Results from the Submesocale Experiment-1 April 2011 -In situ, aircraft and satellite measurements of small eddies, fronts, and filaments in the Southern California Bight

Benjamin Holt, Jet Propulsion Laboratory, California Institute of Technology

Burkard Baschek* and Jeroen Molemaker, UCLA
*now at Helmholtz-Zentrum Geesthacht

Carter Ohlmann, UC Santa Barbara

Geoff Smith and George Marmorino, Naval Research Laboratory

Michelle Gierach, Jet Propulsion Laboratory, California Institute of Technology

SEASAR 2012
Tromso, Norway, June 19, 2012

Supported by NASA Physical Oceanography Program

Submesoscale Experiment (SubEx I)
Catalina Island, April 11 –16, 2011

<u>Objectives:</u>

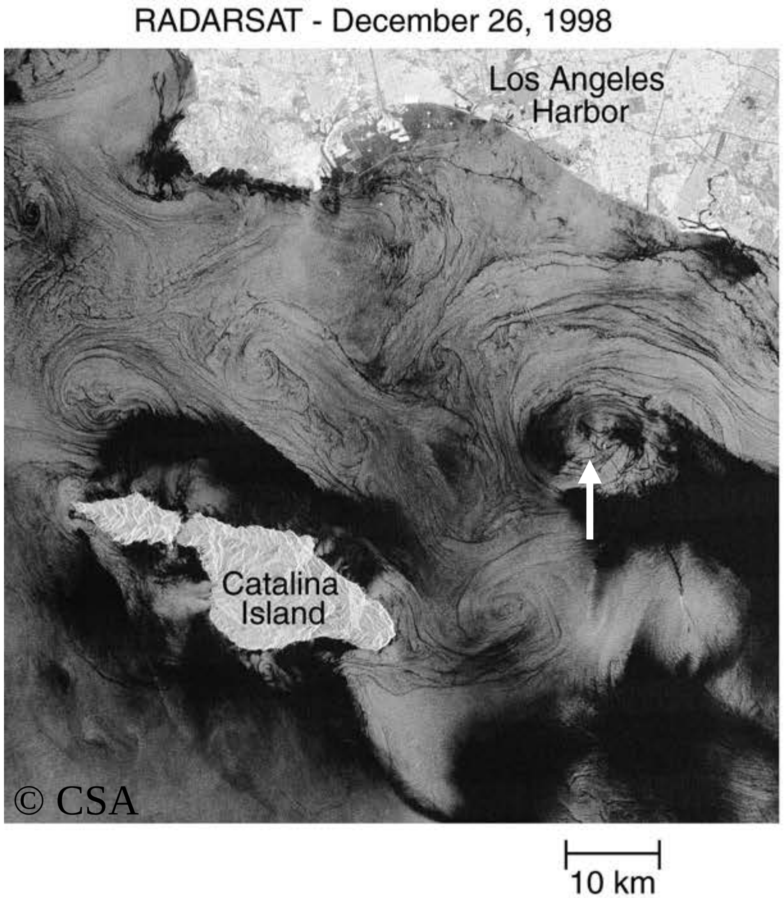
Investigate submesoscale eddies, fronts, and filaments in order to:

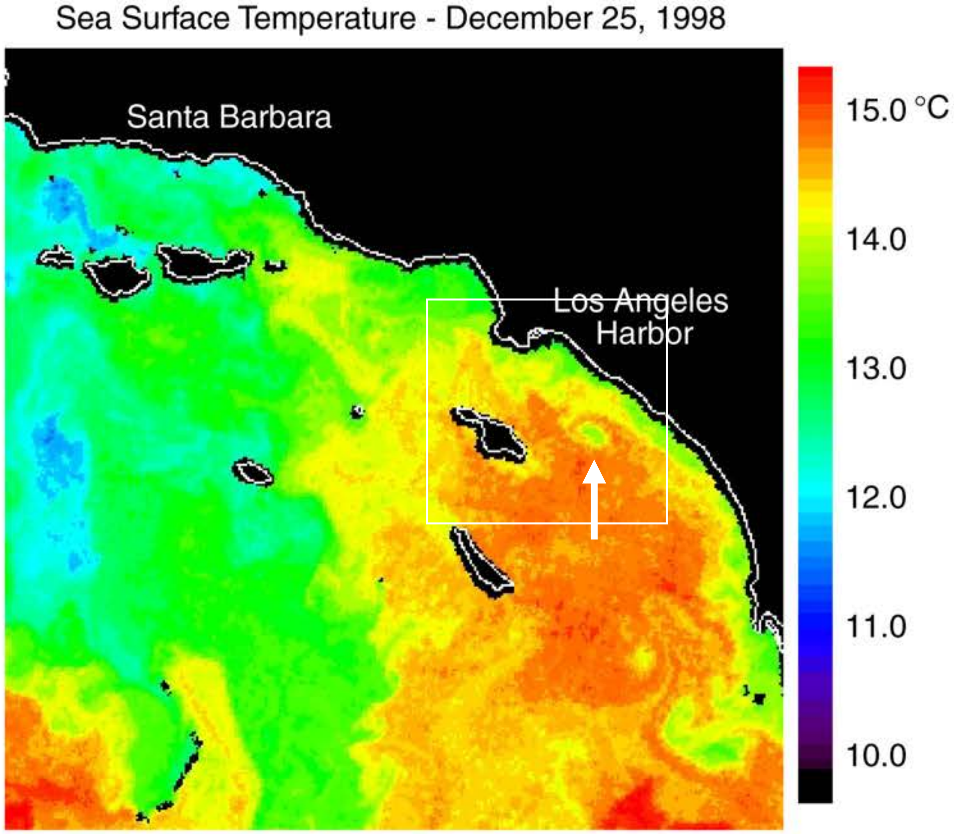
- improve the understanding of their physical properties and generation mechanisms.
- determine their role in the coastal circulation and energy budget.
- determine the connection between their surface expressions and *in situ* signal.
- determine their biological and optical response.
- determine the connection between SAR data, surface slicks, and skin temperature.

=> Pre-mission study for future Surface Water and Topography (SWOT) mission – INSAR-derived sea surface topography

? What is the energetics and resulting SSH of the sampled eddy?

