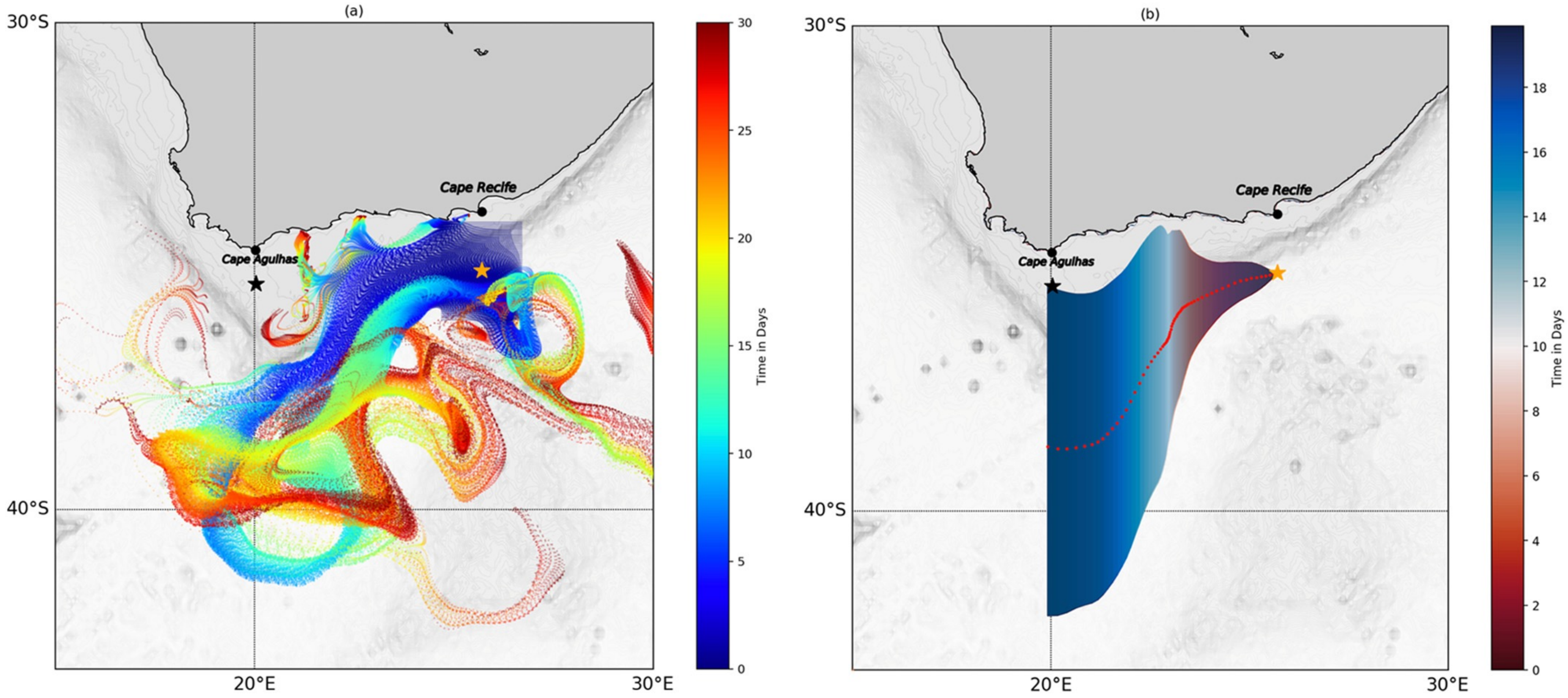
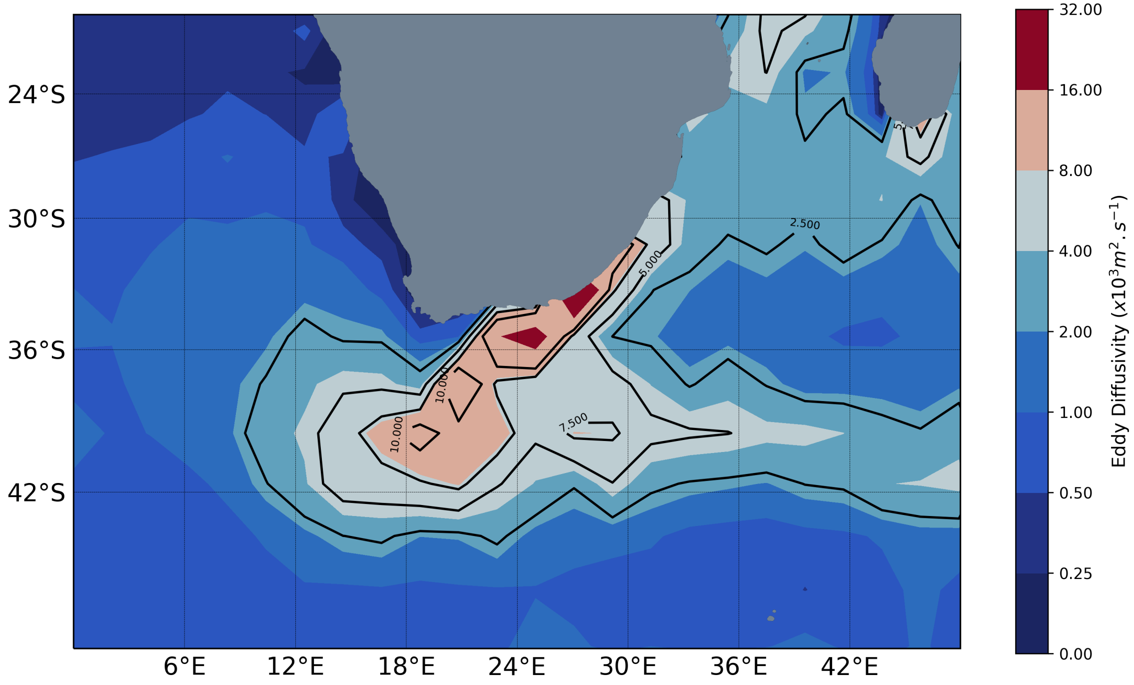
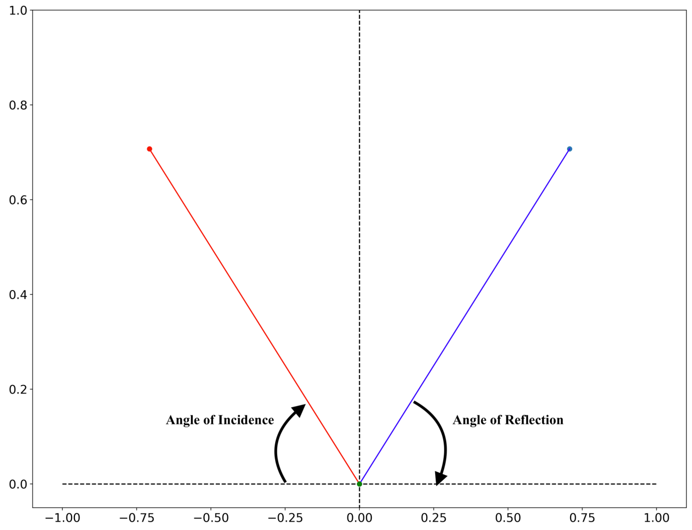


Figure. The simulation of (a) 10,000 virtual drifters deployed for 30 days in a 1° grid centred around the starting location (orange star) of a capsized vessel and (b) a single virtual drifter (red) deployed for 18 days at the same starting location as the capsized vessel with an error probability area which indicates the mean error over time between simulations and observations in the Agulhas Current. The black star represents the final location of the capsized vessel.

