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Airborne and SAR Sinergy reveals the 3D structure of air bubble entrainment in internal waves and fronts

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- ESA & DLR

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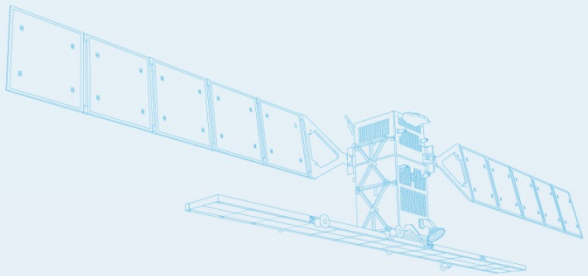
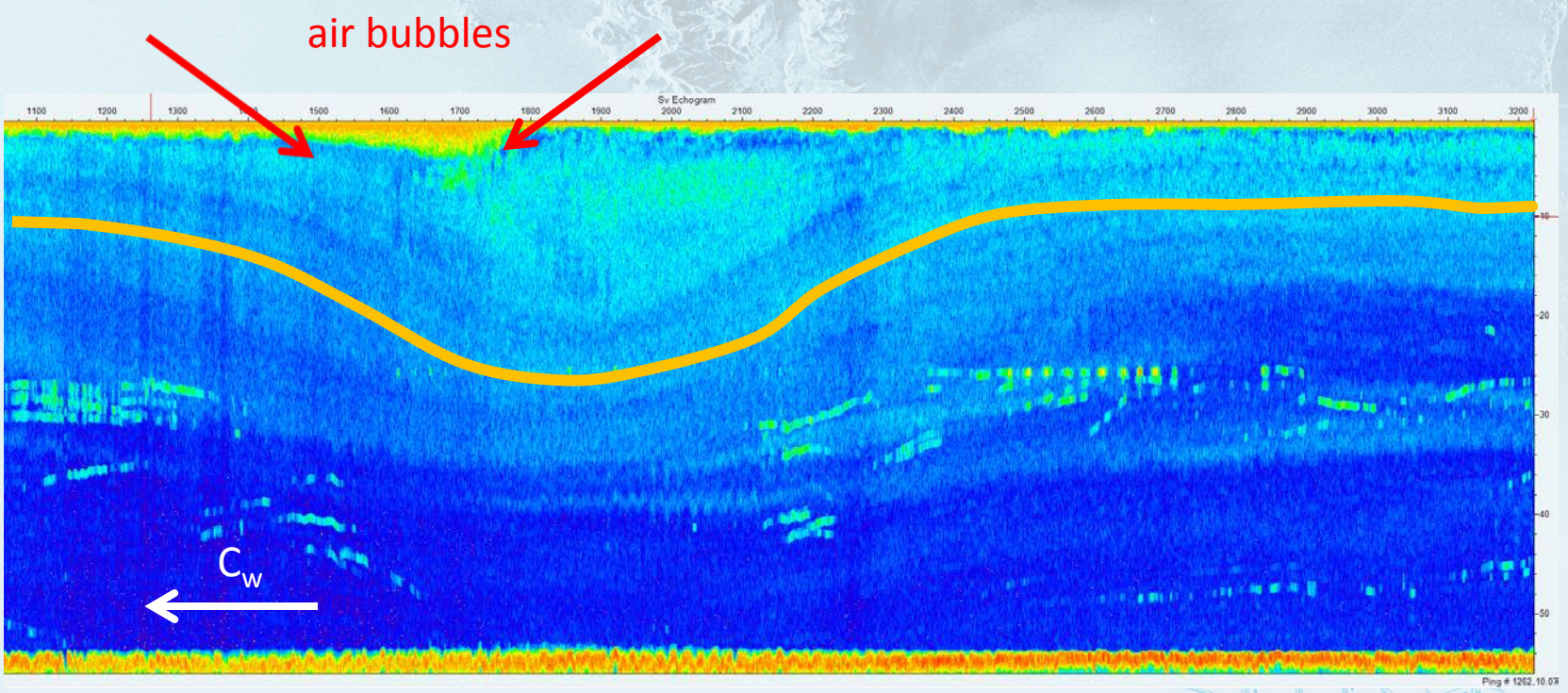


Introduction & Motivation

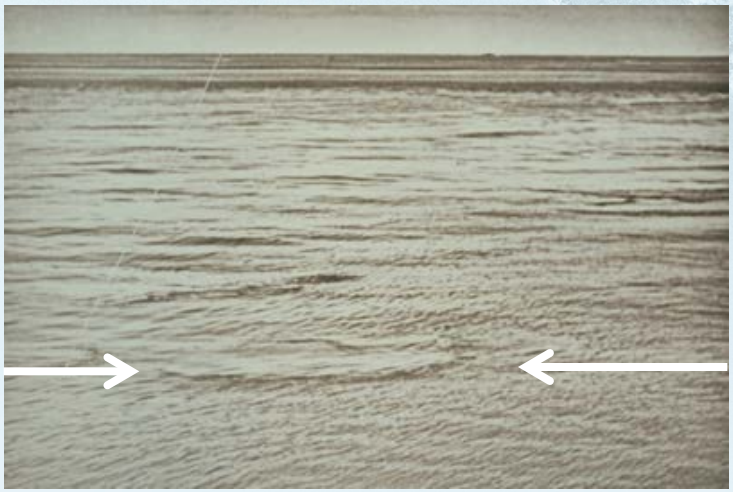
Band of breaking surface waves associated with internal waves in the South China Sea (curtesy of Guozhen Zha)

Introduction & Motivation



- Pineda's echo sounding measurements in Cape Cod (Whales & Waves Project, WHOI)
- Serebryaniy's interpretation of "*structure formation in the bubble layer*" under the influence of internal waves recorded on the shelf of the Sea of Japan.

Introduction & Motivation

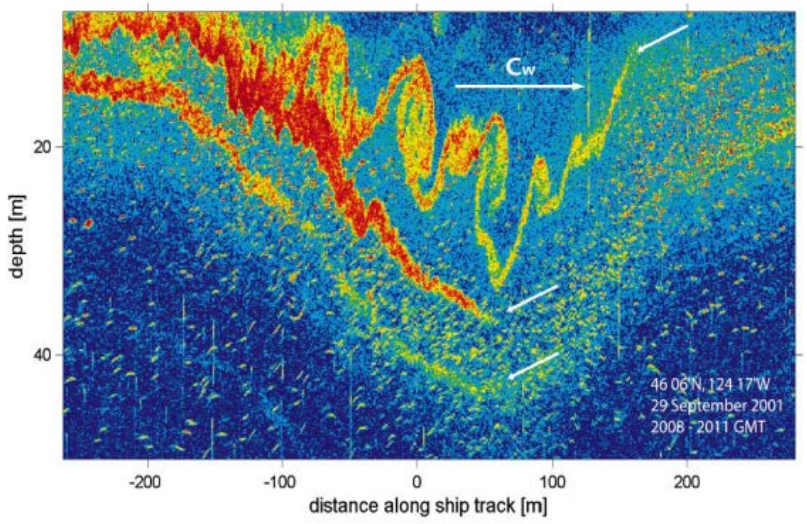


Adrian New's "*boils*" in the Bay of Biscay

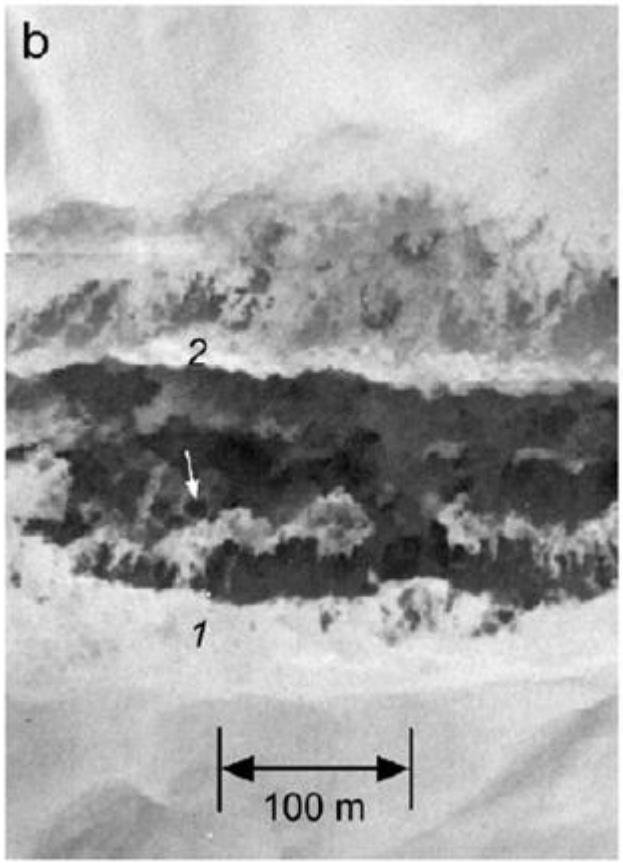
"In the Bay of Biscay 'boils' have been reported on the sea surface in the calm zones (in between bands of breaking surface waves), and appear to be related to pulses of nutrients from the thermocline"