Small-scale Eddies in Southern California Bight





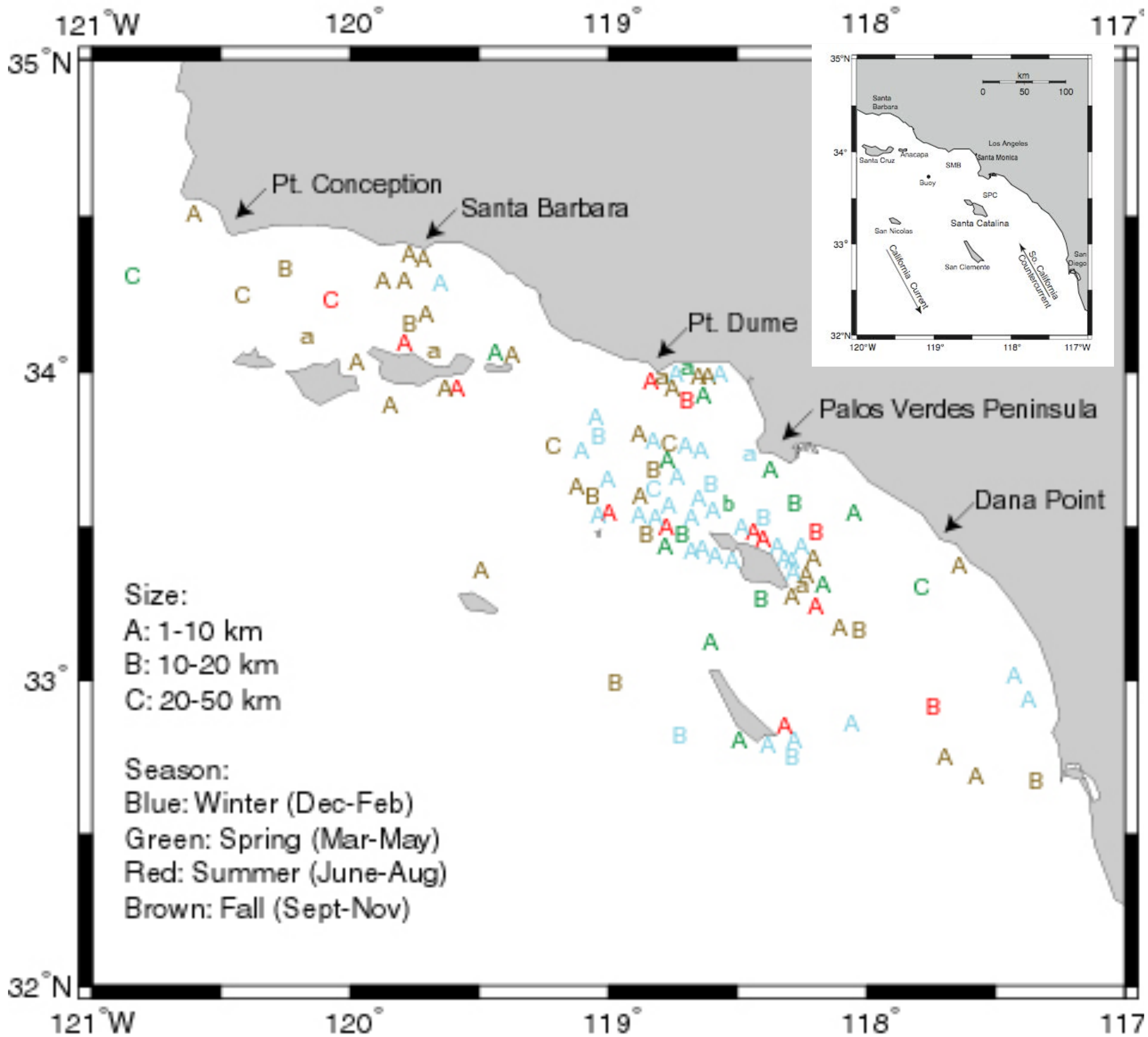
From Holt, 2004

- **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

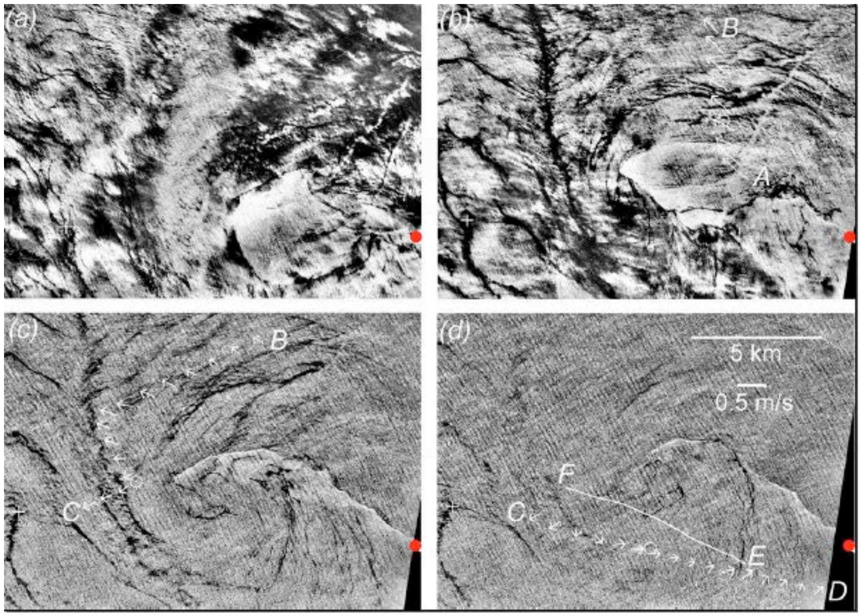


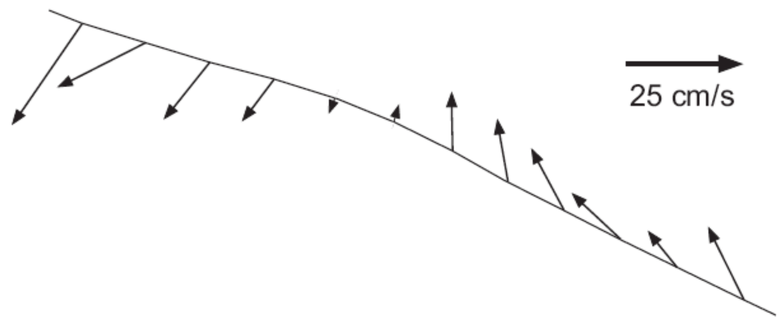
Upper case = cyclonic, Lower case = anticyclonic

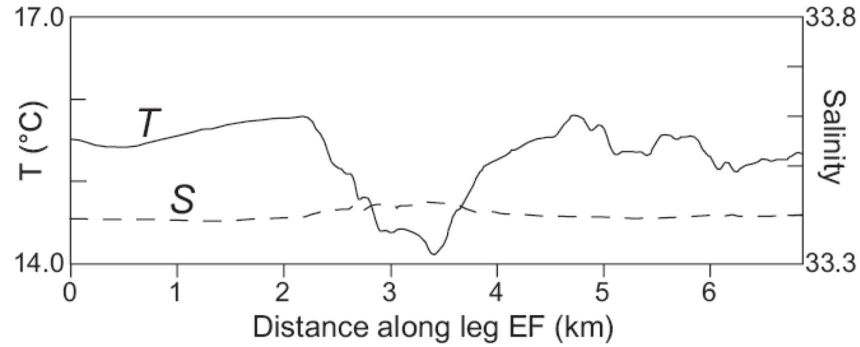
- Eddies were predominantly under 20 km in diameter, predominately cyclonic.
- Many appear to be formed by current-wake instability, as well as topographic and wind forcing.
- Seasonal distribution in eddy field observed : best observed in fall and winter, summer has stronger diurnal wind patterns.
-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

