

Sampling Small Eddies and Fronts with Boats and Planes in the Southern California Bight : Trials, Tribulations, and Some Successes

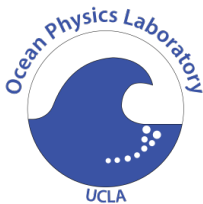
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Carter Ohlmann, UC Santa Barbara

Geoff Smith, George Marmorino, Dave Miller, Naval Research Laboratory

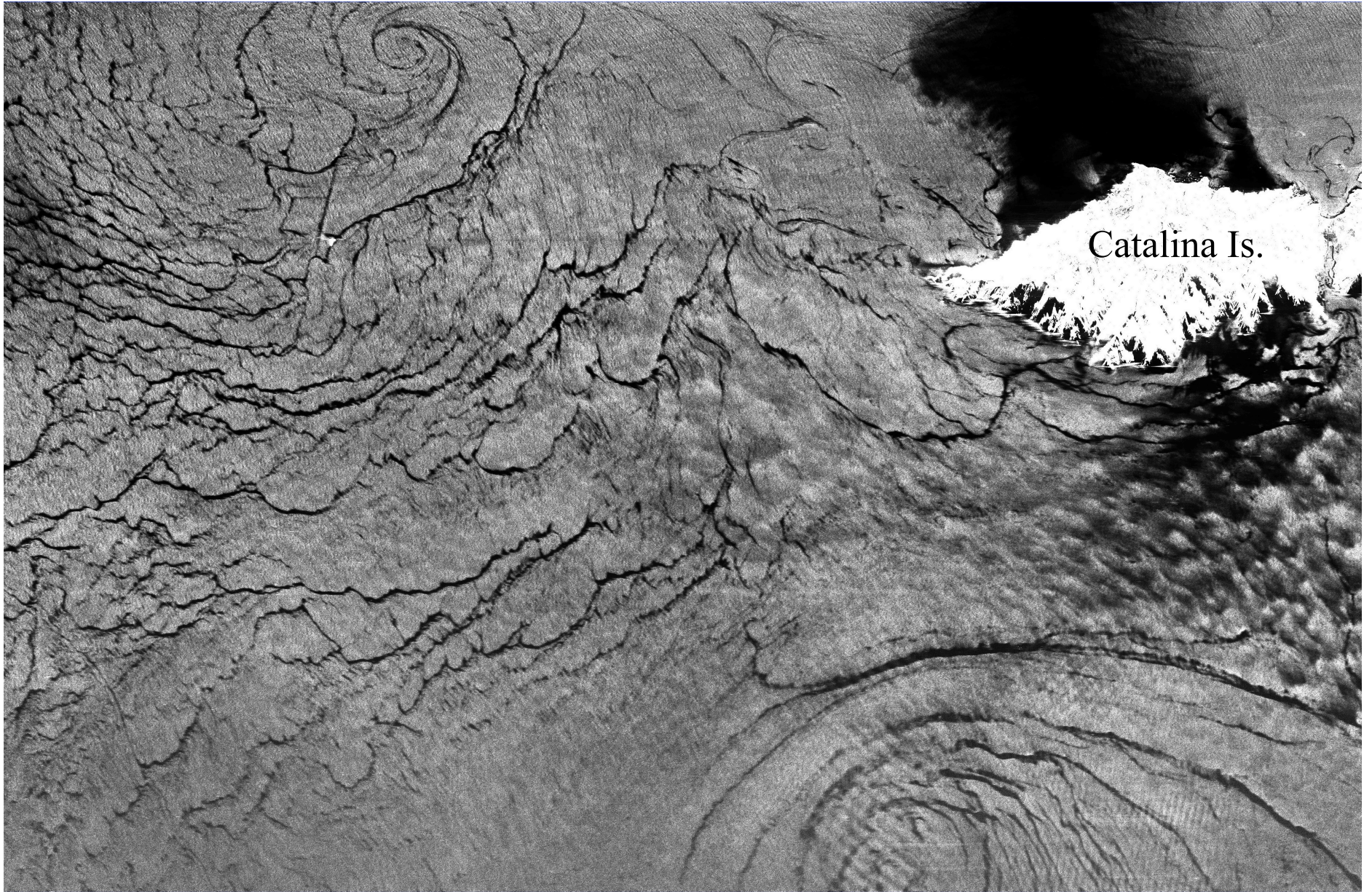
Michelle Gierach, Jet Propulsion Laboratory, California Institute of Technology



UAVSAR Workshop
JPL, March 26-27, 2013



UAVSAR September 16, 2009



Small Eddies and Fronts

Objectives:

Investigate submesoscale eddies, fronts, and filaments in order to:

- Improve the understanding of physical properties and generation mechanisms.
- Determine role in the coastal circulation and energy budget.
- Determine the connection between their surface expressions and *in situ* properties.
- Determine biological and optical response.
- Determine connection between SAR data, surface slicks, SST, Season, mixed layer depth.

⇒ **Submesoscale Experiments 2011 and 2013**

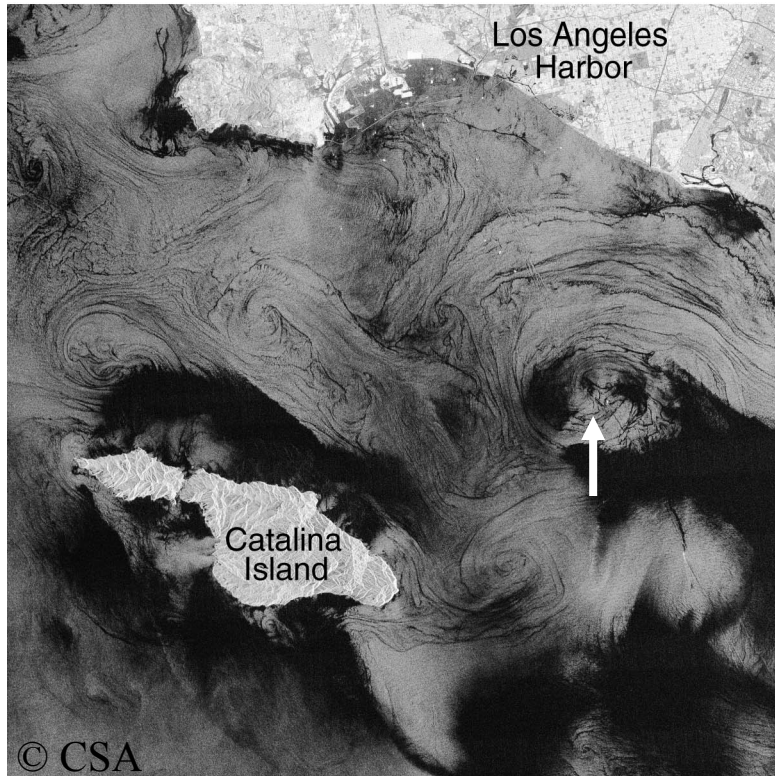
Pre-mission study for future Surface Water and Topography

(SWOT) mission – INSAR-derived sea surface topography

? What are the energetics and resulting SSH of the sampled eddies /fronts?

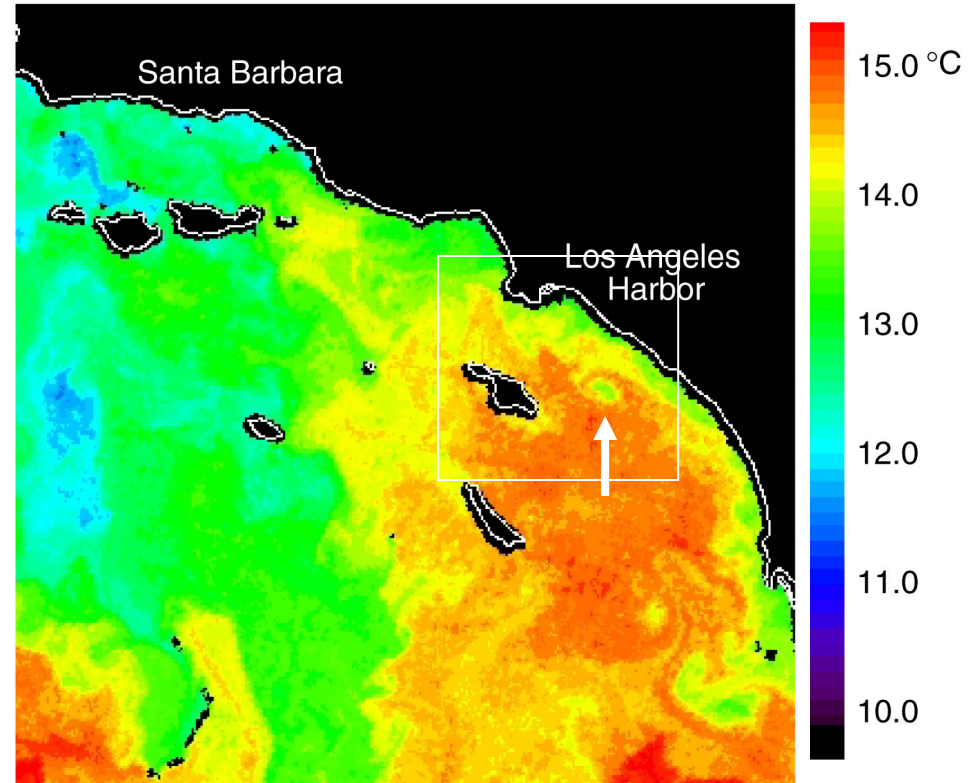
Small-scale Eddies in Southern California Bight

RADARSAT - December 26, 1998



10 km

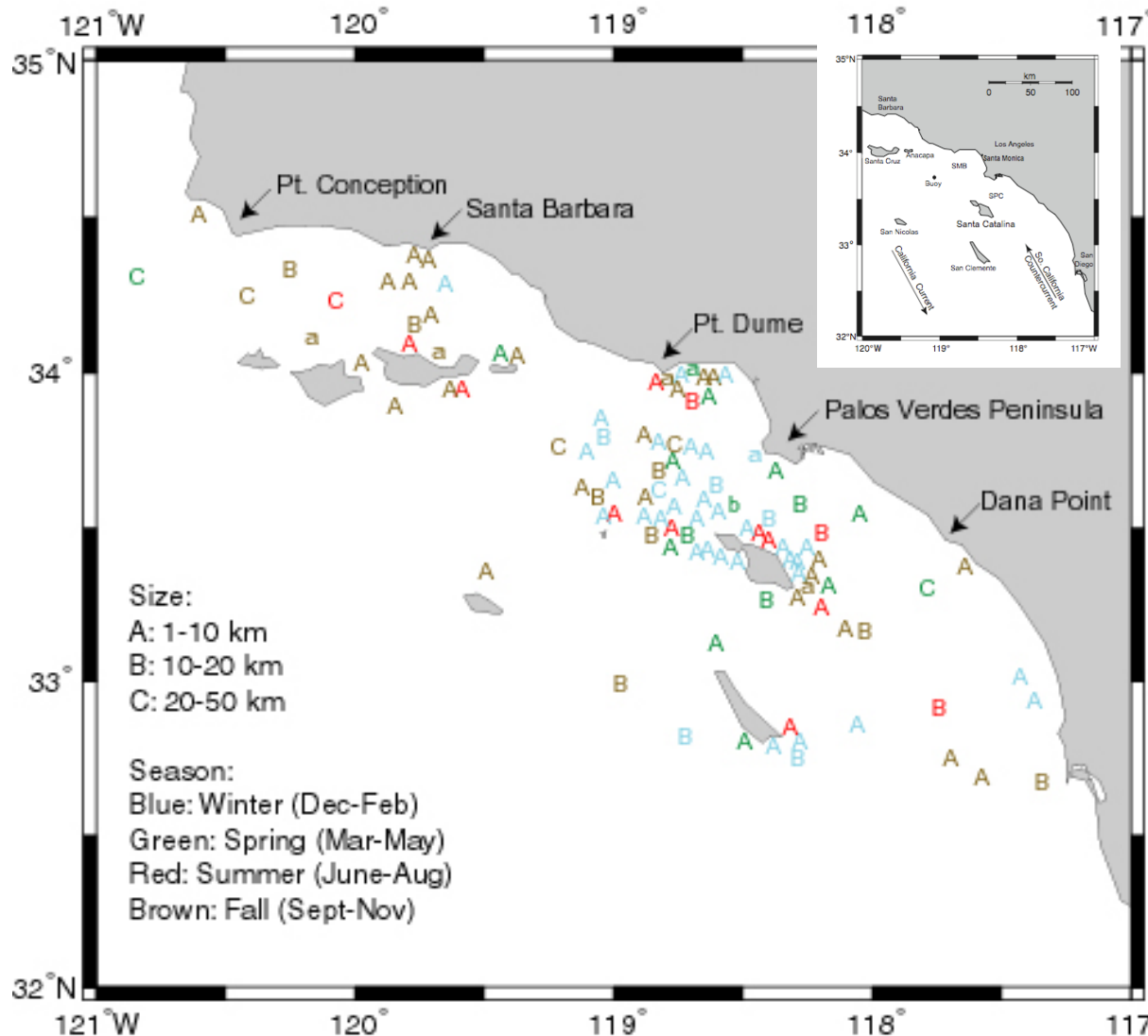
Sea Surface Temperature - December 25, 1998



