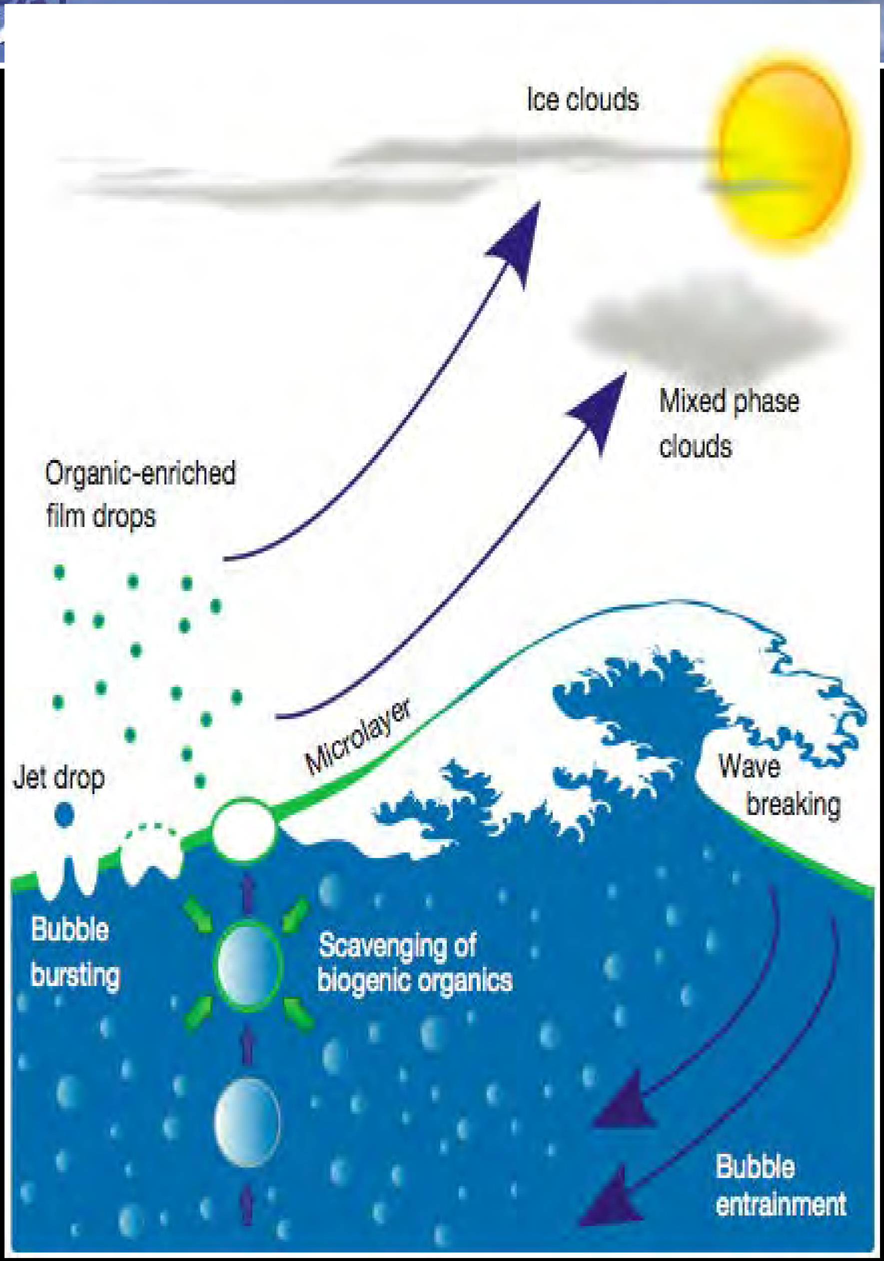
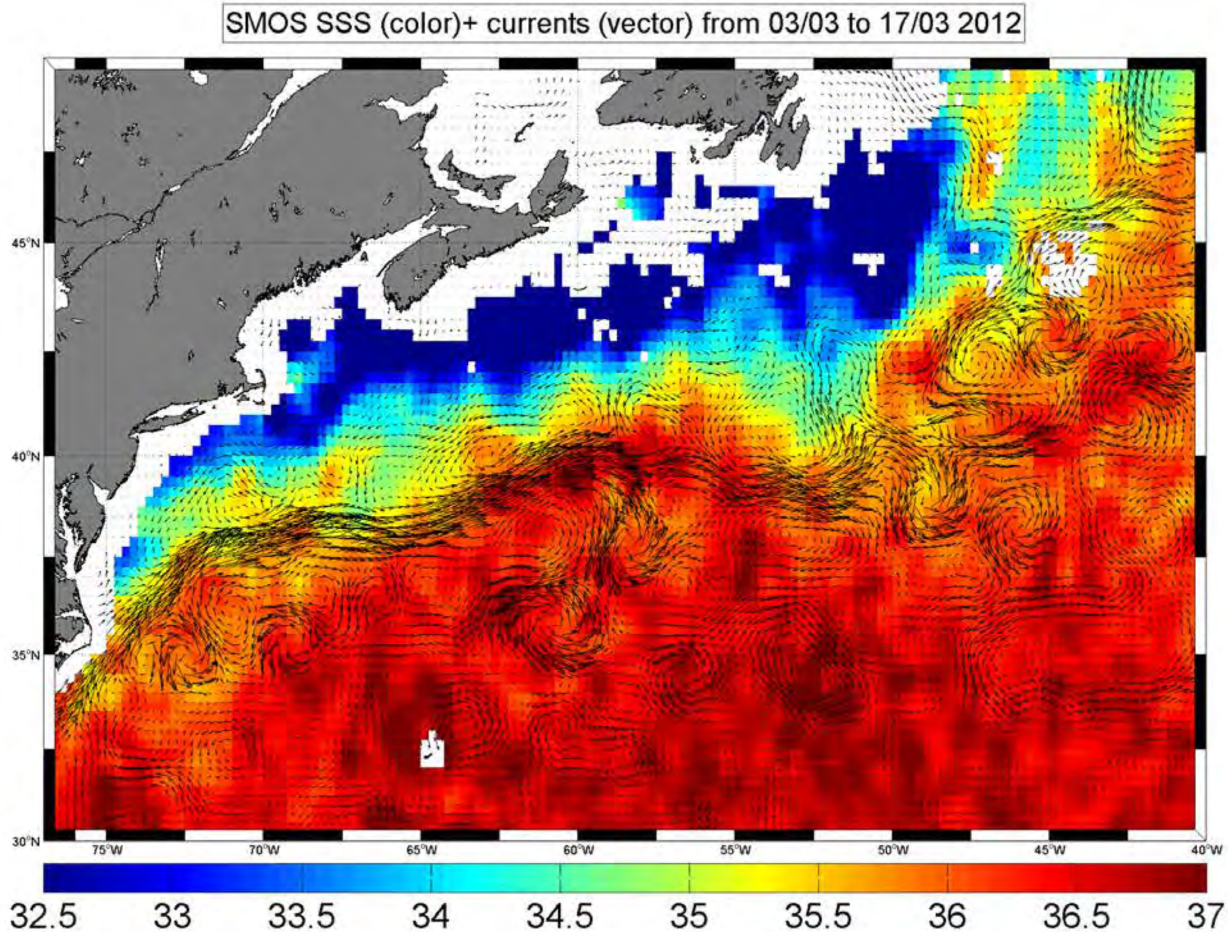
- … most observations are not yet sufficiently explored and used

Synergy between high resolution observations to reveal mean states and trends, near-surface ocean-atmosphere dynamics, local and non-local interactions, convergence/divergence surface fronts and numerous roughness contrasts

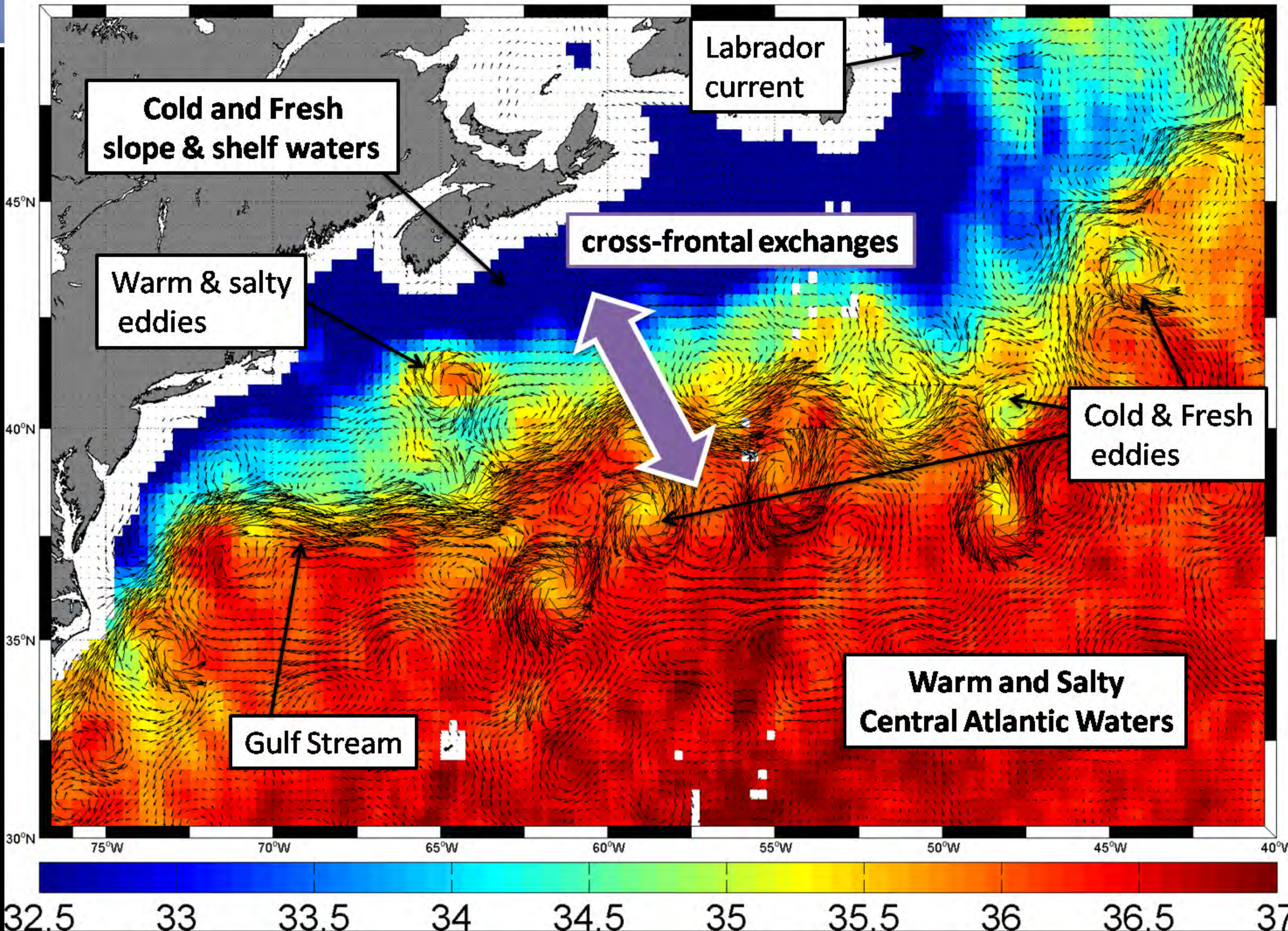
Far from the coasts, Extreme Events are opportunities of high scientific values to investigate how natural processes at their peaks can transfer energy and matter within and across boundaries, and to identify the mechanisms involved and their rates, jointly with their local and/or long term impacts



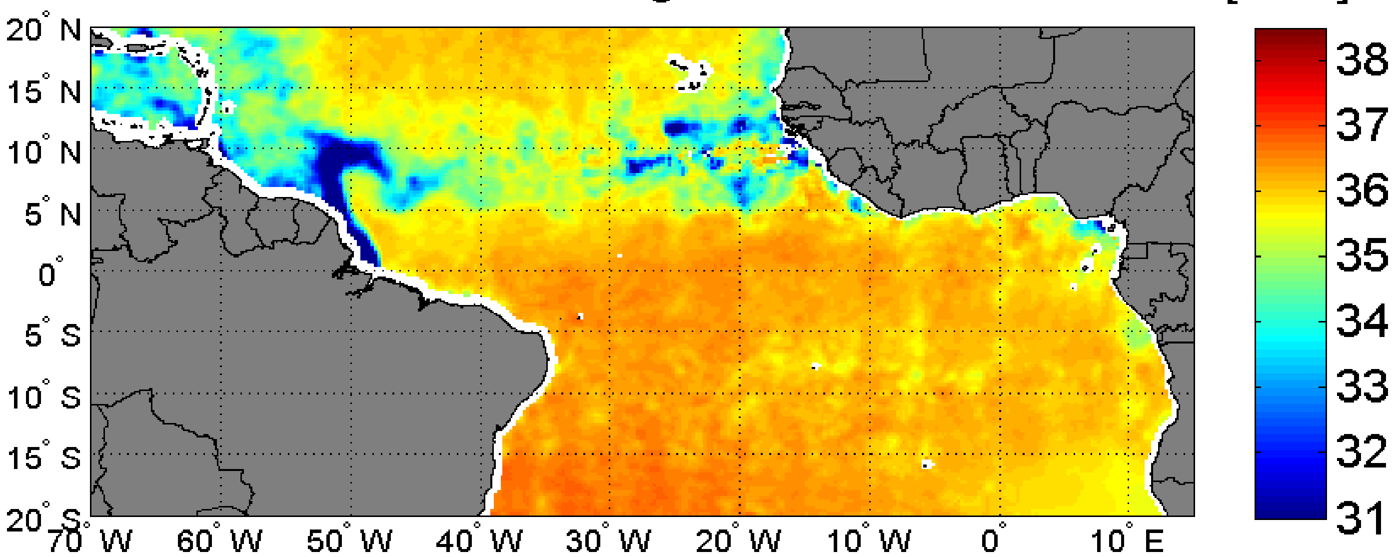
Sea-spray aerosol particles enriched in organic material are possibly generated when the air-sea interface is bursting


SMOS SSS (color)+ currents (vector) from 03/03 to 17/03 2012
45°N
40°N
35°N
30°N
75°W
70°W
65°W
60°W
55°W
50°W
45°W
40°W
32.5
33
33.5
34
34.5
35
35.5
36
36.5
37

SMOS SSS (color)+ currents (vector) from 04/06 to 18/06 2012

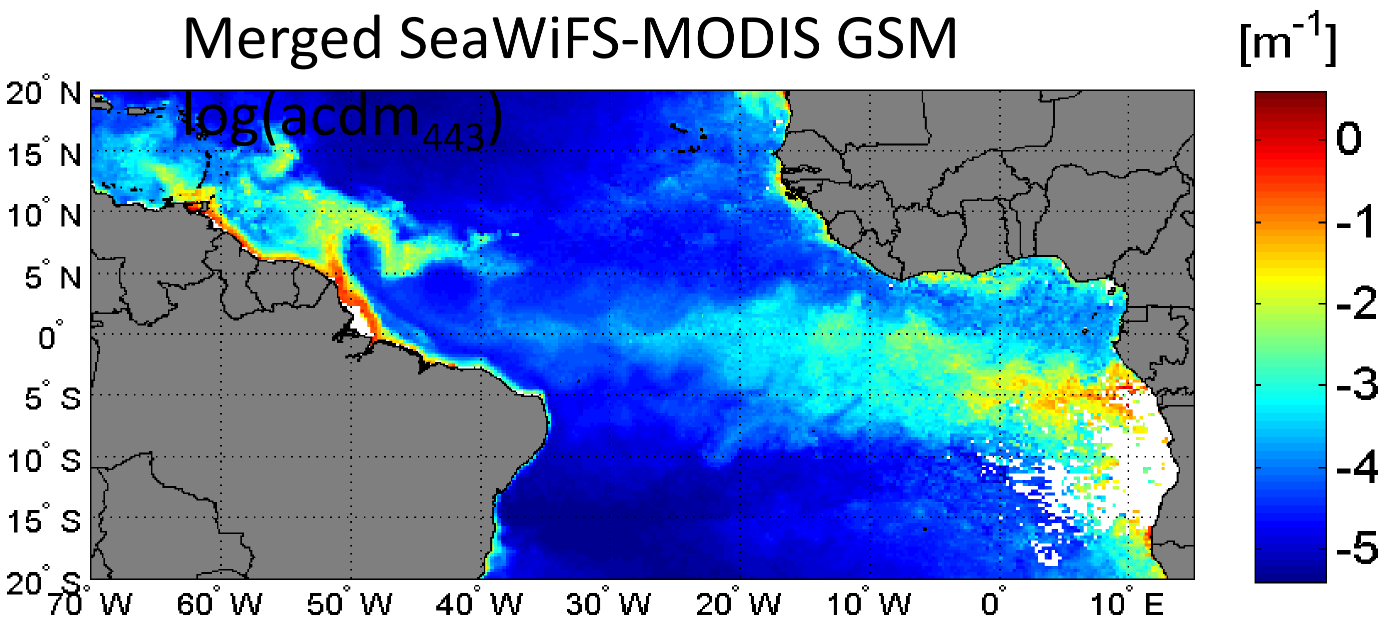


AMSR-E August 2004

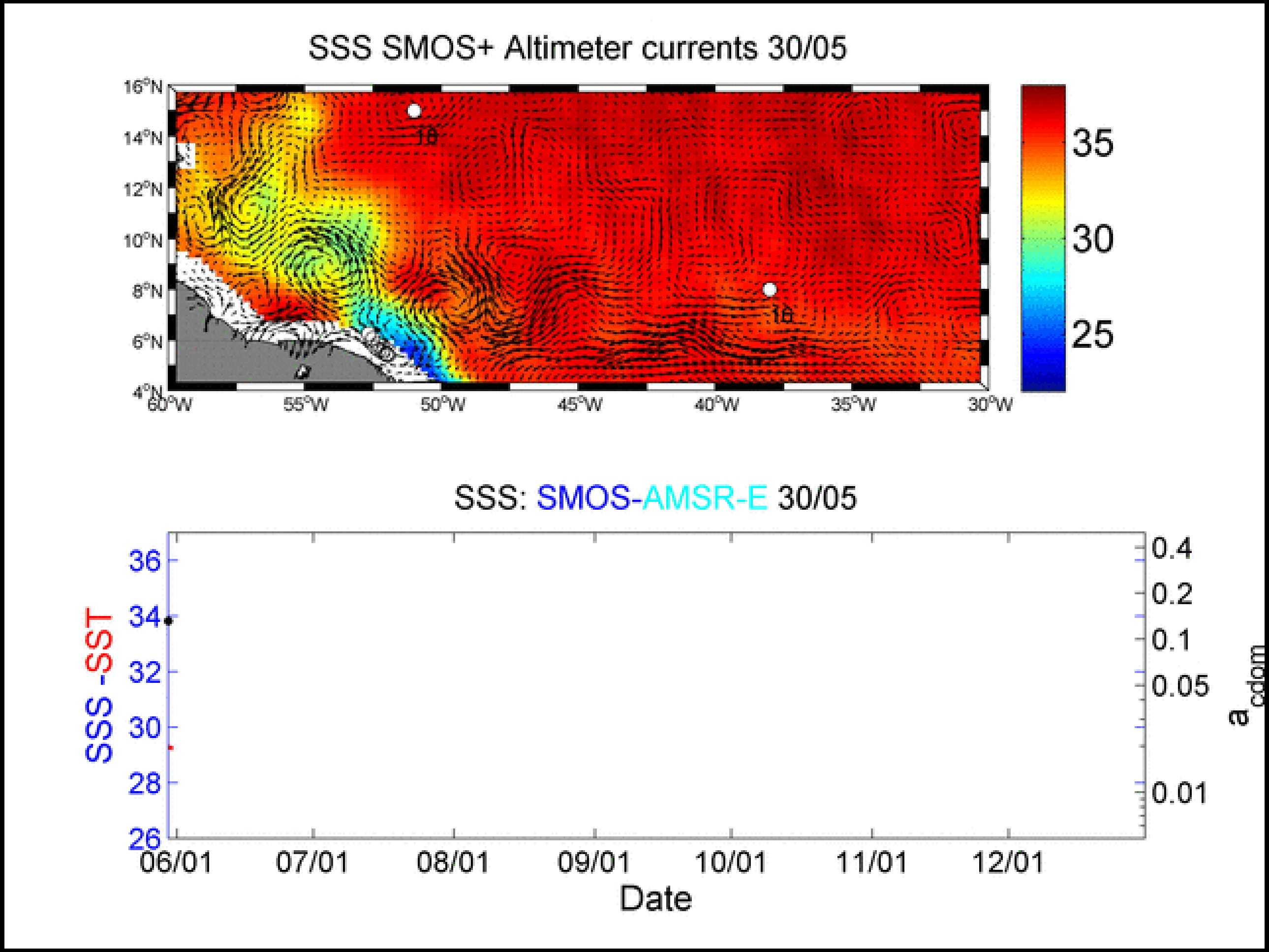


Merged SeaWiFS-MODIS GSM

log($acdm_{443}$)

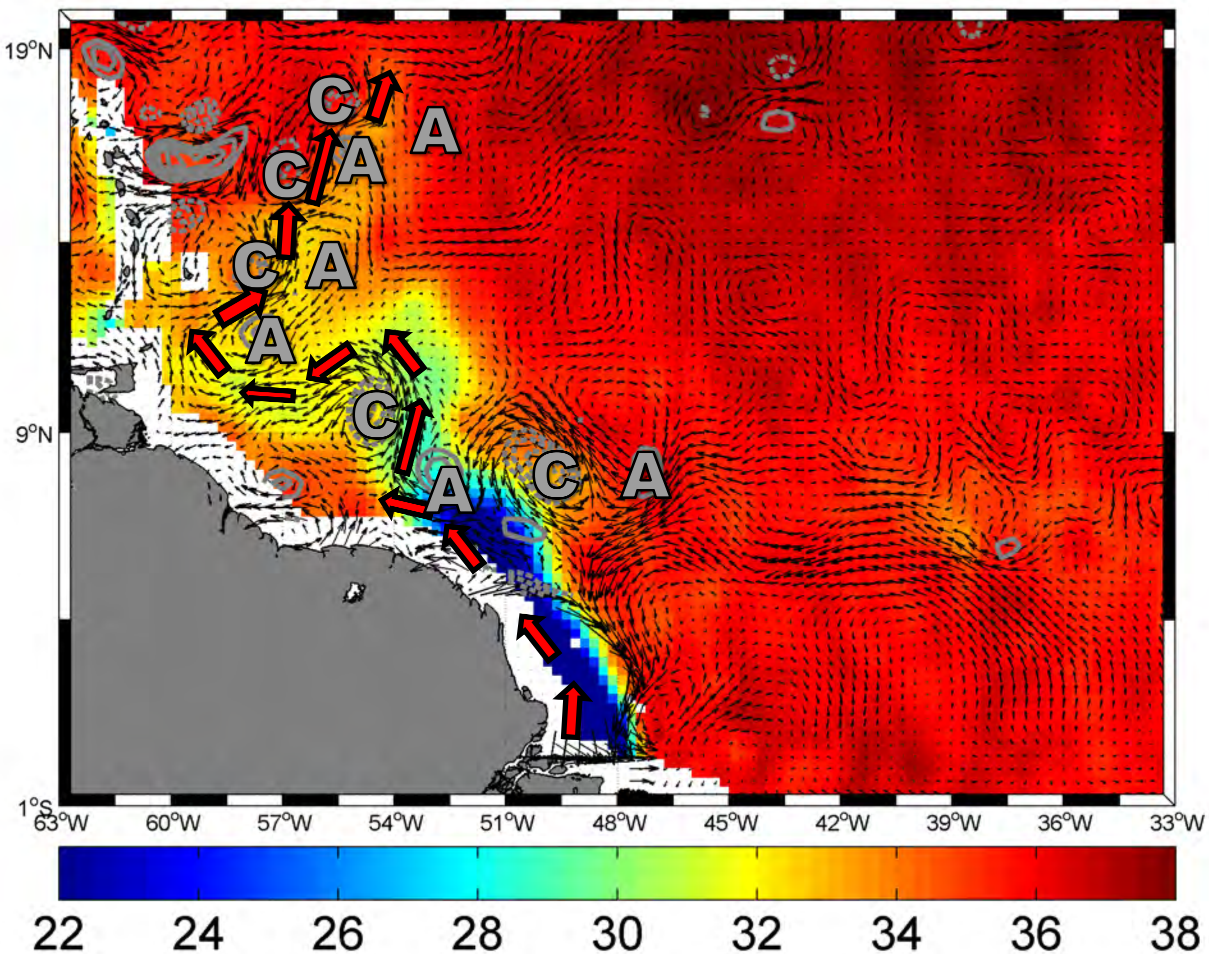


Synergy SSS (SMOS+AMSR-E)+Altimeter-derived surface currents +SST (GHRSST)+ Ocean Colour (CDOM MERIS/MODIS)



