Nicolas Rascle

«Horizontal distribution of air-sea exchange parameters inferred from satellite images of sea surface roughness »

Position since 2012: postdoc at IFREMER, Brest, France

Collaborations:

Remote sensing expertise: Bertrand Chapron, Alexis Mouche, Fabrice Collard

Wave expertise: Fabrice Ardhuin, Frédéric Nouguier

Ocean expertise: Jeroen Molemaker, Louis Marié, Aurélien Ponte

«Horizontal distribution of wave-induced turbulence »

Surface turbulence, transfer velocities…

«Horizontal distribution of wave-induced turbulence »

Surface turbulence, transfer velocities…

How patchy are they?

Aerial picture during Gulf of Mexico experiment LASER 2016

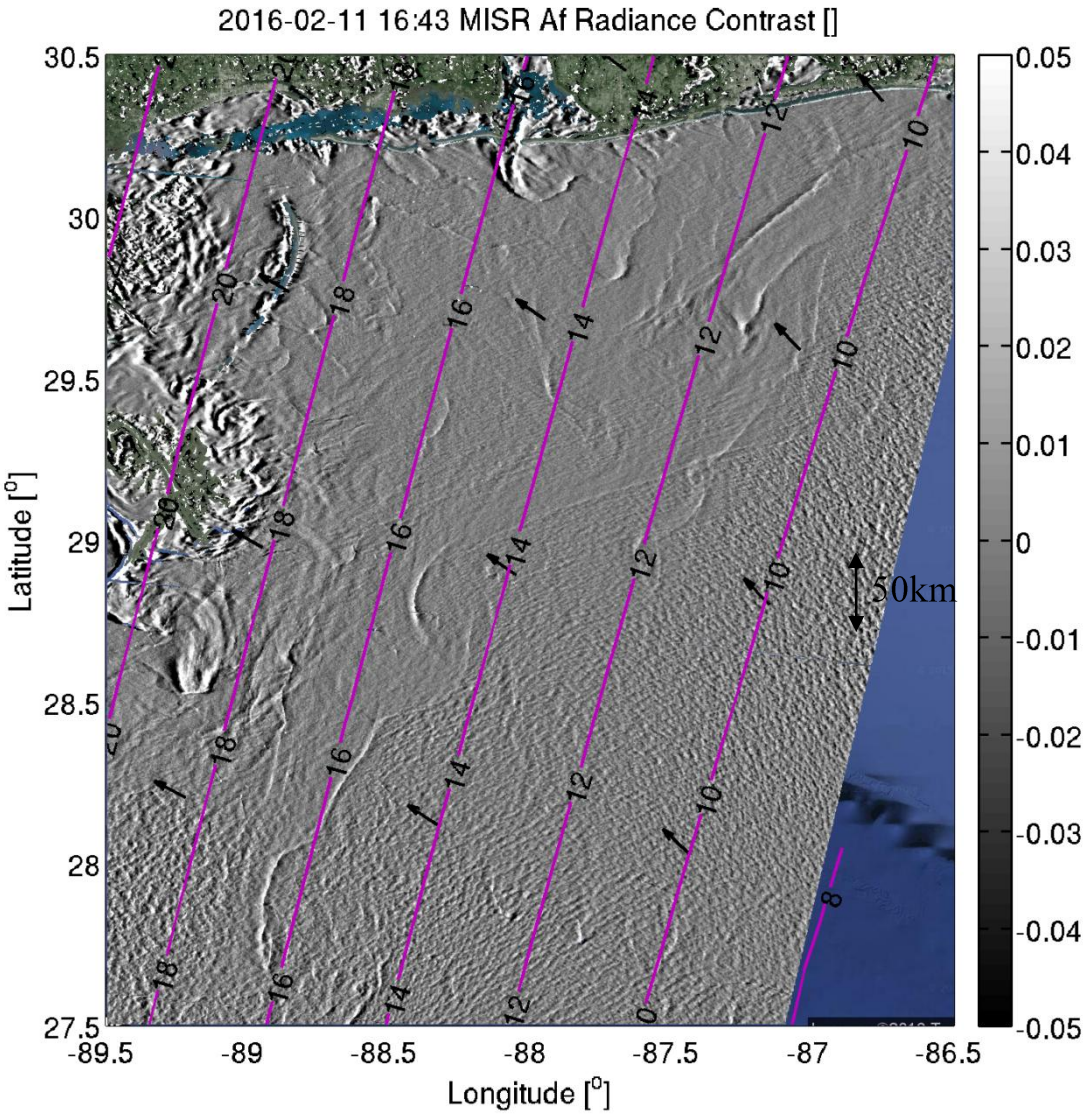
«Horizontal distribution of wave-induced turbulence »

Surface turbulence, transfer velocities…

How patchy are they?

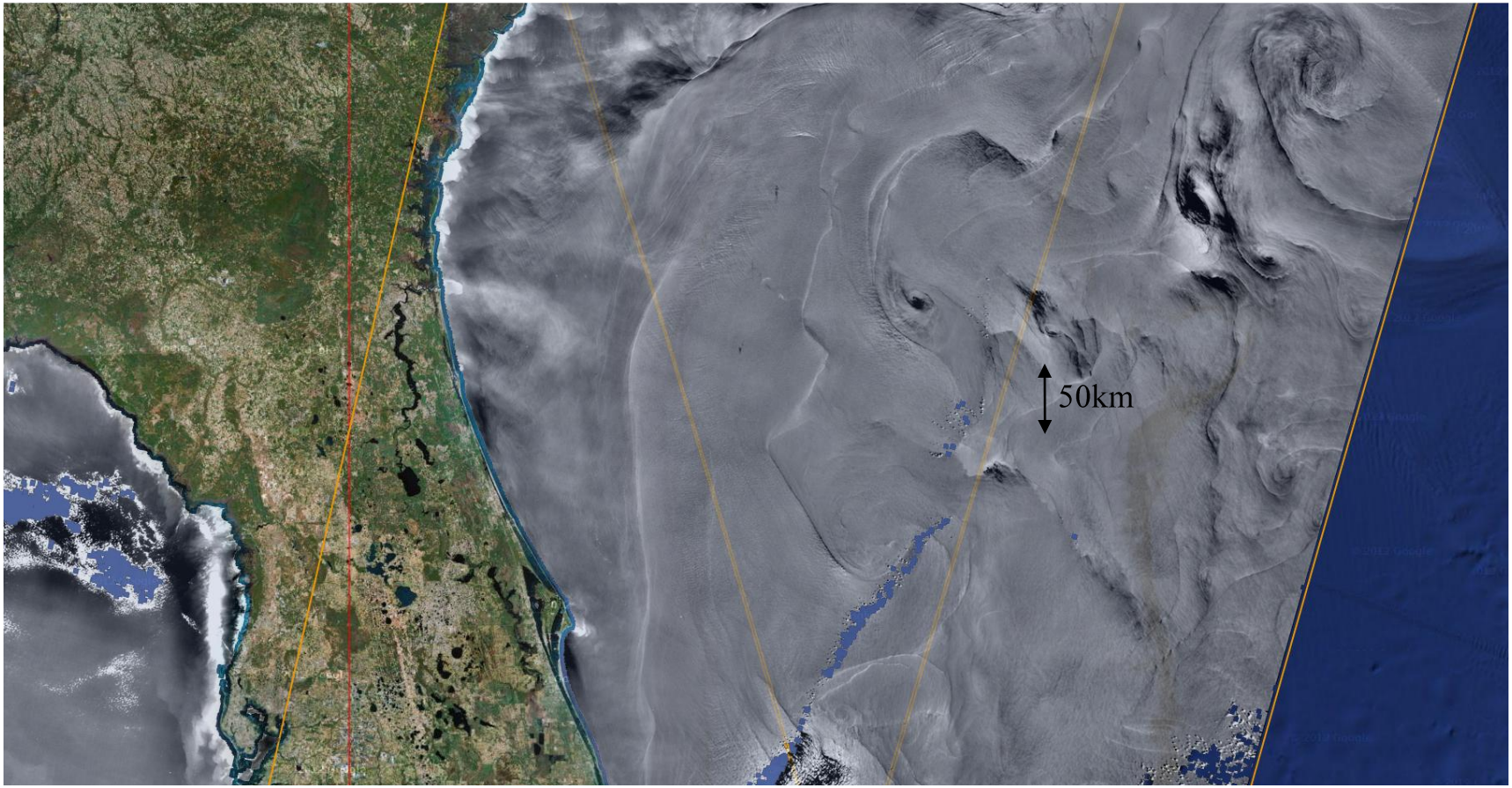
Aerial picture during Gulf of Mexico experiment LASER 2016

Introduction



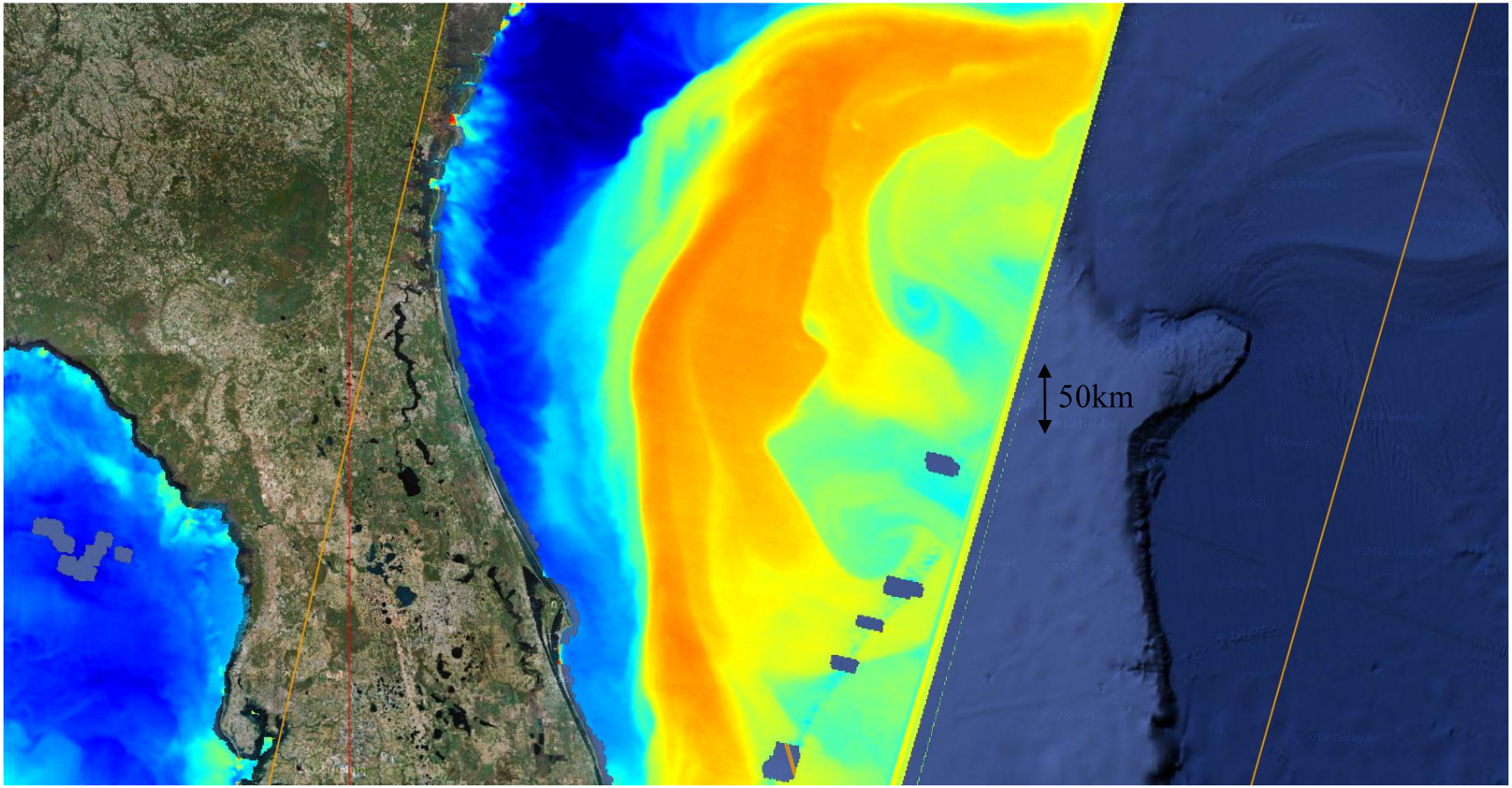
Satellite surface roughness during Gulf of Mexico experiment LASER 2016