From Holt, 2004

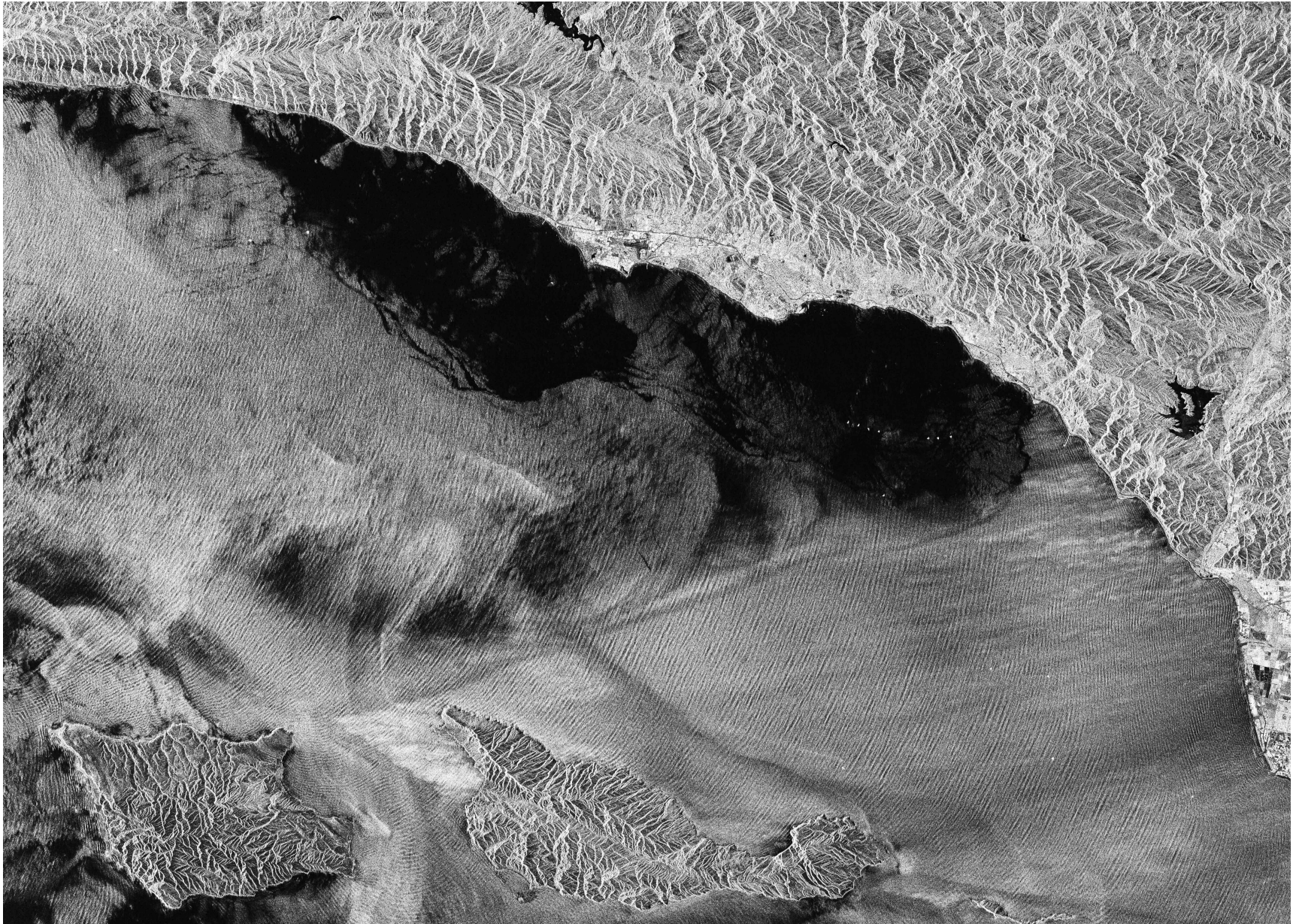
- SAR detects submesoscale eddies primarily via alignment of surfactants by circulation flow field /fine structure
- Rapid repeat imaging can be used to derive rotational velocity
- Differences in SAR eddies and SST likely related to energy, time of generation

Small-scale eddies observed via ERS-1/2 SAR Imagery in the Southern California Bight

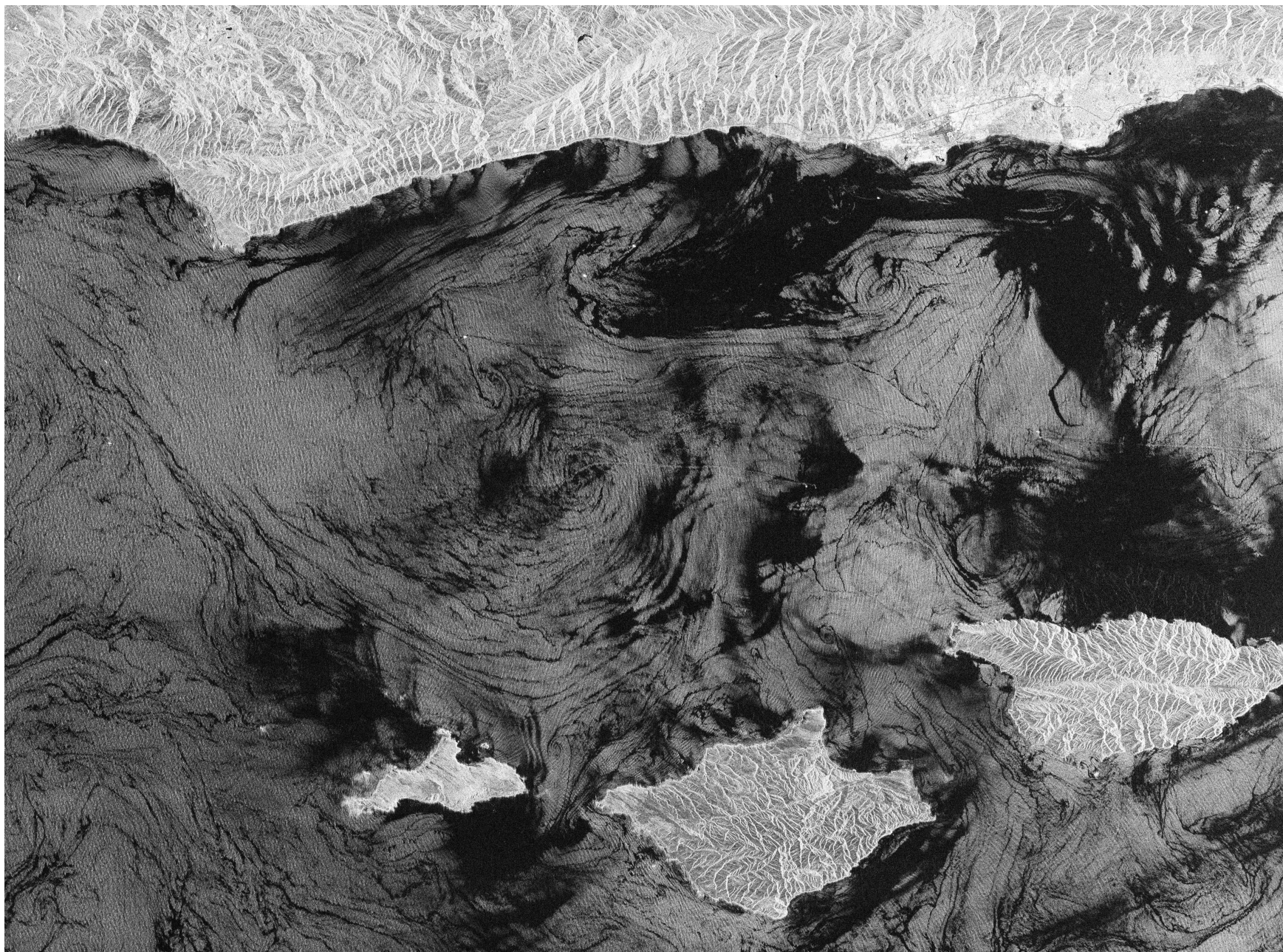


- Eddies were predominantly under 20 km in diameter, predominately cyclonic.
- Many appear to be formed by current-wake instability, as well as topographic and wind forcing.
- Seasonal distribution in eddy field observed : best observed in fall and winter, summer has stronger diurnal wind patterns.
- [Reference: DiGiacomo & Holt, 2001, JGR Oceans](#)

Santa Barbara Channel, 02Z, Jan. 8, 2003, Radarsat



Santa Barbara Channel, 14Z, Jan. 8, 2003, Radarsat



Coordinated Aircraft and In Situ Eddy Sampling

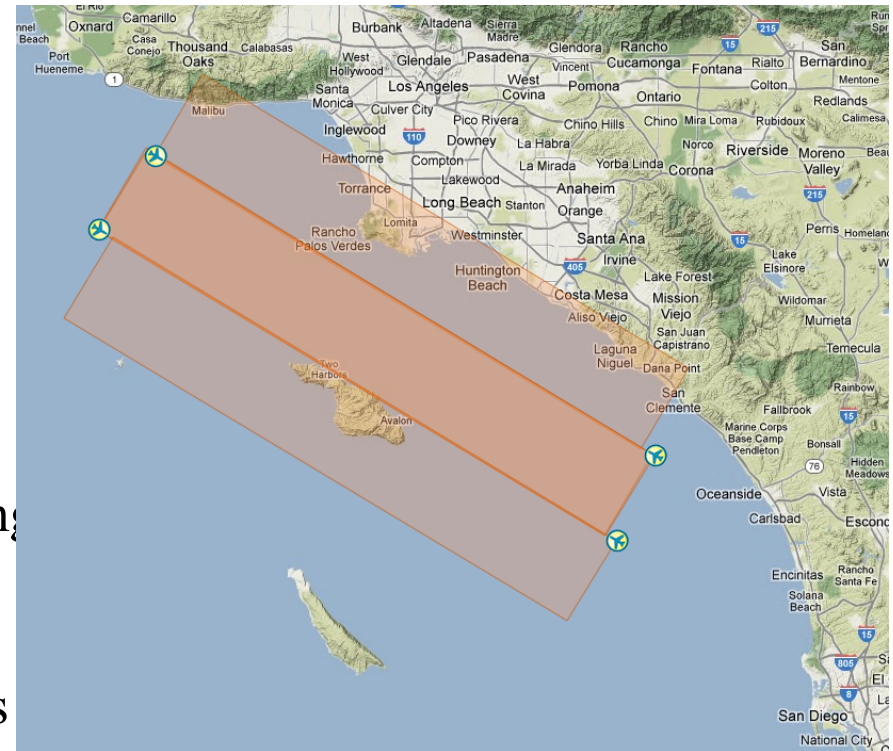
Strategy:

1. Identify eddy/front with aircraft/satellite
2. Vector boat/s to feature for intensive in situ sampling
3. Repeat remote sensing sampling

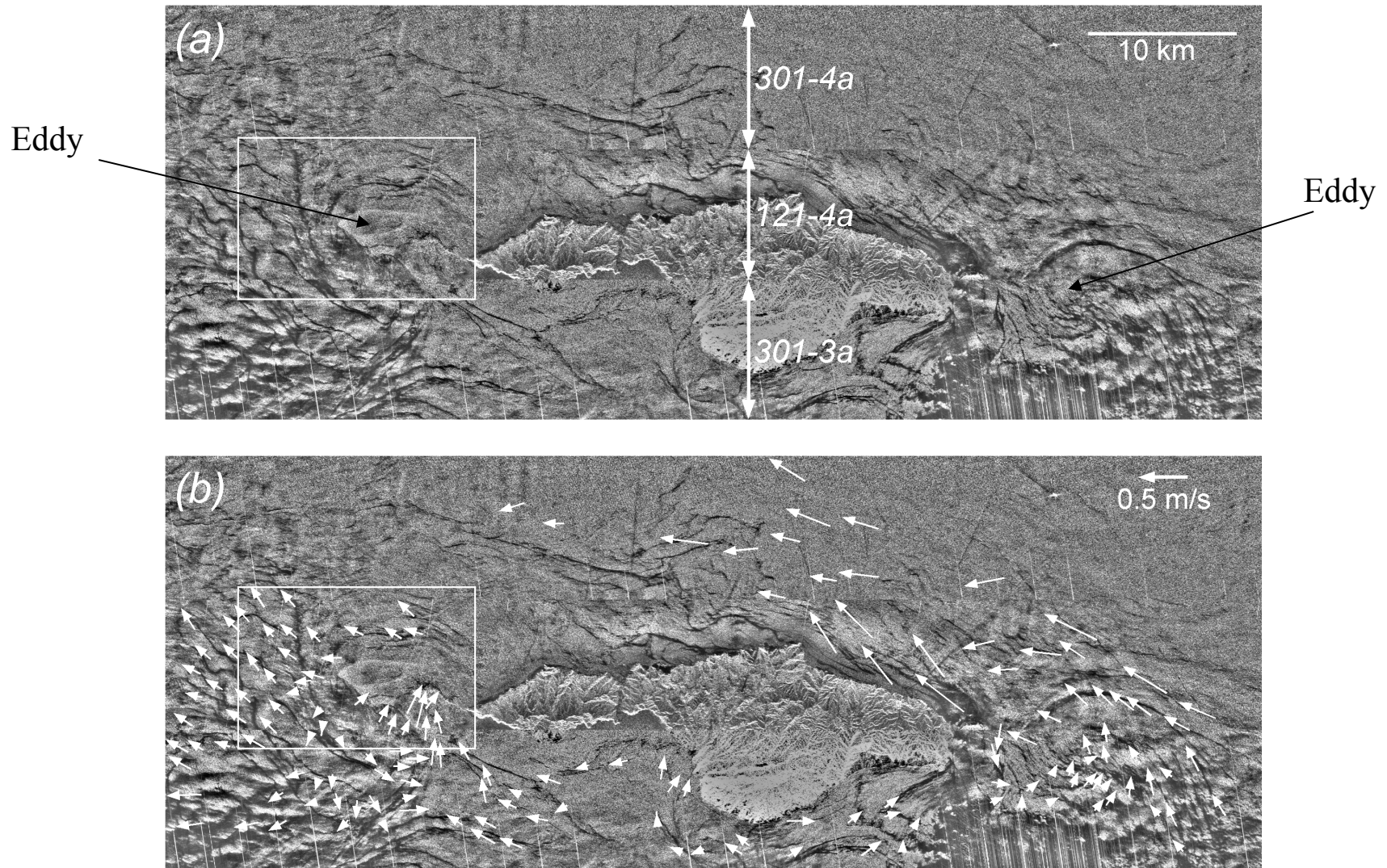
Campaigns

- April 2003- AIRSAR (NRL flight costs), UCLA boat, Radarsat
- September 2009 – Faster UCLA boat, Two planes (NIR, UAVSAR-Demo onboard Processing)
- April 2011 – Two fast boats, Three planes, (NIR, UAVSAR-improved onboard processing, NRL MWIR/Hyperspectral), Envisat ASAR
- Jan-Feb 2013 – Three fast boats, Two Planes (NIR, NRL MWIR/Hyperspectral), ASTER, (no UAVSAR, no spaceborne SAR)

Aircraft SAR lines



AIRSAR April 16, 2003, Catalina Island

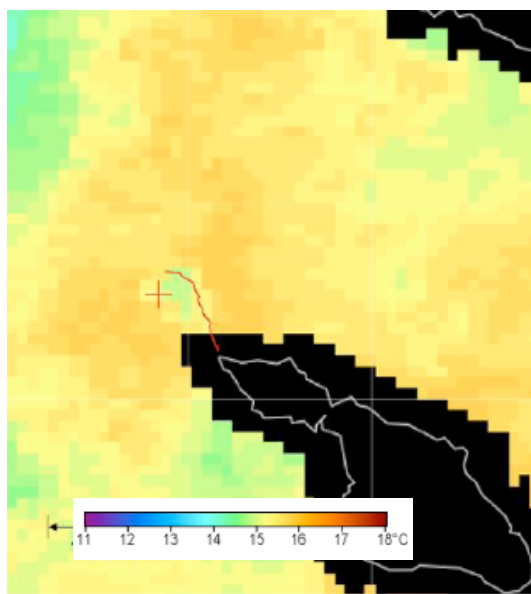
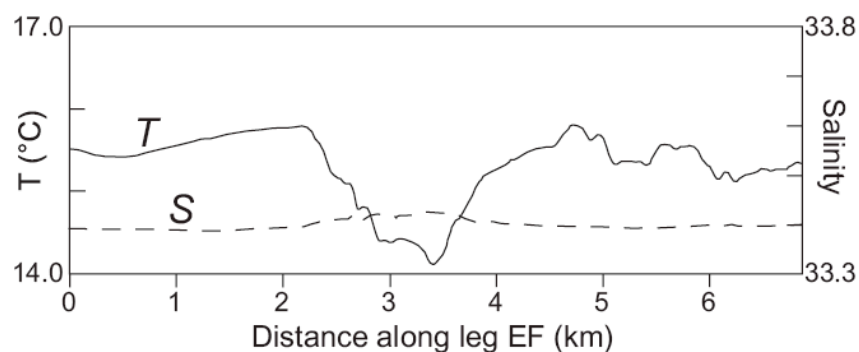
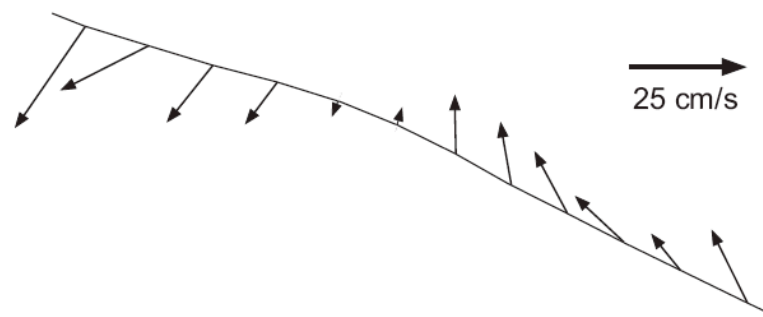
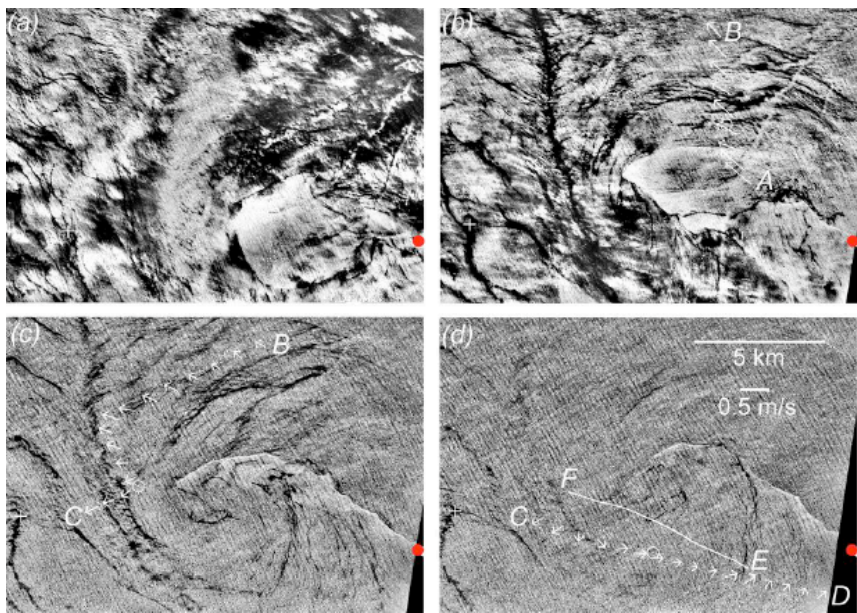


- Repeat imagery (45 minute time difference) used to derive surface vectors

(After Marmorino et al., J. Geophysical Res. Oceans, May 2010)

Airborne-Shipborne Campaign, April 16, 2003 Near Catalina Island

(After Marmorino et al., *J. Geophysical Res. Oceans*, May 2010)



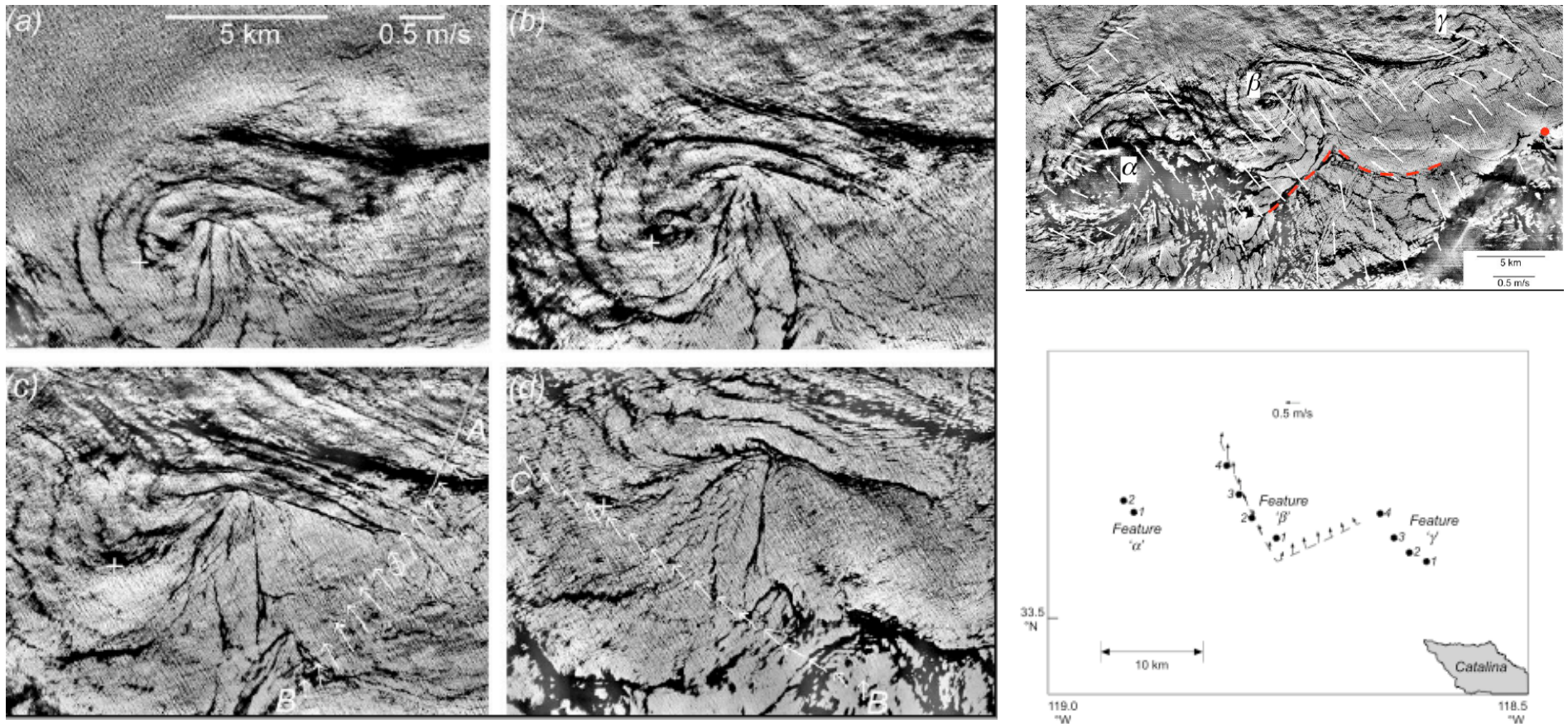
Left top – NASA AIRSAR obtained repeat imagery, 5 hour interval

Right Top – Leg EF (1d). Averaged current vectors (3-25 m depth range). Temperature and salinity at 0.6m depth, indicates cold core near eddy center.

