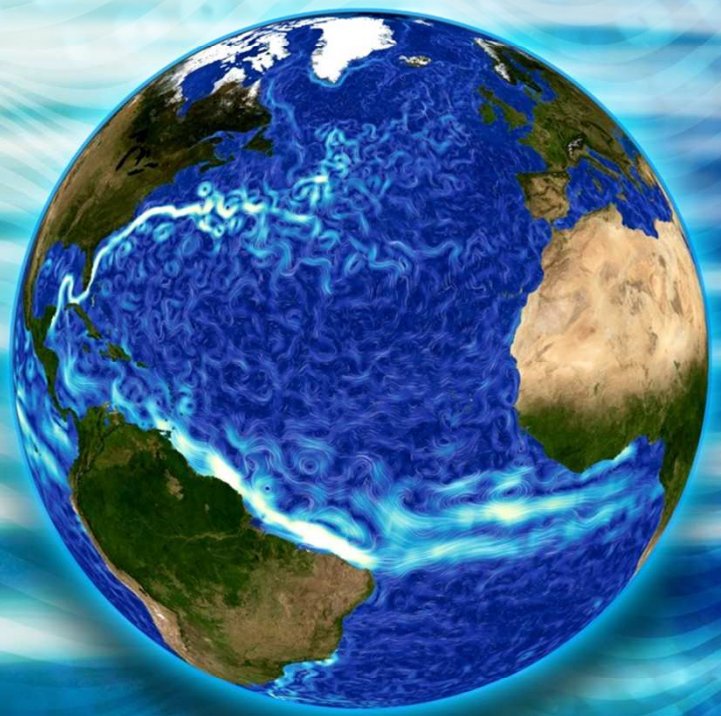

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Team SKIM ("science" side)

MAG Chair: **Fabrice Ardhuin** (LOPS, FR) (new home of the Ifremer remote sensing group)

Other MAG Members:

Alessandro Battaglia (U. Leicester, UK), **Peter Brandt** (GEOMAR, DE), **Fabrice Collard** (OceanDataLab, FR), **Geir Engen** (NORUT, NO), **Paco Lopez-Dekker** (TUDelft, NL) **Adrien Martin** (NOC, UK), **Jamie Shutler** (U. Exeter, UK), **Michel Tsamados** (UCL, UK), **Erik van Sebile** (U. Utrecht, NL)**, Detlef Stammer** (U. Hamburg)

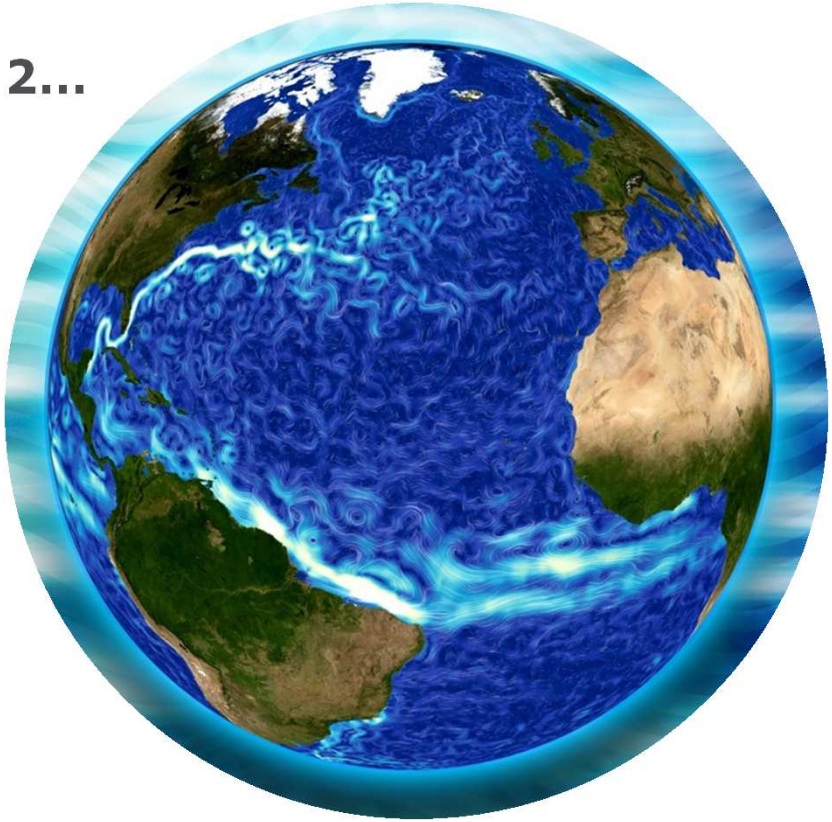
+ contributions from many SKIM friends and supporters:

E. Rodriguez (JPL, USA), M. Bourrassa (FSU, USA), J. Bidlot (ECMWF, UK), E. Remy, M. Drevillon (Mercator-Ocean, FR)
M. Campillo (ISTerre, FR), F. Dias (UCD, Ireland), L. Bertino (NERSC, NO), J. Scutt Phillips, V. Onkin (U. Utrecht, NL)
B. Chapron, F. Nouguier, C. Peureux, L. Marié, C. Maes, A. Ponte, C. Lique (LOPS, FR), T. Holding (U. Exeter),
Y. Li (TUDelft, NL), A. Benetazzo (ISMAR, IT), L. Aouf (Meteo-France, FR), C. Ubelmann, P. Dubois, F. Soulat (CLS, FR),
L. Gaultier (OceanDataLab, FR), G. Dibarboure, F. Boy (CNES, FR), G. Monnier (SCALIAN, FR)…

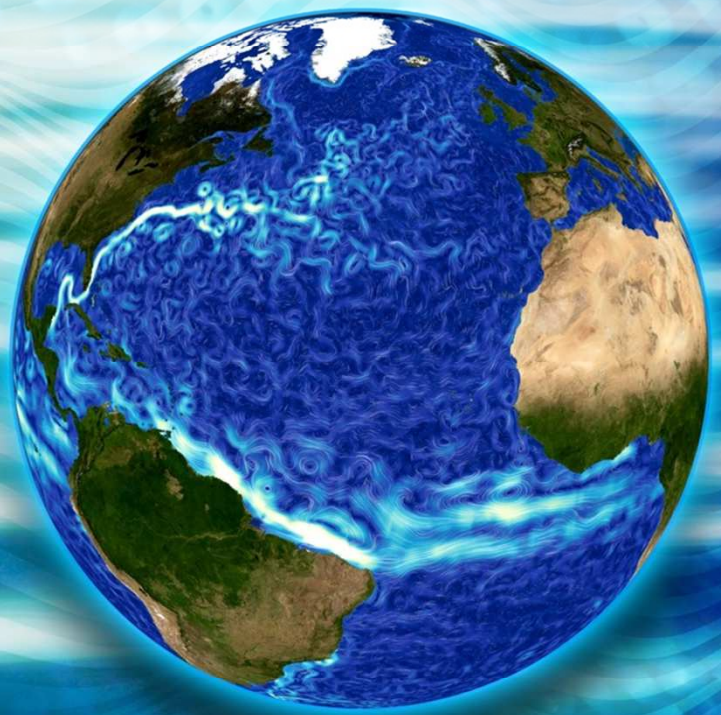
And support by esa including the mission-scientist-cum-guitar-player extraordinaire: **Craig Donlon**

Overview of this talk

- **1. Context: ESA EE9: after GOCE, SMOS, Cryosat 2… who's next?**
- **2. Why currents?**
- **3. Why SKIM?** We need a "HF radar in the sky"
- **4. How does SKIM work?**
- **5. SKIM expected performance**



SKIM Level -2d simulated currents (OceanDataLab)



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1. Context: ESA and EE9

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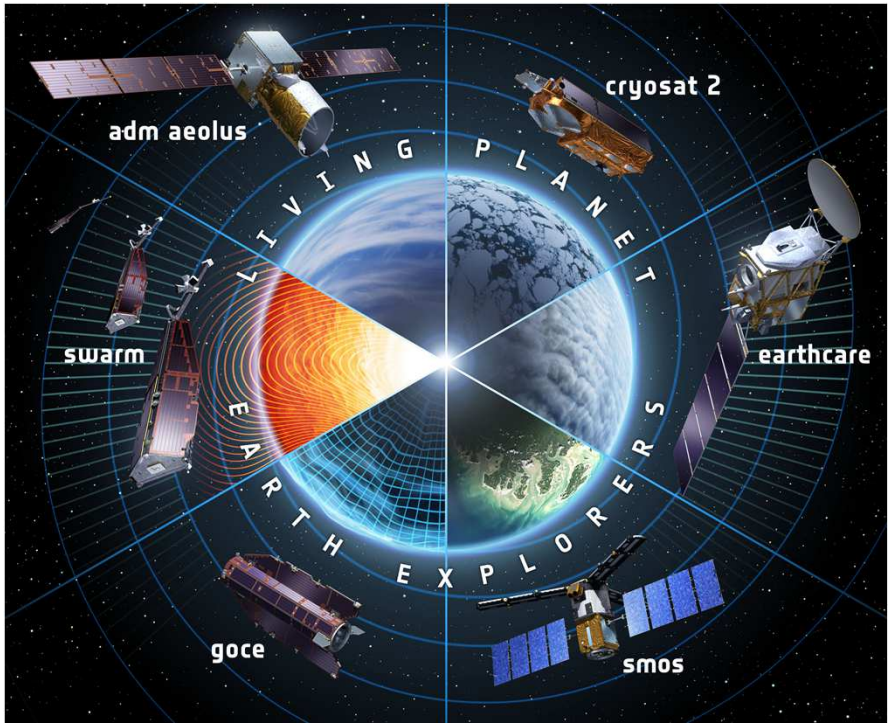
The Earth Explorers family

European Space Agency (ESA) funds « Earth Explorers » (EEs)
→ address key scientific challenges identified by the science community
→ breakthrough technology in observing techniques.

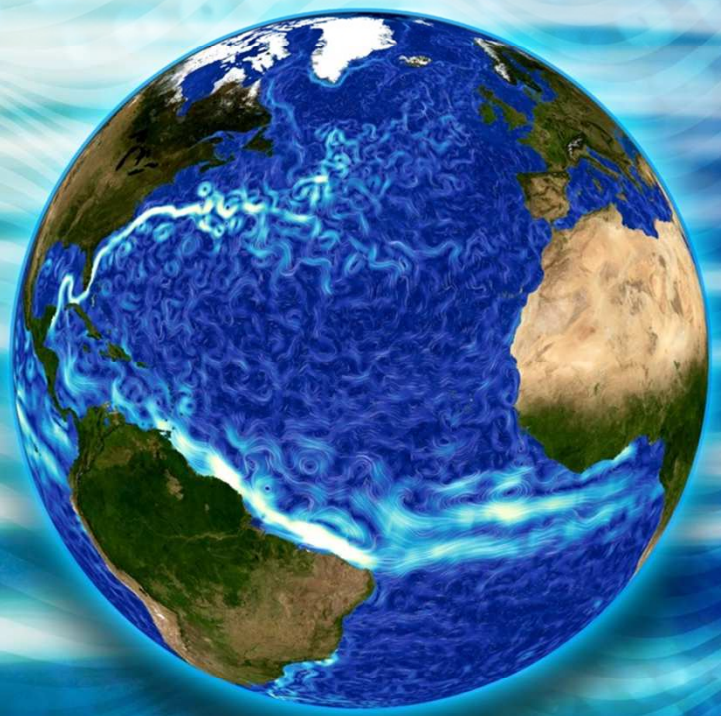


science community involved right from the beginning :
- definition of new missions
- peer-reviewed selection process

8 EEs selected so far
(opportunity missions ~ 250 M€, core missions ~ 450 M€):

EE1 : GOCE **EE2 : SMOS** **EE3 : Cryosat** → **lots of ocean applications**
EE4 : Swarm **EE5 : ADM-Aeolus** **EE6 : EarthCARE**
EE7 : Biomass **EE8 : FLEX** **EE9 : FORUM or SKIM… TBD this fall** → **SKIM is the only Ocean mission**
EE10: Daedalus / Harmony / G-CLASS, **EE 11: call soon**

Report for Mission Selection due June 17 (This Monday)
EE9 Final selection : User Consultation Meeting 16 & 17 July 2019, Cambridge UK
… launch in 2025 (on Vega-C form Kourou)



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2. Why currents?

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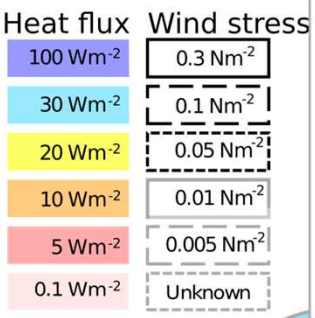
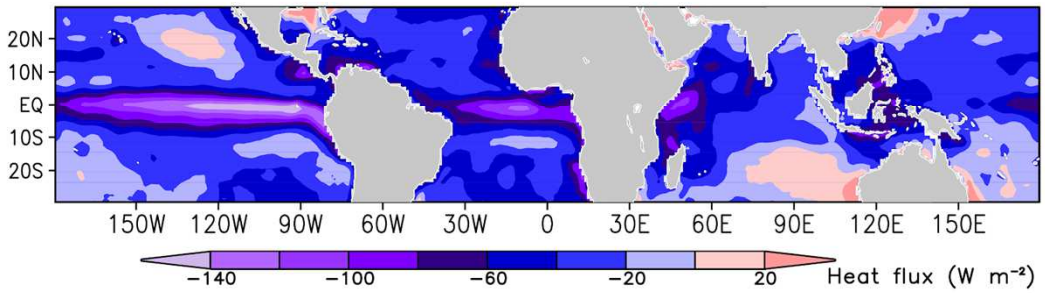
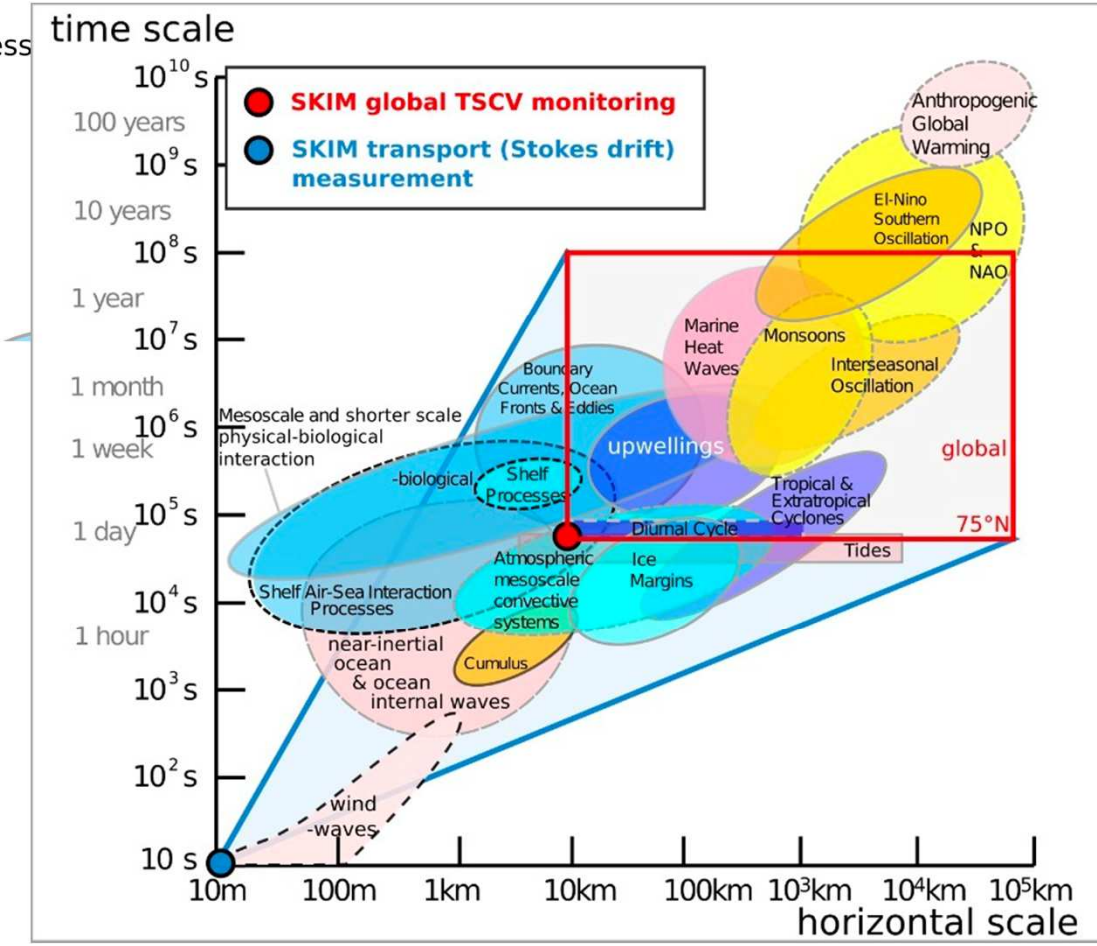
Why currents... and which current?