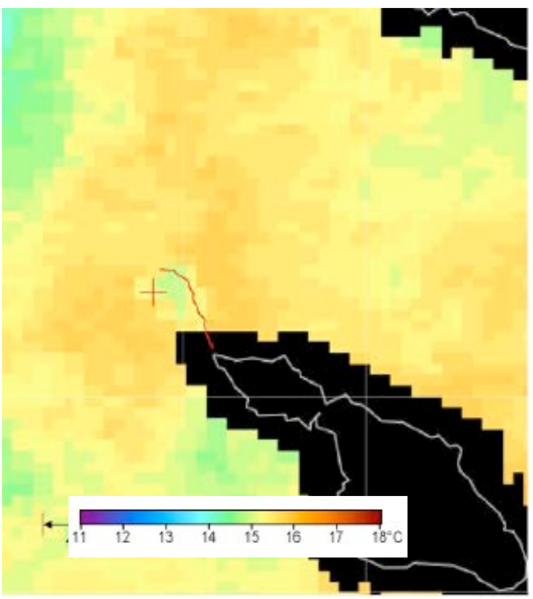
Airborne-Shipborne Campaign, April 16, 2003 Near Catalina Island

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





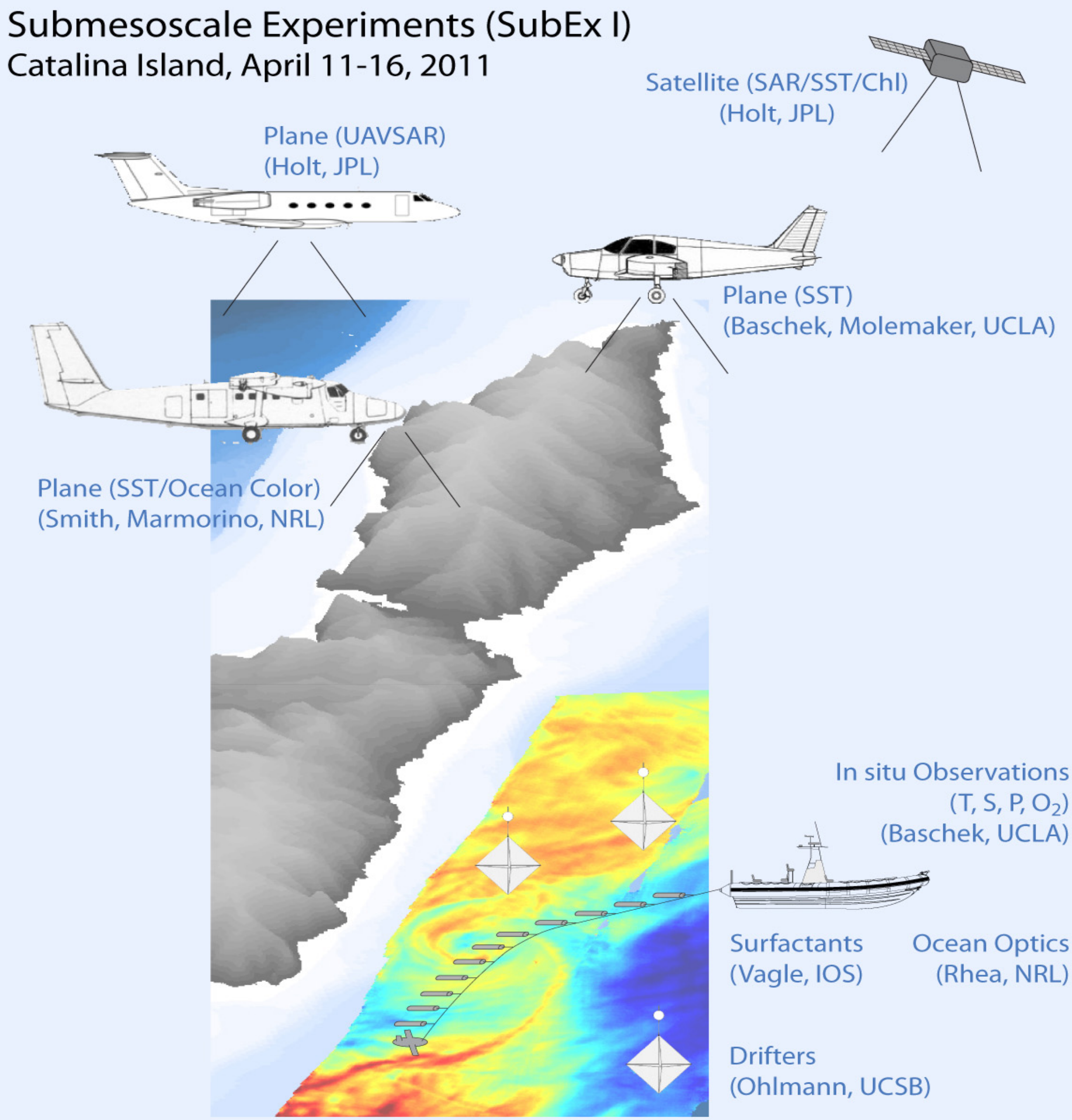




Left top – NASA AIRSAR obtained repeat imagery, 5 hour interval

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.



2009 Preliminary

2011 Full experiment

•**Aerial Measurements**

-Spatial resolution1-20m

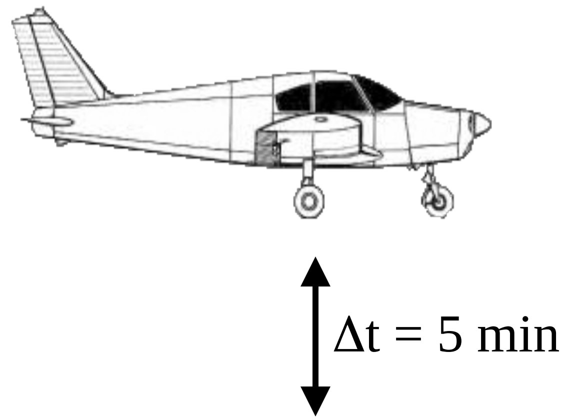
-Repeated every 10-20 min over a 10 km x 10 km area.