Left - AVHRR SST from April 16 showing cold eddy center (“+”) and front (red line) derived from radar bright line seen in 1c.

April 19, 2003 Near Catalina Island

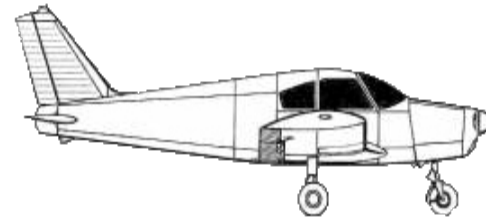
(After Marmorino et al., *J. Geophysical Res. Oceans*, May 2010)



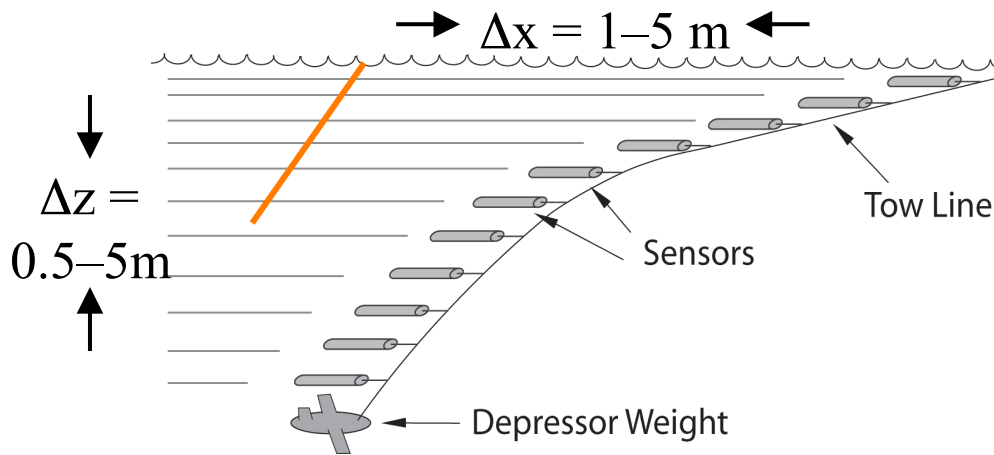
NASA AIRSAR 4-panel sequence of evolving cyclonic eddy over 4 hr period. Overlaid (1b & 1c) are 4-m currents vectors obtained by boat (white circle).

Larger AIRSAR frame showing three eddies (Fig. 1 is center eddy β), off W. Catalina Island (red dot). Residual surface currents derived from repeat images show little cyclonic motion. Sharp front crossed by boat shown with red dashed line. Lower – location of 3 eddies over ~ 5 hour period. 4-m ADCP current vectors legs AB and B \Rightarrow Eddy β appears to be remnant surface appearance of eddy formed earlier and no longer active at depth.

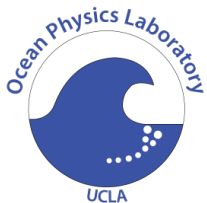
Faster Boat - In Situ Measurements



$\Delta t = 5 \text{ min}$



- Towed Instrument Array (T, S, P):
- RBR TR-1060, TDR-2050, XR-620
 - Accuracy: 5 mK, 3 μ S/cm
 - Tow Speed: 5 m/s
 - Repeat: 20 min (5 km transect)
 - Depth: 0-45 m

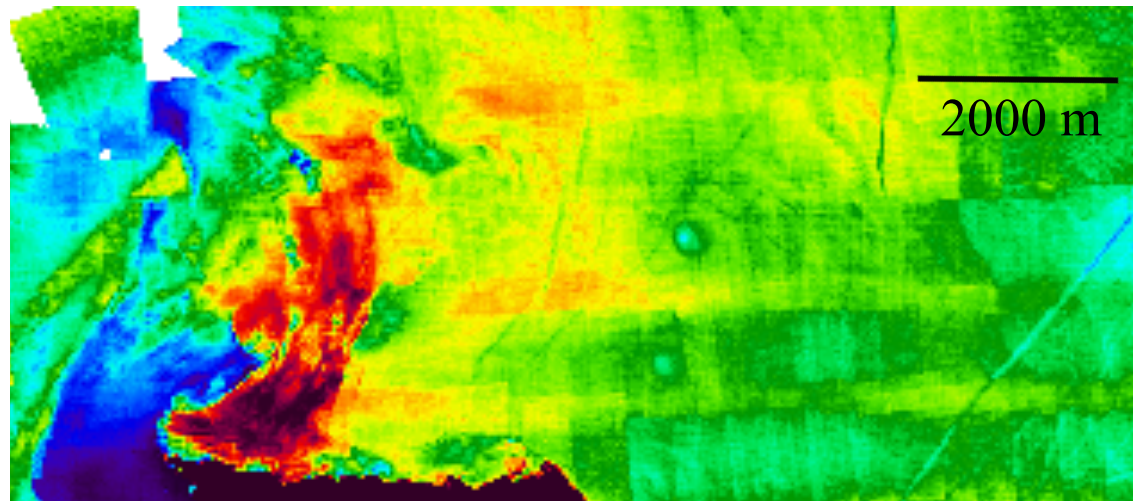


B. Baschek, UCLA

Airborne Instrumentation



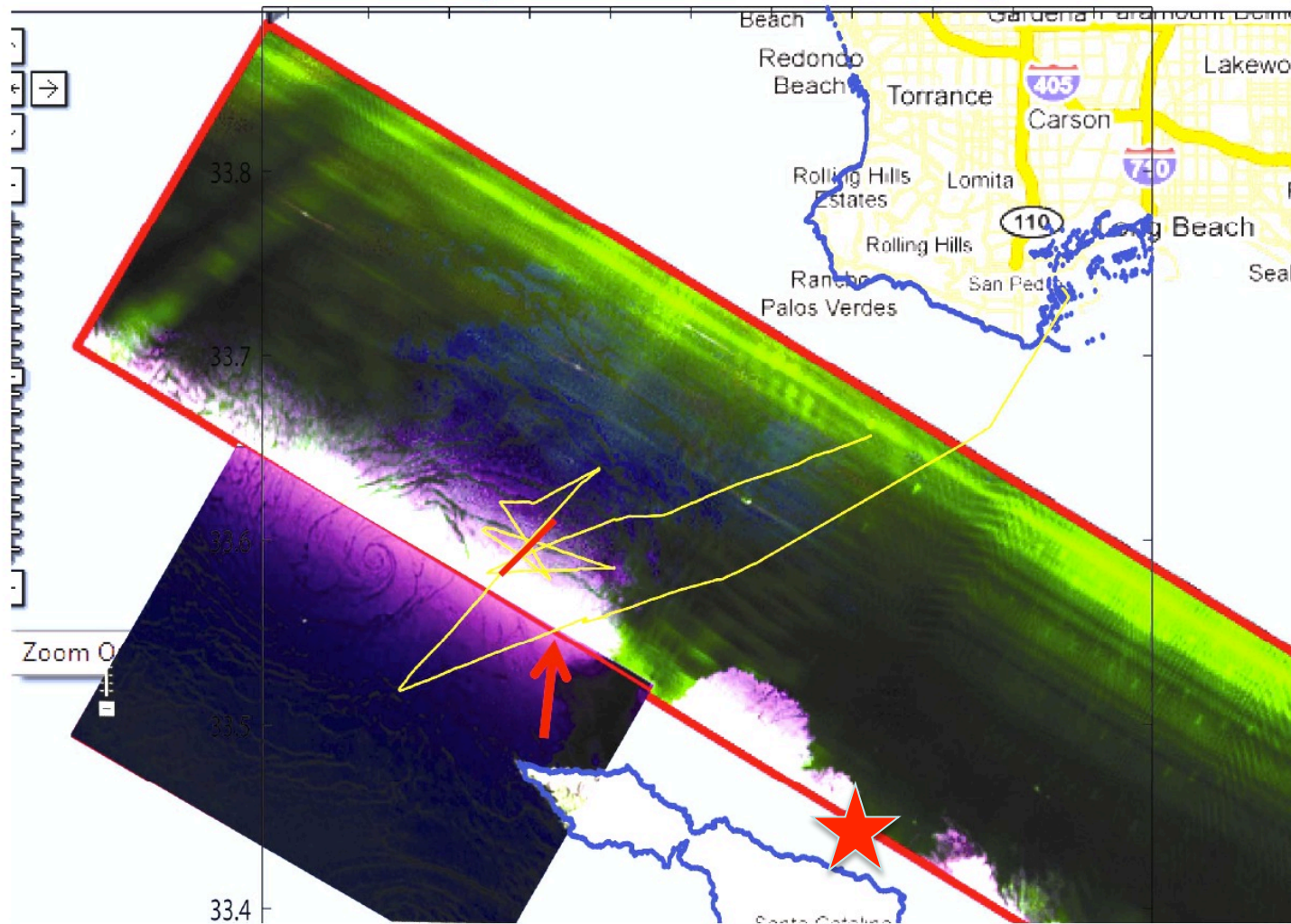
Infrared: 1x LWIR (FLIR A325, 10 m resolution at 3000 m altitude)
Error: 0.07°C + atmospheric effects + lens effect + skin temp. effect