"Breaking of IWs may contribute significantly to turbulent mixing in the near-surface layers, through the continual triggering of instabilities (K-H billows) as they propagate"

Moum's turbulence in the wake of ISW's (JPO, 2003)



Introduction & Motivation



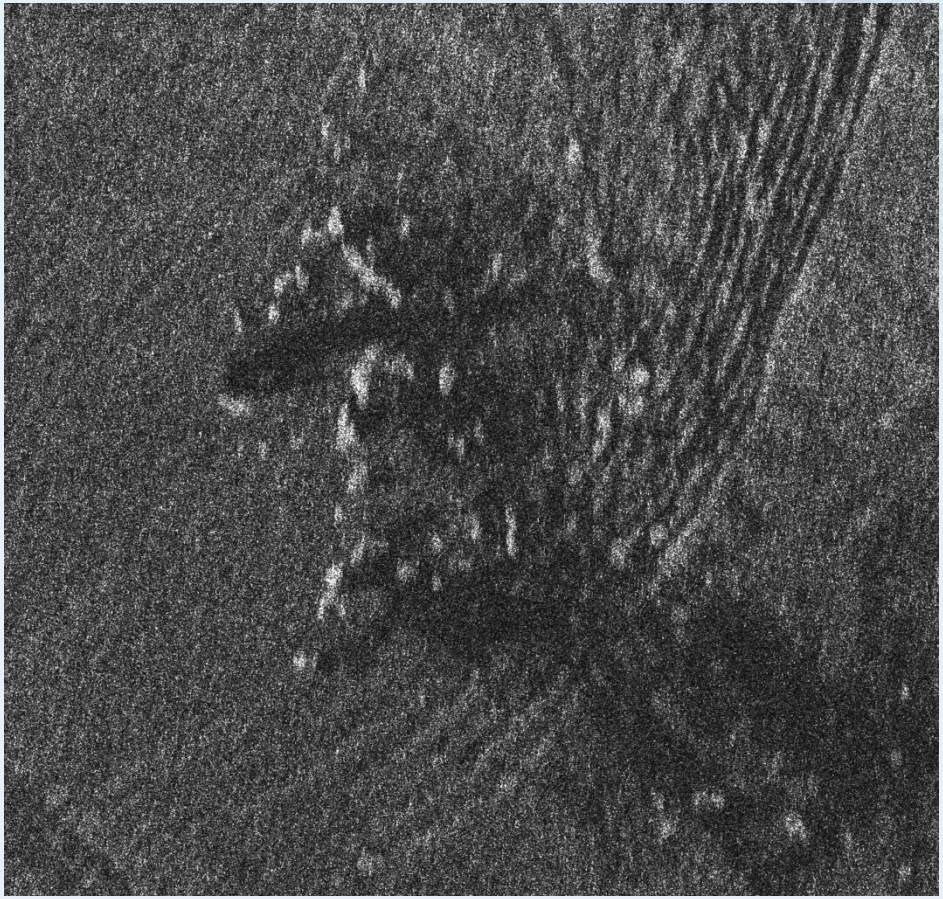
a. “boil” structure observed in the S. China S. by Farmer & Lien (2011)

“O (10 m) diameter surface-renewal ‘boils’ that populate the Wake of the IWs”

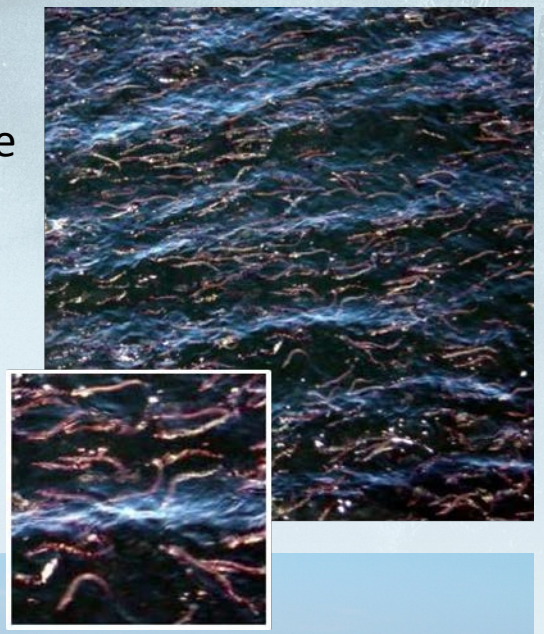
b. Marmorino et al. (2008) observed thermal signatures of a narrow warm wave front and a broader, more intensely cold trailing wake, which they associated to an IW breaking event

Introduction & Motivation

TerraSAR-X image (stripmap) showing features of surface turbulence



Turbulence may be associated to “sand lance” fish schools and whale hunting patterns.

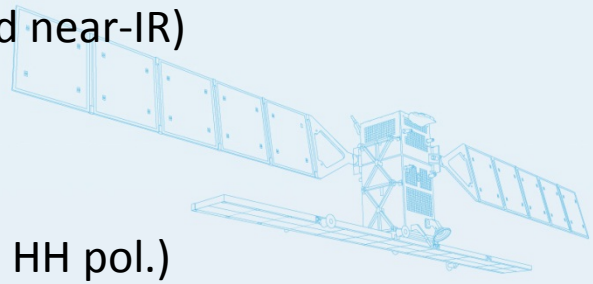


The EUFAR mission

Aircraft: Dornier 228-101 - NERC-ARSF
Operated by: Natural Environment Research Council
Objective: observe small scale structure in the internal wave field off Portugal
Flying altitude: 500 meters (nominal)
Dates: 15-16 July 2010 (jd 196-197)
Light winds: 4 - 4.5 m/s from N-NW

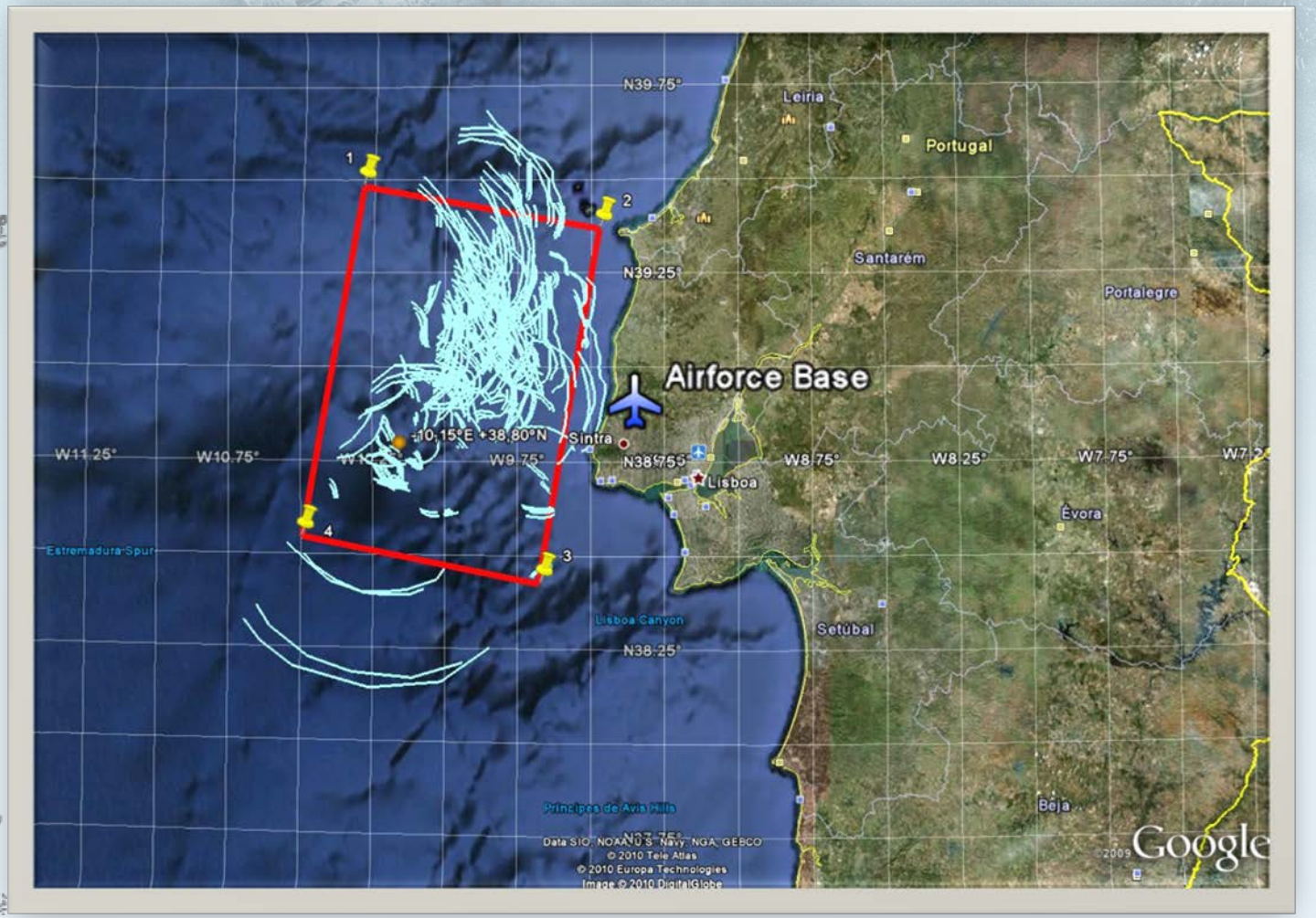
Sensors:

- Side looking Airborne Laser Scanner (imaging LiDAR Leica ALS50-II); near IR 1064nm
- Broadband Thermal IR Imager(TABI-320); 8-12 microns
- Imaging Spectrometers; (Eagle & Hawke in the visible and near-IR)
- High Resolution aerial digital cameras



SAR synergy:
TerraSAR-X stripmap mode 14 July 2010 (3 meter resolution HH pol.)
Envisat ASAR Pricision Mode 15 July 2010 (used in real time during the flight)

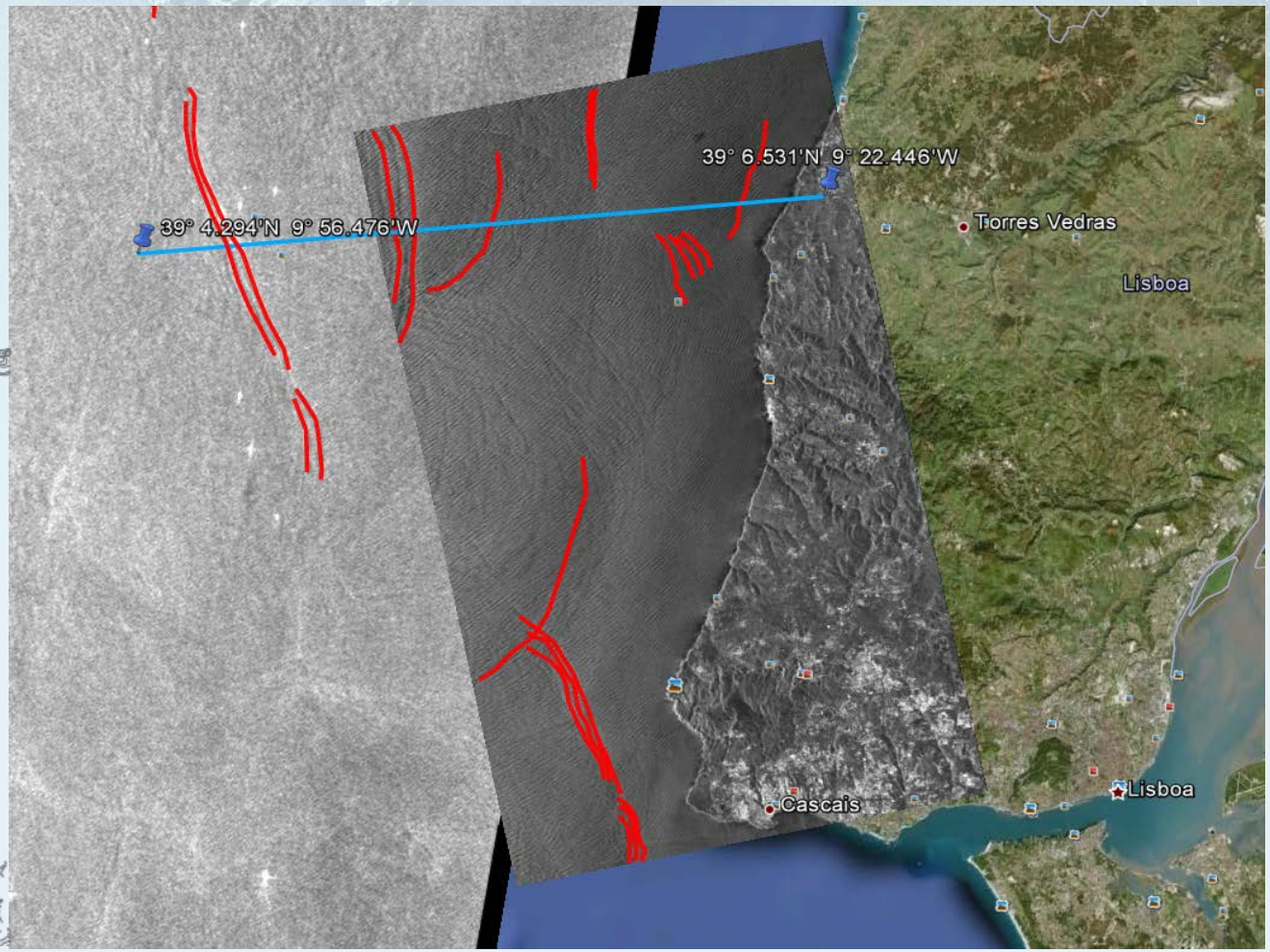
The EUFAR mission



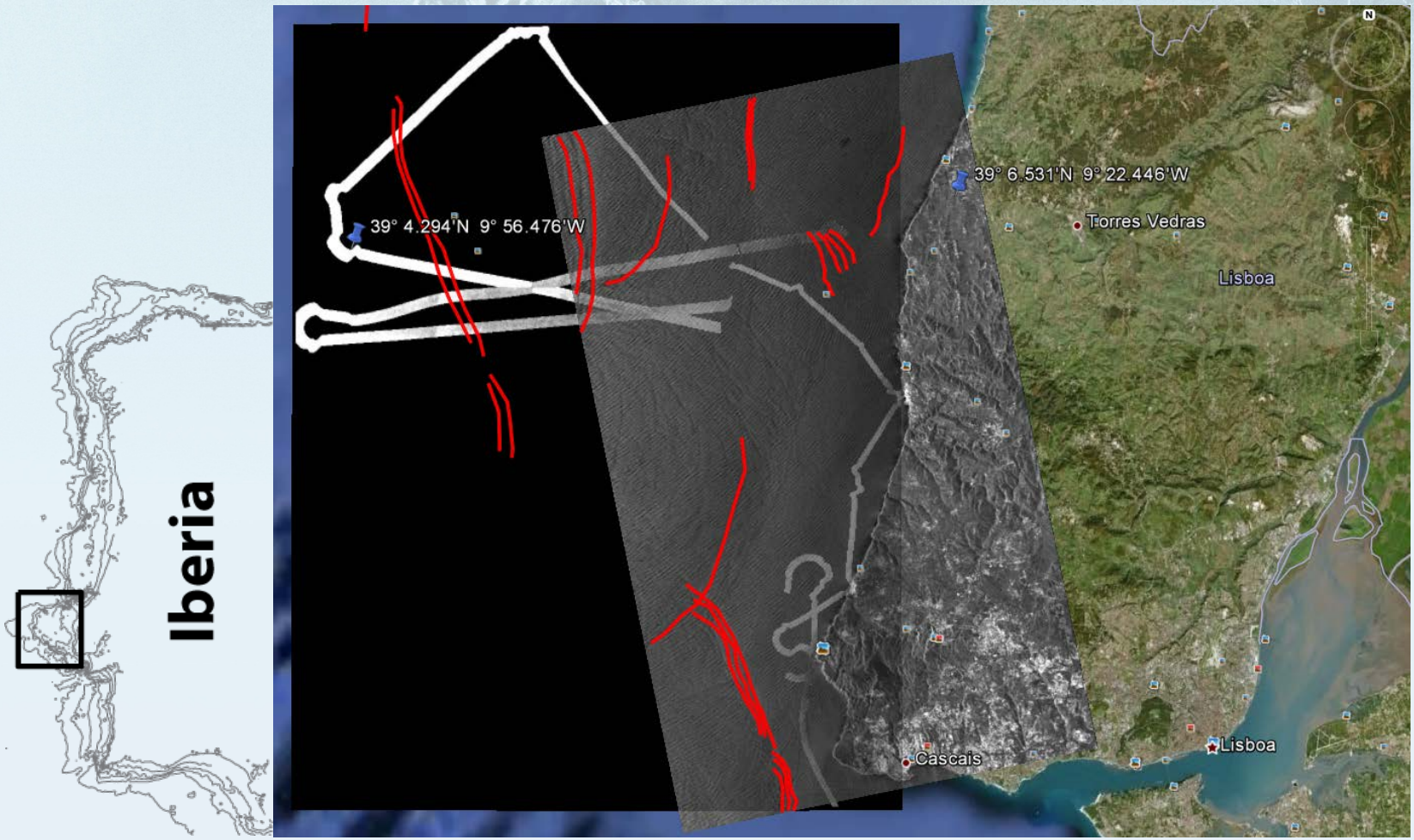
The EUFAR mission

Real time Image.
Acquired at: 10:40 UTC
Downloaded: 12:20 UTC

IRIDIUM Satellite phone call from aircraft: 12:22 UTC



The EUFAR mission