Lagangian Optical-Physical properties

SSS Averaged from Jun 04 through Jun 14



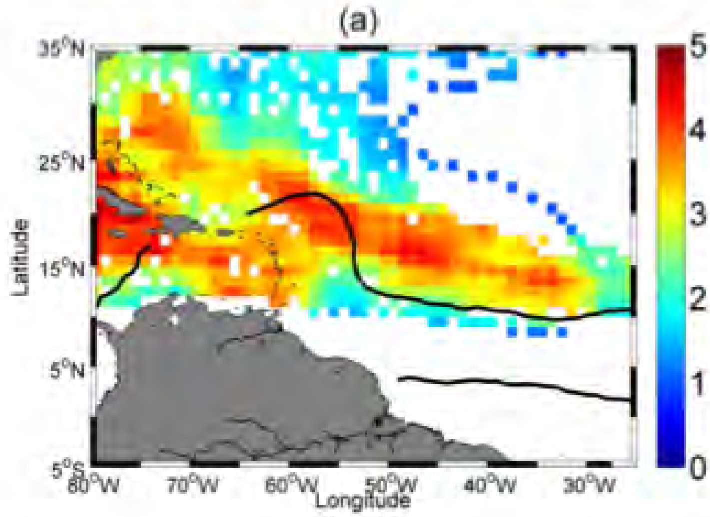
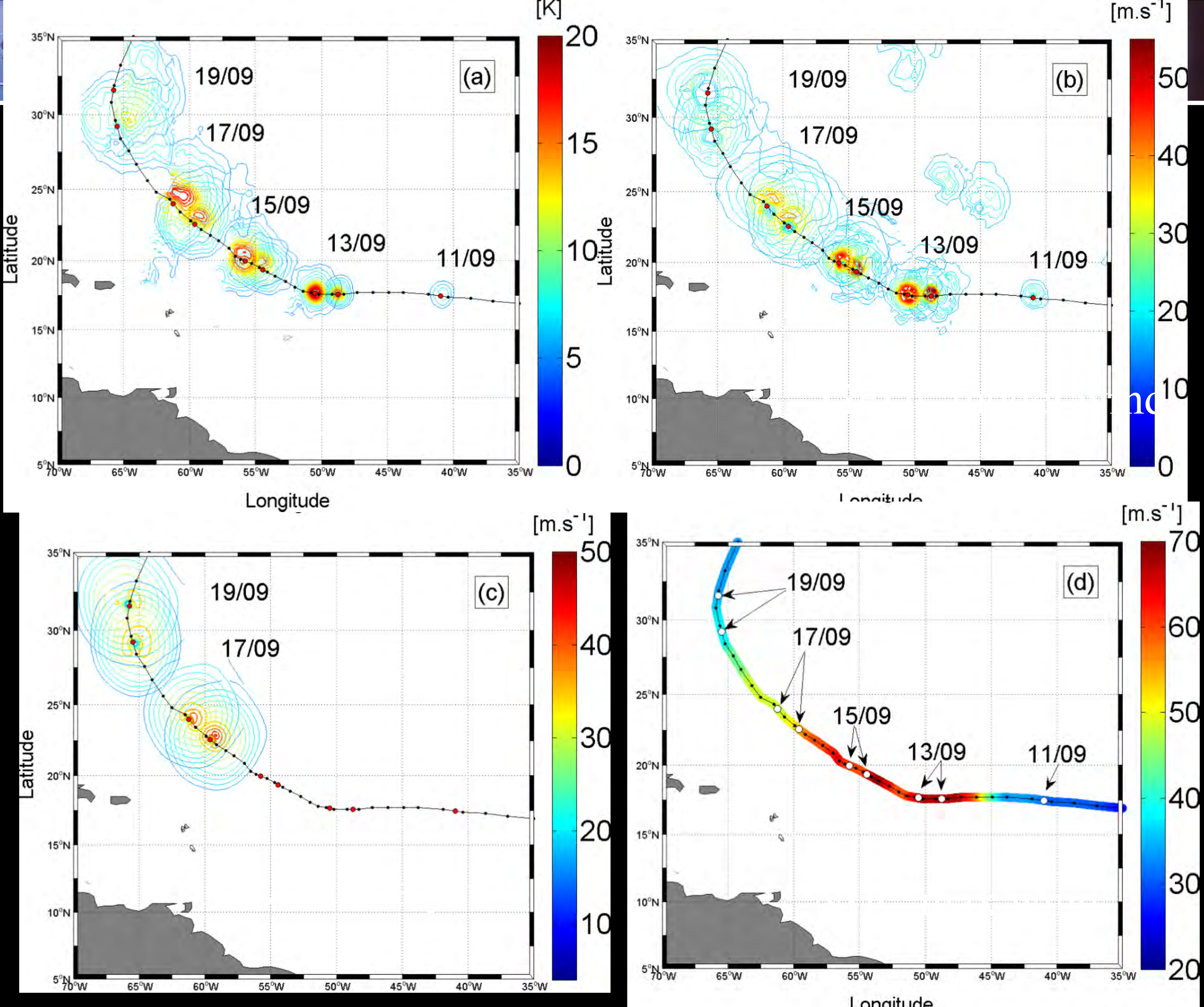
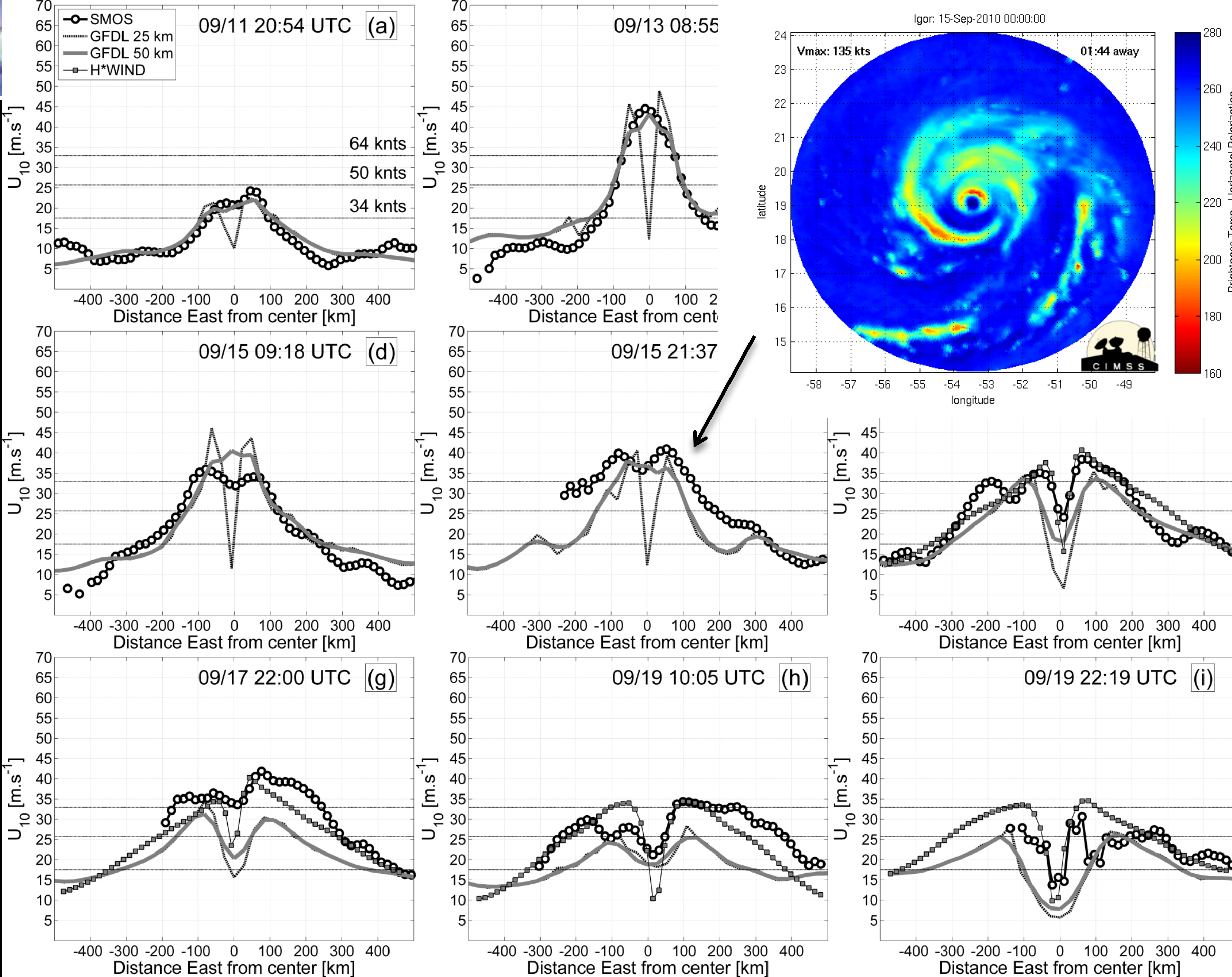


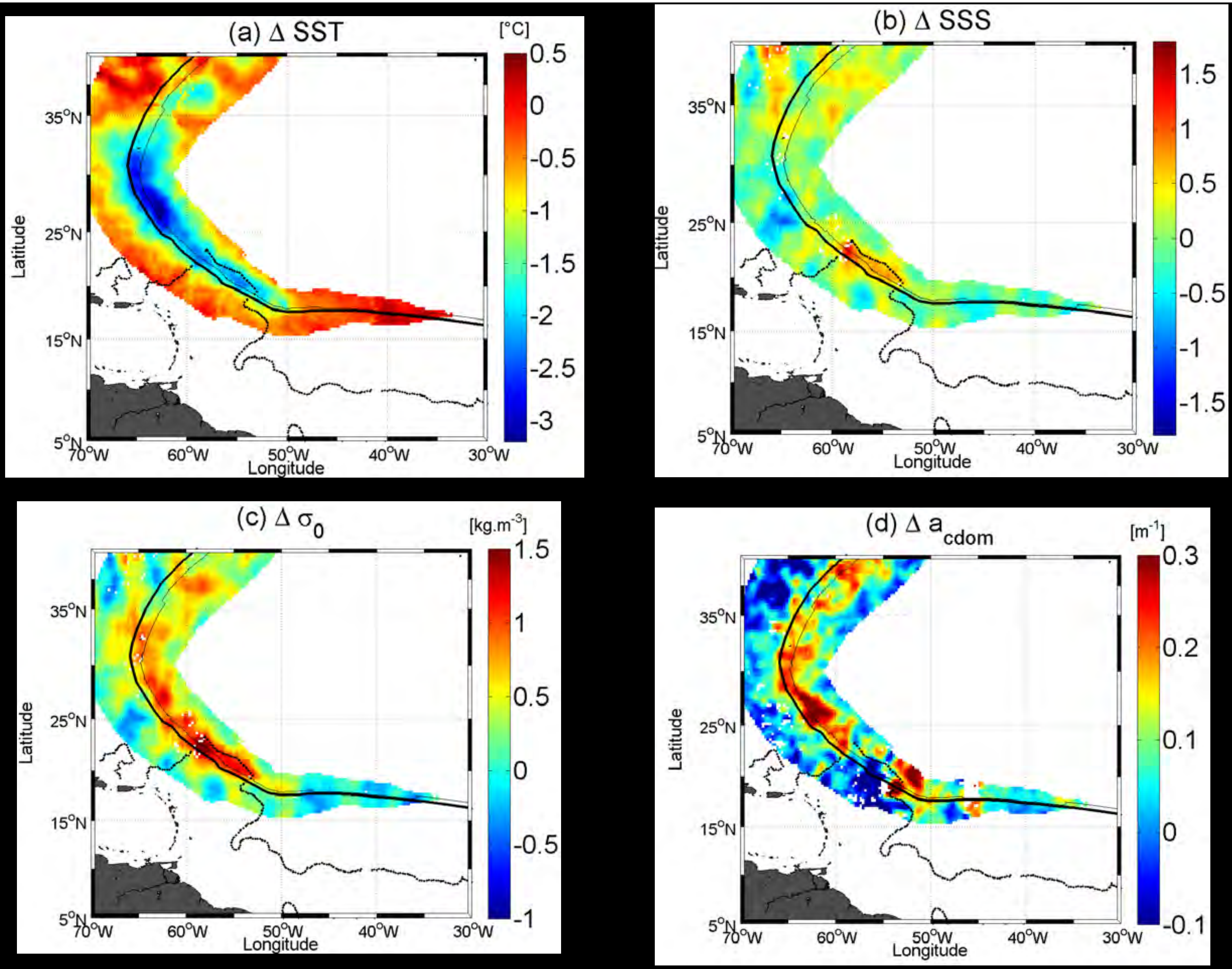
FIG.2 The number of 1950 through 2010 "best track" TC per one degree square (smoothed by a 3° x 3° block average) (a) that evolves as Cat 4-5 somewhere along their path and (b) that intensified locally to Cat 4-5. The black curve is showing the historical extent of the Amazon-Orinoco river plume during the hurricane peak season (August to October).



(a)
[K]
19/09
17/09
15/09
13/09
11/09
Latitude
Longitude
(b)
[m.s-1]
19/09
17/09
15/09
13/09
11/09
Latitude
Longitude
(c)
[m.s-1]
19/09
17/09
Latitude
(d)
[m.s-1]
19/09
17/09
15/09
13/09
11/09
Longitude


SMOS
GFDL 25 km
GFDL 50 km
H*WIND
09/11 20:54 UTC
(a)
64 knts
50 knts
34 knts
09/13 08:55
09/15 09:18 UTC
(d)
09/15 21:37
09/17 22:00 UTC
(g)
09/19 10:05 UTC
(h)
09/19 22:19 UTC
(i)
U10 [m.s-1]
Distance East from center [km]
Igor: 15-Sep-2010 00:00:00
Vmax: 135 kts
01:44 away
latitude
longitude
Brightness Temp - Horizontal Polarization
CIMSS

Surface wakes of Igor



Surface area~ 89000 km^2> Lake Superior, the world largest freshwater lake: a transfer of 1 GTo of Salt in 5 days

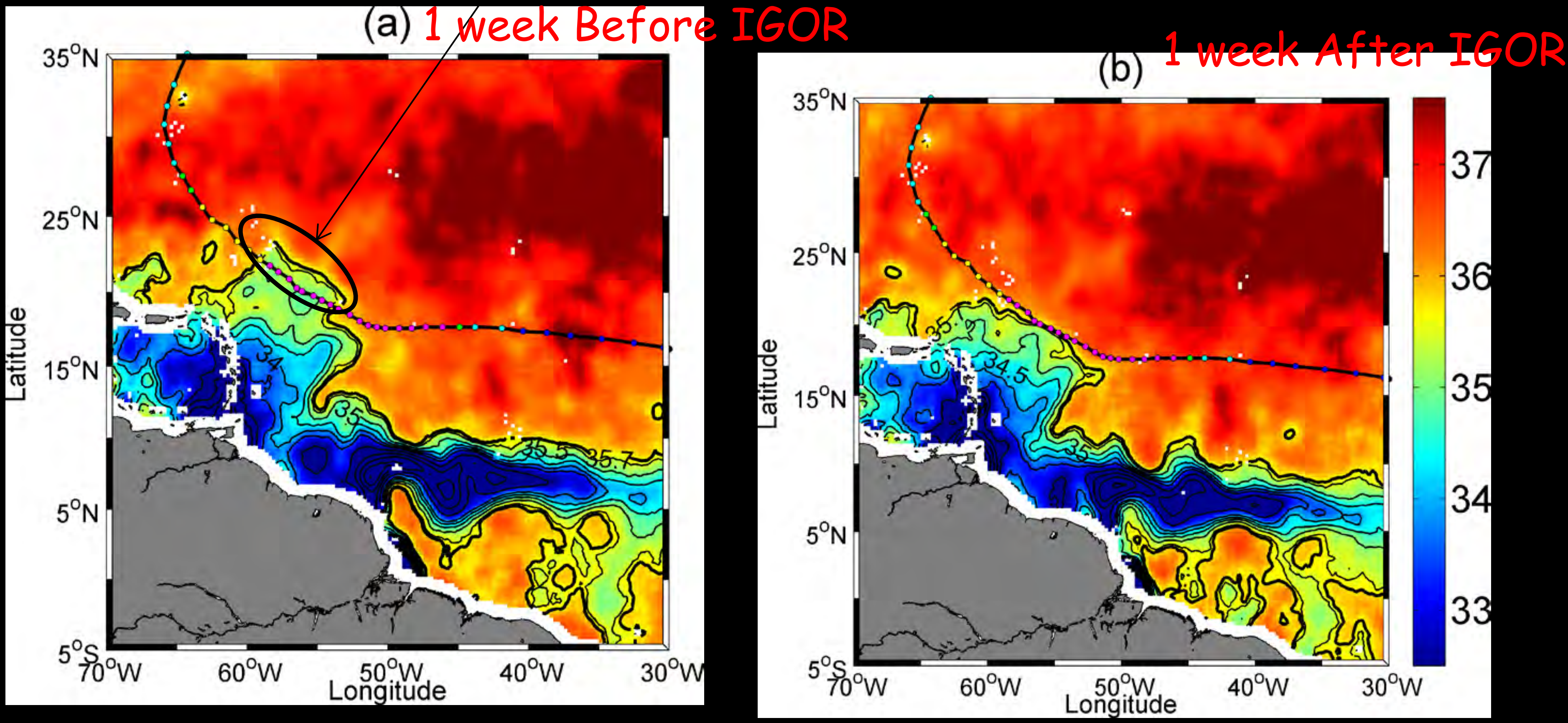
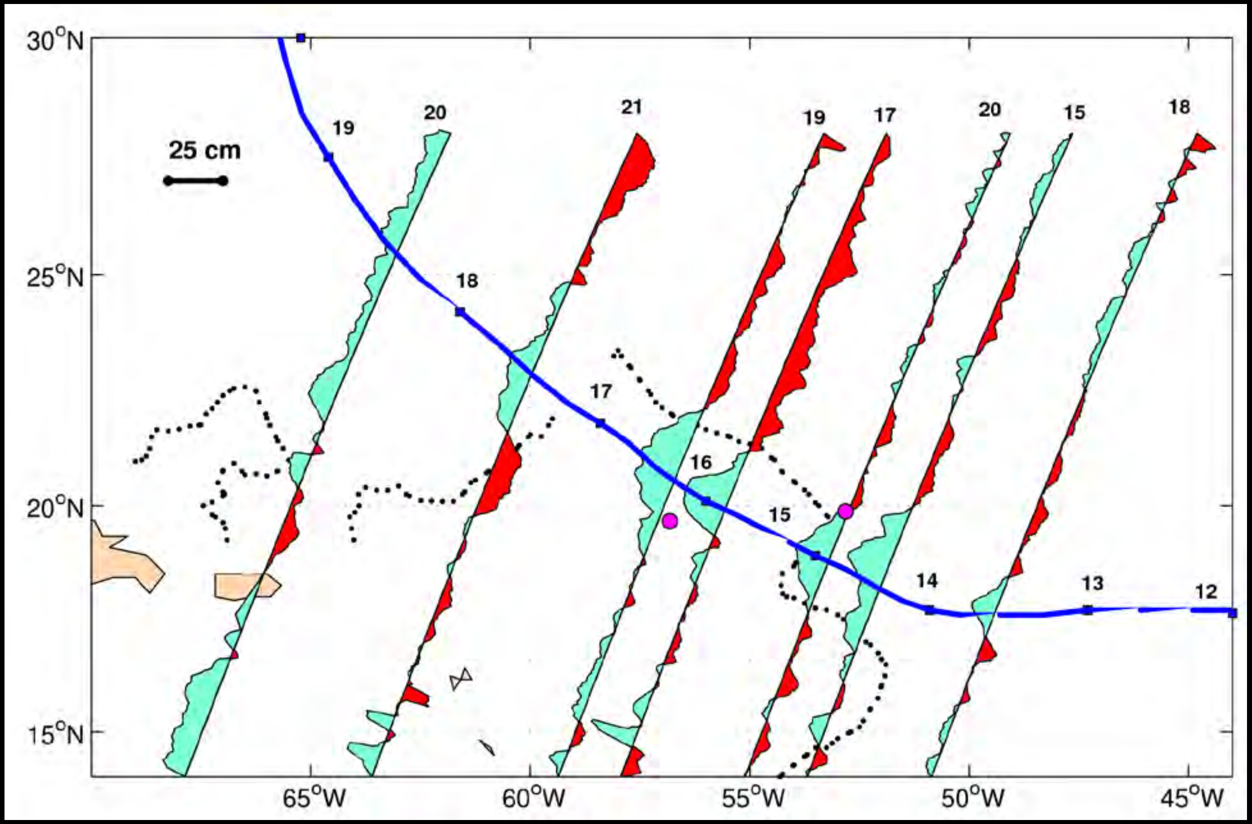
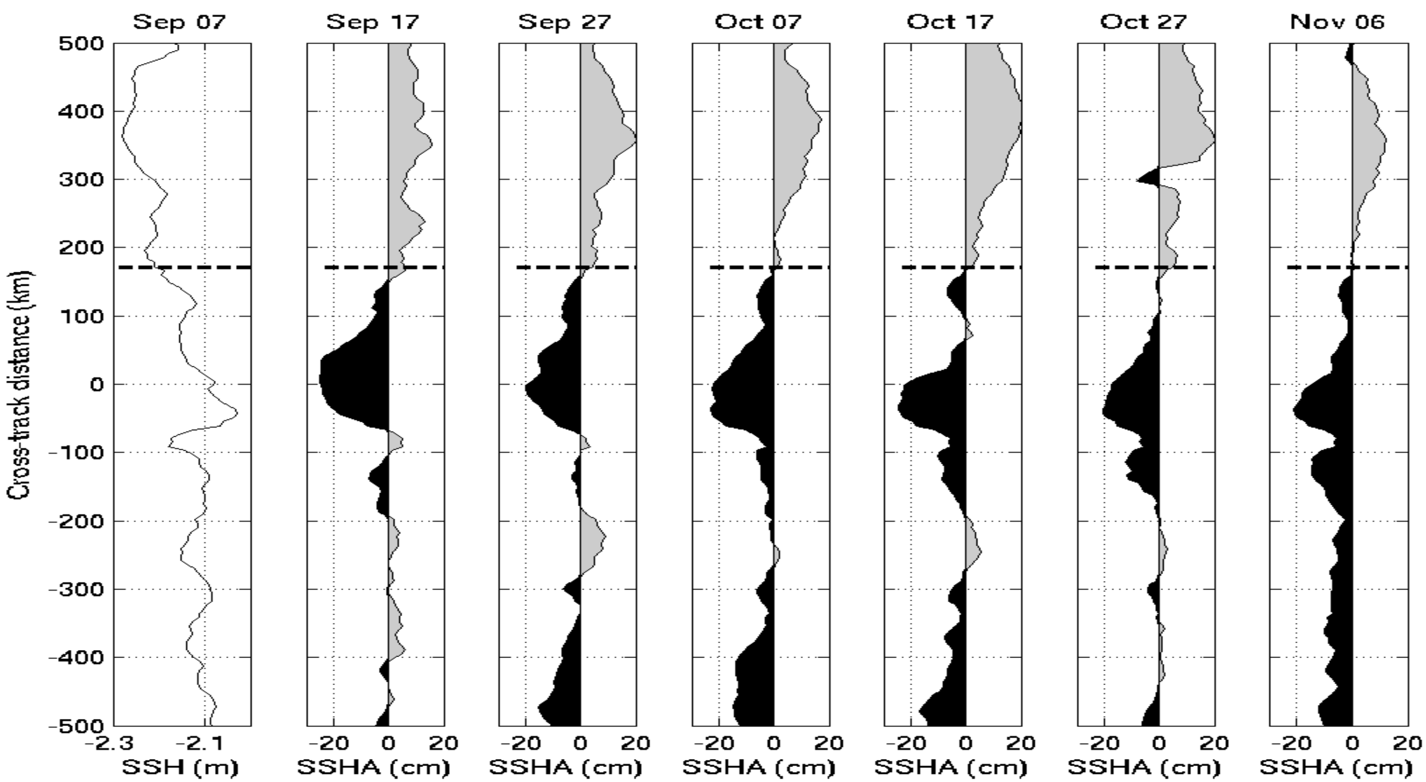
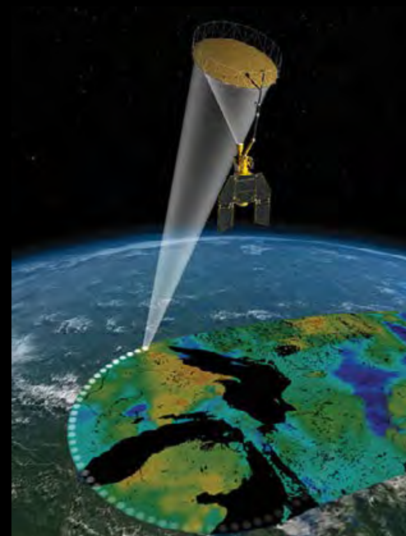


Figure 2: Two SMOS microwave satellite-derived SSS composite images of the Amazon plume region revealing the SSS conditions (a) before and (b) after the passing of Hurricane Igor, a category 5 hurricane that attained wind speeds of 136 knots in September 2010. Color-coded circles mark the successive hurricane eye positions and maximum 1-min sustained wind speed values in knots.
Seven days of data centered on (a) 10 Sep 2010 and (b) 22 Sep 2010 have been averaged to construct the SSS images, which are smoothed by a 1° x 1° block average.


