Satellite observation simulator

SKIM-ATSCV project

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Satellite data simulation

So far, ocean surface currents are only indirectly being observed by satellite:

- Geostrophic current derived from altimeters
- Ekman current reconstructed using Wind, in-situ drifters
- Total surface current component in the radial direction (side looking) from SAR Doppler

New concepts of satellite are being studied to measure directly Total Surface Current Vectors using a rotating or multi-azimuth Doppler sensor:

- SKIM-like instrument (finalist in the EE-9 call)
- STREAM-like instrument (proposal for EE-11 call)
- ODYSEA-like instrument based on DopplerScat demo (collaboration CNES-NASA)
- Harmony or SEASTAR missions

Game changer as it will provide 2d current vector on swath, one needs to experiment how to benefit from these new information:

- Assess 2d reconstruction performance on a swath
- Assess the mapping for global / daily map
- Assess the benefit for model with assimilation experiments

Satellite data simulation

Objective:
Prepare simulated satellite observation for an OSSE, on the globe and for a year

Challenge:
Easily simulate satellite data on large region and temporal period using any model as an input

Solution:
Open source simulators are developed in python. Not instrument simulator but statistical noise parametrized using specs from instrument simulator.

- light: can run on a computer
- parametrizable: can adapt to different sensor geometry
- plugin noise: can evolve easily

Two simulators have been used for the SKIM-ATSCV study (and are publicly available on GitHub)

- SKIMulator
- Swot-simulator

Simulated data are publicly available

Satellite data simulation

1 - Input model chosen

2 - Simulation of SKIM-like data
- Overview of SKIMulator
- Simulated data
- Performance evaluation

3 - Simulation of SSH-like data
- Altimeters already flying
- 12 altimeter S3-like constellation
- 2 Swath altimeter constellation

4 - Odysea / Doppler scatterometer -like data

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Input model data

Mercator 1/12°, hourly model has finally been chosen as it has no tide and no assimilation
- Sea Surface Temperature, Sea Surface Height
- Northward velocity
- Eastward velocity

WW3 has run on the Mercator model to generate correlated Wave Inputs at 1/4º, hourly
- Mean Square Slope
- Significant Wave Height
- Northward Stokes drift
- Eastward Stokes drift

Other ancillary data:
- Wind: ECMWF forcing at 1/4º, 3-hourly
- Rain: IMERG data at 1/12º, hourly

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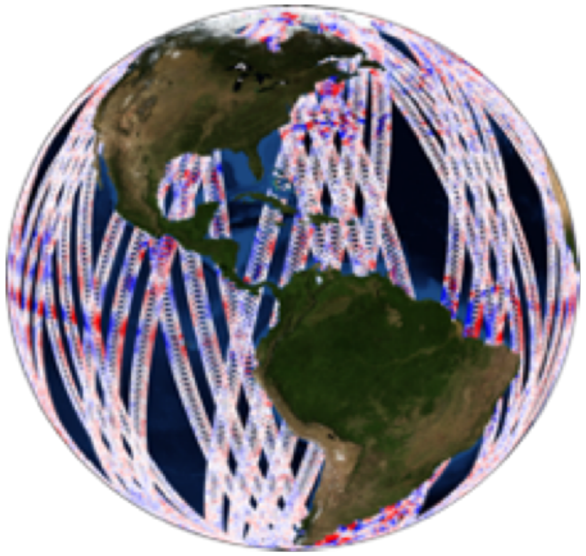
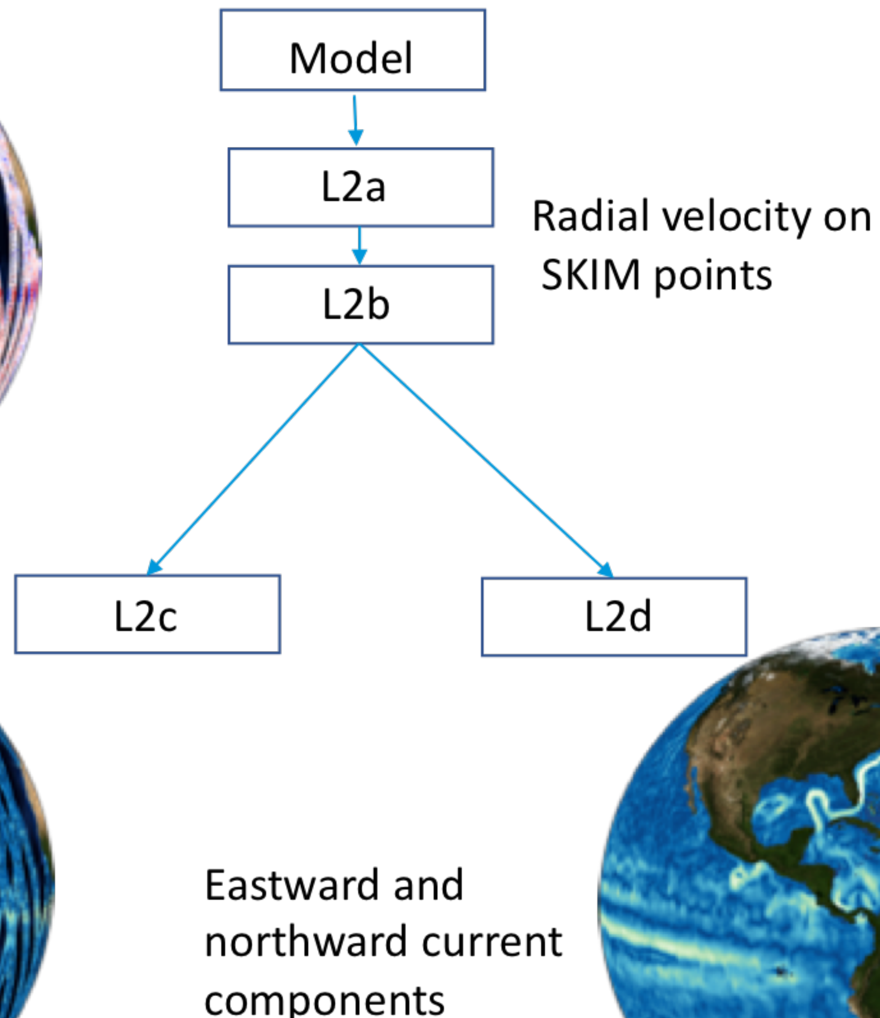
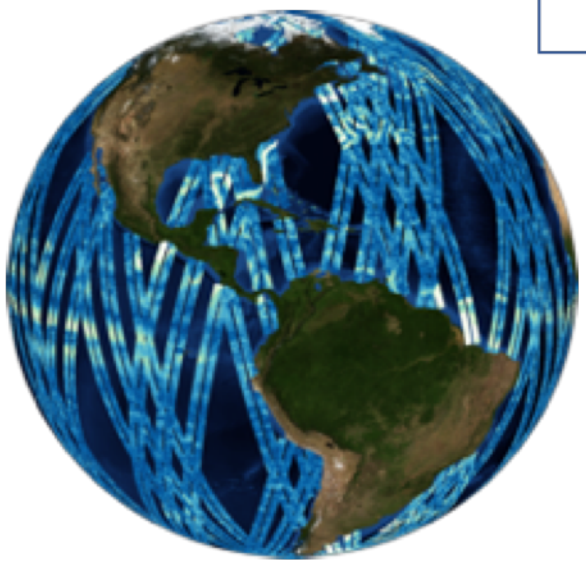
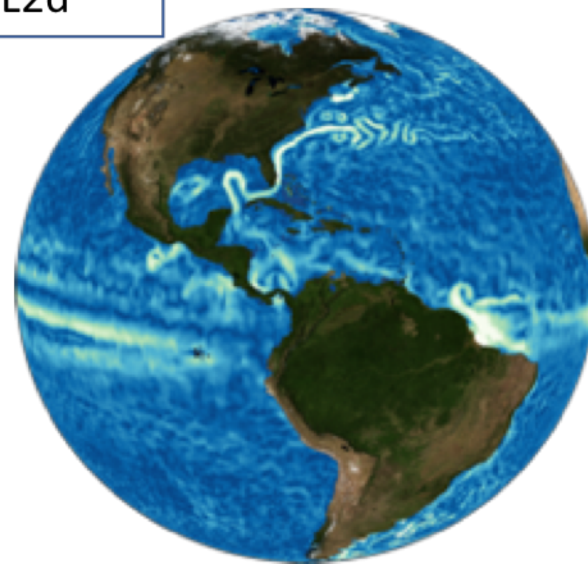
SKIMulator overview