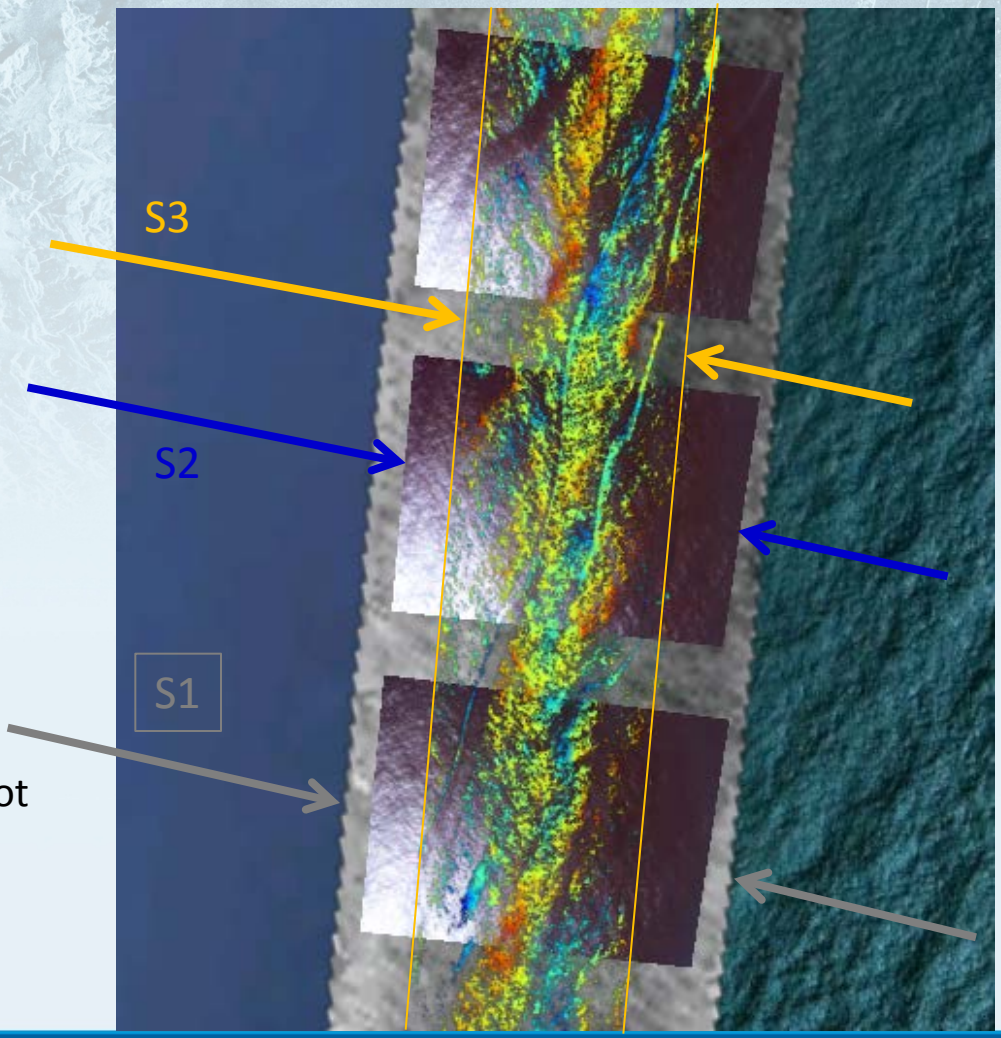
Multisensor airborne observations

S1: Thermal IR Swath aprox. 1000 m
thermal camera TABI 320
spatial resolution: 3 m
thermal resolution: 0.05 K
dynamic range: 8-12 microns (12 bits)

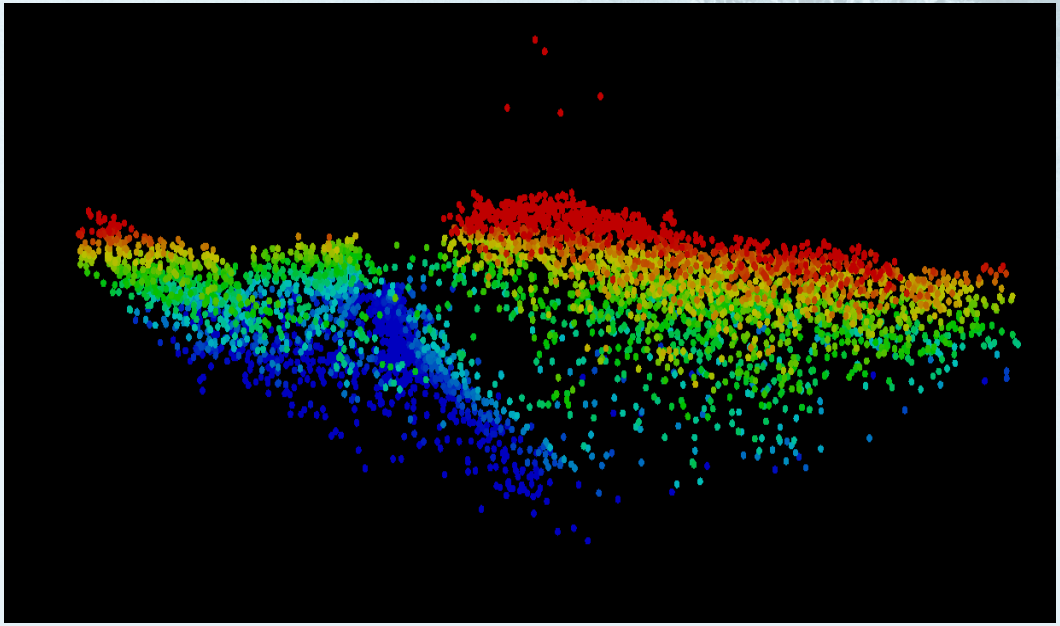
S2: Digital Camera Swath aprox. 820 m

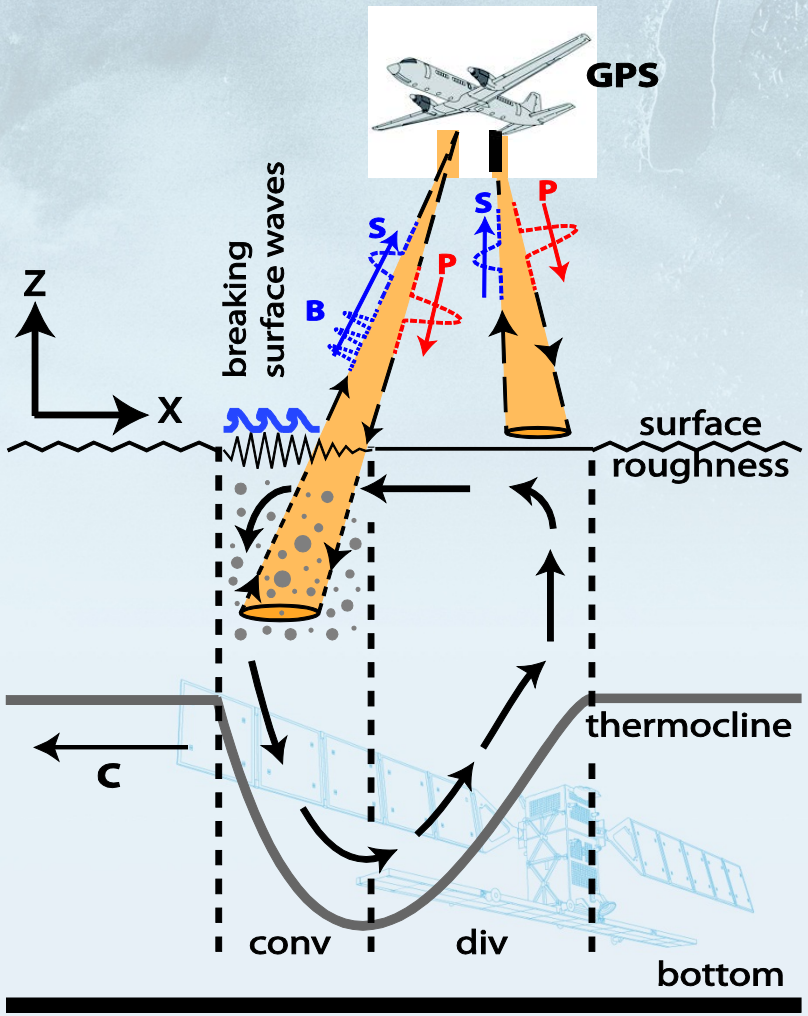
S3: LIDAR Swath aprox. 550 m
Operating principle:

- measures GPS coordinates (altitude), attitude and distance to ground and scan angle
- ground position for the impact point of each laser pulse can be determined (but not intensity)
- hit rate greater than 1/m^2 and a vertical resolution of approximately 15 cm.