30°N
25°N
20°N
15°N
65°W
60°W
55°W
50°W
45°W
25 cm
19
20
21
19
17
20
15
18
18
17
16
15
14
13
12


Sep 07
Sep 17
Sep 27
Oct 07
Oct 17
Oct 27
Nov 06
Cross-track distance (km)
500
400
300
200
100
0
-100
-200
-300
-400
-500
-2.3
-2.1
SSH (m)
-20 0 20
SSHA (cm)

Three Low-frequency Microwave radiometers enhancing High Wind Speed ocean Surface monitoring capabilities from Space



SMOS-ESA

Interferometric Radiometer
Frequency: 1.4 GHz L-band
Spatial Resolution: ~43 kms
Swath Width: ~1000 kms
Revisit time Equator: ~3 days
Incidence angles: 10° -60°
Fully polarimetric
Launched Nov 2009

SMAP-NASA

Real Aperture Radiometer
Frequency: 1.4 GHz L-band
Spatial Resolution: ~30 kms
Swath Width: ~1000 kms
Revisit time Equator: ~3 days
Incidence angle: 40°
Fully polarimetric
Launched Jan 2015

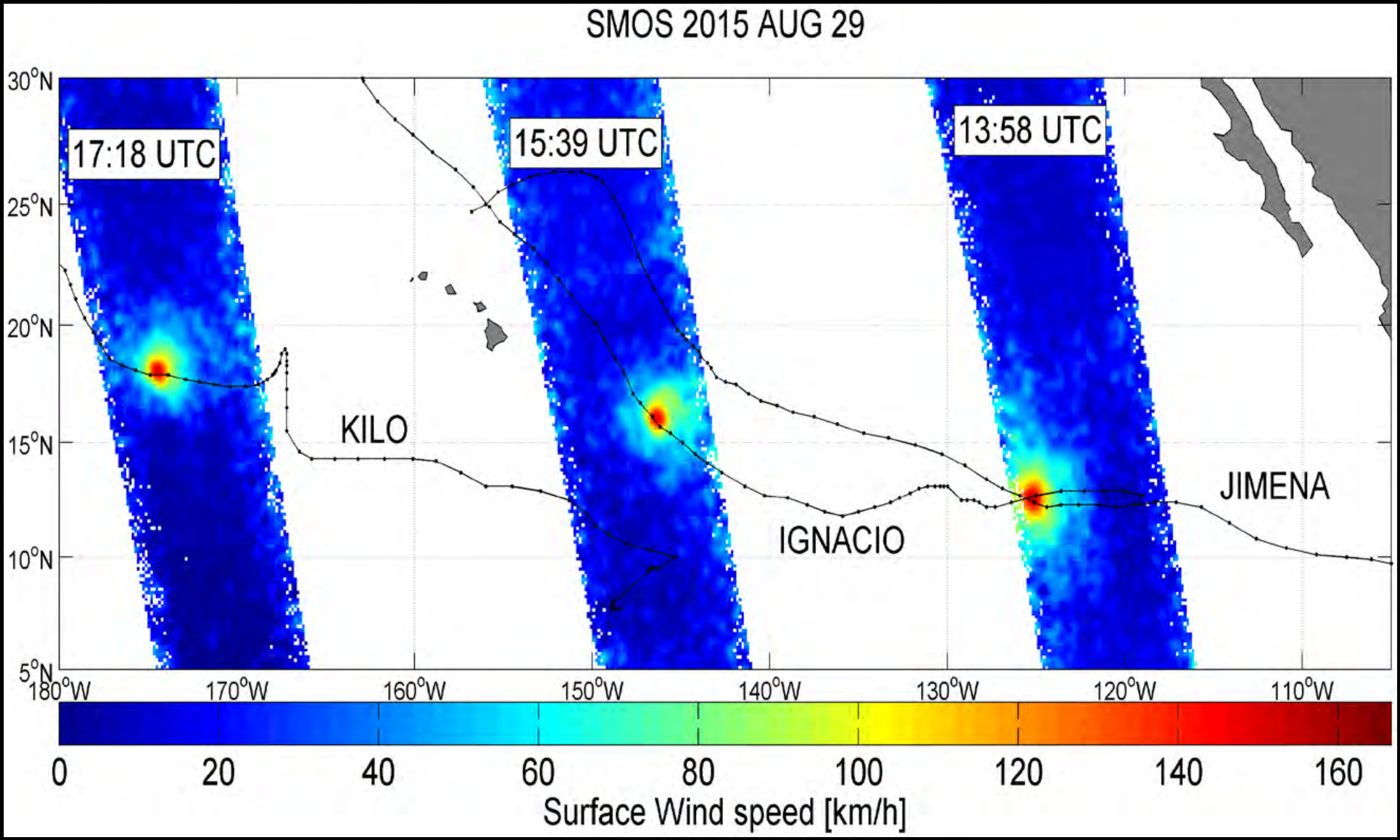
AMSR-2-JAXA

Real Aperture Radiometer
Multi Frequency including 6.9 and 7.3 GHz C-band
Spatial Resolution: ~30 kms
Swath Width: ~1450 kms
Revisit time Equator: ~3 days
Incidence angle: 50°
Linear polarizations
Launched may 2012

Signatures of 3 co-evolving 2015 major Hurricanes from 22 Aug to 9 Sep in the East and Central tropical Pacific as seen from SMOS, SMAP and AMSR-2 observations (beyond others)

A work in progress…

N. Reul, B.Chapron, A. Mouche, J-F Piolle
J. Tenerelli and F. Collard (ODL),
E. Zabolotskihk, P. Golubkin and V. Kudryavtsev (SOLAB)



Dataset used for Analysis

STORM TRACKS: NOAA NHC Automated Tropical Cyclone Forecast (ATCF) and NRL

SMOS surface Tbs and wind speed products along SMOS swaths. Algorithm following Reul et al., 2012 & updated in Reul et al., 2015. Image Reconstruction based on JRECON (J. Tenerelli, 2011).

SMOS Level 1b Tbs are retrieved at antenna level are corrected for extra-terrestrial sources contributions, smooth sea surface emission, and atmospheric path effetcs to estimate a storm-surface induced Tb residual. A Quadratic Wind speed GMF is applied to the First Stokes parameter residual to obtain U. Current validation reveals an rms of ~5 m/s up to 50 m/s with respect SFMR flight data or H*Wind analysis

AMSR-2: Algorithm developed by Zabolotskikh et al. (2013, 2015a,b) combined used of highest frequency channels (for rain retrieval) and atmosphere corrected 6.925 and 7.3 GHz channels for surface wind inversion.

SMAP: Level 1B data from NSIDC are used, surface first-stokes residual contributions are evaluated (corrections for atmospheric, cosmic background reflections and smooth ocean surface emission), data with significant galactic reflections are not used (asc fore beam data are not considered). GMF of Reul et al. 2015 developed for SMOS is applied to retrieved SWS. A systematic offset of -5m/s was added to the retrievals for consistency with ECMWF & NCEP winds for winds <20 m/s)

Dataset used for Analysis

SST MW OI analysis of REMSS. Optimally Interpolated (OI) SST daily products, using only microwave data at 25 km resolution. High wind above 20 m/s are environmental conditions precluding SST retrieval. SST is thus observed after or before the passage of a TC. It combines the through-cloud capabilities of all the operational microwave radiometers for a given day.

Precipitation from CMORPH products (CPCP MORPHing technique) which include global precipitation analyses at high spatial (~8km) and temporal resolution (~3 hourly). This technique (Joyce et al., 2004) uses precipitation estimates that have been derived from low orbiter satellite microwave observations exclusively, and whose features are transported via spatial propagation information that is obtained entirely from geostationary satellite IR data. At present NOAA incorporate precipitation estimates derived from the passive microwaves aboard he DMSP 13, 14 & 15 (SSM/I), the NOAA-15, 16, 17 & 18 (AMSU-B), and AMSR-2 and GMI aboard NASA's Aqua, and GPM spacecraft, respectively.

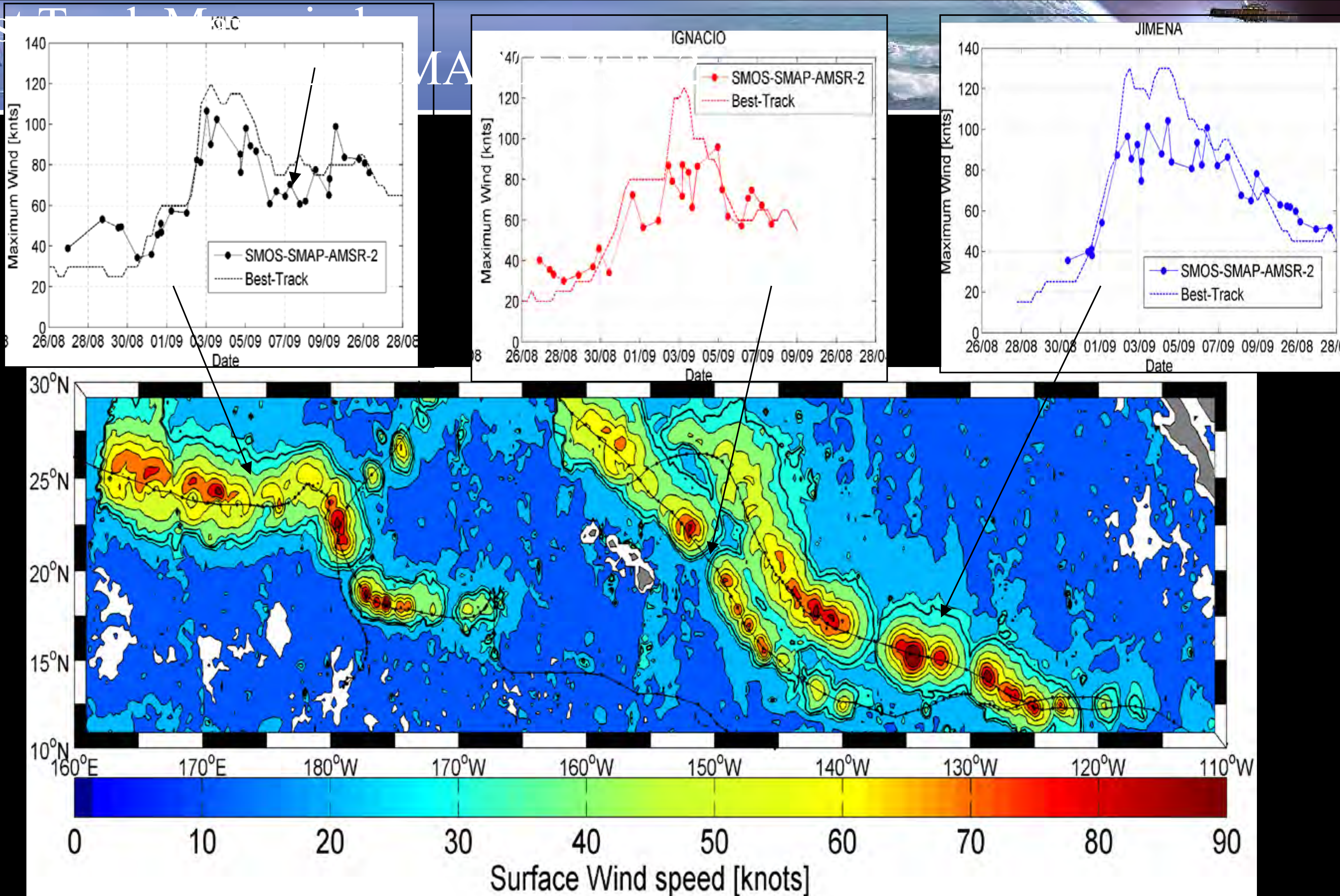
Chlorophyll-a from Aqua/Modis and NPOESS/VIIRSS

In Situ Oceanic structure :Vertical (every 10 m) and horizontal (with 0.5° x0.5° resolution) optimally interpolated monthly fields of *in situ* salinity and temperature data generated using the IFREMER In Situ Analysis System (ISAS, Gaillard, 2009) are used to described the vertical structure of the upper 100 m ocean=> used to evaluate the pre-storm vertical stratification N(z)

Waves: Hs and wind from Jason-2 and AltiKa altimetersSentinel-1 wave mode images and spectral analysis

Time laps of SMOS-SMAP-AMSR-2 winds

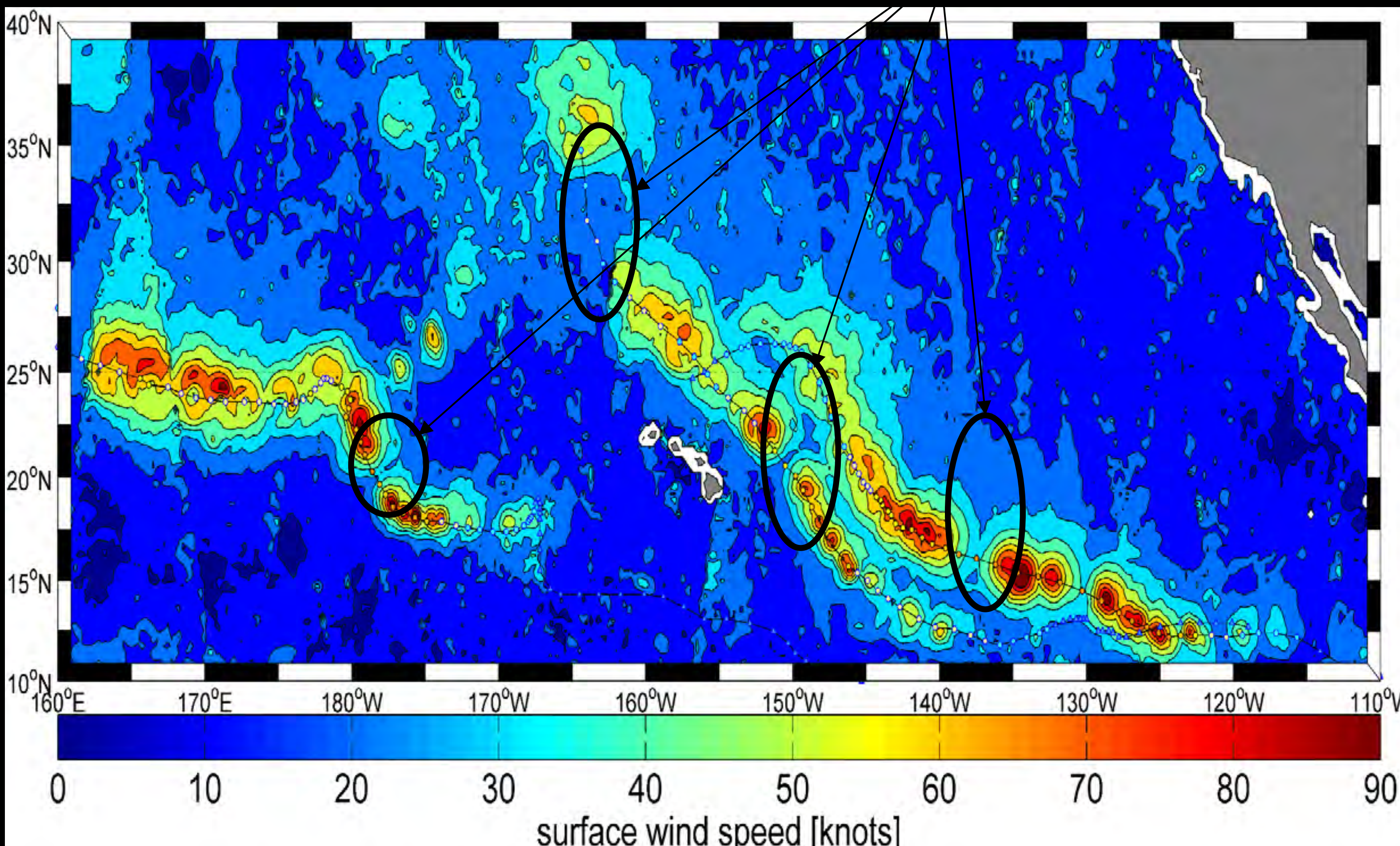
A time-series mosaic of surface wind speed measurements from 25 Aug to 8 Sep 2015 over Hurricanes Kilo, Ignacio and Jimena is shown in this animation. Data from three satellite microwave radiometer missions: the ESA L-band SMOS mission, the recently launched NASA L-band SMAP mission and JAXA C-band AMSR-2 mission are combined before your eyes to reveal the track of each Hurricane and the maximum surface wind speed. 32, 26 and 35 intercepts of Jimena, Ignacio and Kilo respectively



Contours of the domains showing the maxima of surface winds obtained from the combined multiple observations of SMOS, SMAP and AMSR-2 sensors from 22 Aug to 9 Sep 2015 showing the high wind trails over Hurricanes Kilo and Loke (left), Ignacio (center), Jimena (right).

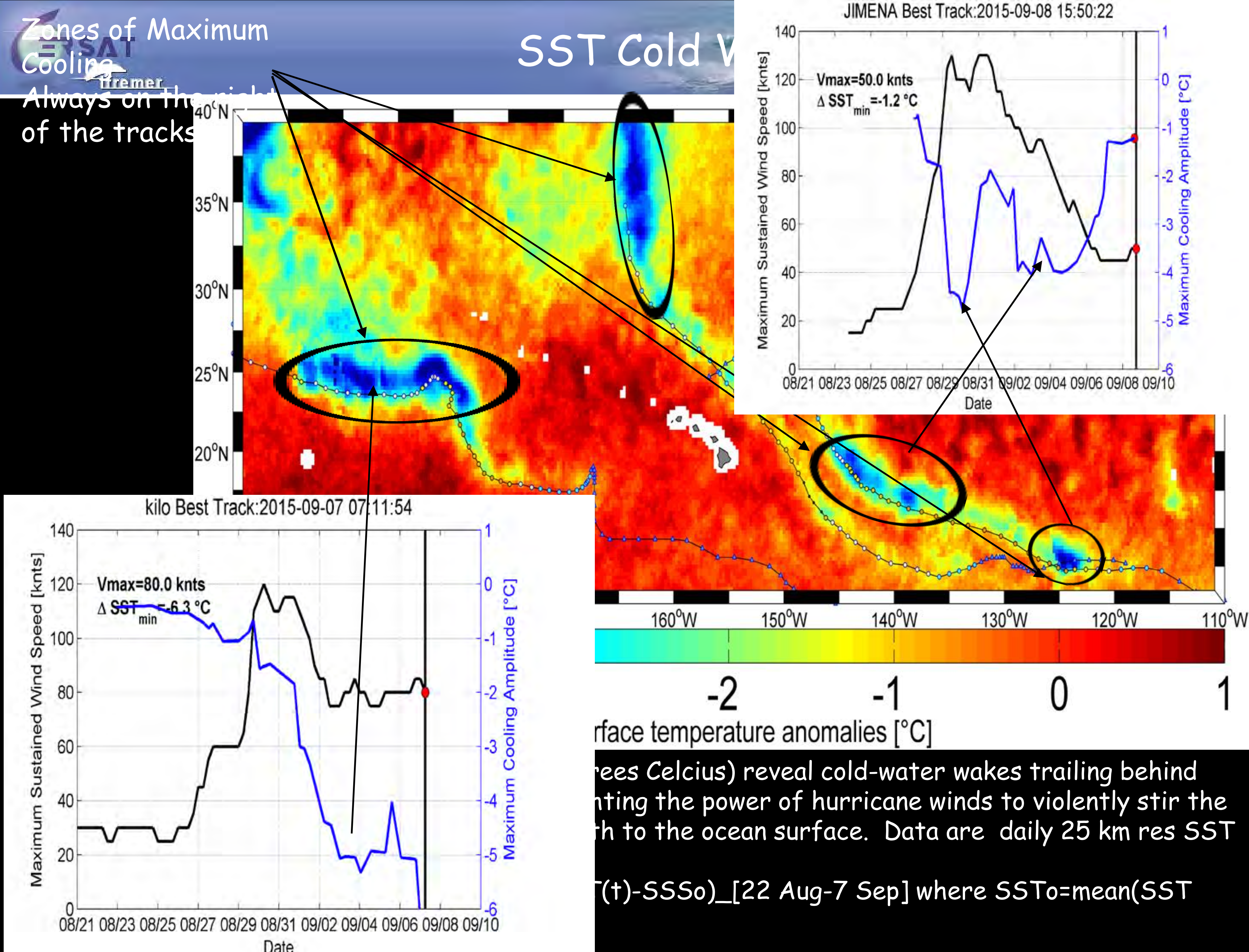
Maximum surface Wind wa

Gaps in the satellite coverage of the storms



Zones of Maximum Cooling
Always on the
of the tracks

SST Cold W



rees Celcius) reveal cold-water wakes trailing behind
nting the power of hurricane winds to violently stir the
h to the ocean surface. Data are daily 25 km res SST

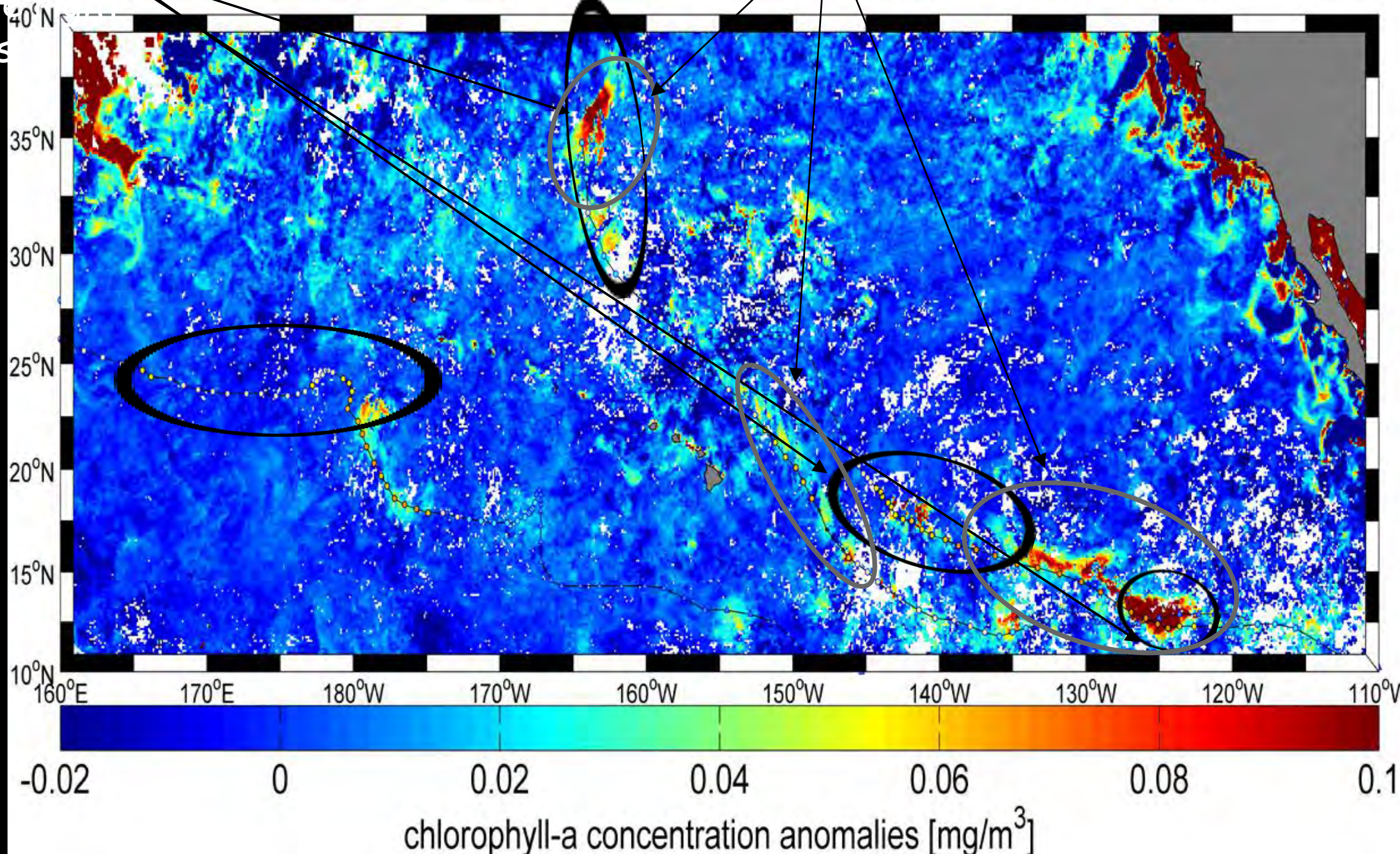
T(t)-SSSo)_[22 Aug-7 Sep] where SSTo=mean(SST

Zones of Maximum Cooling Always on the right of the tracks

Chlorophyll-a wake

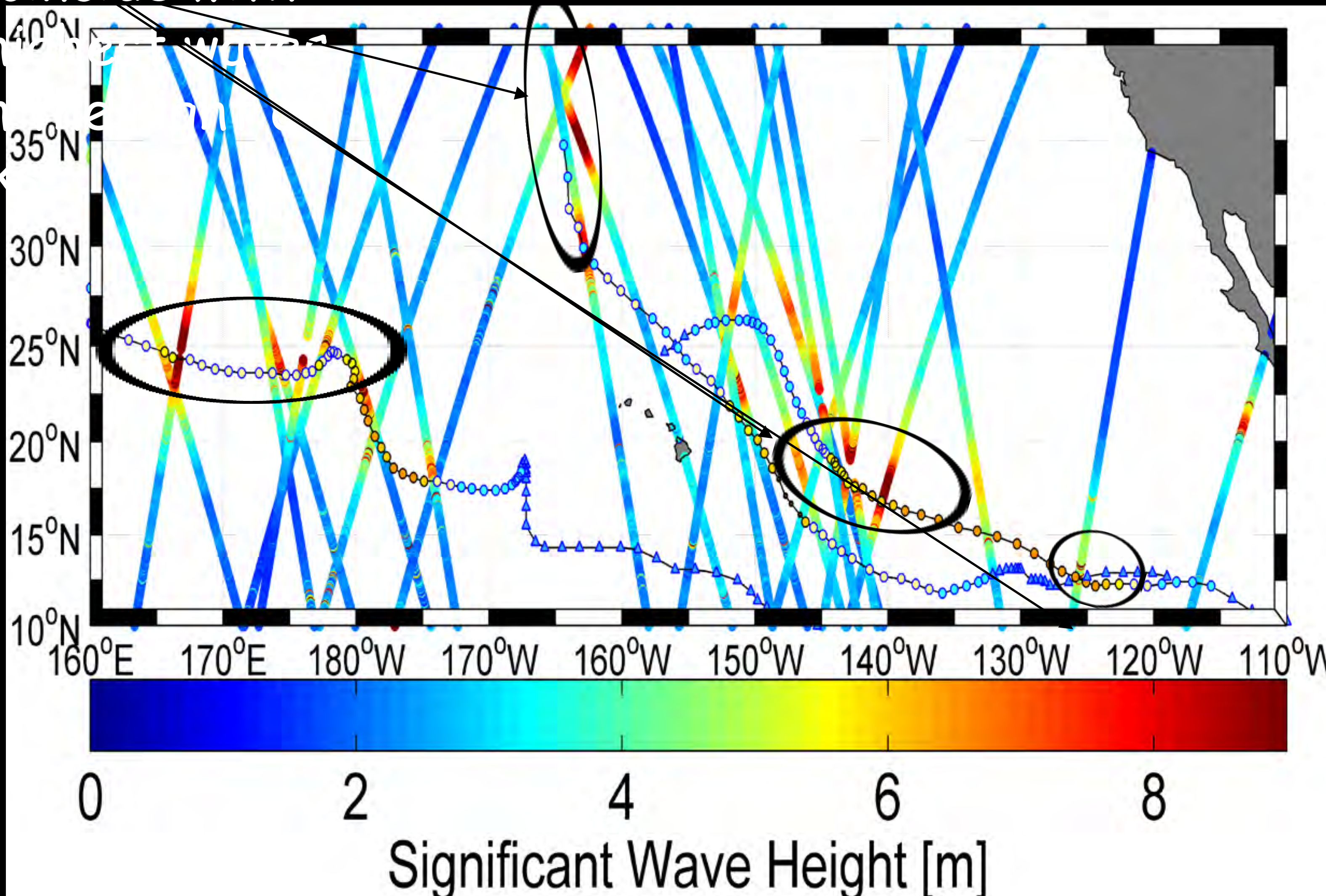
Zones of Max Chl-a ch

Rich water below the



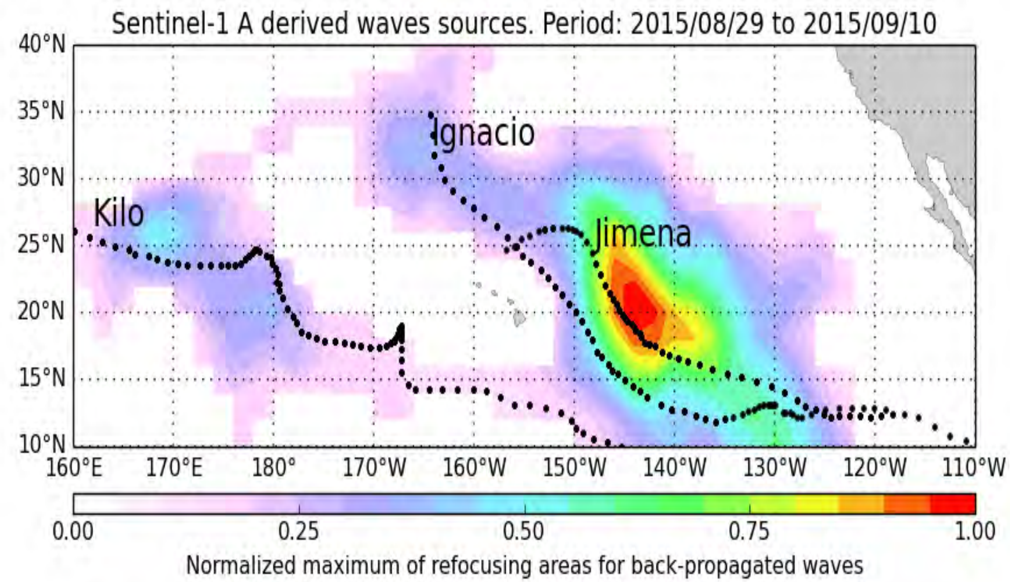
Chlorophyll Concentration anomalies (mg/m3) reveal upwelled richer waters wakes trailing behind hurricanes Kilo, Ignacio, and Jimena highlighting the power of hurricane winds to violently stir the upper ocean and bring richer waters at depth to the ocean surface. Data are daily chl at 4 km from NASA/MODIS and NASA/VIRSS ChlA=max (Chl(t)-Chlo)_[22 Aug-7 Sep] where Chlo=mean(chl (t=12-21 Aug))