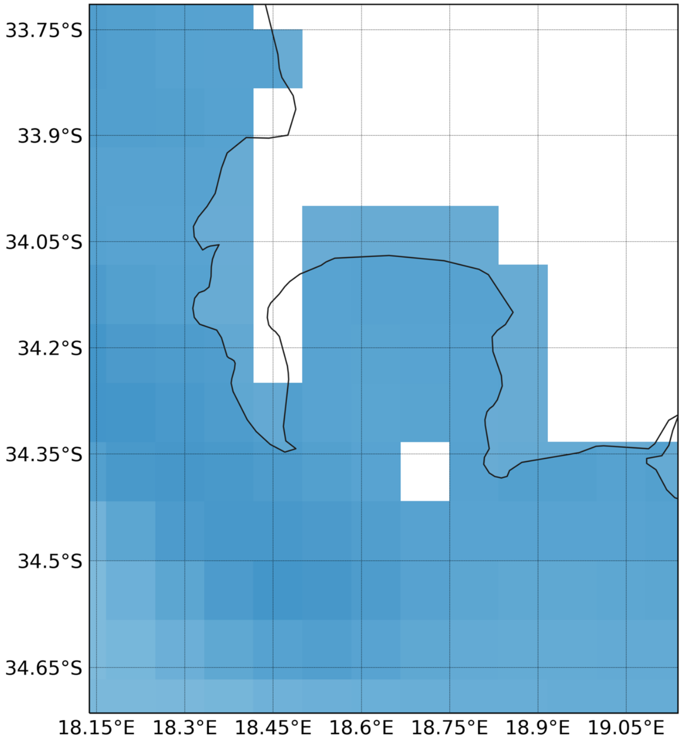
Simple Particle Tracking Implementations

Horizontal Eddy Diffusivity (from climatology of drifter observations) for Brownian Motion