Introduction



Surface roughness, sun glitter, Meris
(250m)

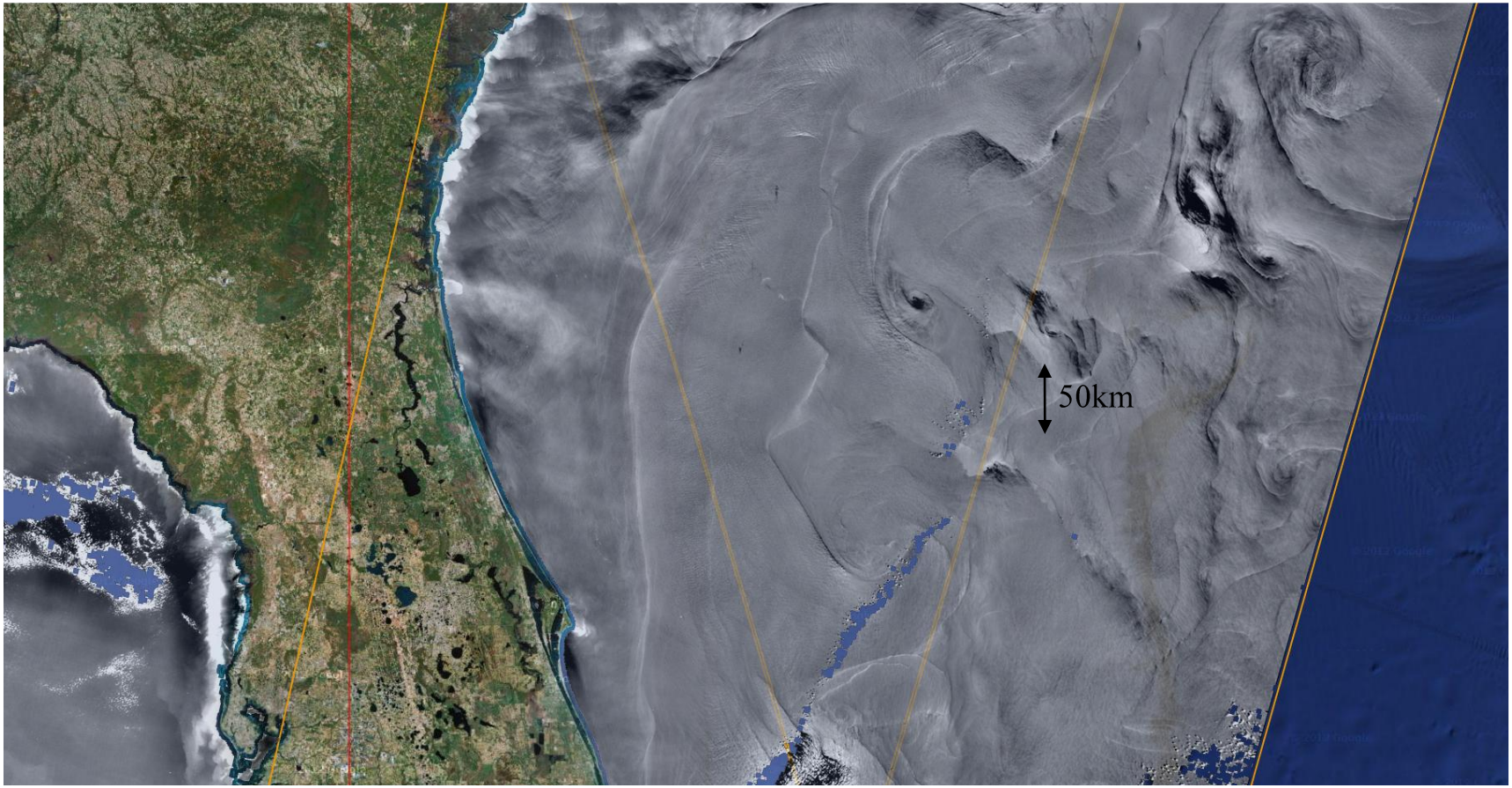
Introduction



SST, Modis (250m)

Introduction

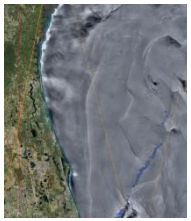
Far from horizontally homogeneous…



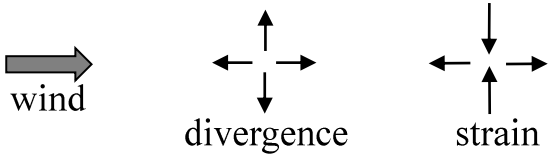
Surface roughness, sun glitter, Meris (250m)

Outline

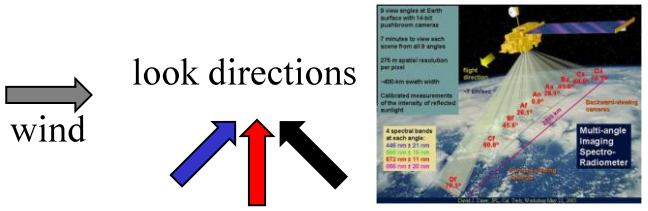
1) Introduce roughness images



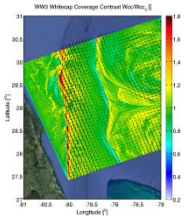
2) Surface roughness and current deformations



3) Observing at multiple azimuth view angles



4) Surface roughness and air/sea fluxes horizontal distributions



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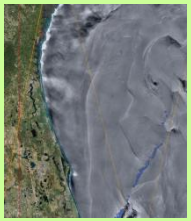

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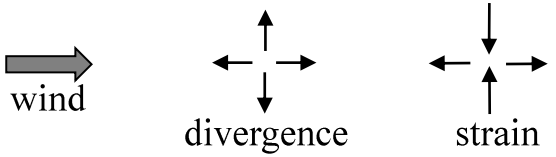

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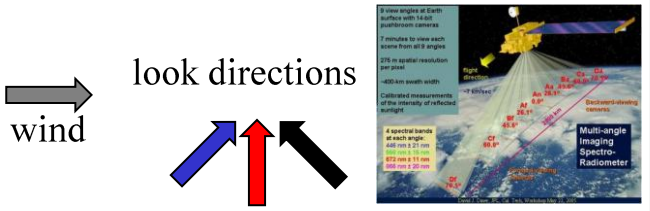

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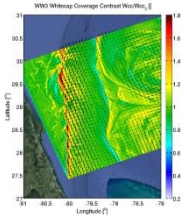


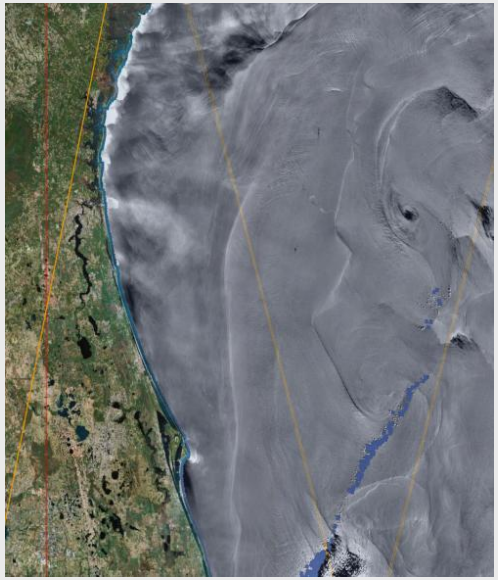
1) Surface roughness

Surface roughness images

- radar (SAR): intensity of the backscatter (σ_0), similar to scatterometry

or

- optical radiometer : intensity of the radiance of the sun glitter (Meris, Modis,…)

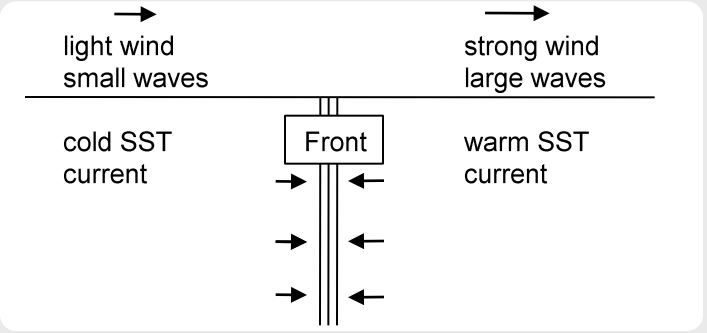


Meris glitter

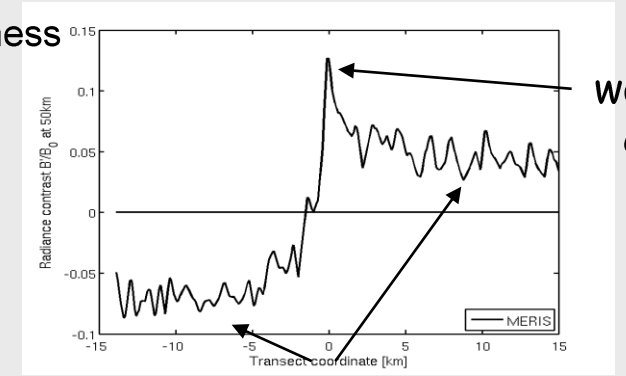
≠

Essentially related to the variance of the slope (MSS =mean square slope mean surface slope) of short waves (roughly 1cm -1 m)
Those waves are related to local **wind** and **current** (and surfactants)

1) Surface roughness

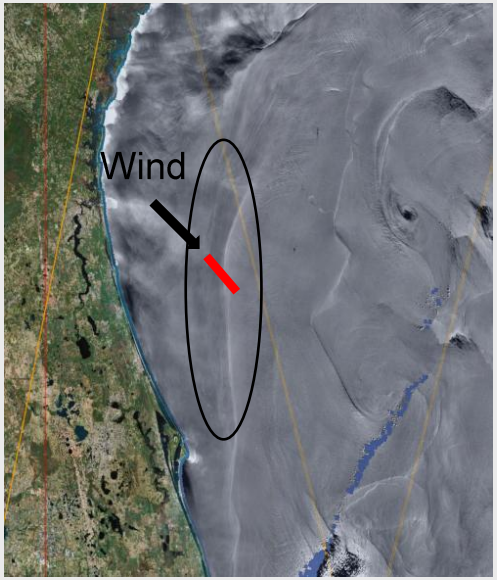


Roughness



wave refraction by current gradient at scales < 5 km

wind-SST coupling at scales > 10 km



Meris glitter

Essentially related to the surface slope (mean square slope MSS) of short waves (roughly 1cm -1 m)
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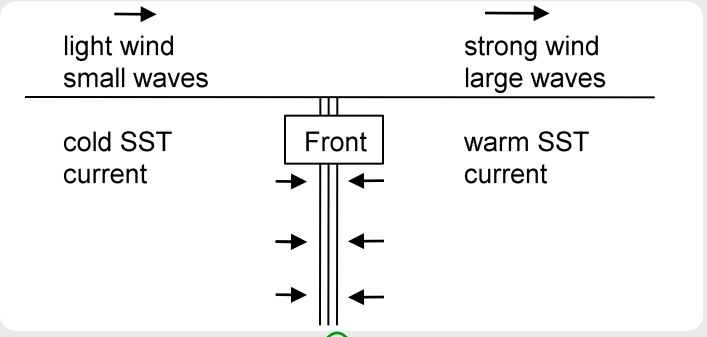

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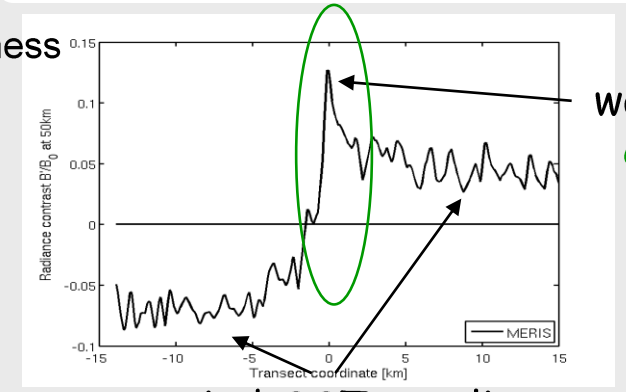