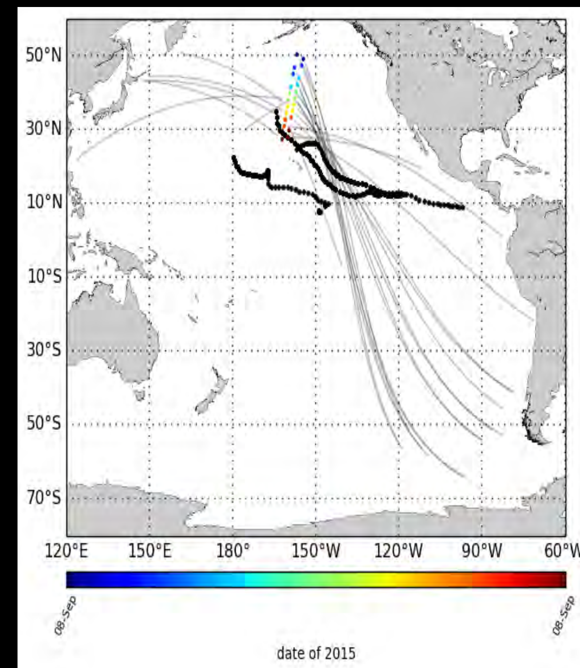
Zones of Maximum
Cooling coincide with
zone of h
always on
the track



Data from Jason 2 and AltiKa

Sources of wave generation from Sentinel-1 A swell observations

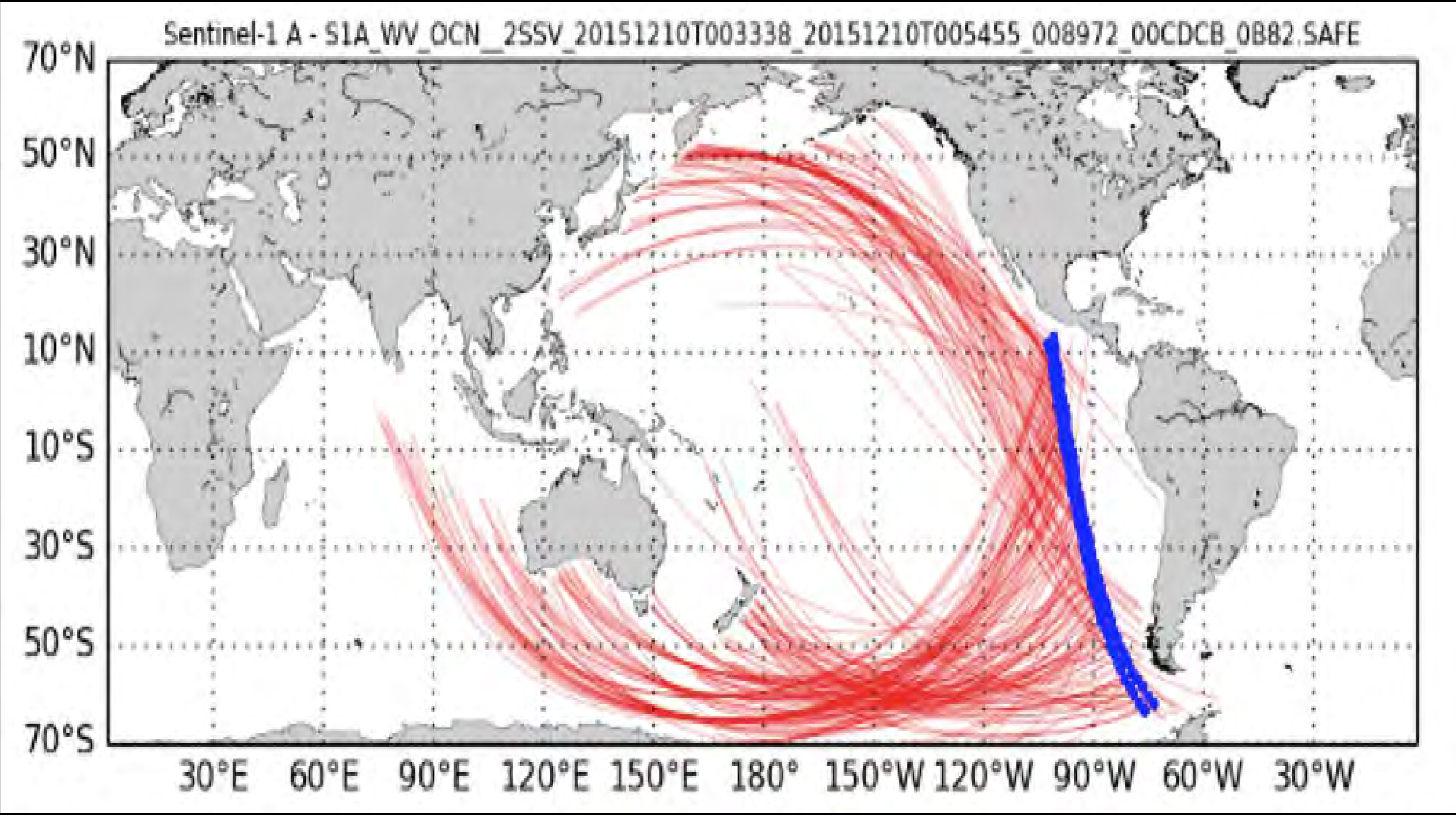




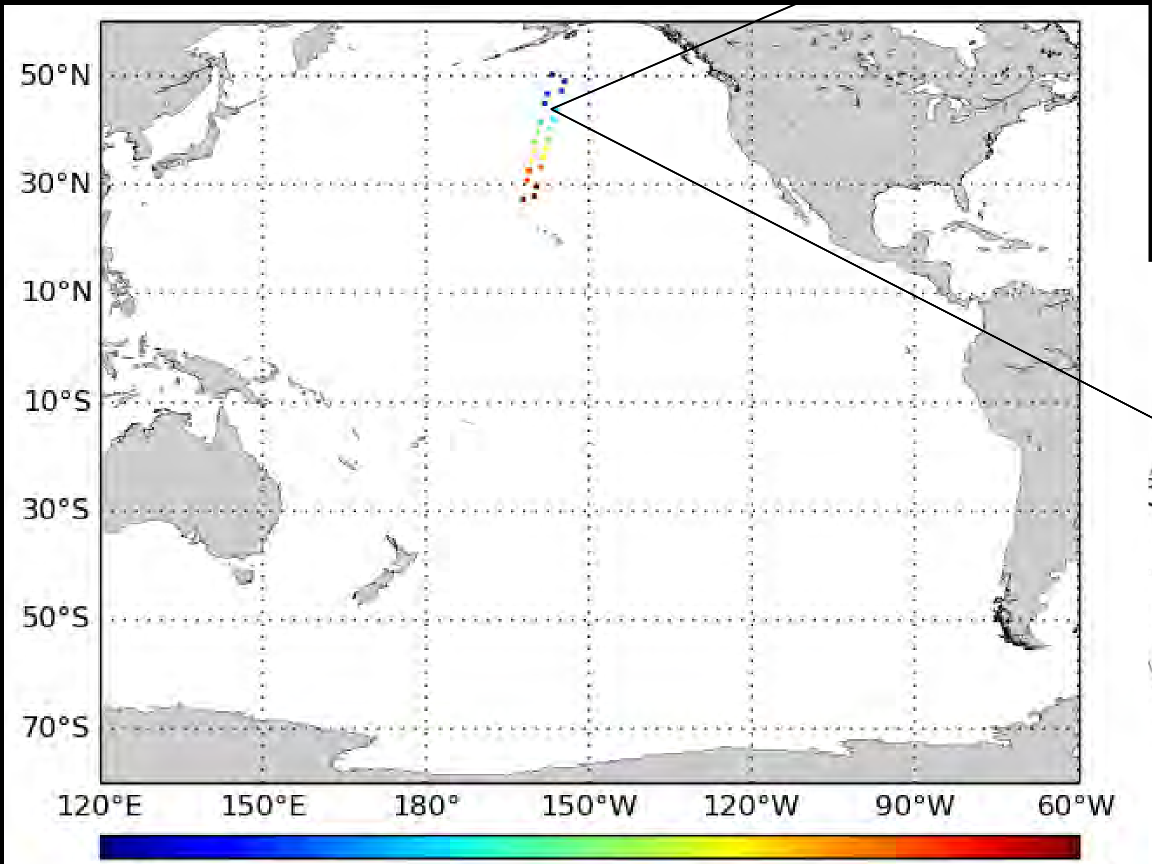
Distribution of the storm sources derived from Sentinel-1 A swell observations back-propagated up to their generation areas. Analysis is done from all Wave Mode data available from 2015/08/23 to 2015/09/22 and describe storm generation areas from 2015/08/29 to 2015/09/10.

Location is mostly on the left with respect to the track for each storm. Maximum of retropropagations are located where hurricanes speeds are the lowest (obvious for Jimena=). Note that each point along track is given every 6 hour, so very close (apart) black dots mean

Great-Circle propagation determined by the detected wavelength direction and related group velocity

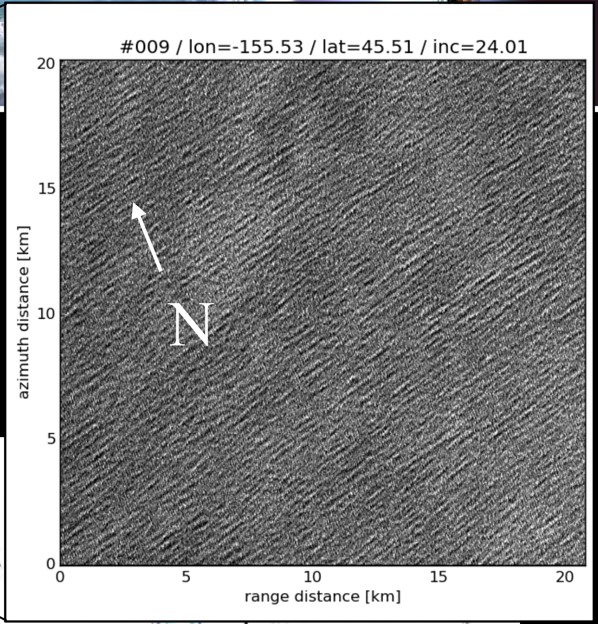


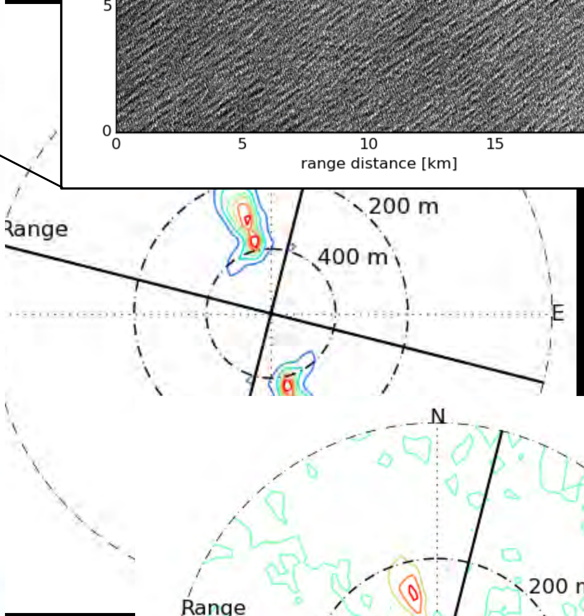
Jimena : wave generation

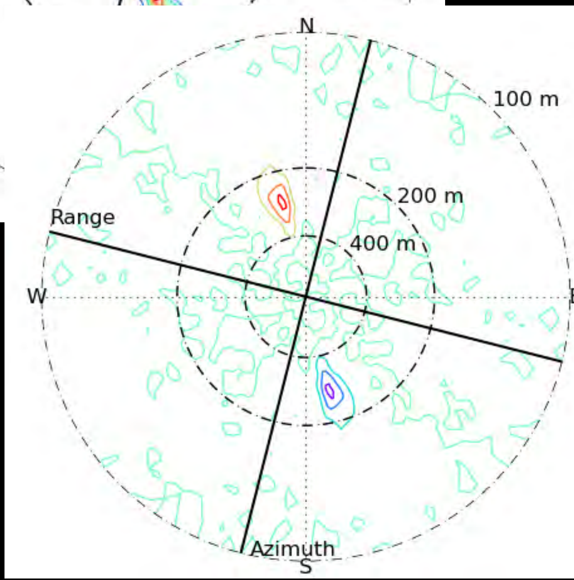


Example of Sentinel-1 A Acquisition
2015 Sept 8. From 16:40 to 16:46 UTC

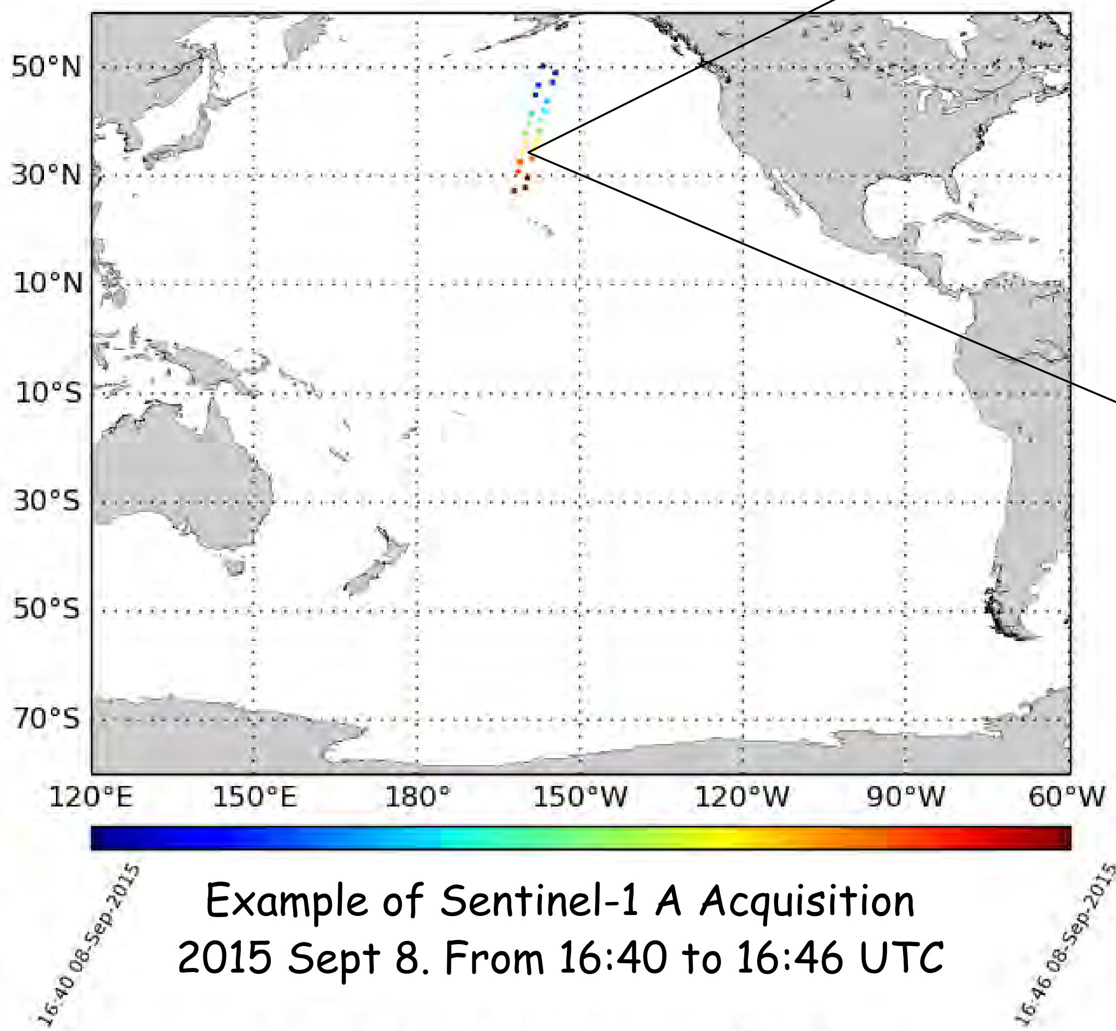
From 2015/09/08 16:40:00 to 2015/09/08 16:46:00





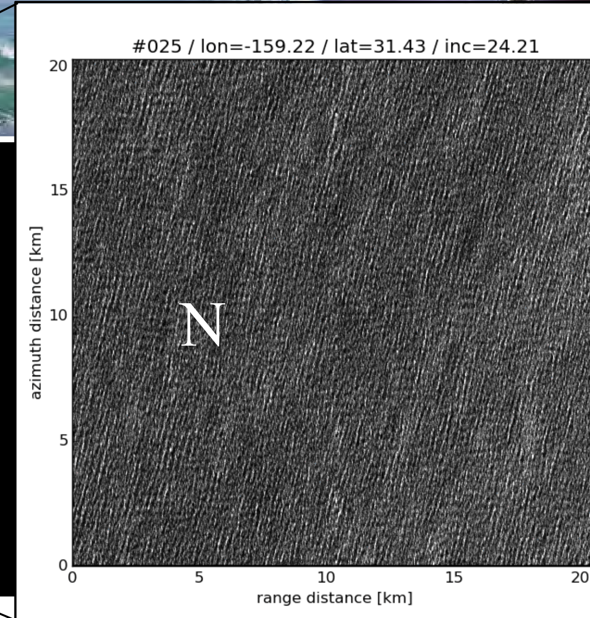


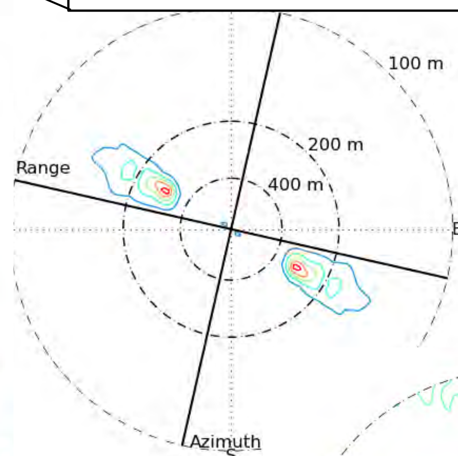
Jimena : wave generation

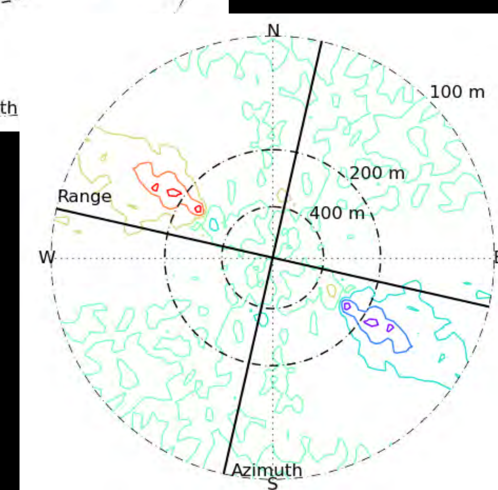


Example of Sentinel-1 A Acquisition
2015 Sept 8. From 16:40 to 16:46 UTC

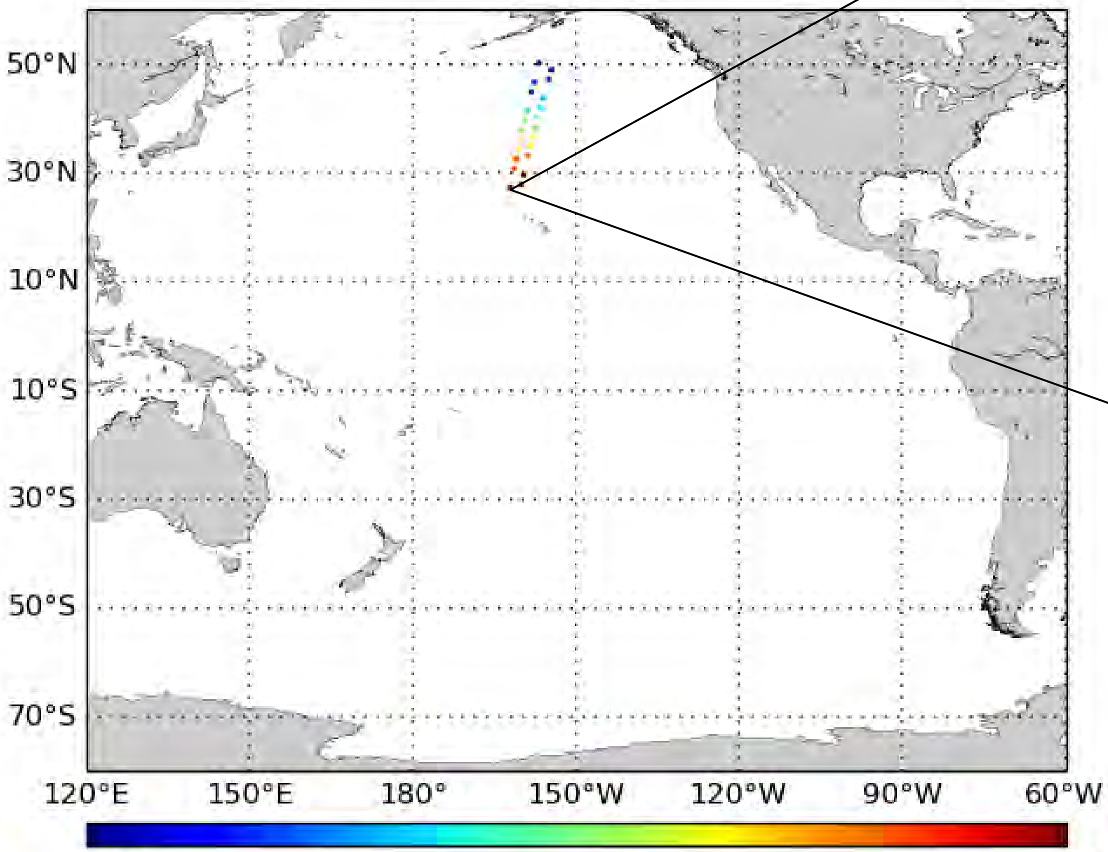
From 2015/09/08 16:40:00 to 2015/09/08 16:46:00







Jimena : wave generation

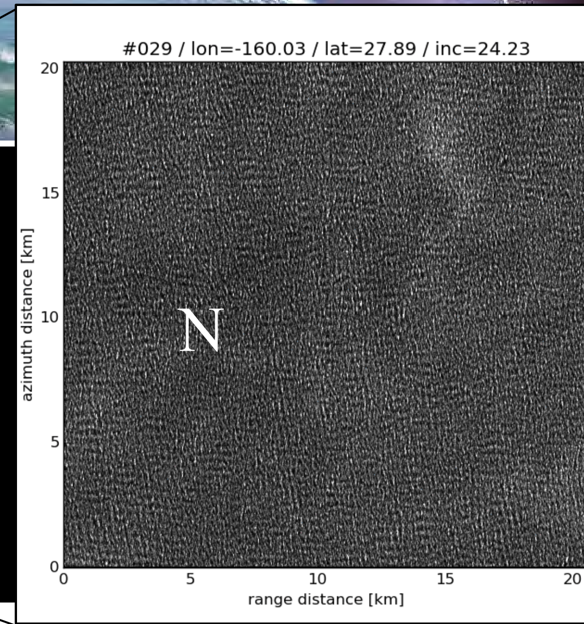


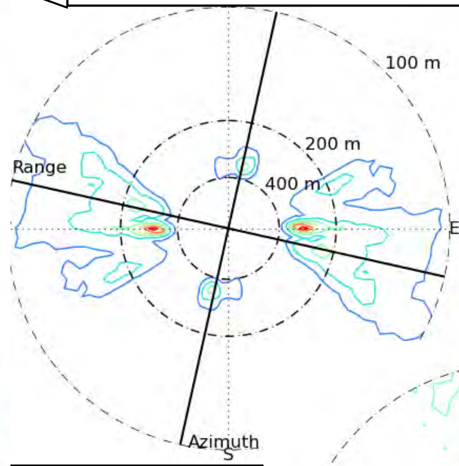
16:40 08-Sep-2015

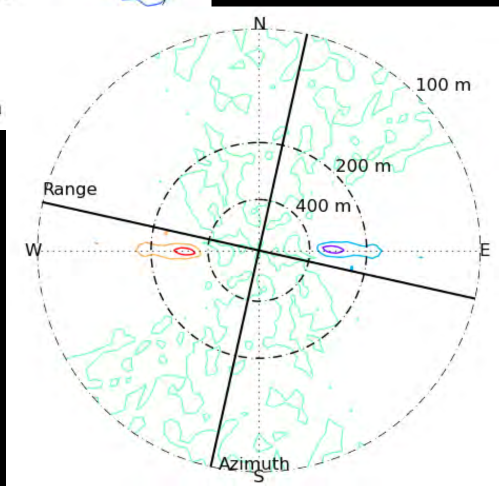
Example of Sentinel-1 A Acquisition
2015 Sept 8. From 16:40 to 16:46 UTC