Multisensor airborne observations





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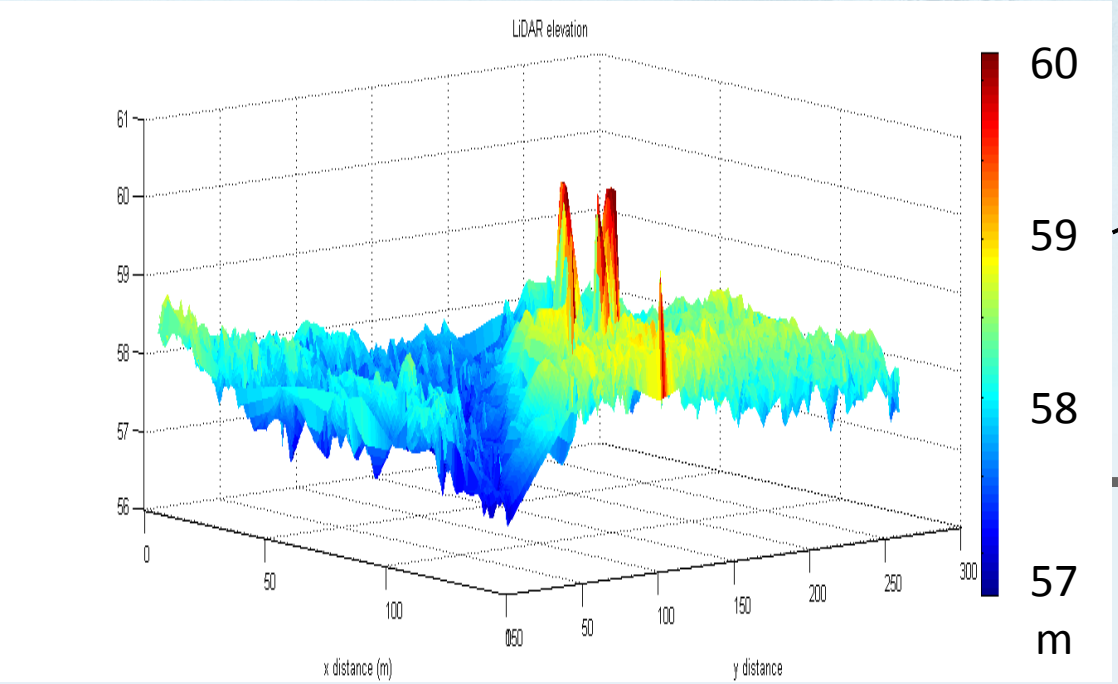

