



The **SKIM** Mission : a Pathfinder for **Doppler Oceanography** from Space

Fabrice Ardhuin¹ and the SKIM team(s)

- Mission Advisory Group
- ESA SKIM team (led by C. Donlon and E. de Witte)
- CNES contributors
- studies teams at LOPS, ODL, CLS, TUDelft, NORUT, U. Exeter, U. Utrecht, UCL
- campaign team at ESA, LOPS, LATMOS, SAFIRE, CNES, NOC

¹Laboratoire d'Océanographie Physique et Spatiale (LOPS), Plouzané, France
(the new home of the Ifremer remote sensing group)





Outline of talk

- 1. Science goals**
- 2. Mission status** → more details with C. Donlon
- 3. How SKIM works** → poster 249 by E. Caubet
- 4. Space & time sampling issues**
- 5. Expected performances** → talk by C. Ubelmann yesterday
- 6. SKIM and altimetry : MDT, SSB...**

1

Science goals : exploring ocean surface velocities (currents, ice drift, waves)

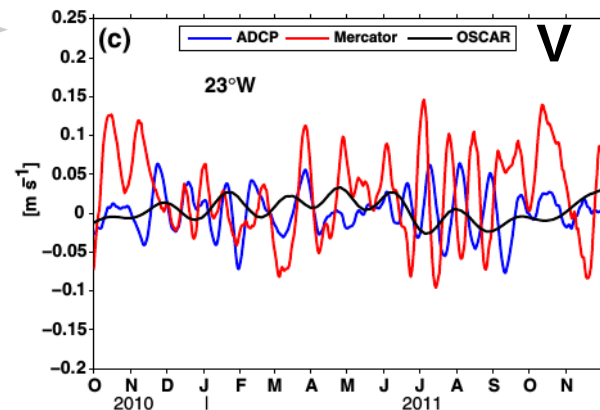
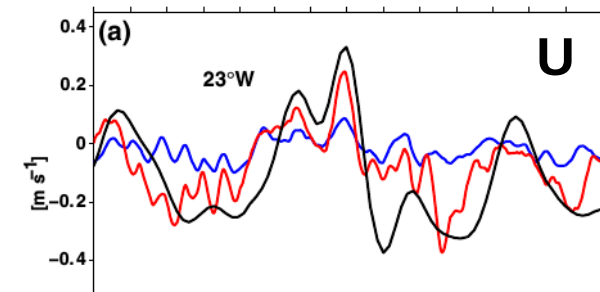
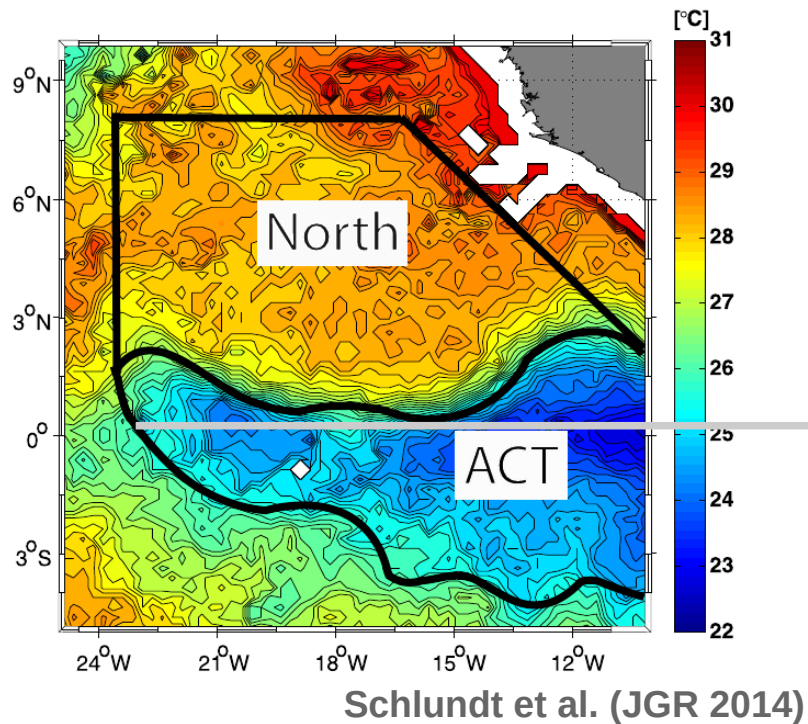
- tropics
- marginal ice zones
- wave-current interactions
- surface drift

...

1. Science goals : equatorial dynamics

Atlantic cold tongue, Pacific warm pool, TIWs, upwelling ...

- fronts and mixing impact on the equatorial heat budget
- very poorly constrained by today's obs., even at low frequency



1. Science goals : marginal ice zones

Around the ice edge (Arctic and Southern ocean)

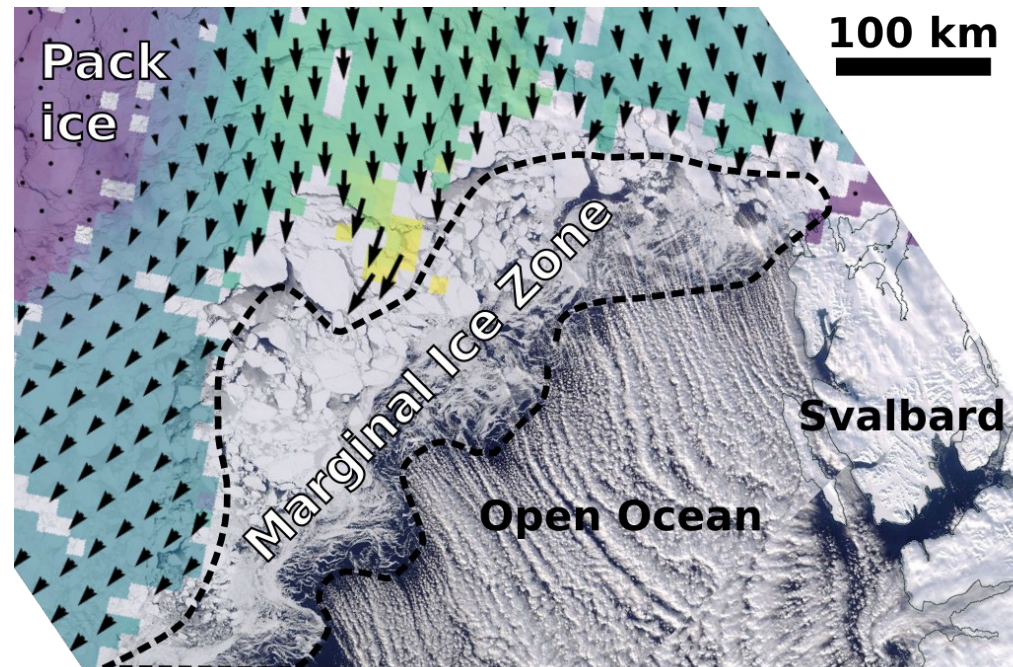
- a wide & poorly measured Marginal Ice Zone

- polar front dynamics & impact on sea ice

- mesoscales not resolved

- wave – ice interactions : only SWH data, in water

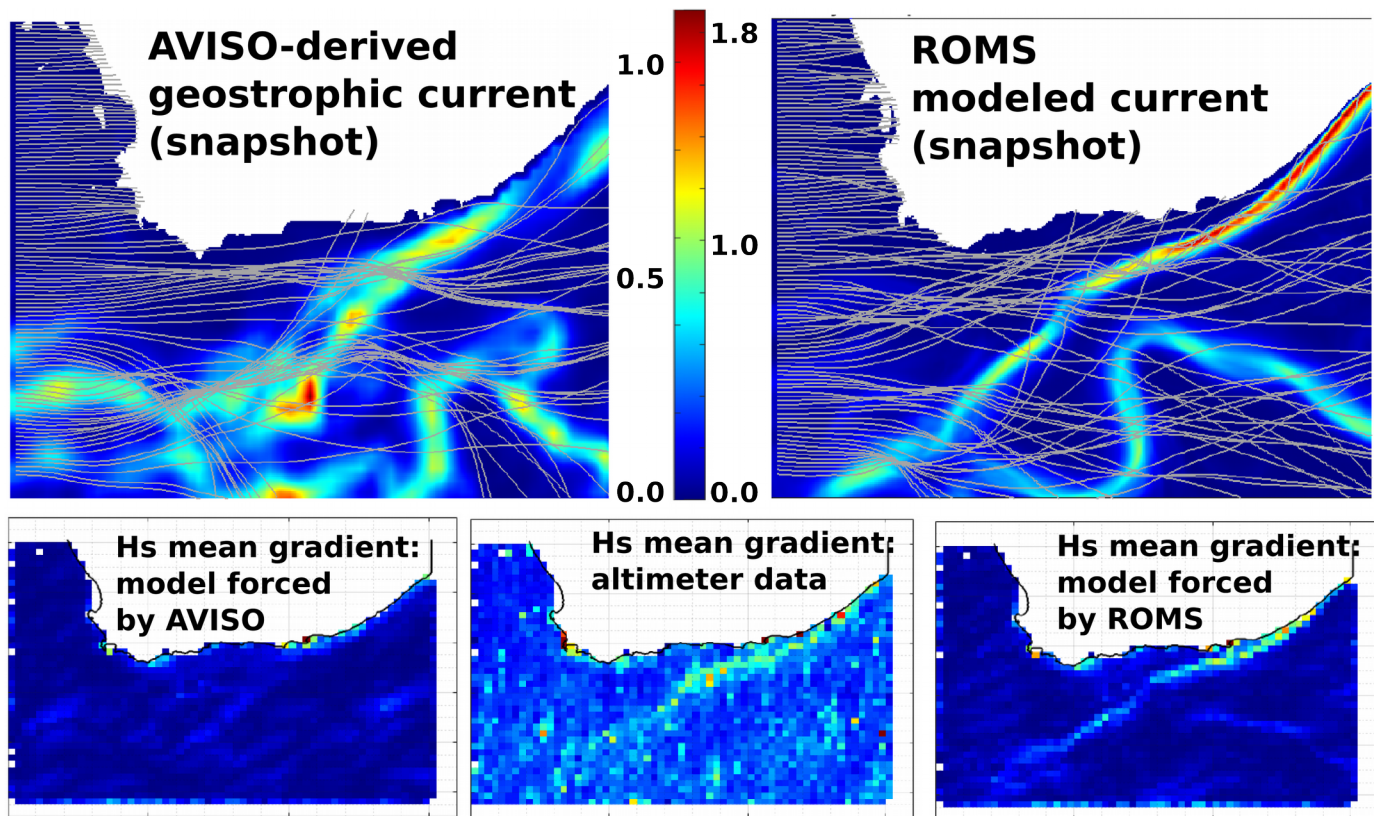
What will happen by 2030 ?



Optical imagery
+ SAR-derived ice drift

1. Science goals : sea states & currents

Understanding large waves ... requires high(er) resolution currents

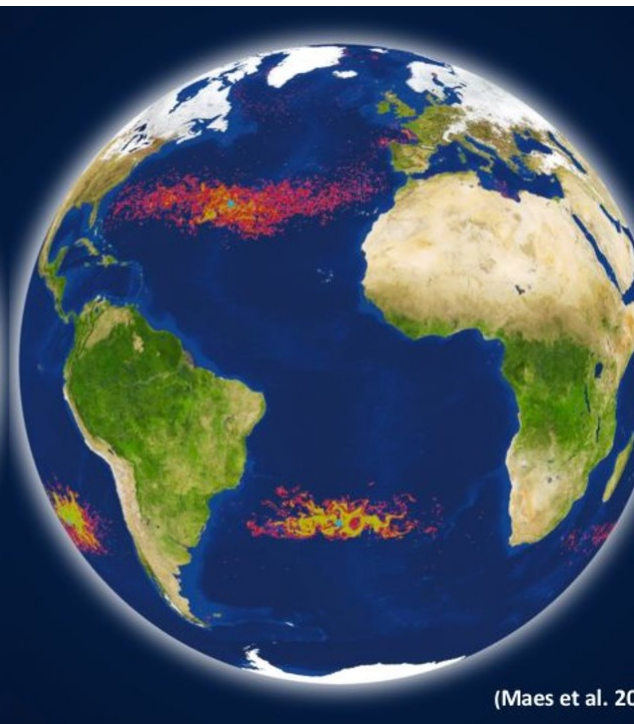


(Durand, C. Sc. thesis, 2018)

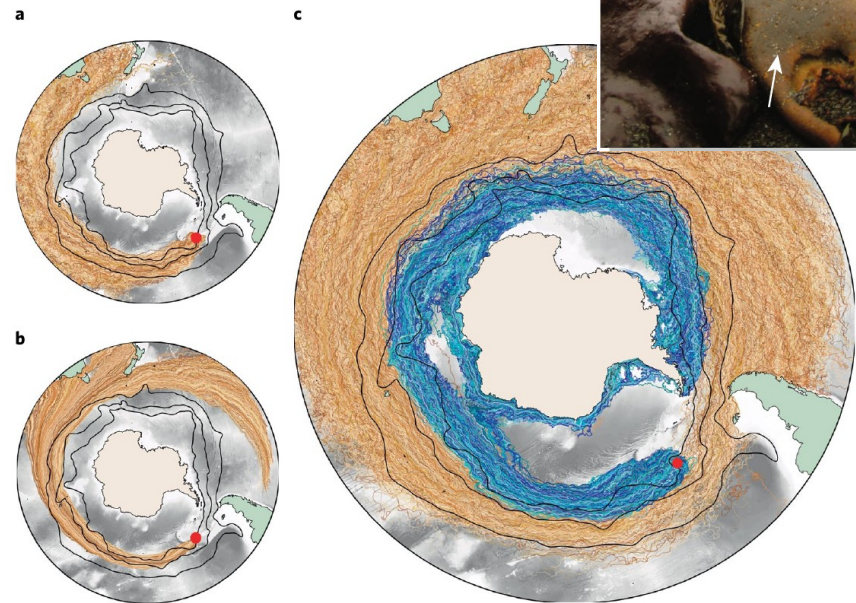
1. Science goals : transport & dispersion

Small mesoscales and waves (Stokes drift) are important for drift

- mesoscale < 200 km is poorly monitored
- what impact on surface transport ?
- Ecosystems ?