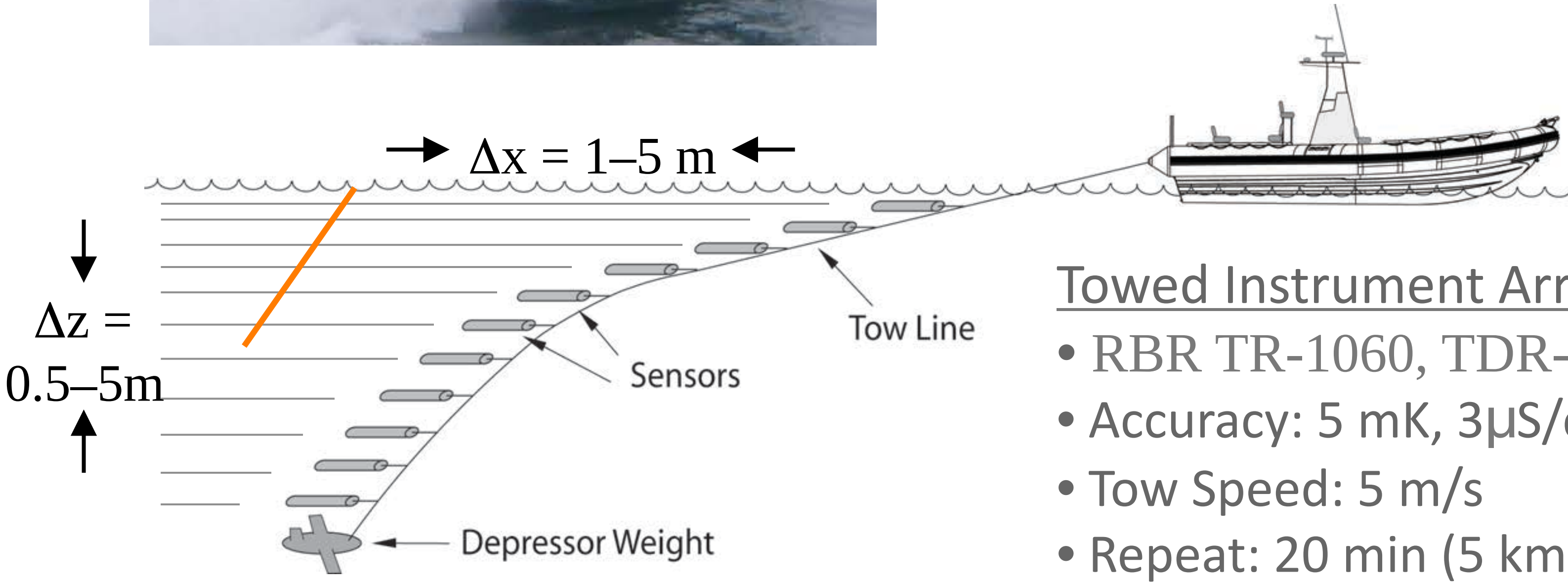
•**In situ Sampling**

- horizontal and vertical resolution of 1-5 m

-repeated every 20 min for a 5km transect.

In Situ Measurements





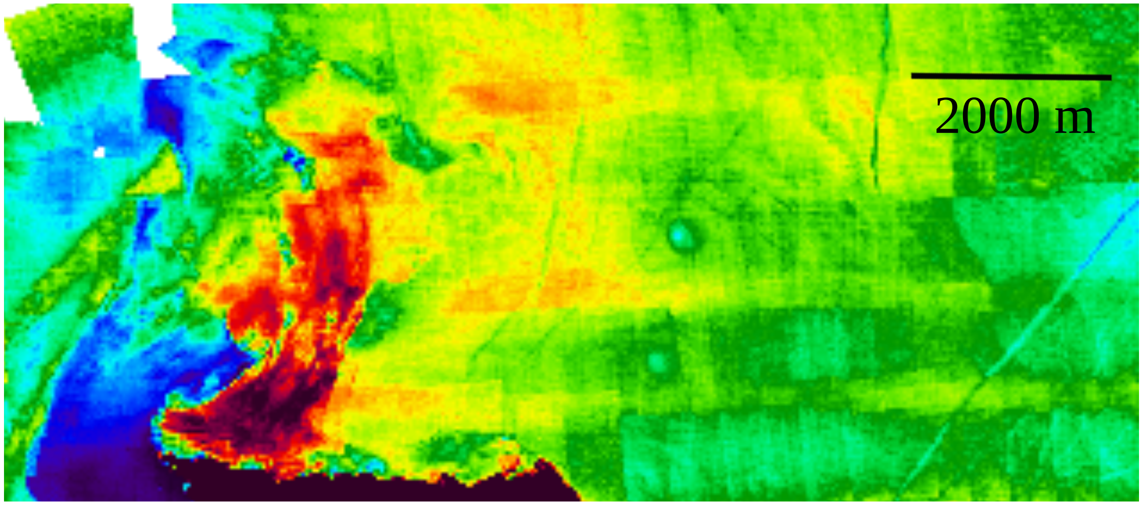
Towed Instrument Array (T, S, P):

- RBR TR-1060, TDR-2050, XR-620
- Accuracy: 5 mK, 3μS/cm
- Tow Speed: 5 m/s
- Repeat: 20 min (5 km transect)
- Depth: 0-45 m

B. Baschek, UCLA

Airborne Instrumentation

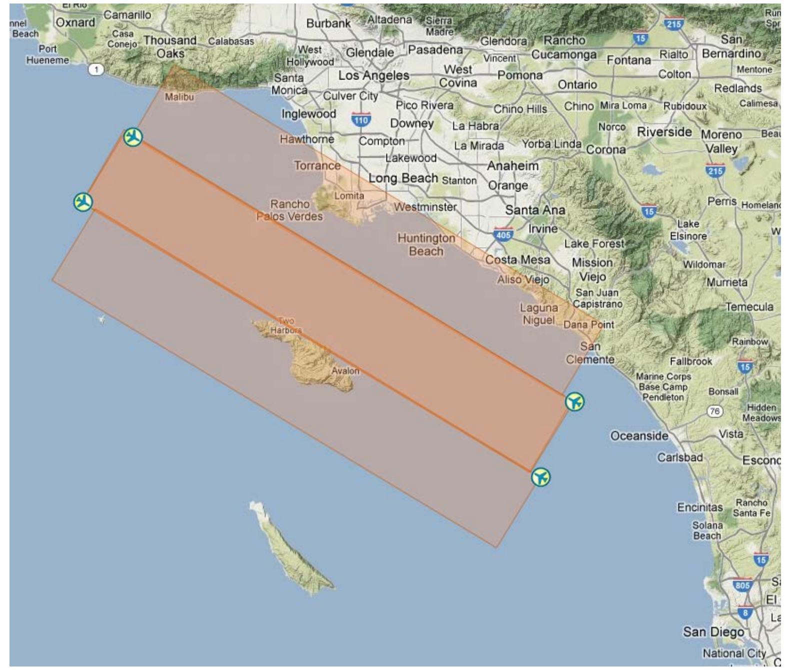
Infrared: 1x LWIR (FLIR A325, 10 m resolution at 3000 m altitude)
Error: 0.07°C + atmospheric effects + lens effect + skin temp. effect