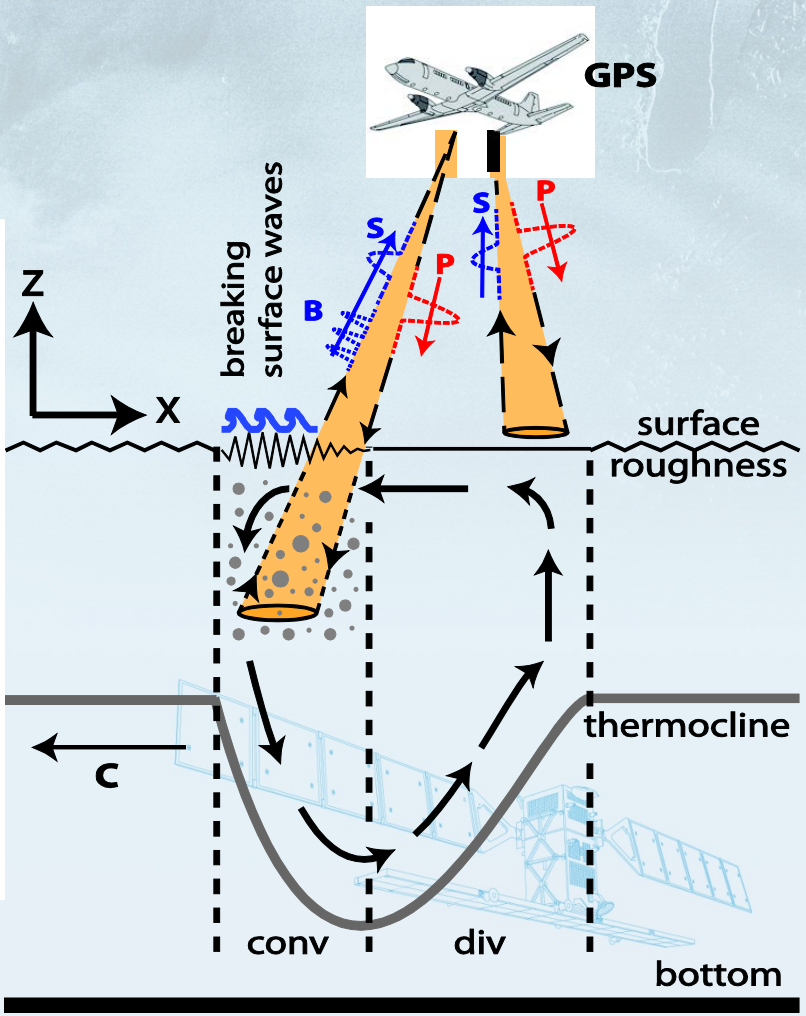

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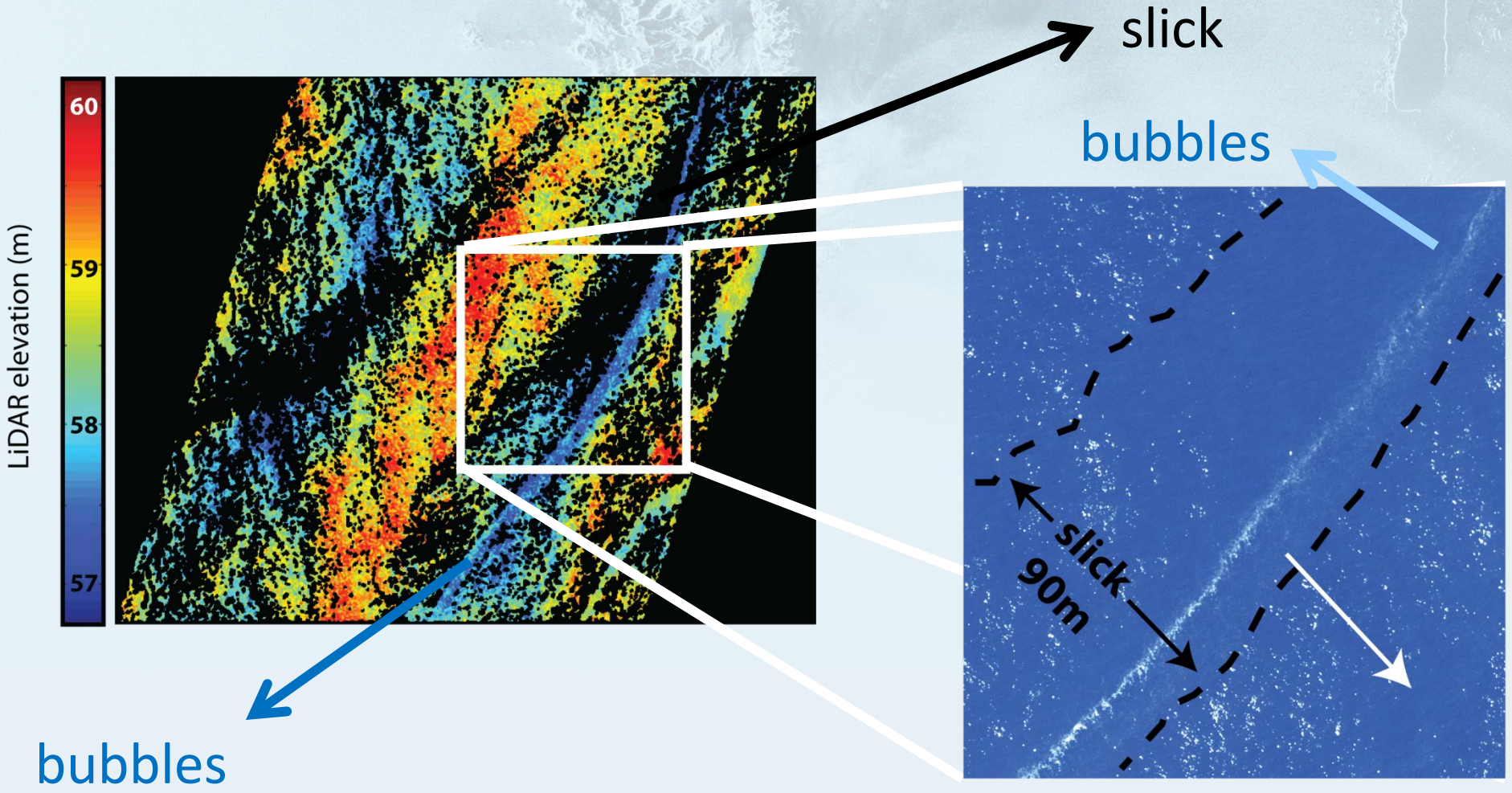
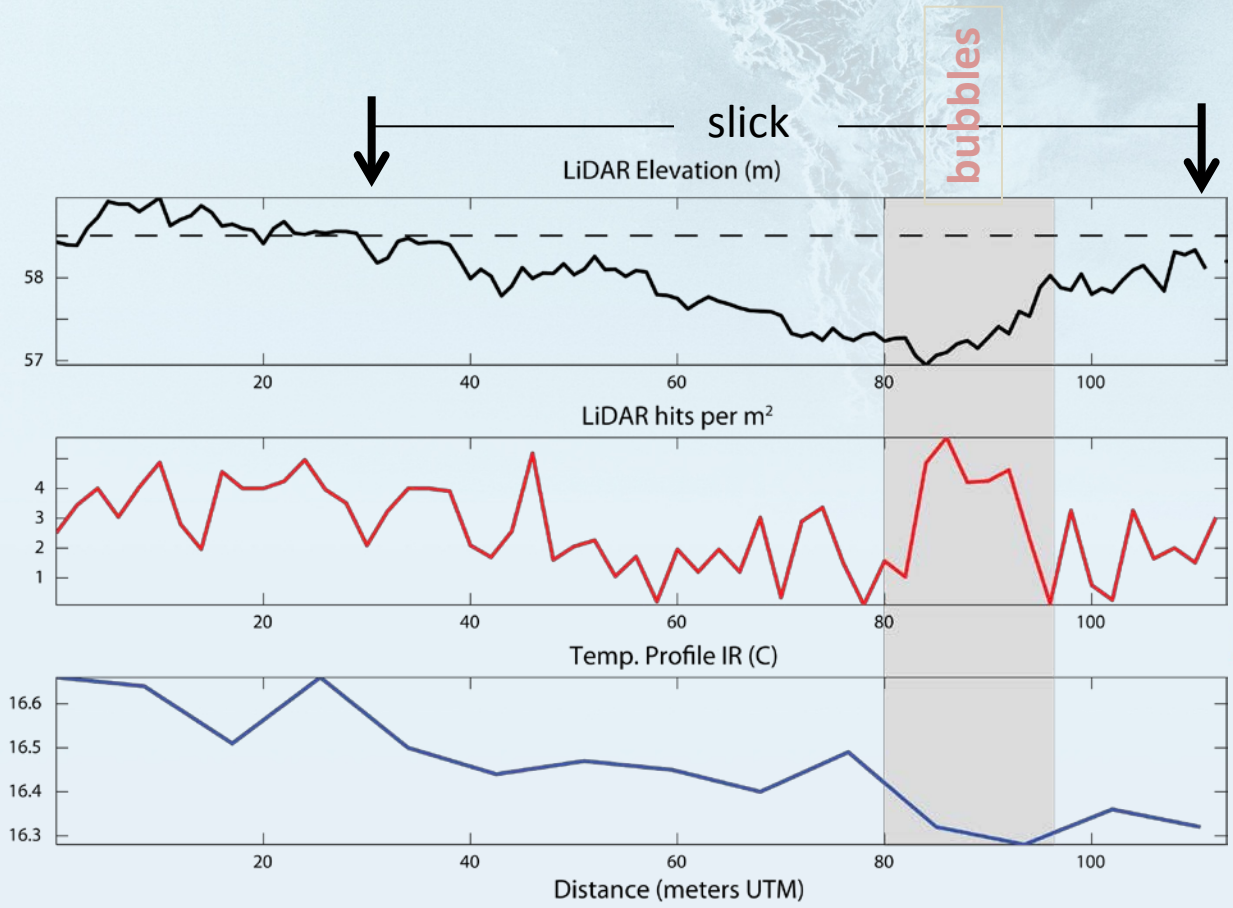
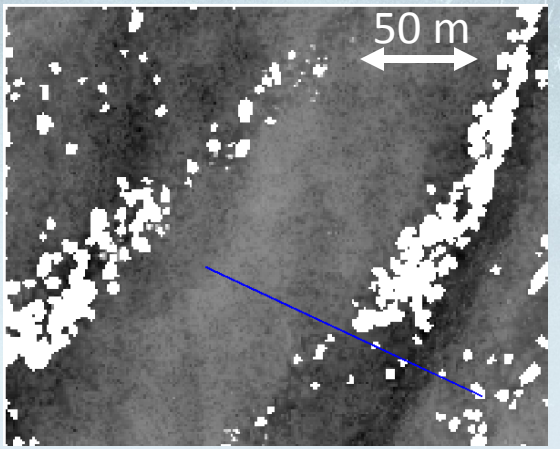
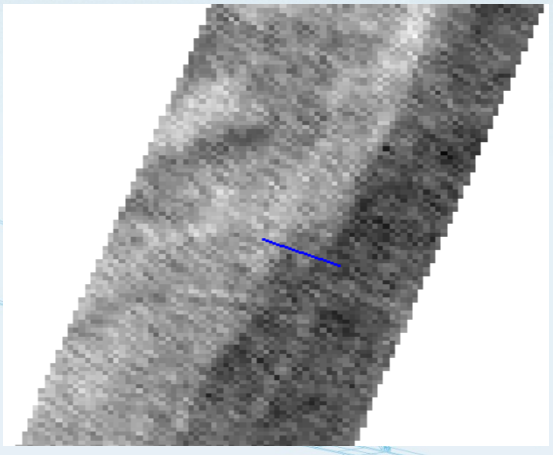