(Maes et al. GRL 2018)
Garbage patches



(Fraser et al. Nature Climate Change, 2018)



2

Mission status

2. Mission status

ESA « Earth Explorer » program

Earth explorers are research missions

- 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 |
| EE4 : Swarm | EE5 : ADM-Aeolus | EE6 : EarthCARE |
| EE7 : Biomass | EE8 : FLEX | EE9 : FORUM or SKIM... TBD in 2019 |
| EE10 : ... | | |

EE9 proposal submitted June 2017
EE9 pre-selection announced November 2017
EE9 Phase A : Nov 2017 → July 2019
EE9 Final selection : User Consultation Meeting 15 & 16 July 2019, Cambridge UK

2. Mission status

Selection process

Industry,
Support Activities,
MAG

Industry
produces:
Technical notes
with evidence on
technical concept
and feasibility
(TRL)

**Science
support
activities /
campaigns**
produces:
Technical notes
on scientific
concept,
scientific
performance
and feasibility
(SRL)



Now

ESA

**Report for
Mission
Selection**



June '19

YOU

**User
Consultation
Meeting**

Presentations
from MAG and
ESA



July '19

ACEO

Evaluation and
recommendation
of the candidate
mission



Evidence that $SRL \geq 5$

 $TRL \geq 5$ reachable at
the end of Phase B1

PB-EO

Down-selection
of a single
candidate
mission and
start of Phase
B1



Sept '19

**Mission
implementation**
(phase B2/C/D/E) after
confirmation that the
necessary conditions
(TRL, SRL, cost,
schedule) are met at
the end of Phase B1



Launch
2025



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Launch
2025



How you can contribute :

- Ask the tough questions now (it is also your tax money!)
- Join in at the UCM

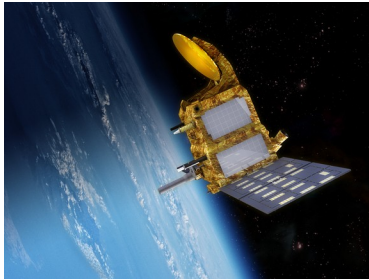
3

How SKIM measures velocities

3. How SKIM measures velocities

SKIM is a combination of Ka-band

radar altimeter, disco ball, and speed gun ...



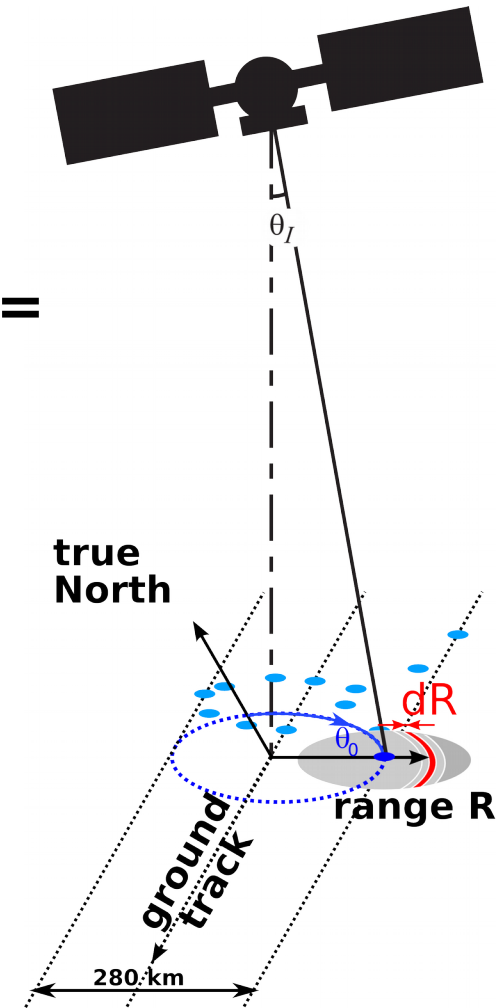
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3. How SKIM measures velocities

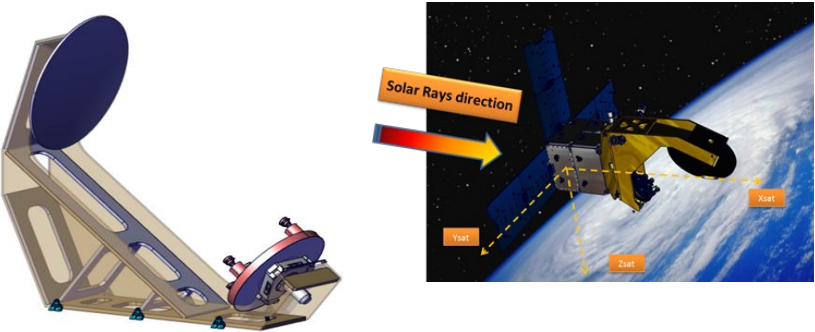
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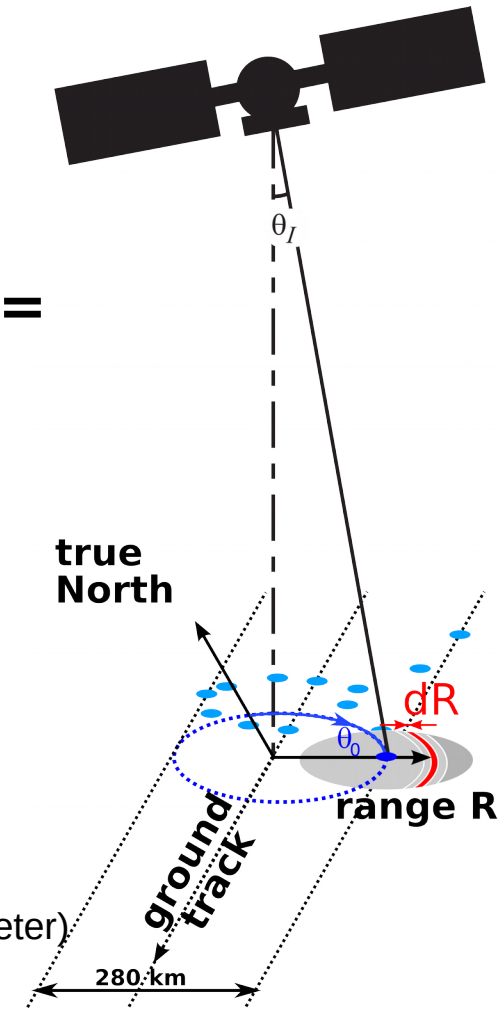
- « super-duper altimeter » : best ever flown
(Ka-band, 32 KHz PRF, 200 MHz bandwidth, SAR unfocused)
→ very low noise for sea level, wave height, ice freeboard ...

- « disco ball » : fixed reflector (1.2 m reflector – in pink)
turning « spotlights » (horn feeds on near focal point).
Result : radar beams dancing around ground track



Preliminary design :
1 nadir beam (classic altimeter)

7 other beams
at 6 and 12° incidence



3. How SKIM measures velocities

Horn plate rotation

Footprints on ground

Measured « radial current » (color),
is projection of current vector (black).

Updated design :

Orbit altitude : 820 km

Incidences : 0, 6, 12°

Swath width : 320 km

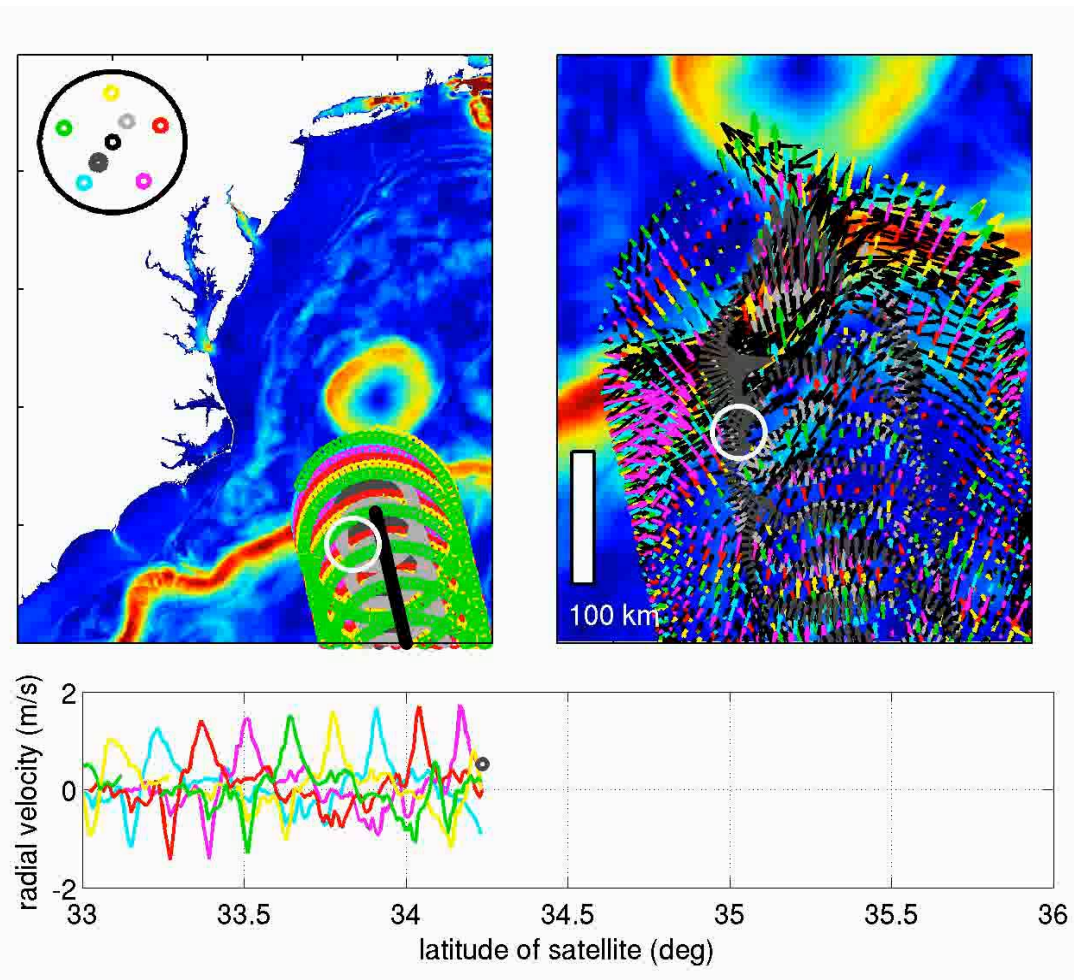
Footprint diameter : 7 km

one full vector at least every
15 km in most of the swath
(t with 512 pulses per footprint)

SKIM also measures :

- wave spectrum
- sea level

See <https://youtu.be/UYPwTwzg9nY>



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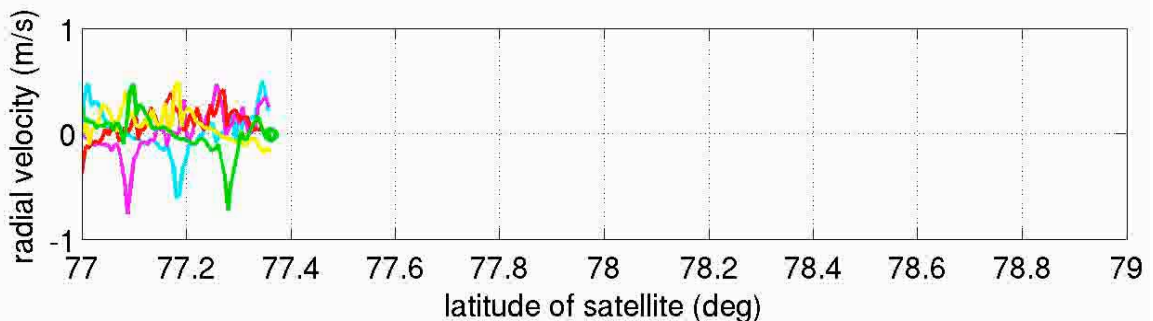
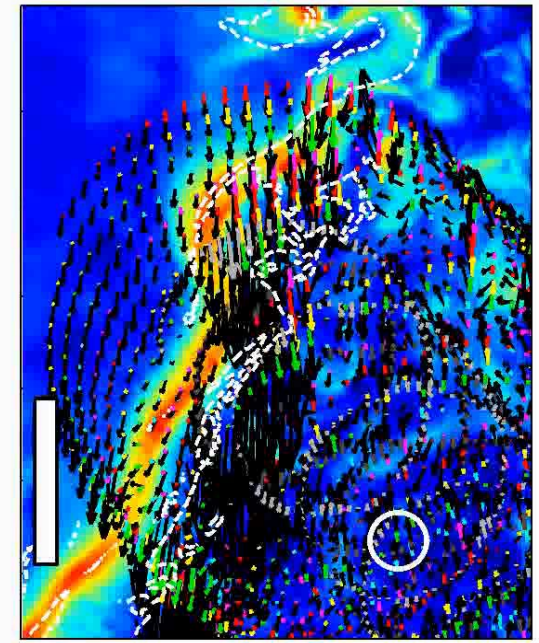
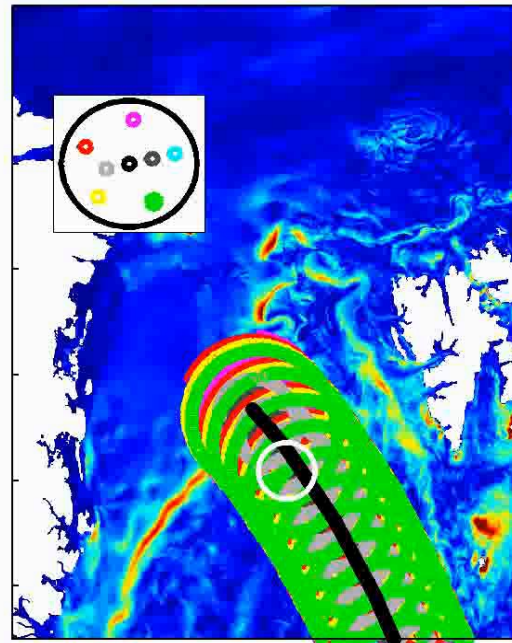
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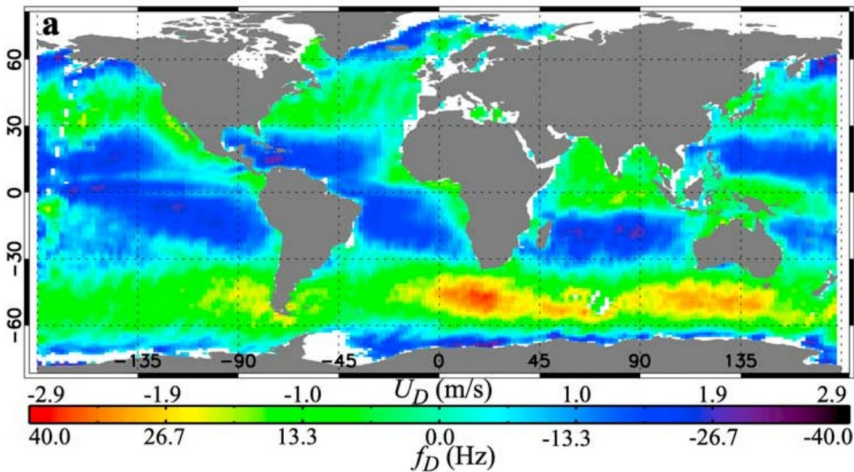
See <https://youtu.be/RZLdr2N1qf4>