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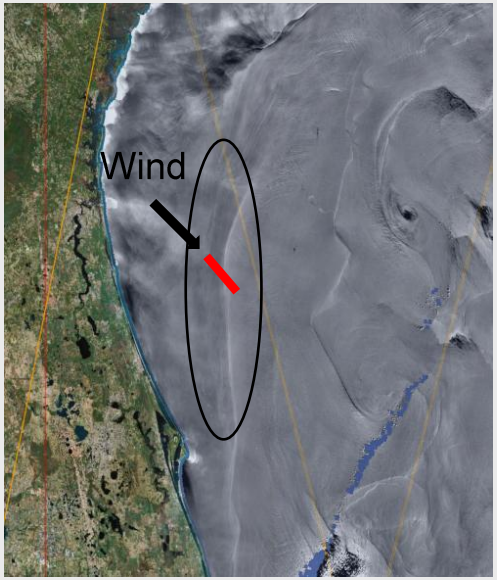

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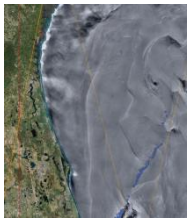
2) Roughness and current deformation properties

1) Introduce roughness images



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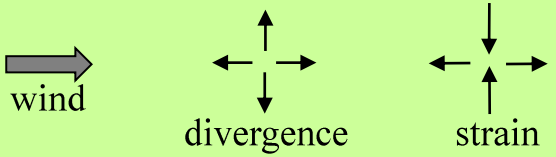

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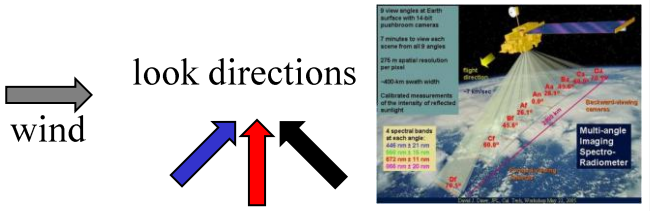

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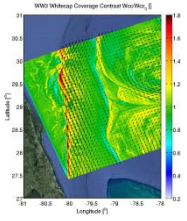
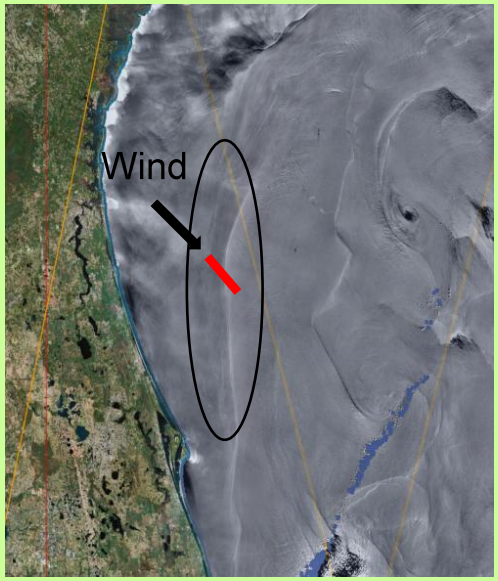


2) Roughness and current deformation properties

"Current gradient"
Which deformation property of the surface currents?



Meris glitter

Wind waves in the presence of current

2) Roughness and current deformation properties

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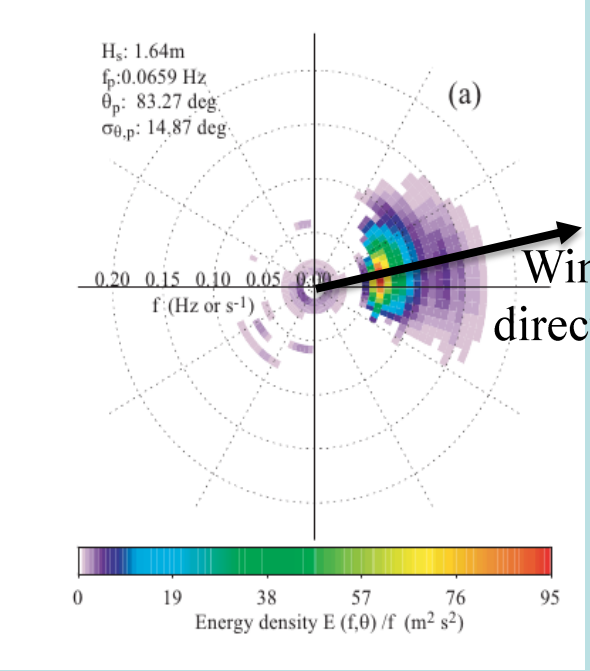
Wind waves in the presence of current

Background wave spectrum



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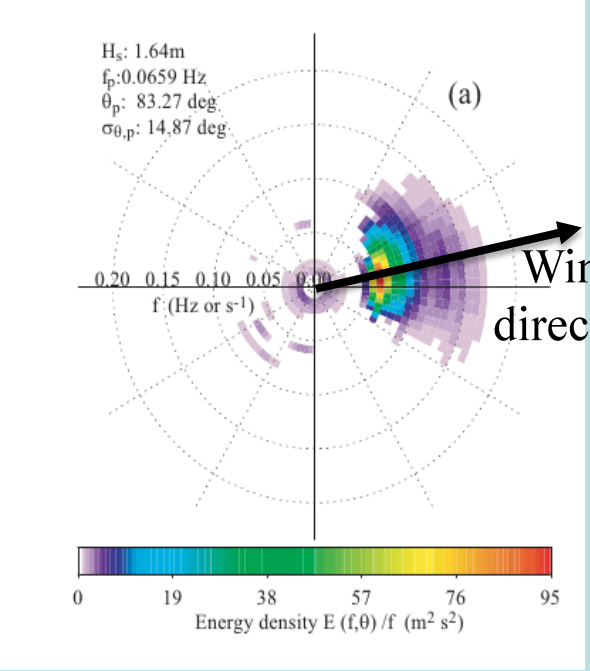

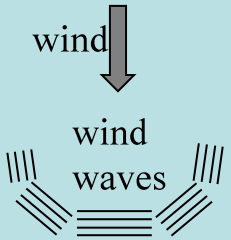

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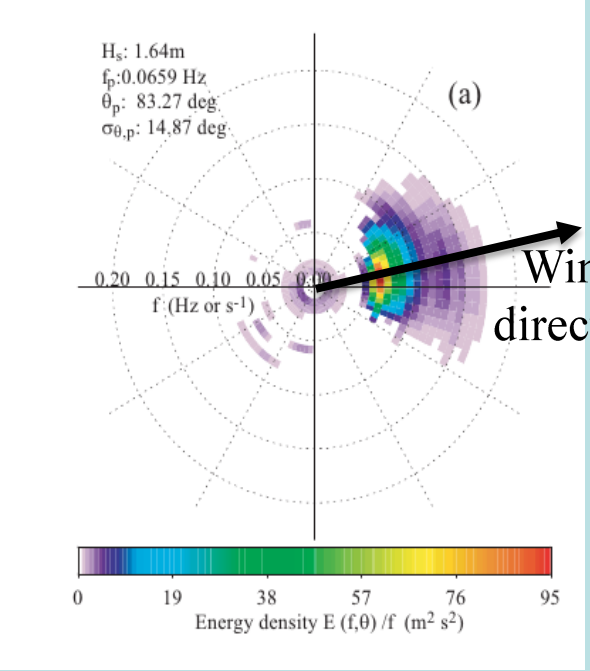

Wind waves in the presence of current

1) Conservation of wave action

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

Propagation | Current gradient | Sources, Sinks (wind, breaking,...)

2) Approximate relaxation solution

$$\tilde{N}(\mathbf{x}, k, \phi) = \tau_c \begin{bmatrix} \cos\phi & \sin\phi \end{bmatrix} \begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} \begin{bmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{bmatrix} \begin{bmatrix} \frac{\partial N_0}{\partial \ln k} \\ \frac{\partial N_0}{\partial \phi} \end{bmatrix}$$

- for small anomalies
- neglecting propagation (i.e. local)

3) Surface roughness

$$\widetilde{mss}_x(\mathbf{x}) = \int_k \int_\phi \omega^{-1} k \tilde{N} \; k^2 \cos^2\phi \; \mathrm{dkd}\phi$$

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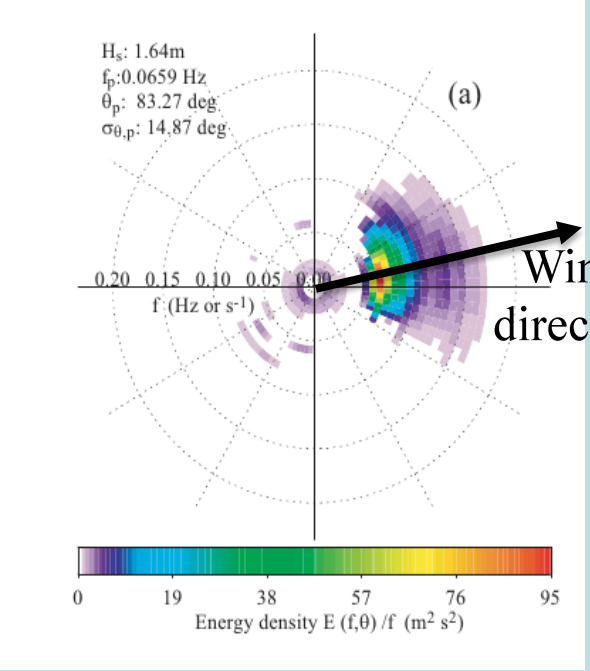
Wind waves in the presence of current

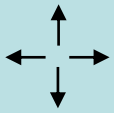
Background wave spectrum



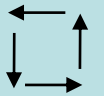
4) Separation of the current gradient into 4 types :

$$\begin{bmatrix} \frac{\partial u}{\partial x} & \frac{\partial u}{\partial y} \\ \frac{\partial v}{\partial x} & \frac{\partial v}{\partial y} \end{bmatrix} = \frac{1}{2}\begin{bmatrix} D+S_t & -R+S_h \\ R+S_h & D-S_t \end{bmatrix}$$

divergence

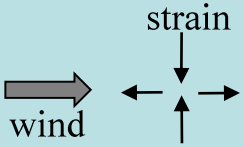


vorticity



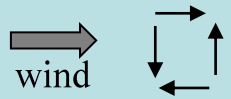
$$D = \frac{\partial u}{\partial x}+\frac{\partial v}{\partial y},\ S_t = \frac{\partial u}{\partial x}-\frac{\partial v}{\partial y},$$
$$R = \frac{\partial v}{\partial x}-\frac{\partial u}{\partial y},\ S_h = \frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}.$$

strain



wind

wind



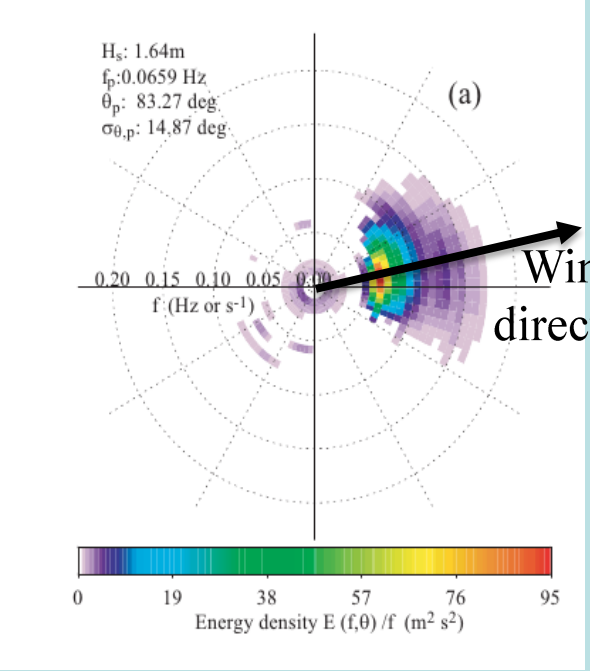
shear

2) Roughness and current deformation properties

"Current gradient"
Which deformation property of the surface currents?