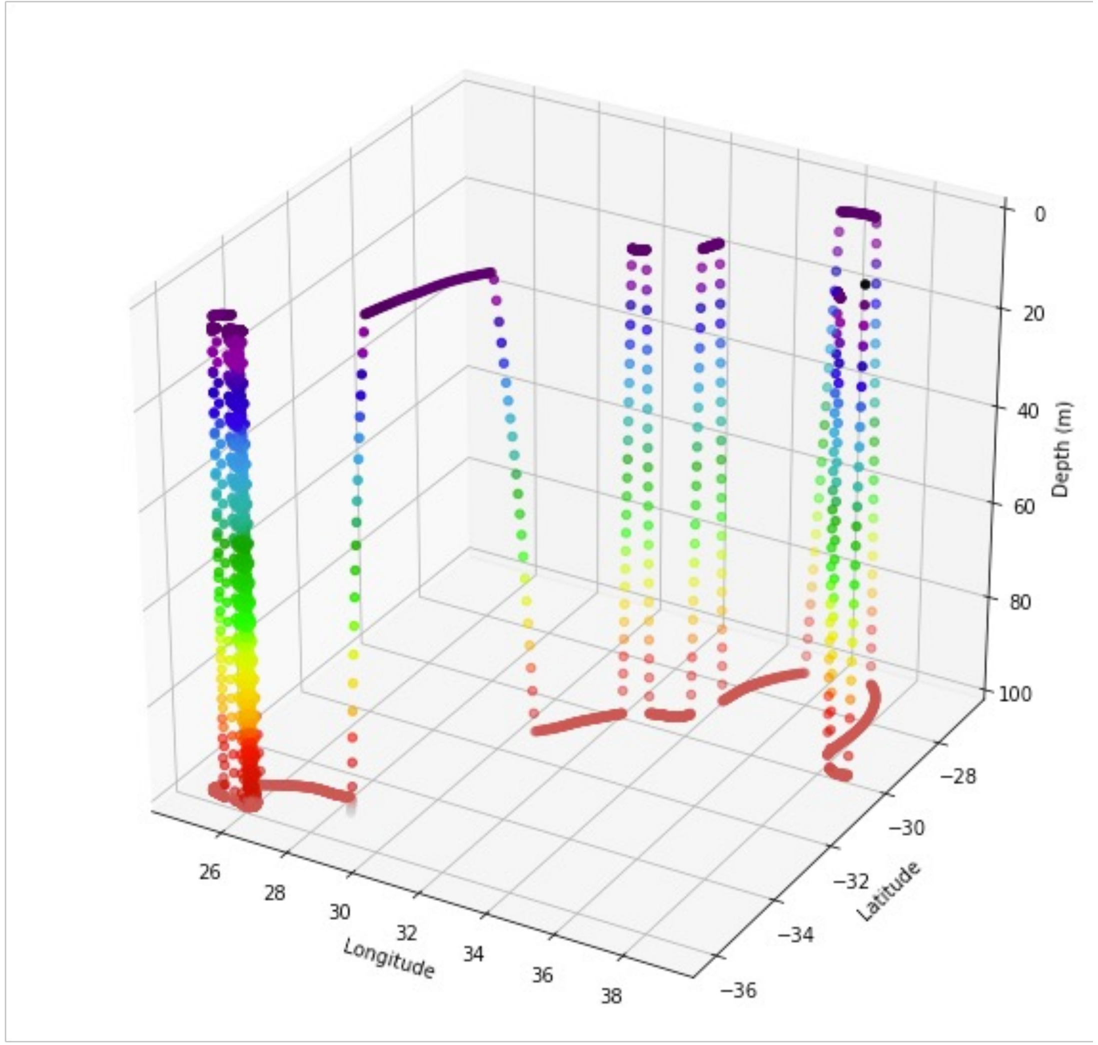


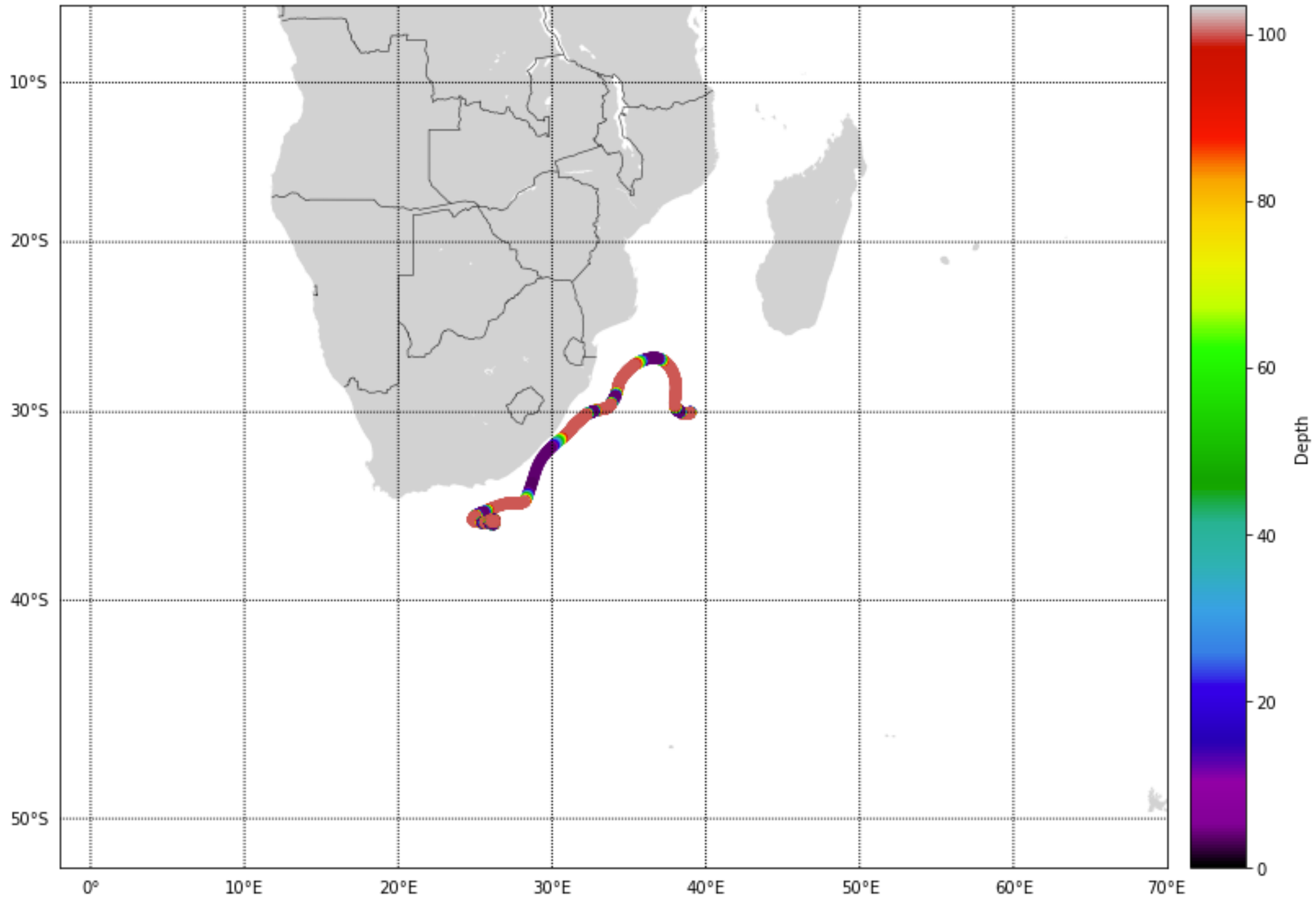
Reflective Boundary



Argo Floats

https://nbviewer.org/github/OceanParcels/parcels/blob/master/parcels/examples/tutorial_Argofloats.ipynb





Search and Rescue

JOURNAL OF OPERATIONAL OCEANOGRAPHY
https://doi.org/10.1080/1755876X.2021.1911485

Taylor & Francis
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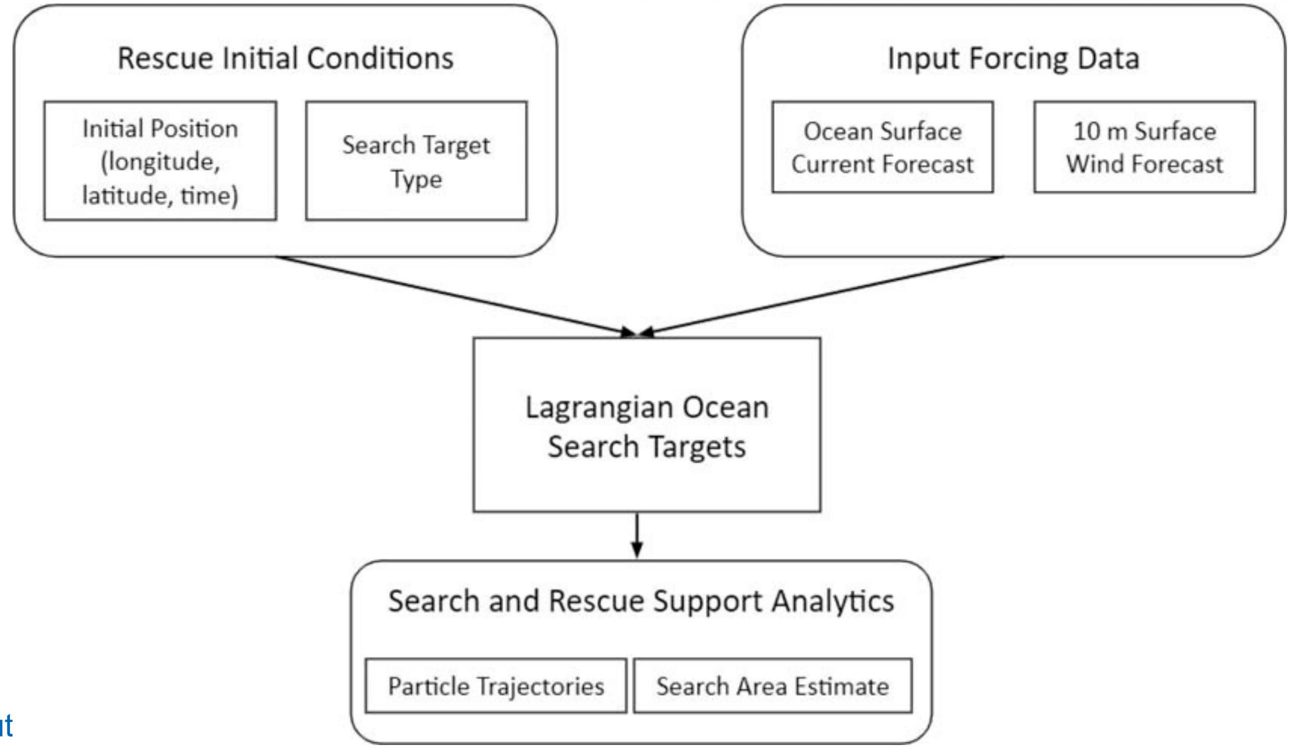
Towards a particle trajectory modelling approach in support of South African search and rescue operations at sea

M.G. Hart-Davis [a,c,d,e] and B.C. Backeberg [b,c,f]

[a]Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), München, Germany; [b]Deltares, Delft, Netherlands; [c]Nansen-Tutu Centre for Marine Environmental Research, University of Cape Town, Cape Town, South Africa; [d]Egagasini Node, South African Environmental Observation Network, Cape Town, South Africa; [e]Institute for Coastal and Marine Research, Nelson Mandela University, Port Elizabeth, South Africa; [f]Nansen Environmental and Remote Sensing Center, Bergen, Norway



- To provide more accurate decision support for rescuers looking for persons or objects lost at sea, a virtual particle tracking tool was combined with an empirical Leeway drift model.
- The Lagrangian Ocean Search Targets (LOST) application builds on a Lagrangian ocean analysis framework which has been adapted to provide real-time estimates of the positions of objects based on operational ocean and wind forecasts.
- LOST incorporates the impact of ocean currents, surface winds and stochastic motion, the latter being critical in accounting for sub-grid scale processes that are not resolved in the ocean and wind forecasts.

Search and Rescue

Published in Journal of Operational Oceanography, Hart-Davis and Backeberg 2021: https://doi.org/10.1080/1755876X.2021.1911485

Table 1. Wind drift and divergence table, where A is the wind speed, indicating the drift response of various types of objects to wind over the ocean. Courtesy of the South African National Sea Rescue Institute, based on guidelines produced by the International Maritime Organisation & International Civil Aviation Organisation (2016)