3. How SKIM measures velocities

Reality is a little more complex : the measured velocity contain a (large) **wave-induced bias** U_{wb} .
From theory & data (Nouguier et al. IEEE TGRS 2018) the Ka-band bias U_{wb} at 12° is very similar to the C-band bias at 23° :

large scale are dominated by wave signatures

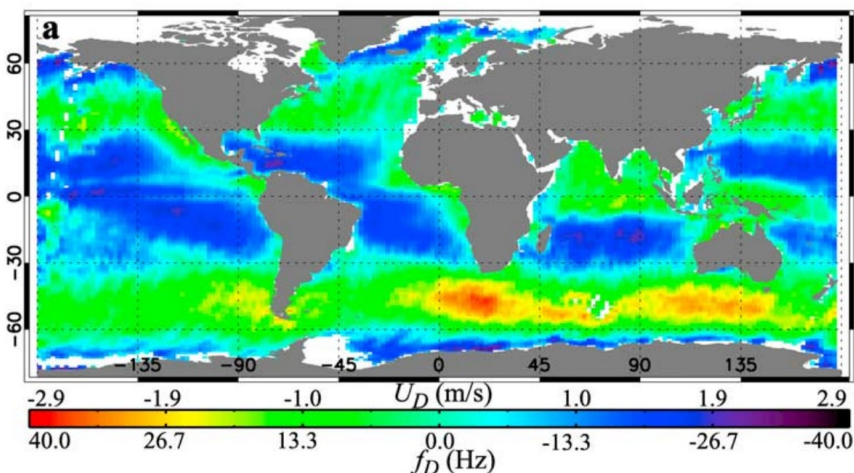


Chapron, Collard & Ardhuin (JGR 2005)

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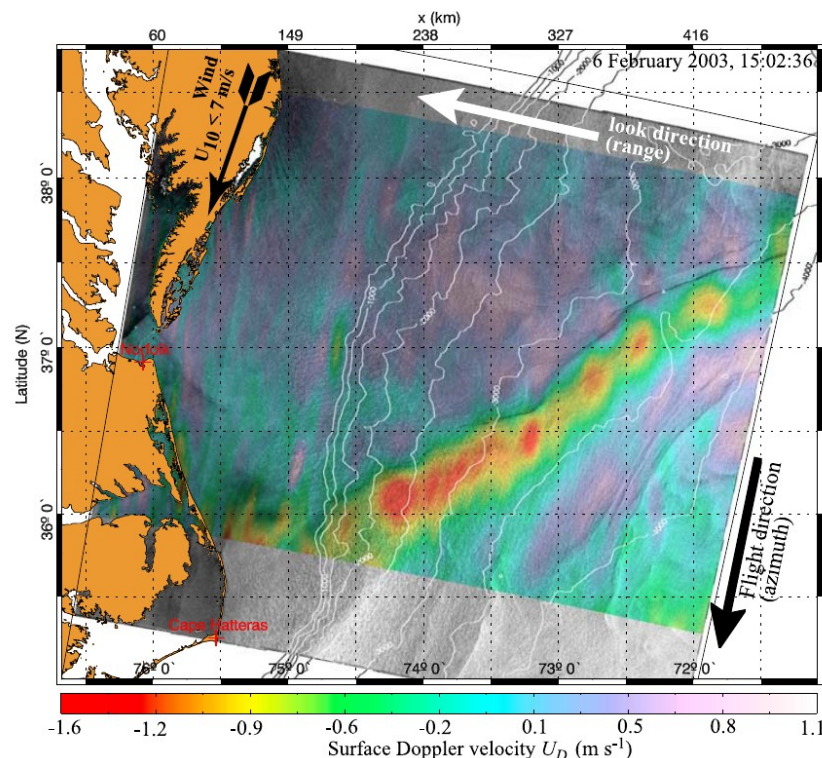
large scale are dominated by wave signatures



On Envisat & Sentinel 1 : use of a wind-based « C-DOP » proxy for U_{wb} as a function of wind speed (+/-40%)
→ Rouault et al. (JGR 2010), Hansen et al. ...

For SKIM : accurate U_{wb} thanks to wave measurements

small scales by currents :



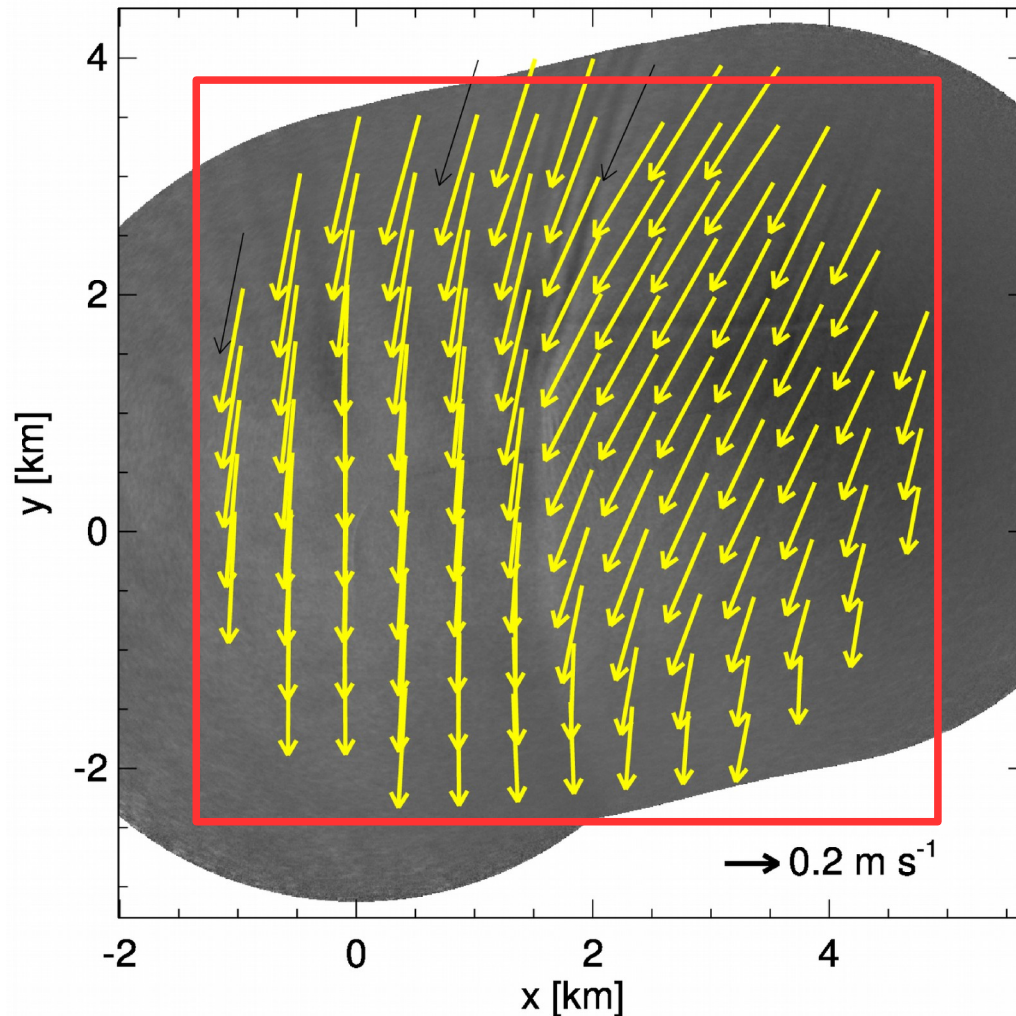
Chapron, Collard & Ardhuin (JGR 2005)