16:46 08-Sep-2015

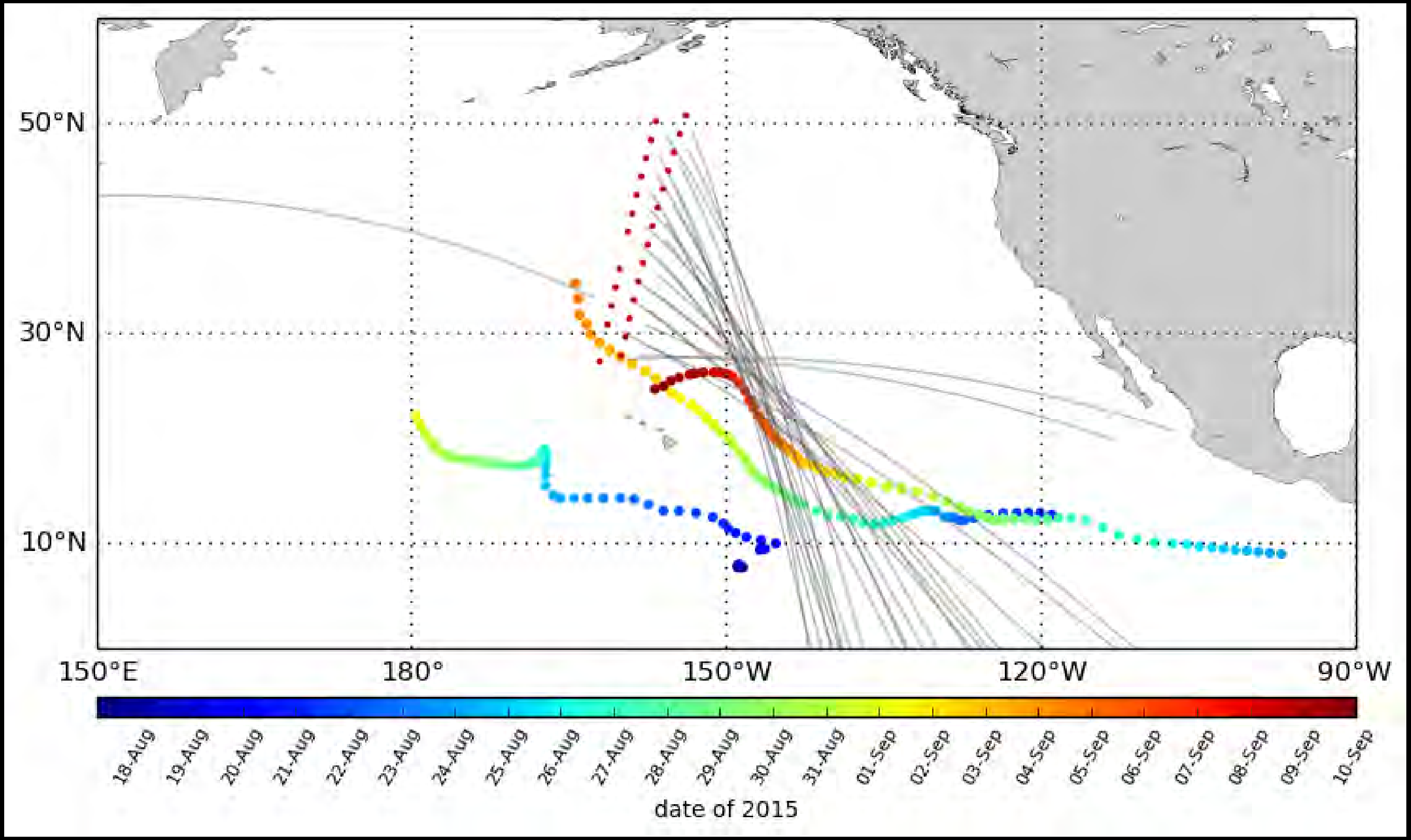
From 2015/09/08 16:40:00 to 2015/09/08 16:46:00





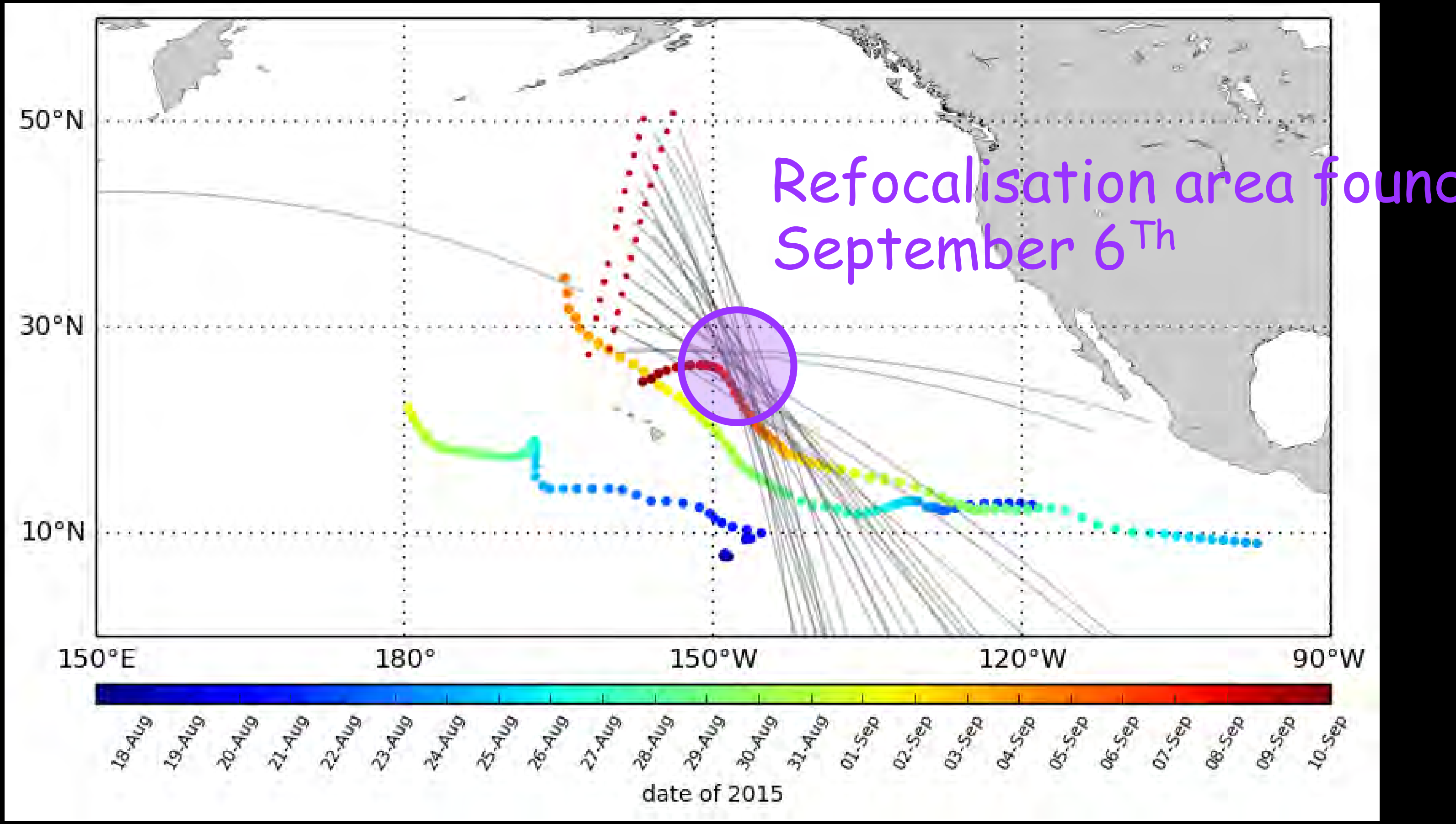


Jimena : wave generation



- Example of retro-propagated Sentinel-1 A Swell Measurements. Data acquired the 2015 Sept 8 16:40 to 16:46 UTC
- 3 tracks corresponding to the 3 hurricanes Kilo, Ignacio and Jimena (from left to right) are overplotted. Color code is time.

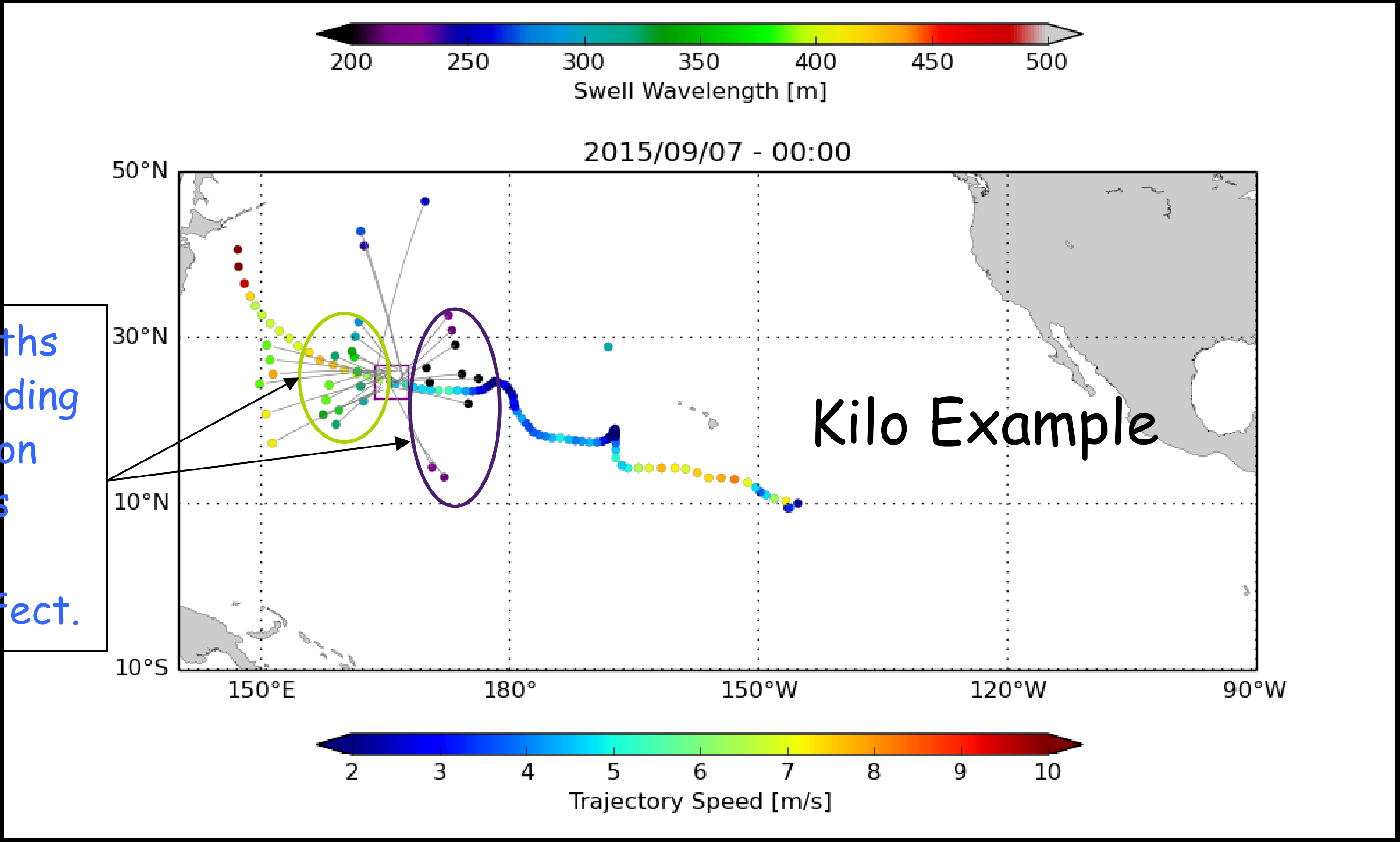
Jimena : wave generationx



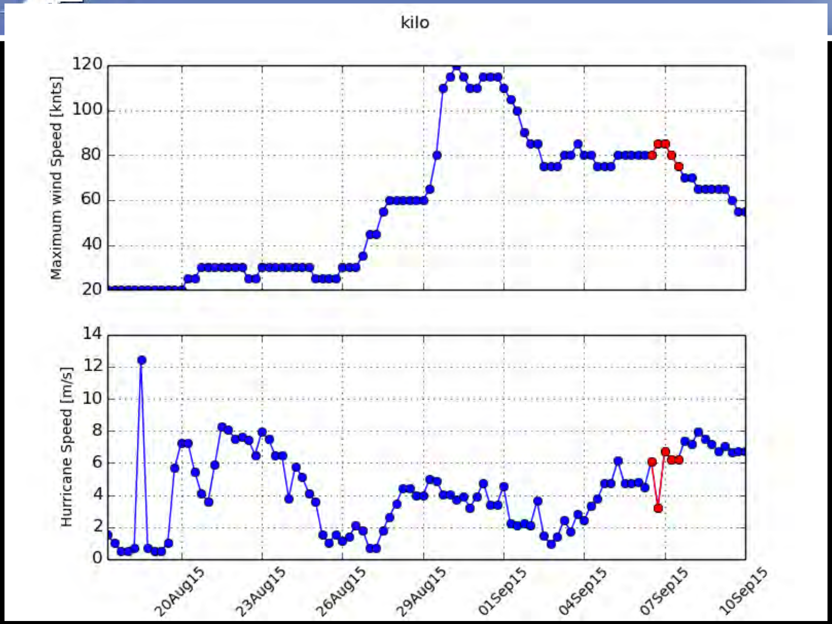
- Example of retro-propagated Sentinel-1 A Swell Measurements. Data acquired the 2015 Sept 8 16:40 to 16:46 UTC
- Refocalisation area is found along the Jimena track the 6th of September. On the right hand side of the track.

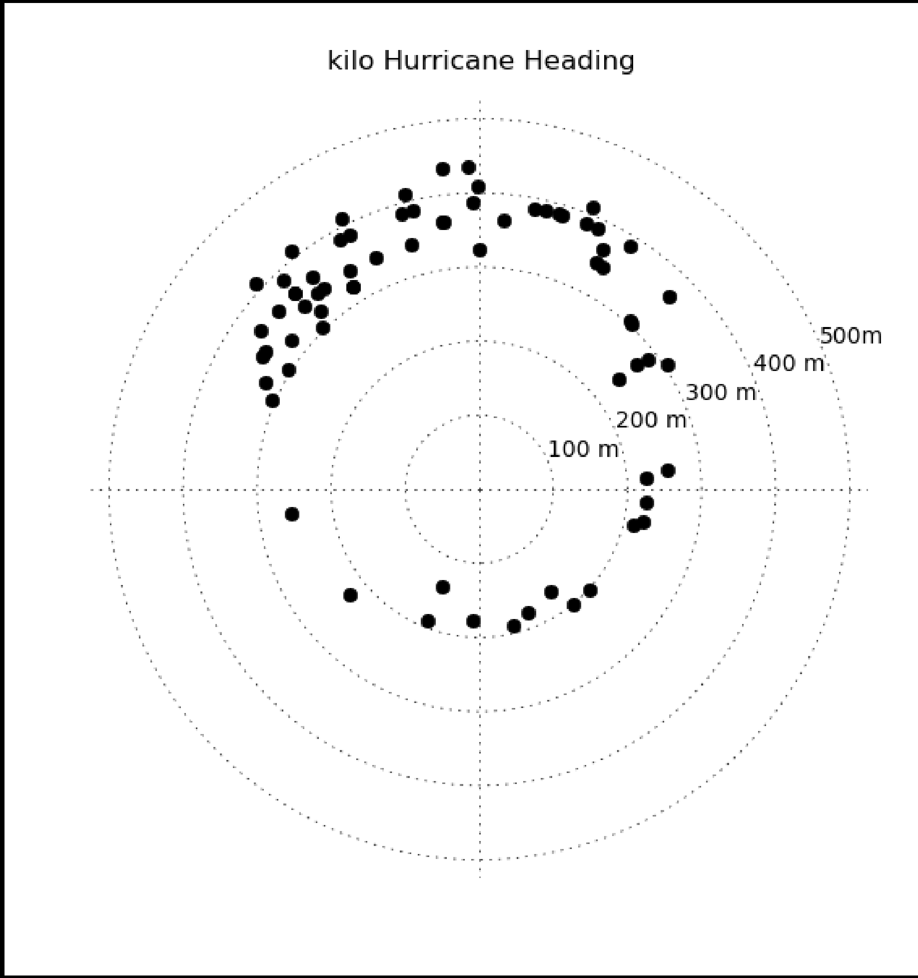
Kilo : wave generation

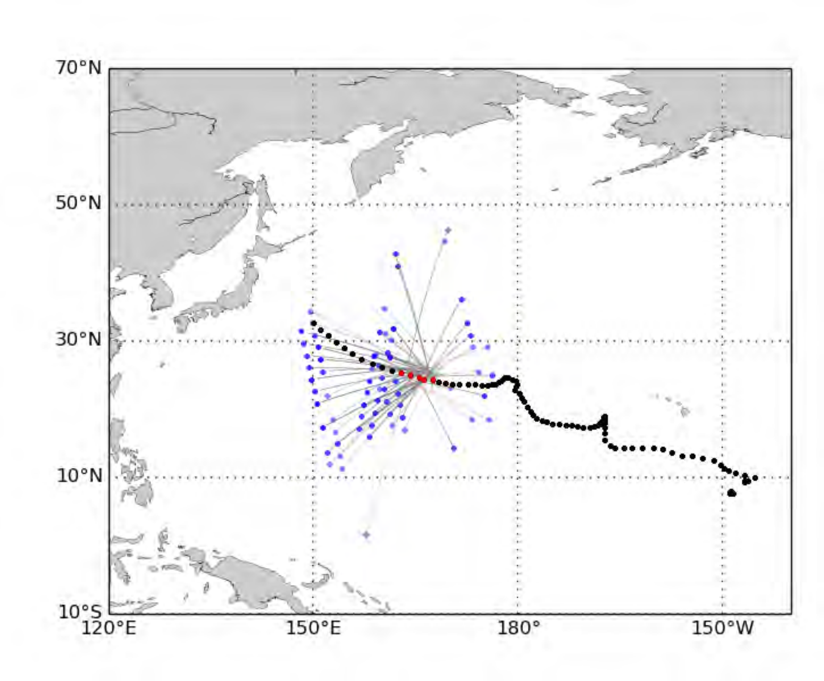
Different wavelengths are observed depending on the swell direction of propagation. This may be due to effective-fetch effect.