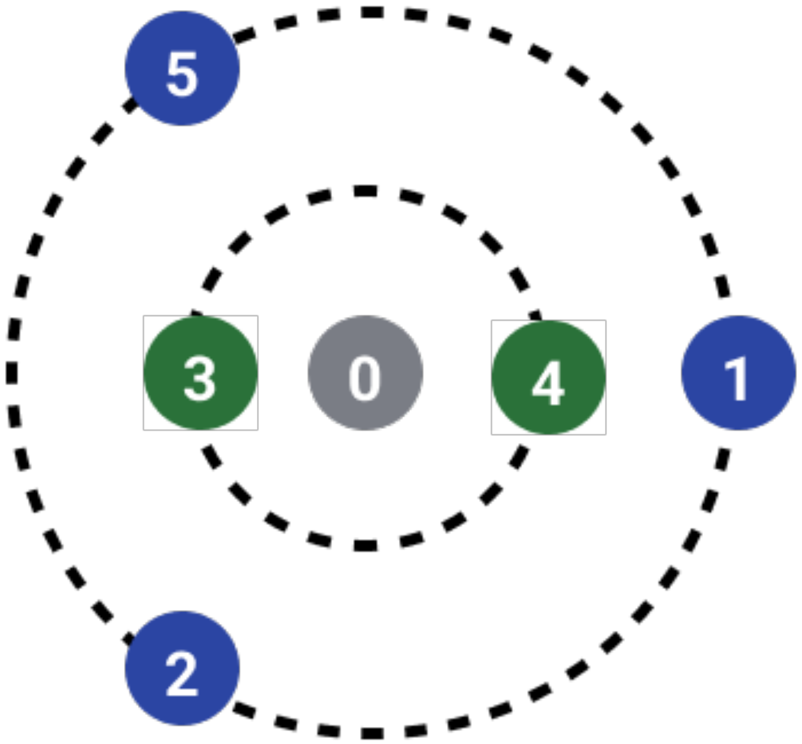




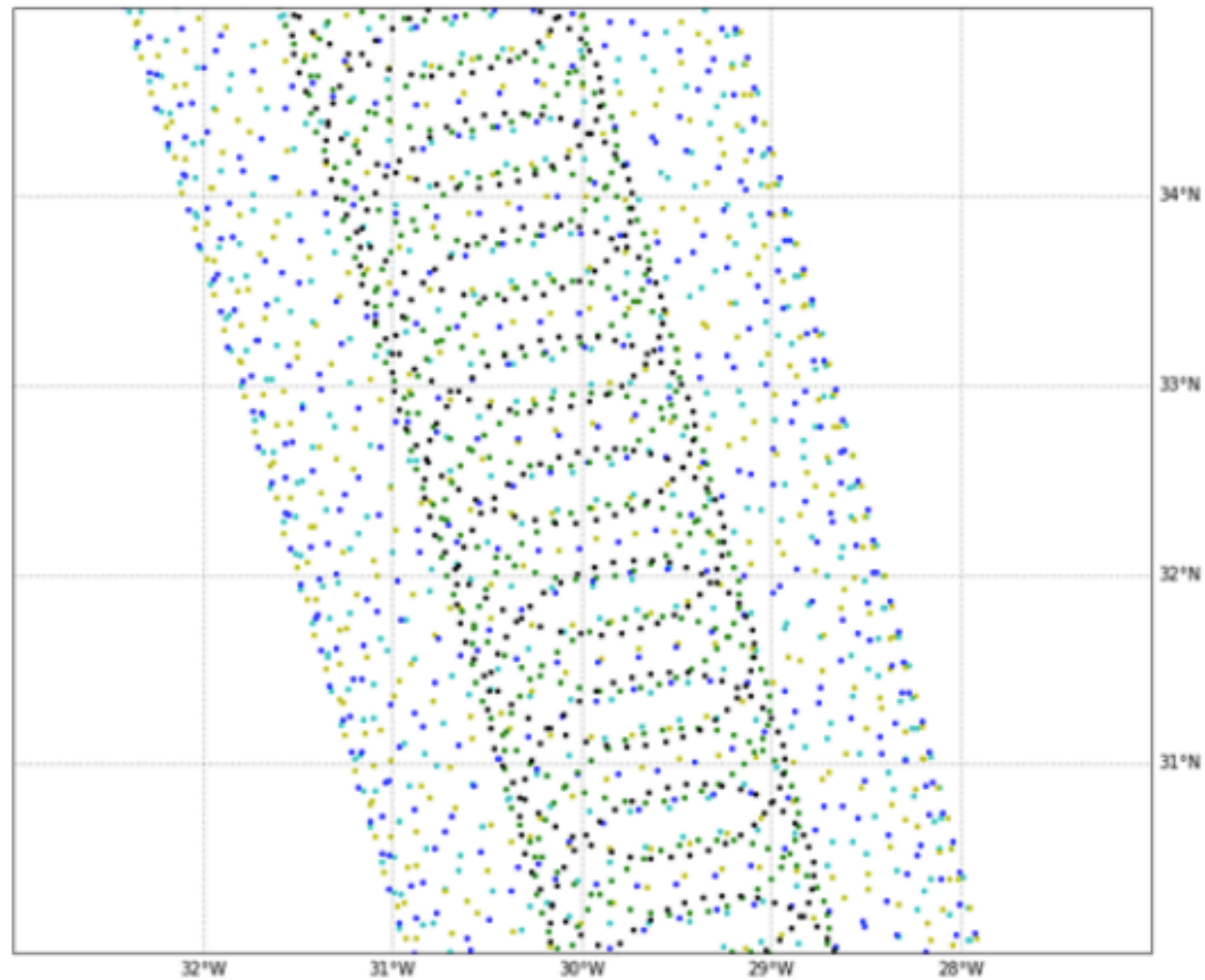
- **Community SKIMulator**: simulation of SKIM geometry and parametrization of geophysical and error signals using an OGCM model.
- **Open source** python simulator, available on git
  https://github.com/oceandatalab/skimulator
- **Highly scalable and configurable, to perform evaluation of different SKIM SKaR instrument geometry, orbits, uncertainty, resolution…**

Coded in python 3, tested with python 3.5-3.11
can be downloaded from GitHub

SKIMulator L2b

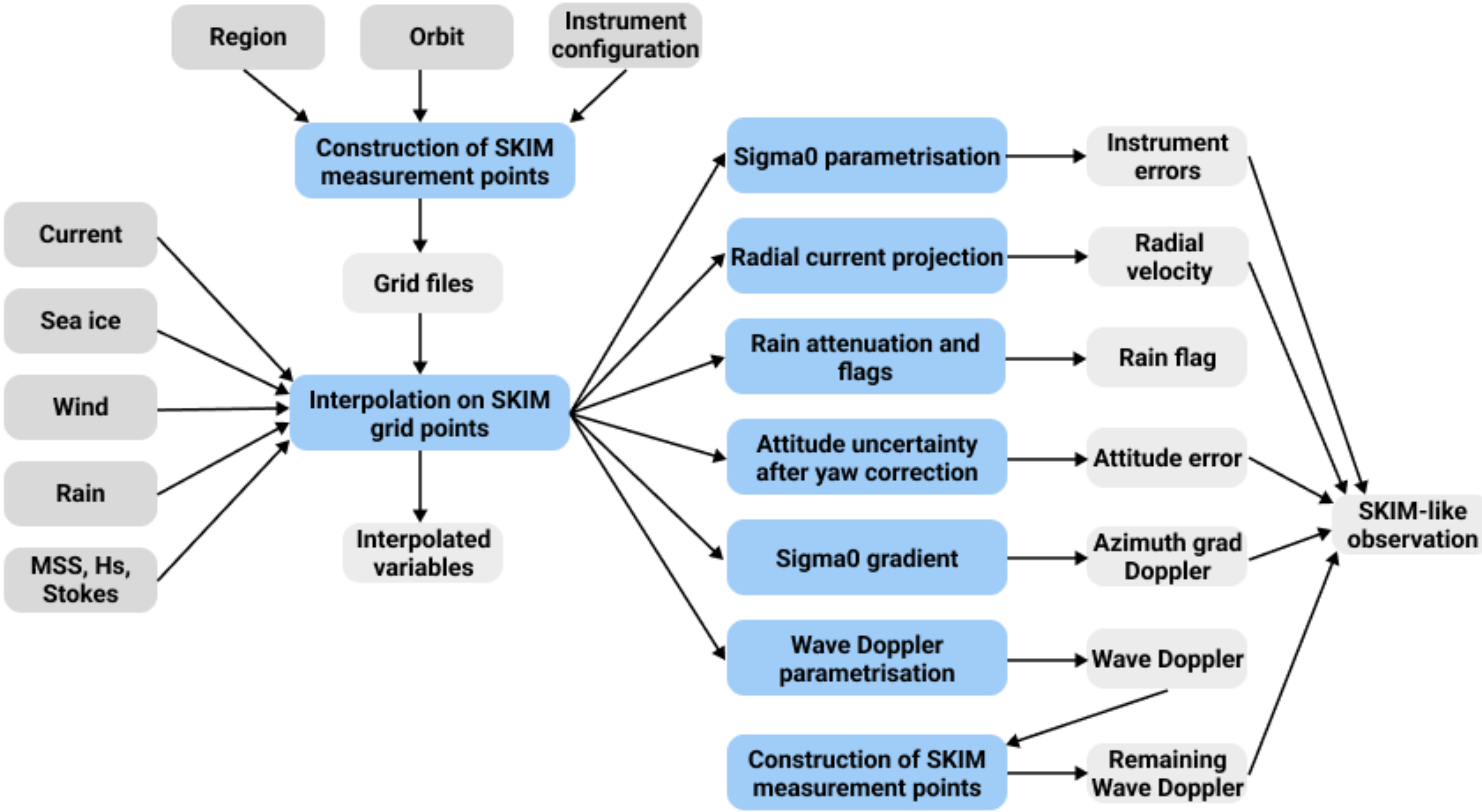


Illumination Scheme



- Orbit SKIM new generation built: 17 days, 750 km, 98.4º, LTAN 6am
- instrumental error budget same as SKIM
- Configuration Similar as 2019-6b: three 12º beams, two 6º beams, one nadir