Ocean Physics Laboratory UCLA

B. Baschek, J. Molemaker, UCLA

NASA – JPL UAVSAR



• Gulfstream jet, soon also Global Hawk

•Data available http://www.asf.alaska.edu/

•Data Collections – Sept. 2009, April 14-15-16, 2011

•L-band (1.2 GHz), polarimetric, 20 km swath

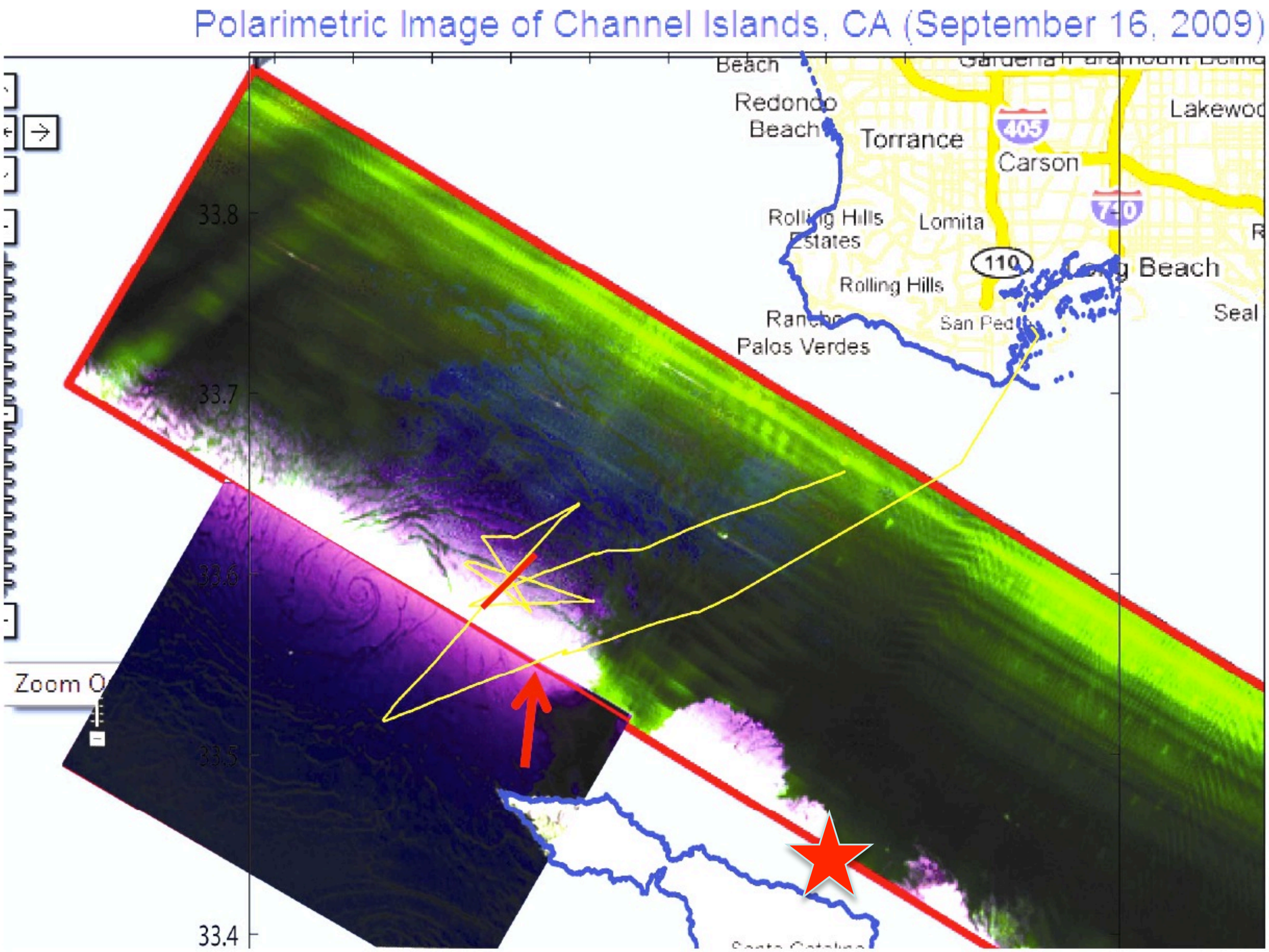
•Repeat-pass interferometry (deformation)

•Resolution - 7.2 m x 5 m (inherent 1 m)