Wind waves in the presence of current

Background wave spectrum



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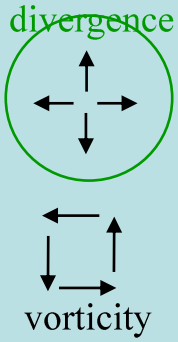

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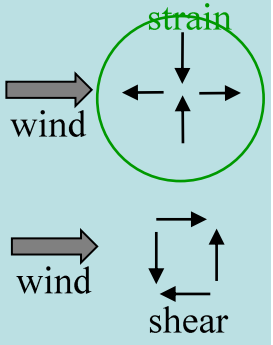
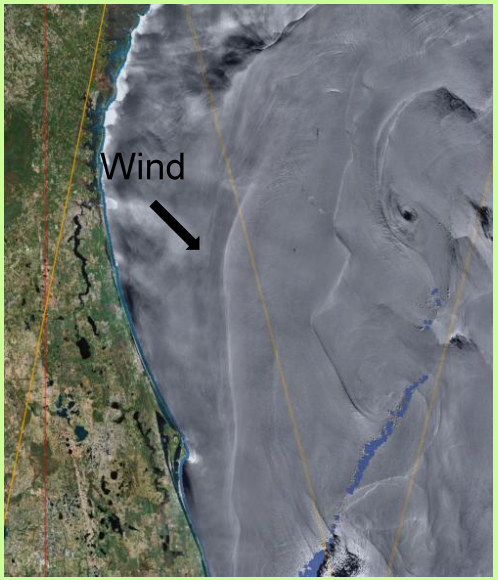


-> For a spectrum symmetrical about the wind direction: Only 2 over 4 types of current deformations will sign on roughness images (details in Rascle et al 2014 JPO)

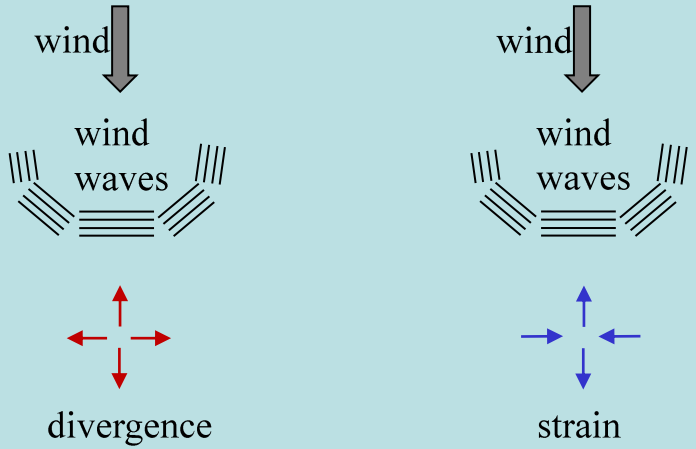
2) Roughness and current deformation properties

"Current gradient"
Which deformation property of the surface currents?



Meris glitter

Roughness images show the interactions of wind waves with current divergence and strain in the wind direction.



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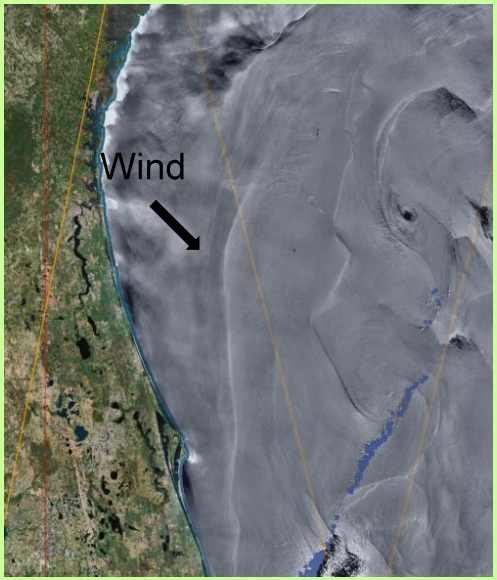

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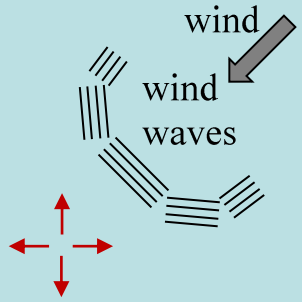
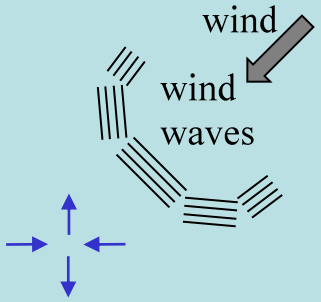


divergence



strain

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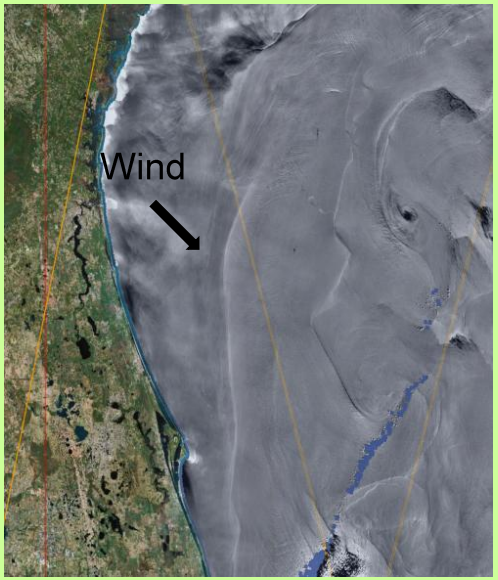

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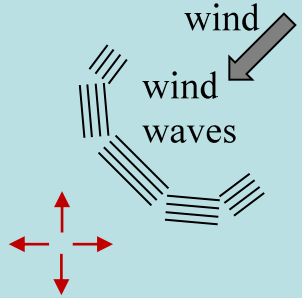

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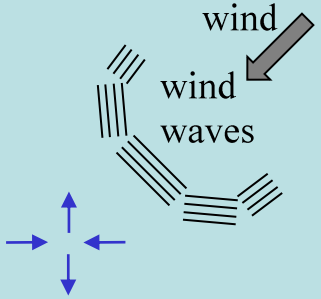

strain

Divergent currents appear independently of the wind direction

Strained currents appear with a 45°-sensitivity to the wind / current angle

Sensitivity of the imaging mechanism to the angle wind / current

2) Roughness and current deformation properties

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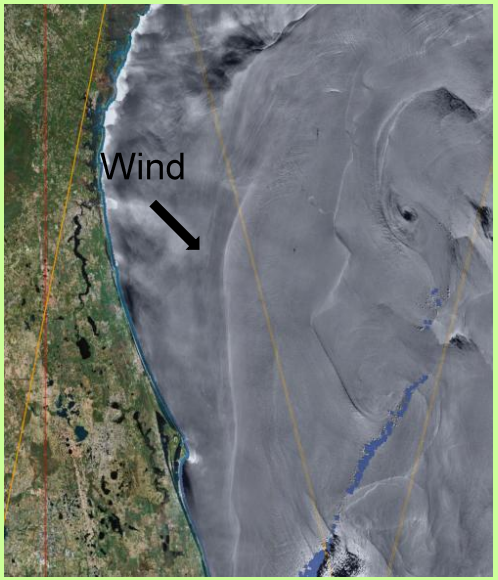

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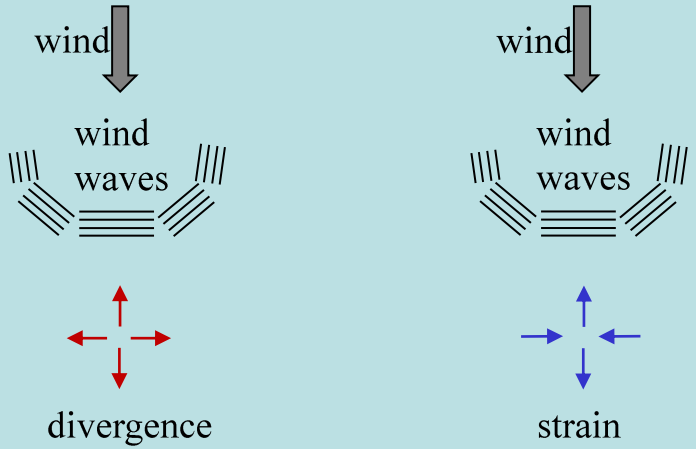

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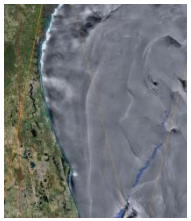
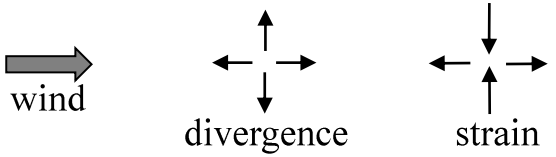
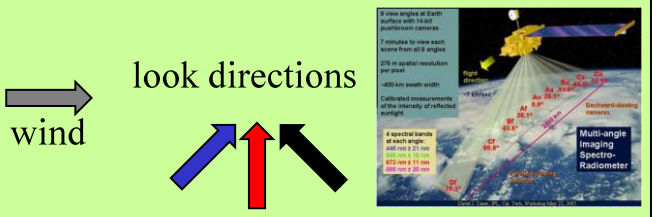
1) Introduce roughness images



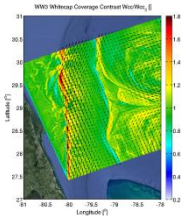
2) Surface roughness and current deformations



3) Observing at multiple azimuth view angles



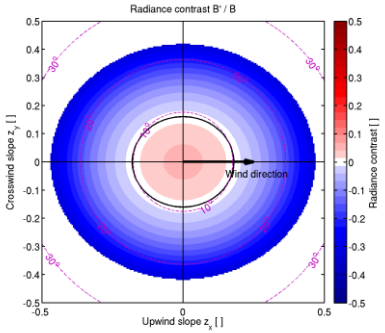
4) Surface roughness and air/sea fluxes horizontal distributions



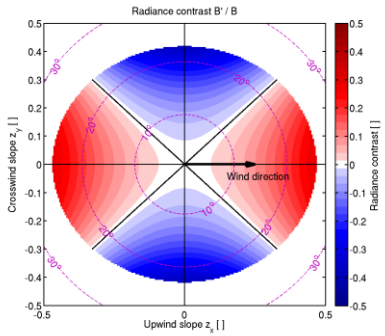
3) Multiple view angles

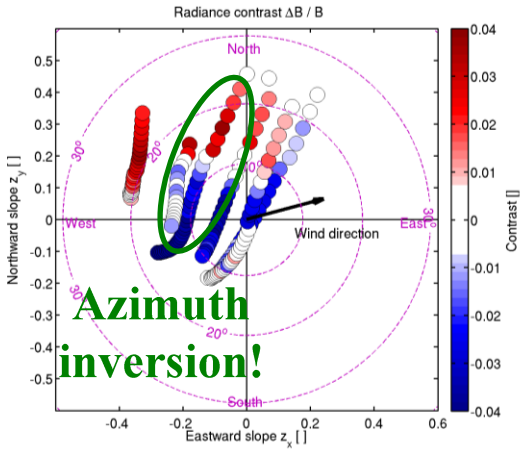
Also a sensitivity of the imaging mechanism on the azimuth view angle (satellite position)

Divergence



Strain



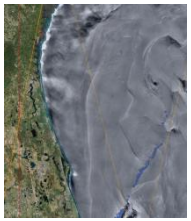


Azimuth inversion!