B. Baschek, J. Molemaker, UCLA

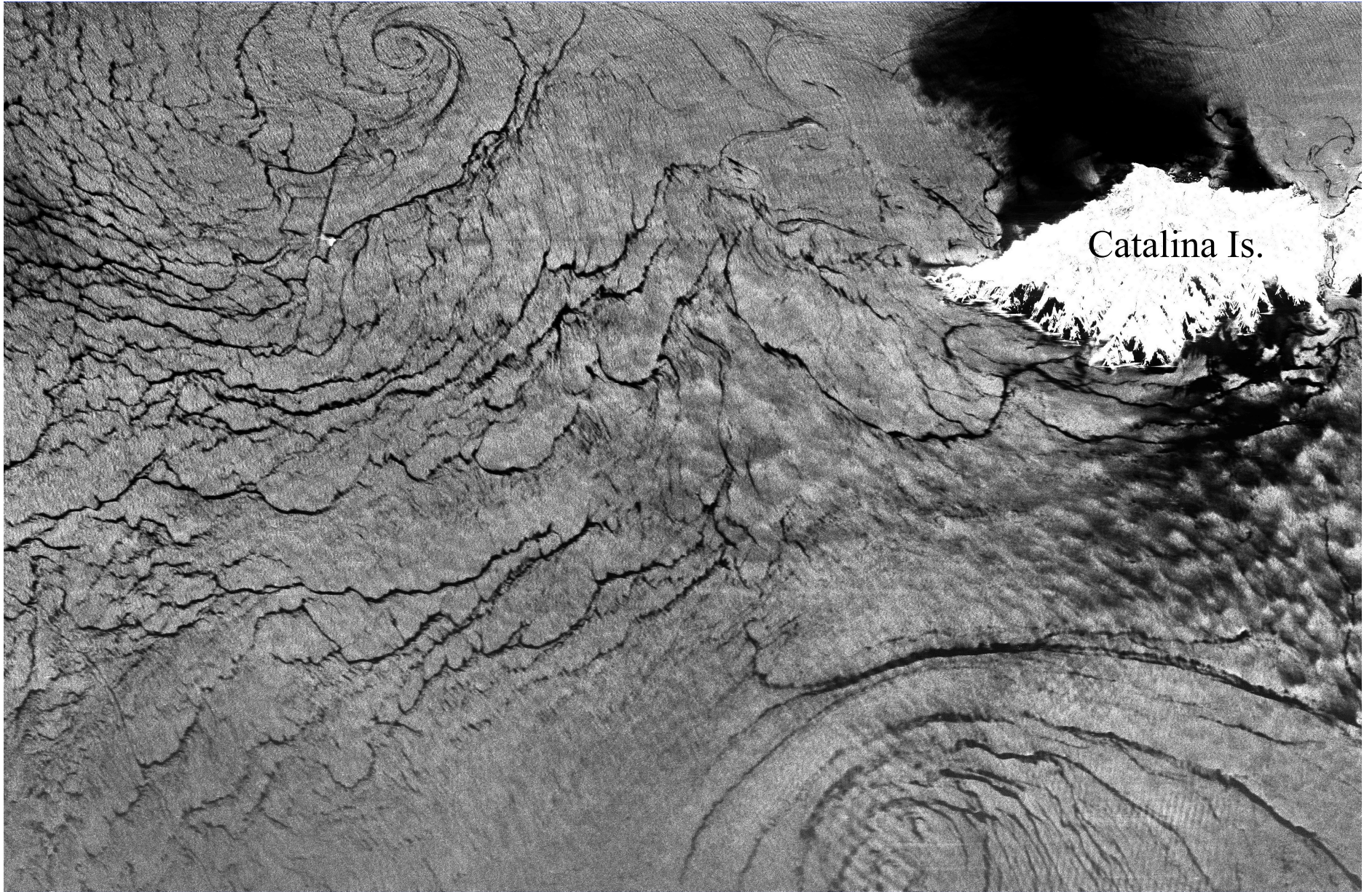
2009 - UAVSAR + NIR Overflights

Polarimetric Image of Channel Islands, CA (September 16, 2009)

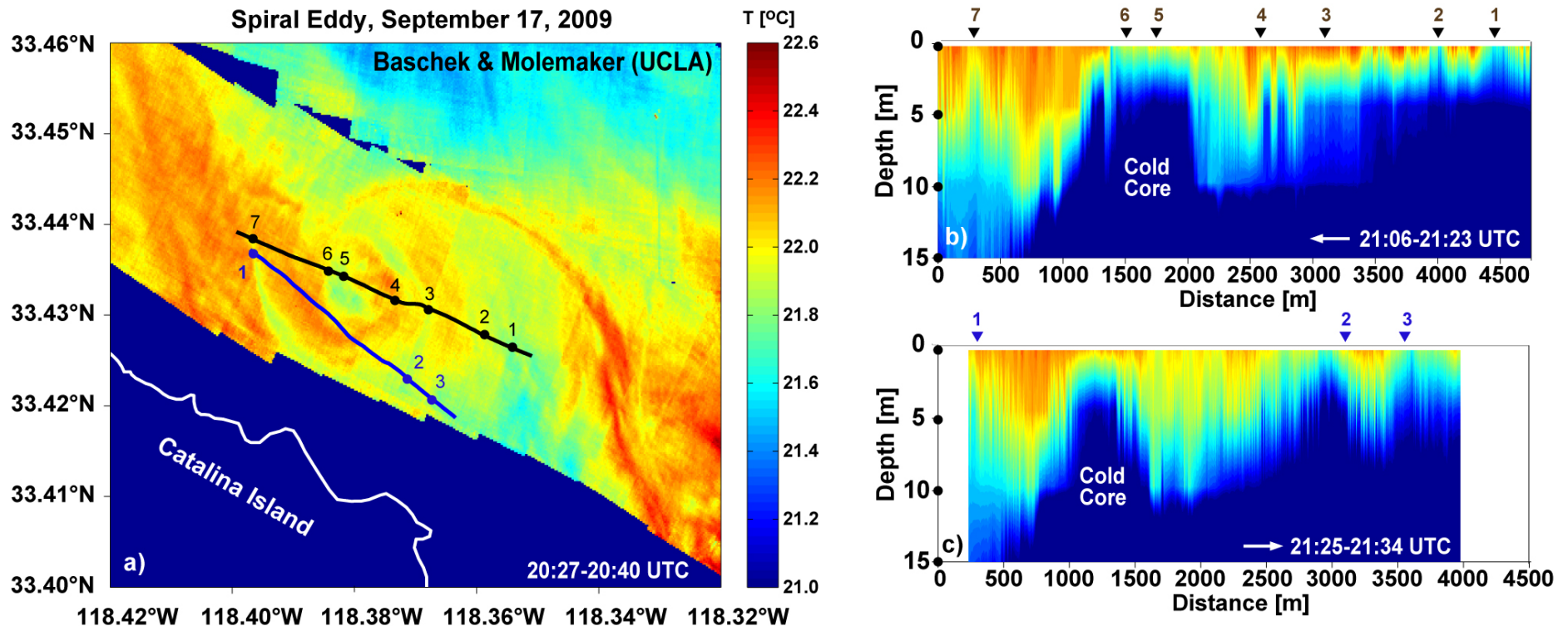


- UAVSAR tested onboard image processor, operator relayed eddy identification but not for eddy shown which was nearly sampled as well by small plane-NIR.
- Actual eddy sampled located at  => still need improved coordination.

UAVSAR September 16, 2009



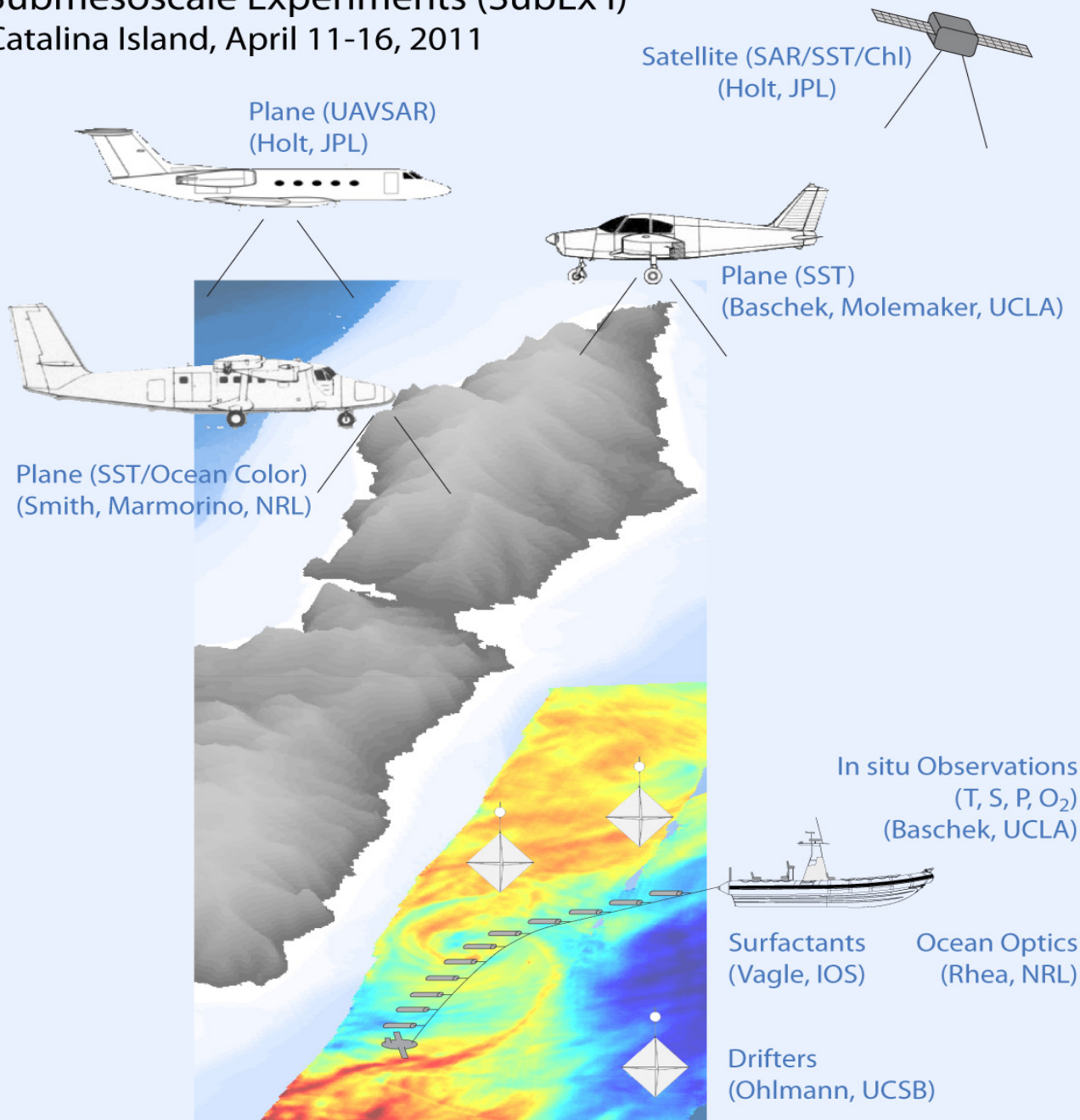
2009 - Detection and Sampling of a Spiral Eddy, SST – First Results



- Tested sampling methodology with UAVSAR, small airplane with SST, boat with towed string (CTD/Pressure sensors)

- Preliminary results indicate viability of methodology, with perhaps first ever in situ measurements of a spiral eddy, in this case an eddy of **~diameter 2.5 km** located adjacent to Catalina Island in the So. California Bight. Airborne SST imagery (left) is shown with two overlaid boat tracks and in situ temperature transects from two tracks (right), obtained less than one hour after airborne SST data. Note close correspondence of temperatures at black track points 1, 5-6, 7 and blue track points 2-3 plus at adjacent cold core.