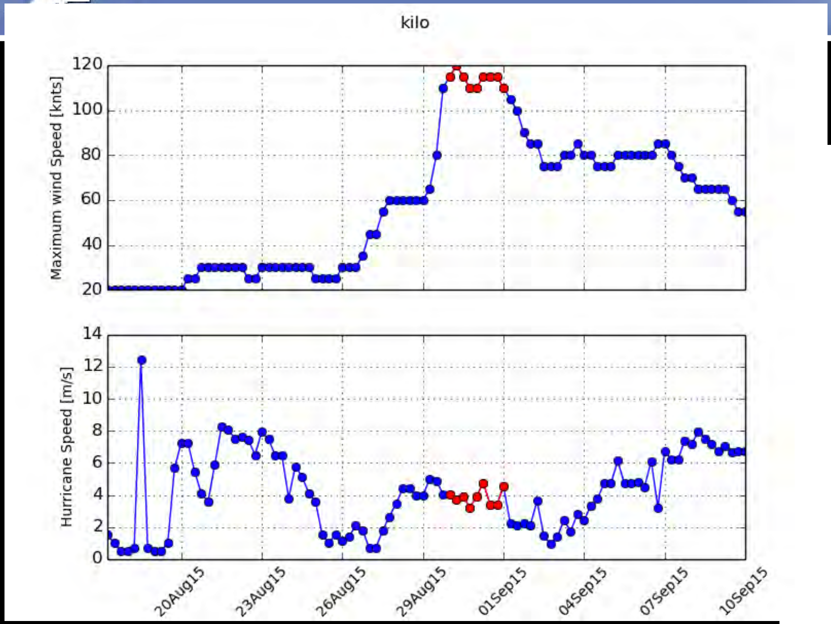
Kilo wave generation : trapping fetch

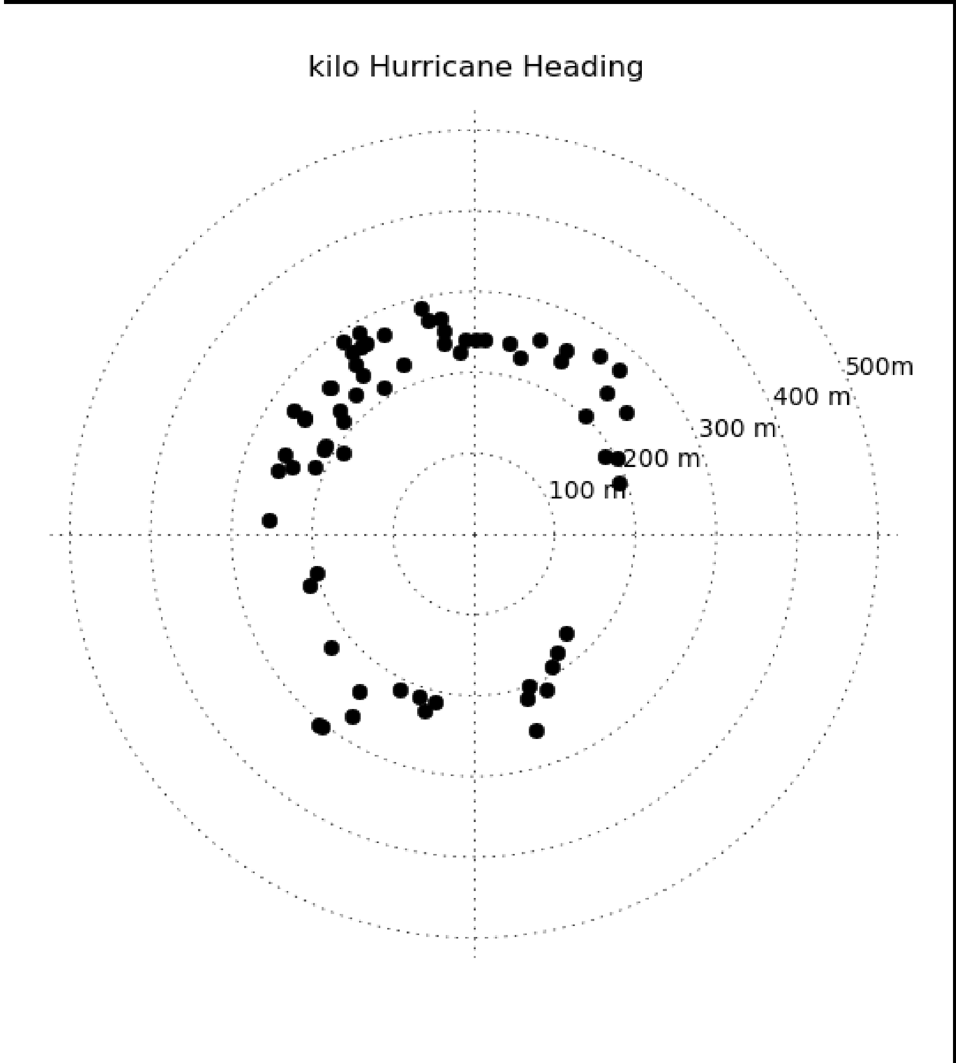


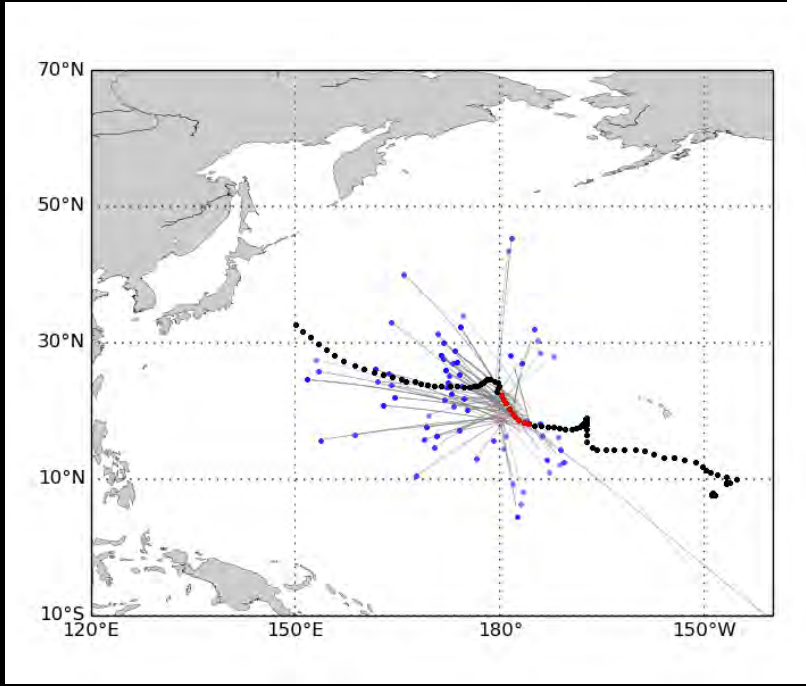


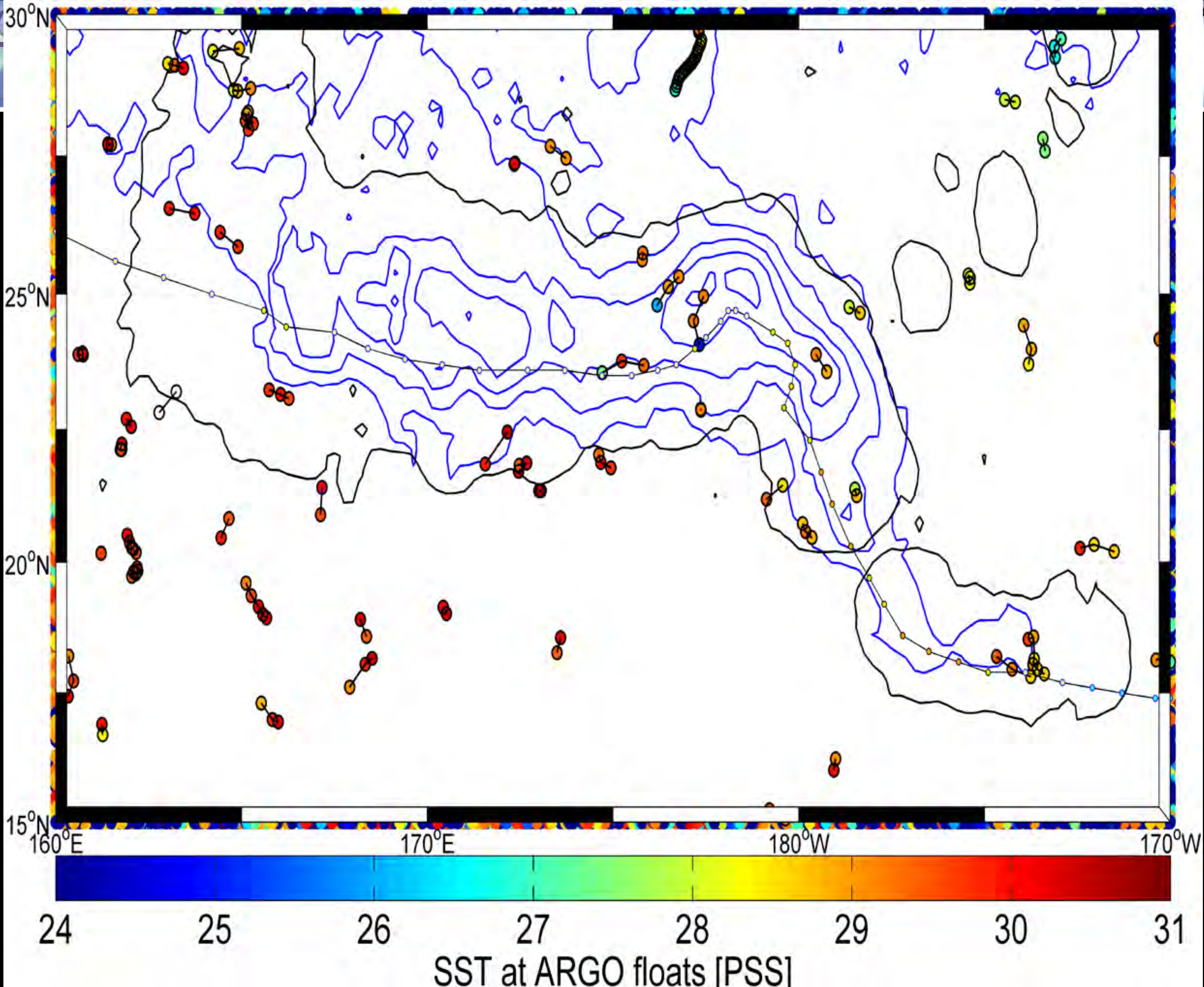


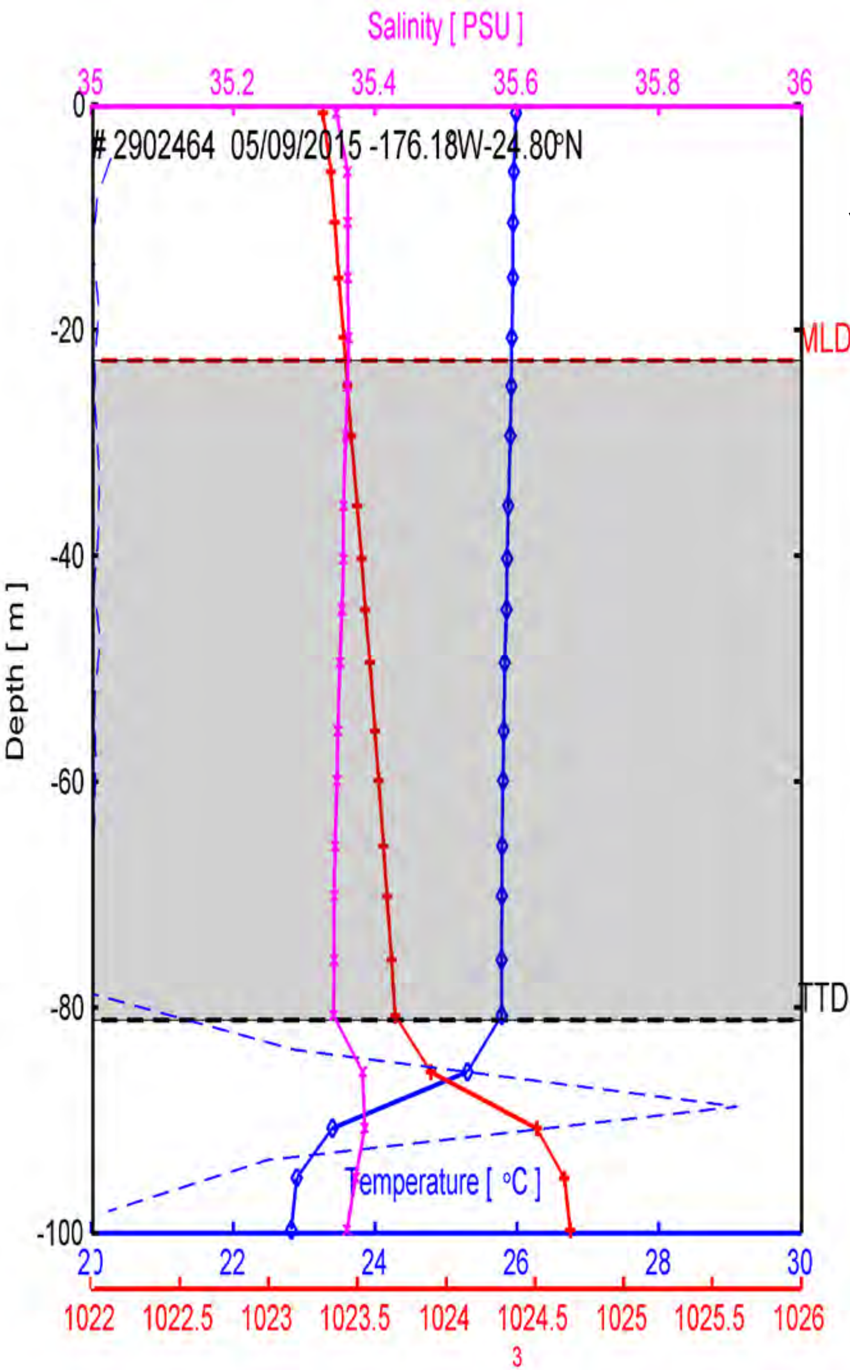
Kilo wave generation : intensity peak



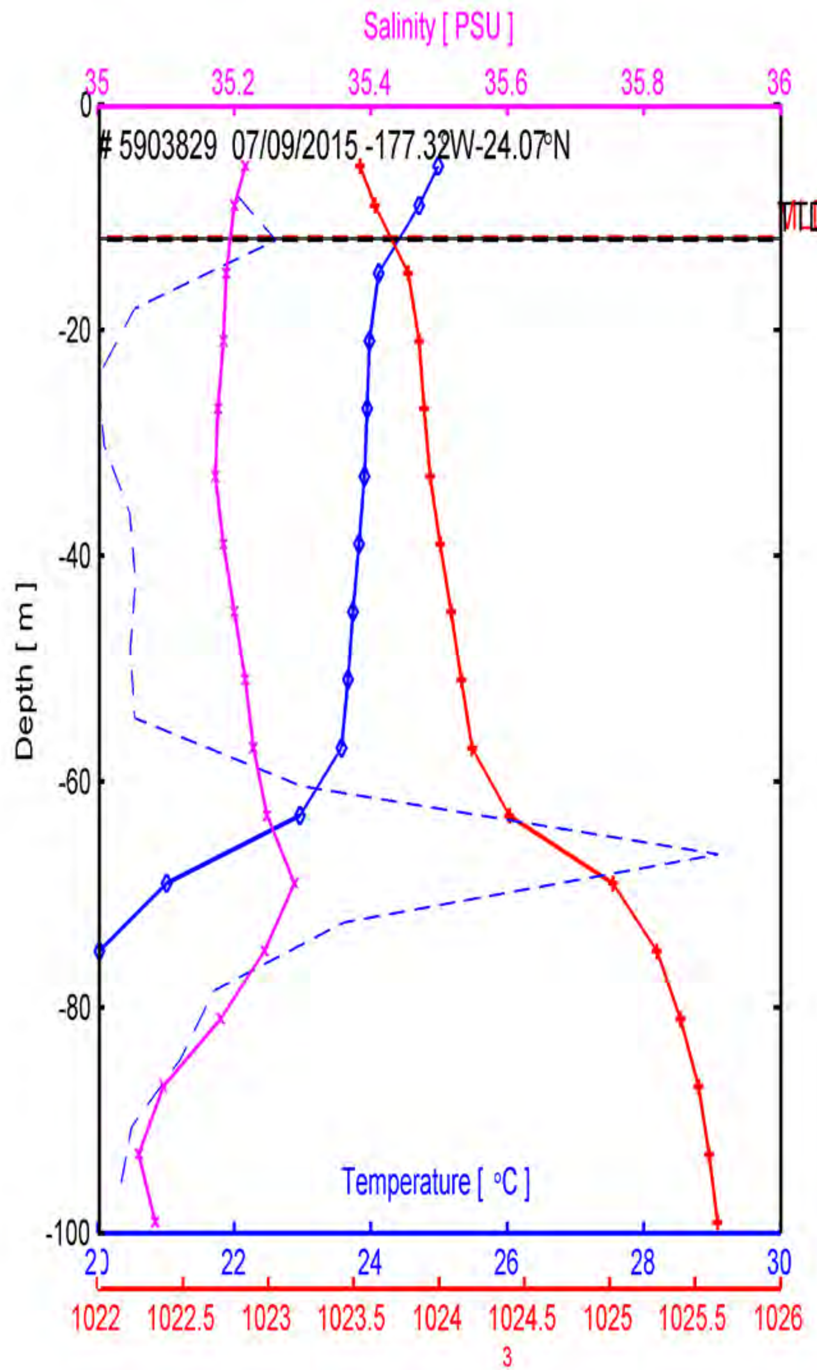




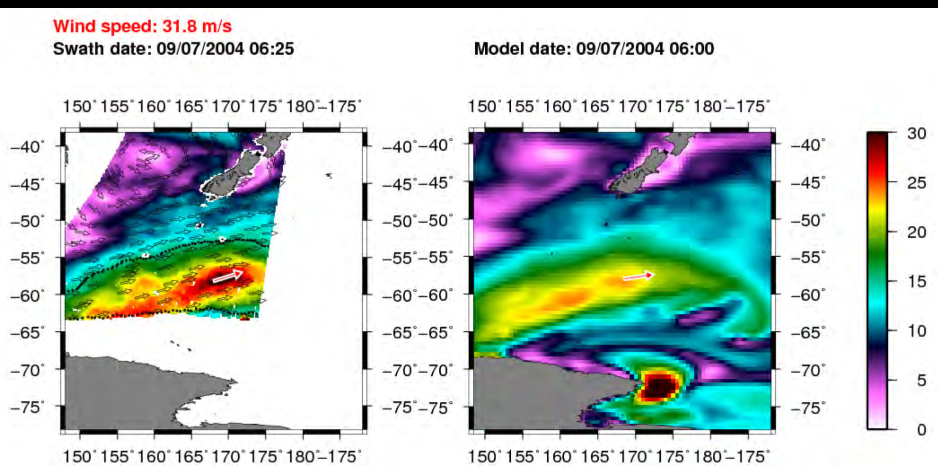

30°N
25°N
20°N
15°N
160°E
170°E
180°W
170°W
24
25
26
27
28
29
30
31
SST at ARGO floats [PSS]

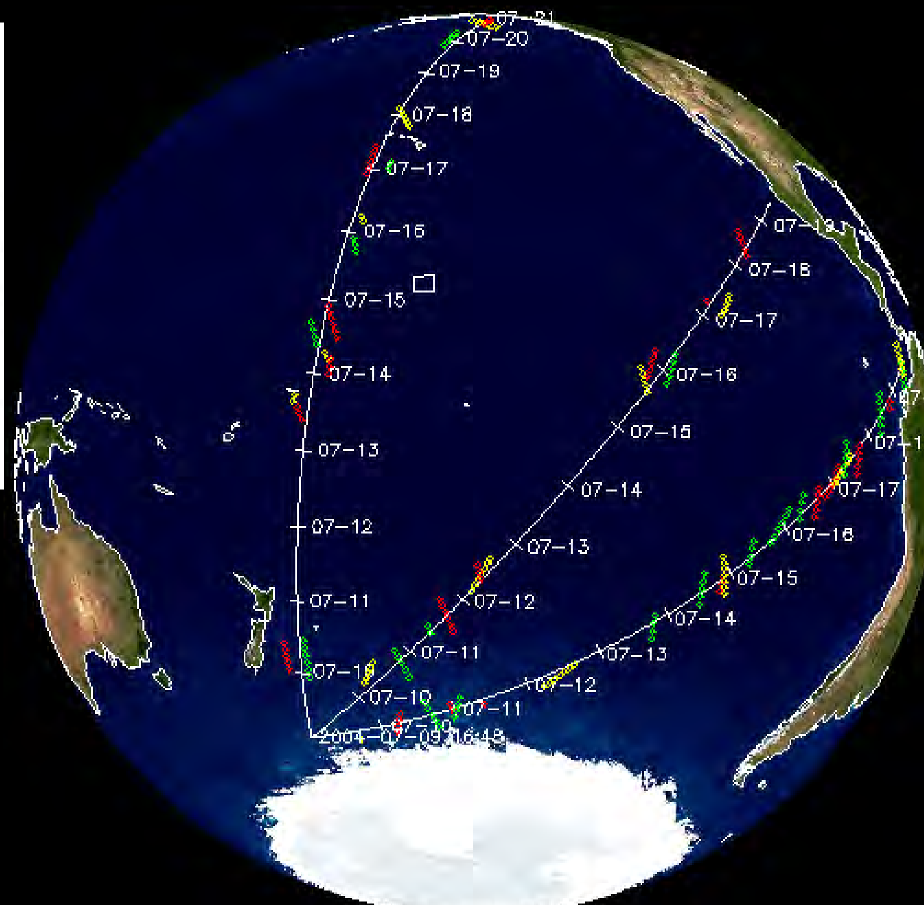


Salinity [PSU]
35
35.2
35.4
35.6
35.8
36
2902464 05/09/2015 -176.18W-24.80ºN
MLD
TTD
Depth [m]
0
-20
-40
-60
-80
-100
Temperature [ºC]
22
24
26
28
30
1022
1022.5
1023
1023.5
1024
1024.5
1025
1025.5
1026
3



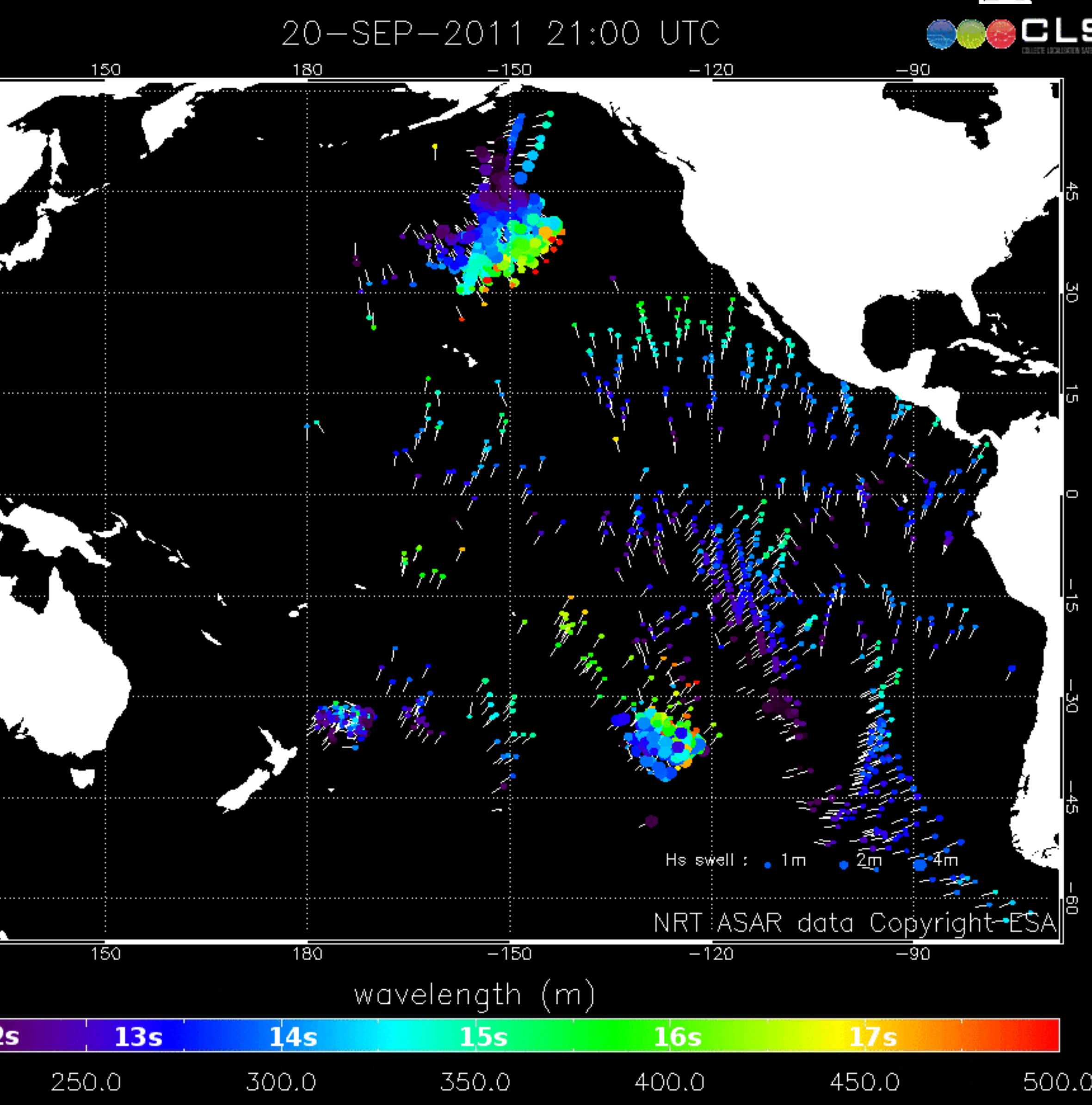
Salinity [PSU]
35
35.2
35.4
35.6
35.8
36
5903829 07/09/2015 -177.32W-24.07ºN
Depth [m]
0
-20
-40
-60
-80
-100
Temperature [ºC]
22
24
26
28
30
1022
1022.5
1023
1023.5
1024
1024.5
1025
1025.5
1026
3



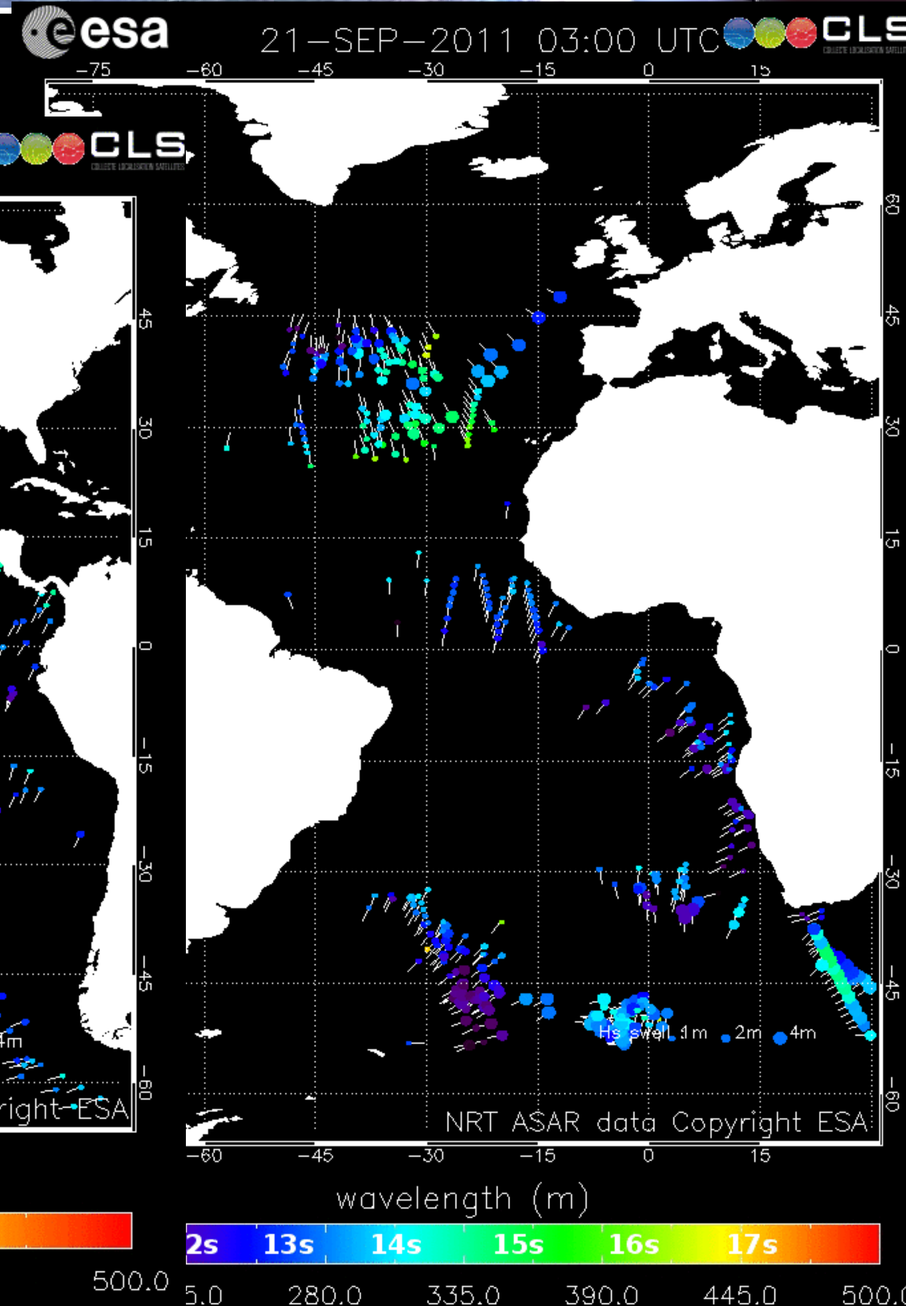


RED : ENVISAT ASAR
GREEN : ENVISAT RA2
YELLOW : JASON ALTIMETER

Fireworks



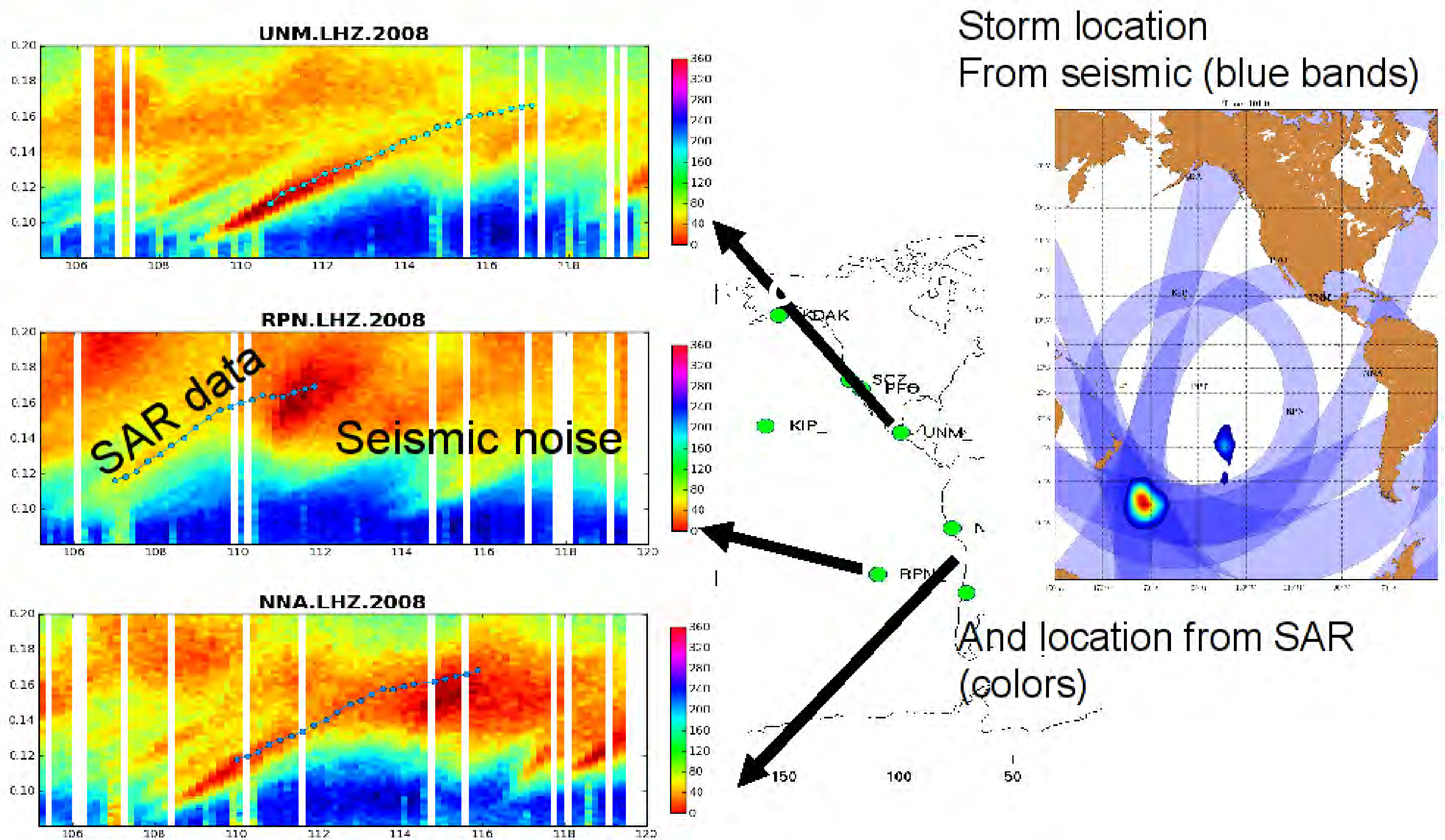
20-SEP-2011 21:00 UTC
CLS
Hs swell : 1m 2m 4m
NRT ASAR data Copyright ESA
wavelength (m)
13s
14s
15s
16s
17s
250.0
300.0
350.0
400.0
450.0
500.0



esa
21-SEP-2011 03:00 UTC
Hs swell 1m 2m 4m
NRT ASAR data Copyright ESA
wavelength (m)
2s
13s
14s
15s
16s
17s
280.0
335.0
390.0
445.0