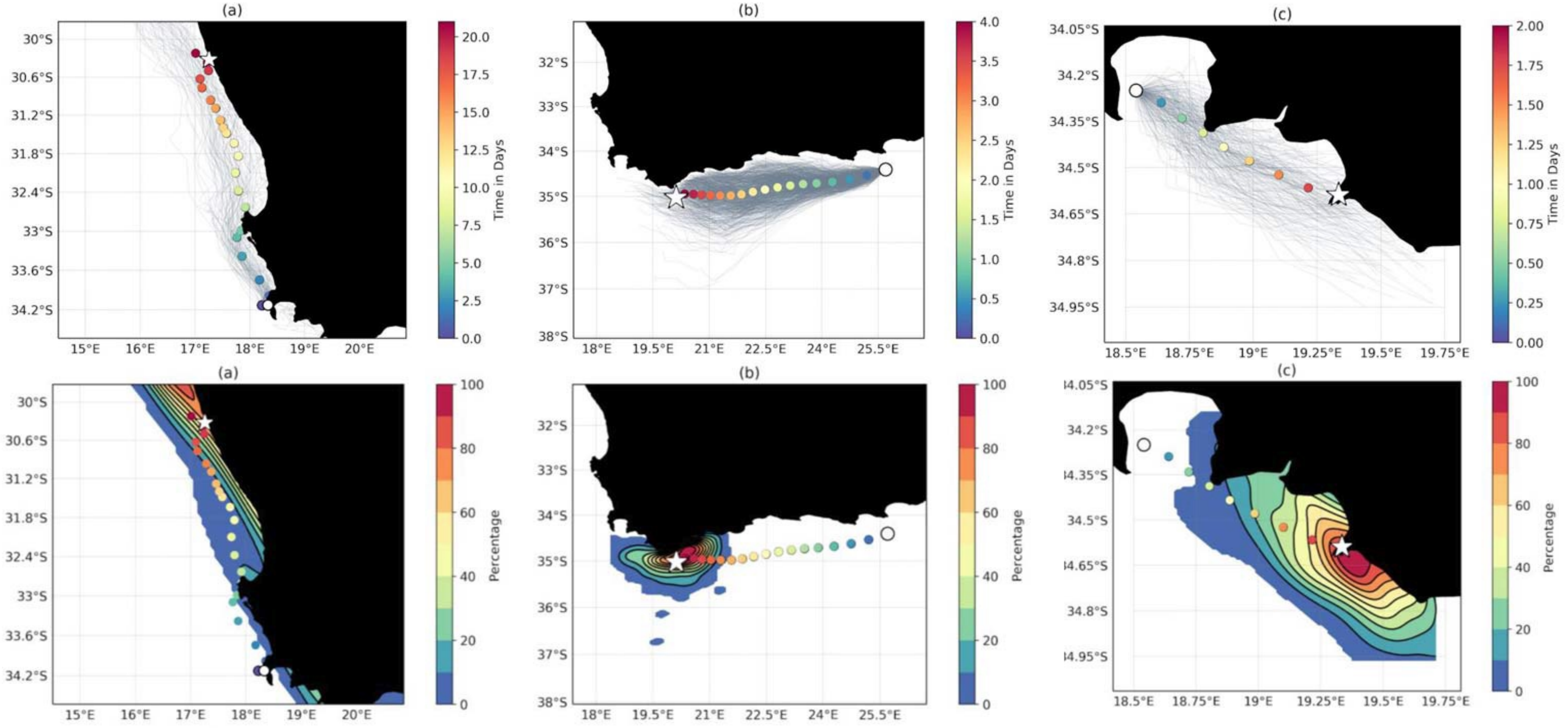
Search Target Type	Leeway Drift Formula	Divergence
Person in water: State Unknown	(A x 0.01) + 0.08	40°
Person in water: with life jacket	(A x 0.02)	45°
Person in water: vertical	(A x 0.01) + 0.08	25°
Person in water: sitting / huddled	(A x 0.02) + 0.01	25°
Person in water: floating on back	(A x 0.02) + 0.08	40°
Liferaft: no ballast pockets, general type	(A x 0.05) + 0.03	38°
Liferaft: no ballast pockets, no canopy, no drouge	(A x 0.06) + 0.20	32°
Liferaft: no ballast pockets, with canopy, with drouge	(A x 0.03)	38°
Liferaft: shallow ballast pockets with canopy, capsized	(A x 0.02) − 0.10	12°
Liferaft: 4–6 man, with canopy, with drouge	(A x 0.03) + 0.04	20°
Liferaft: 15–25 man, with canopy, with drouge	(A x 0.04) + 0.08	15°
Aviation raft: 4–6 man, with canopy, no drouge	(A x 0.04) + 0.12	32°
Personal watercraft: Sea kayak, with person	(A x 0.01) + 0.26	20°
Personal watercraft: Homemade wood raft	(A x 0.02) + 0.18	25°
Personal watercraft: Homemade wood raft, with sail	(A x 0.08) + 0.18	45°
Personal watercraft: Surfboard with person	(A x 0.02)	20°
Personal watercraft: Windsurfer with person, sail and mast in the water	(A x 0.03) + 0.1	16°
Sailing vessel: mono hull, keel, medium displacement	(A x 0.04)	65°
Power vessel: Enclosed Lifeboat	(A x 0.04) − 0.08	30°
Power vessel: Vessel with outboard motors no drouge	(A x 0.07) + 0.04	35°
Power vessel: Flat bottomed board, boston whaler	(A x 0.04) + 0.04	30°
Power vessel: V hull boat	(A x 0.03) + 0.08	25°
Power vessel: Sport fisher, centre open console	(A x 0.06) + 0.09	30°
Power vessel: Commercial fishing vessel type unknown	(A x 0.04) + 0.02	65°
Power vessel: Commercial fishing vessel longline, stern or net	(A x 0.04)	65°
Power vessel: Coastal freighter	(A x 0.03)	65°
Flotsam: Fishing vessel general debris	(A x 0.02)	15°
Flotsam: Cubic metre bait box, loading unknown	(A x 0.02) + 0.2	30°

- Leeway terms as determined and used by the National Sea Rescue Institute (NSRI).
- Leeway accounts for the interaction between surface winds and object / search target type. This is due to the shape and size of certain objects having different interactions and therefore specific treatment should be taken into account.
- There are several versions of this table, but this was chosen to serve the same operational practices used at the NSRI.

Search and Rescue

Published in Journal of Operational Oceanography, Hart-Davis and Backeberg 2021: https://doi.org/10.1080/1755876X.2021.1911485

Surfboard | Capsized Catamaran | Rigid Inflatable

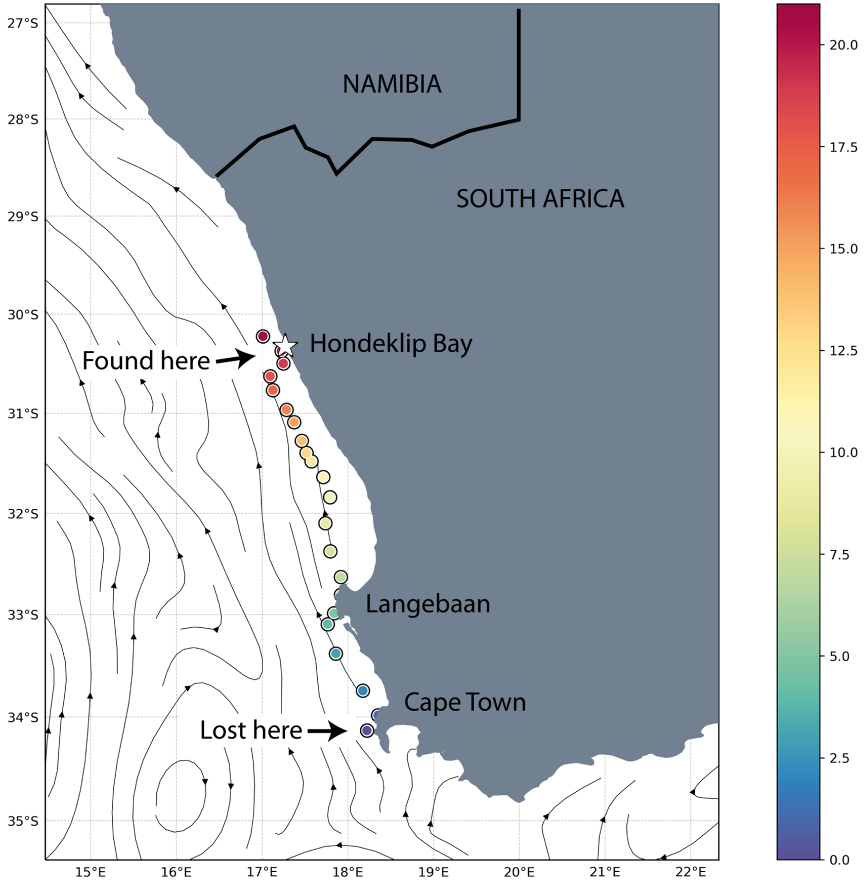


Search and Rescue

In popular media:

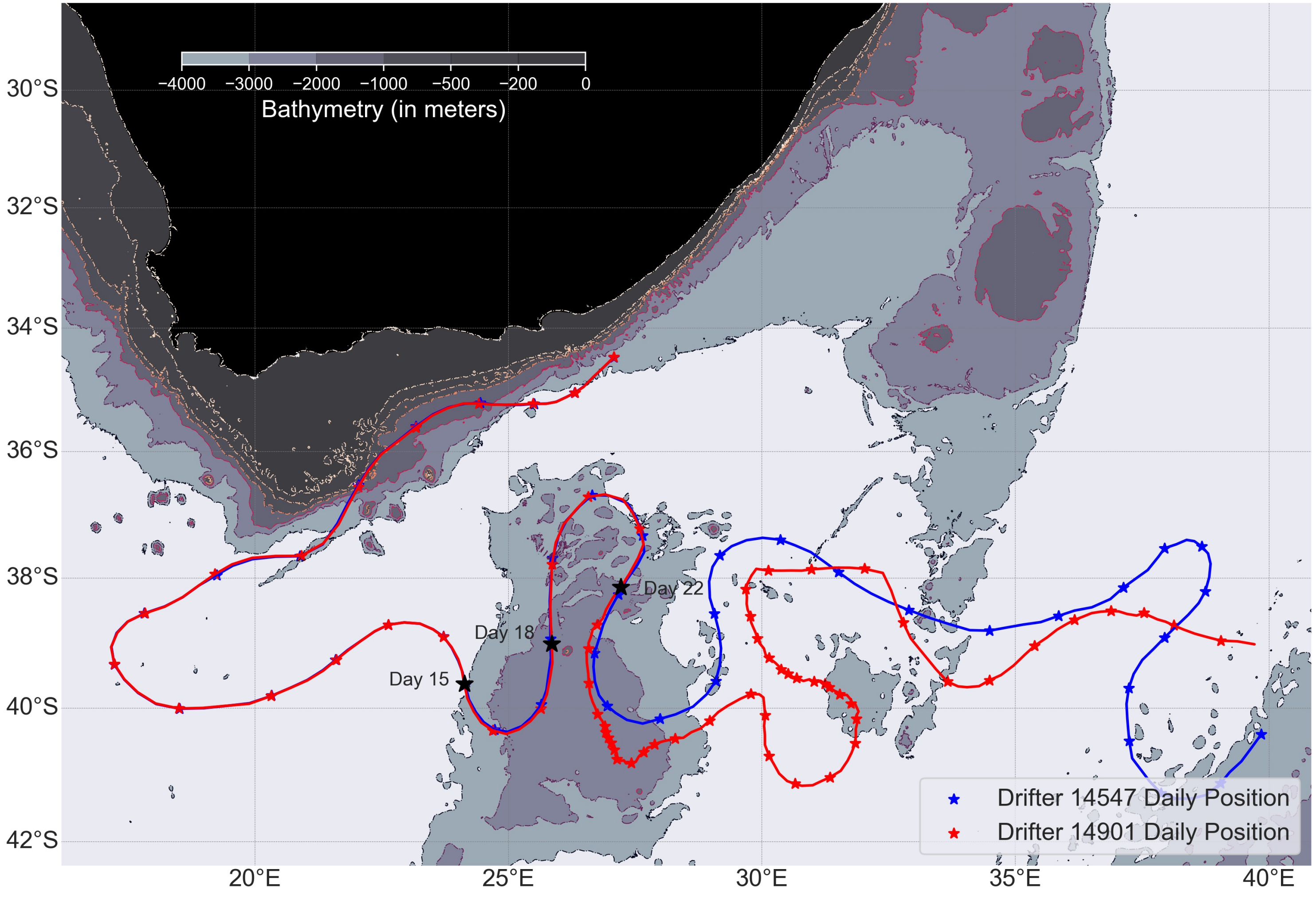
https://magicseaweed.com/news/how-a-surfboard-washing-up-1600kms-away-raises-serious-concerns-over-ocean/11198/

https://magicseaweed.com/news/the-strange-case-of-a-lost-surfboard-washing-up-425kms-away/11177/



Two Drifters

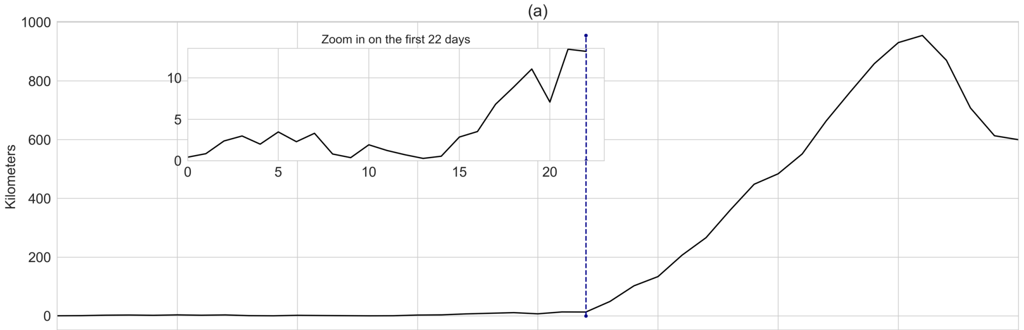
Submitted in 2020 to JGR: Oceans (major revisions, no time)