- Air sea fluxes
- Surface transport
- -> Total Surface Current Velocity (TSCV)



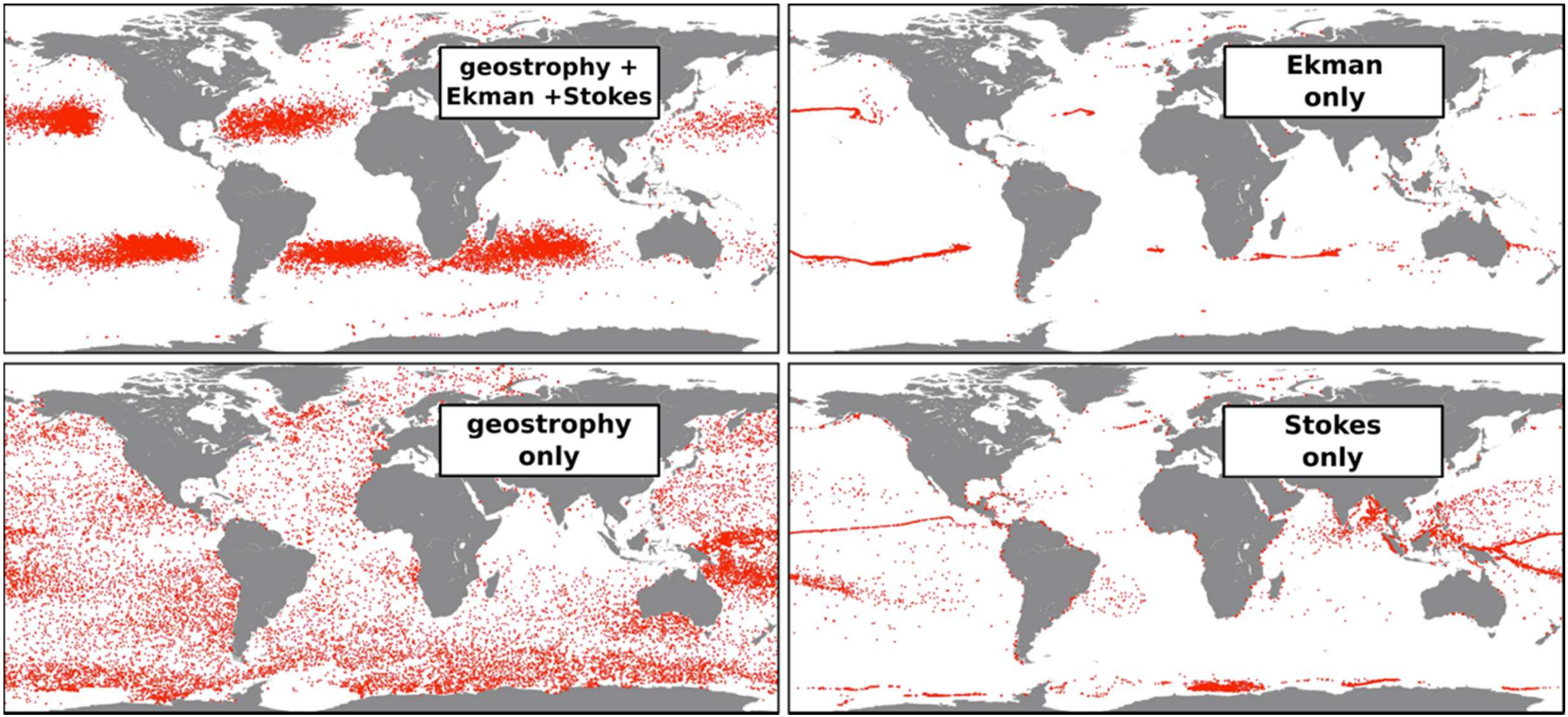


Mean heat budget residual (2003-2017): sum of horizontal heat advection and vertical turbulent cooling (Foltz et al. 2019)

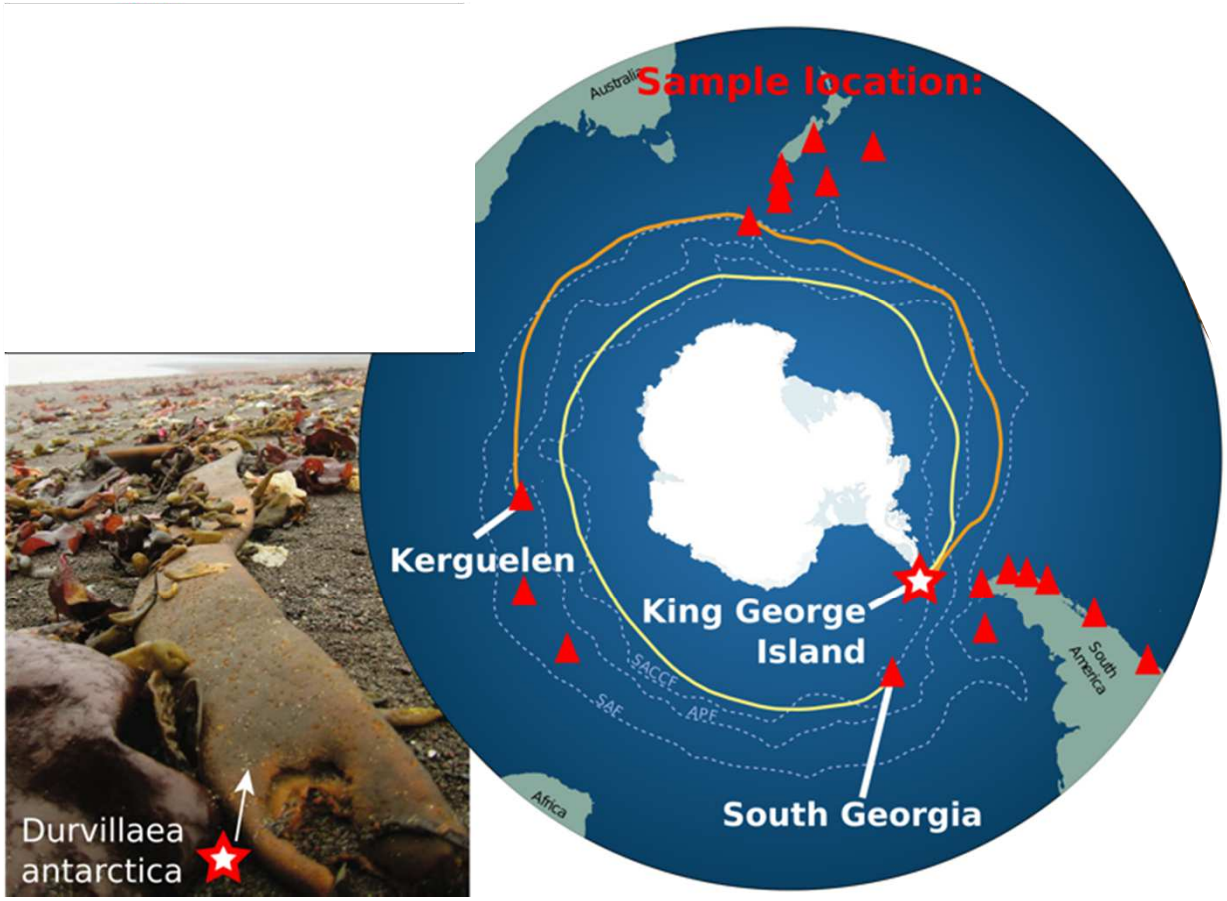


(adapted from Cronin et al. 2019)

Which current ? We want the *Total* velocity (TSCV)

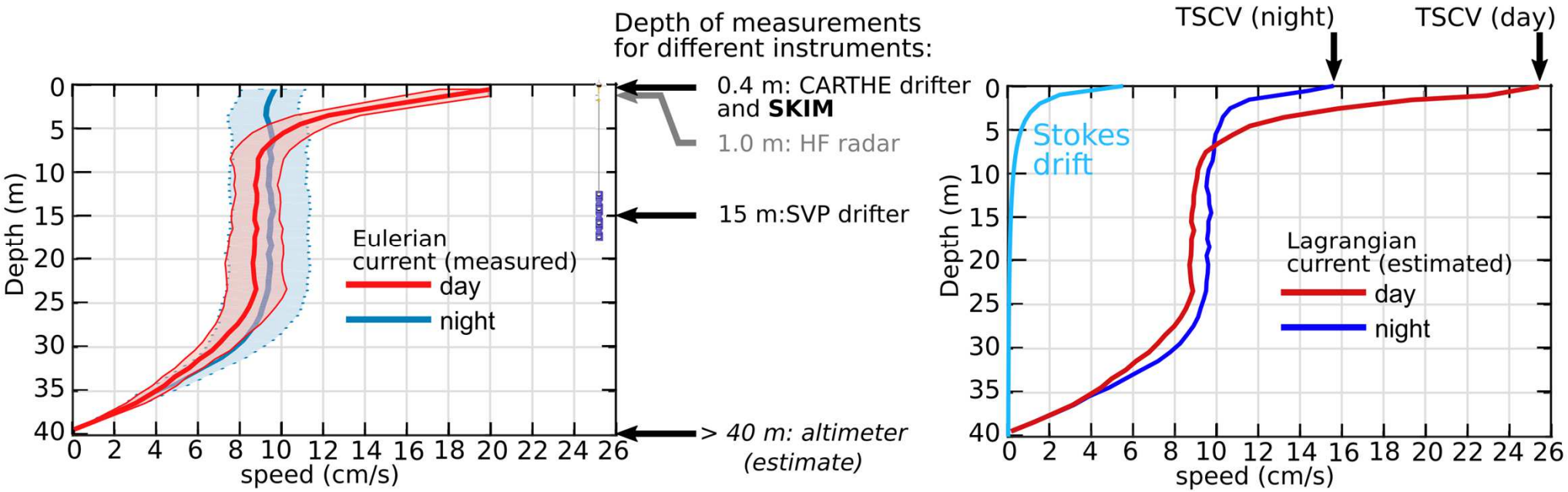


Which current ? We want the *Total* velocity (TSCV)

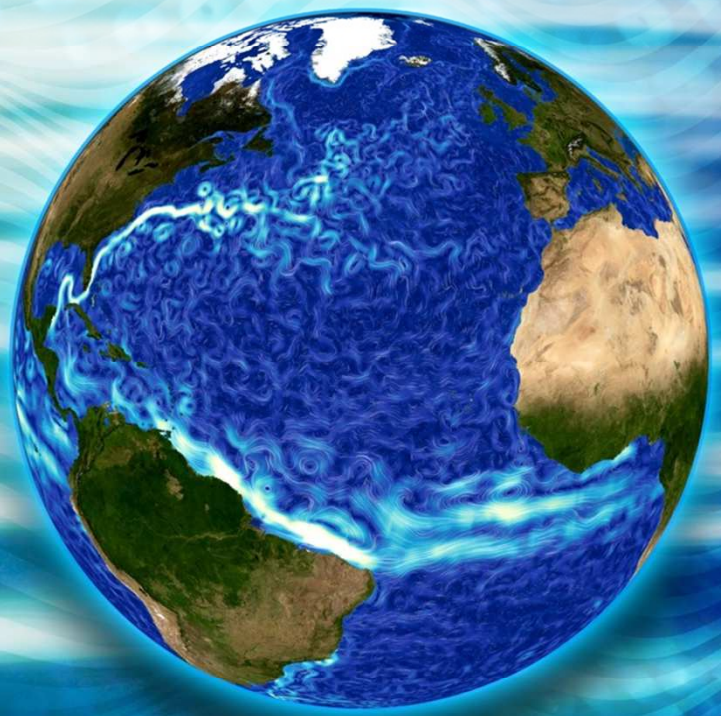


(Fraser et al., Nature Comm. 2018)

Which current ? We want the *Total Surface* velocity (TSCV)



(Sutherland et al., JPO 2015)



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3. Why SKIM?