Consistency and storm severity

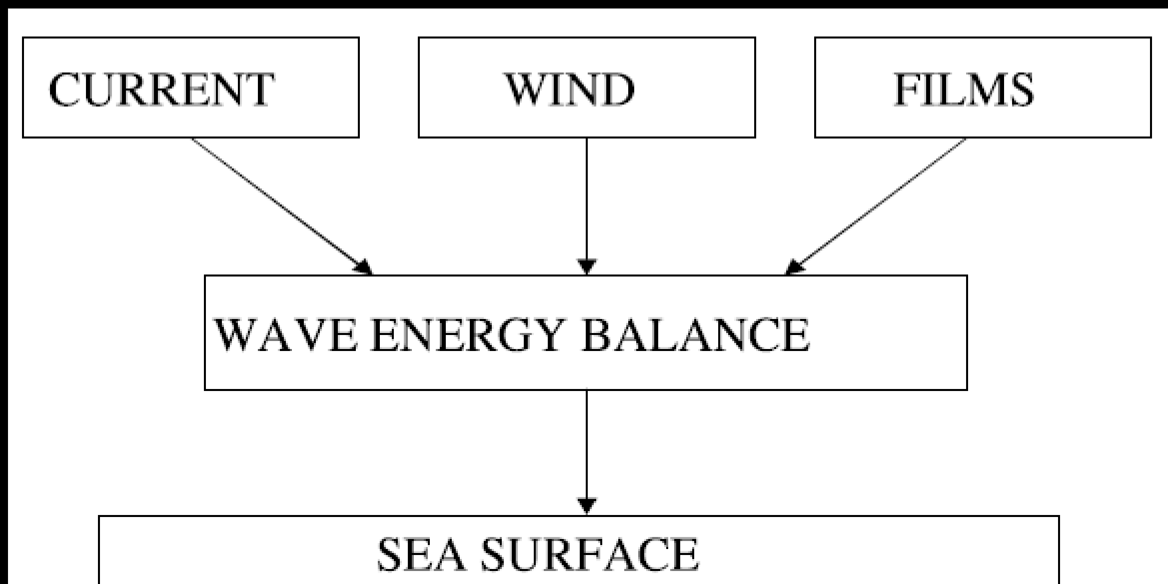
Example of seismic - SAR synergy



Sea Surface Roughness

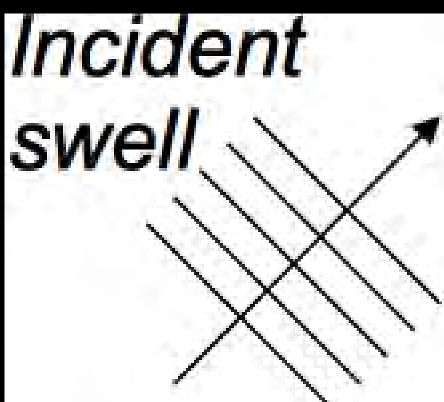
$$\frac{\partial N(\mathbf{k})}{\partial t} + \left(c_{gi} + u_i\right)\frac{\partial N(\mathbf{k})}{\partial x_i} - k_j\frac{\partial u_j}{\partial x_i}\frac{\partial N(\mathbf{k})}{\partial k_i} = Q(\mathbf{k})/\omega$$

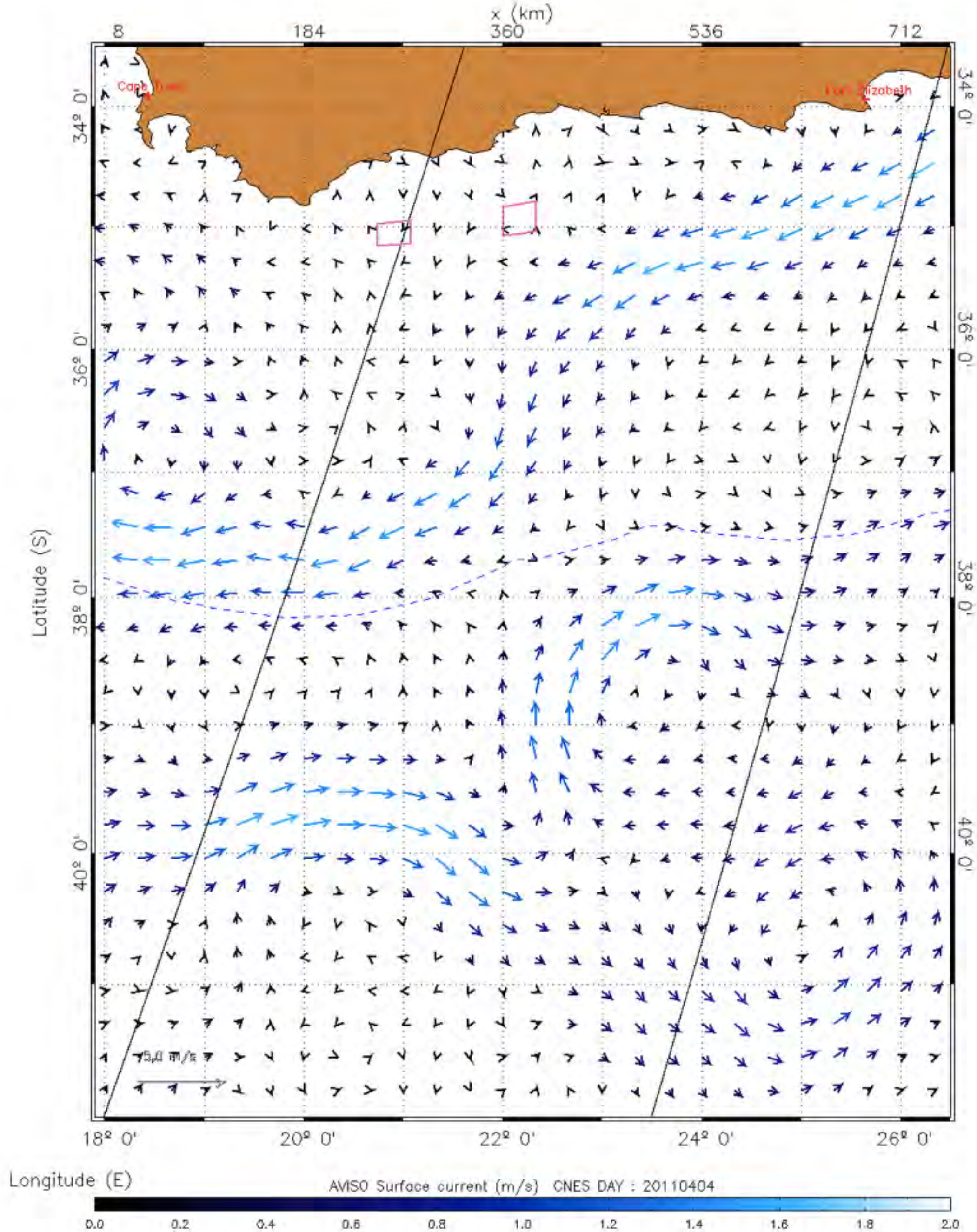
$$Q(\mathbf{k}) = \beta_\nu(\mathbf{k})\omega E(\mathbf{k}) - D(\mathbf{k}) - Q^{nl}(\mathbf{k}) + Q^{wb}(\mathbf{k})$$

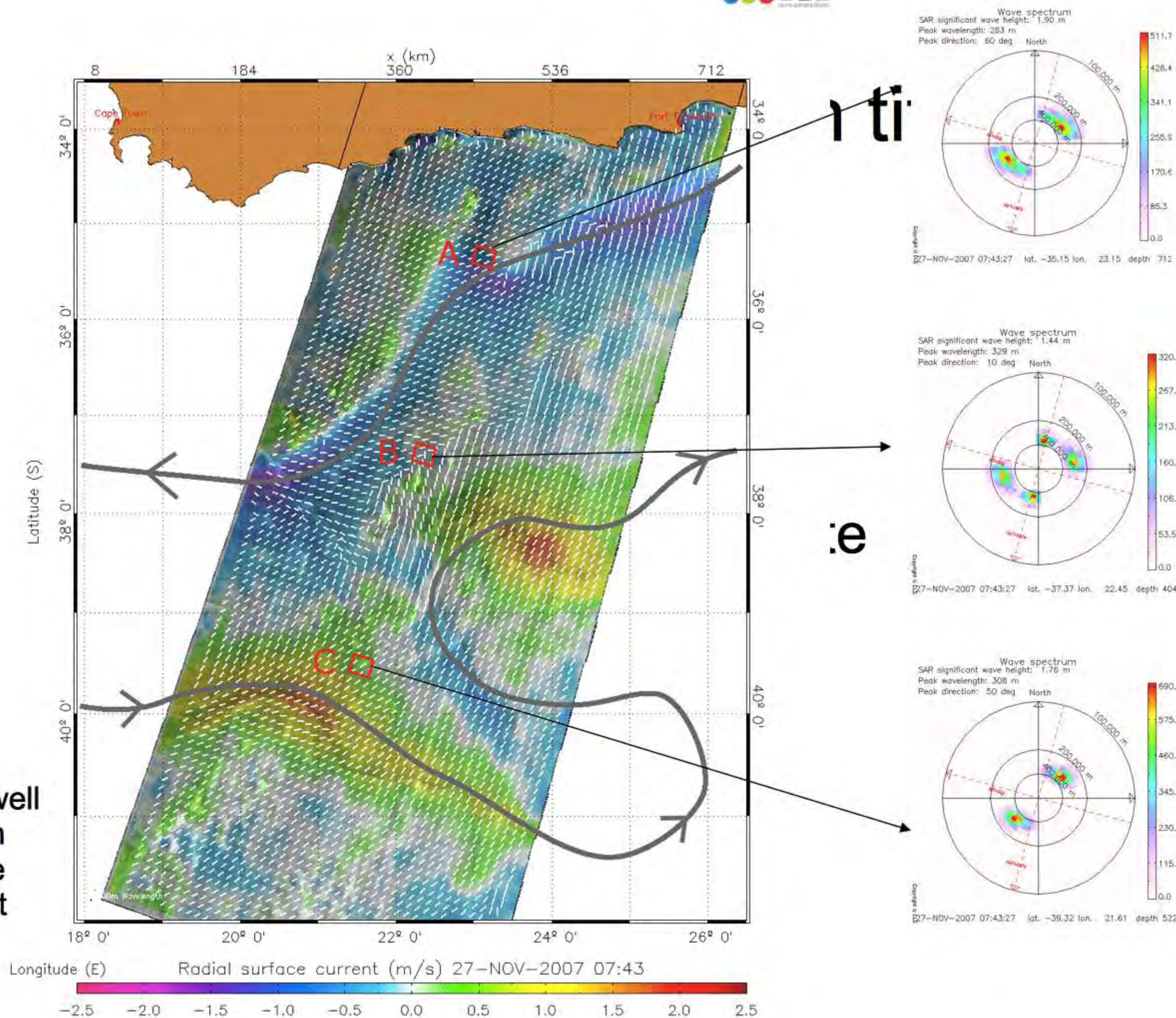


$$\begin{aligned}\partial\tilde{N}(\mathbf{k})/\partial t + c_{gi}\partial\tilde{N}(\mathbf{k})/\partial x_i \\ = \omega^2 k^{-5}\left[\omega^{-1} m_k^{ij} u_{i,j} B_0 - \tilde{B}/\tau + \tilde{\beta} B_0 + \tilde{I}_{sw}\right]\end{aligned}$$

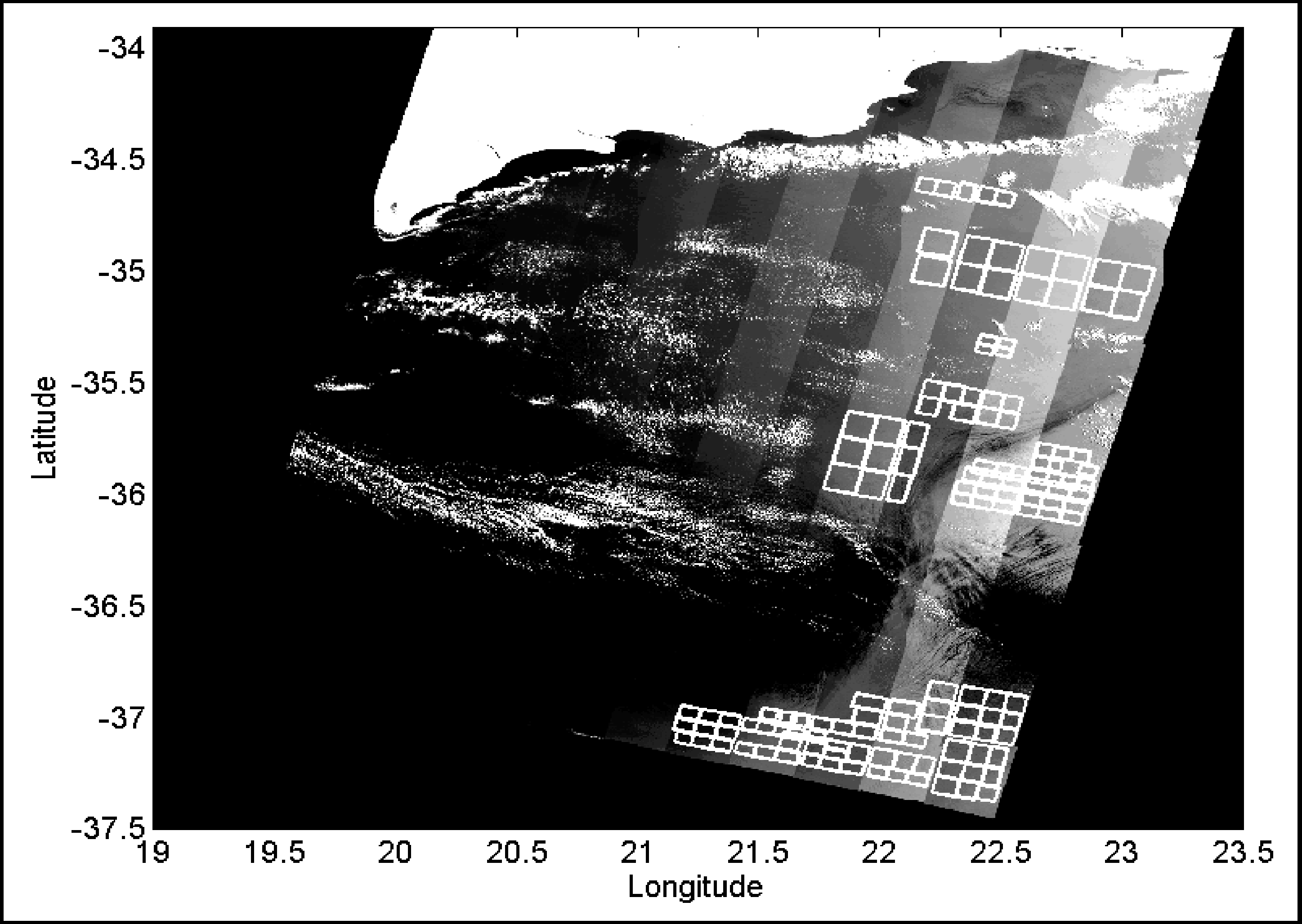
$$m_k^{ij} = k_j \partial \ \ln \ N_0/\partial k_i$$


Incident
swell

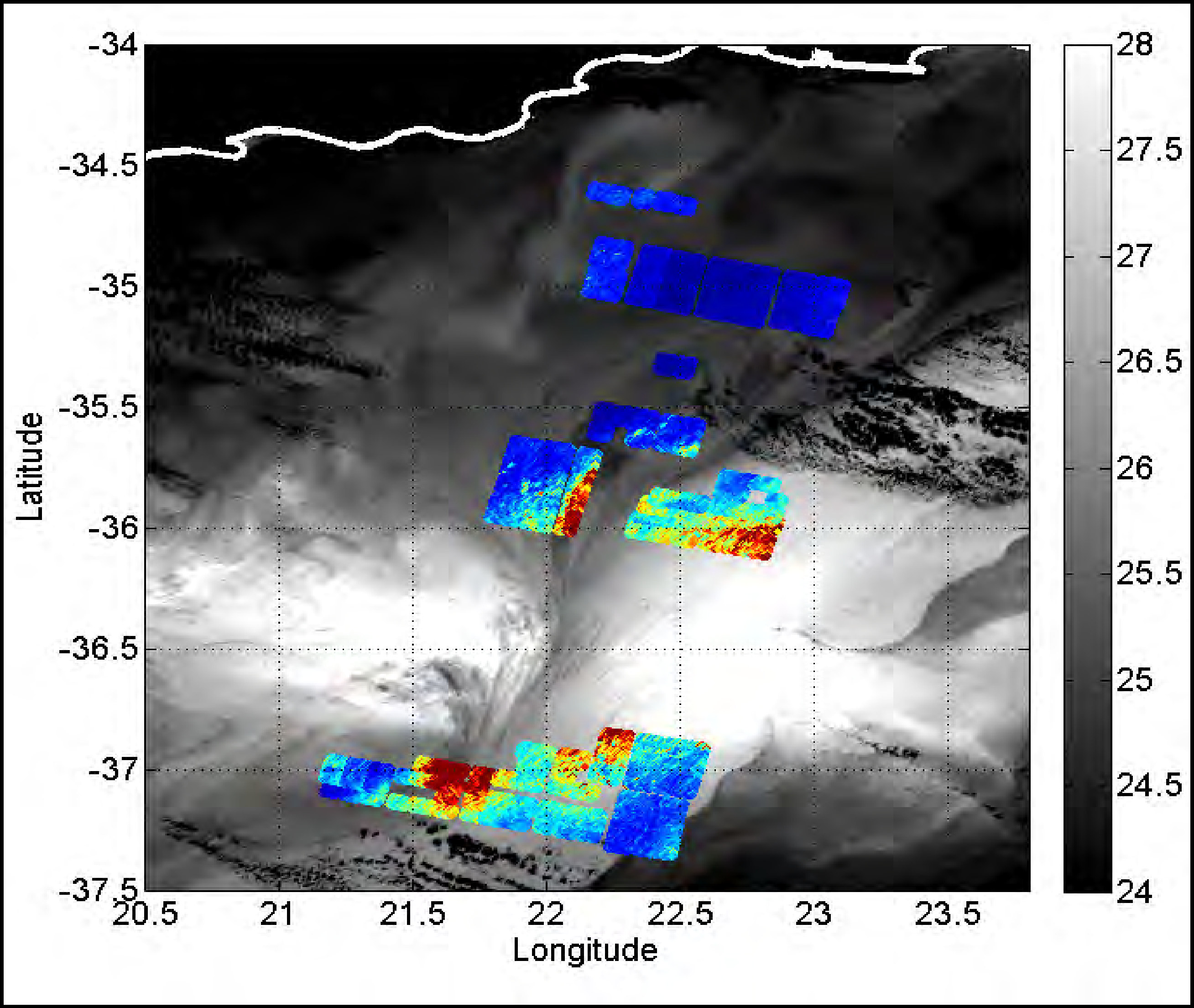

x (km)
8
184
360
536
712
34° 0'
36° 0'
38° 0'
40° 0'
Latitude (S)
18° 0'
20° 0'
22° 0'
24° 0'
26° 0'
Longitude (E)
AVISO Surface current (m/s) CNES DAY : 20110404
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0



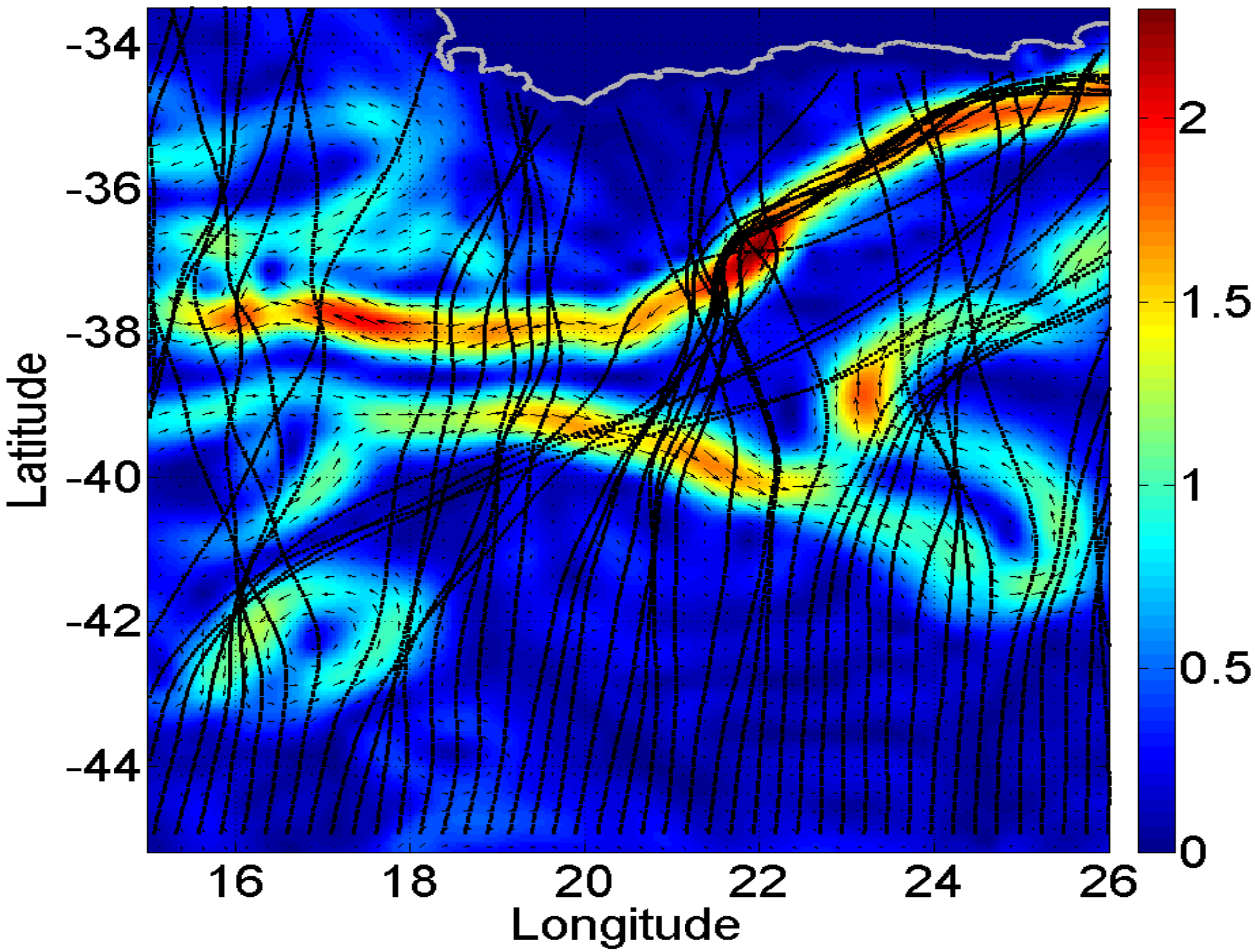
Local swell
direction
As white
segment



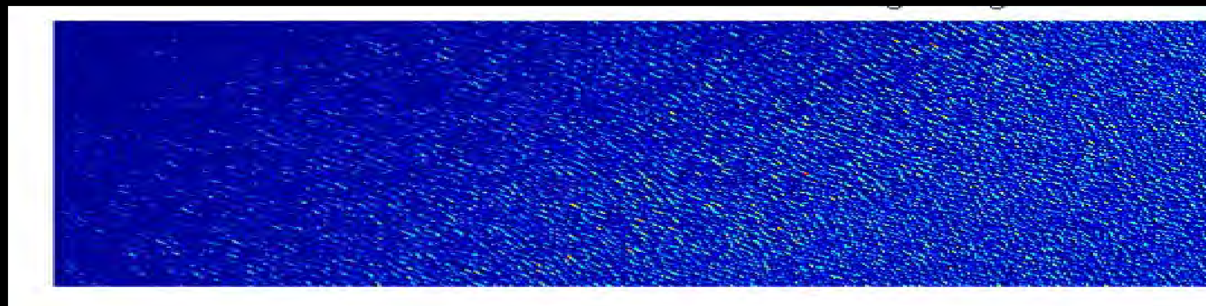
-34
-34.5
-35
-35.5
-36
-36.5
-37
-37.5
Latitude
19
19.5
20
20.5
21
21.5
22
22.5
23
23.5
Longitude

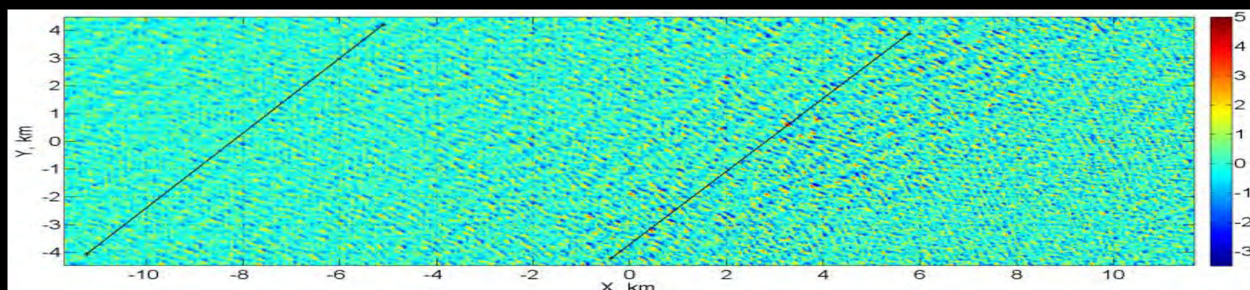


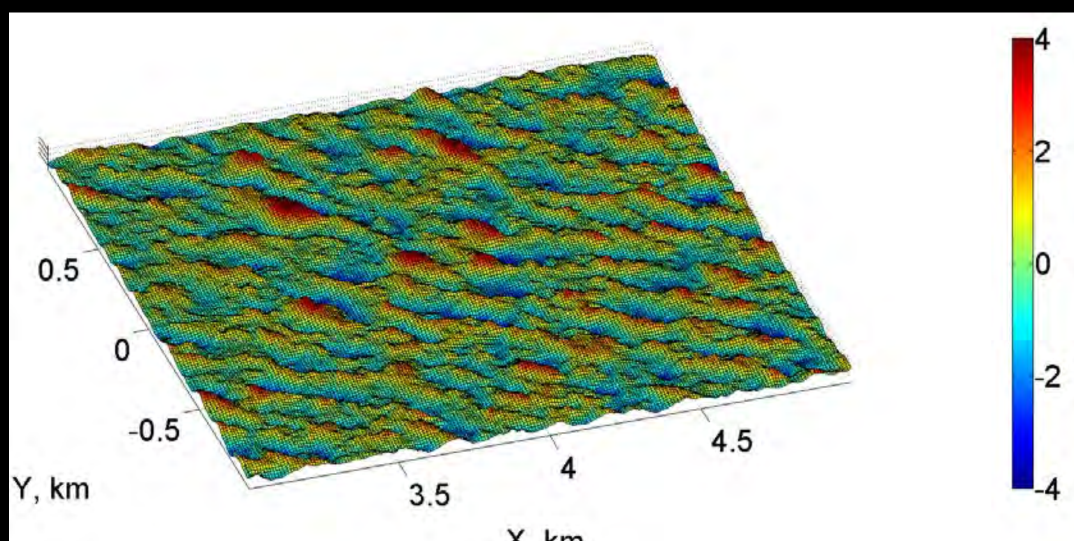
-34
-34.5
-35
-35.5
-36
-36.5
-37
-37.5
Latitude
20.5
21
21.5
22
22.5
23
23.5
Longitude
28
27.5
27
26.5
26
25.5
25
24.5
24