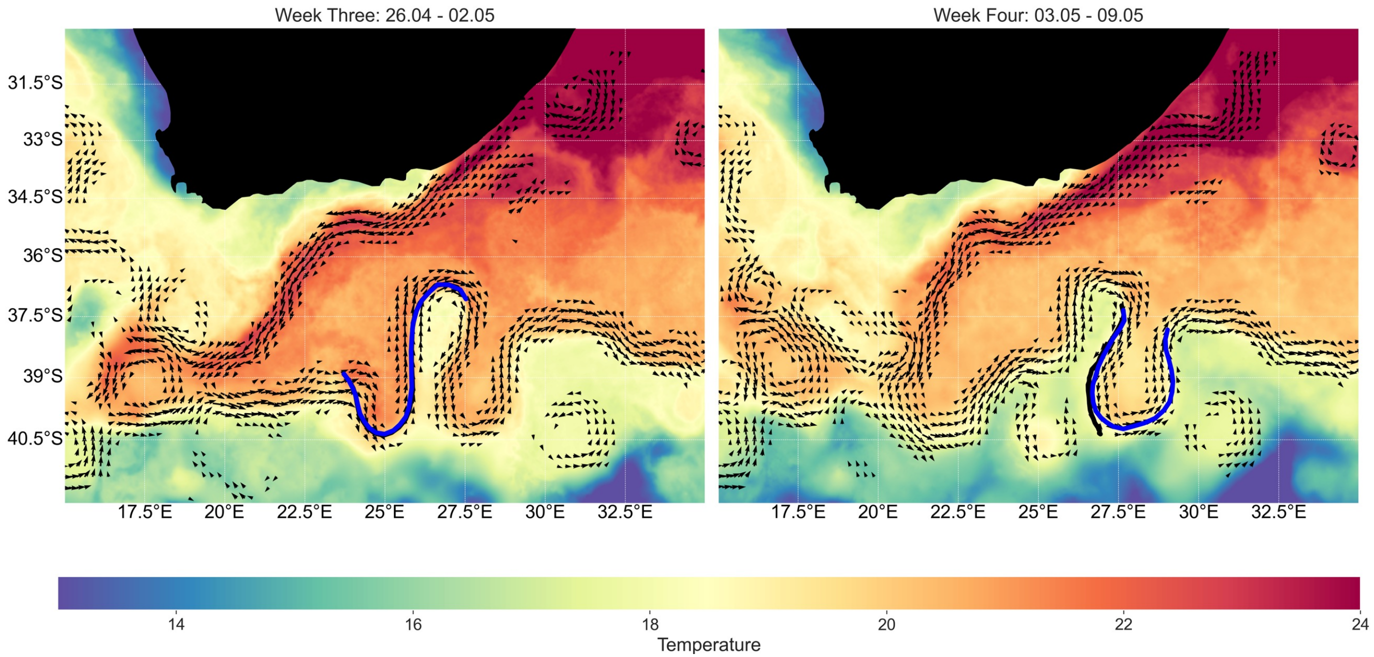


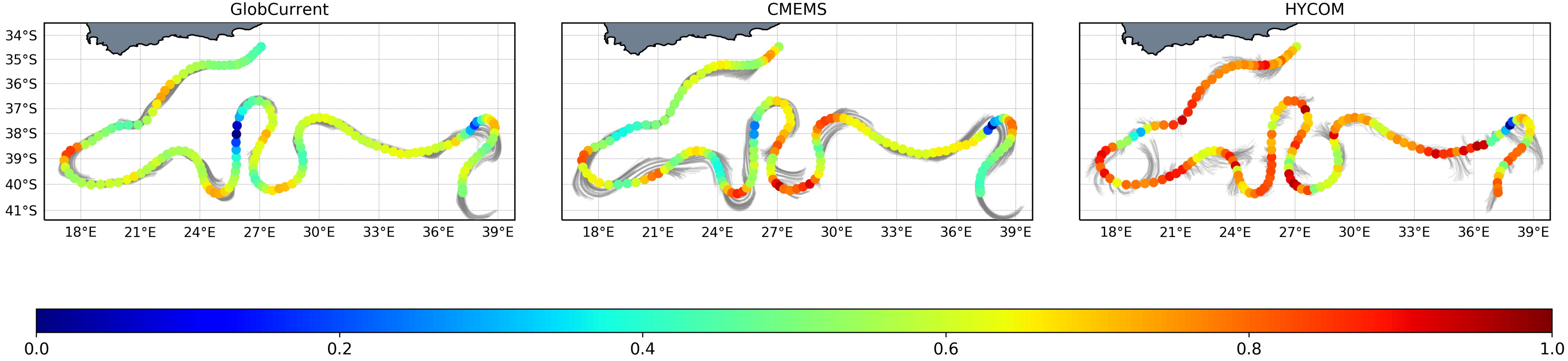
- Two drifters deployed exactly together at the exact same time.
- After 22 days, the two drifters experienced a major separation event while meandering around the Agulhas Plateau.
- We used all publicly available models (CMEMS, HYCOM and GlobCurrent) and observations (SST and altimetry) to try understand why they stayed together but also why they separated when they did.
- It was hypothesised that the mesoscale variability induced by the formation of an eddy on-top of the Agulhas Plateau caused the one drifter to be ‘pulled-out’ of the main current and more influenced by the local variabililty.

Two Drifters

Submitted in 2020 to JGR: Oceans (major revisions, no time)







Coastal Retention Index

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

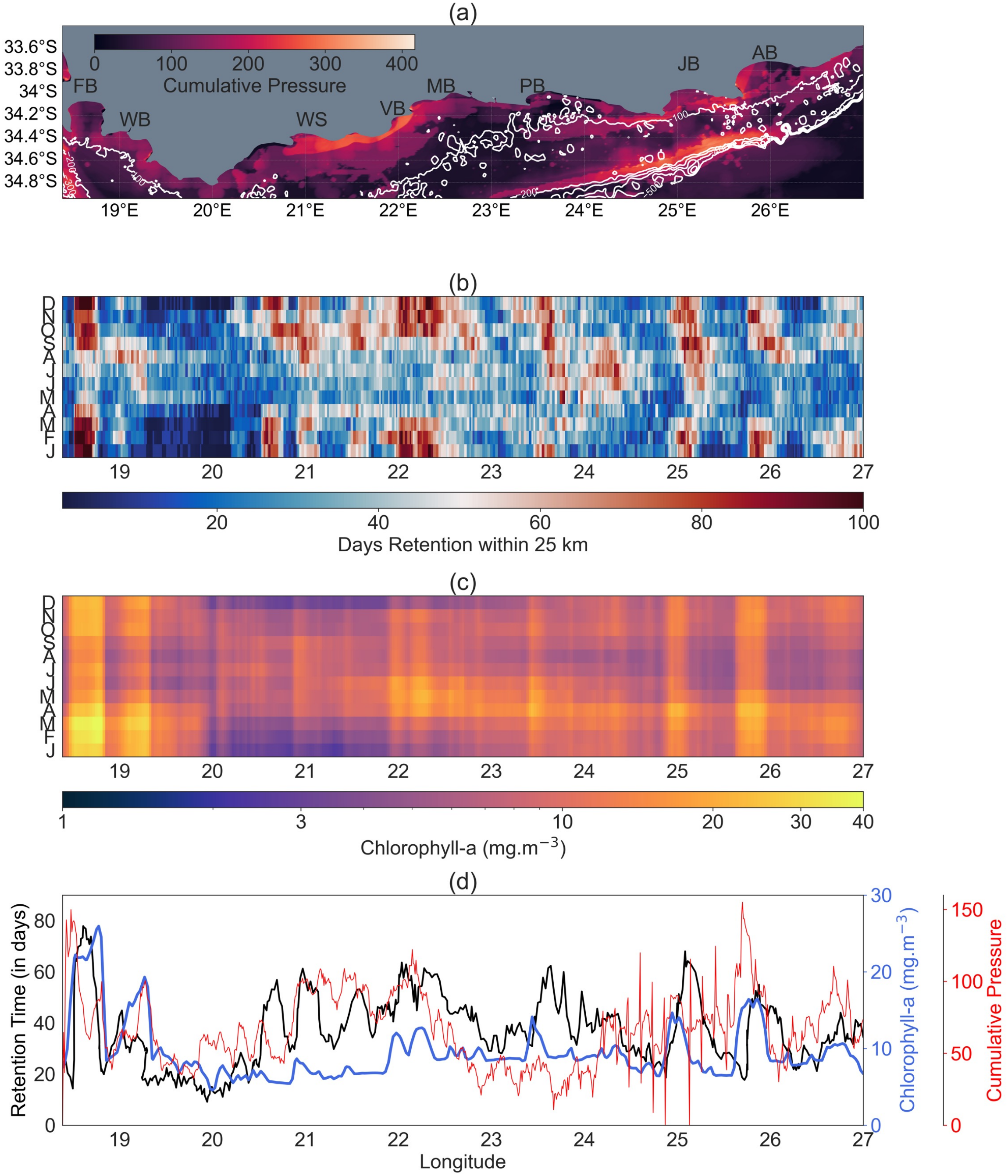
journal homepage: www.elsevier.com/locate/ecss

A new model-based coastal retention index (CORE) identifies bays as hotspots of retention, biological production and cumulative anthropogenic pressures

Maya C. Pfaff[a,b,*], Michael Hart-Davis[c], Marié E. Smith[d,f], Jennifer Veitch[e,f]

[a] Oceans and Coasts, Department of Forestry, Fisheries and the Environment, Cape Town, 8001, South Africa
[b] Department of Biological Sciences, University of Cape Town, Rondebosch, 7701, South Africa
[c] Deutsches Geodätisches Forschungsinstitut der Technischen Universität München (DGFI-TUM), Arcisstrasse 21, 80333, München, Germany
[d] Coastal Systems and Earth Observation Research Group, Council for Scientific and Industrial Research, Rosebank, 7700, South Africa
[e] South African Environmental Observation Network, Cape Town, 8001, South Africa
[f] The Nansen-Tutu Centre, Department of Oceanography, University of Cape Town, South Africa