SKIMulator L2b



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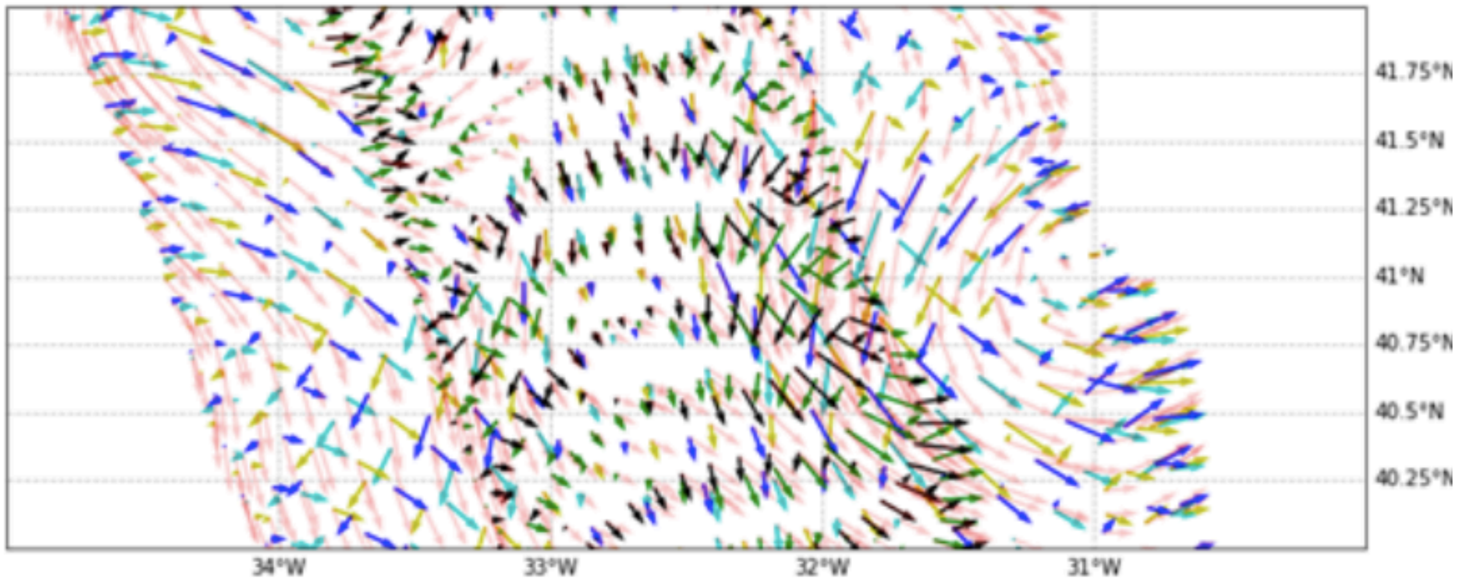
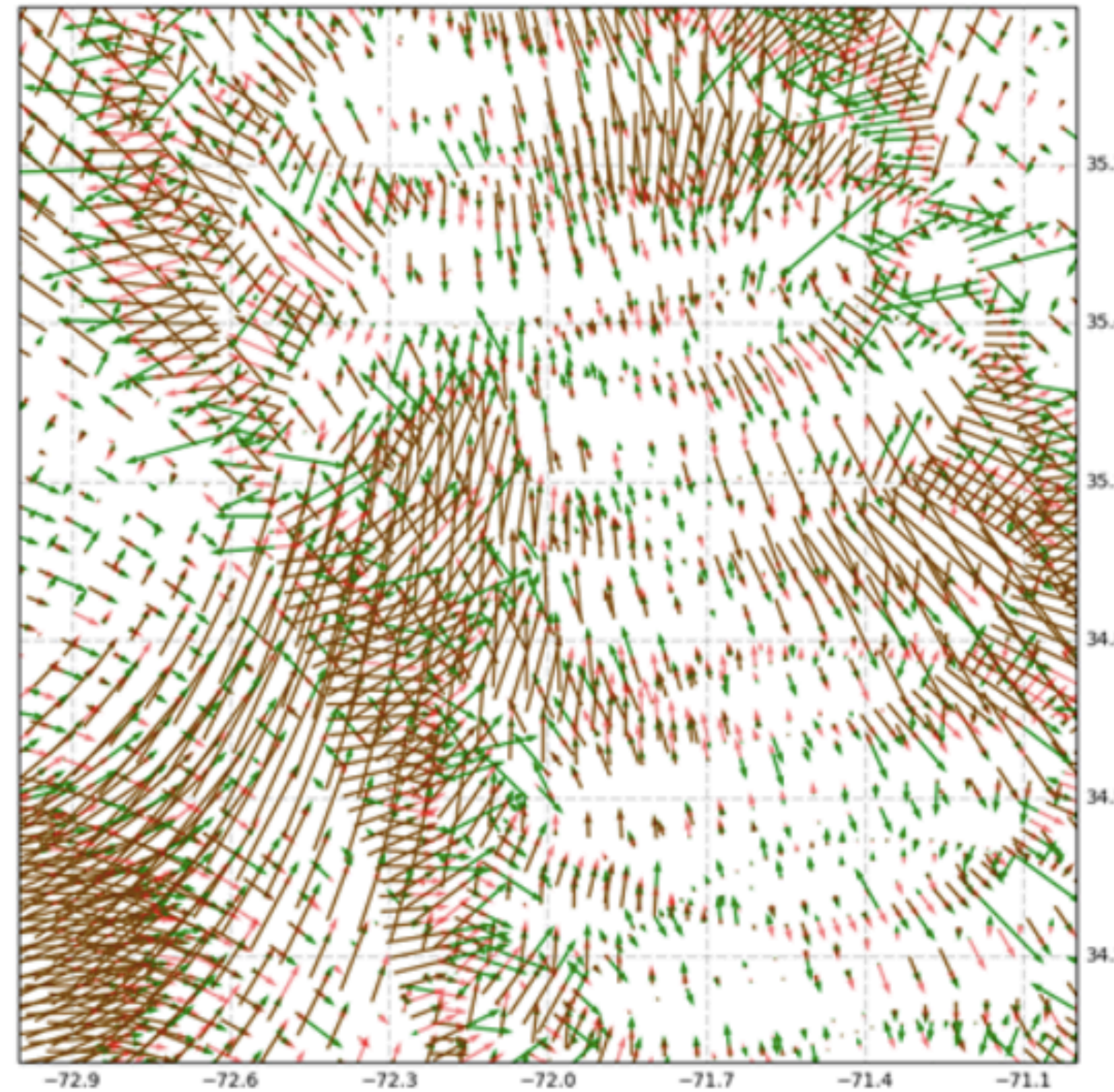


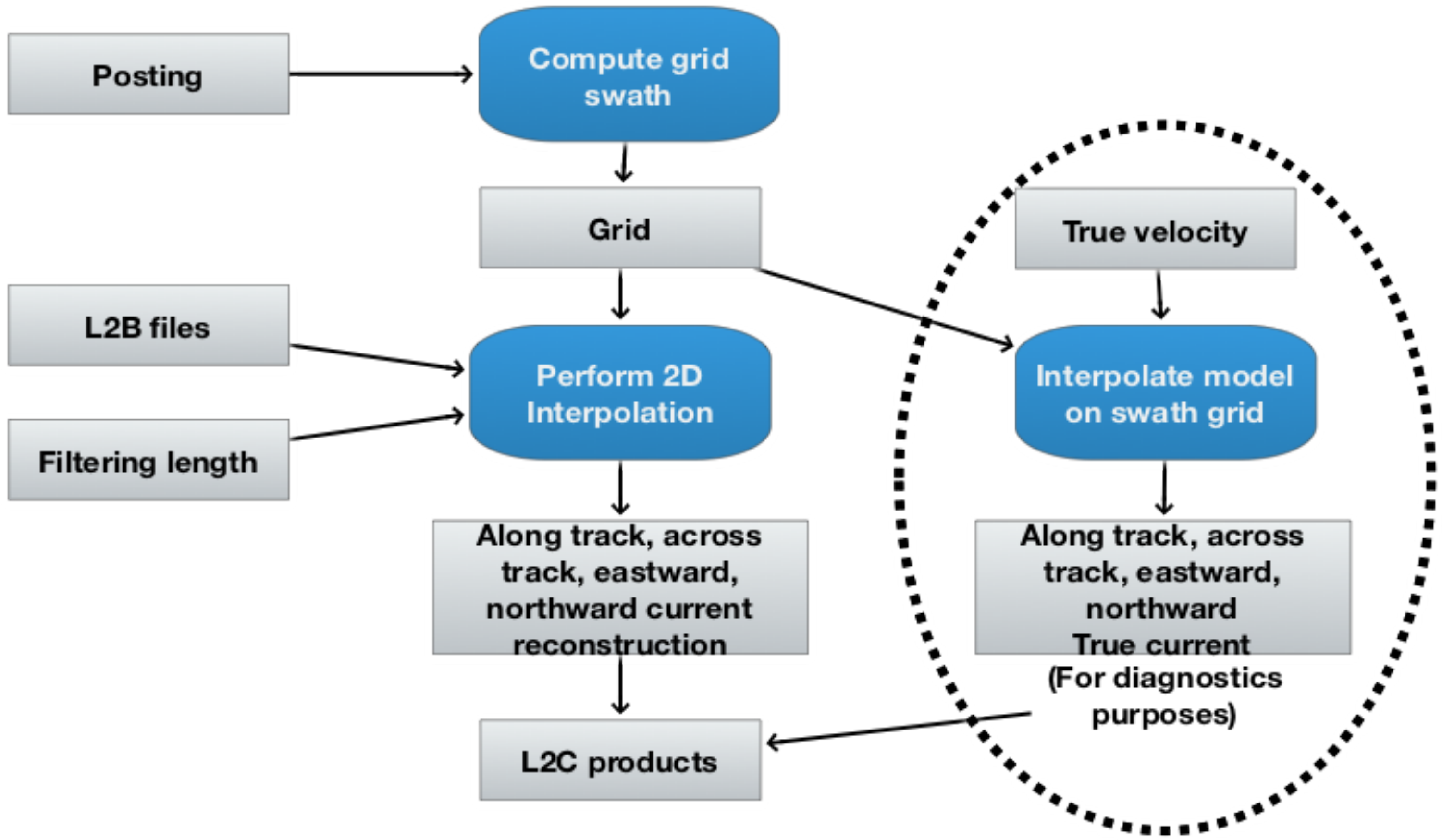
Radial Velocity observed by the different beams