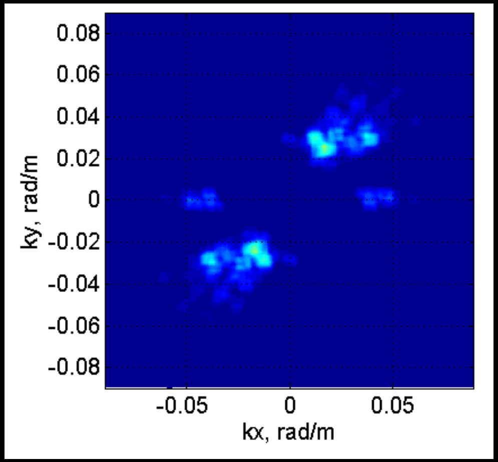


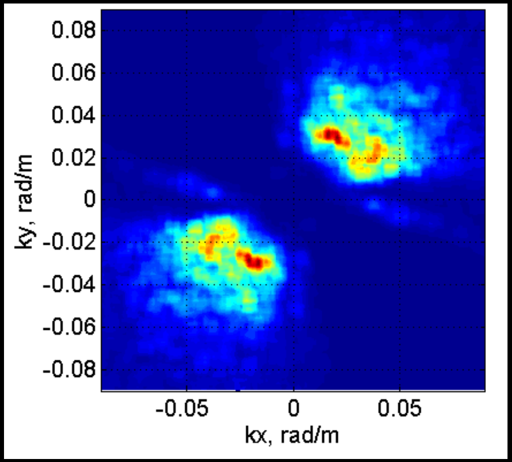
-34
-36
-38
-40
-42
-44
Latitude
16
18
20
22
24
26
Longitude
2
1.5
1
0.5
0

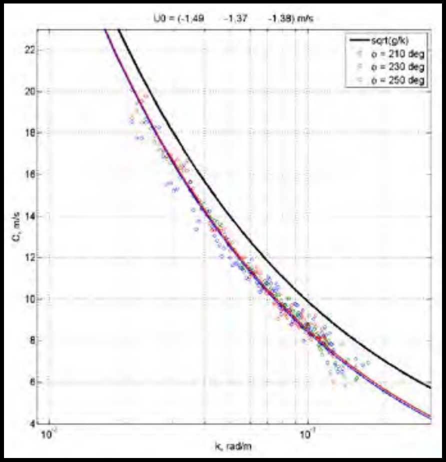


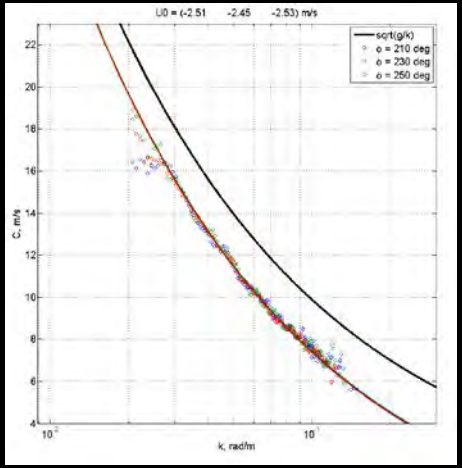

Y, km
4
3
2
1
0
-1
-2
-3
-4
-10
-8
-6
-4
-2
0
2
4
6
8
10
X, km
5
4
3
2
1
0
-1
-2
-3

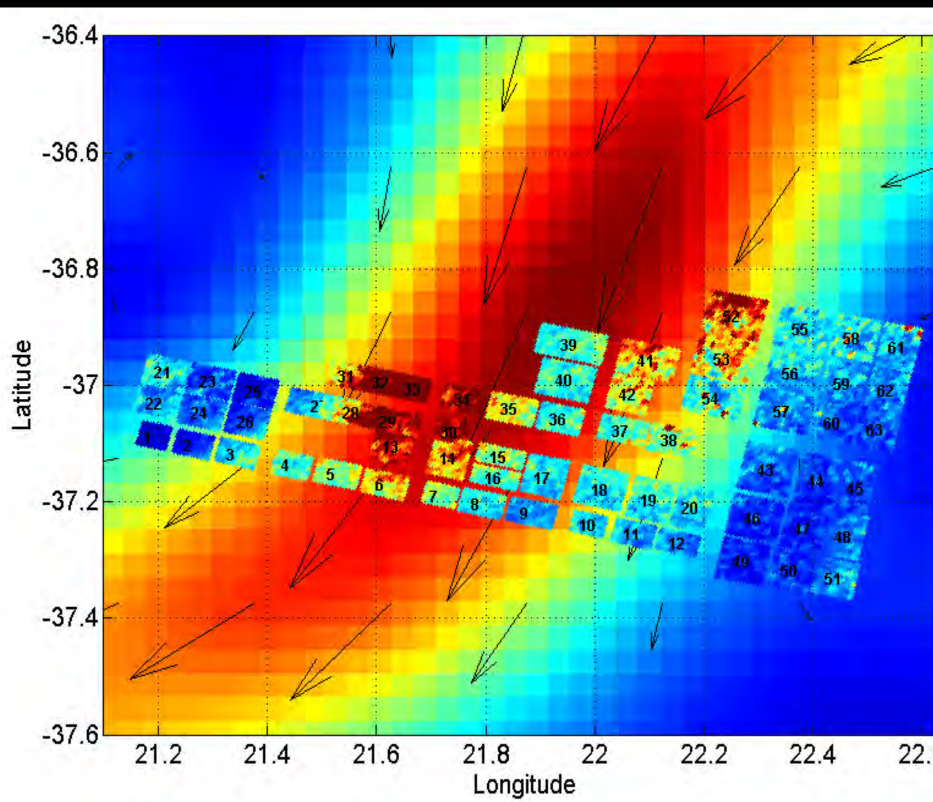

0.5
0
-0.5
Y, km
3.5
4
4.5
X, km
4
2
0
-2
-4


0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
ky, rad/m
-0.05
0
0.05
kx, rad/m

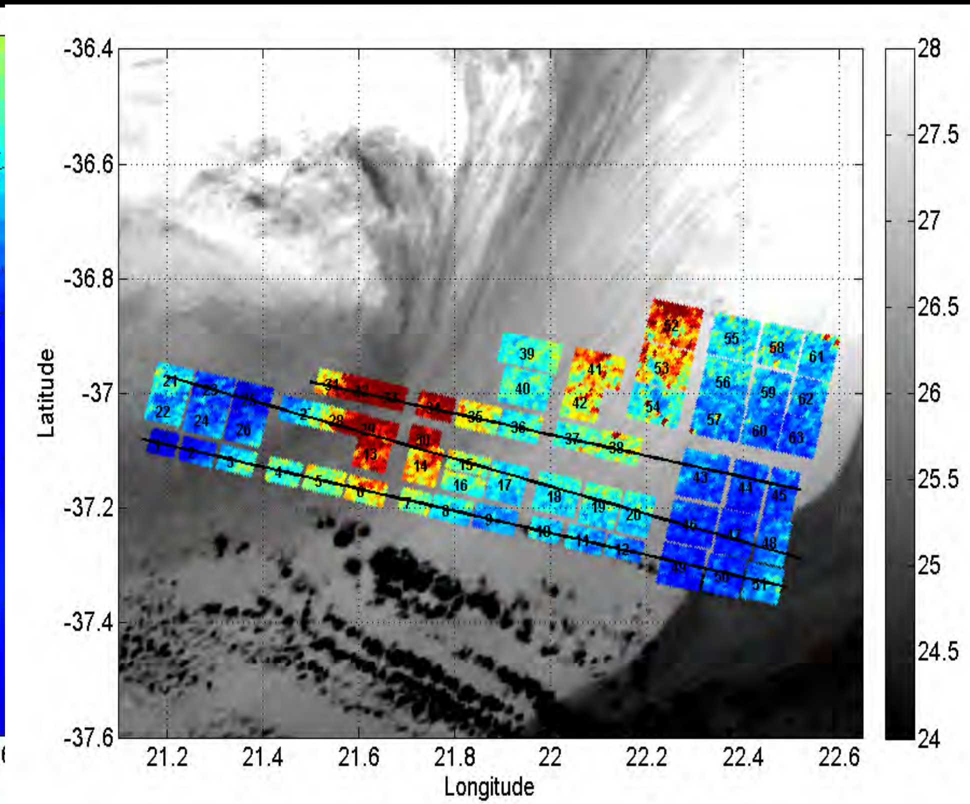

0.08
0.06
0.04
0.02
0
-0.02
-0.04
-0.06
-0.08
ky, rad/m
-0.05
0
0.05
kx, rad/m


U0 = (-1.49 -1.37 -1.38) m/s
sqrt(g/k)
φ = 210 deg
φ = 230 deg
φ = 250 deg
C, m/s
k, rad/m


U0 = (-2.51 -2.45 -2.53) m/s
sqrt(g/k)
φ = 210 deg
φ = 230 deg
φ = 250 deg
C, m/s
k, rad/m



Latitude
Longitude
-36.4
-36.6
-36.8
-37
-37.2
-37.4
-37.6
21.2
21.4
21.6
21.8
22
22.2
22.4



Latitude
Longitude
-36.4
-36.6
-36.8
-37
-37.2
-37.4
-37.6
21.2
21.4
21.6
21.8
22
22.2
22.4
22.6
28
27.5
27
26.5
26
25.5
25
24.5
24

Main message …

- Today ideal instrument … (wide-swath, high-resolution, topography, roughness, Doppler, emissivity, reflectance, …) = the combined use of observations, including in situ measurements
- Very (too) large number of spatio-temporal scales under local and non-local interactions
- Improved technologies (instruments, resolution, computer capabilities, storage, dissemination) all contribute to improved combined analysis
- Theoretical frameworks and numerical simulations can be used to assess the causes and contexts of the different observations (including sensor physics, observability conditions and instrument capabilities), to refine dynamical/statistical gap filling methods
- New challenges, new altimeter instruments (SARAL, Sentinel-3, SWOT, …, CubeSat opportunities) and combined roughness contrasts as local quantitative proxies to trace strong surface gradient areas

Et encore ... *Towards an observation-driven framework*

Thematically-driven Mining applications shall rapidly emerge to avoid the data deluge, and to emphasize the synergy between observations (in situ and satellite), numerical simulations and theoretical developments

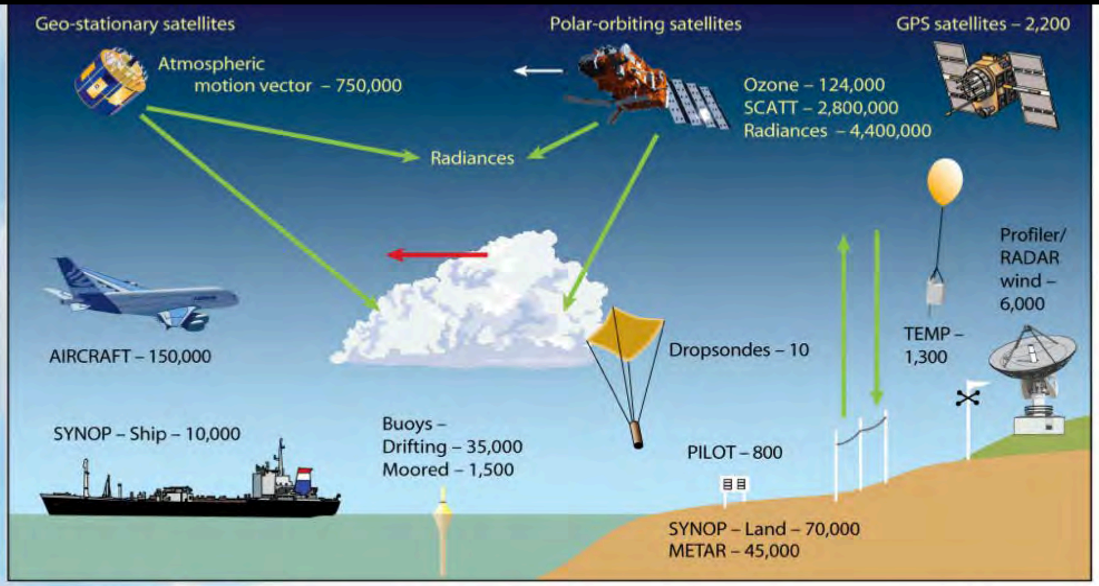
'collaborative' efforts to promote future developments to avoid (limit) computation burden and/or (redundant) archive volume growth.

Data on an EO-'cloud' and software utilities/applications more efficiently developed to search, process, visualize, analyze the data in a common approach.

Usual discussions – the need for standard data formats, metadata conventions, open access etc.

Data Ecosystem

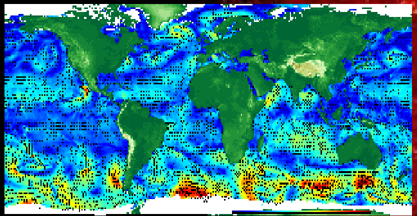
In situ

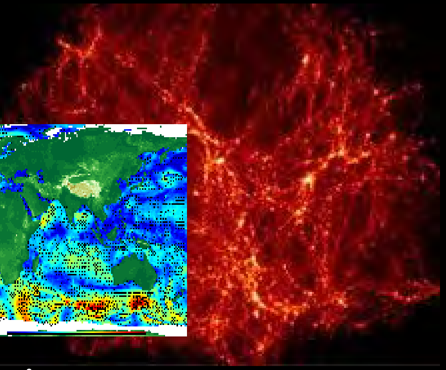


Data sources for the ECMWF Meteorological Operational System (EMOS)

In vivo

Données sociétales et économiques





In silico

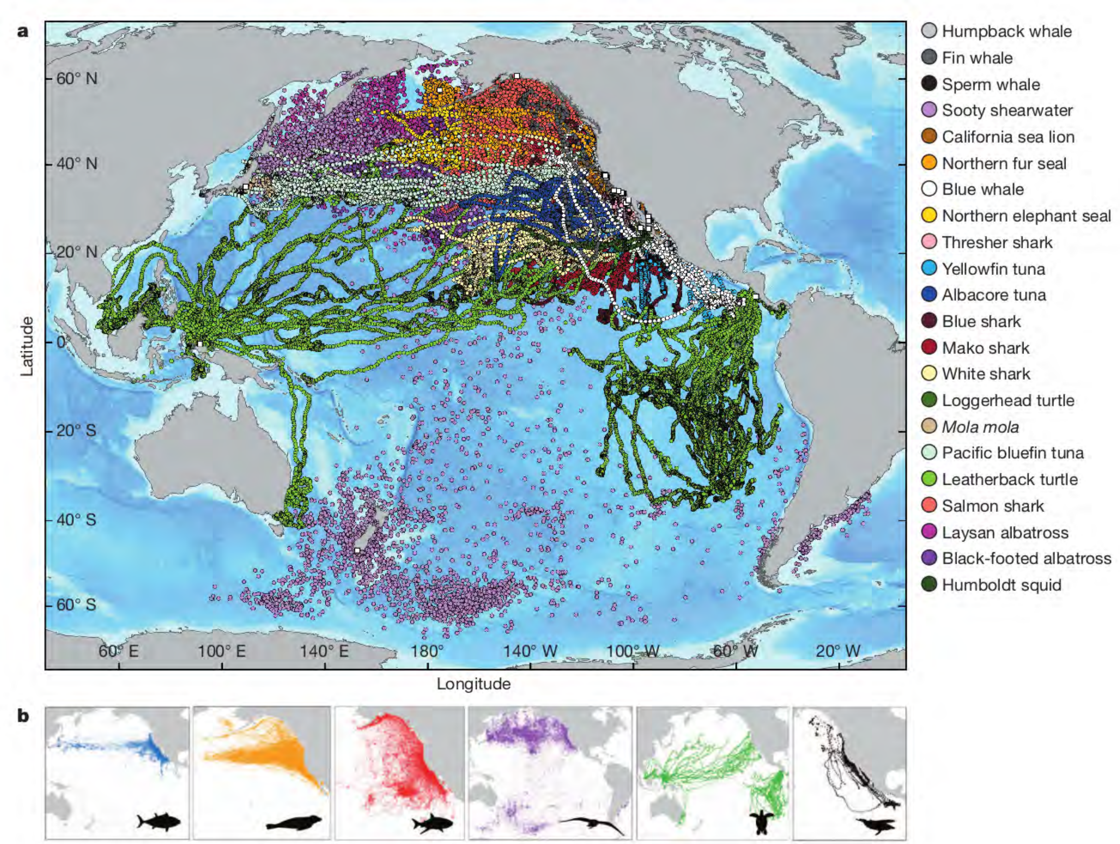
Altimetry for ecology 2: the invisible landscape

LETTER

doi:10.1038/nature10082

Tracking apex marine predator movements in a dynamic ocean

B. A. Block[1], I. D. Jonsen[2], S. J. Jorgensen[1], A. J. Winship[2], S. A. Shaffer[3], S. J. Bograd[4], E. L. Hazen[4], D. G. Foley[4], G. A. Breed[2,5], A.-L. Harrison[5], J. E. Ganong[1], A. Swithenbank[1], M. Castleton[1], H. Dewar[6], B. R. Mate[7], G. L. Shillinger[1], K. M. Schaefer[8], S. R. Benson[9], M. J. Weise[5], R. W. Henry[5] & D. P. Costa[5]



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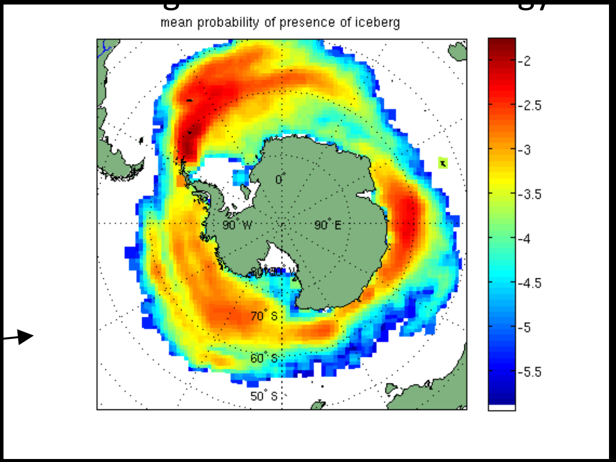
In their displacements, top predators encounter environmental heterogeneity at multiple scales.

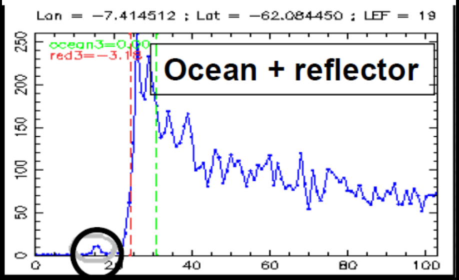
Until now, observations where sparse, and matched large-scale current information was enough

Extracting new knowledge

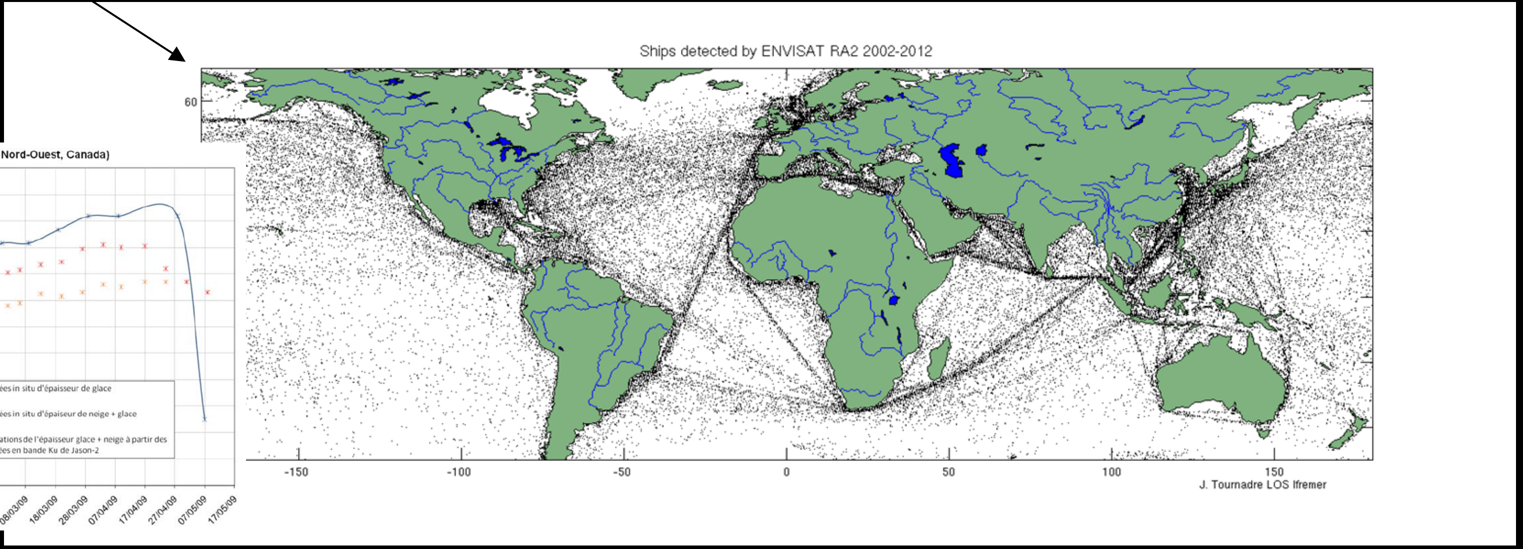
Analysis of altimeter wave forms :
ERS 1 & 2, Envisat, Jason 1 & 2, Cryosat, AltiKa (12 TB)

Disposing of a sandbox with permanent access to all data and processing power greatly ease bridging the gap between initial idea and full demonstration / long term assessment

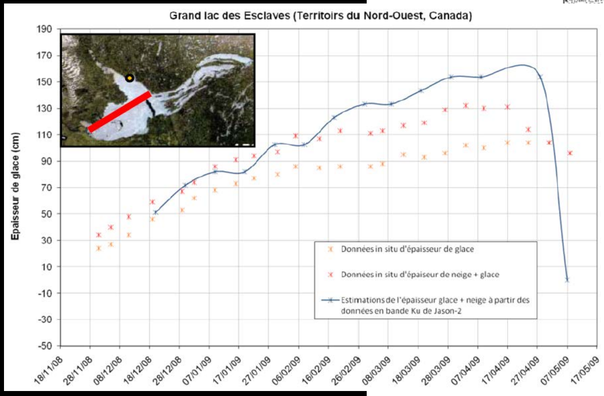




Ship detection

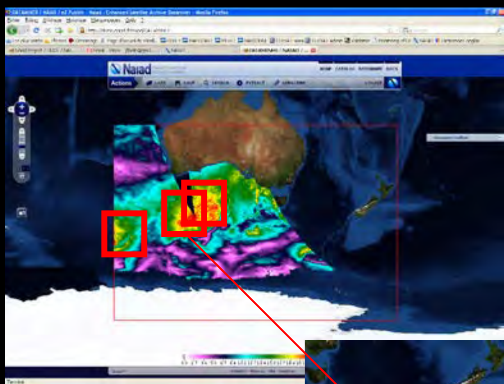
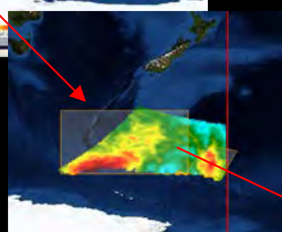


Lake ice thickness

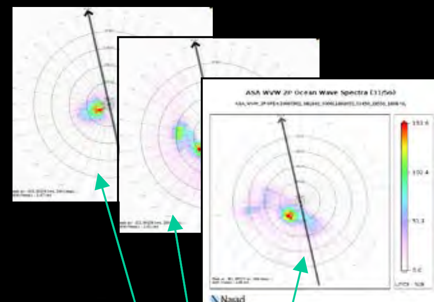


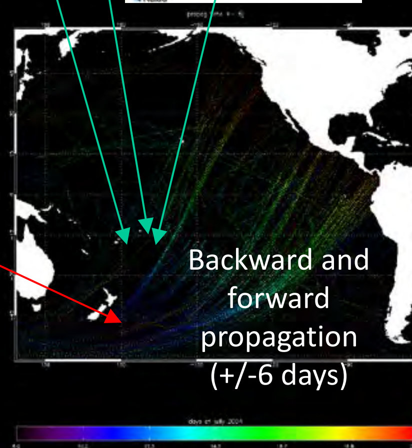
Big questions....

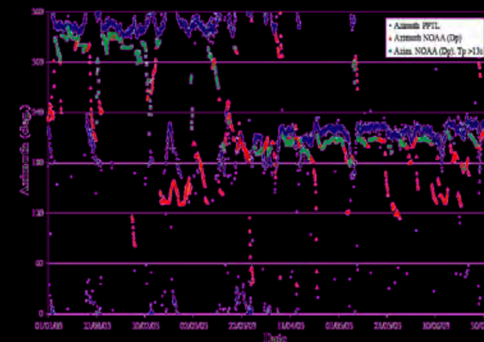
Are storms more numerous and intensifying with climate change ?

Scatterometer and SAR (20 years)

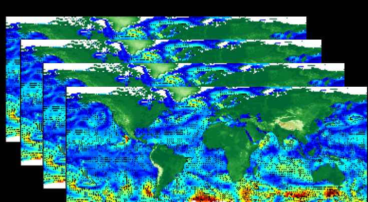




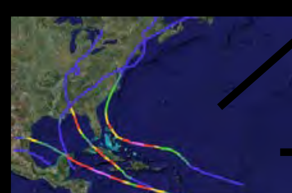


Seismic noise (50 years)

Buoys (30 years)



Weather model (25 years)



Feature and tracks extraction