DOFS, Brest 2018, slide 18

3. How SKIM measures velocities

SKIM stands for **Sea surface Kinematics Multiscale monitoring**

Multiscale : resolving wave & front patterns inside of the 6 km footprint



**Footprint: same as
X-band ship radar**

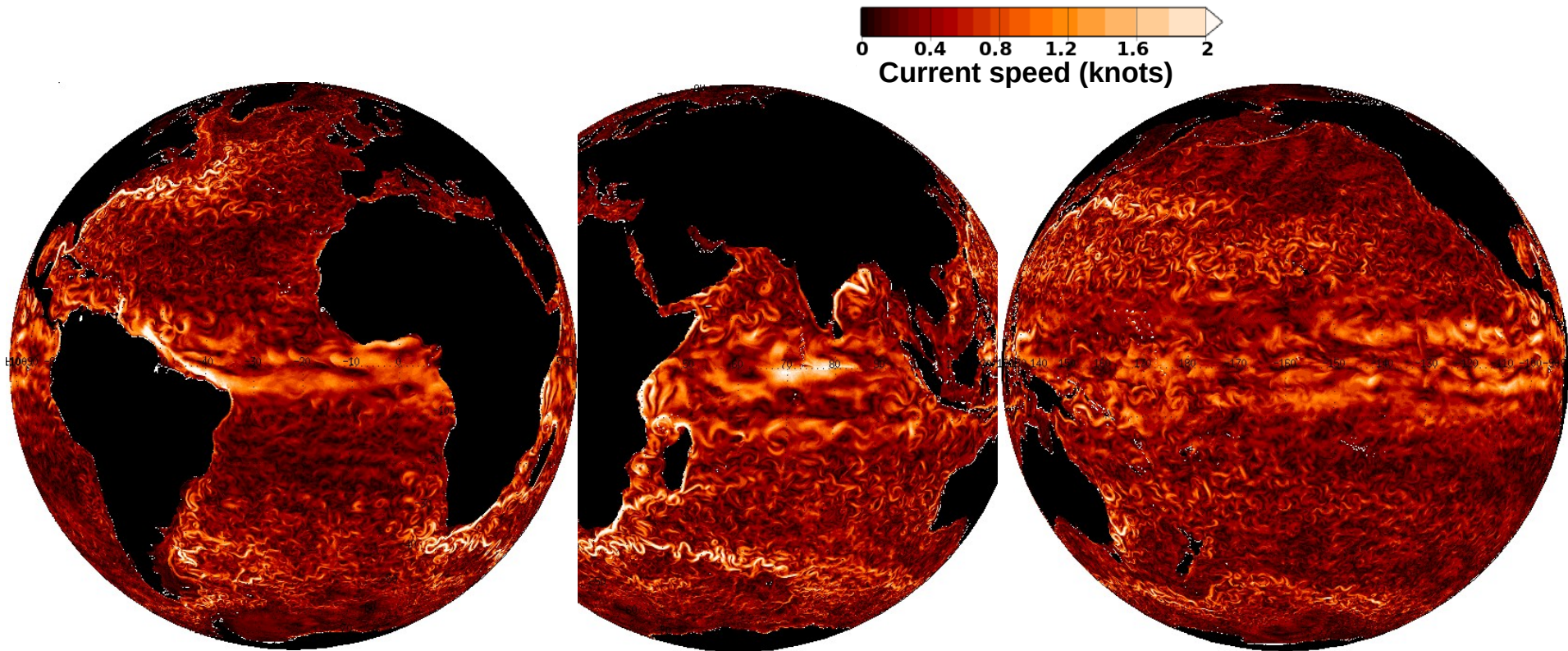
4

Space and time sampling issues

4. Space and time sampling

Surface currents are forced by

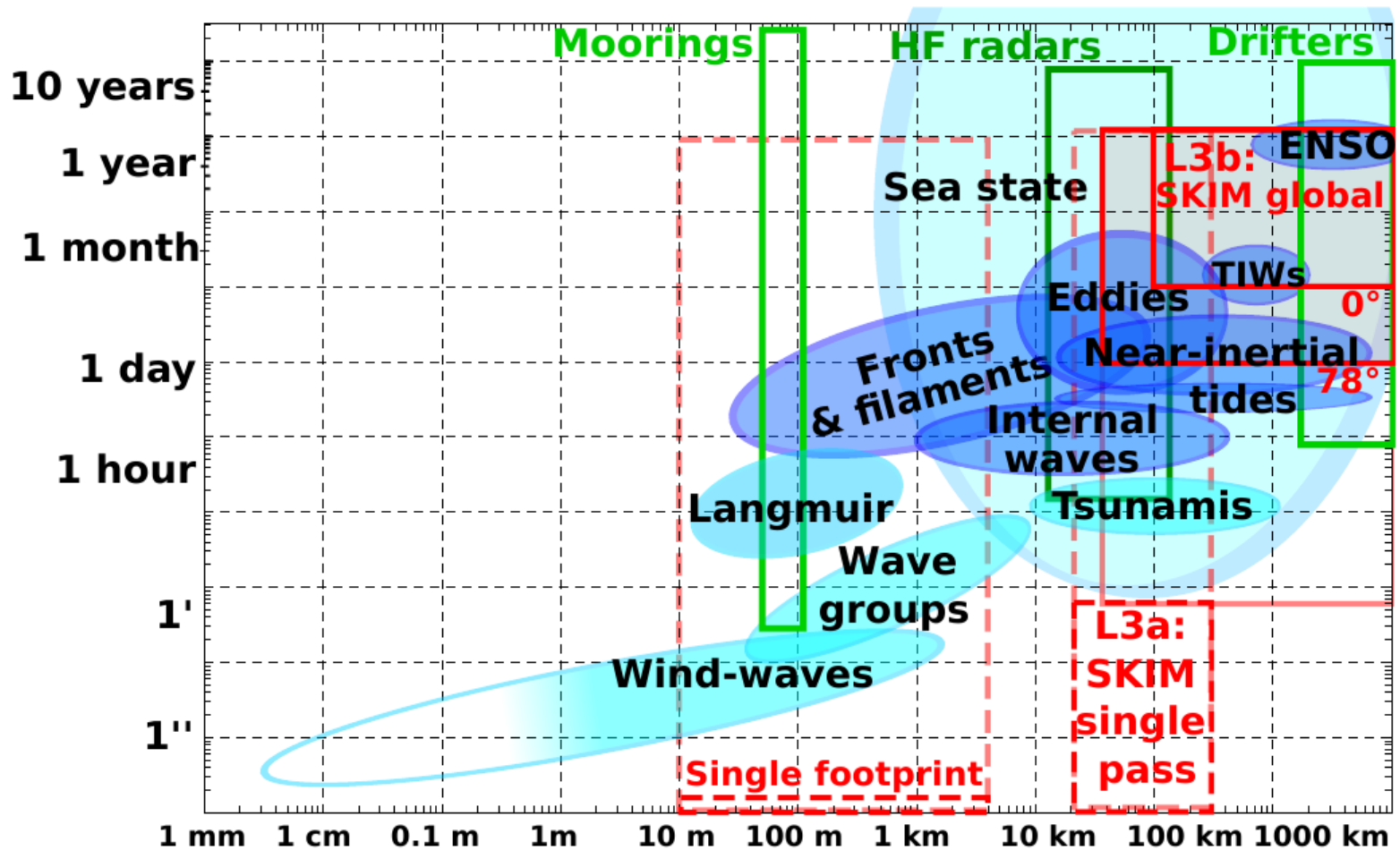
- density gradients (balanced part accessible via altimetry + gravimetry)
- winds
- tides



Global currents from CMEMS, May 1st 2017

4. Space and time sampling

Processes that can be resolved in space & time :



4. Space and time sampling

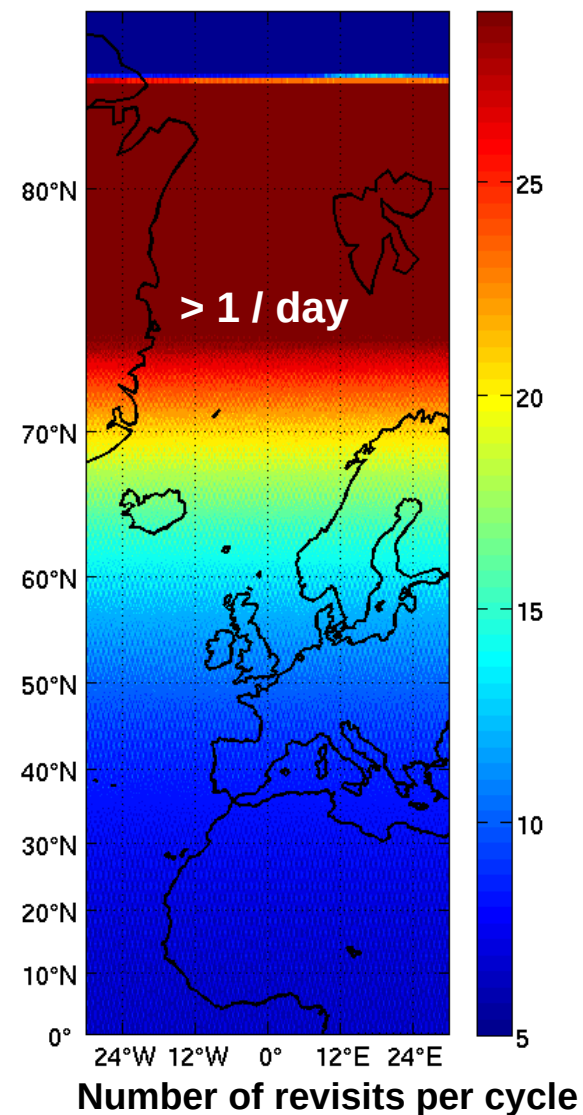
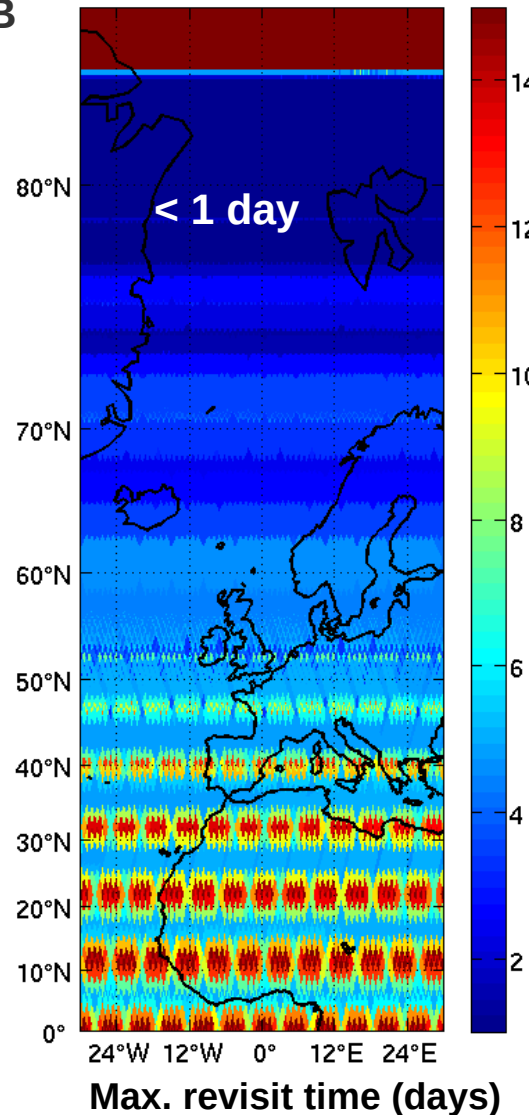
Orbit choice : sun-synchronous
1st choice : phased with METOP-SGB
29 day cycle
Coverage up to 82.5° N

Number of revisits : 6 to 100+
Maximum time : 0.5 to 18 days

Why follow METOP ?

+ synergy with wind & radiometer
measurements (rain flags ...)

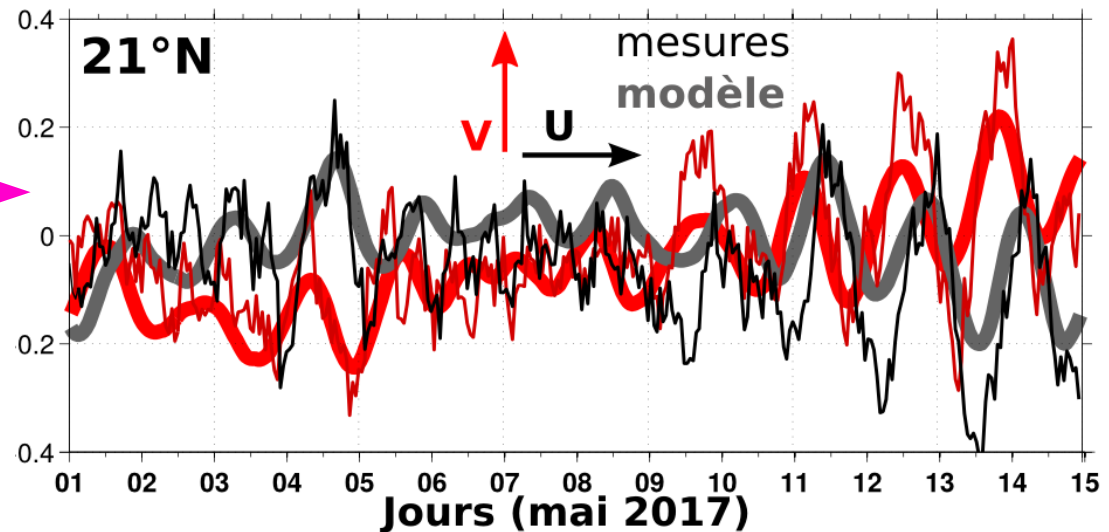
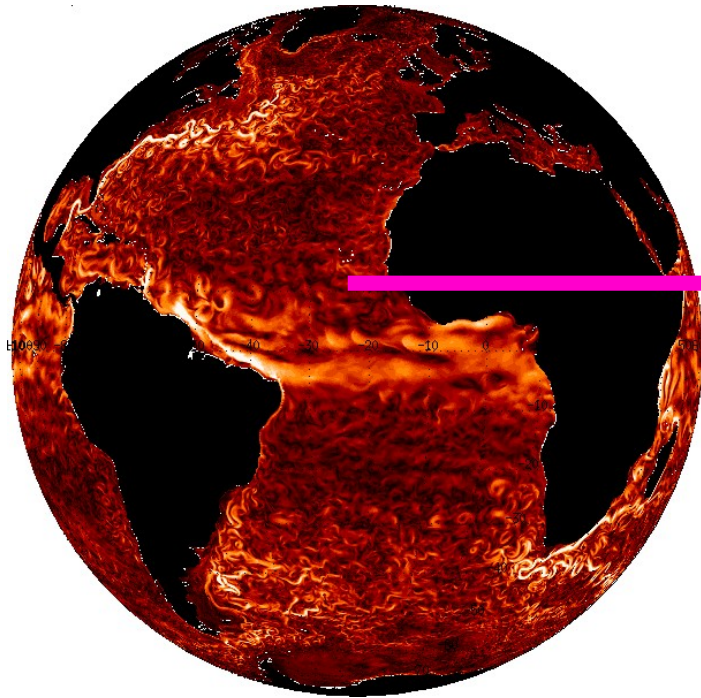
- large gaps in time around 0, 12, 24°
(it is worse with S3 orbit)



4. Space and time sampling

Model-data correlation typically ~ 0.5 (when low-passed):

- high frequency motions
- away from equator, altimetry gives large scales ($L > 200$ km, $T > 15$ days)
- marginal ice zones not covered
- inside ice : first results
- no validation of surface divergence except with HF radars

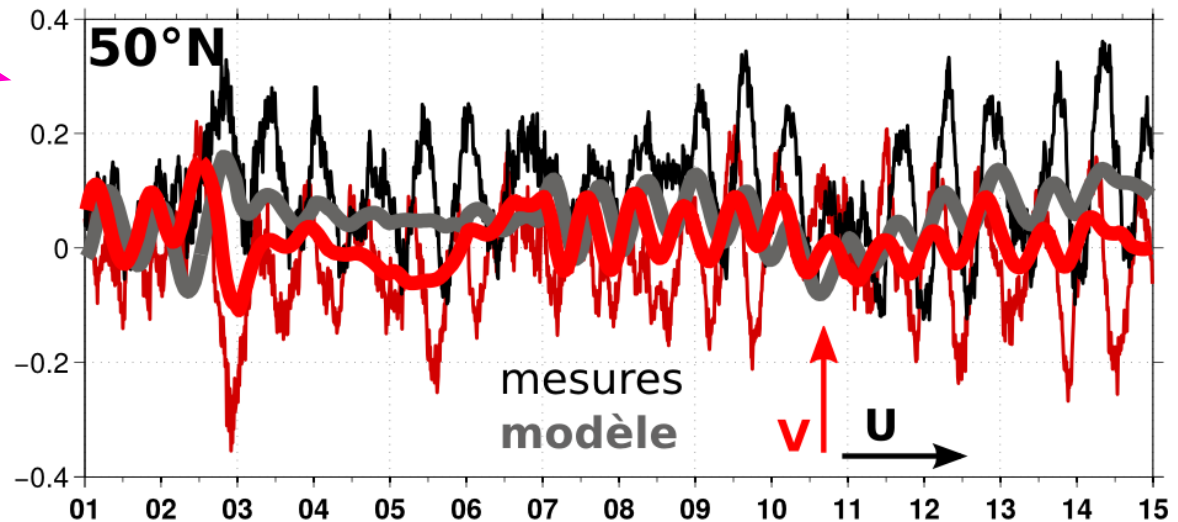
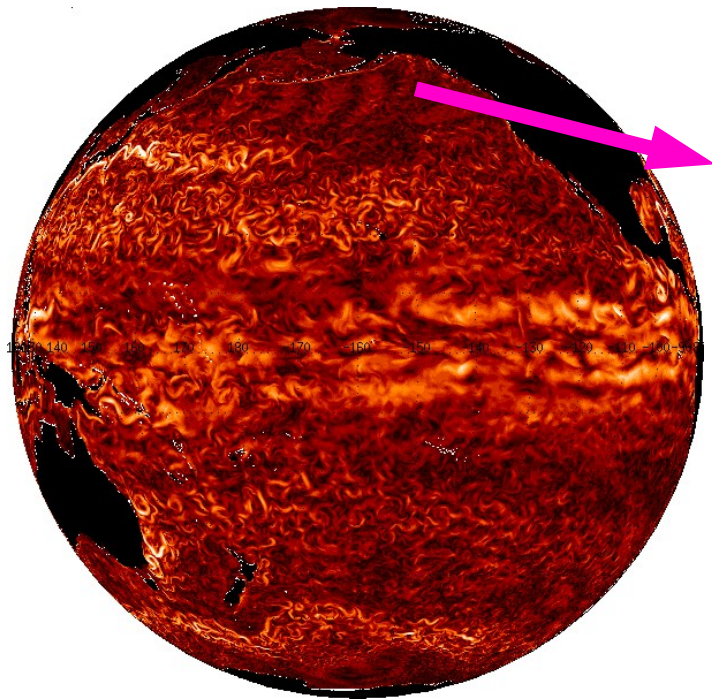