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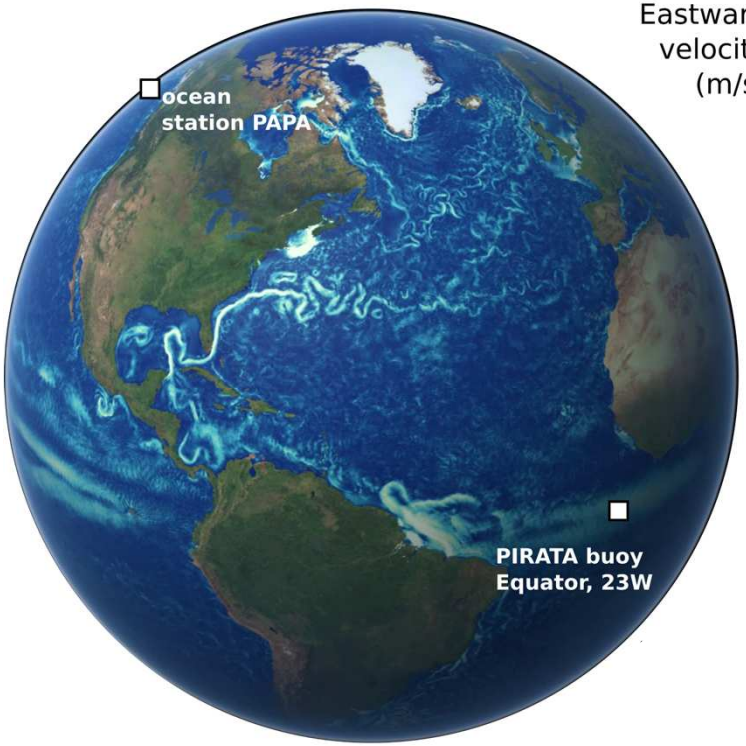
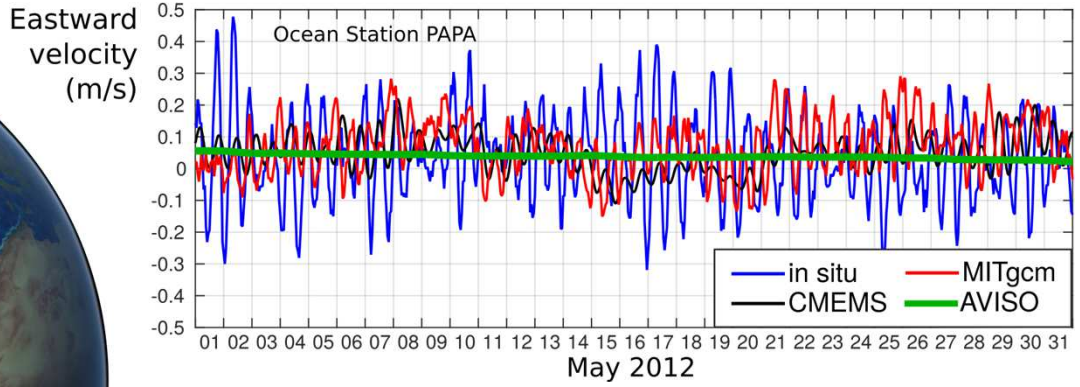
3. Why SKIM ?

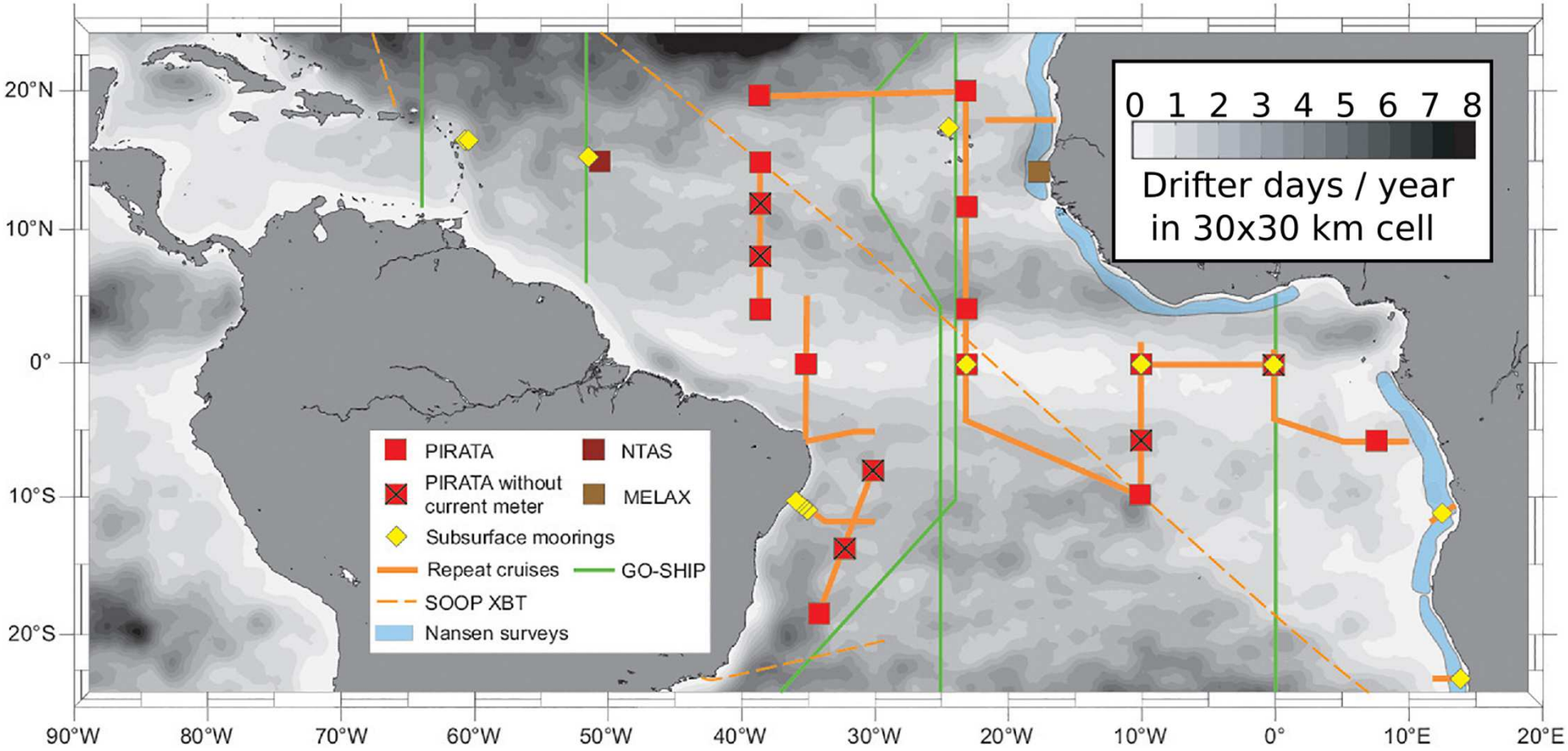
Currents have been estimated routinely from space for 25 years using satellite altimetry – why do we need another satellite mission for the same purpose?





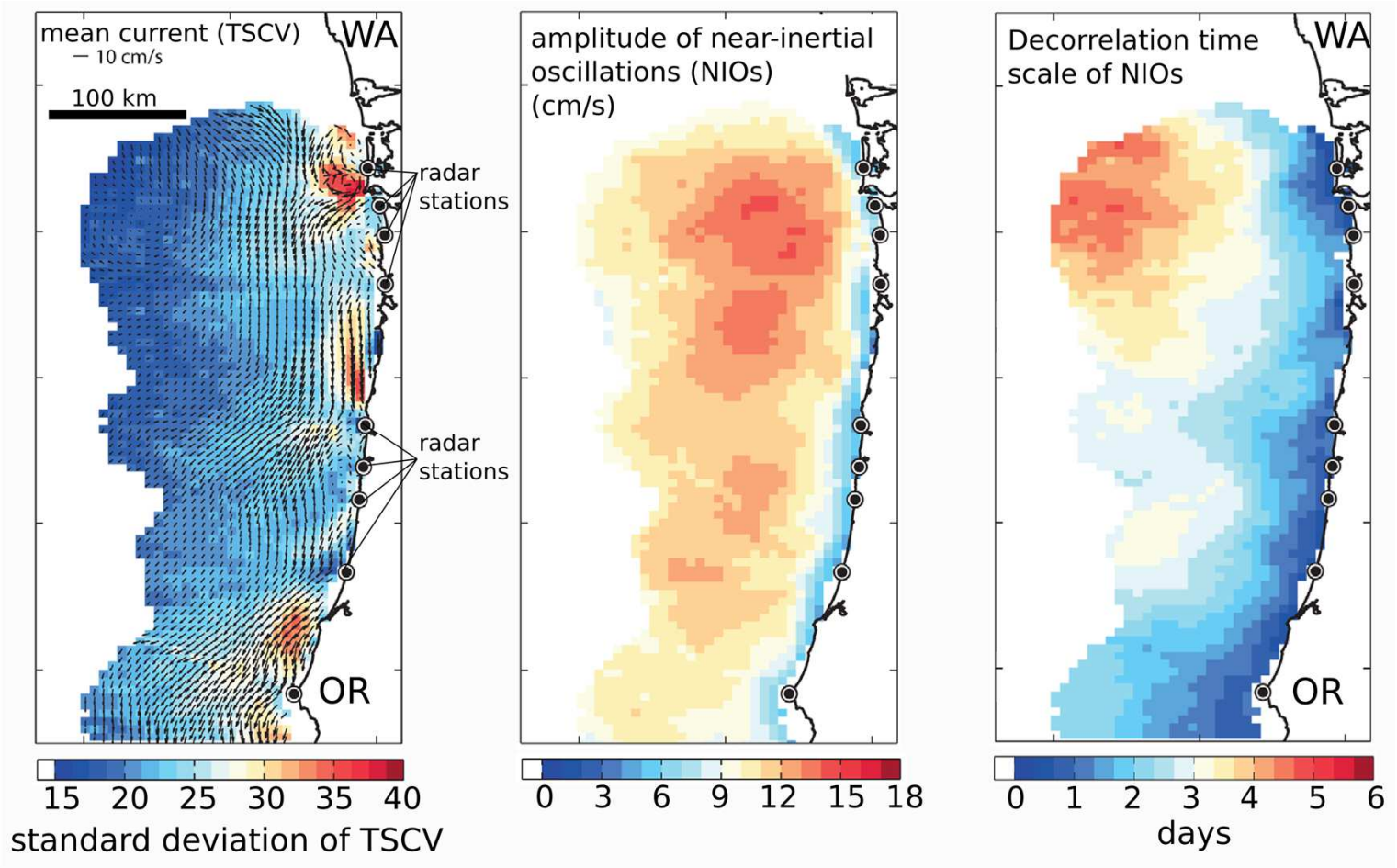
It seems that altimetry does not agree
With near-surface currents

3. Why SKIM ? The closest we get are 15 m depth (SVP)

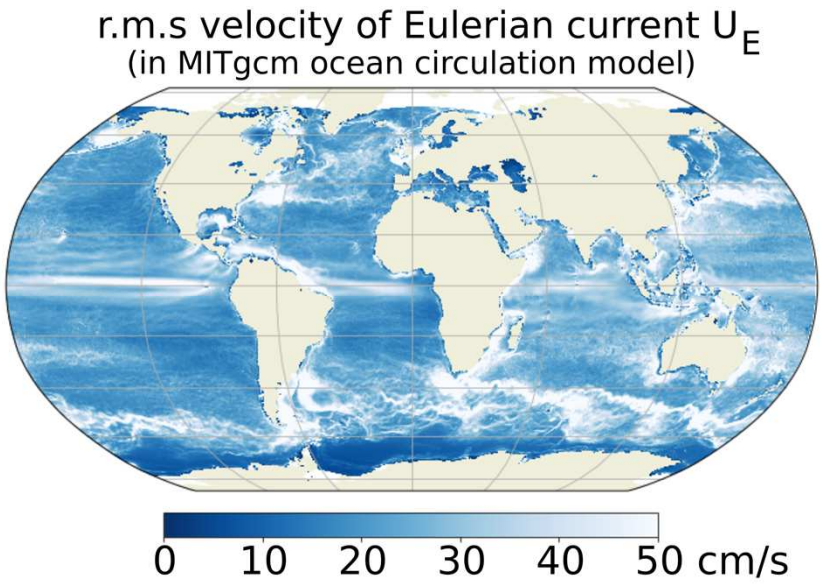


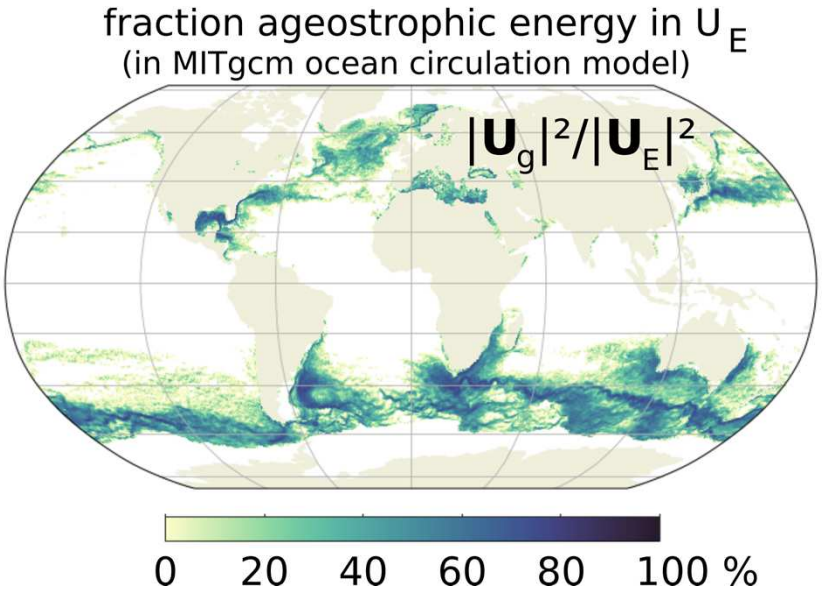
At the equator, SKIM will gives 100 times more data … Foltz et al. (2019)

3. Why SKIM ? We need a “HF radar in the sky”



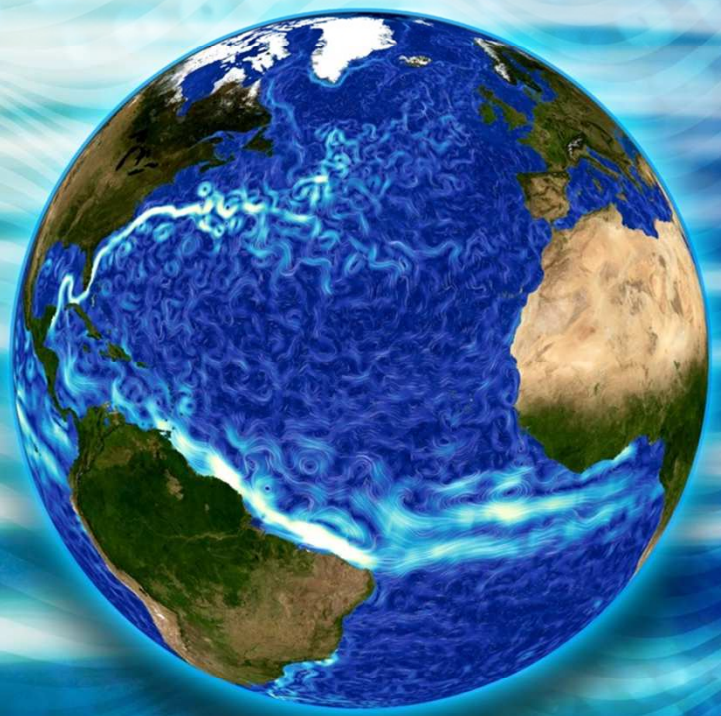
3. Why SKIM ? How much of surface current is geostrophic?