Total radial velocity (red) vs radial velicity without noise (green)

- Orbit SKIM new generation built: 17 days, 750 km, 98.4º, LTAN 6am
- instrumental error budget same as SKIM
- Configuration Similar as 2019-6b: three 12º beams, two 6º beams, one nadir

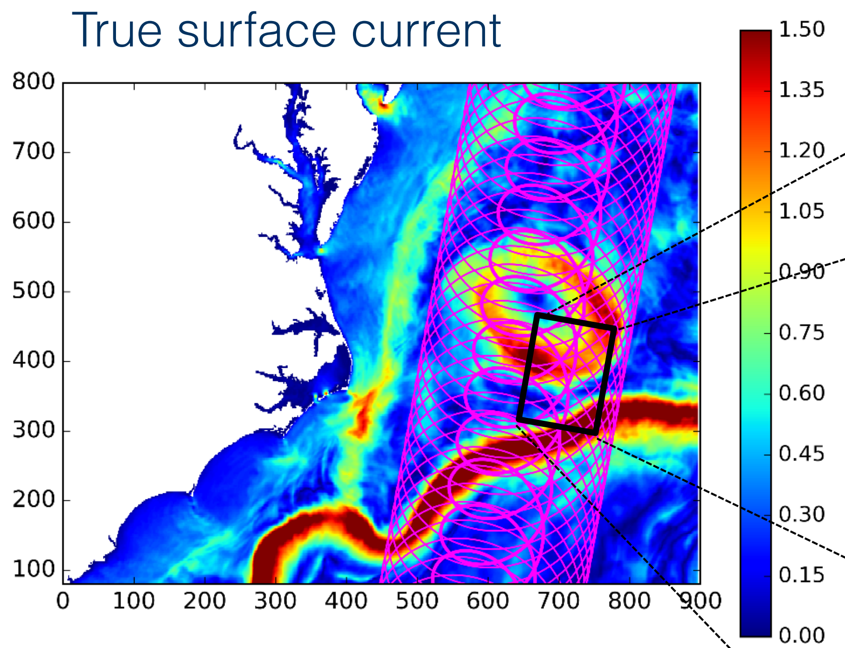
SKIMulator: L2c

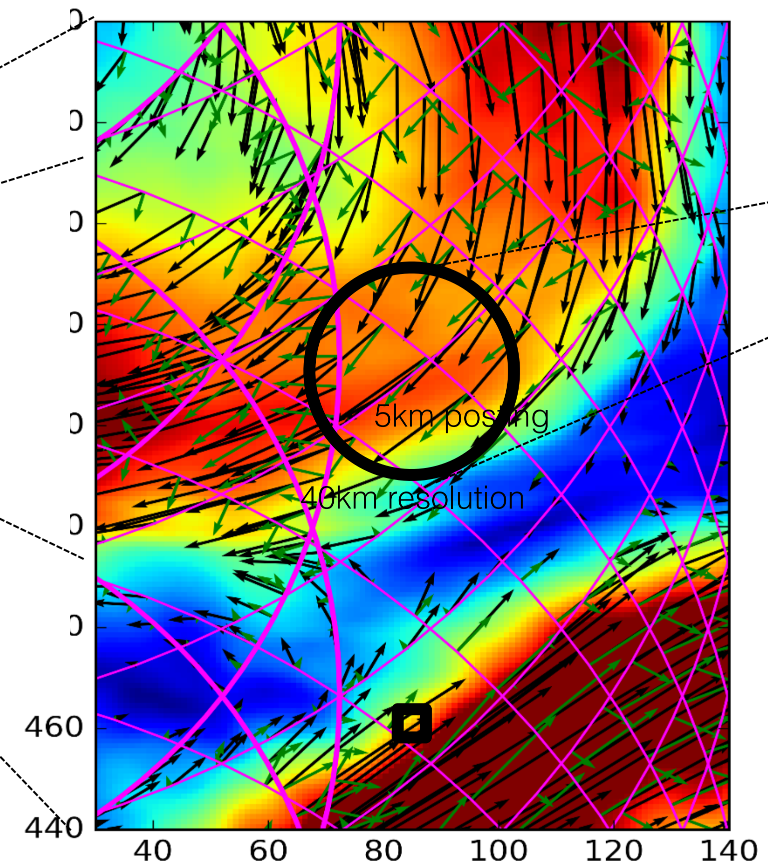


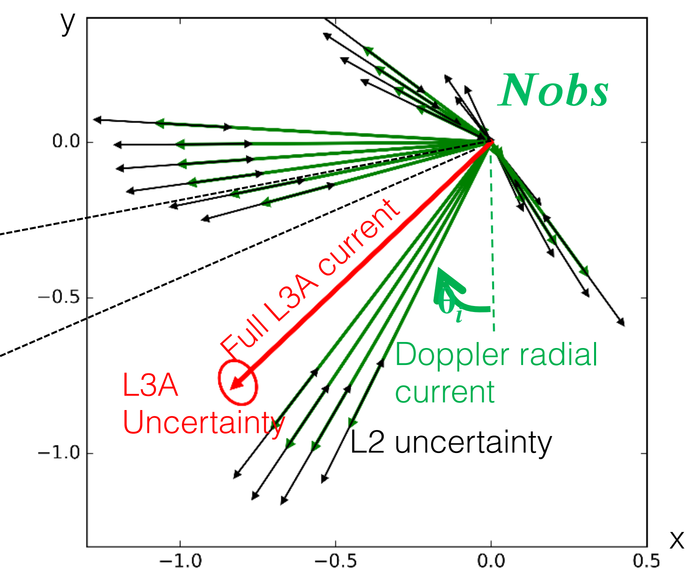
A post processing is performed before the TSCV reconstruction to ensure that erroneous pixels do not pollute the Optimal Interpolation (OI). The following flagging has been used:

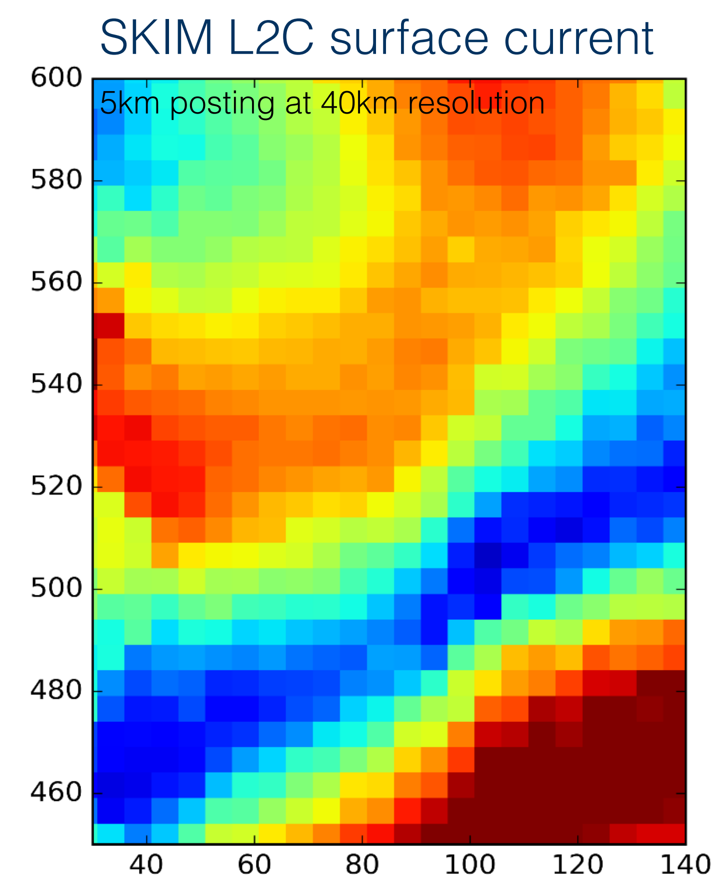
- rain above a defined threshold
- presence of ice
- MSS above a defined threshold
- High or very low wind (which correspond to very high or very low NRCS)

SKIMulator: L2c









$$\begin{pmatrix} V_x \\ V_y \end{pmatrix} = (H^T R^{-1} H)^{-1} H^T R^{-1} \begin{pmatrix} Vr_0 \\ \vdots \\ Vr_N \end{pmatrix}$$