•Onboard processing – 2009, then display 2011

•Repeated tracks 2-3 times per flight

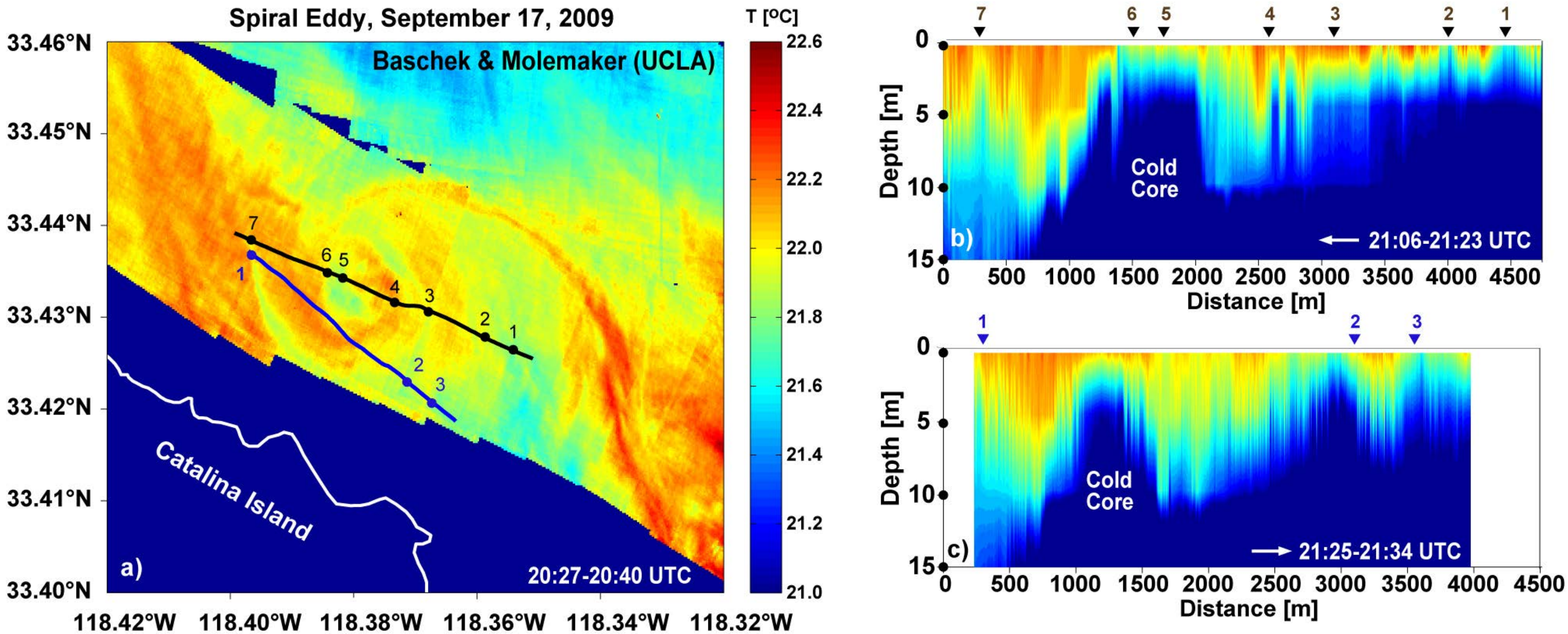
2009 - UAVSAR + NIR Overflights



•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.

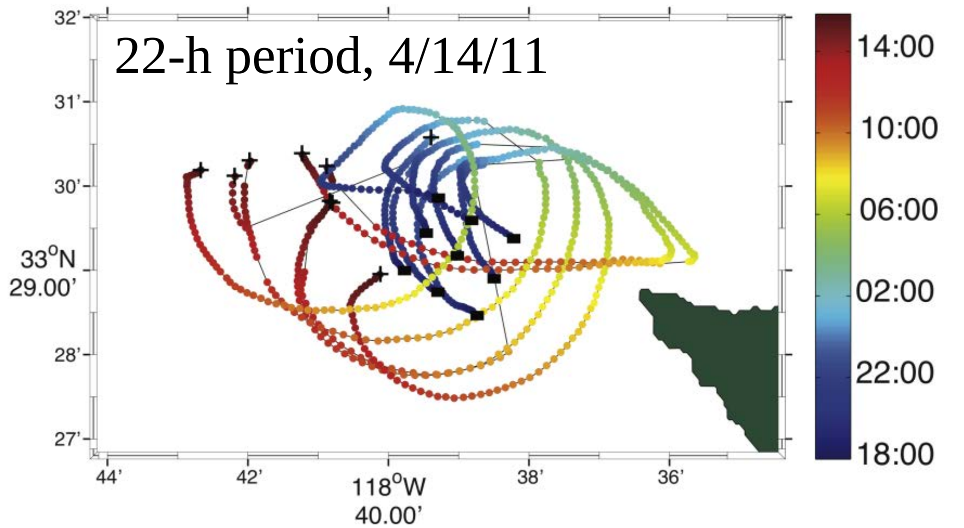
2009 - Detection and Sampling of a Spiral Eddy – First Results

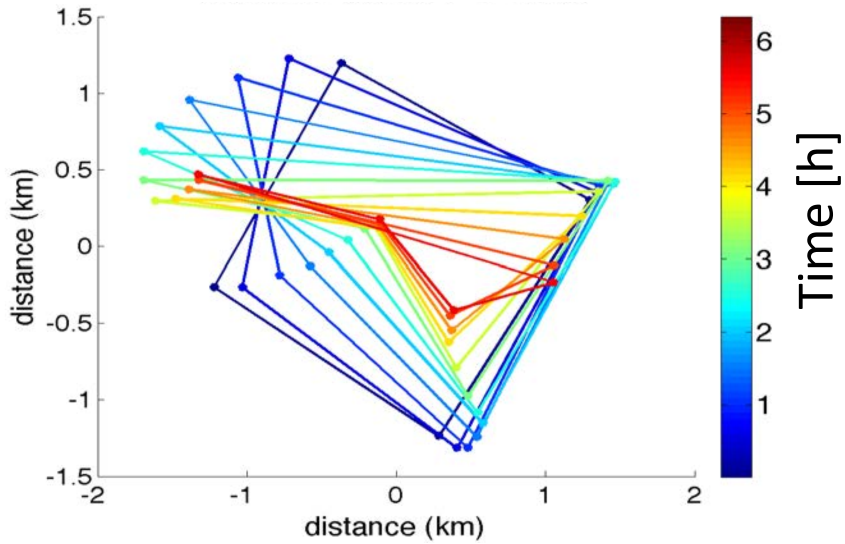


•Tested sampling methodology with UAVSAR, small airplane with SST, boat with towed string (CTD/Pressure sensors)

•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.

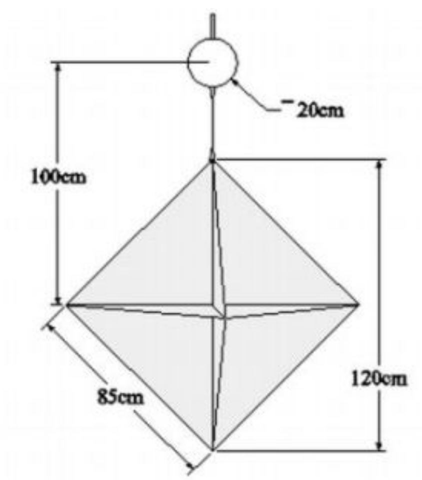
Added 2011 -> Surface Drifter Measurements





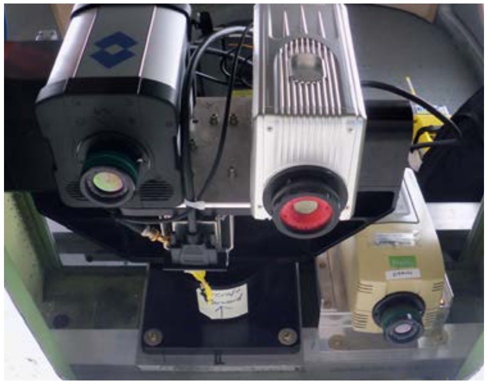
Relative motion within drifter clusters provide velocity differentials. Divergence and vorticity is quantified from differential kinematic property calculations.

→ Cyclonic rotation and convergence on a 2 km length scale. Values can be many times *f* and vary by hour.