Global currents from CMECS and PIRATA mooring data
(B. Bourles)

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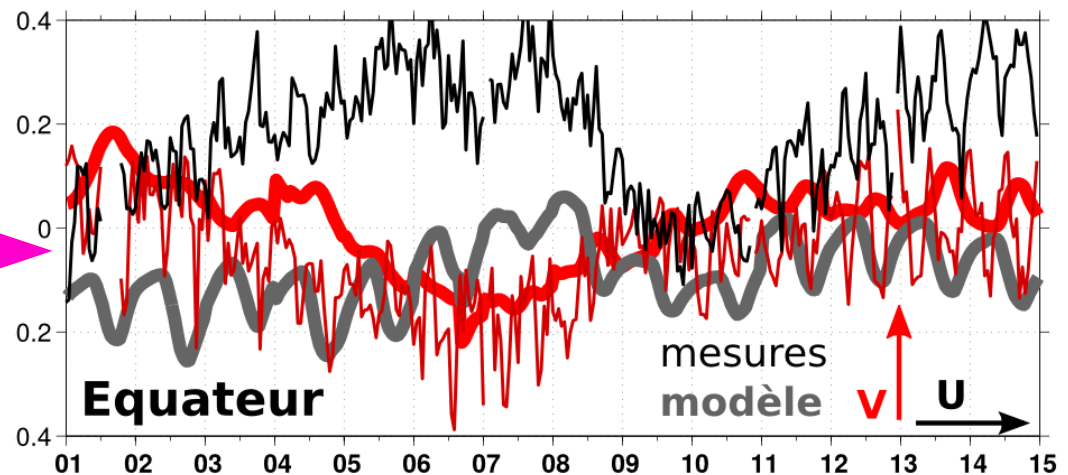
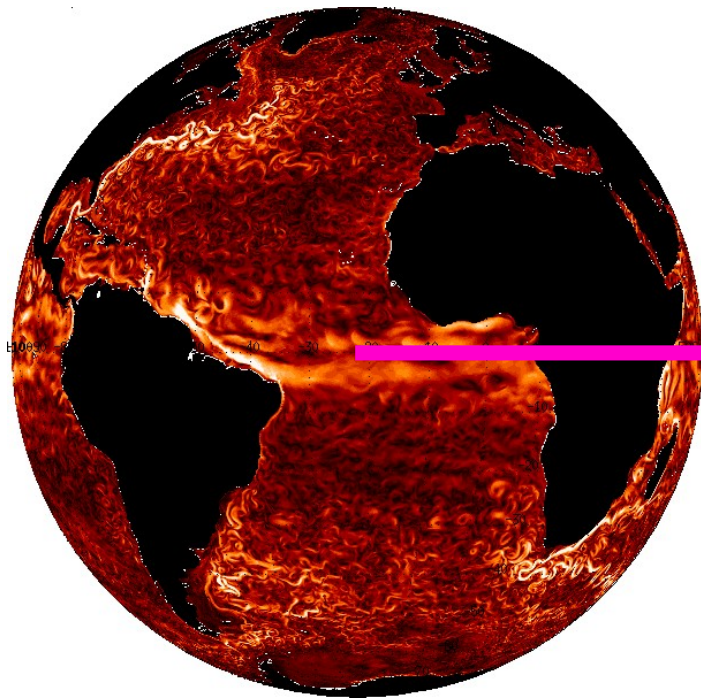


Global currents from CMEMS and PAPA buoy

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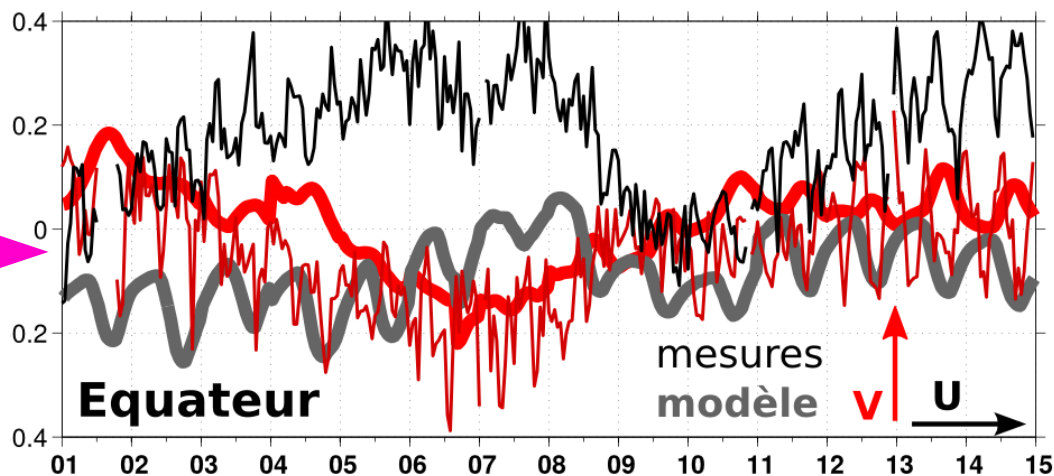
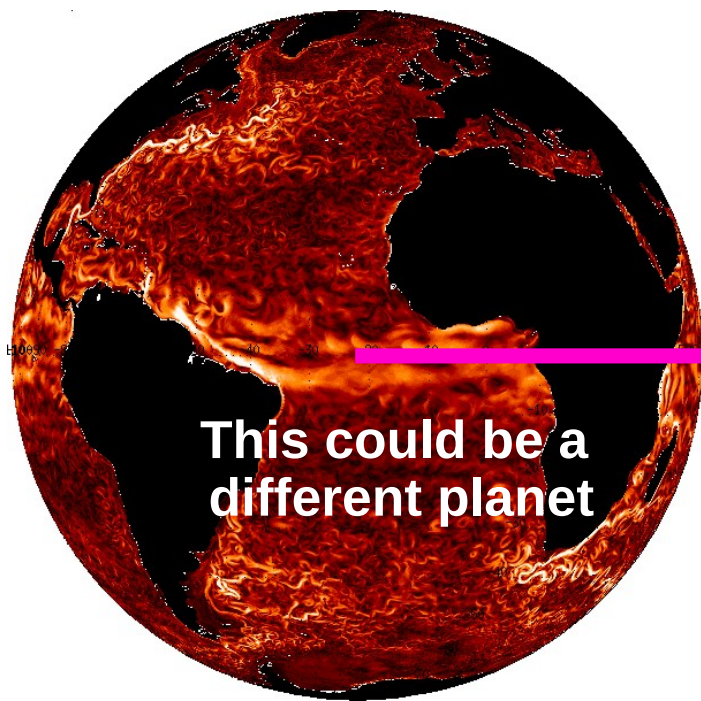


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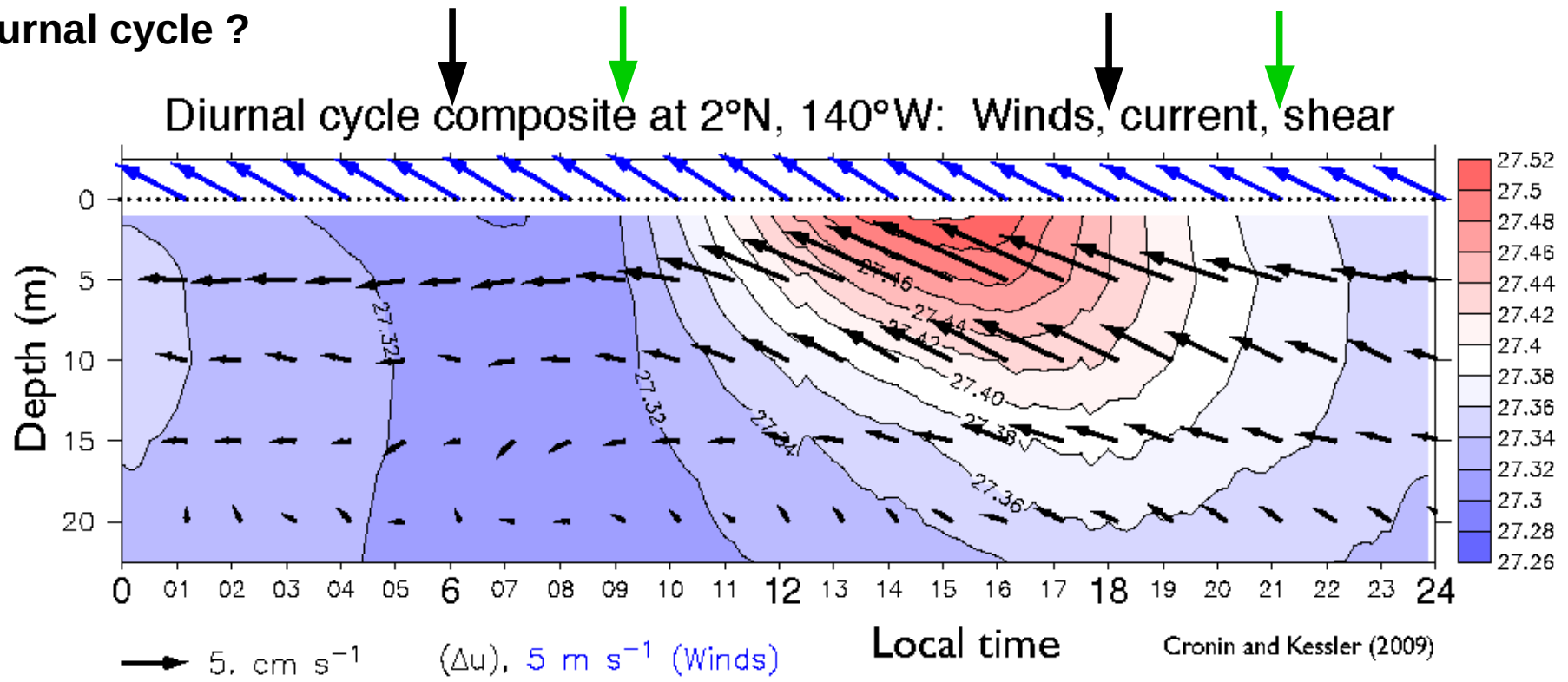


Global currents from CMEMS and PIRATA mooring data
(B. Bourles)

4. Space and time sampling

Possible equator crossing time, from 6 AM / 6 PM to **9 AM / 9PM**

Diurnal cycle ?



See also Wenegrat & McPhaden JGR 2015

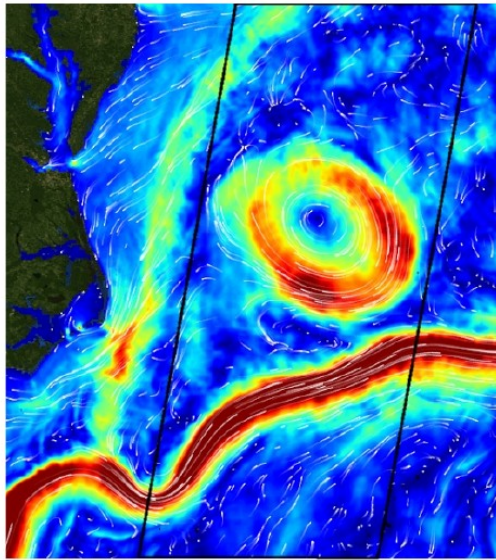
Other constraint : diurnal cycle on rain & wind speed in the tropics

5

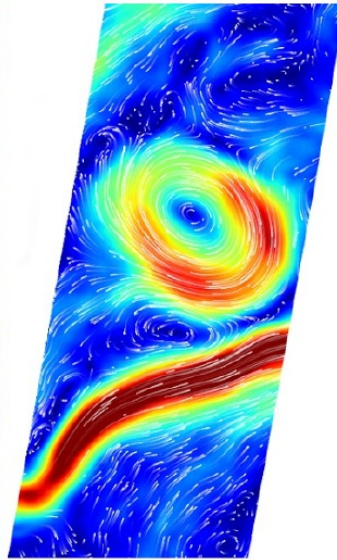
Expected performance

5. SKIM effective resolution

It 's all about « how wide is your swath »
... and a little about noise level ...