- This study made use of a high resolution CROCO (Coastal and Regional Ocean Community Model) model along with the Parcels particle-tracking tool to develop a spatio-temporal coastal retention index (CORE) for the South African coastal ocean.
- To explore links between retention, biological productivity and anthropogenic impacts, a monthly time series of CORE (2001–2012) was evaluated in relation to satellite-derived coastal chlorophyll-a (Chl-a) and an index of cumulative human pressure.
- https://doi.org/10.1016/j.ecss.2022.107909



Lobster Larvae Connectivity (vs. Genetic Connectivity)

Received: 11 May 2018 | Revised: 13 September 2018 | Accepted: 14 September 2018
DOI: 10.1002/ece3.4684

ORIGINAL RESEARCH

WILEY Ecology and Evolution Open Access

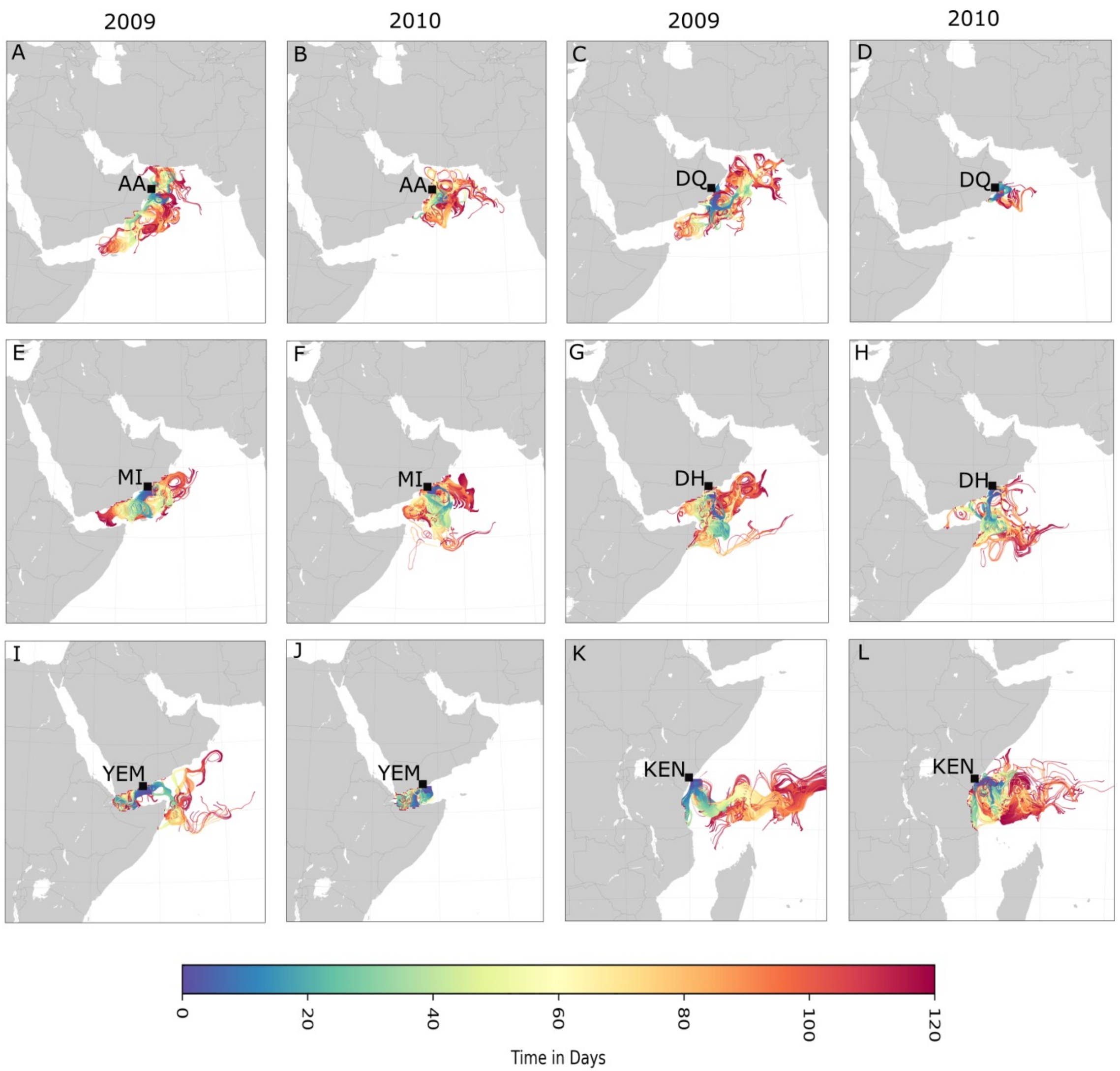
Seascape genetics of the spiny lobster *Panulirus homarus* in the Western Indian Ocean: Understanding how oceanographic features shape the genetic structure of species with high larval dispersal potential

Sohana P. Singh[1,2] | Johan C. Groeneveld[1,2] | Michael G. Hart-Davis[3,4,5] | Björn C. Backeberg[4,6,7] | Sandi Willows-Munro[2]

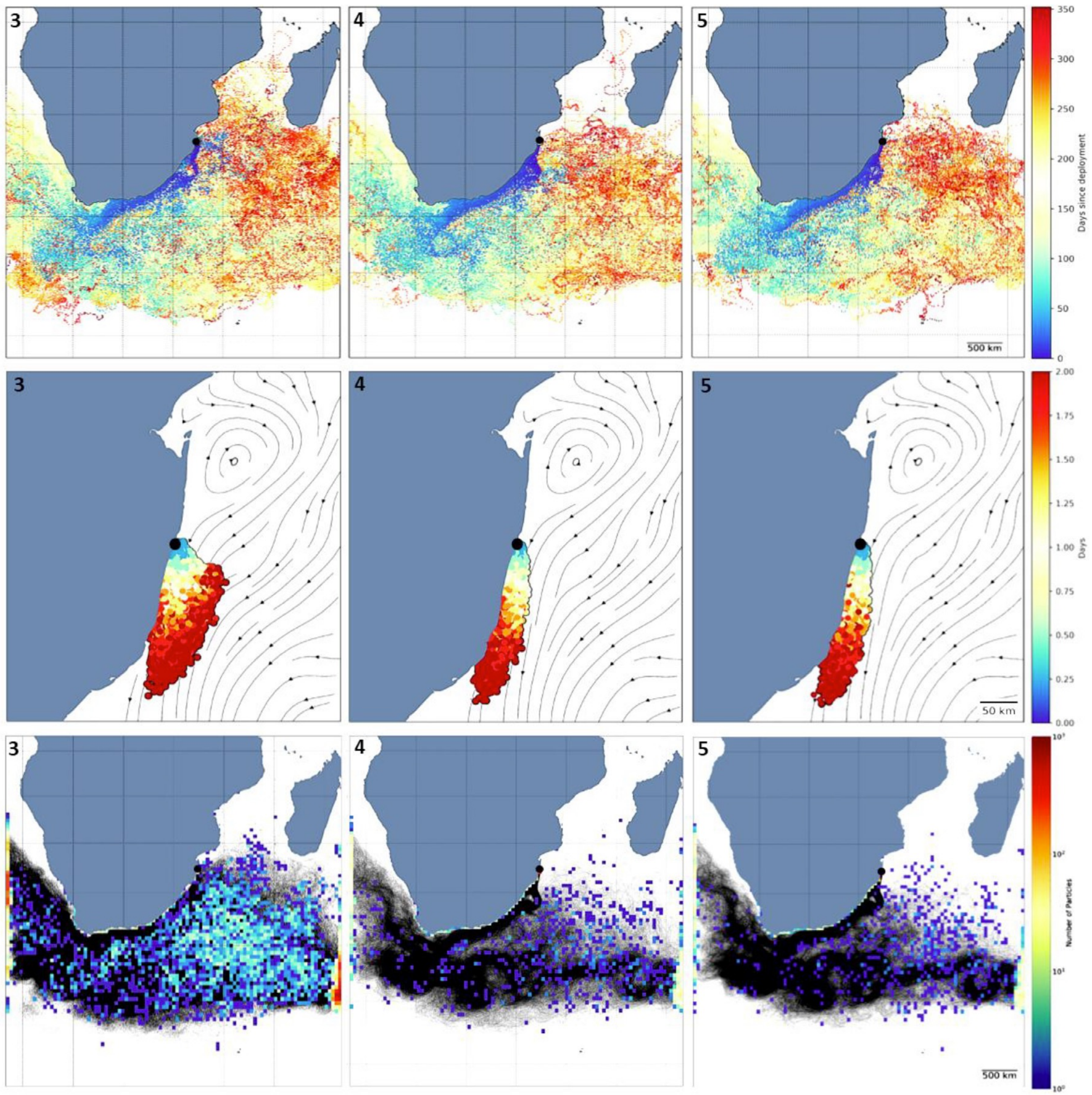
- This study compared the connectivity from a particle tracking simulations (representing the physical oceanographic connectivity) with genetic connectivity of lobster larvae.