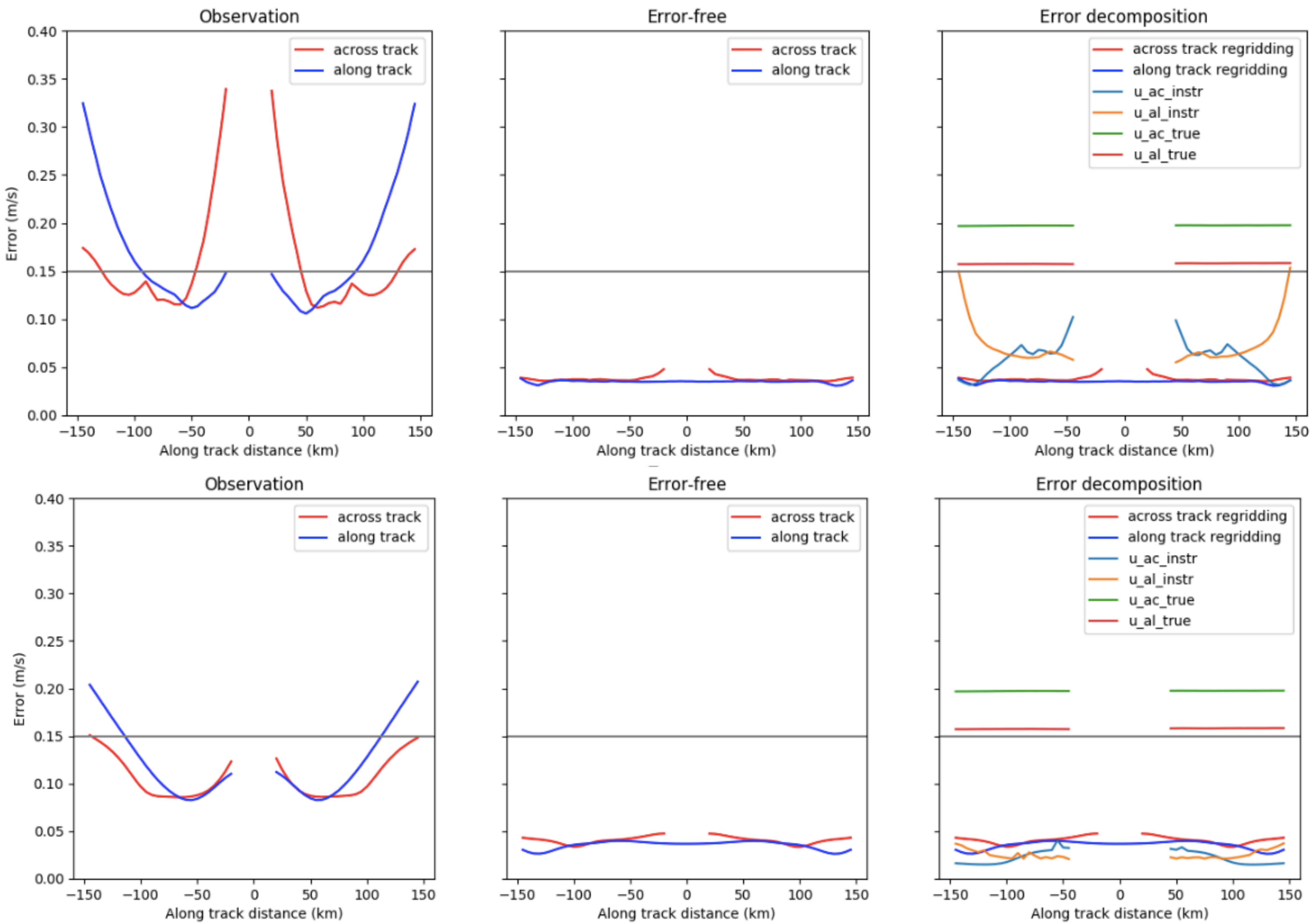
$$H = \begin{pmatrix} \cos(\theta_1) & \sin(\theta_1) \\ \vdots & \vdots \\ \cos(\theta_N) & \sin(\theta_N) \end{pmatrix} \quad \updownarrow \text{Nobs}$$

Standard L2C: Improve windowing (through R matrix) of L2B vectors and uncertainty description (U and V ellips)
DA-focused-L2C: Build a new observation operator H to constrain to purely rotational flow (new scalar current function as state vector). Impact on geostrophic DA to be tested then

SKIMulator L2c: performance

20 km filtering

60 km filtering



SKIMulator available data

- Orbit SKIM new generation built: 17 days, 750 km, 98.4º, LTAN 6am
- Configuration Similar as 2019-6b: 6 beams (nadir, 12, 12, 12, 6, 6)
- Temporal Coverage: 2009/01/15 - 2009/12/30

Level of Product	Content	Path/pattern
L2b	Radial velocity in the sensor geometry	l2b/WW3_GL_skimng_2019_6b_A_c{cycle}_p{pass}.nc
L2c20	Velocity interpolated on the swath, 5 km posting, 20 km sigma for the gaussian footprint	l2c/WW3_GL_skimng_2019_6b_Al20_l2c_c{cycle}_p{pass}.nc
L2c40	Velocity interpolated on the swath, 5 km posting, 40 km sigma for the gaussian footprint	l2c/WW3_GL_skimng_2019_6b_Al40_l2c_c{cycle}_p{pass}.nc
L2c60	Velocity interpolated on the swath, 5 km posting, 60 km sigma for the gaussian footprint	l2c/WW3_GL_skimng_2019_6b_Al60_l2c_c{cycle}_p{pass}.nc

Software used to simulate data:
https://github.com/oceandatalab/skimulator, v4.0

ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_skimulator/WW3_GL_skim_atscv

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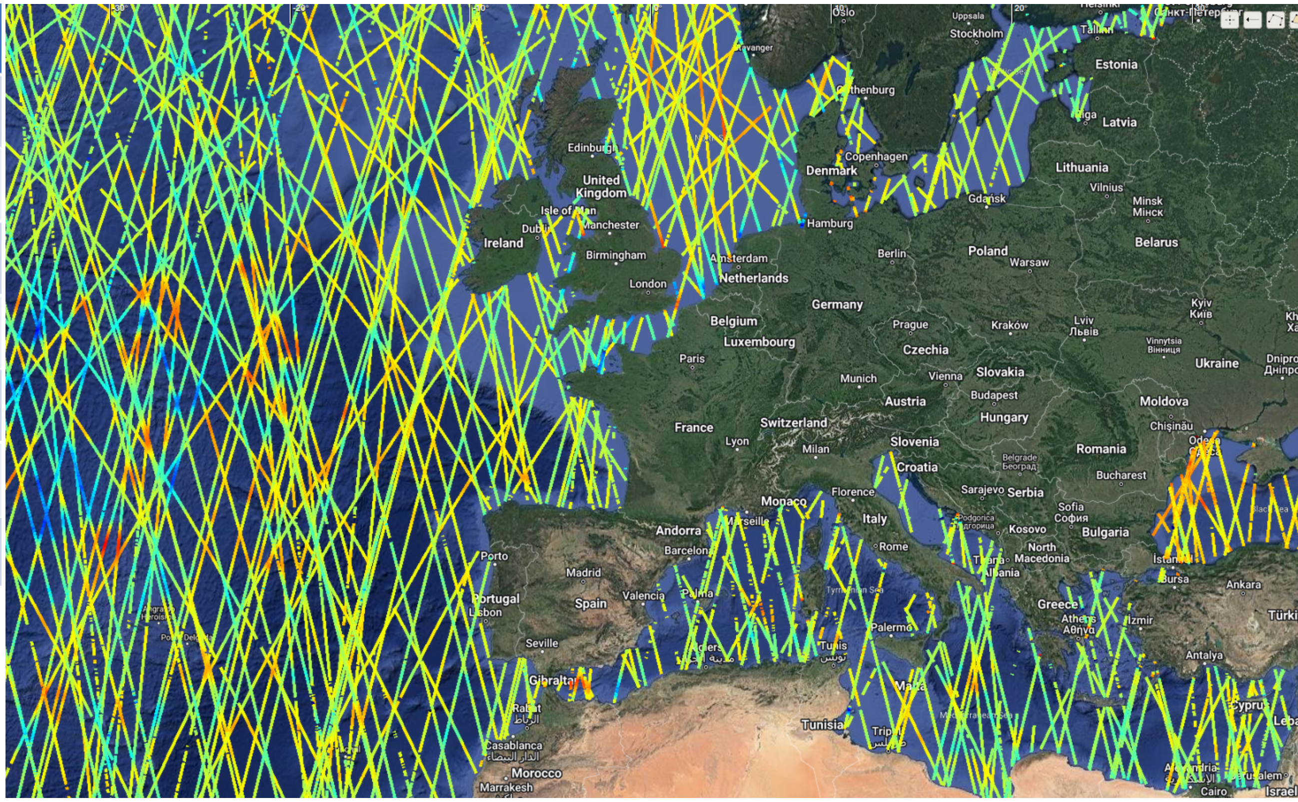
SSH simulator

L3 like already flying altimeters are simulated, posting is 6 km
The following altimeters are simulated

1-day of 6 altimeters

Altimeters	Altitude (km)	Inclination	Cycle (days)	orbits
Altika	790	98.55	35	501
Hy2a	972	99.3	14	386
Cryosat	717	92	369	5344
Jason2	1336	66.039	9.9156	127
SKIM	750	98.4	17	
S3A	814.5	98.650	27	385
S3B	interleaved with S3A (+ 0.5º, 17 days), on the same plan			