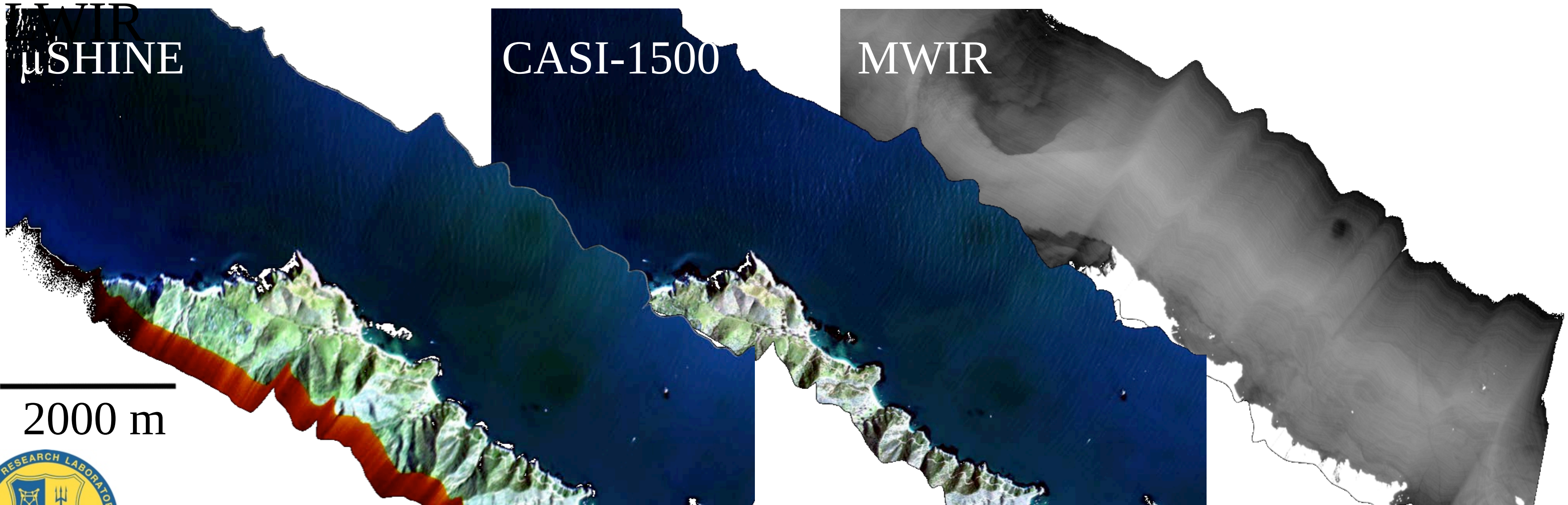
C. Ohlmann, UCSB

ADDED 2011 – NRL Airborne Instrumentation



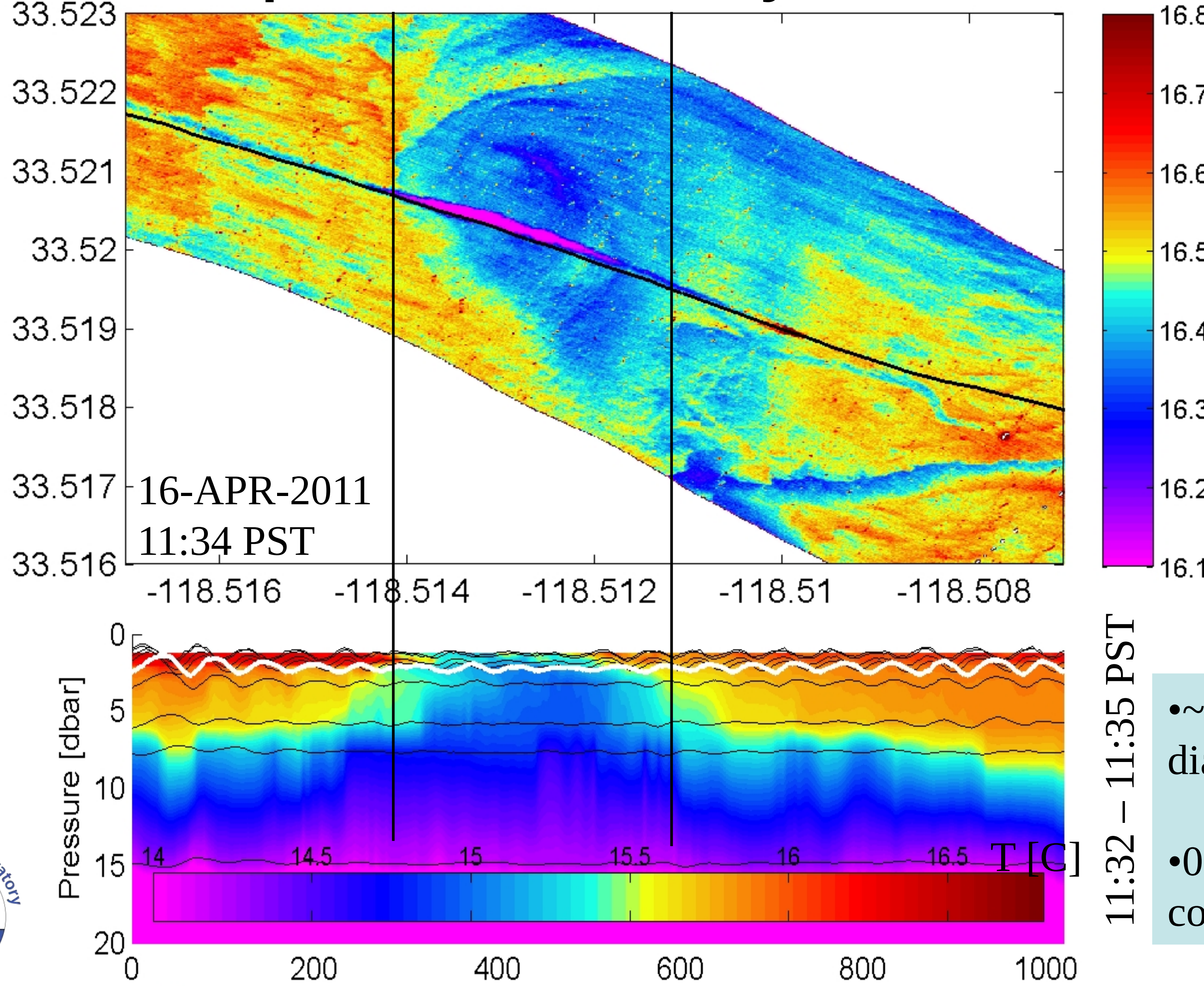
Hyperspectral Ocean Color (2x)