Submesoscale Experiments (SubEx I) Catalina Island, April 11-16, 2011



2009 Preliminary

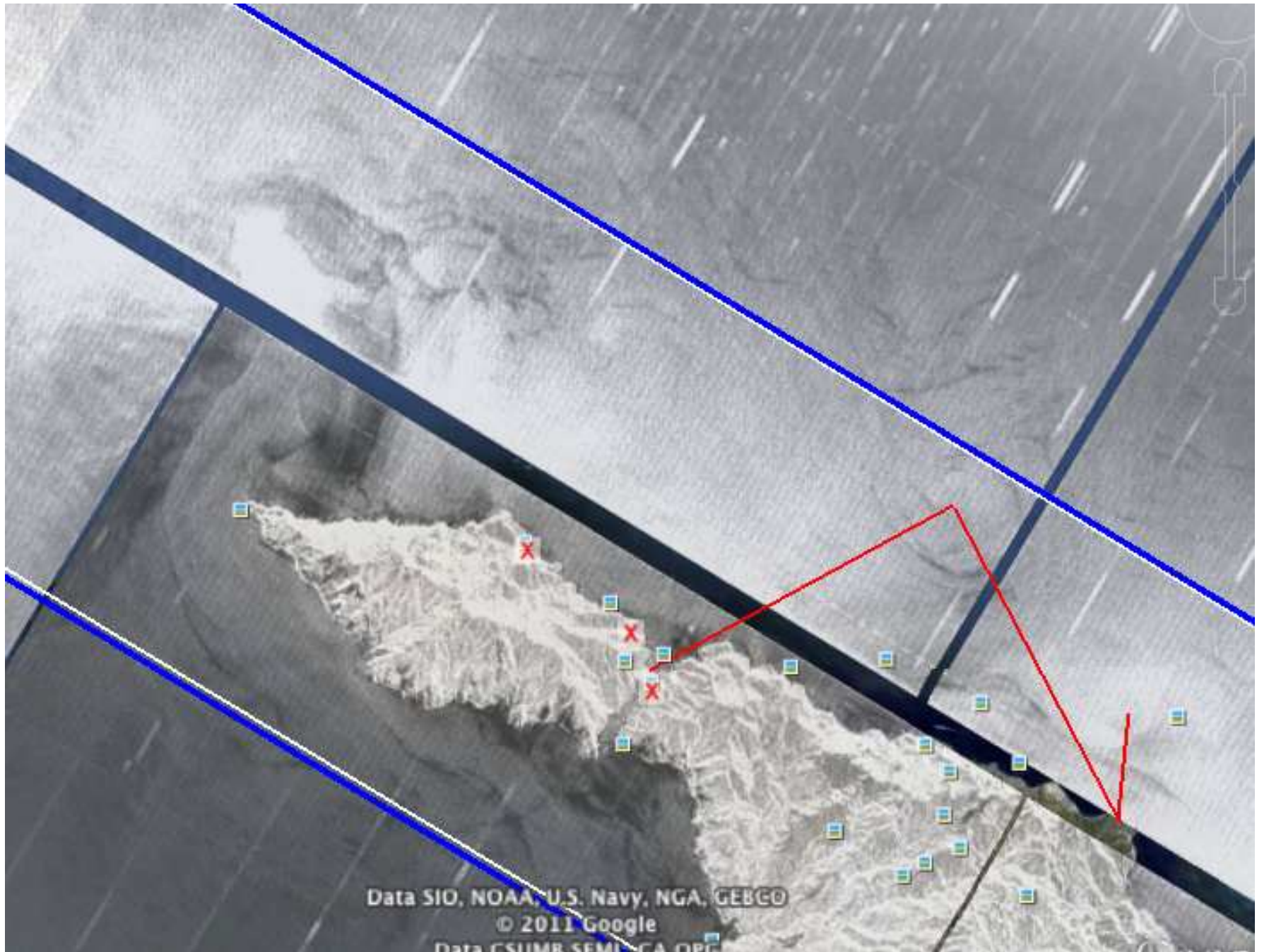
2011 Full experiment

• **Aerial Measurements**

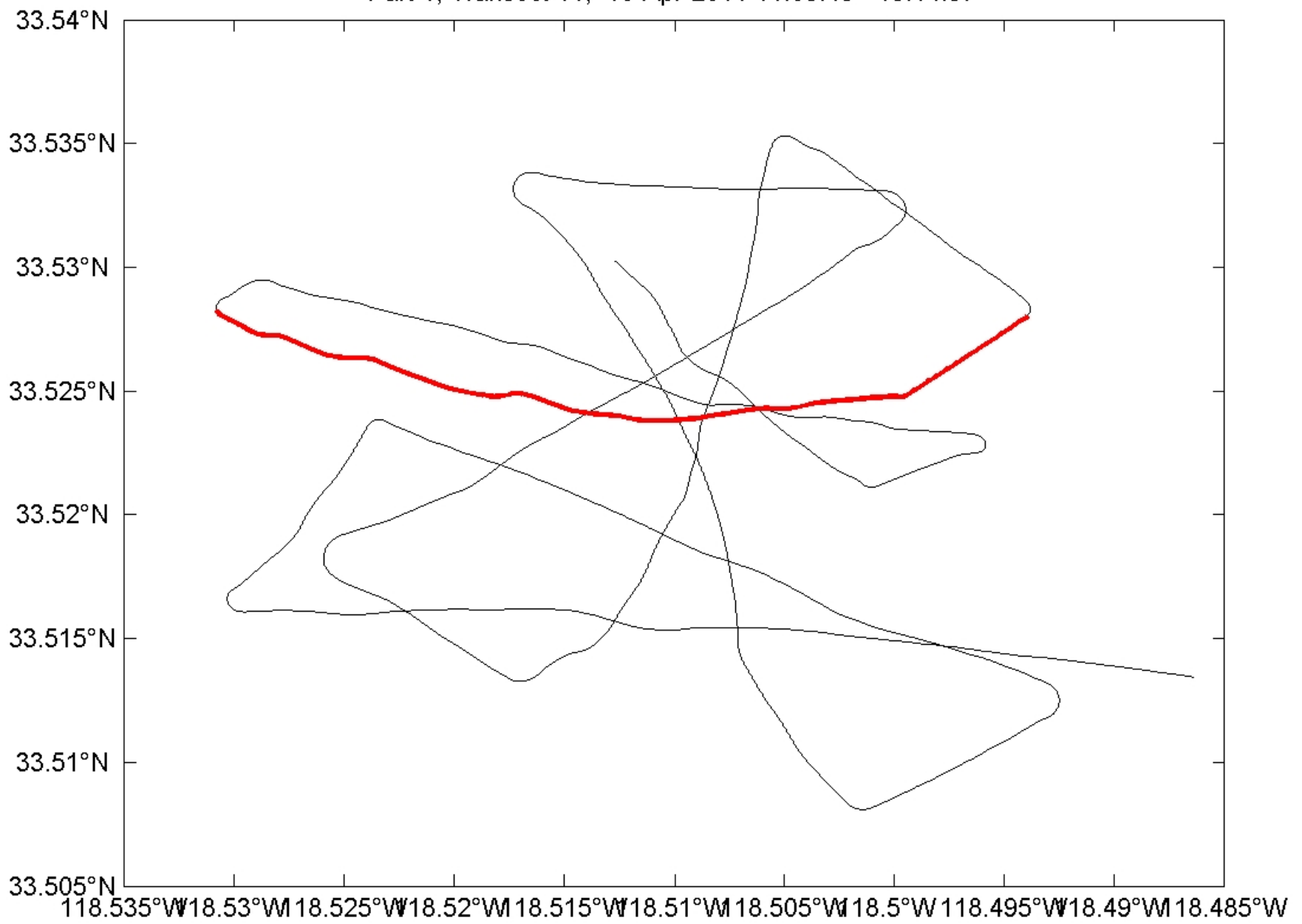
- Spatial resolution 1-20m
- Repeated every 10-20 min over a 10 km x 10 km area.

• **In situ Sampling**

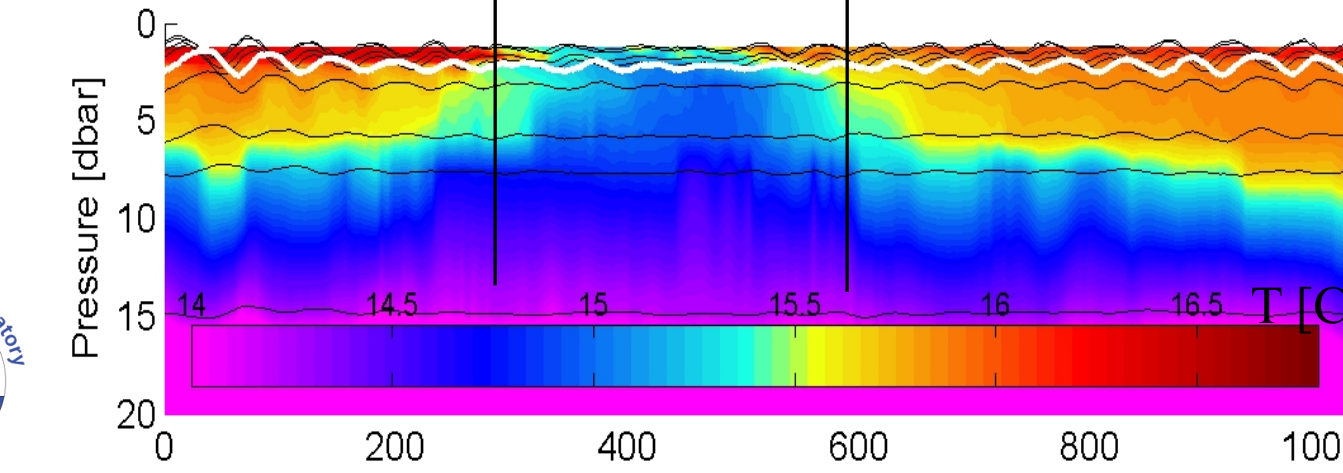
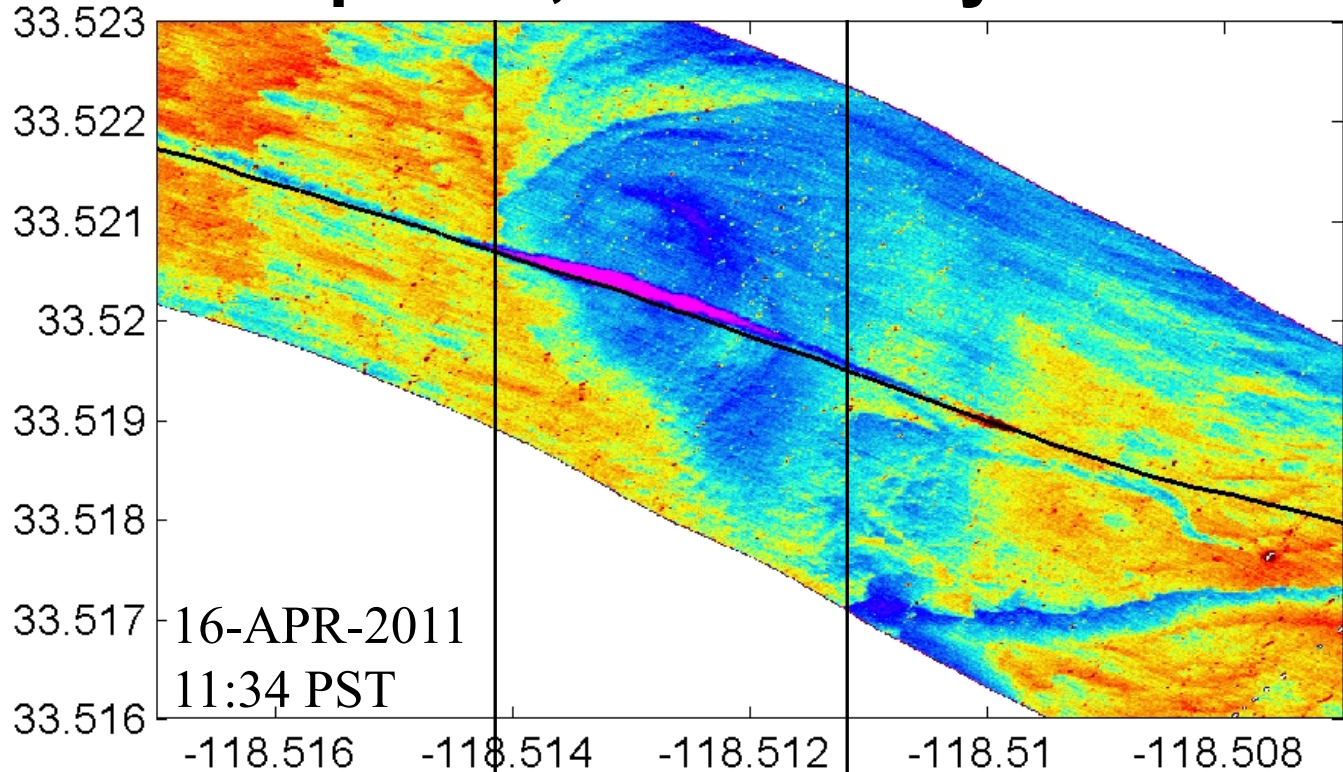
- horizontal and vertical resolution of 1-5 m
- repeated every 20 min for a 5km transect.