Software used to simulate data:
github.com/SWOTsimulator/swotsimulator, v4.0

ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_altimeter

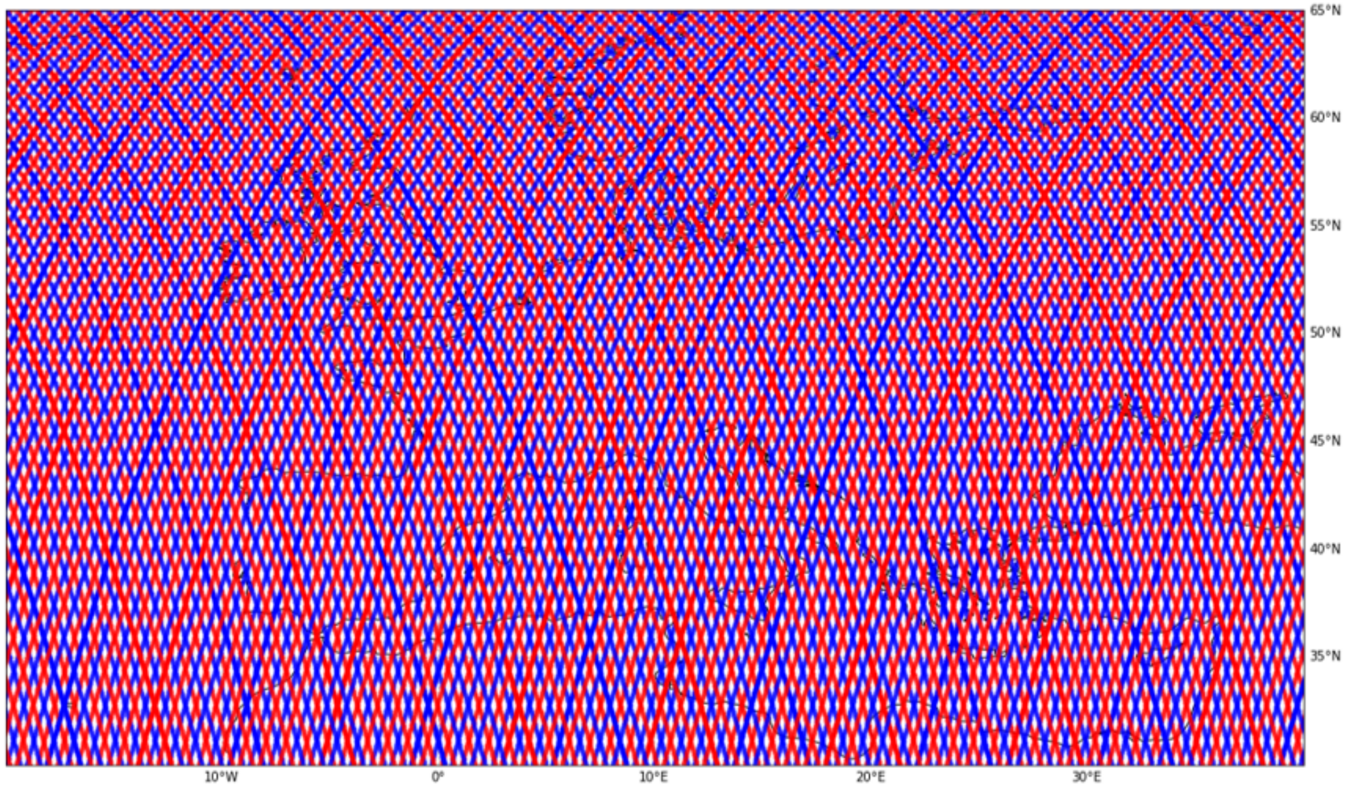
SSH simulator

L3 like altimeters are simulated, posting is 6 km

- 12 altimeters in the same orbital plane
- Orbits similar to either S3A, S3B
- Order A-A-B-B-A-A-B-B-A-A-B-B with 3.7 min between A-A or B-B, 13.1min between A-B or B-A

Altimeters	Type	Dt (min)
s3a12	A	0
s3b12	A	3.7
s3c12	B	16.8
S3d12	B	20.5
S3e12	A	33.6
S3f12	A	37.3
S3g12	B	50.4
S3h12	B	54.1
S3i12	A	67.2
S3j12	A	70.9
S3k12	B	84.0
S3l12	B	87.7

On ground track for all altimeters,
5 days coverage
Blue: S3A type
Red: S3B type



Software used to simulate data:
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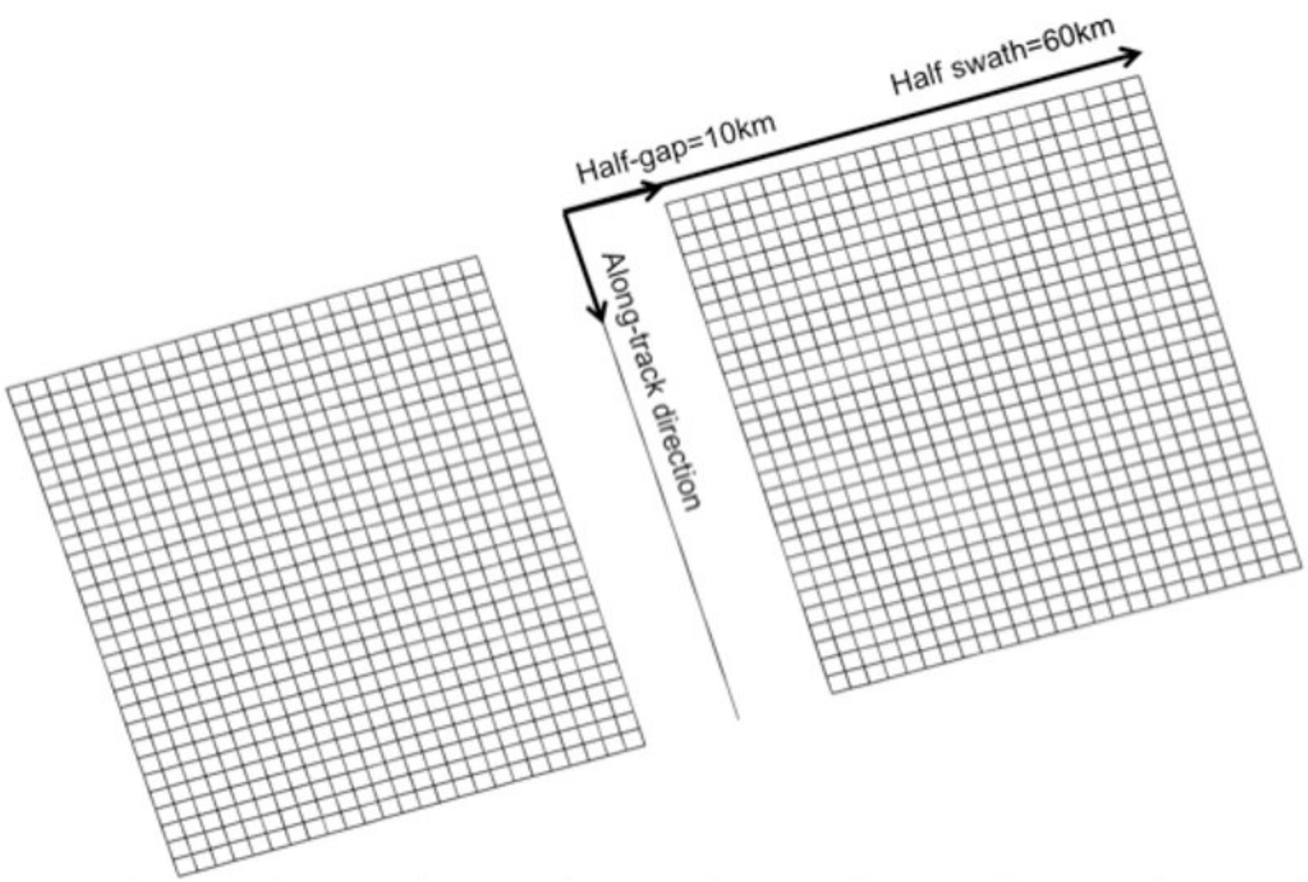
ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_altimeter

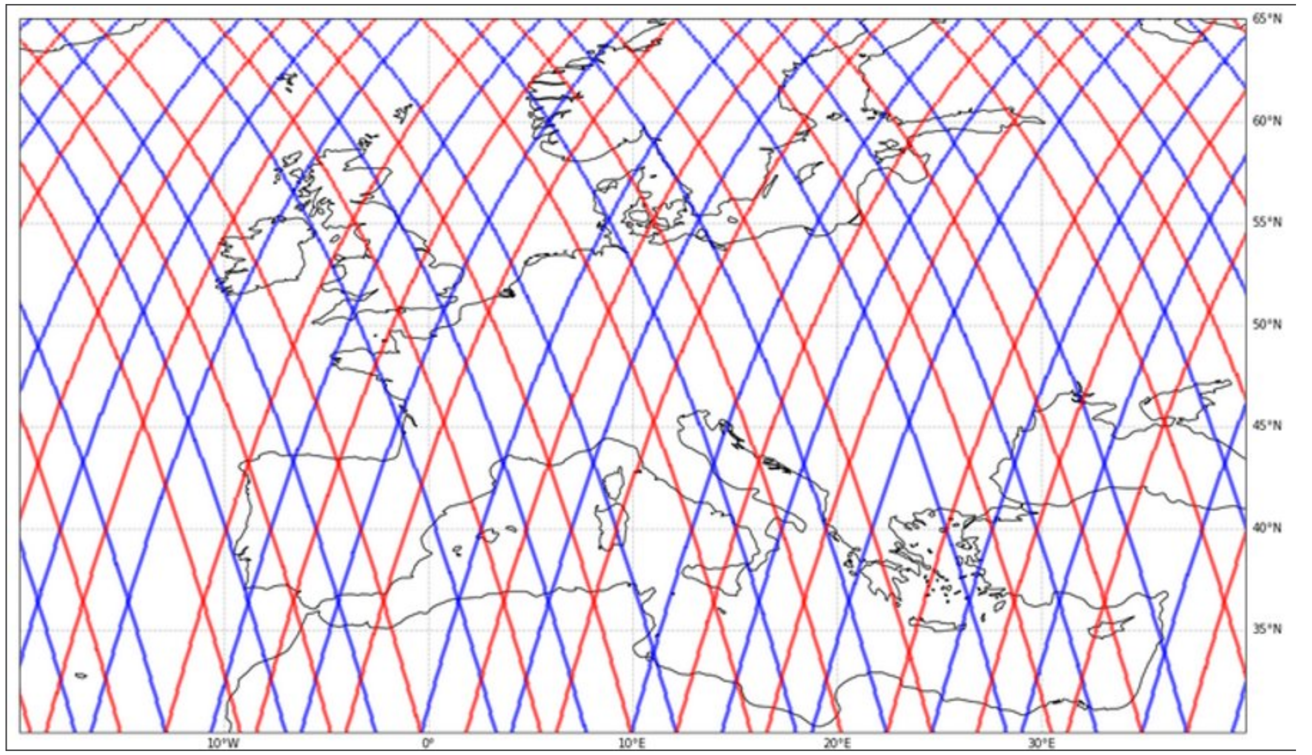
SSH simulator

L2-LR swath data are simulated, posting is 2x2 km

- 2 swath instrument in the same orbital plane
- 750 km, 17 days, 98.4º, 245 orbits
- 180º shift between two satellites, interleaved