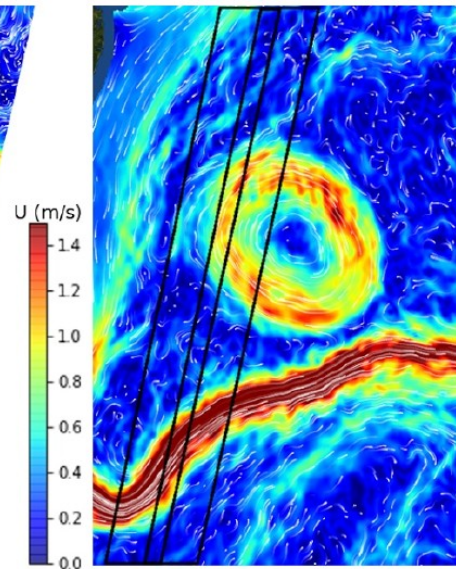
Model « truth »



SKIM L2b



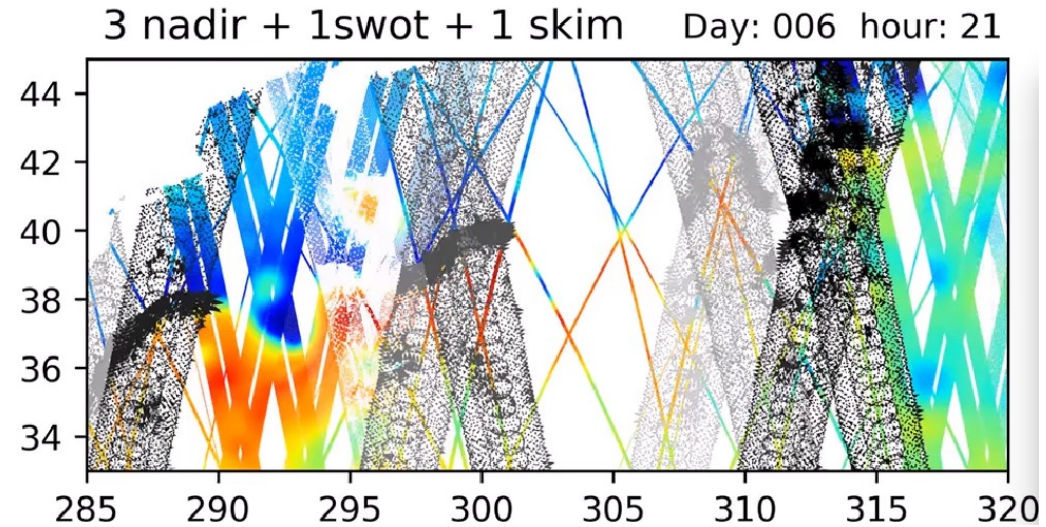
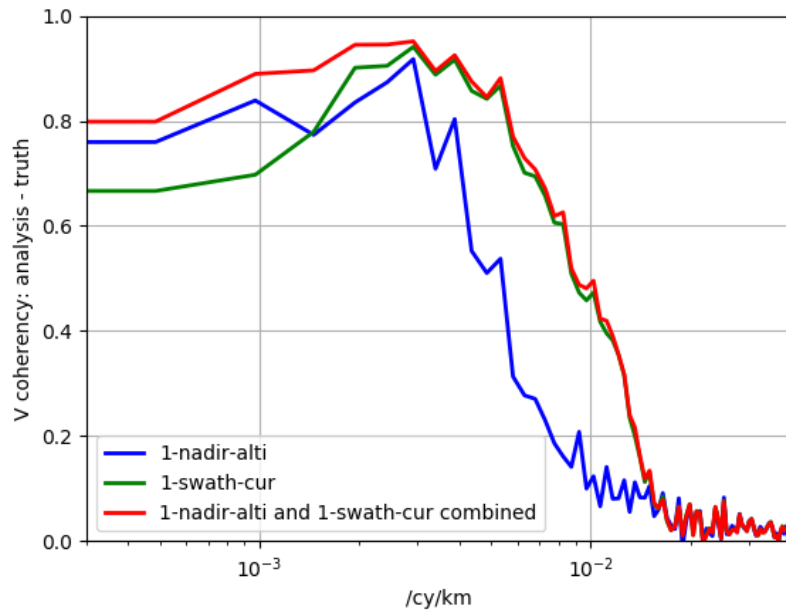
SWOT



current from SSH

5. SKIM effective resolution

Analysis of « effective resolutions » (Ubelmann et al., talk yesterday)



5. SKIM effective resolution

Now for 3 regions from equator to Arctic:
in blue, effective resolved **wavelength L_e**

Regions	Equator	Gulf-Stream	Fram
Input Level-2a error (12& 6° beams)	0.08 & 0.15 m/s	0.16 & 0.20m/s	0.10 & 0.16 m/s
Level-2b error (along&across track) and effective resol.	0.03 & 0.05 m/s 89 km	0.09& 0.14 m/s 65km	0.11 & 0.14 m/s 59km
Level-3a error (zonal&meridional) and effective resol.	0.14 & 0.18 m/s 290km	0.23 & 0.24 m/s 71km	0.12 & 0.13 m/s 62km
Level-2b W/O instr. err.	53km	0.08& 0.12 m/s 51 km	0.10 & 0.13 m/s 53 km
Level-3a W/O instr. err.	0.14 & 0.17 m/s 277km	0.22 & 0.24 m/s 71km	0.08 & 0.10 m/s 44km

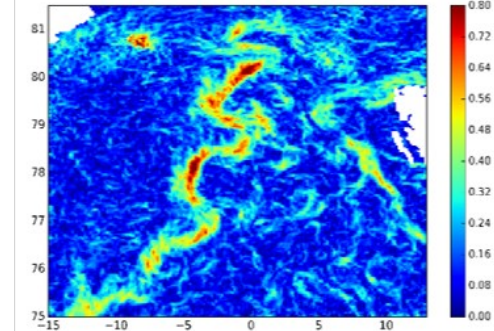
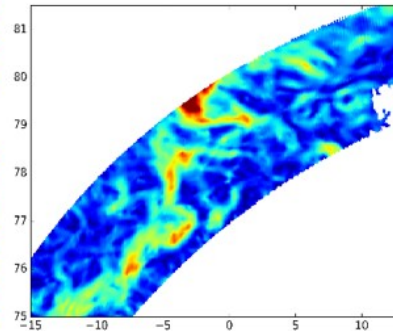
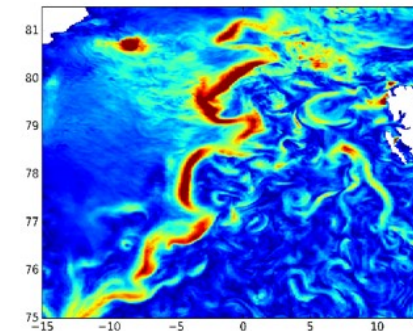
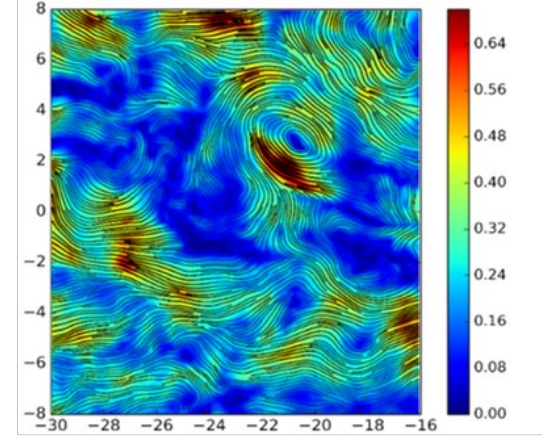
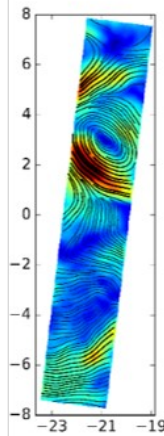
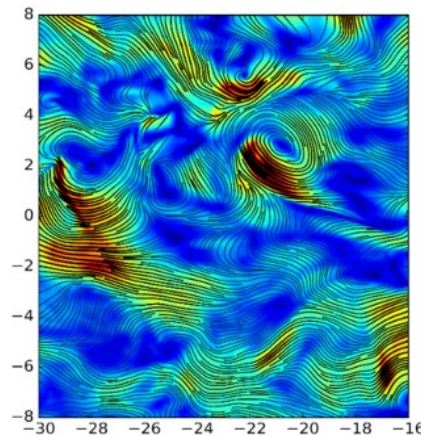
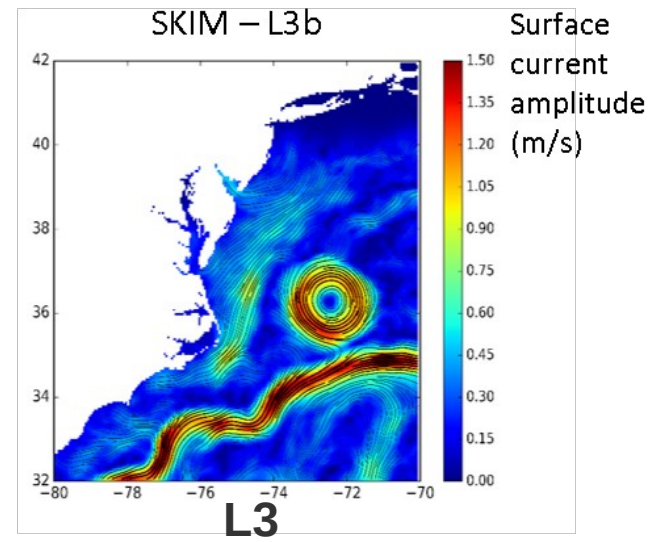
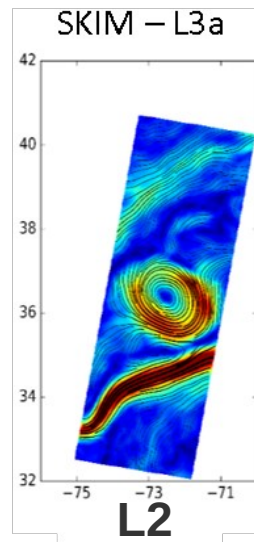
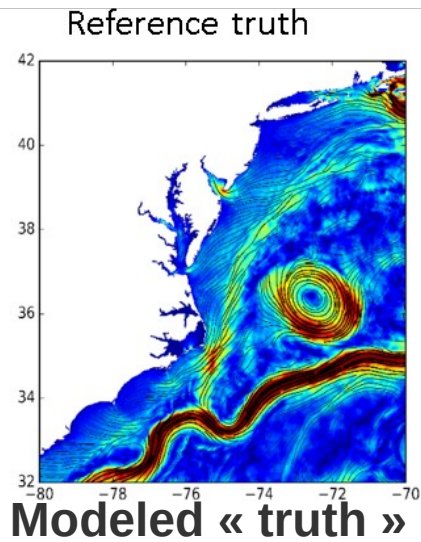
5. SKIM

What these
scales looks
Like ...

Gulf Stream

Equator

Fram Strait

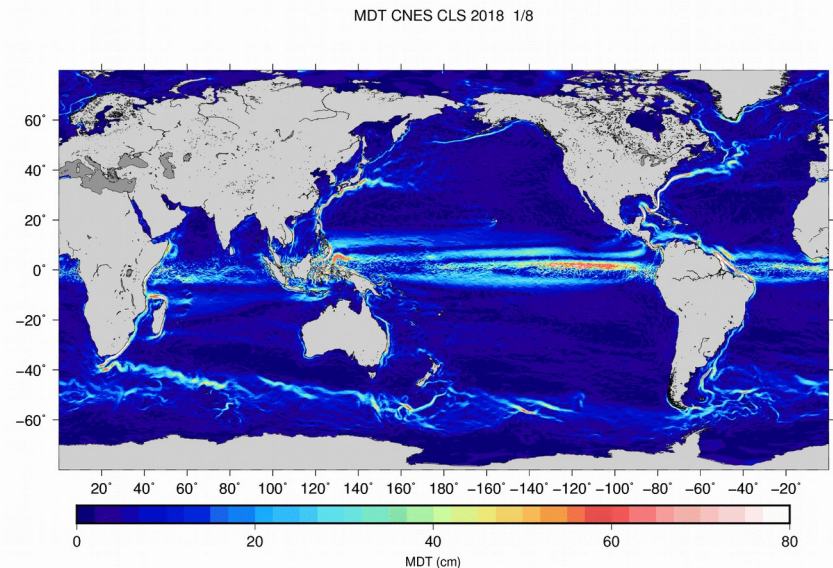


6

SKIM and altimetry : Adding to constellation + MDT, SSB ...

6. SKIM and altimetry

- For the ocean altimetry community **SKIM** offers :
 - one more (very good) **nadir altimeter** (Delay-Doppler Ka band)
(imagine the child of S3 and AltiKa)
(but without POD payload and radiometer) → **small scale topography**
 - a detailed SSB correction based on the full spectrum (first tests with CFOSAT)
 - a global mean current field
→ **mean dynamic topography**
(e.g. Rio et al. 2018 → remember that many regions have very few surface drifters)
- Potential secondary objectives : river flows ?
river or lake level (to be evaluated) ... warm rain



7

Conclusions

Conclusions

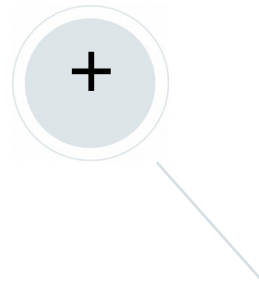
- SKIM adds new variable for Earth monitoring : **total surface velocity**
focus : **tropical currents & marginal ice zones**
- leap forward for **waves** : beyond CFOSAT, spectral measurements ($L > 30 \text{ m}$)
- complementarity with other missions : nadir altimeters, SWOT, SST, winds ...
 - opportunities for synergy (wind work, balanced vs unbalanced motions ...)
 - future nadir instruments : SKIM +POD ?
- Come and support SKIM :
 - Workshop in Brest (Doppler Oceanography : 10-12 October, sold out)
 - **User Consultation Meeting : 15-16 July 2019, Cambridge, UK**Choice between **SKIM** and **FORUM**

Launch in mid-2025

more soon on : www.skim-ee9.eu

#SKIM4EE9 **@FabriceArdhuin**

<http://tinyurl.com/SKIMonRG>



Back-up slides

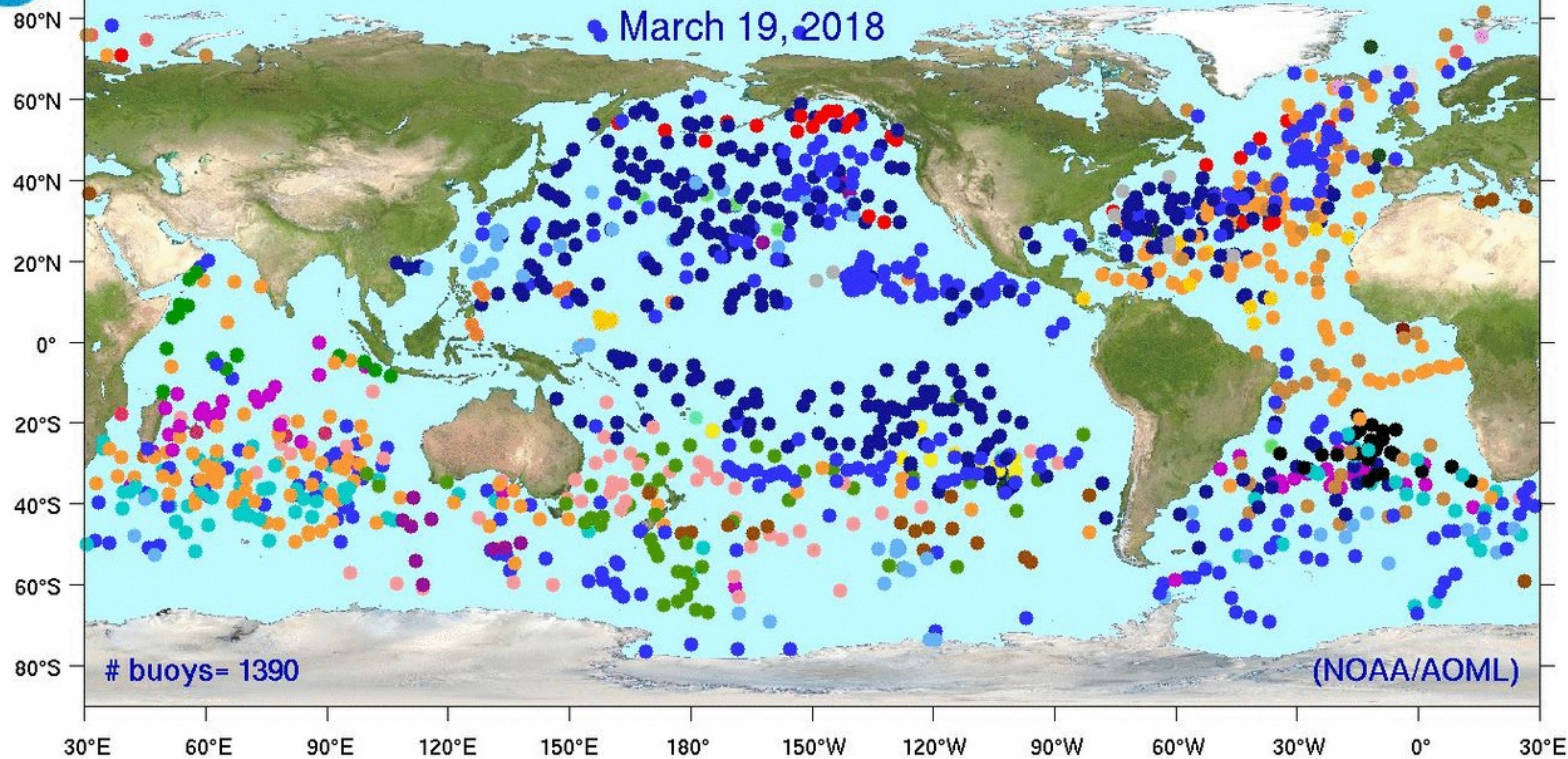
2. Why we need (more) current measurements