(A. Ponte & X. Yu, LOPS) (M.H. Rio & al., CLS)

Foltz et al. (2019)



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4. How does SKIM work?

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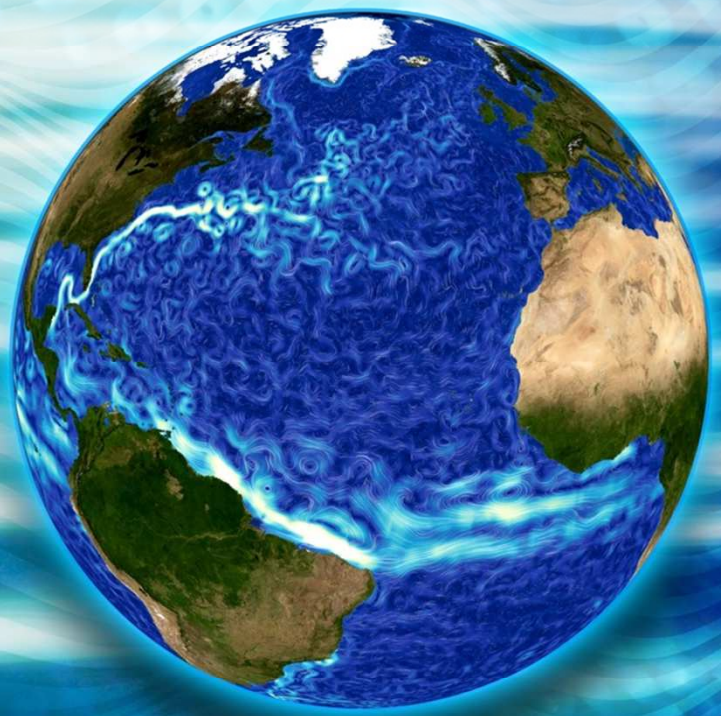

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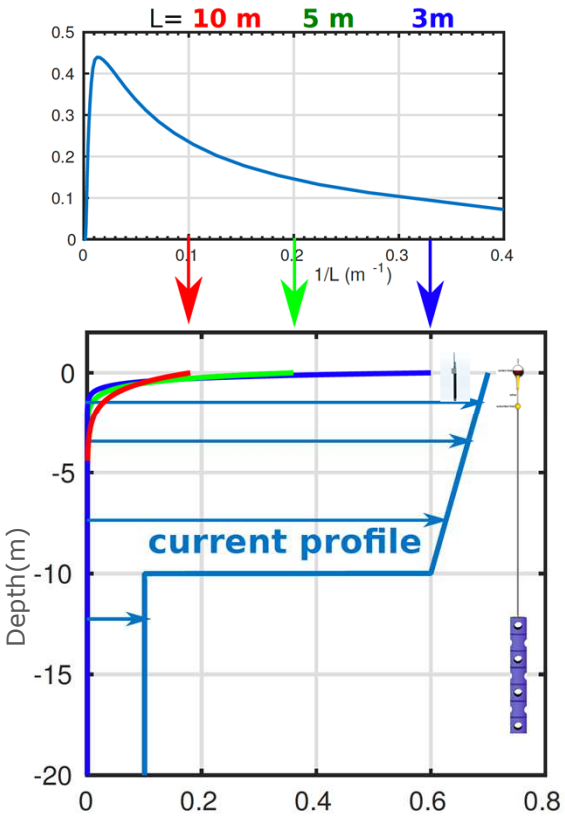
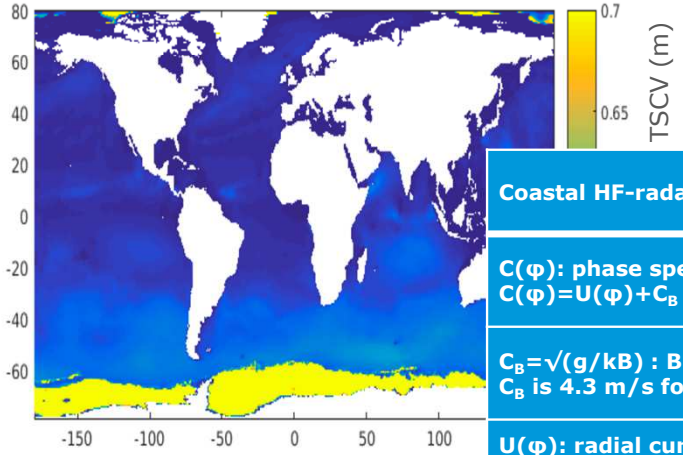
What is the depth of SKIM TSCV measurement?



average surface slope spectrum

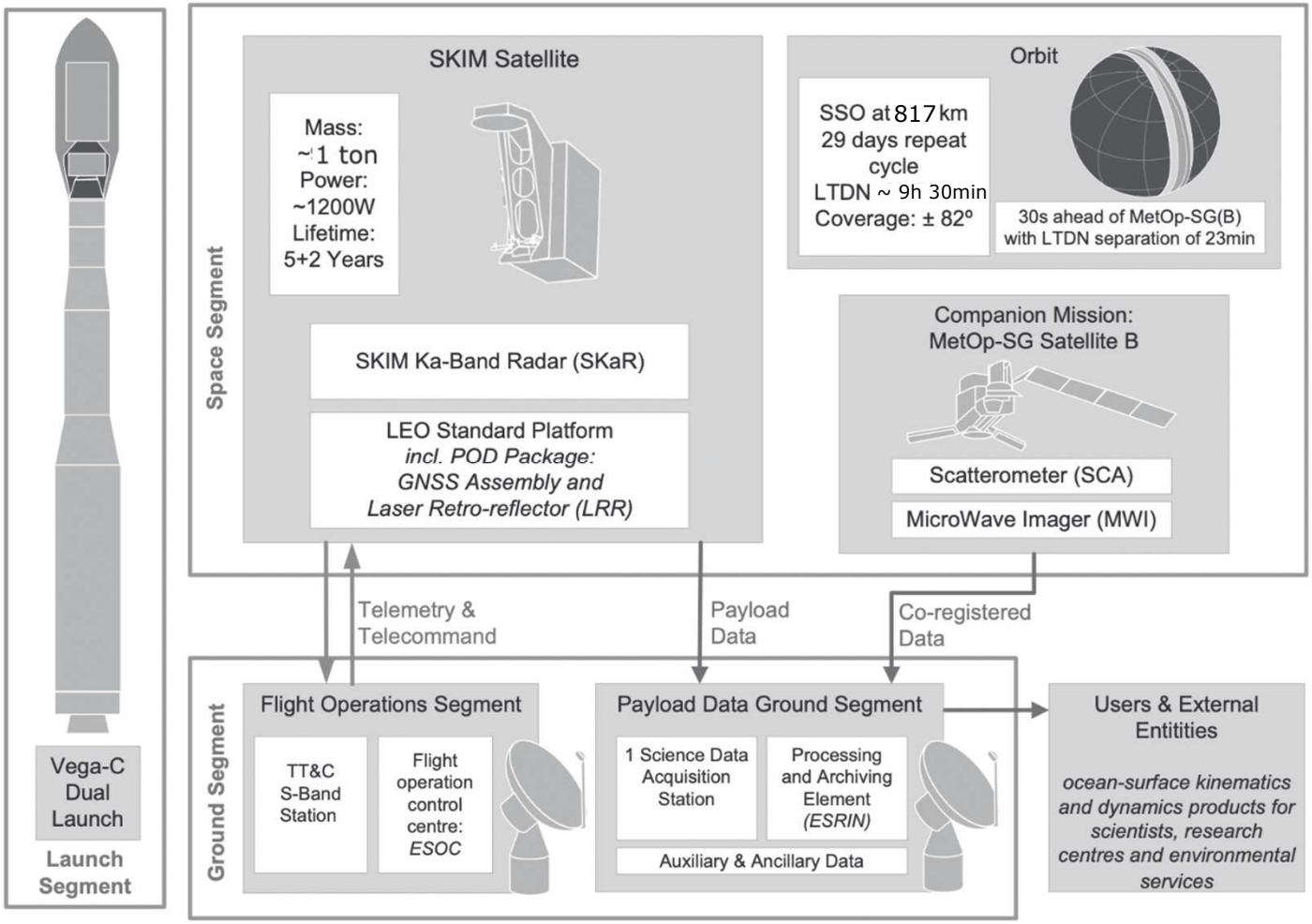
Average depth of measurement



- Like a HF radar, depth is wavelength/(4π) (*Stewart and Joy* 1974, valid for linear shear)
- … weighted by the surface slopes spectrum.
- "depth of meas." = 0.55 m
- -> "**average over the top 1 m of the sea surface**".

Coastal HF-radar	**SKIM**
C(φ): phase speed in azimuth φ **$C(\varphi)=U(\varphi)+C_B$**	U_{GD} (φ): geophysical Doppler velocity $U_{GD}(\varphi)=U_{CD}(\varphi)+U_{WD}(\varphi)$
$C_B=\sqrt{(g/kB)}$: Bragg phase speed **C_B is 4.3 m/s for a 12 MHz radar**	$U_{WD}(\varphi) = (C_0 + \Delta C)\cos(\varphi-\varphi_{WD})$ C_0 varies between 1-2.5 m/s for Ka band at θ=12°
U(φ): radial current in azimuth φ	$U_{CD}(\varphi)$
kB/4π: depth of measurement **= 1 m for 12 MHz radar**	$\int k/4\pi\, k^2E(k,\varphi)\, dk\, d\varphi$: depth of measurement = 0.5 to 0.7 m for SKIM

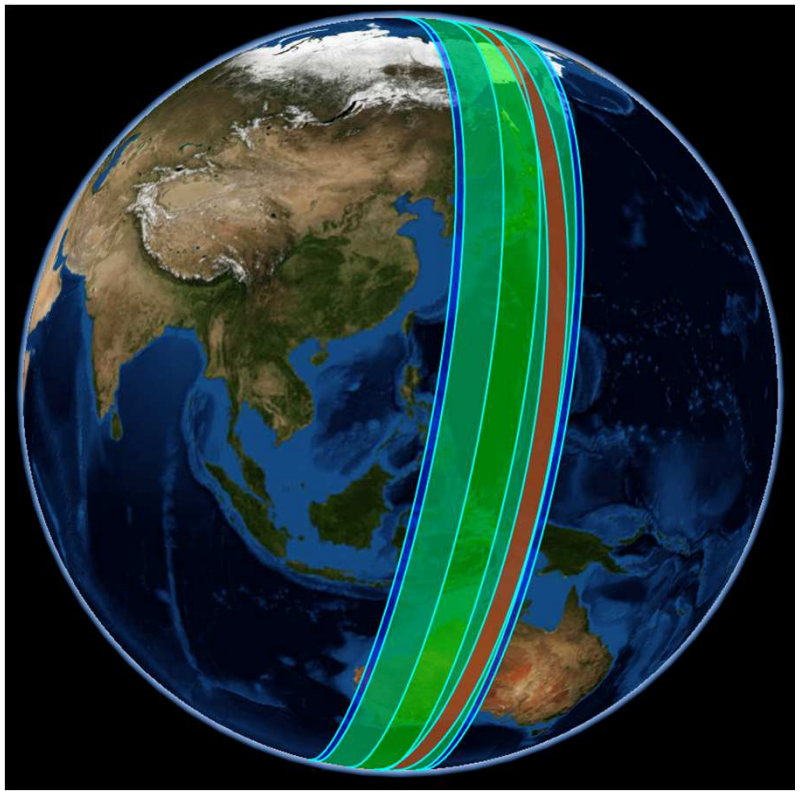
4. How SKIM works: Mission Elements



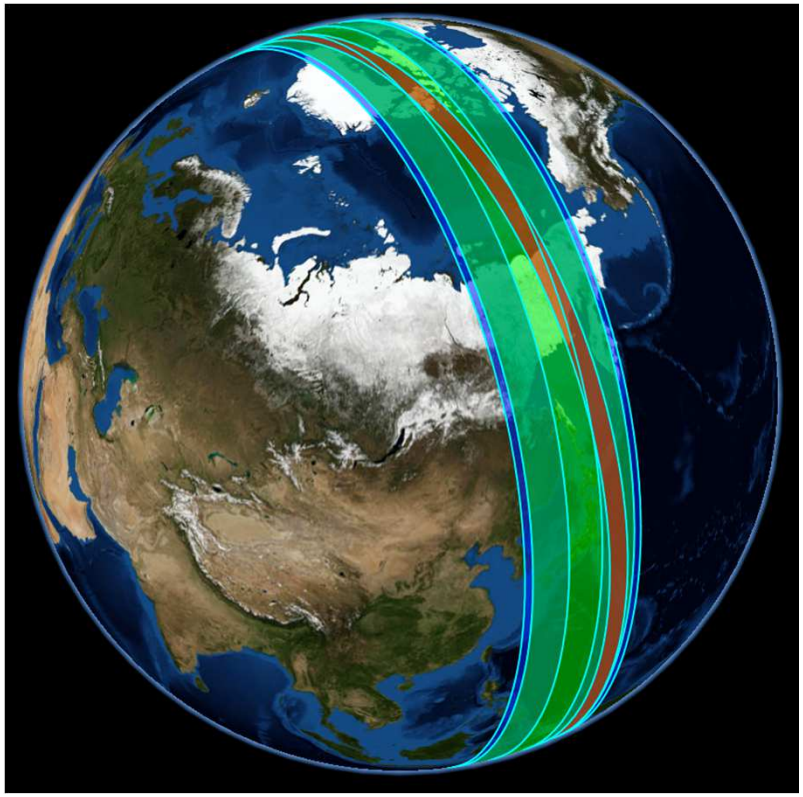
4. How SKIM works: Mission Elements

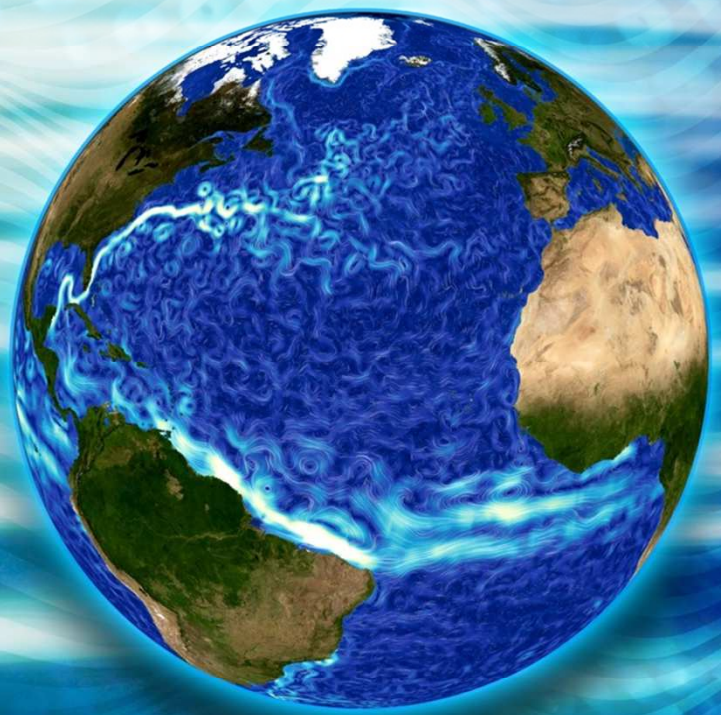
SKIM is designed to fly in loose formation with MetOp-SGB1:

- sun-synchronous, 9 AM / 9 PM
- joint measurement of wind vector (SCA), current & waves (SKIM) …



SKIM
MWI
SCA





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5. SKIM expected performance

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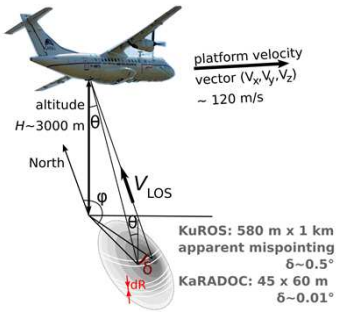
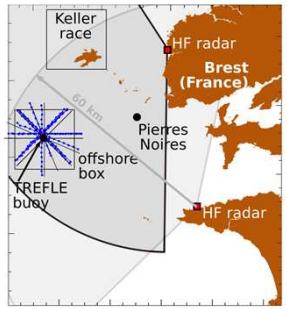
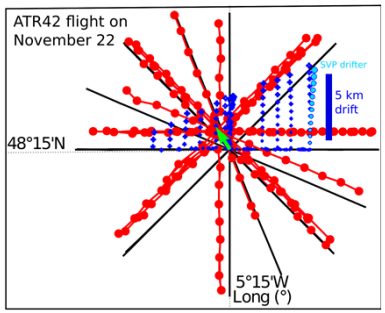
5. Performance: it can be done, see DRIFT4SKIM campaign

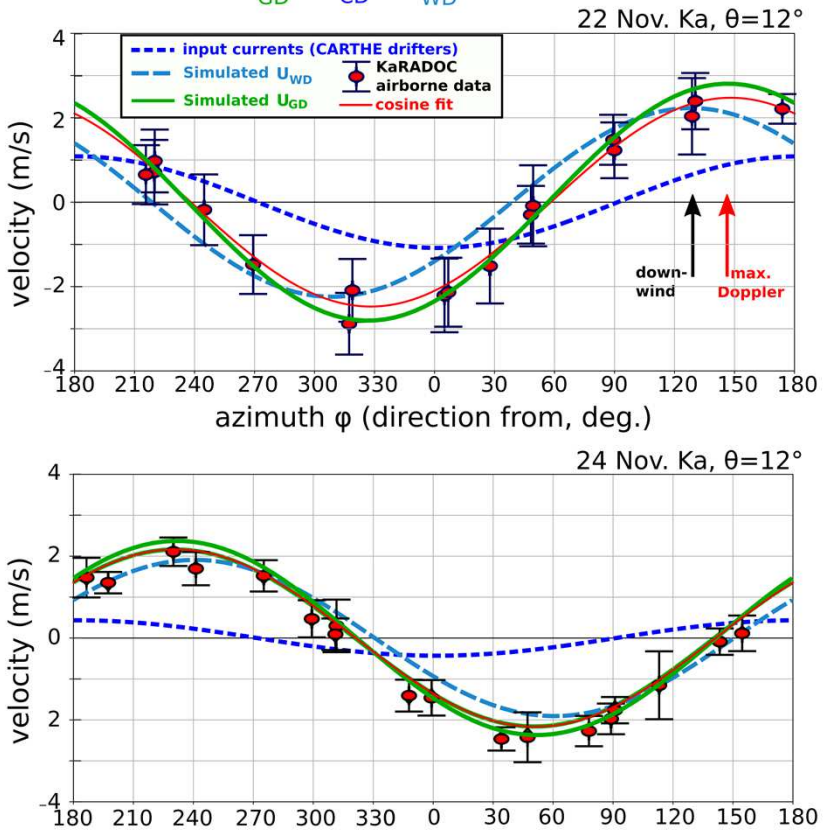
See Marié et al. (2019… to be submitted Monday) for details (oo l'aventure météo, en replay sur France5)







forward model: $U_{GD} = U_{CD} + U_{WD}$

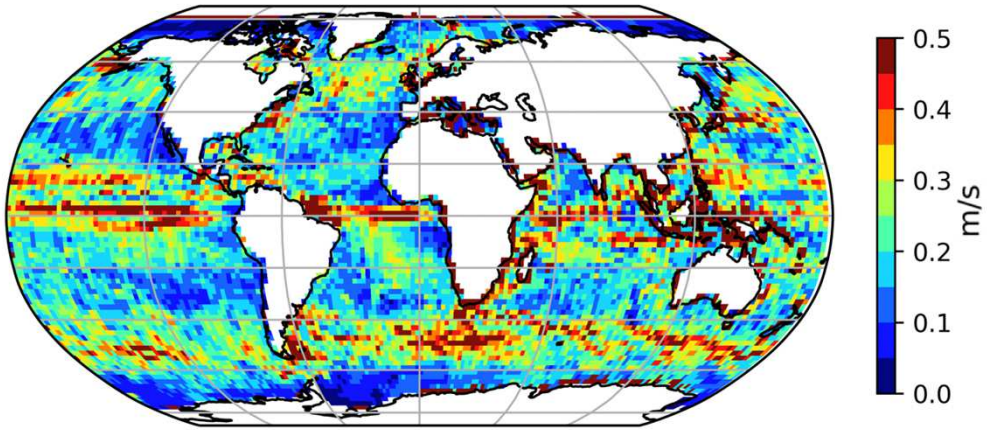


This uses the KaRADOC instrument (IETR / CNES)

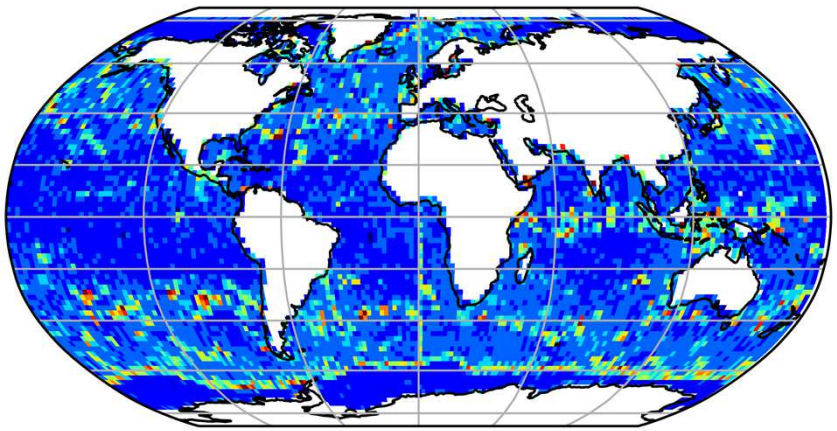
5. Required TSCV accuracy : 15 cm/s @30 km , 3 days.

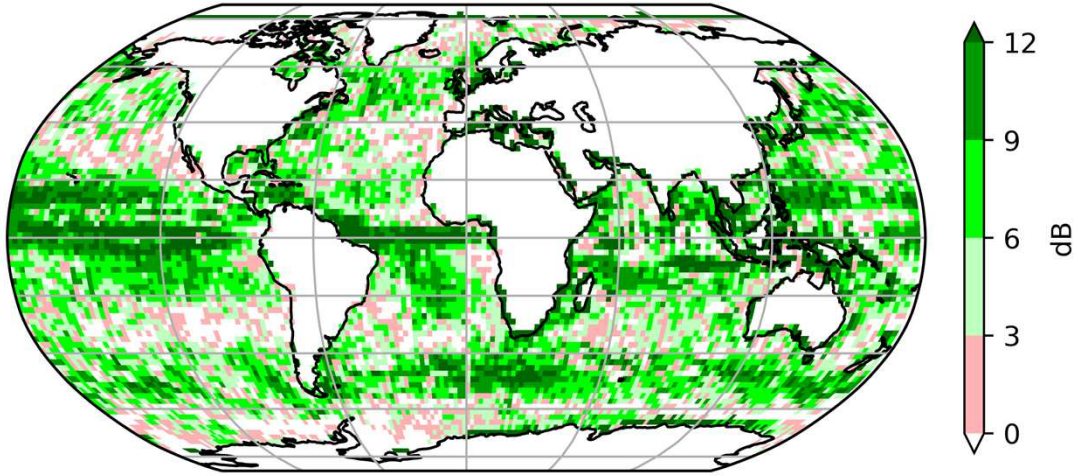
SKIM simulated single-swath data (i.e. on average every 3 days):

Signal (MITgcm + Stokes)



Noise (total error for U_AC or U_AL)



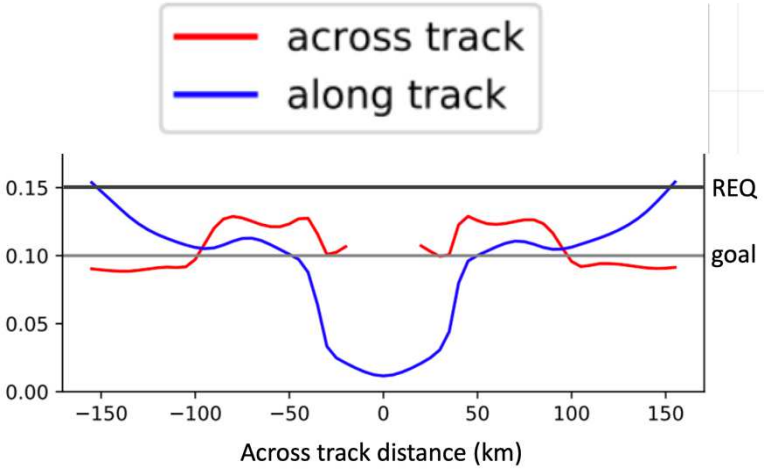


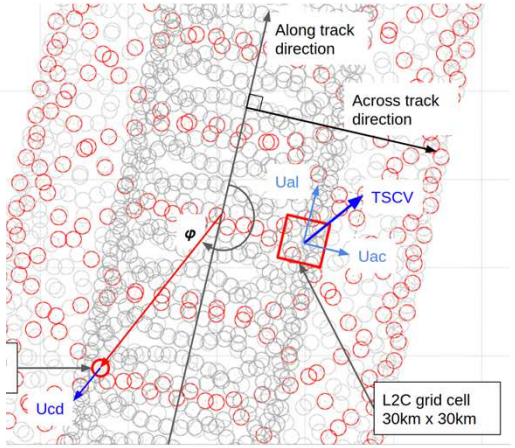
Signal to noise ration:
Where SKIM works
(**with today's "1st cut" algorithm**)
Remember than NIOs are ½ of real in MITgcm

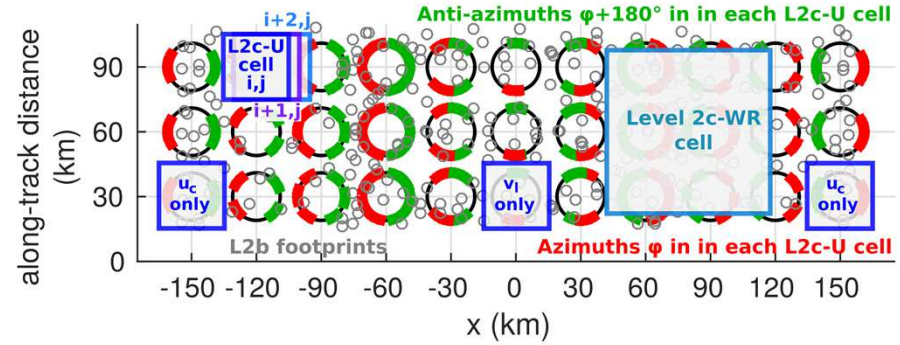
5. Goal: 10 cm/s @30 km , 3 days... Or better

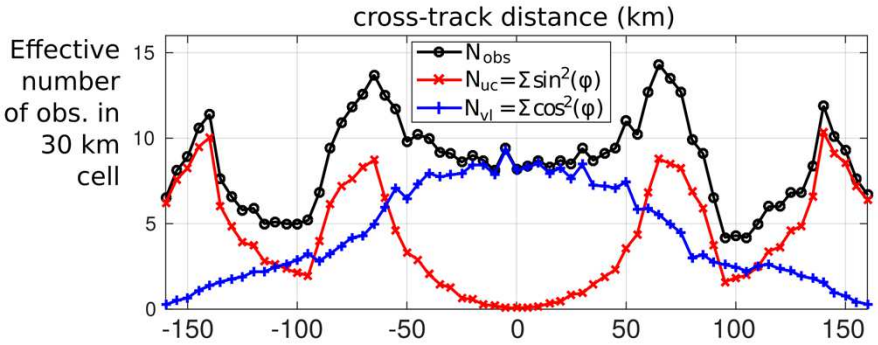
Why we can do it and better: let's have a look at the error budget …