On ground track for swath
5 days coverage
Blue: S3A type
Red: S3B type



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ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_swath/

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    preliminary study

Odysea concept: preliminary study

Difference in geometry

	SKIM concept	Odysea concept
Number of beams	6 (5 + nadir)	1
View angles	6º and 12º	~52º
Measure in range	—	20 points (+/-0.9º)
Orbit	17 days / 750 km / 98.4º	4 days / 590 km
PRF	~10 ms	varying, 0.12-> 1ms
rotation speed	3.5 tr / min	12.5 tr / min

Difference in noise:
Statistical noise as a function of the wind and the azimuth angle

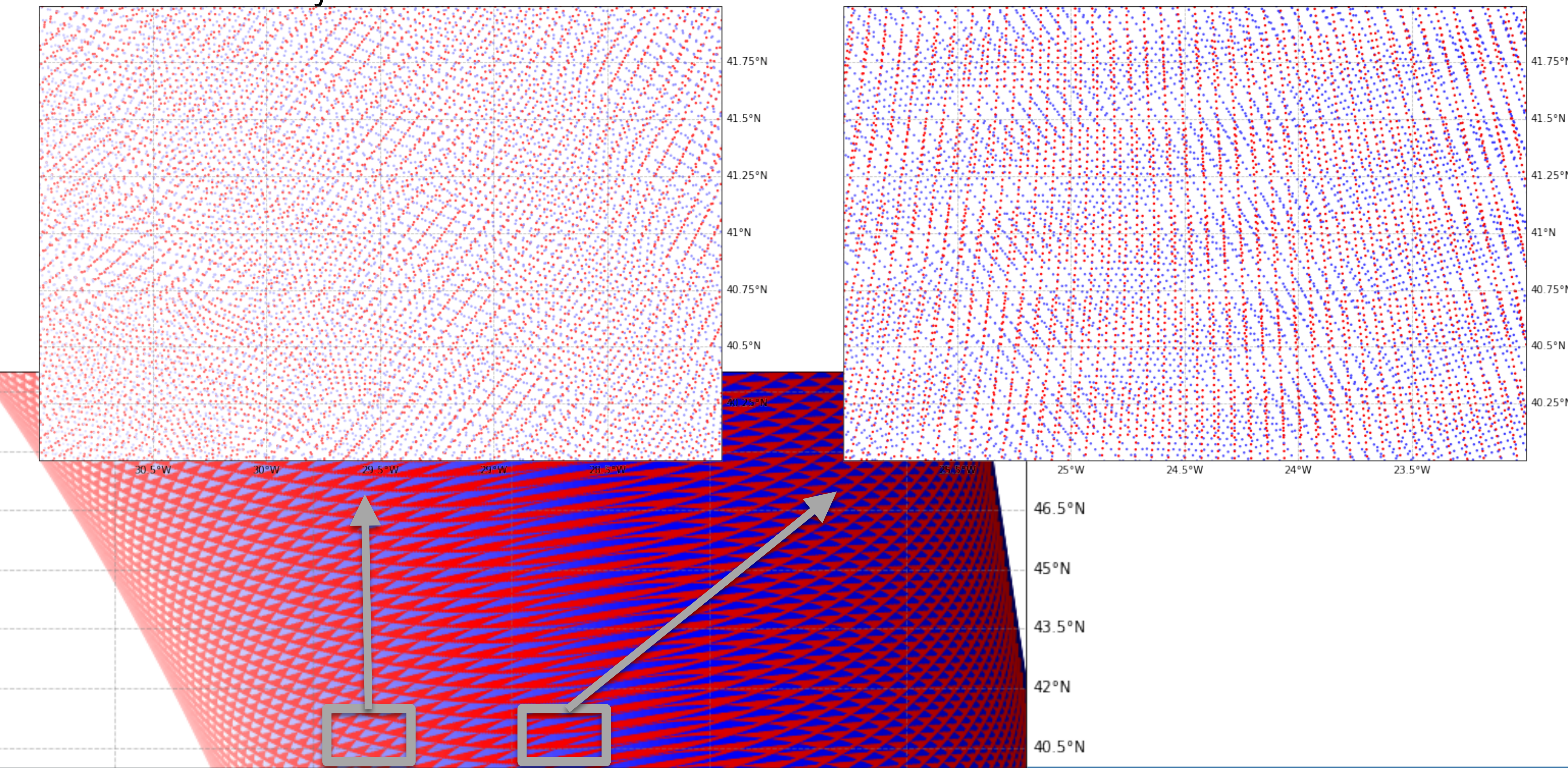
- SKIMulator adapted to simulated L2B / L2C: https://github.com/oceandatalab/skimulator
- L2C light simulator (JPL): https://github.com/awineteer/odysea-science-simulator

Odysea experiments

Odysea: Geometry L2b

- Many more data points that for the SKIM concept, more difficult to handle L2B
- limited diversity of angle in part of the swath
- Possible asymmetrical noise with fore and aft view

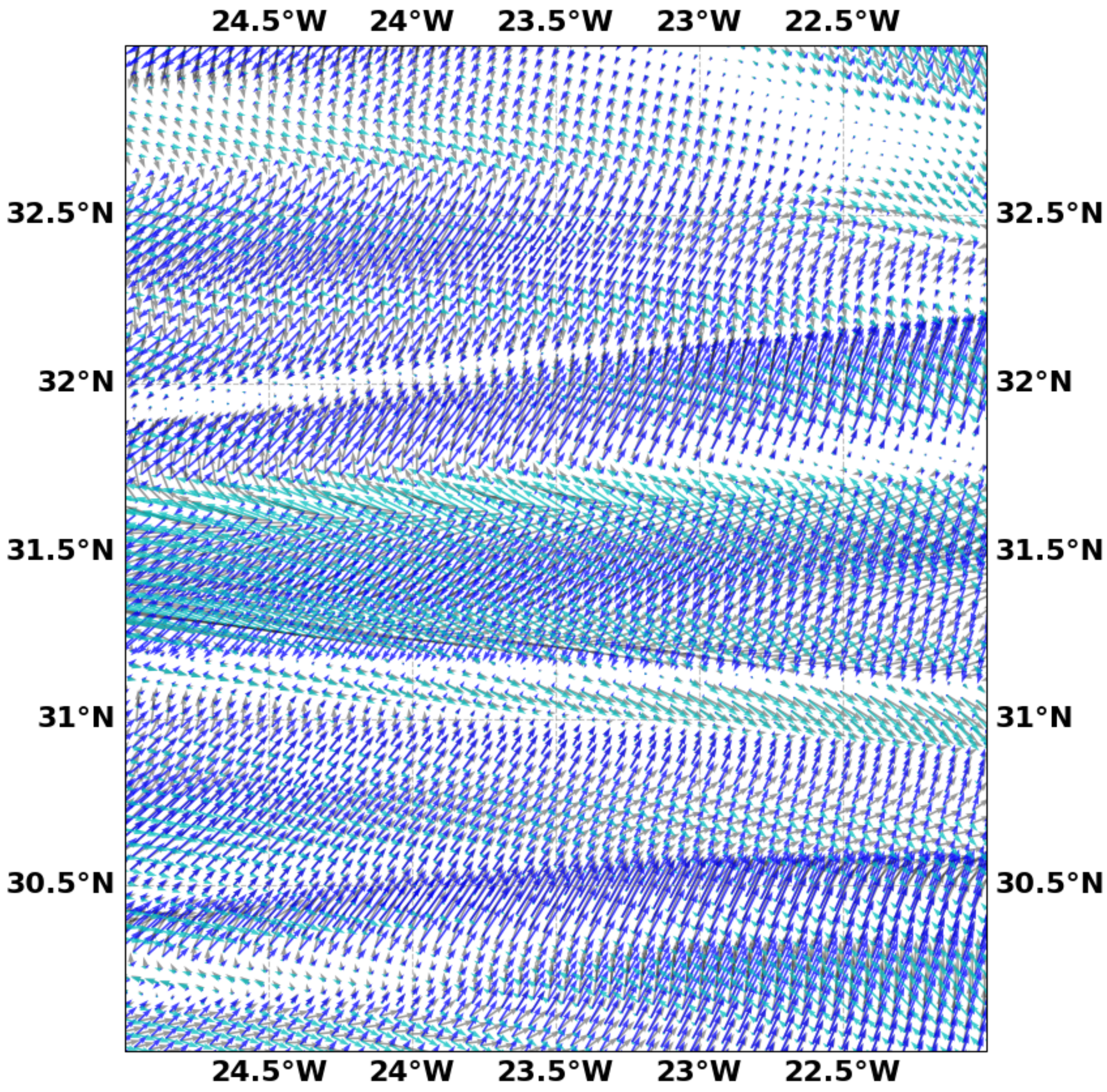
  => Study the reconstruction of L2B



Odysea experiments

Odysea: L2C swath simulation, 5kmx5km cell grid, different type of products have been generated:

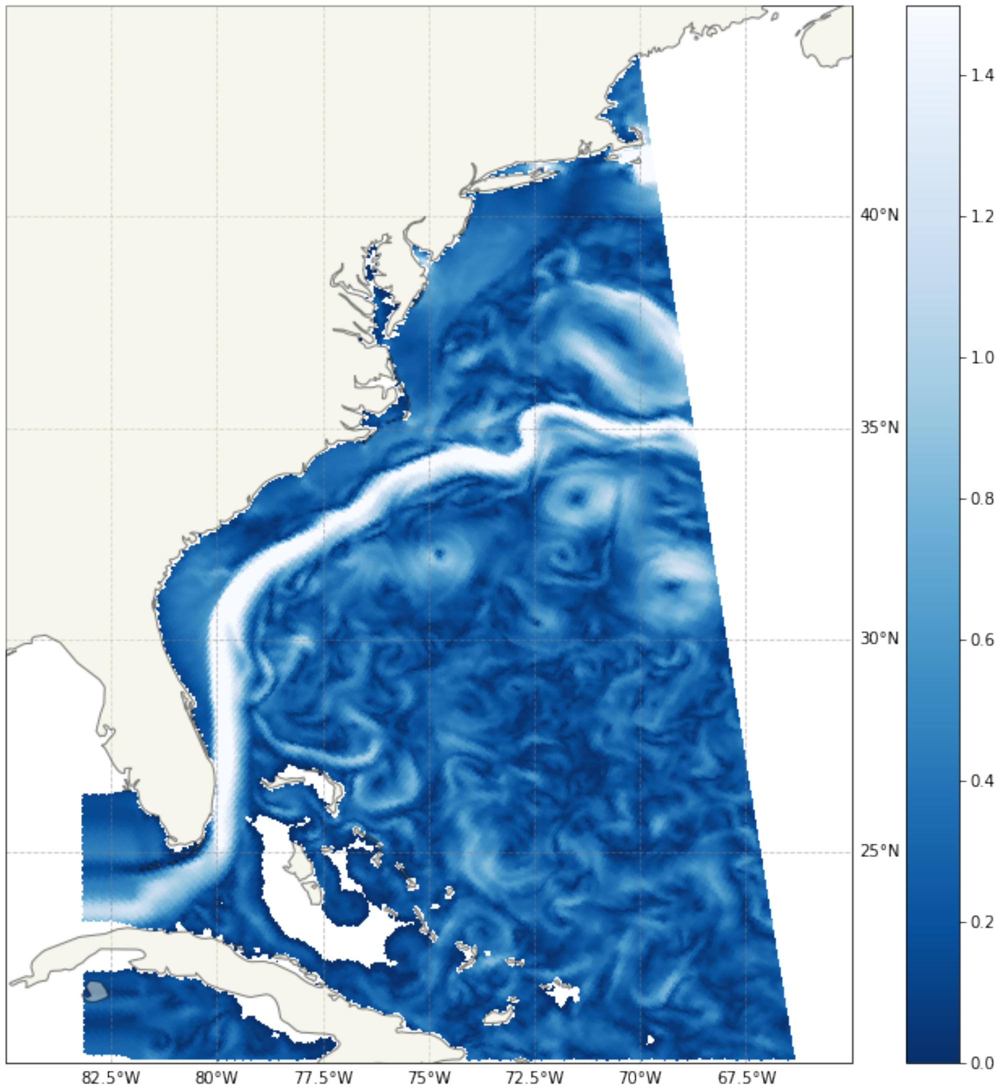
- Direct Simulation of 2D current using JPL simulator (simulation of the noise on u and v on the point of the swath)
- Simulation of fore and aft radial velocity in each point of the swath
- Mapping of current using OI algorithm with L2B points



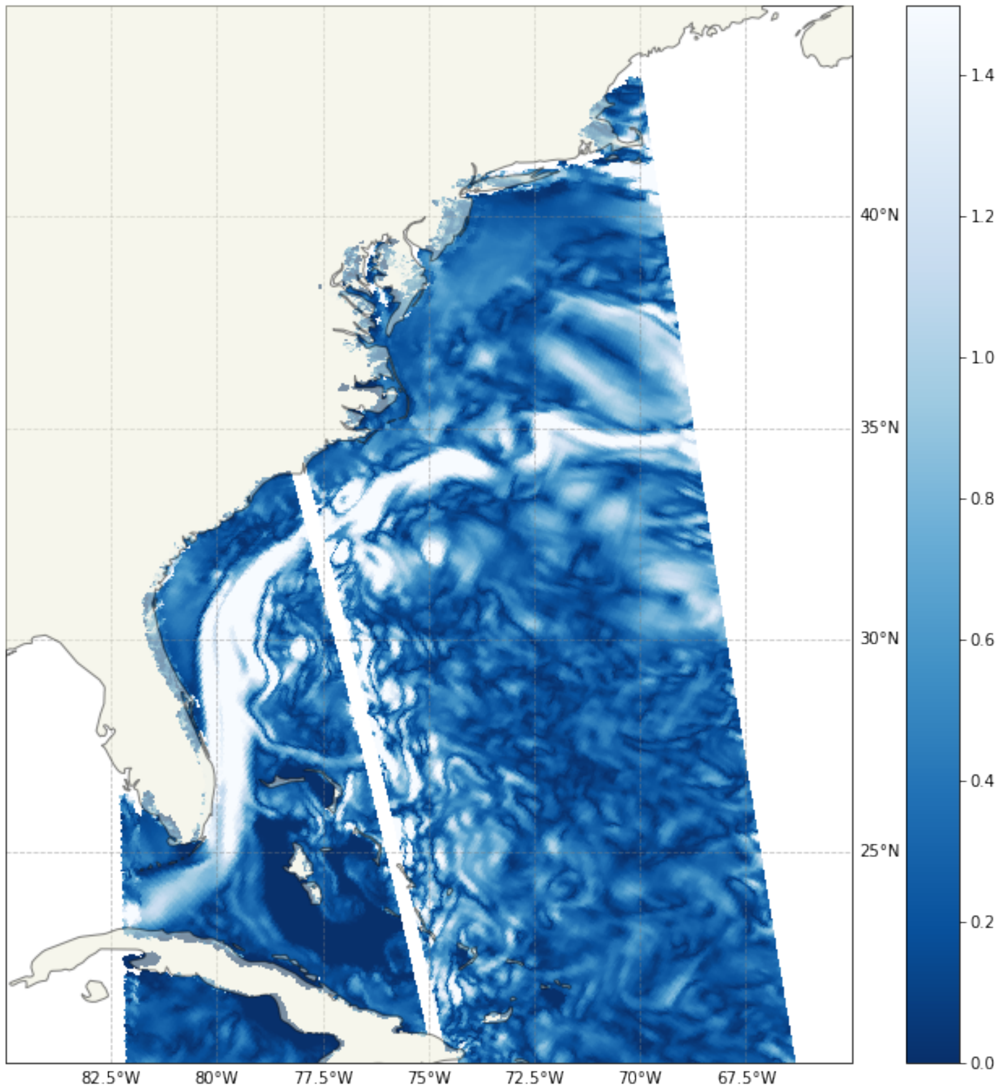
Odysea experiments

Odysea: L2C, first test of OI mapping, using algorithm similar to SKIM

Odysea: L2C, true velocity



Odysea: L2C reconstructiom



Summary of all available data

- Existing altimeter + SKIM Nadir: - Altika -Hy2A -SKIM
  - Cryosat2 - S3A
  - Jason - S3B

  ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_altimeter

- 12 Nadir Altimeters constellation: - s3a12 - s3d12 - s3g12 - s3j12
  - s3b12 - s3e12 - s3h12 - s3k12
  - s3c12 - s3f12 - s3i12 - s3l12

  ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_altimeter

- Swath altimeter data: - swath A - swath B

  ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_swath/

- SKIMulator L2b

  ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_skimulator/WW3_GL_skim_atscv

- SKIMulator L2c:
  - 20km gaussian filtering
  - 40 km gaussian filtering
  - 60 km gaussian filtering

  ftp.ifremer.fr:/ifremer/ww3/PROJECT/SKIM/output_skimulator/WW3_GL_skim_atscv

Summary

- A lot of data have been simulated during the project: with light and fast simulator, one year of global satellite observations have been generated. Potential for studying the benefit of different kind of sensors

- Different Datasets are available for different satellites and have been used :
  - altimeters
  - swath instrument
  - SKIM-like
  - Odysea-like (produced, not public yet)

- The different simulator that have been used are publicly available on GitHub and coded in python 3
  - Altimeter / swath: SWOT-simulator: https://github.com/oceandatalab/skimulator
  - L2b / L2c for SKIM-like and Odysea like data: SKIMulator: https://github.com/oceandatalab/skimulator
  - L2c for Odysea like data: https://github.com/awineteer/odysea-science-simulator

- If interested in simulators or simulated data, you can contact me: lucile.gaultier@oceandatalab.com