Multisensor airborne observations



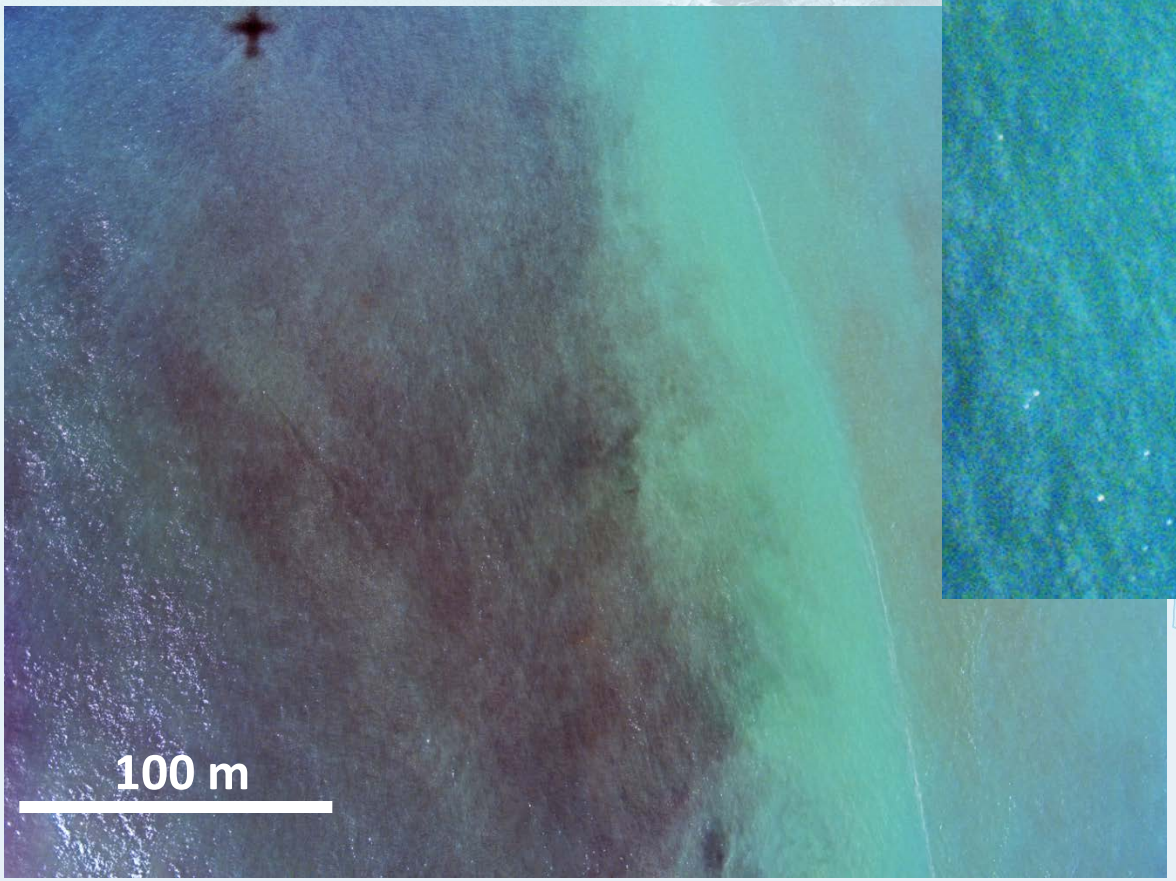


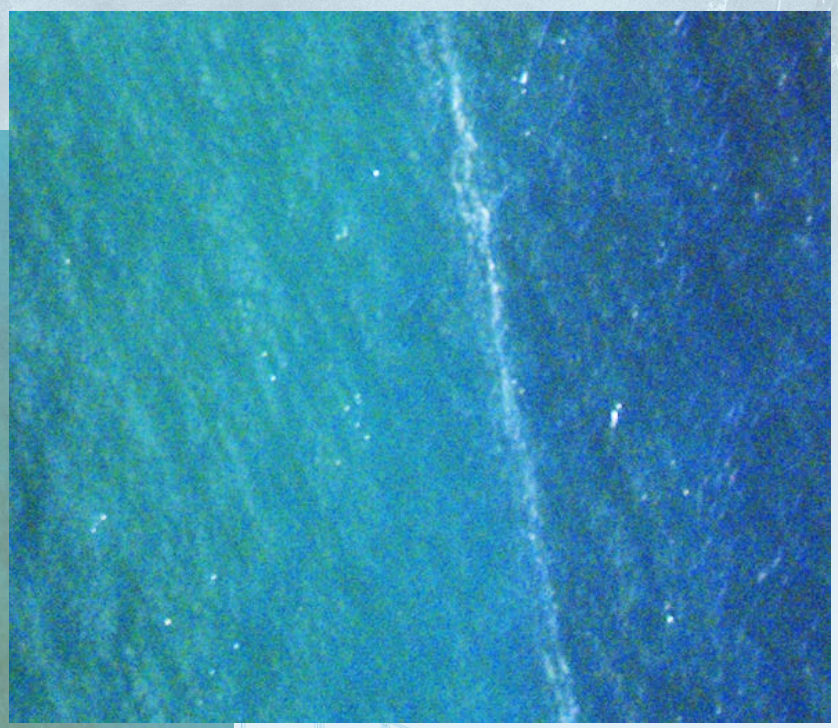


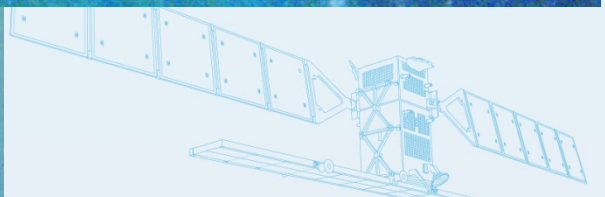
Multisensor airborne observations

Rich Pawlowicz observations in Strait of Georgia, British Columbia

Injection of bubbles shifts ocean color towards green, resembling phytoplankton blooms





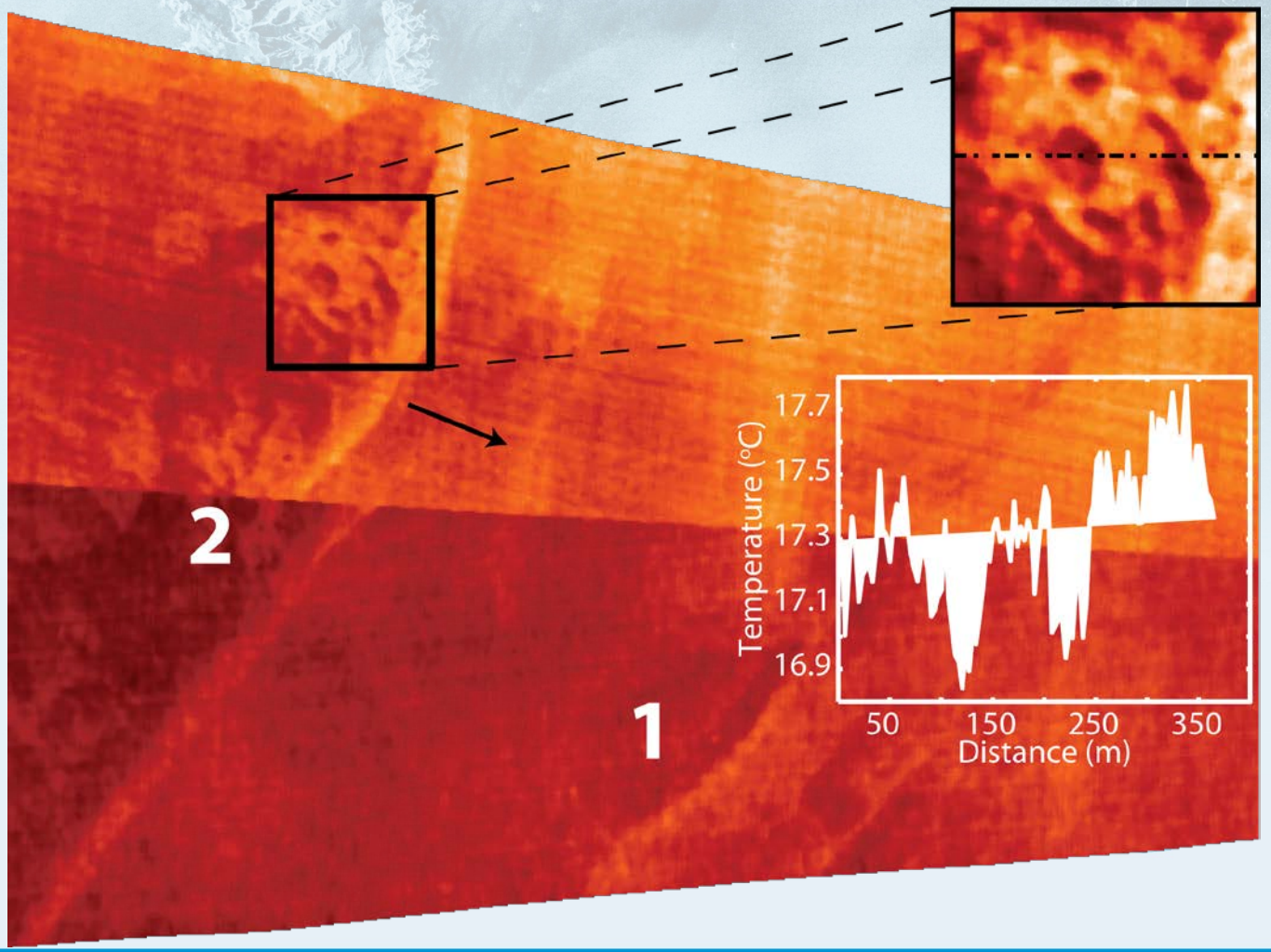


Hence introduces error in ocean color remote sensing

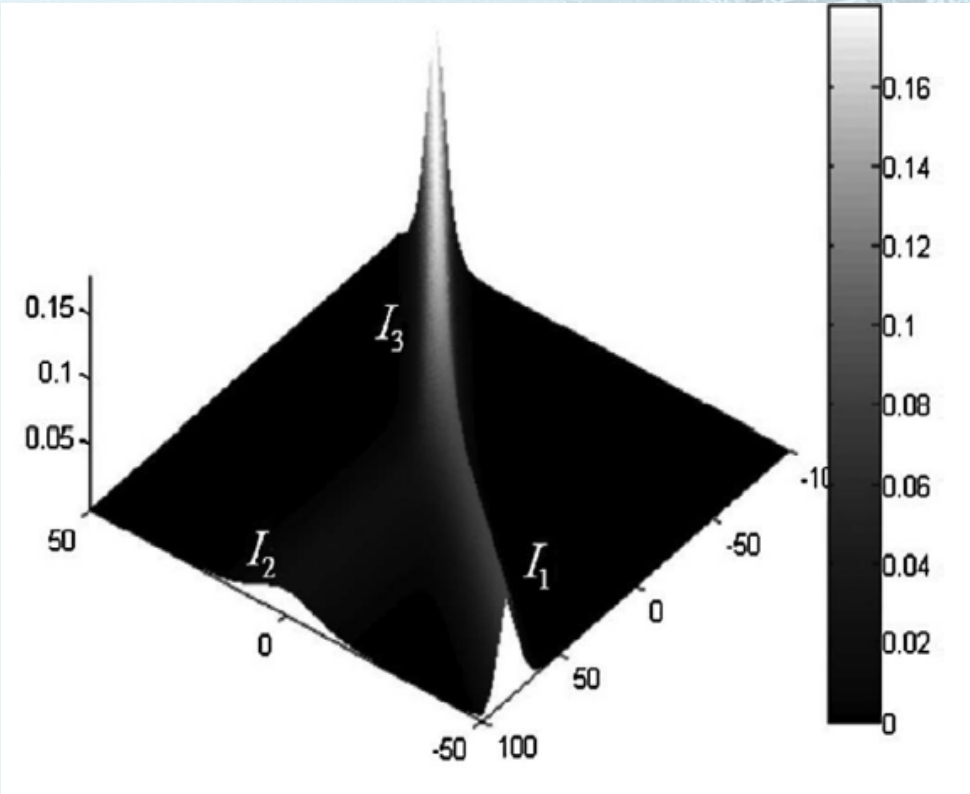
Multisensor airborne observations

Surface thermal expressions associated with internal waves that become unstable and break over the shelf (Marmorino et al., 2008)