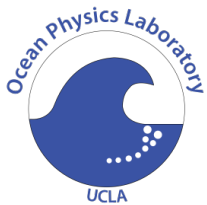
Part 1, Transect 11, 16-Apr-2011 11:09:45 - 13:14:37



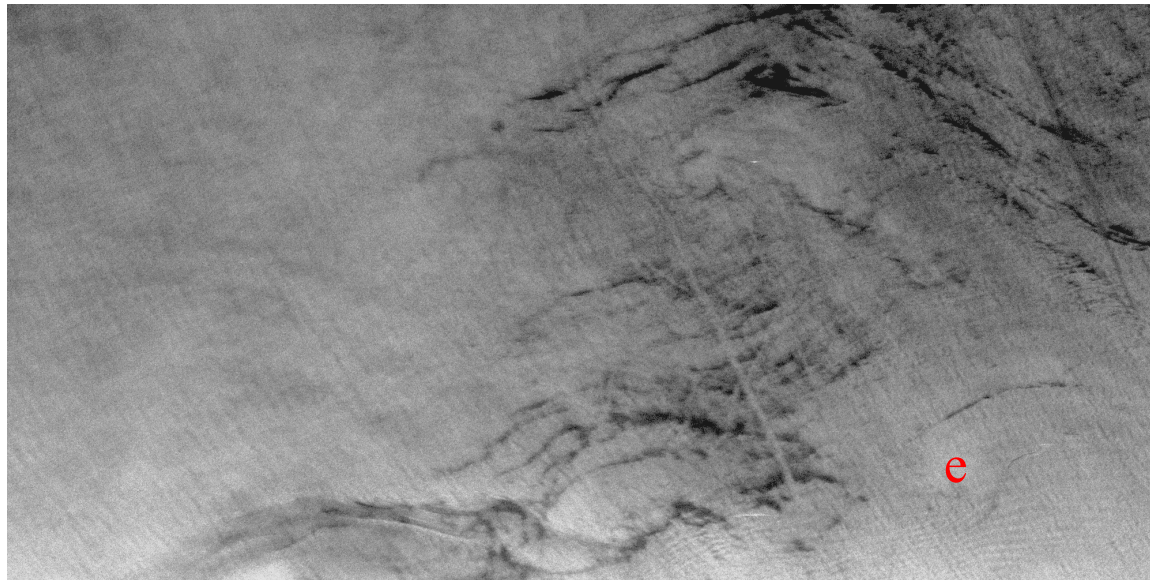
April 16, 2011 - Eddy "16E"



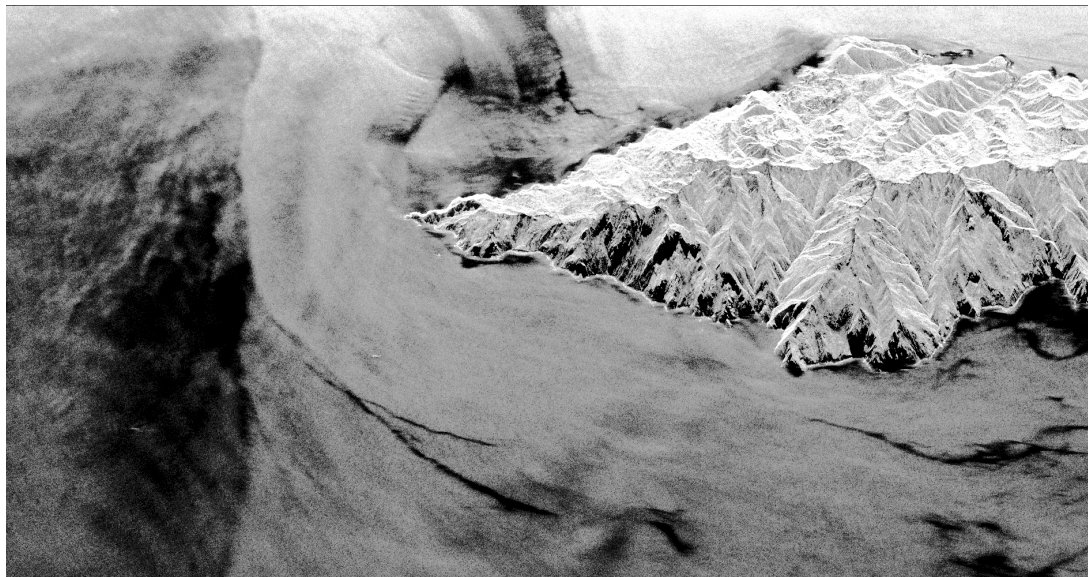
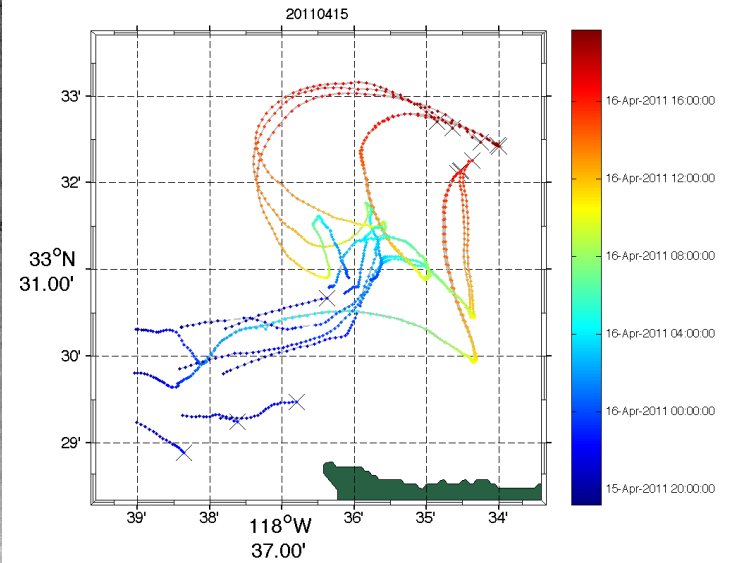
• ~500 m diameter
• 0.5°C contrast



Frontal Feature, UAVSAR –Overview, April 16, 11:11



UCSB Drifters

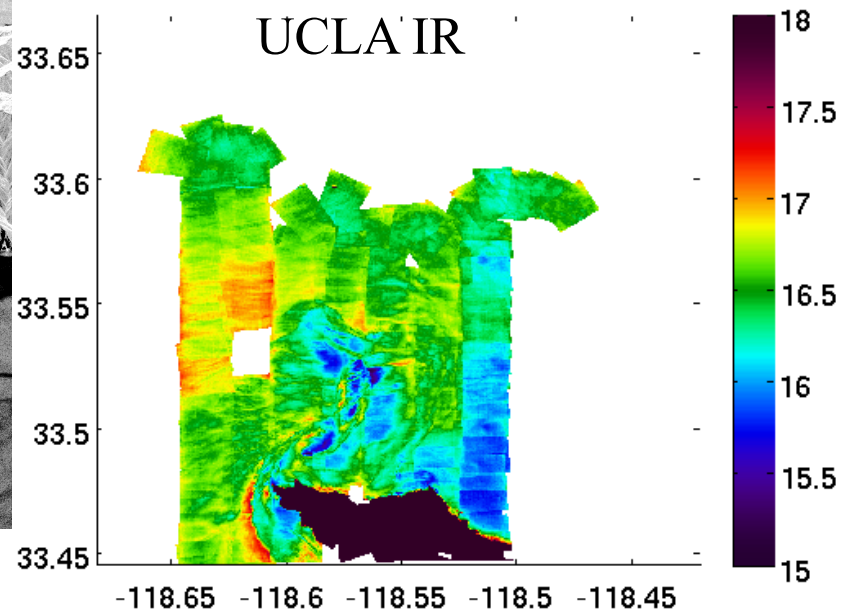


~1 deg C° gradient

3 km

Saturday April 16 12:20pm-1:30pm PST

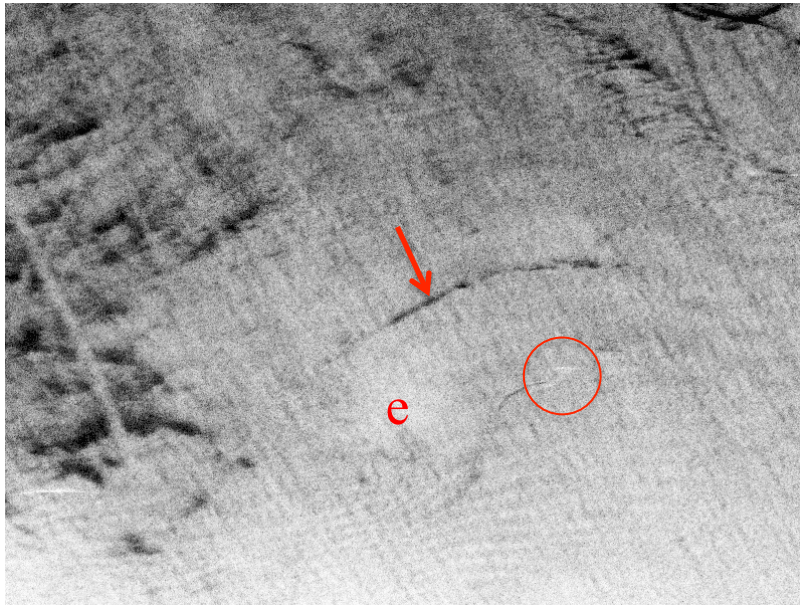
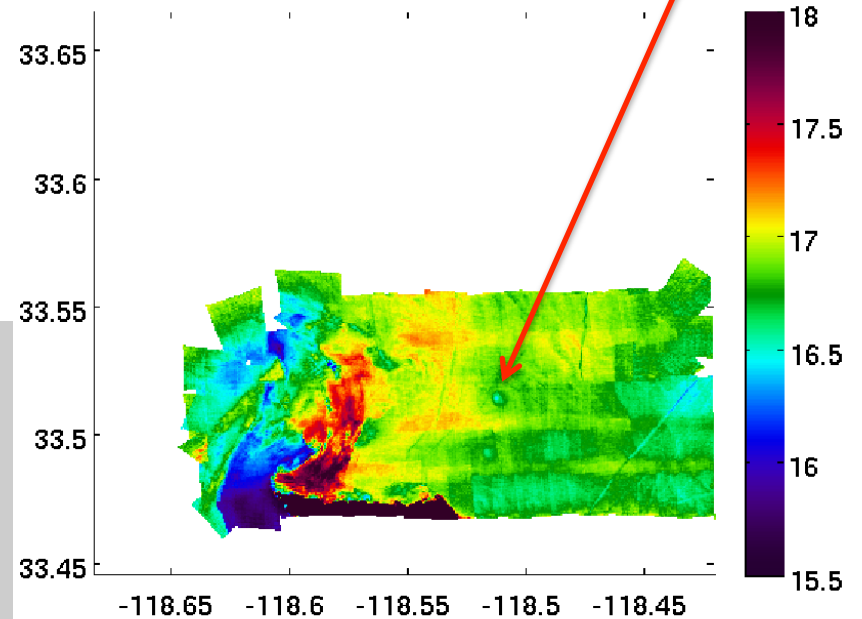
UCLA IR