Uncertainty (global average): depends on measurement geometry





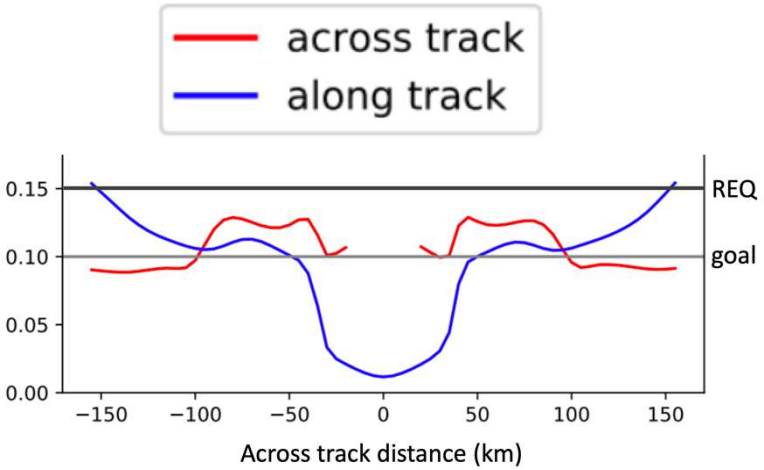


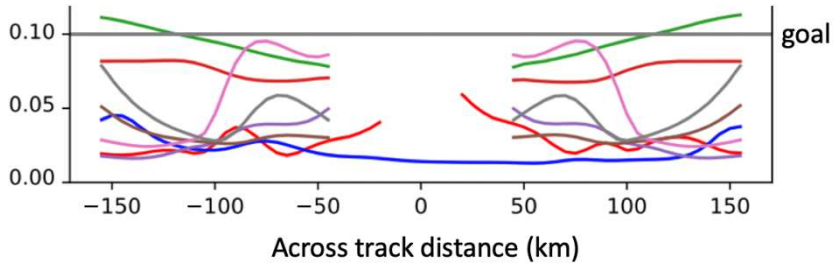


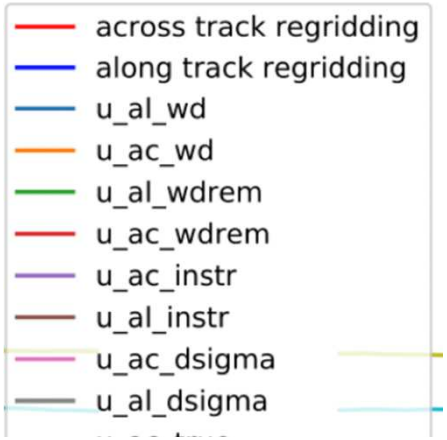
5. Goal: 10 cm/s @30 km , 3 days... Or better

Why we can do it and better: let's have a look at the error budget …

Uncertainty (global average):







1. Largest error is : residual on wave Doppler (especially along-track).

Why? Because small scale gradients in U_{WD}
(@coast, ice edge + current effect on waves)
-> work at SIO with B. Cornuelle (August 2019 -> July 2020)

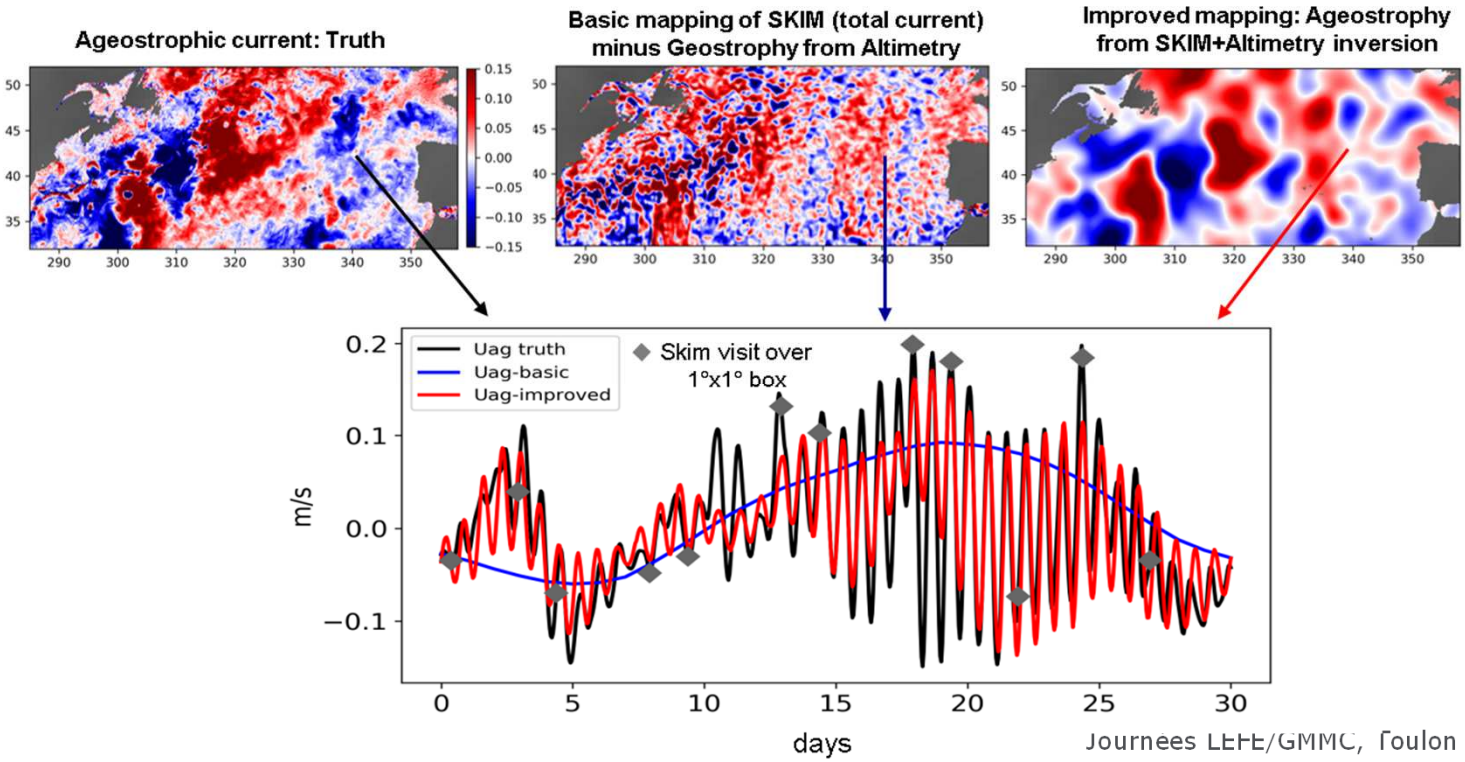
2. Effects of NRCS gradients : possibly pessimistic (based on easured AltiKa data) + we can improve with alternative acquisition mode (full close burst) and Doppler power

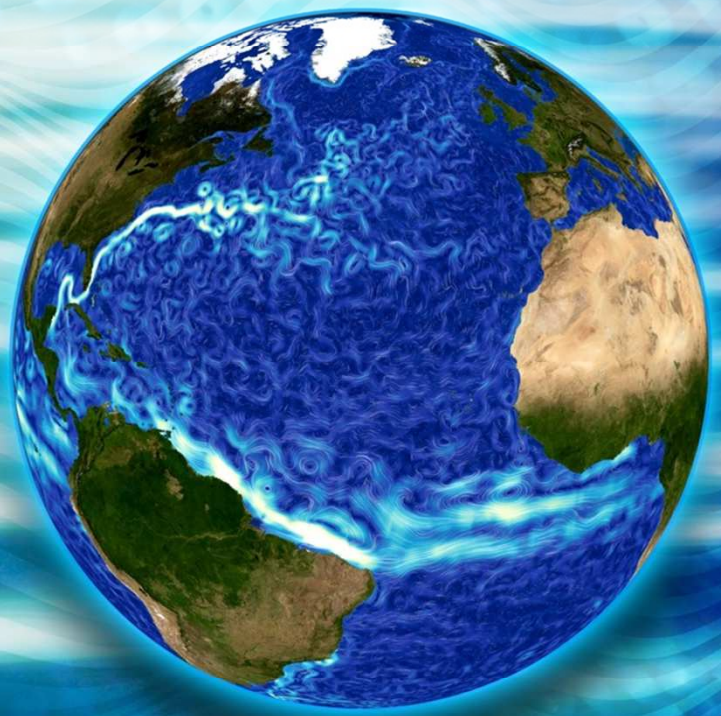
3. Instrument noise: hard limit? (bit of help from full close burst)

5. Performance: from snapshots to time-varying (Level-2d)

Yes … surface current vary rapidly …
issue with separation of NIOs and slower dynamics
similar to balanced / unbalanced with SWOT-> great complementarity of SWOT and SKIM

Preliminary work by C. Ubelmann, using space and time coherence of NIOs:





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6. summary

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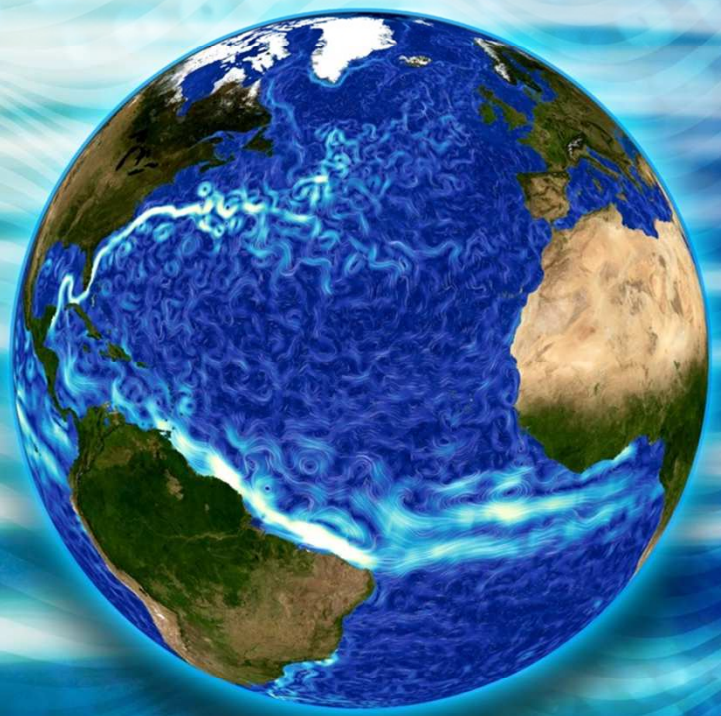
Summary

- SKIM is the only Earth Explorer for the **oceans** in more than 1 decade
- SKIM is targeting the **Total Surface Current Velocity** because it is needed
- SKIM is built on a novel Doppler Wave and Current Scatterometer concept
- SKIM is designed to fly with MetOp SG(1B): joint wind, wave, current data
- SKIM should provide (U,V) every 3 days at 30 km resolution with accuracy ~ 10 cm/s
- Can we do better: certainly! We just need to think a bot more about ocean waves ☺

- Separation of balanced & un balanced motions: highly complementary to SWOT
- SKIM can be the baseline for future nadir altimeters & prepare future Doppler scatterometers.

- Next steps:
  - Monday: Report sent to ESA's Advisory Committee on Earth Obs. Members
  - July 16 & 17: see you in Cambridge for User Consultation meeting
  - Official selection: PBEO meeting in September
  - Launch from Kourou in 2025.



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→ UNDERSTANDING OCEAN SURFACE MOTION

BACKUP slides

www.esa.int

European Space Agency

2.b. The dawn of Doppler Oceanography from space

Home > BAMS > Early Online Releases > Satellite Doppler observations for the motions of the oceans

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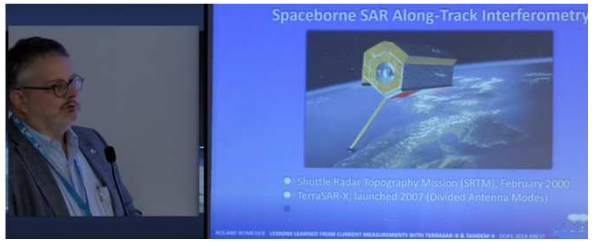
MEETING SUMMARIES

Next Article >

Brest, October 2019



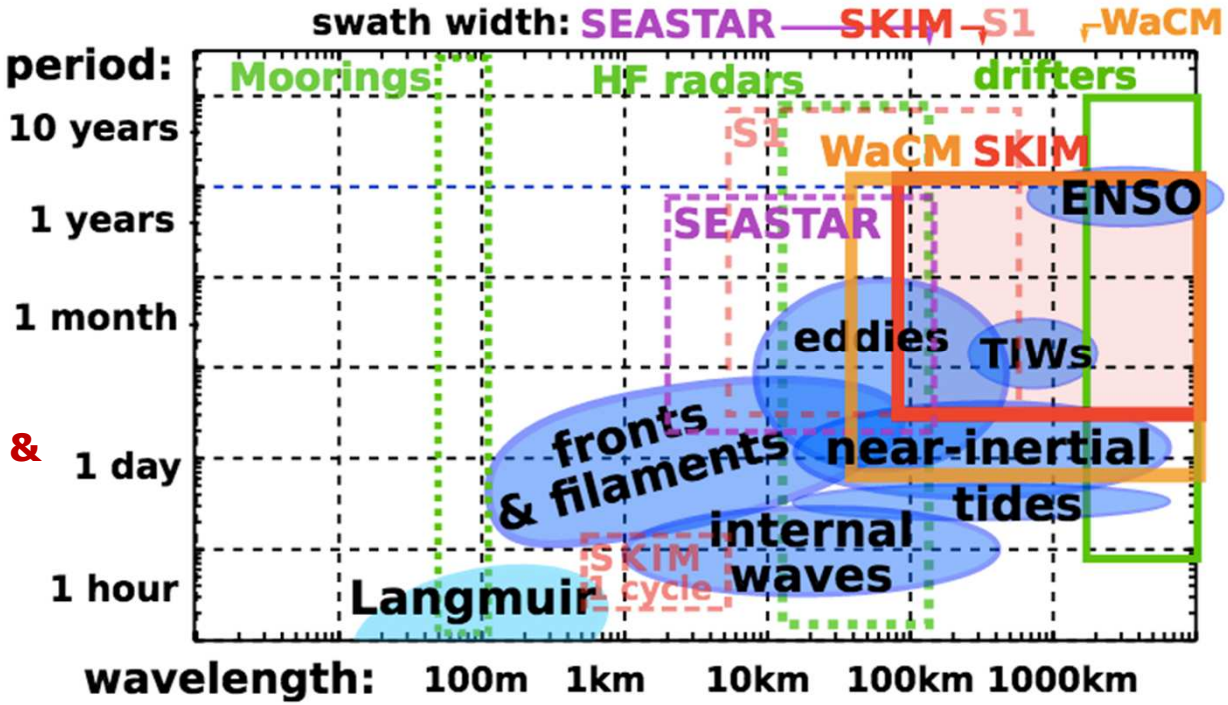
Satellite Doppler observations for the motions of the oceans

Fabrice Ardhuin*, Bertrand Chapron, *and* Christophe Maes
LOPS, Brest, France

Roland Romeiser
RSMAS, Miami, FL

Christine Gommenginger
NOC, Southampton, UK

Sophie Cravatte *and* Rosemary Morrow
LEGOS, Toulouse, France

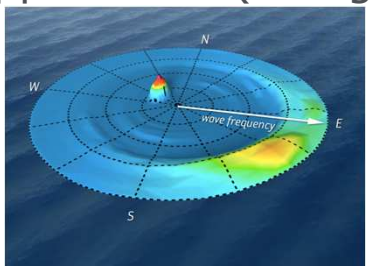


- Two types of concepts: **Doppler Wave Current & Scatterometers (DWCS)** or **interferometric SARs (InSARS)**: **global** vs **high-res** trade-off

Links to videos and more …
https://www.skim-ee9.org/Events

Ocean waves?