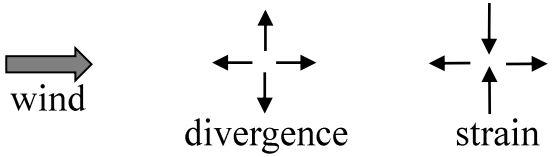
Airborne measurements using visible cameras within the sun glint
with J. Molemaker, L. Marié and O. Ménage

3) Multiple view angles

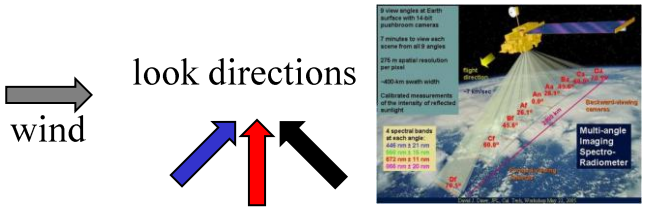
1) Introduce roughness images



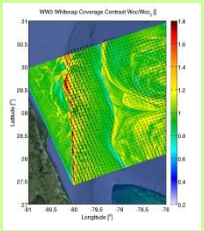
2) Surface roughness and current deformations



3) Observing at multiple azimuth view angles

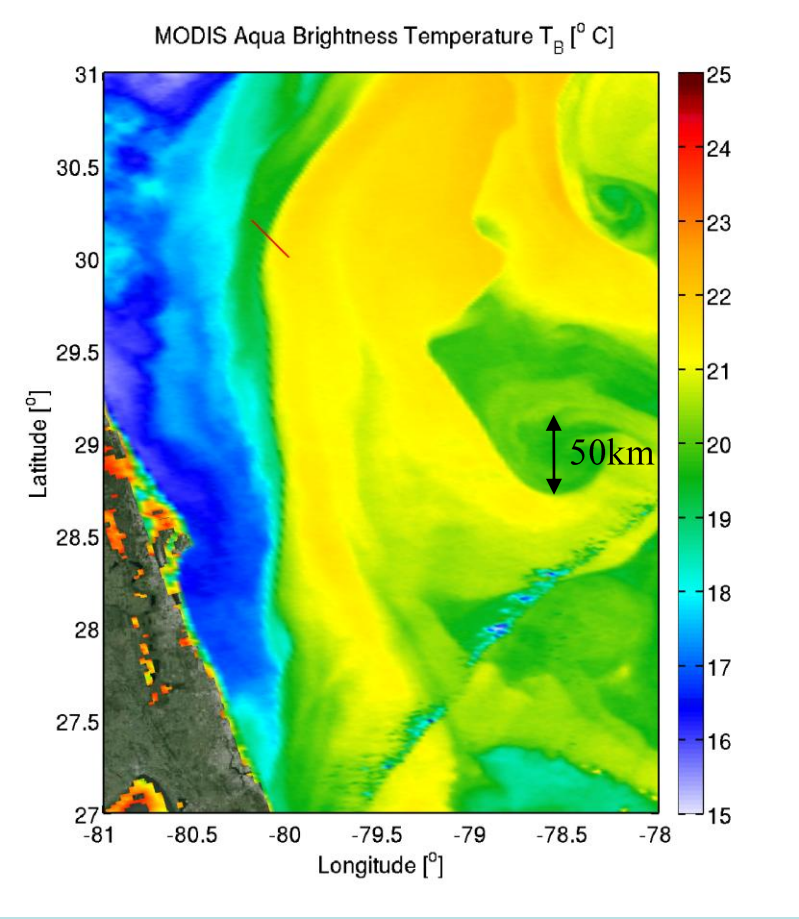


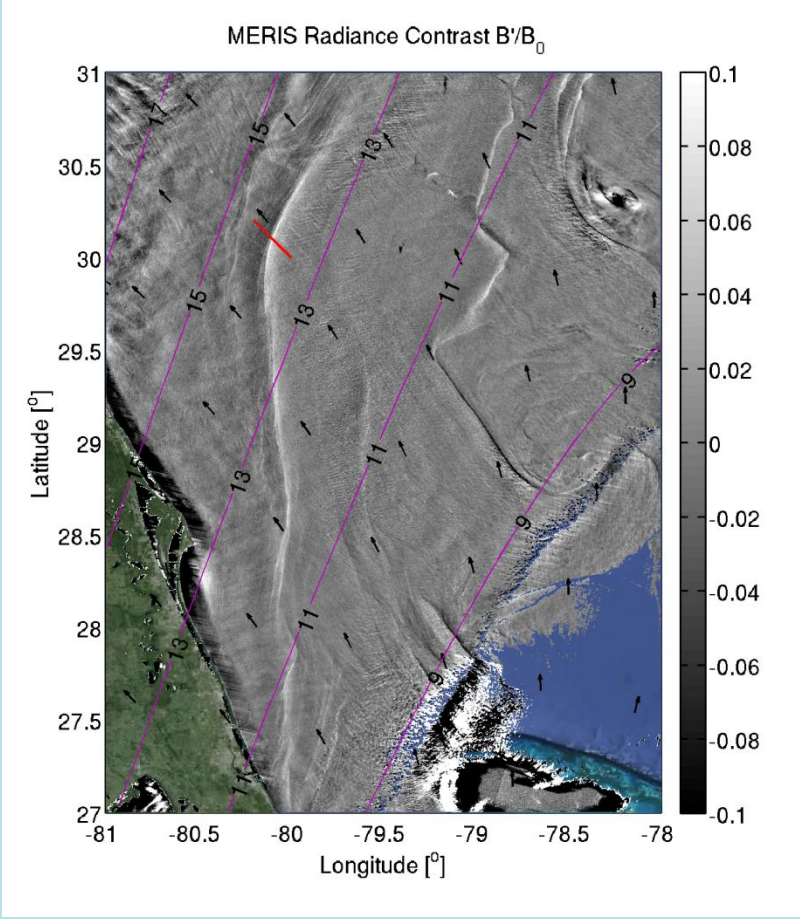
4) Surface roughness and air/sea fluxes horizontal distributions



4) Horizontal distributions

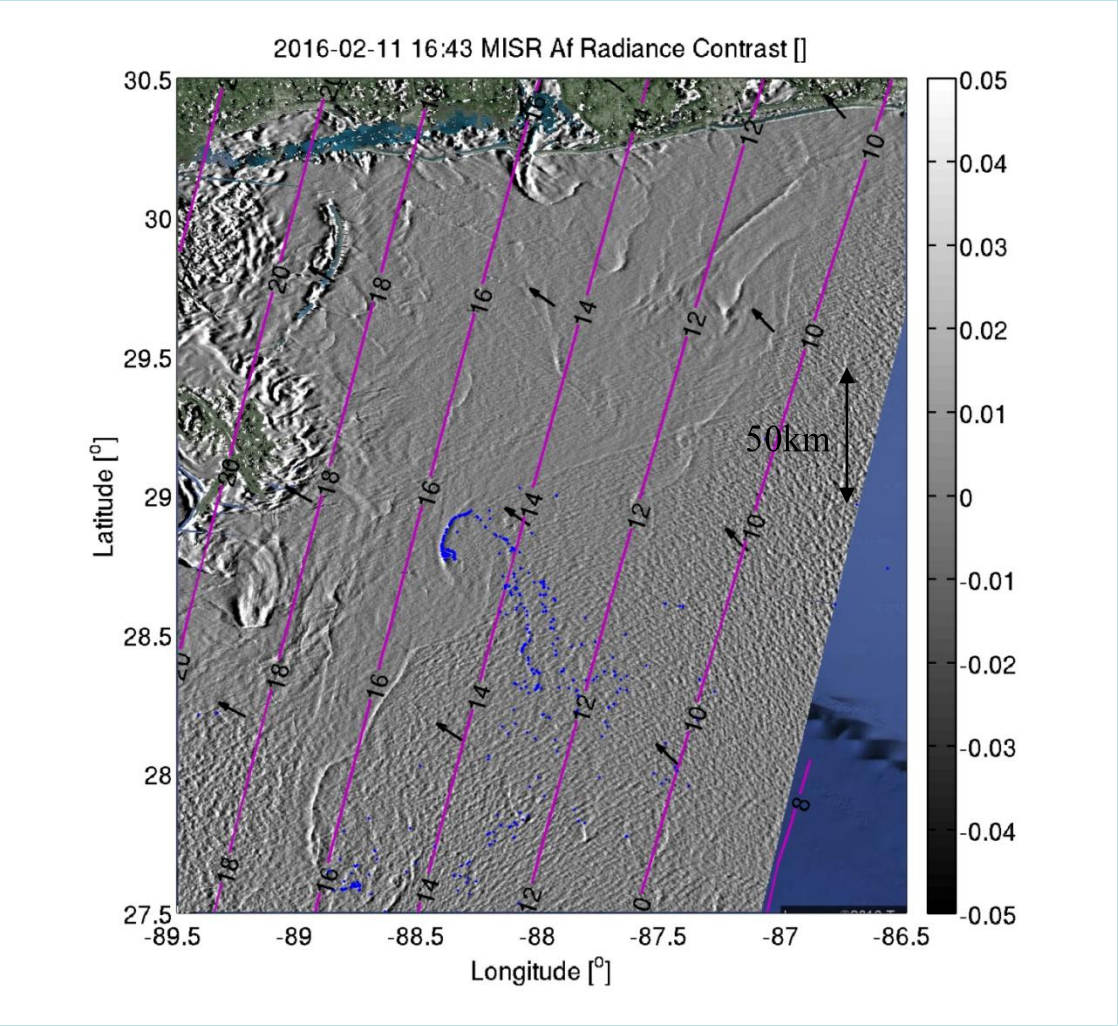
mss <-> Current gradient (divergence + strain)
Observations at scales [250m 25km]





4) Horizontal distributions

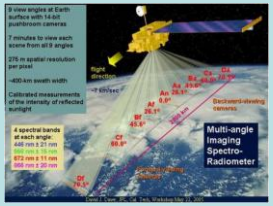
mss <-> Current gradient (divergence + strain)
Observations at scales [250m 2.5km]