UAVSAR – April 16, Coincident With SST data from UCLA and NRL

Eddy center= ~118.515, 33.52

Saturday April 16 10:40am-11:15am PST

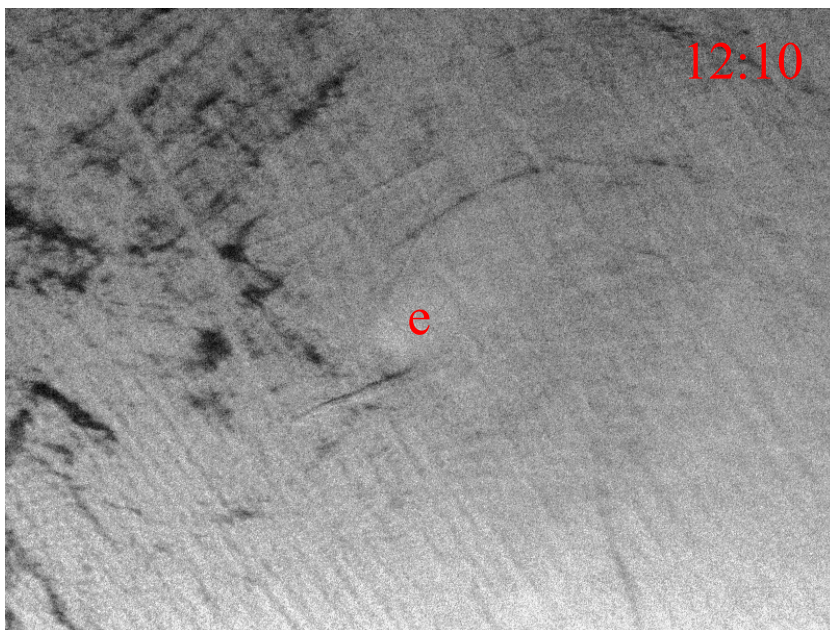
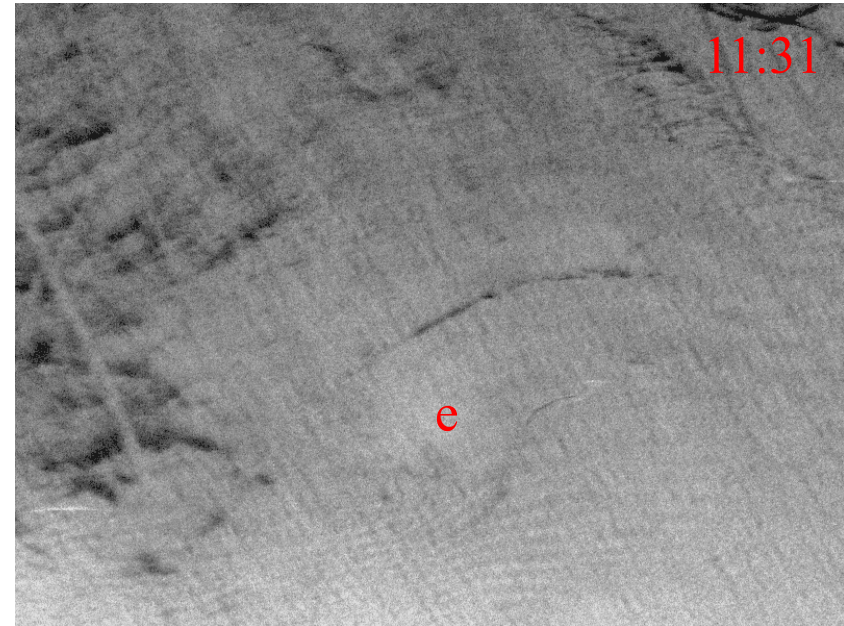
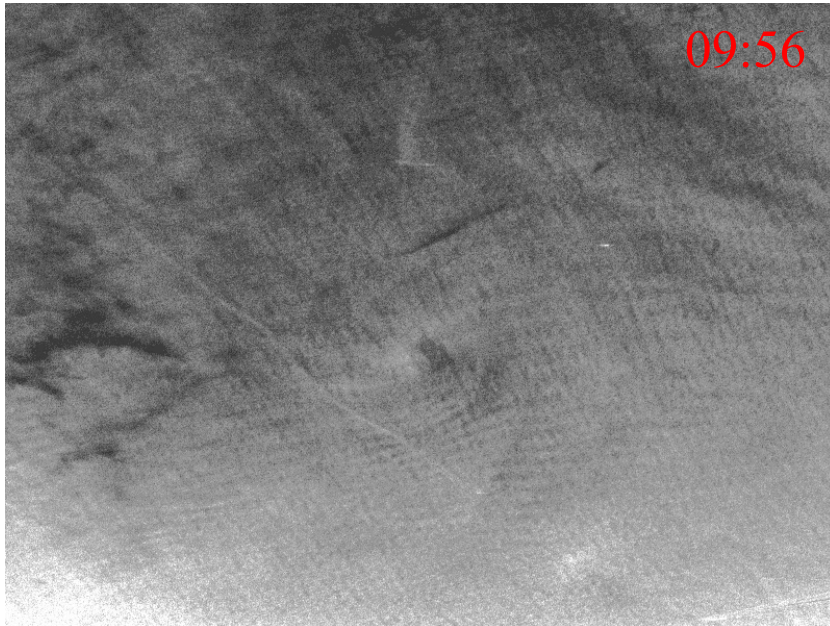


2 km



- 2nd boat, Never Satisfied, seen in both SAR and NRL IR at ~11.30
- Surfactant line shows SST differences
- Microlayer sampling for surfactants

UAVSAR, Sampled Eddy (16e) – April 16

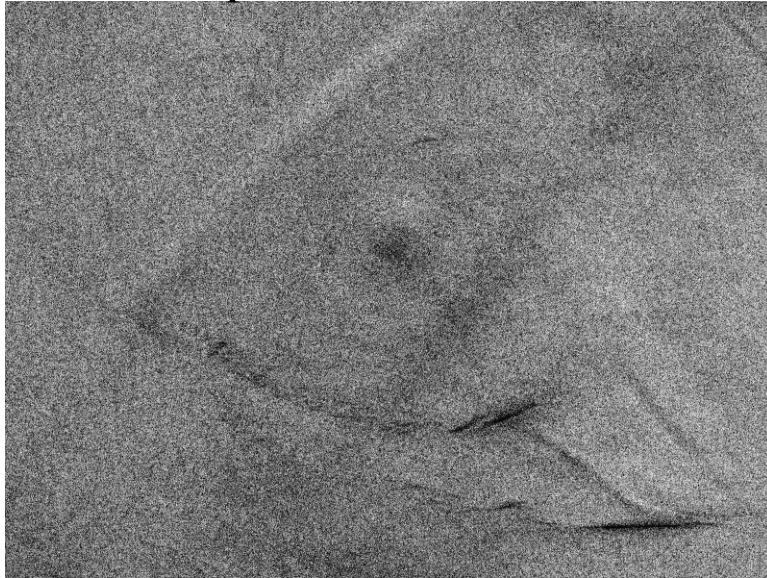


- Eddy has weak SAR signature, location based on NRL IR
- Due to recent formation and/or small size/reduced energetics?
- Flow fields still derivable from surrounding patterns.

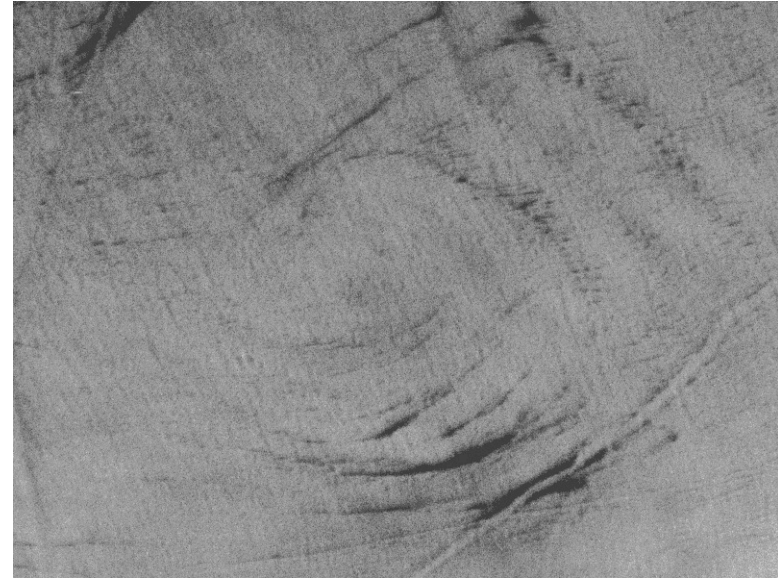
2 km

UAVSAR – 5 km Eddy to East of In Situ Sampling!!

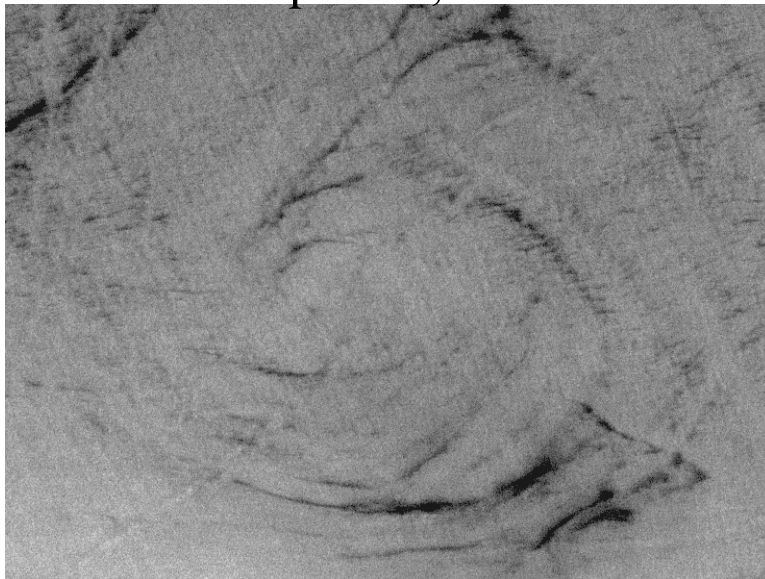
April 15, 16:50



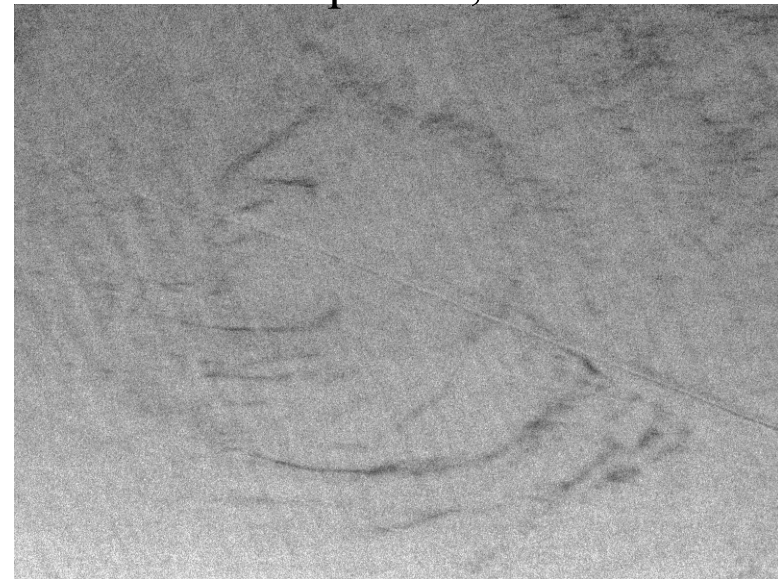
April 16, 16:56



April 16, 18:31



April 16, 19:10



— 2 km

•Derive rotational velocity field

Summary

- Coordination difficult and critical to sample temporally rapidly varying sub-mesoscale ocean features
- September 2009 – partial sample of 2.5 km eddy, bigger eddy in vicinity not sampled
- April 2011 – very good sampling of small (<1km) eddy, but weren't able to sample 5 km eddy to east.
- Jan/Feb 2013 campaign (not shown)– sampled small eddies (<2km) and rapidly varying fronts but still not larger one
- Repeat coverage enables feature tracking for surface current flow and rotational velocity, to help determine energetics
- Next Strategy – Periodic, shorter, focused in situ sampling based on aircraft and/or satellite plans (not blocked out 2-3 week periods) and weather patterns.