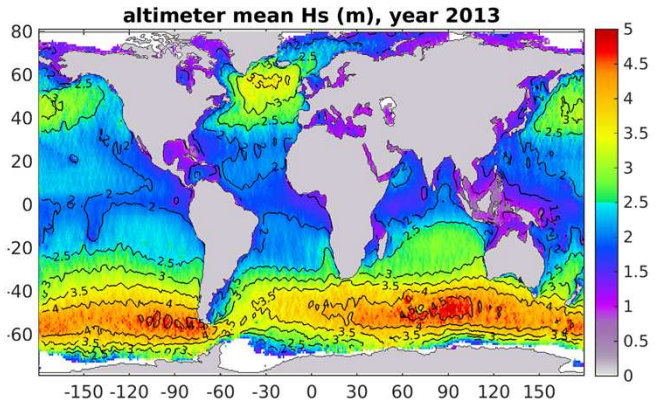
- Ocean waves can have complex patterns with "**wind seas**" associated to the local wind, and "**swells**" from remote storms
- This is fully described by a "**spectrum**": the distribution of energy ***E*** as a function of wave frequency ***f*** and azimuth **φ**
- The full spectrum is computed by models. Altimeters sum it up in **only one number**: the significant wave height $\mathbf{H_s}$
- Hs says nothing on **horizontal scales** that are critical for many applications (energy flux, flooding ...)

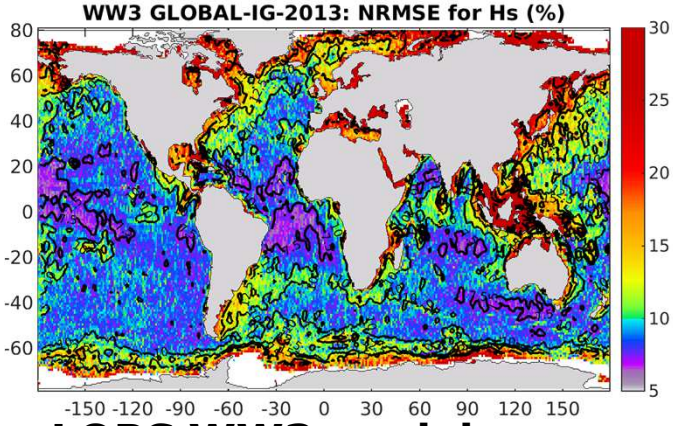


→ $\mathbf{H_s}$

- **Spectrum shape** with **SAR** (f < 0.1 Hz), **wave scatterometer** such as SWIM (f < 0.13 Hz), or SKIM (f < 0.3 Hz)

ESA Sea State CCI – V1





LOPS WW3 model errors

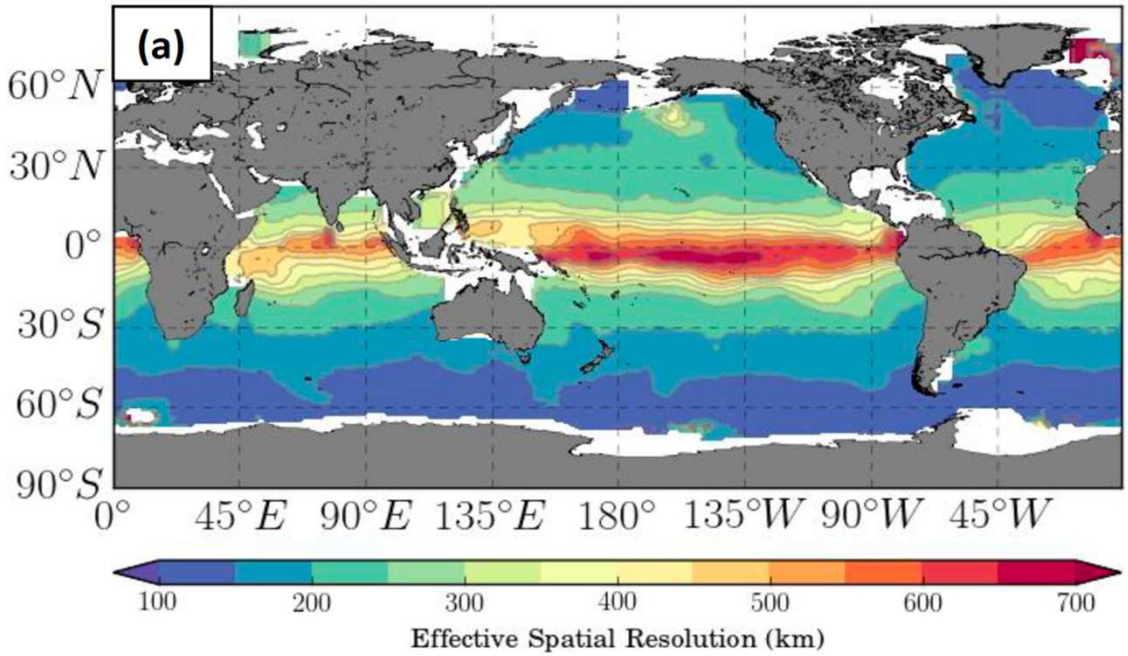
- but **even Hs** is not measured everywhere …

2.a. A very incomplete view: resolution issues

(Ballarotta et al. 2019)

On the resolutions of ocean altimetry maps

Maxime Ballarotta[1], Clément Ubelmann[1], Marie-Isabelle Pujol[1], Guillaume Taburet[1], Florent Fournier[1], Jean-François Legeais[1], Yannice Faugere[1], Antoine Delepoulle[1], Dudley Chelton[2], Gérald Dibarboure[3], Nicolas Picot[3]



Ocean Sci. Discuss., https://doi.org/10.5194/os-2018-156
Manuscript under review for journal Ocean Sci.
Discussion started: 7 January 2019

Ocean Science Discussions Open Access EGU

- We know a lot about currents from Sea Level Anomaly + MDT + gravimetry: assumes **geostrophic balance** (pressure gradient = Coriolis force)
- **Effective spatial resolution** of Sea Level Anomaly from 3 Altimeters today is >700 km at the Equator to ~100 km in high latitudes **(50% SNR)**
- **Effective temporal resolution** is 13-49 days (global average ~28 days).
- **This misses 30-50% of geostrophic currents** (especially at high latitudes)

2. Currents today: a very incomplete view

- Still discovering new currents in 2018

AGU PUBLICATIONS

Geophysical Research Letters

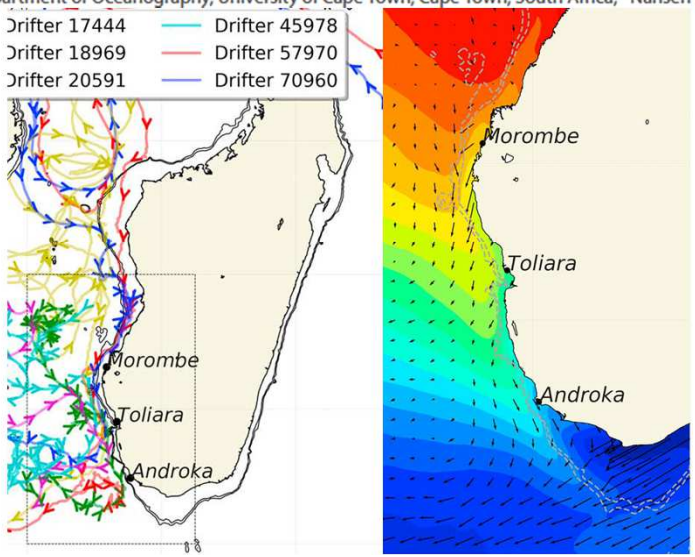
RESEARCH LETTER
10.1002/2017GL075900

Uncovering a New Current: The Southwest MAdagascar Coastal Current

Key Points:
- The Southwest MAdagascar Coastal Current (SMACC) is a newly discovered surface poleward current

Juliano D. Ramanantsoa[1,2,3], P. Penven[4], M. Krug[1,2,5], J. Gula[4], and M. Rouault[1,2]

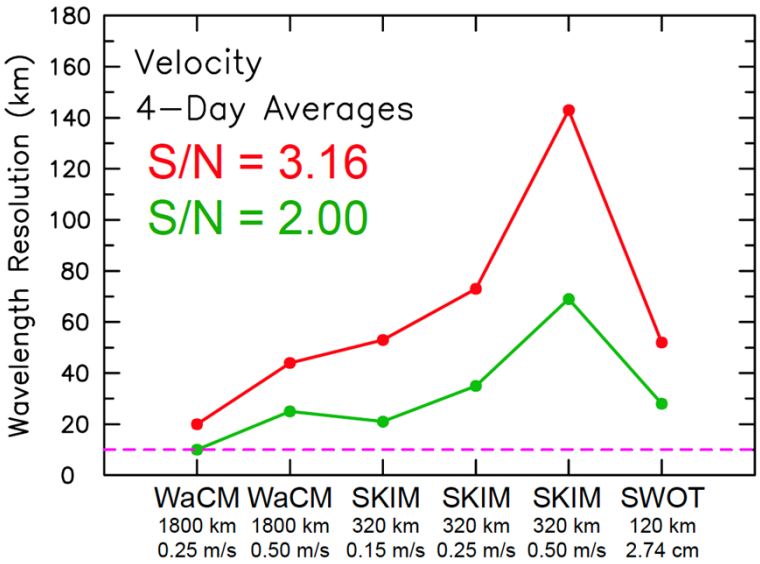
[1]Department of Oceanography, University of Cape Town, Cape Town, South Africa, [2]Nansen Tutu for Marine

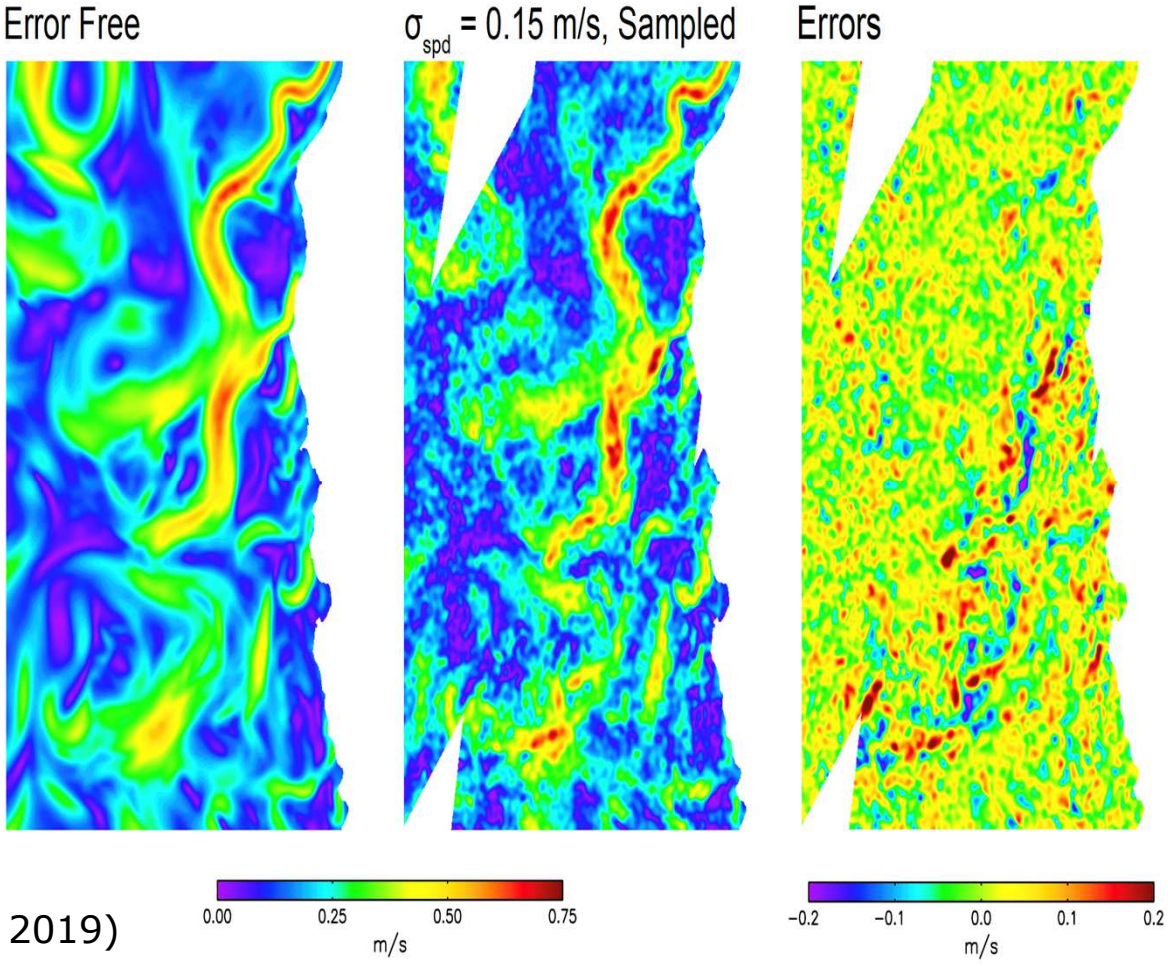


2.b. The dawn of Doppler Oceanography from space

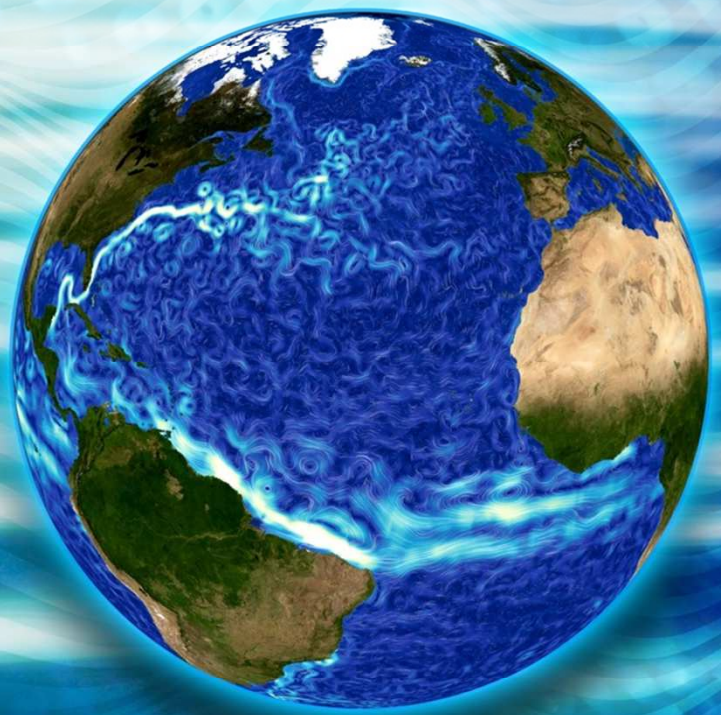
DWCS are scatterometers… intrinsically noisier than SAR, you just need to average in space (SKIM) or time (WaCM)