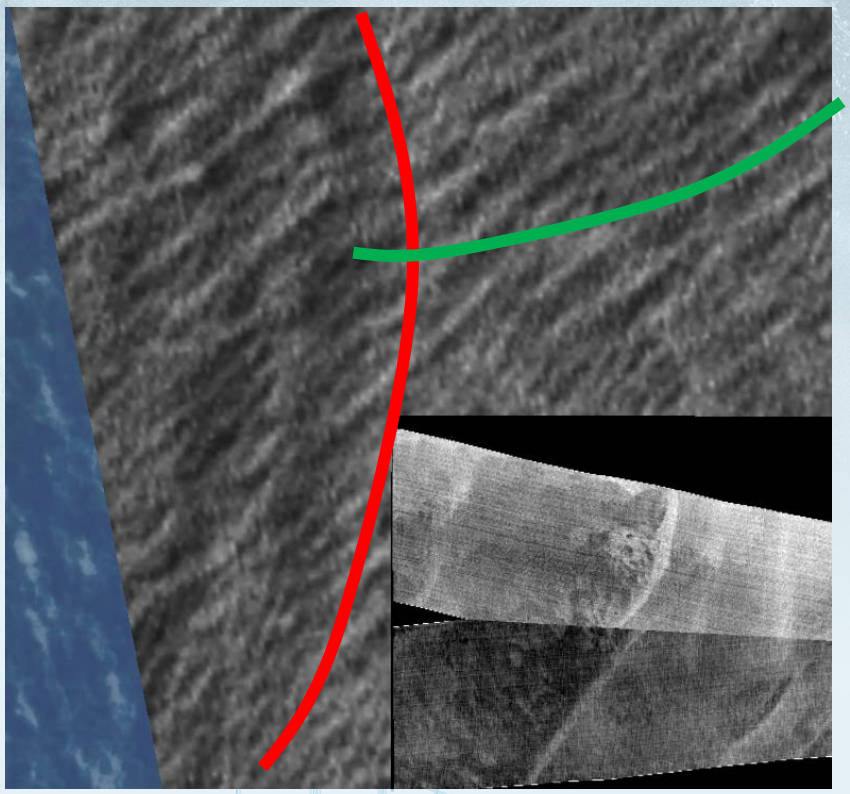
- narrow wave front that is warmer than the ambient
- wide, spatially intermittent ‘wake’ that is colder than the ambient
- O (50 m) diameter surface-renewal ‘boils’ that populate the wake.



SAR observations



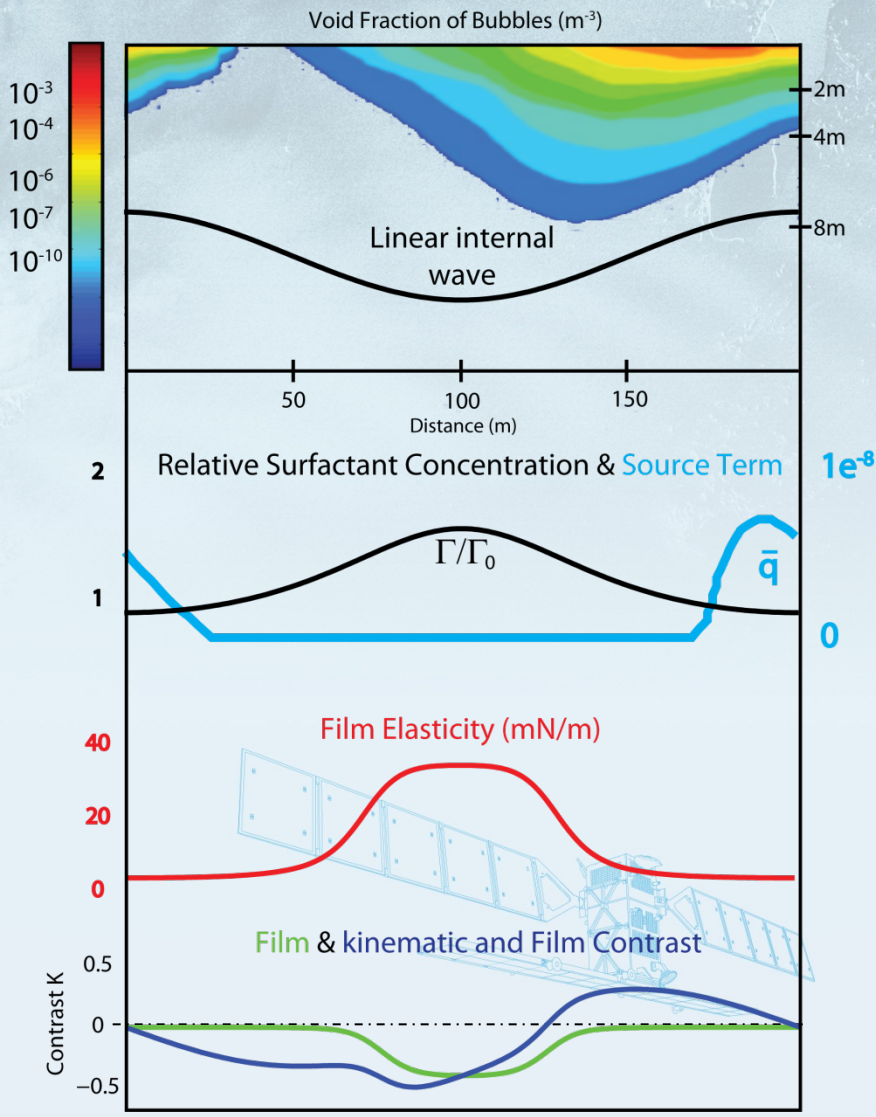
Oblique nonlinear interactions may amplify internal waves and generate instabilities (amplitudes can grow up to 70 m (Jeans and Sherwin, 2001; Chen *et al*. 2011).



Instabilities may generate localized mixing, vertical transport of nutrients relevant for primary production, and be at the origin of boils.

Model approach

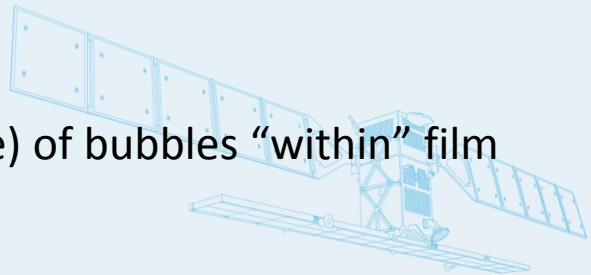
- Grimshaw et al. (2010) model the effects of internal waves on the structure of the sea subsurface bubble layer, generated by breaking surface waves
- **q** is the bubble injection source term due to breaking surface waves (consider λ=2.5 m)
- Linear IWs with A=3 m & thermocline at h=8 m & wavelength Λ=200 m
- Ermakov et al. (1992) & da Silva et al. (1998) model to describe dynamics of surfactant films and surface wave damping (λ=21 cm)
- Results give a subsurface bubble layer some 50-100 m wide & 2 m deep over the forward slope of IWs
- This is followed by a film slick band some 50-70 m wide over the IW trough



Conclusions & Future Work

- Imaging (near-IR) LiDAR detects IW slicks & subsurface bubble layer (2 m deep)
- Thermal IR signatures of IWs have been observed off Portugal
- Surface circular structures denominated "*boils*" are detected with thermal-IR, having "cold" skin SST some 0.3 - 0.4 ˚C below average field
- Large "Boils" may be a result of extraordinary-large-amplitude IWs due to resonant Wave-Wave interaction (common features off Portugal with 70 m amplitude)

Planned work



- Linear models do not explain a visible (white structure) of bubbles "within" film slick bands.
- Need to develop new nonlinear models that account for observations

Thank you!