What we have today

VOS Crew Deploy Next Generation SVP Drifter
Photo by: ODP



STATUS OF GLOBAL DRIFTER ARR



Deploying Country

Australia (60)	Europe (4)	India (23)	Korea, Rep. of (58)	Palau (9)	Spain (16)
Brazil (27)	France (181)	Indonesia (3)	Mauritius (1)	Peru (10)	UK (47)
Canada (29)	Gabon (1)	Italy (21)	New Zealand (49)	Senegal (5)	USA-NOAA (338)
Chile (2)	Germany (31)	Japan (14)	Netherlands (5)	Seychelles (1)	USA-other (337)
China (6)	Greenland (2)	Kenya (18)	Norway (3)	South Africa (79)	Unknown (10)



6. SKIM and altimetry

- For the ocean altimetry community **SKIM** offers :
 - one more (very good) **nadir altimeter** (Delay-Doppler Ka band)
(imagine the child of S3 and AltiKa)
 - a detailed SSB correction based on the full spectrum (first tests with CFOSAT)
 - a global mean current field → **mean dynamic topography**
(remember that there are many regions with very few surface drifters)



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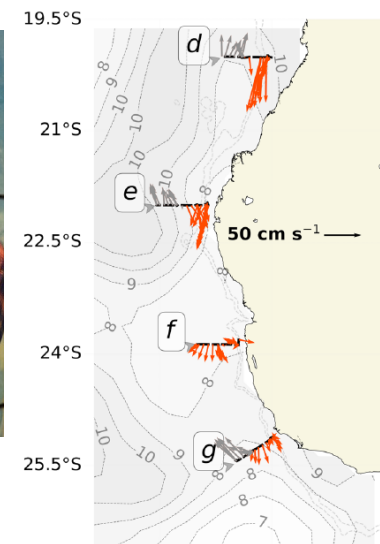
Key Points:

- The Southwest Madagascar Coastal Current (SMACC) is a newly discovered surface poleward current
- The SMACC exhibits a seasonal cycle and is driven by the wind stress curl
- The SMACC influences the coastal upwelling region south of Madagascar

Uncovering a New Current: The Southwest Madagascar Coastal Current

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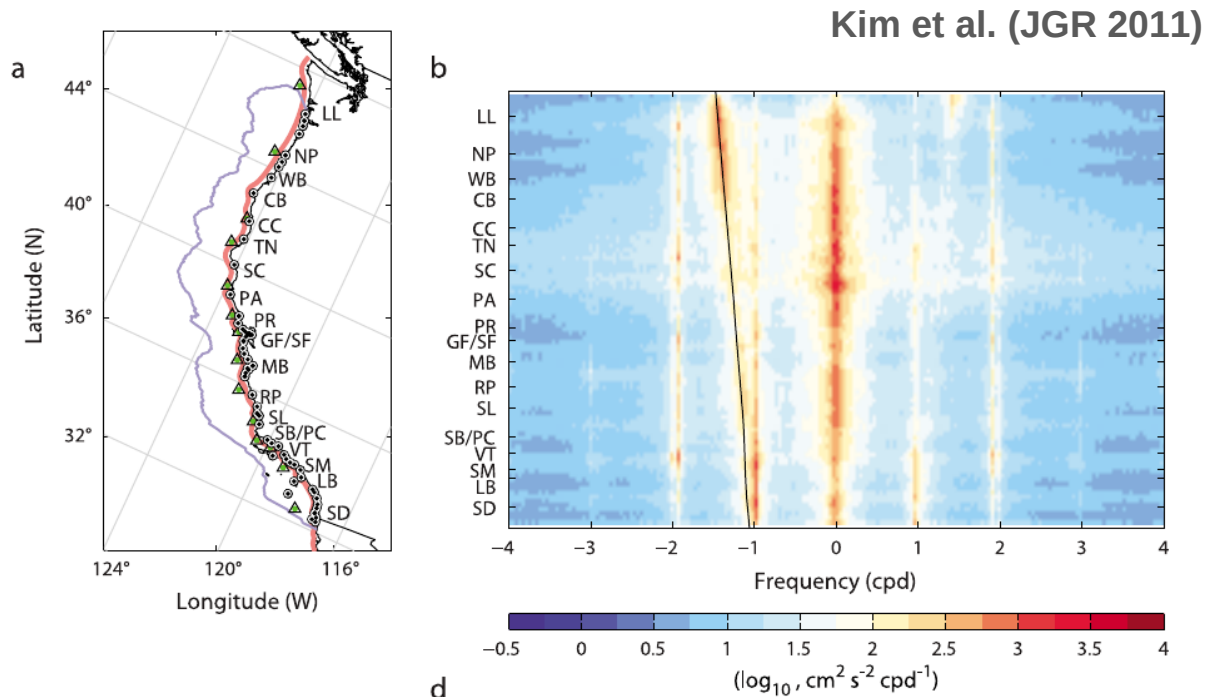


UCT student, Juliano discovered the South Madagascar Coastal Current

2. Why we need (more) current measurements

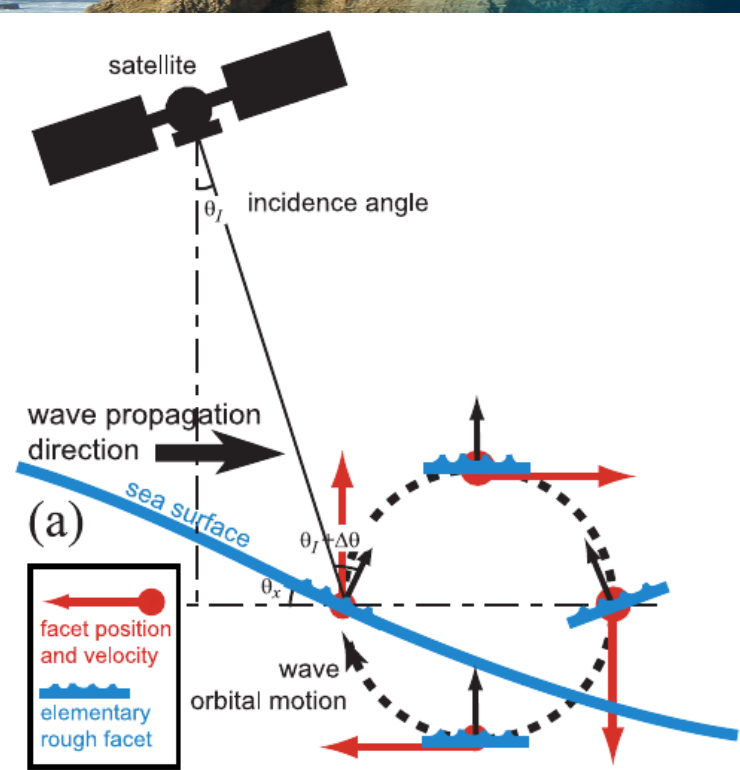
What we have today

HF radars can cover coastal regions up to ~ 200 km



4. SKIM and waves

The Doppler current (projected on horizontal), contains U_{WB} due to **wave orbital velocity** :



4. SKIM and waves

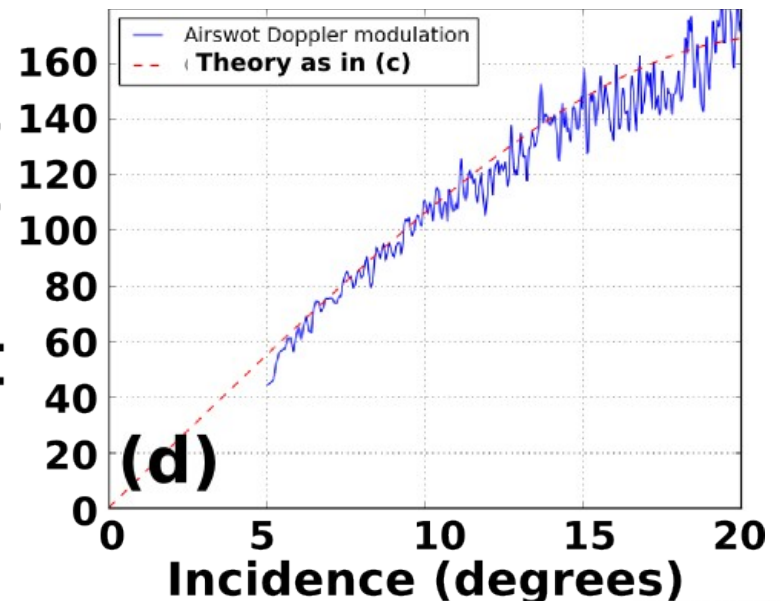
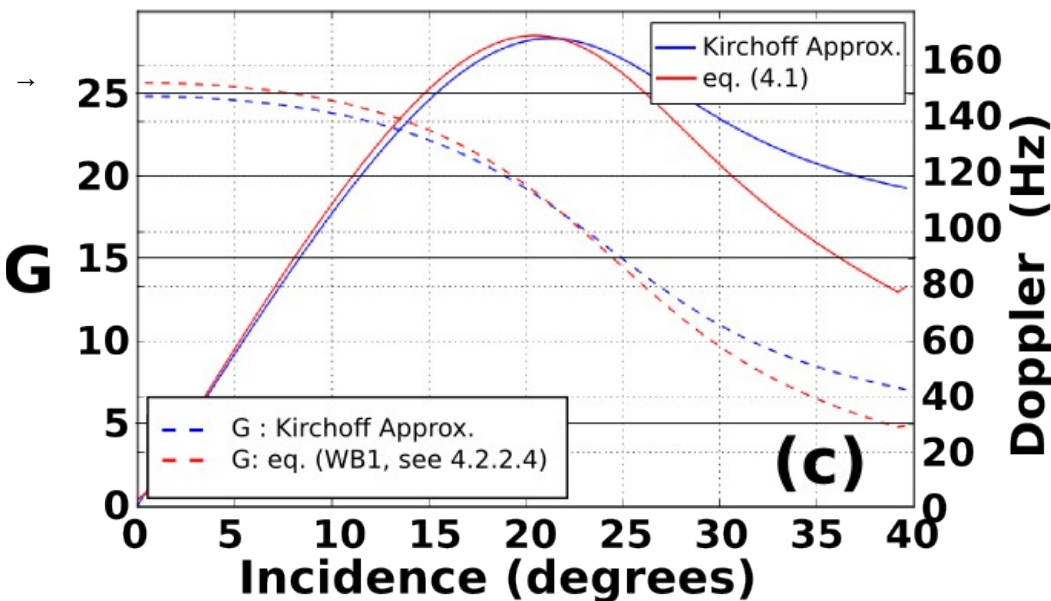
The Doppler current (projected on horizontal), contains U_{WB} .