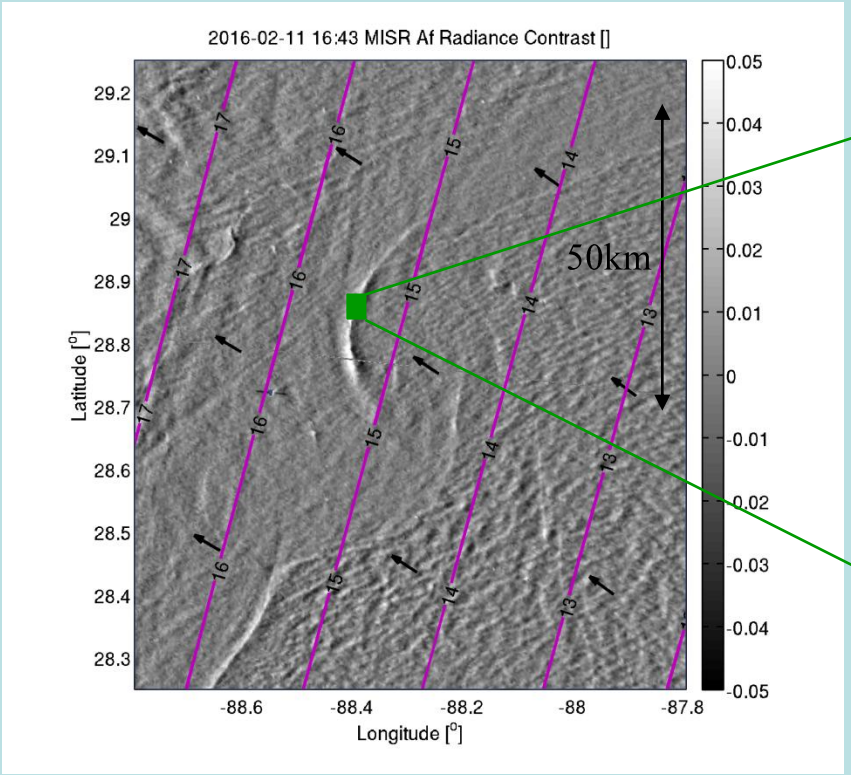


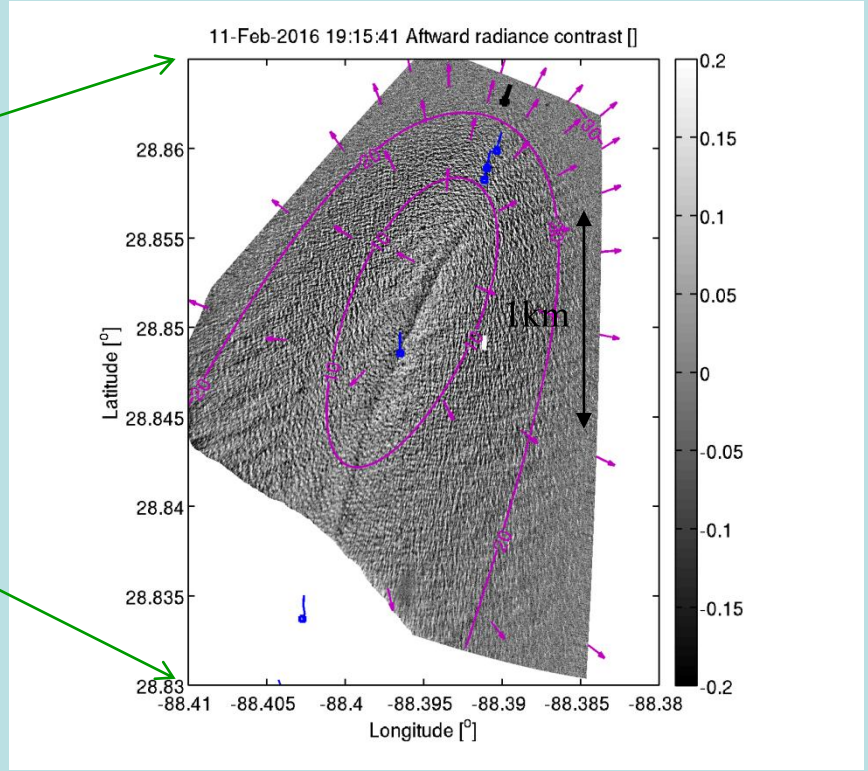
Satellite surface roughness during Gulf of Mexico experiment LASER 2016 (Ozgokmen et al.)

4) Horizontal distributions

mss <-> Current gradient (divergence + strain)
Observations at scales [250m 2.5km] and [5m 200m]



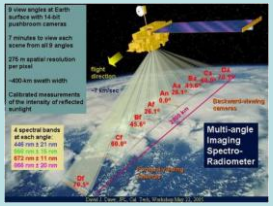




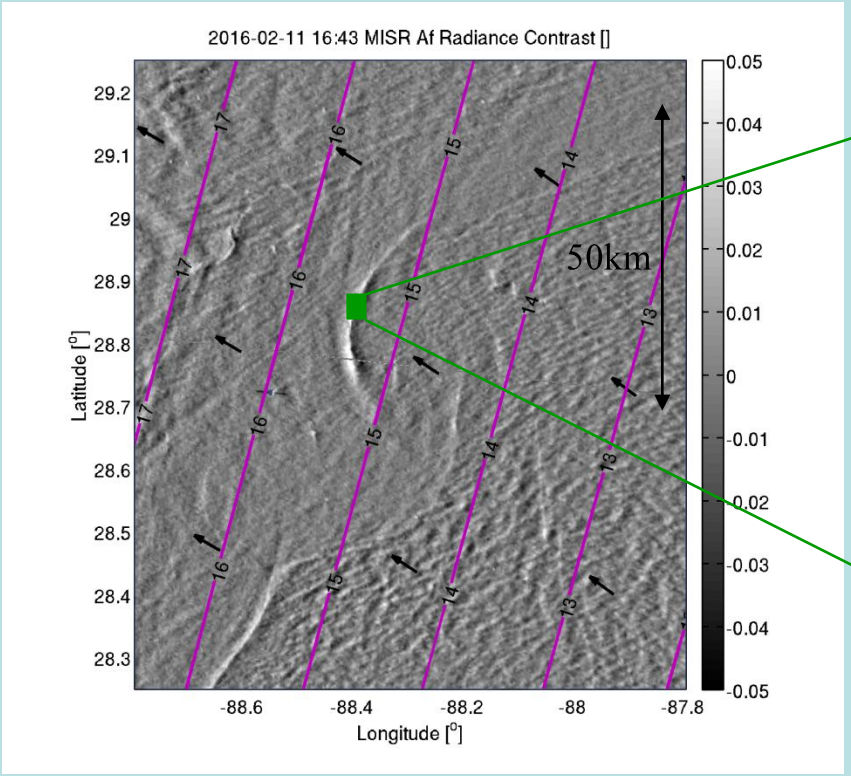
Satellite and airborne surface roughness during Gulf of Mexico experiment LASER 2016 (Ozgokmen et al.)

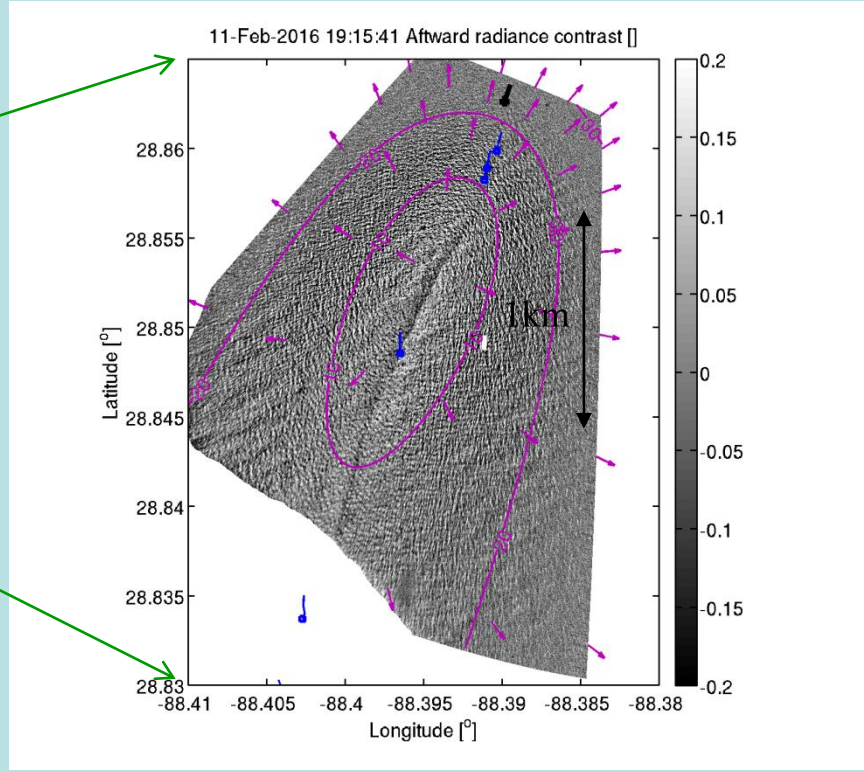
4) Horizontal distributions

mss <-> Current gradient (divergence + strain)
Observations at scales [250m 2.5km] and [5m 200m]



mss changes of 15% over 50m !

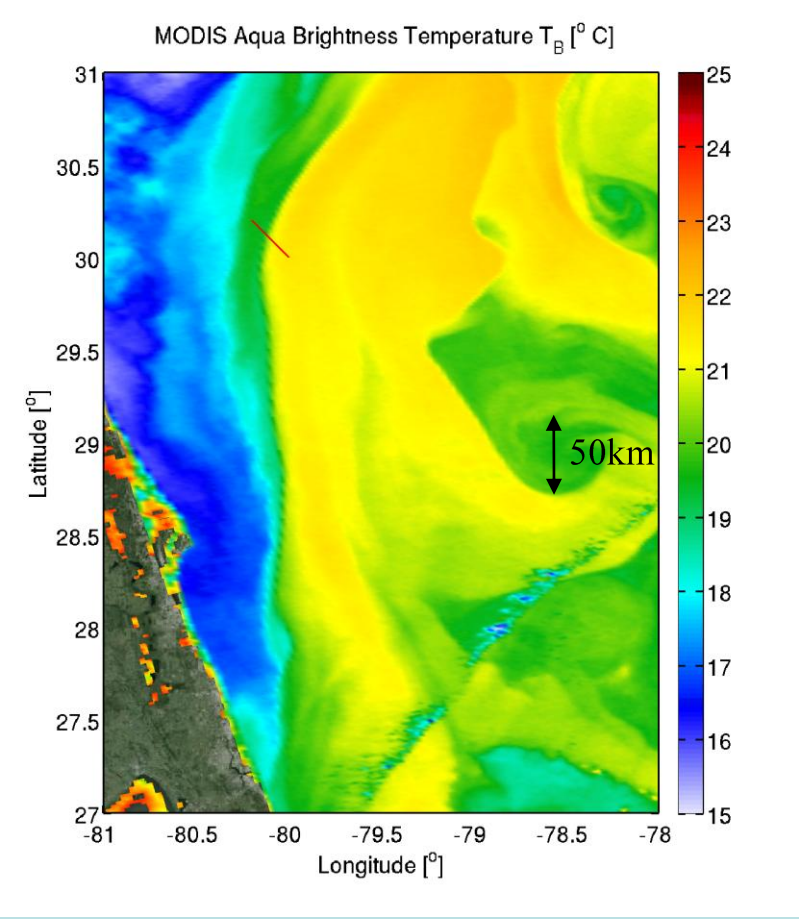


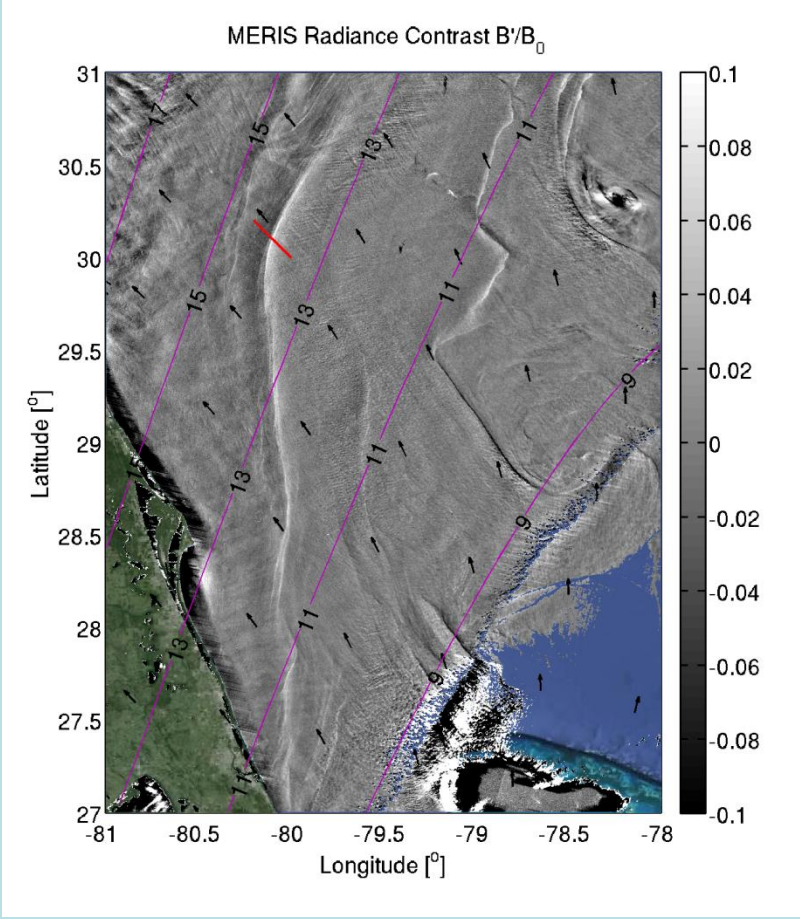


Satellite and airborne surface roughness during Gulf of Mexico experiment LASER 2016 (Ozgokmen et al.)