4-Day Average Velocity with Filter Cutoff Wavelength 25 km SKIM with 320 km Swath and 0.15 m/s Noise





It is all about "how wide is your swath" (Chelton et al. 2019)



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→ UNDERSTANDING OCEAN SURFACE MOTION

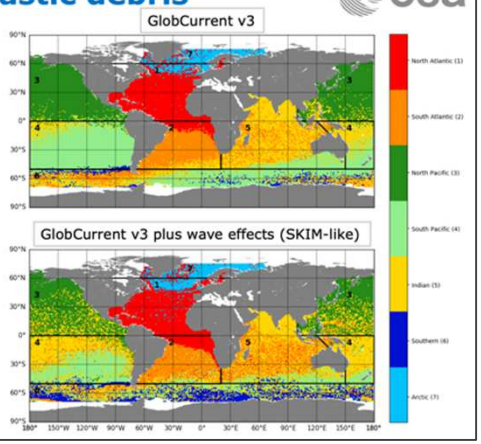
3. SKIM research objectives

SKIM: Science and Society studies

SKIM for tracking marine plastic debris

- Marine plastic litter is major environmental problem.
- Yet unclear whose plastic ends up where
- Observational data sets lack global coverage, or miss processes like transport by waves
- SKIM will create flow maps to track, directly from EO, floating plastic from source to sink

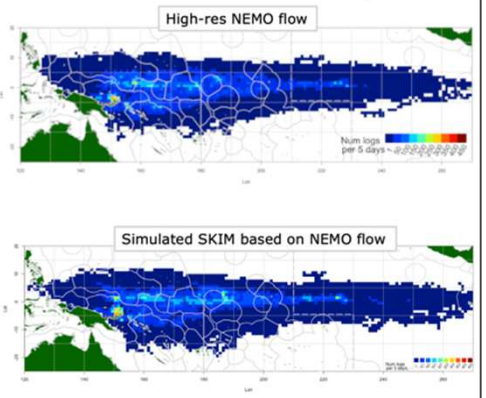
- Figure on right shows basin that floating microplastic accumulates in after 13 years.
- **Using SKIM (wave effects) significantly increases cross-basin exchange [Figure from Onink et al., (2019), Journal of Geophysical Research - in press]**



SKIM for tracking dFADs in the Tropics

- Tuna Fisheries in the Tropical Pacific use drifting Fish Aggregating Devices (dFADs)
- Use is controversial, as it is difficult to monitor effect of dFADs on tuna stocks
- EO-based flow maps in the Tropics presently not good enough to track dFADs
- SKIM will create flow maps to compute connectivity of dFADs, and understand how e.g. they drift through different EEZs

- **Figure on right shows that simulated SKIM fields can be used to reconstruct dFAD density in Tropical Pacific [Figure from Scutt Phillips et al (2019) *Environmental Research Communications* - under review]**



SKIM for monitoring Polar Oceans & Sea Ice

- The Arctic is undergoing Atlantification & Antarctification, with thinner, younger, faster and more fragmented sea ice.
- Projections predict enhanced wave ice break-up and the fragmented ice or Marginal Ice Zone (MIZ) to expand rapidly throughout the 21st century to more than 50% coverage.
- In the Barents and Kara Seas a warming hotspot indicates a climatic shift linked to a decline in sea ice import.
- The ice retreat creates new opportunities (shipping, tourism) but also challenges (coastal erosion, ecosystems, pollution).
- **SKIM will fill a gap in current EO techniques to measure sub-daily sea ice drift, thickness, and waves in the MIZ and pack ice to better constrain sea ice fluxes in and out of the Arctic.**

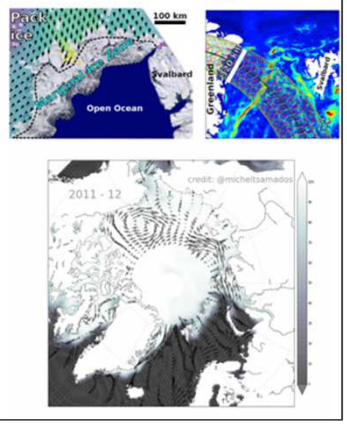


Figure shows the seasonal sea ice cover overlaid with geostrophic currents from radar altimetry. SKIM will improve the resolution of surface currents and drift in the MIZ and at short timescales [Heorton et al., (2019) *JGR-Oceans* - under review]

SKIM for quantifying shelf-sea carbon export

- Oceans are a carbon sink. Shelf-seas are responsible for 10-20% of this sink, but absorption is impacting ecosystems and food security (via ocean acidification).
- Cross-shelf water transport drives the corresponding deep water export of carbon rich water (the Continental Shelf Pump, CSP).
- EO and model analysis shows that cross-shelf transport is controlled by geostrophic, Ekman and ageostrophic components and their interactions.
- **SKIM will provide measurements to parameterise and challenge a model-based CSP monitoring approach that is now needed to support policy.**

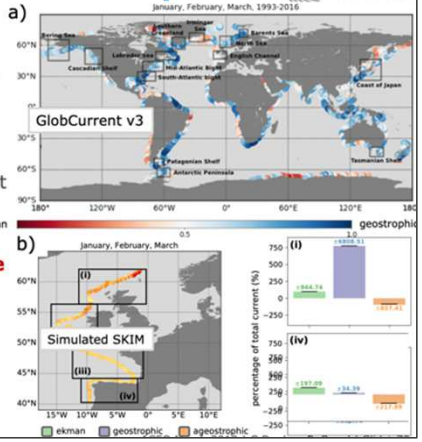
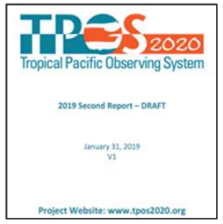


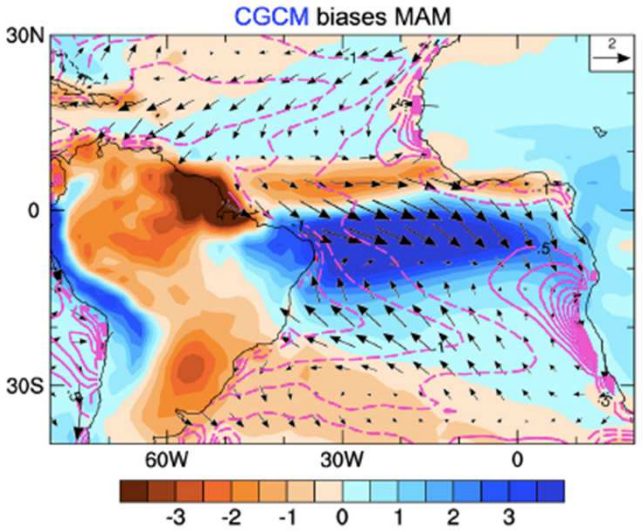
Figure (a) Variable dominance of cross-shelf ocean current components in global shelf-seas from EO (b) Simulated SKIM data shows ageostrophic cross-shelf flow dominance varies by region and season [Figures from Shutler et al., (2019) *Environmental Research Letters* - under review]

SKIM User Community development

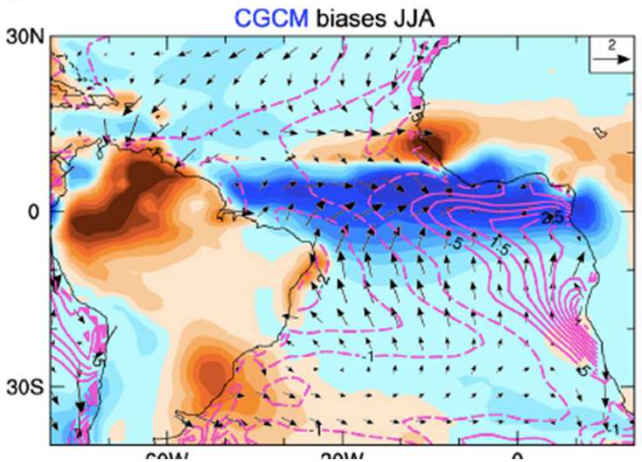
- Active dialogue with:
  - Ocean Surface Topography Science Team (OSTST) 2018:
  - Doppler Oceanography from Space (DOfS) 2018
  - Tropical Pacific Observing System 2020 statement
  - Tropical Atlantic Observing System
  - SCOR WG Marine Litter: Statement on SKIM
  - World Ocean Current Meeting 2019
  - Surface Ocean Lower Atmosphere Study (SOLAS)
  - CMEMS/GODAE Ocean View
- **Several community statements/recommendations of support to SKIM**
- **21 SKIM papers either in press or submitter and is growing to date…**

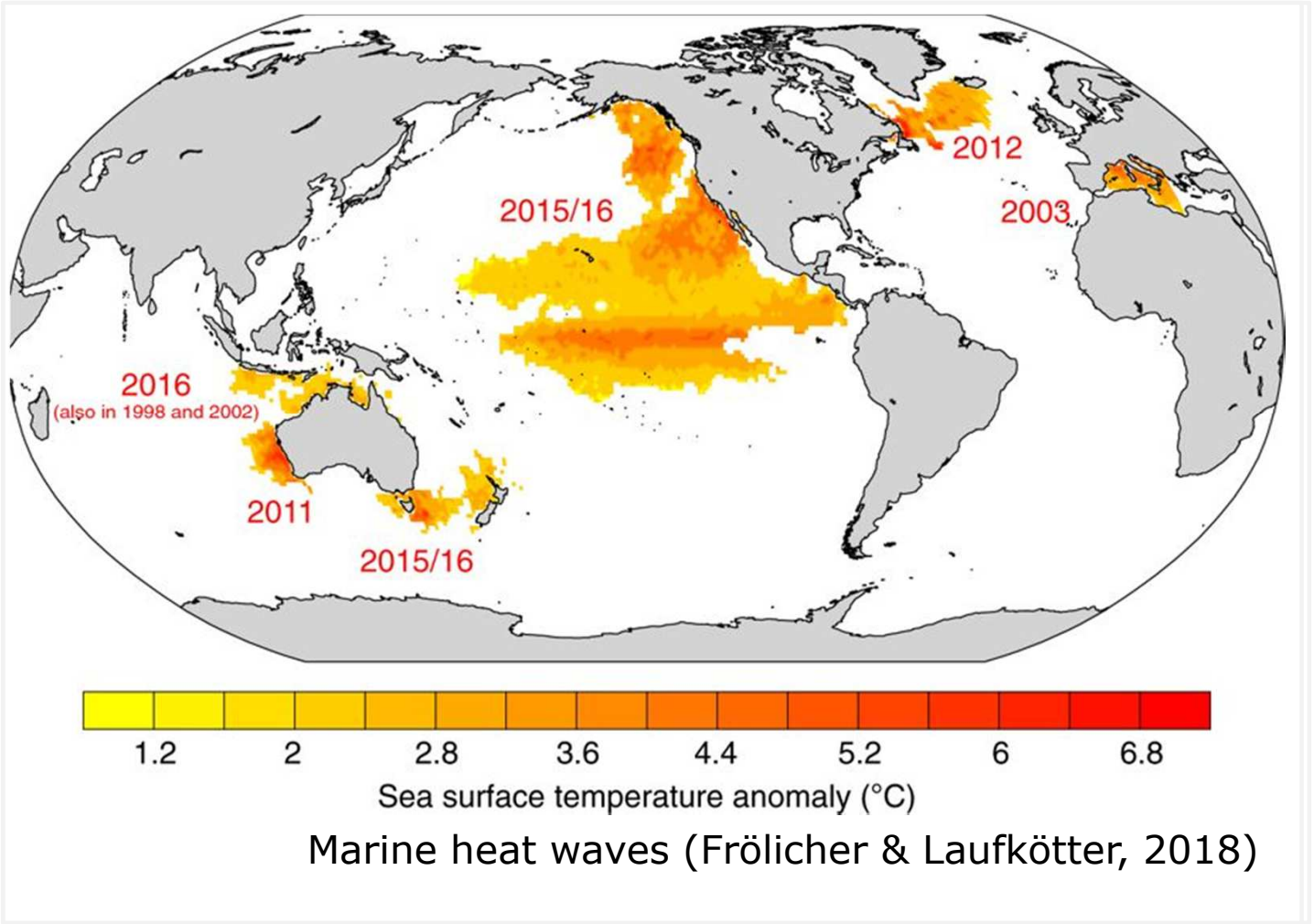


SKIM Research objectives: P1. global heat, carbon and water cycles



Rain bias in models





Marine heat waves (Frölicher & Laufkötter, 2018)

3. Research objectives: hard numbers

Given today's errors on surface current estimates or primary objectives could benefit from 10 cm/s accuracy for 2-weak averages at 50 to 100 km scales.

Primary research objective	Error with existing data	Threshold for meaningful results	End goal to fully meet the science objective
1. Tropical surface currents and heat budget[3]	velocity: 20-50 cm/s, monthly heat flux: 50-400 W/m²	10 cm/s 2-week average 25-200 W/m²	3 cm/s 2-week average 10-50 W/m²
2. Cross-shelf carbon flux	Unknown variability	10 cm/s monthly average[5]	5 cm/s monthly average[6]
2. Surface transport pathways[4]	Unknown	30 cm/s 5-day average with Stokes drift	5 cm/s 5-day average with Stokes drift

From dream to reality: SKIM mission objectives

Over the global ice- and precipitation-free ocean and inland seas from 82°S to 82°N and a revisit of ≤ 10 days at the equator:

- **PRI-OBJ-1: Measure and investigate** the instantaneous (single swath i.e. L2C) **total surface current velocity (TSCV)** at a resolution of **30 km** and a combined **standard uncertainty in *u* and *v* ≤0.1 m/s or 15%** of standard deviation across the full swath (whichever is greater).

- **PRI-OBJ-2: Measure and investigate the directional wave spectrum simultaneously with TSCV** at a gridded spatial resolution of ≤70 km for Hs between 1-25 m and a combined standard uncertainty of ≤30 cm or 10% (whichever is greater). The directional resolution shall be ≤10° in all directions for **wavelengths of ≤30 - 500 m**.

- **PRI-OBJ-3:** Characterise and quantify ocean surface kinematics (i.e. waves, fronts, large-scale TSCV) and their impact on climate relevant ocean-atmosphere exchange of momentum, heat, mass, carbon dioxide (and other climatically important gases) in different regions (e.g. equatorial ocean polar regions continental shelves, large frontal regions) and their impact at different time scales.

2. Back to currents: a very incomplete view

- **We need much better knowledge of Total Surface Current Velocity (TSCV):**
  - Large scale currents in *geostrophic balance* can be determined quite well using current infrastructure (altimetry, gravimetry)
  - Local and regional TSCV *not in geostrophic balance* are not observed globally.
- **Therefore our knowledge of TSCV, their kinematics and impact on societal issues is incomplete**
- **That's what SKIM is designed to address**