- Here, the particles were forced with GlobCurrent surface currents and the particles were passive (i.e. did not include swimming) to try represent their 'realistic' drift.

- Links between genetic and oceanographic connectivity were found for the different sites studied along the Western Indian Ocean.
- https://doi.org/10.1002/ece3.4684



Juvenile Turtle Dispersion



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Ecological Modelling

Volume 431, 1 September 2020, 109130

Effects of swimming behaviour and oceanography on sea turtle hatchling dispersal at the intersection of two ocean current systems

Diane Z.M. Le Gouvello [a], Michael G. Hart-Davis [a, b, e, f], Björn C. Backeberg [c, d, e], Ronel Nel [a]

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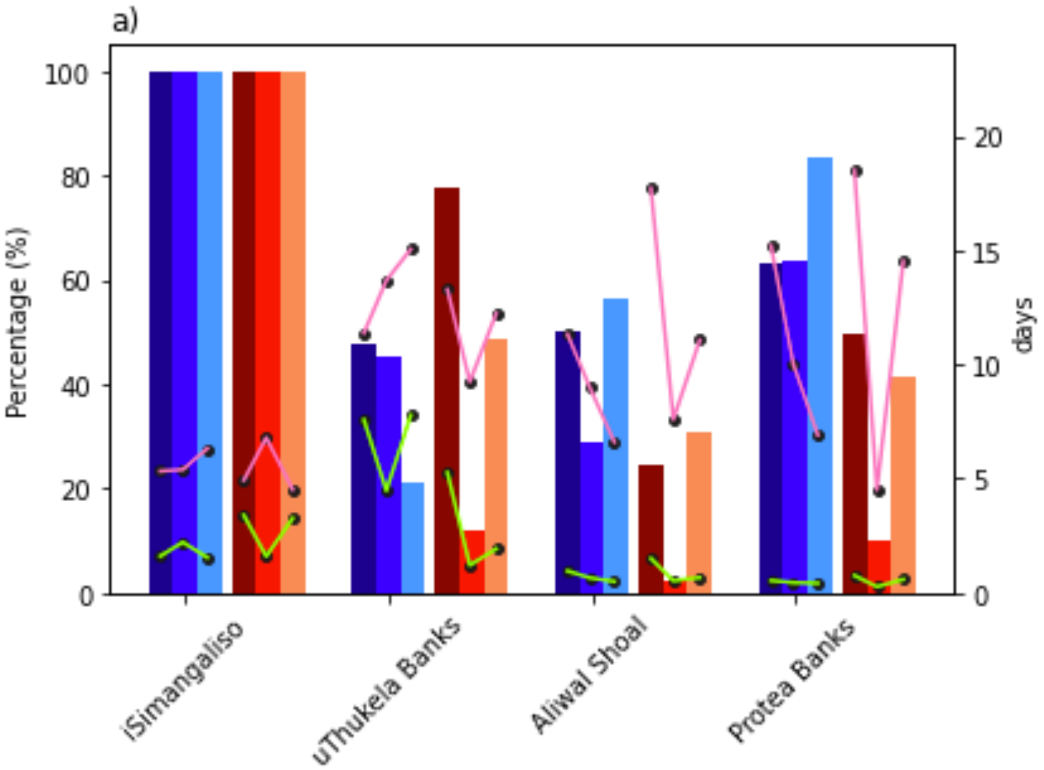
https://doi.org/10.1016/j.ecolmodel.2020.109130   Get rights and content

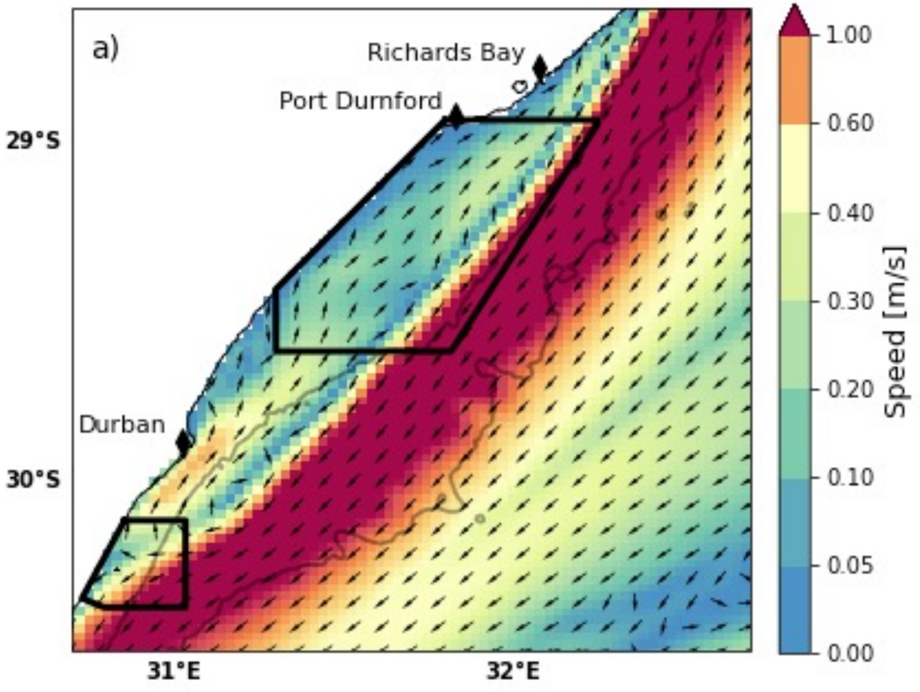
- We studied the importance of juvenile swim behaviour on the dispersal of newly hatched turtles in an aid to map where these turtles eventually end up. Particles forced in Parcels using Copernicus modelled data. Involved programming a behaviour into the Parcels to account for different swim speeds. https://doi.org/10.1016/j.ecolmodel.2020.109130

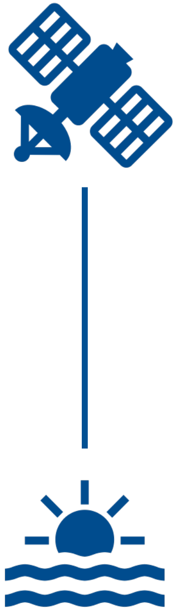
- Work being extended with my MSc student, using the STAMM model (integrated into Parcels)

Surface Current Study and MPA Connectivity

Supervision of MSc of S. Heye 2020 – 2021, Submitted to Continental Shelf Research (2022).







Thank you! Questions?

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