4) Horizontal distributions

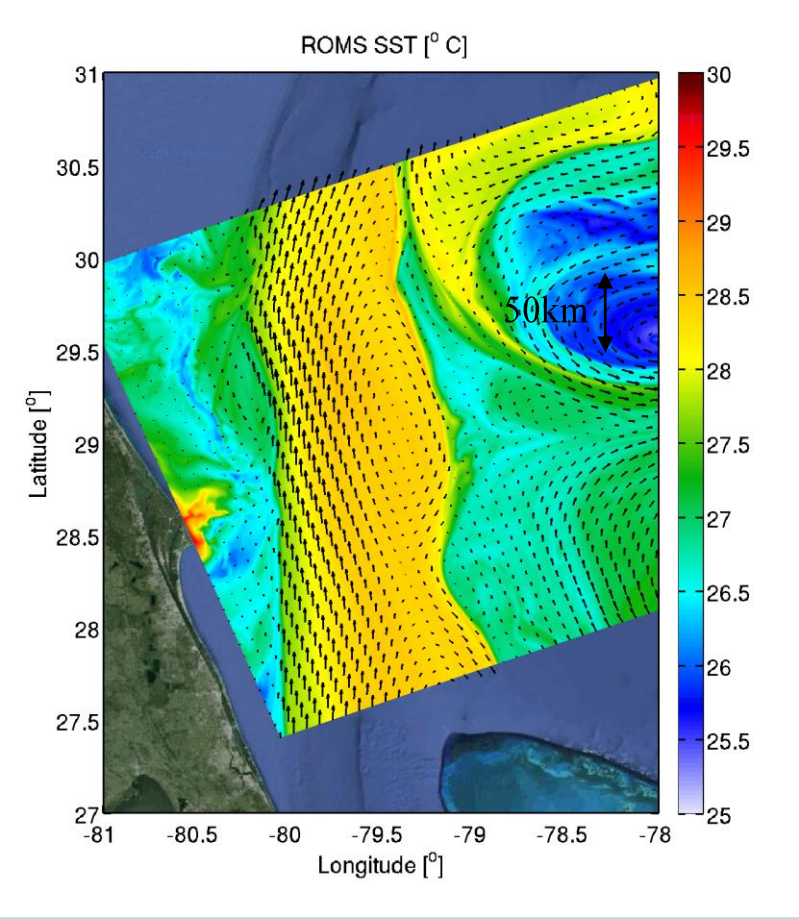
mss <-> Current gradient (divergence + strain)
Observations at scales [250m 25km]

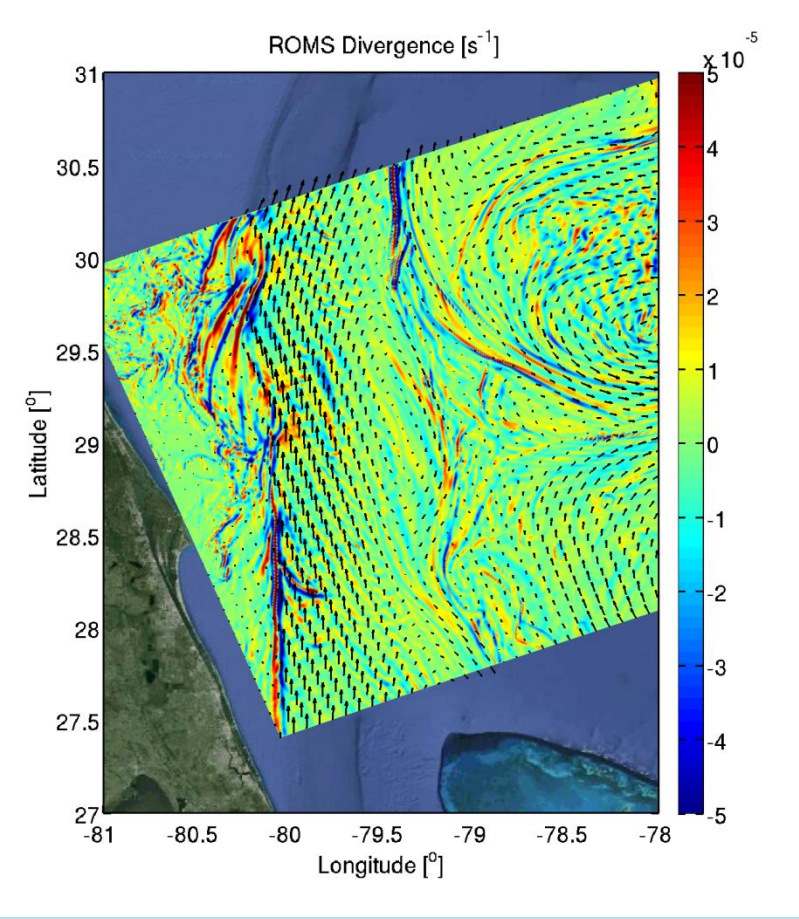




4) Horizontal distributions

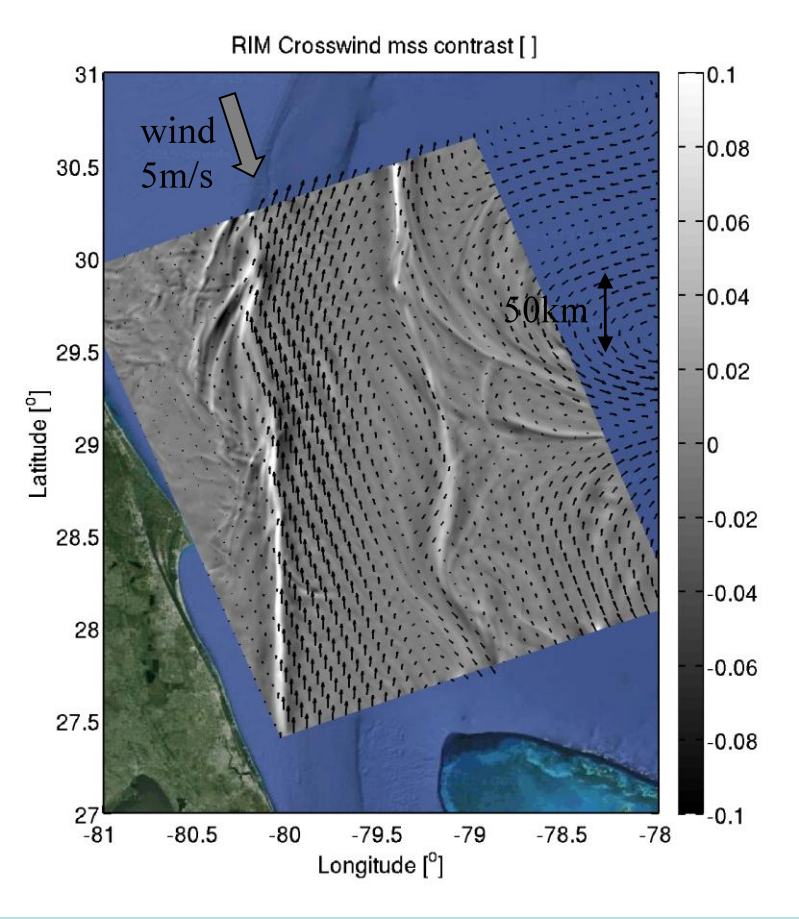
mss <-> Current gradient (divergence + strain)
Models at resolution ~ 750 m

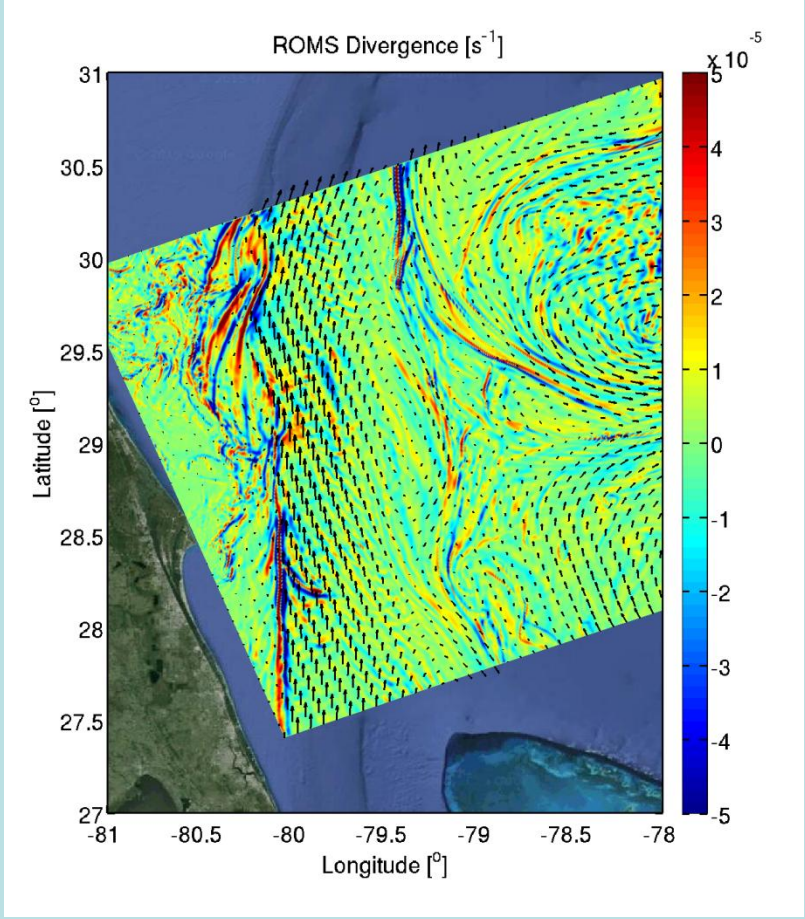




4) Horizontal distributions

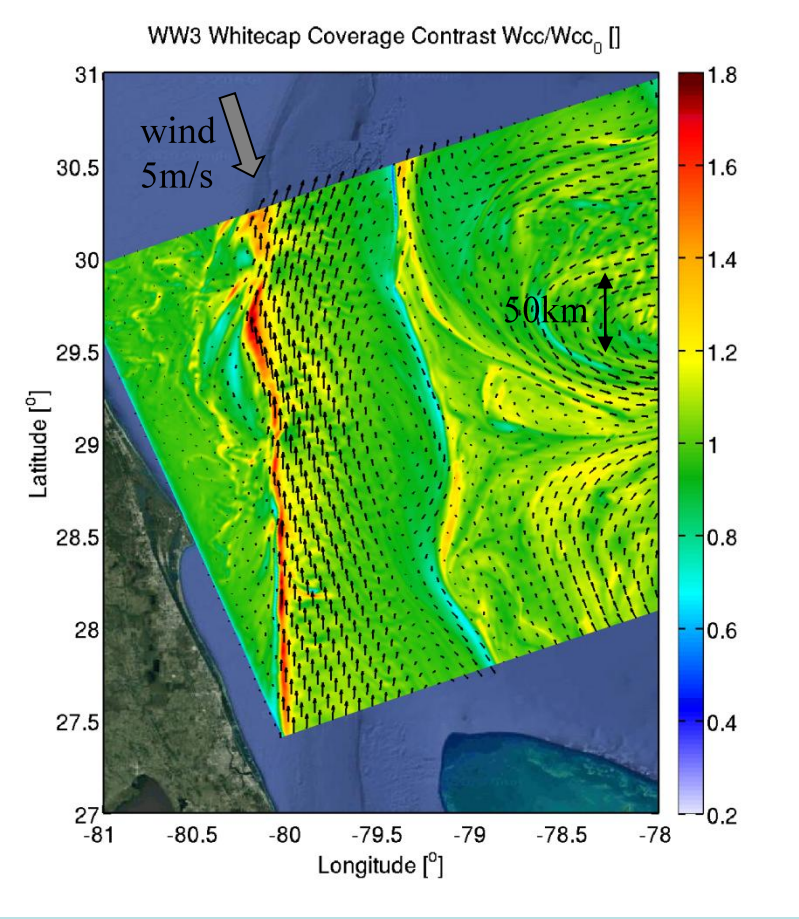
mss <-> Current gradient (divergence + strain)
Models at resolution ~ 750 m