- 2 scale model in Chapron et al. (2005)
- Kirchoff approximation in Nouguier et al. (in review) :

U_{WB} is proportional to « mean slope velocity » = $2G$ msv

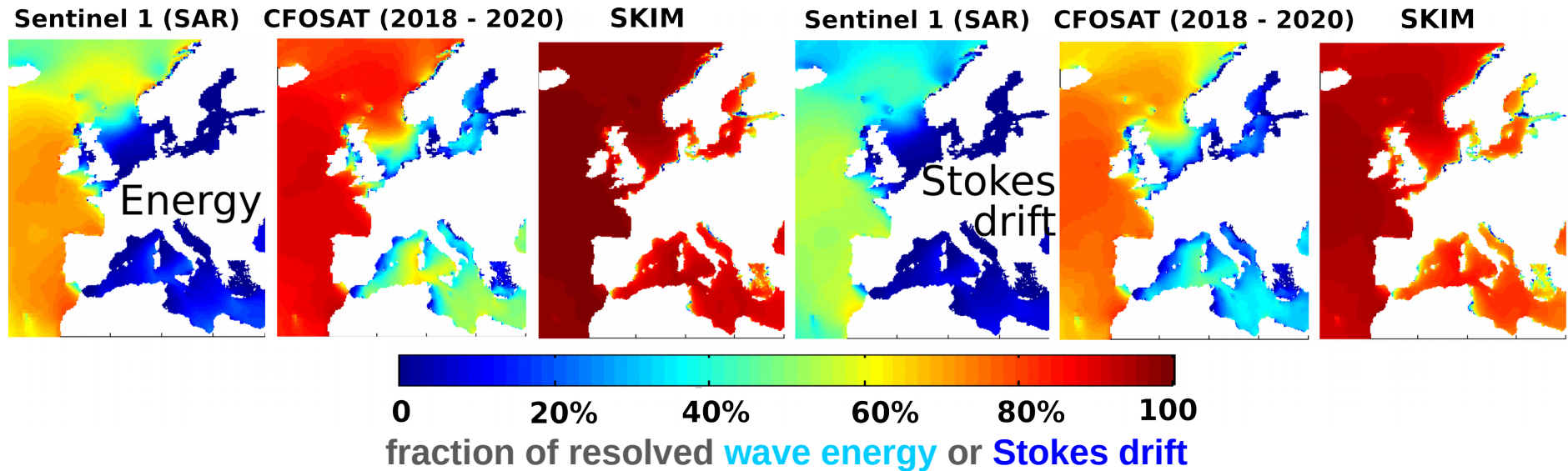
(NB : msv happens to be Surface Stokes drift /2) $\rightarrow U_{WB} = G U_s$

For SKIM : $G \sim 25$: validated with AirSWOT :



4. SKIM & waves

SKIM will resolve **much shorter waves** (20 m) than Sentinels (~ 150 m) CFOSAT (70 m)

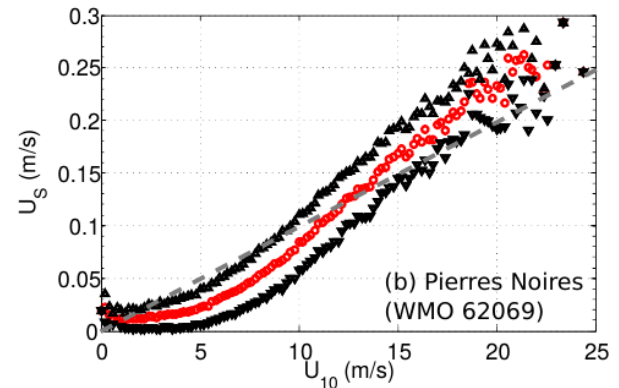
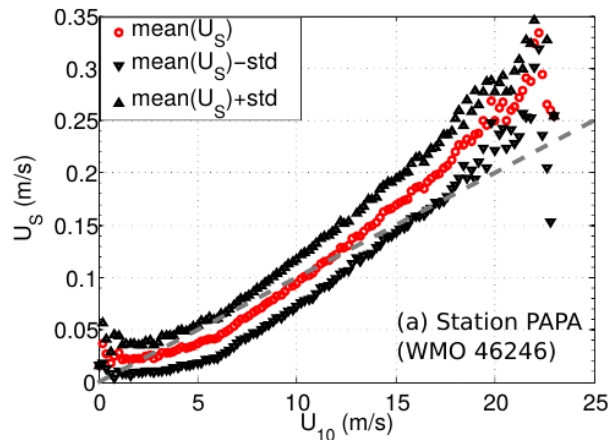


Measuring **shorter waves**

→ **surface Stokes drift U_{ss}**

→ **U_{WB} bias for currents :**

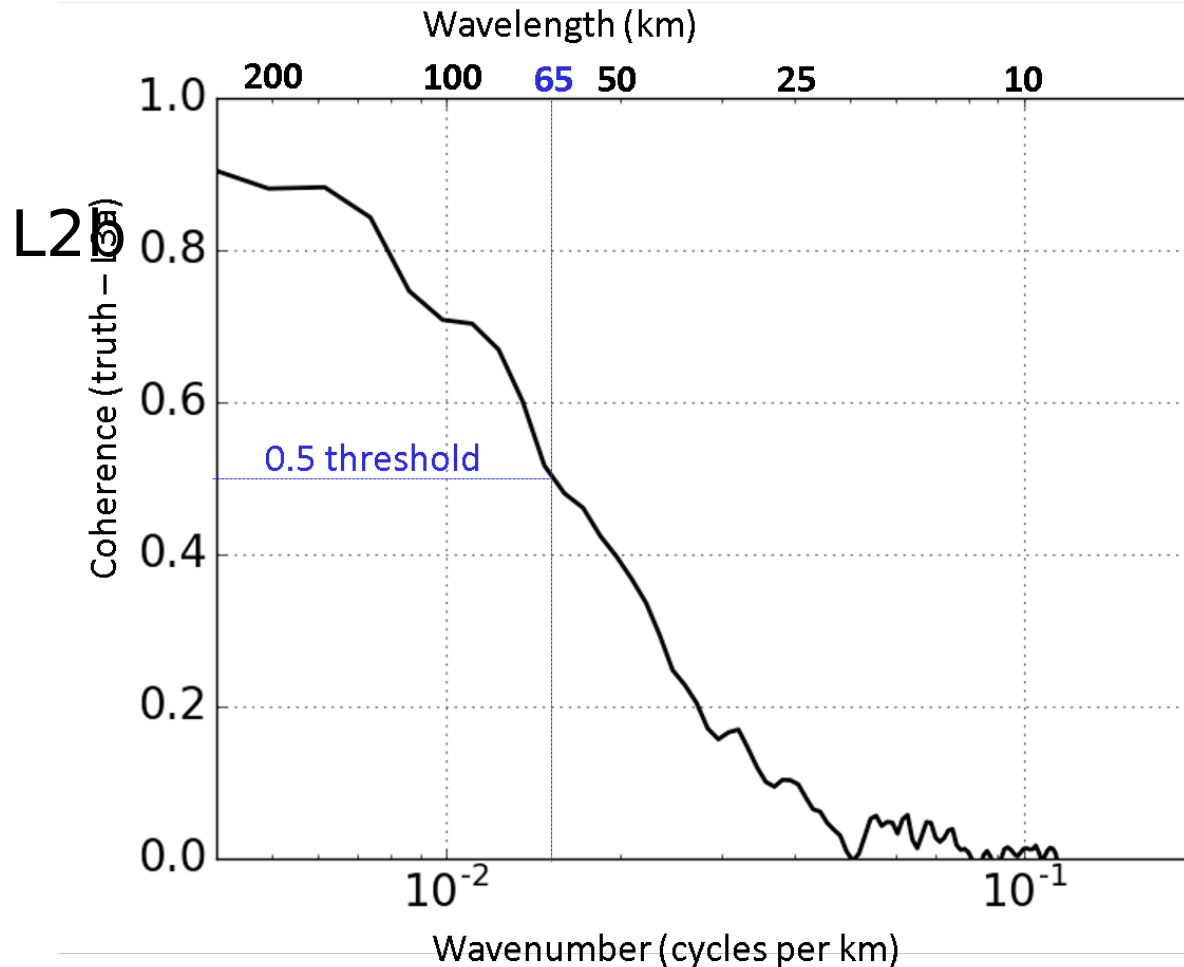
$$U_{WB} = G U_{ss}$$



5. SKIM effective resolution

So what are we resolving in terms of ocean scales ?

Here is for the Gulf Stream case : effective resolved wavelength $L_e = 65$ km



Extra slide : How do we know it works ? Thanks to AirSWOT...

AirSWOT measures SSH and range-resolved Doppler Doppler + ATI & XTI

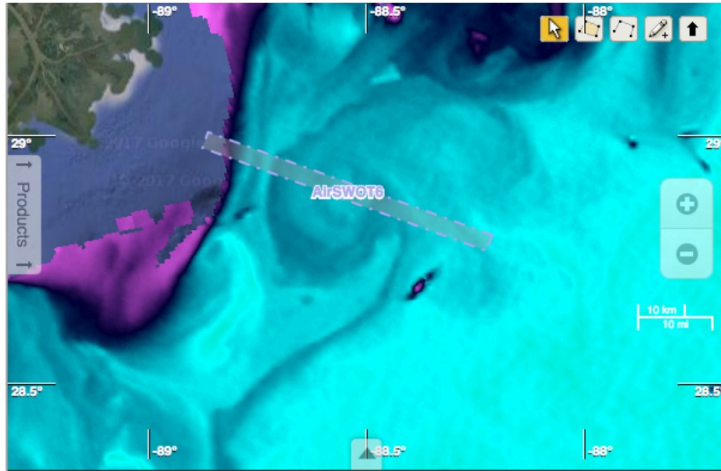
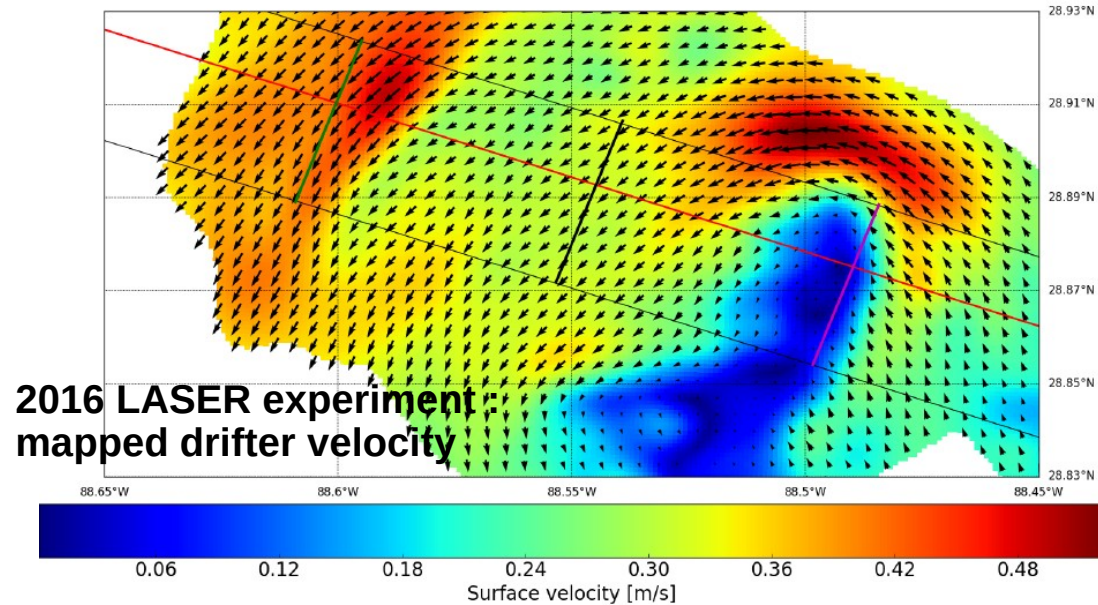
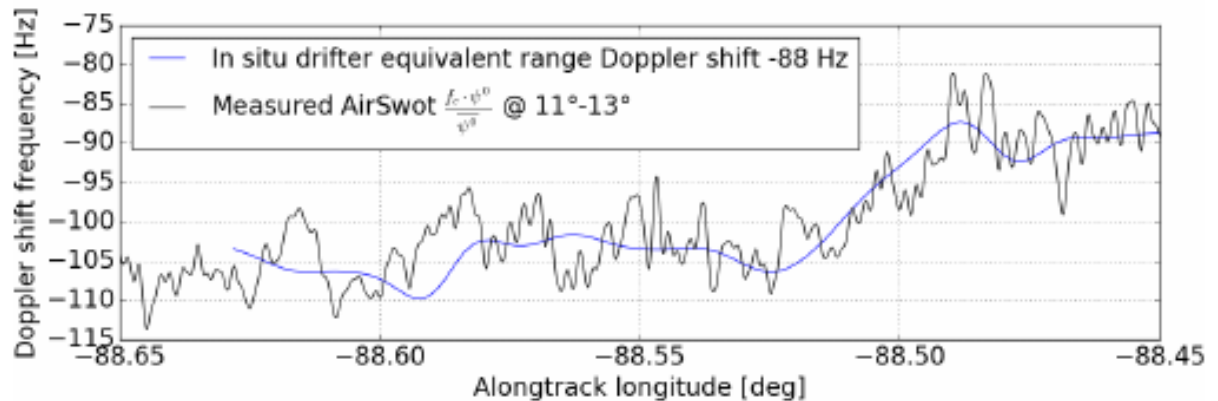


Fig. 9. AirSWOT flight #172803 on 2016/02/07 over the Hammer-Head mushroom seen by the VIIRS instrument (Sea Surface Temperature).



Doppler in Ka band (12° incidence) responds to currents in range direction:

Nouguier et al. (revised)



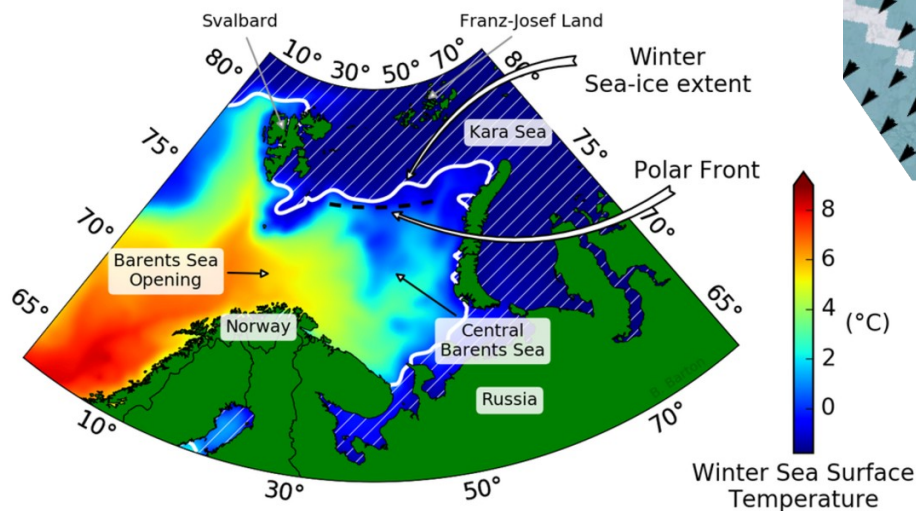
1. Science goals : marginal ice zones

Around the ice edge (Arctic and Southern ocean)
- a wide & poorly measured Marginal Ice Zone

- polar front dynamics &
impact on sea ice

- wave – ice interactions

What will happen by 2030 ?



Barton et al. (JPO 2018)