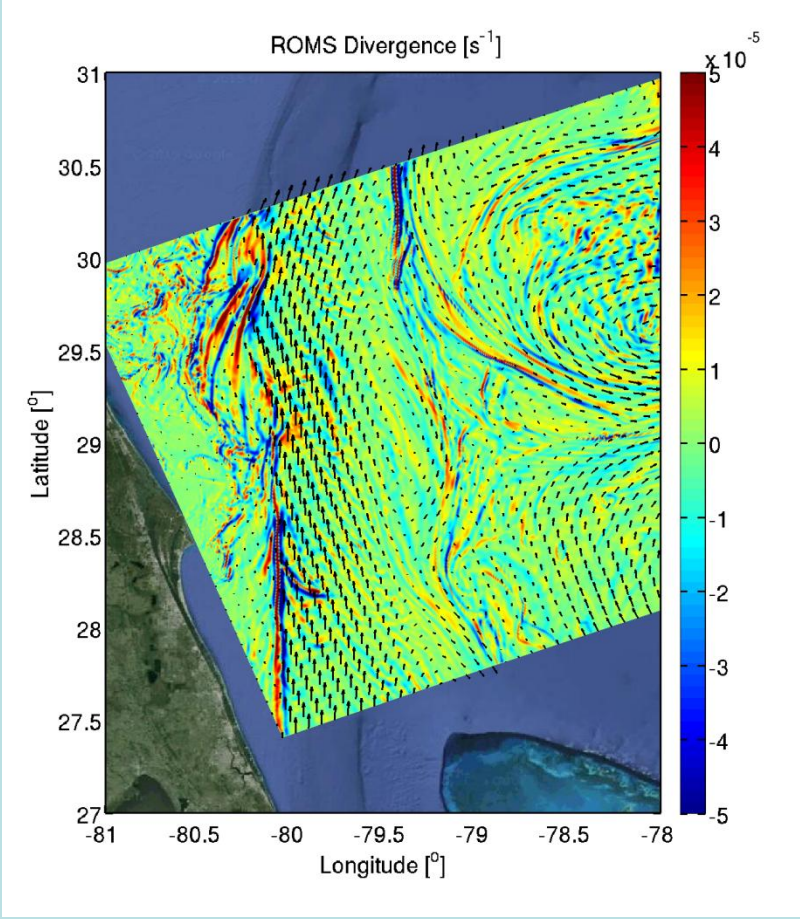




4) Horizontal distributions

mss <-> Current gradient (divergence + strain)
Models at resolution ~ 750 m





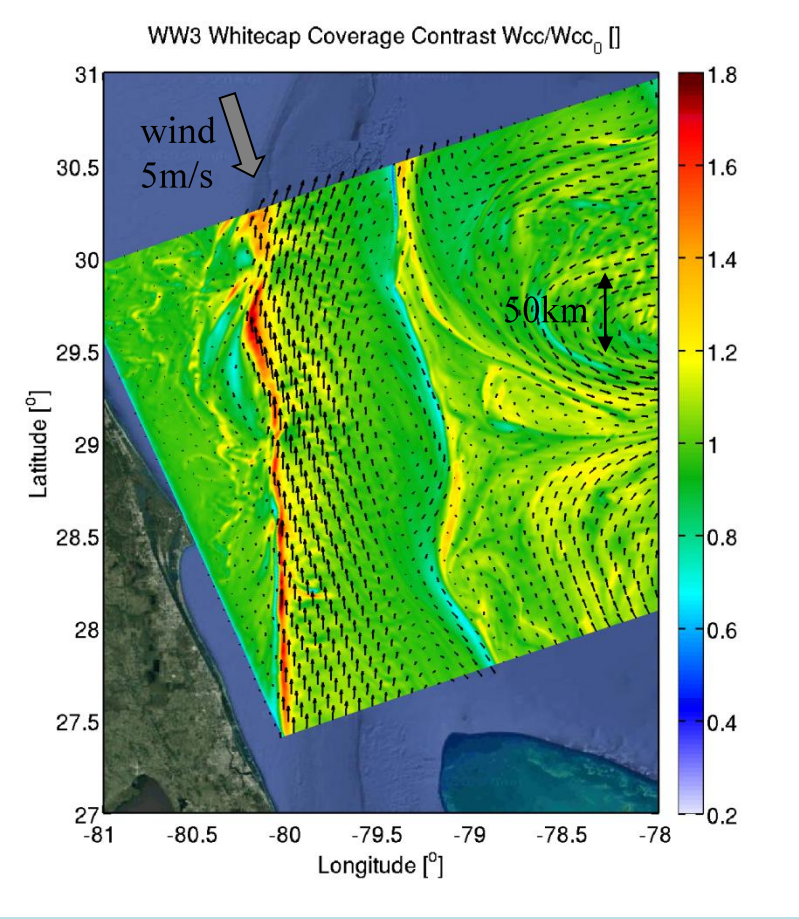
4) Horizontal distributions

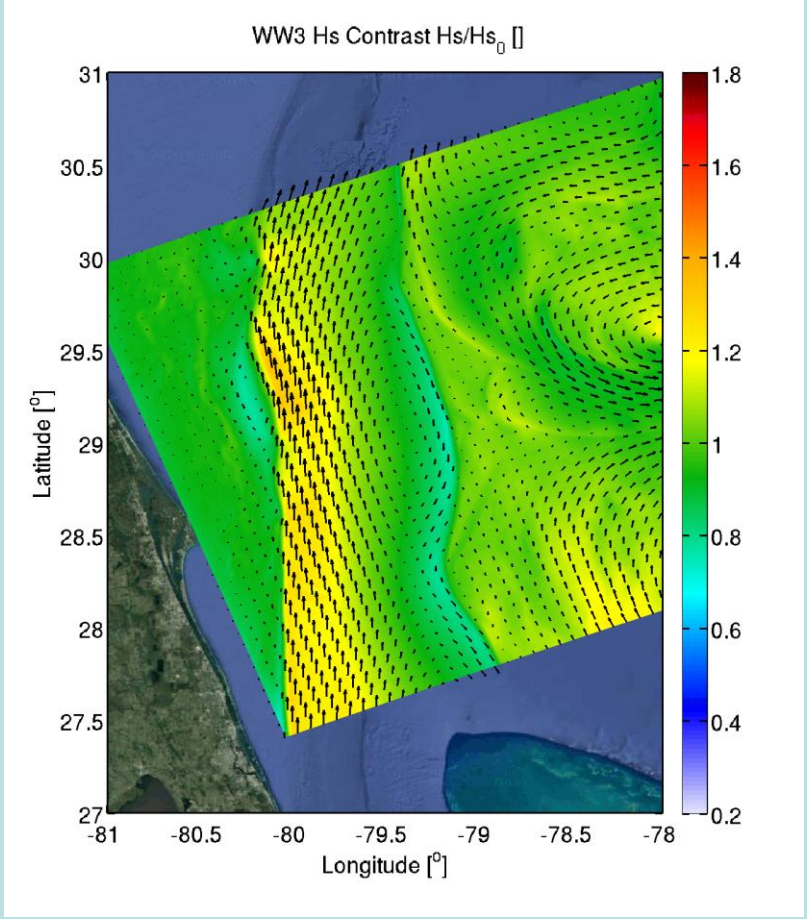
mss <-> Current gradient (divergence + strain)
Models at resolution ~ 750 m

1) Conservation of wave action

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

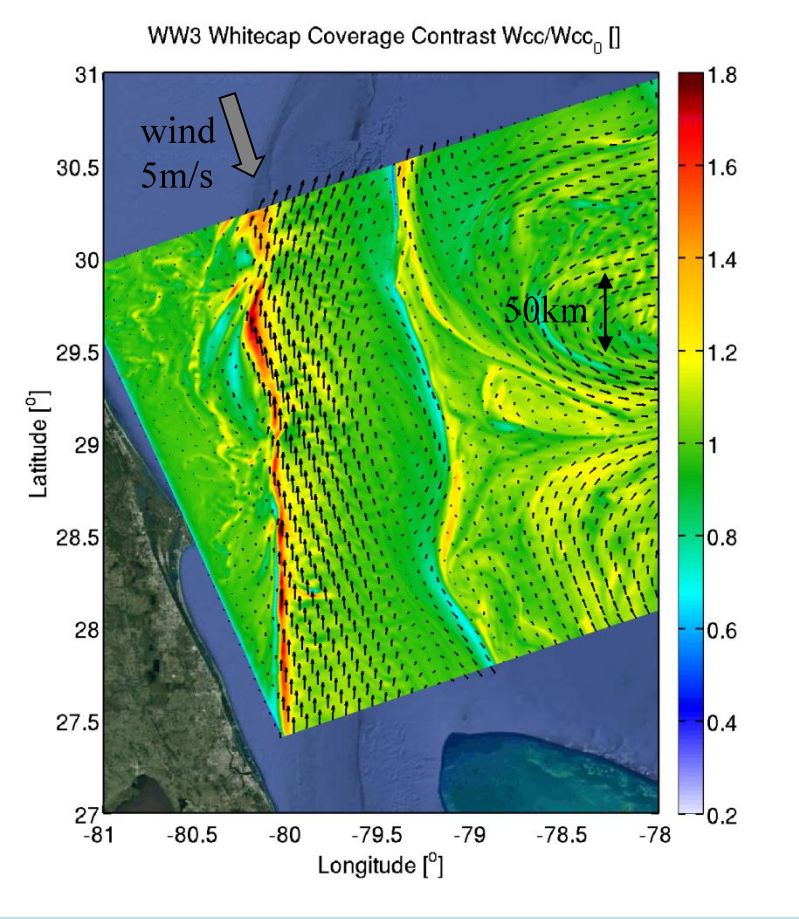
Propagation | Current | Sources, Sinks (wind, breaking,...)

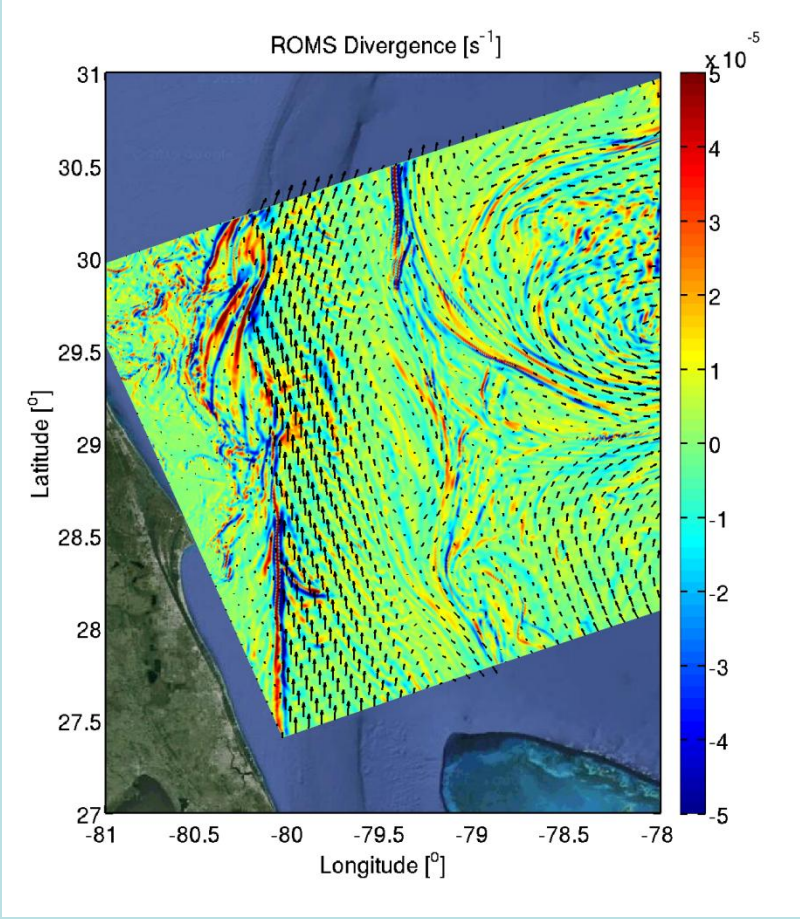




4) Horizontal distributions

mss <-> Current gradient (divergence + strain)
Models at resolution ~ 750 m





Conclusion

- At scales < 5km, surface roughness is related to current gradients.
- Surface roughness variations occurs mainly around fronts with divergence or strain in the wind direction.
- Observations during LASER 2016 show large mss variations at scales from 1km down to 50m
- If transfer velocities are correlated to mss (i.e. short waves),
  export towards the ocean interior might be concentrated around oceanic fronts

  Oceanic fronts to account for regional / seasonal variations of gaz transfers

Thank you.