Infrared: 2x MWIR, 1x LWIR



G. Smith, G. Marmorino, NRL

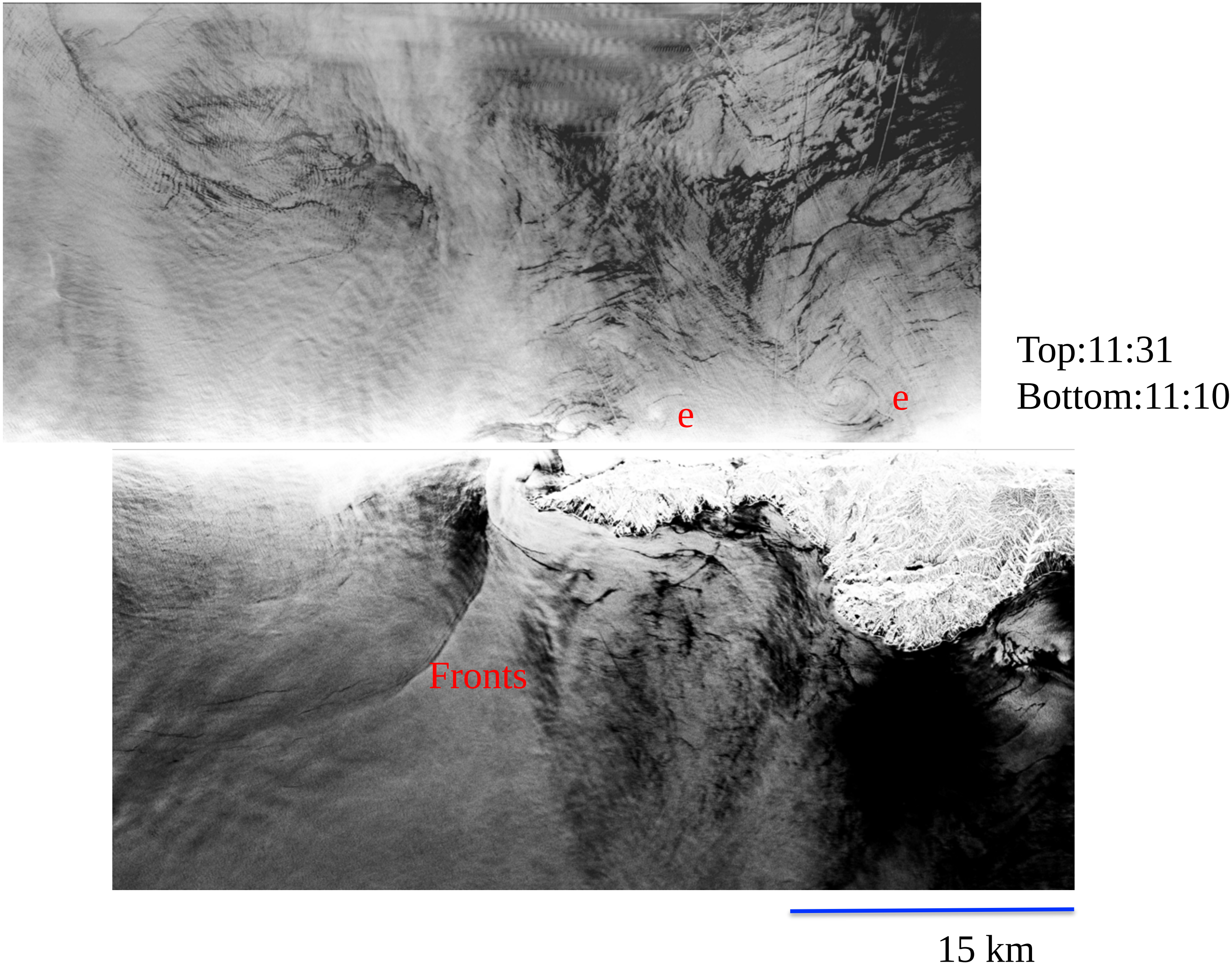
April 16, 2011 - Eddy “16E”



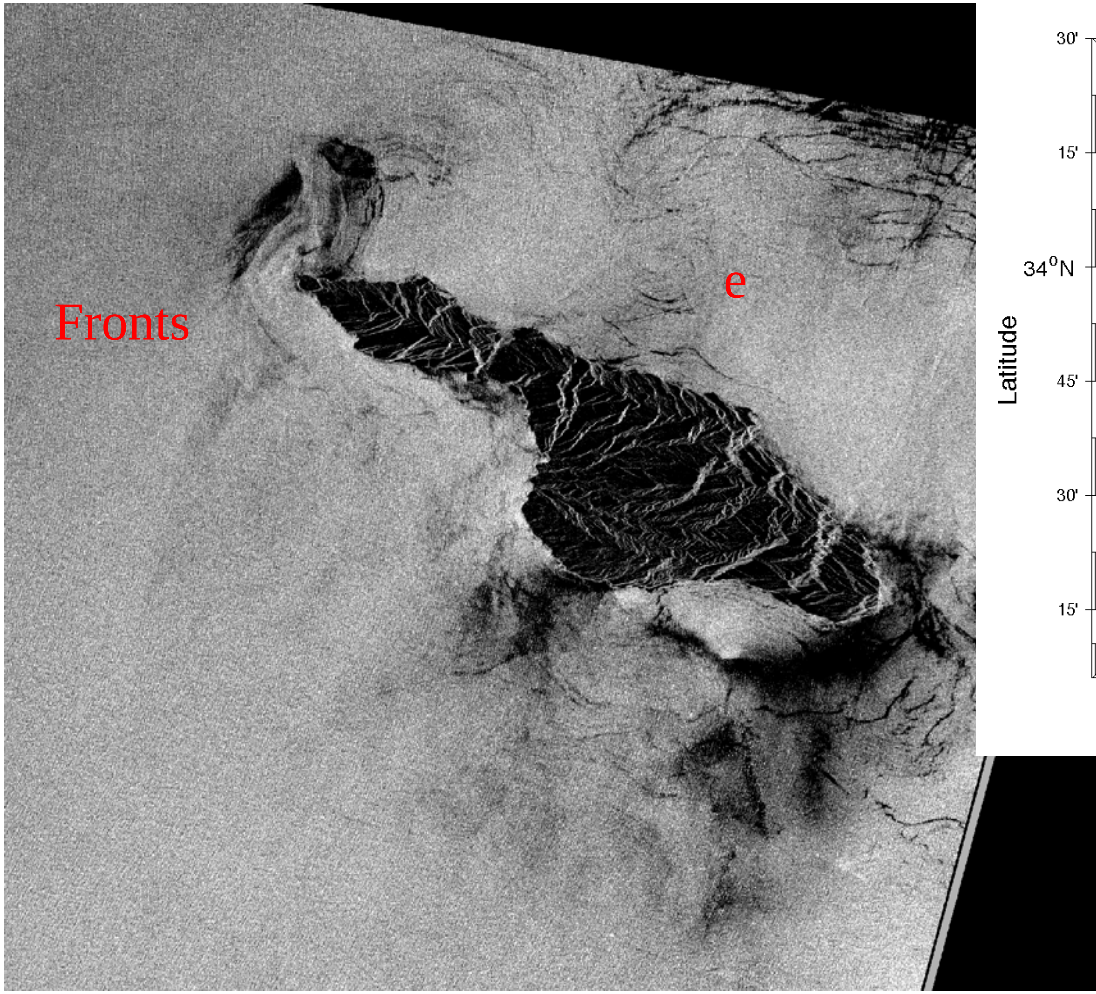
•~500 m diameter

•0.5°C contrast

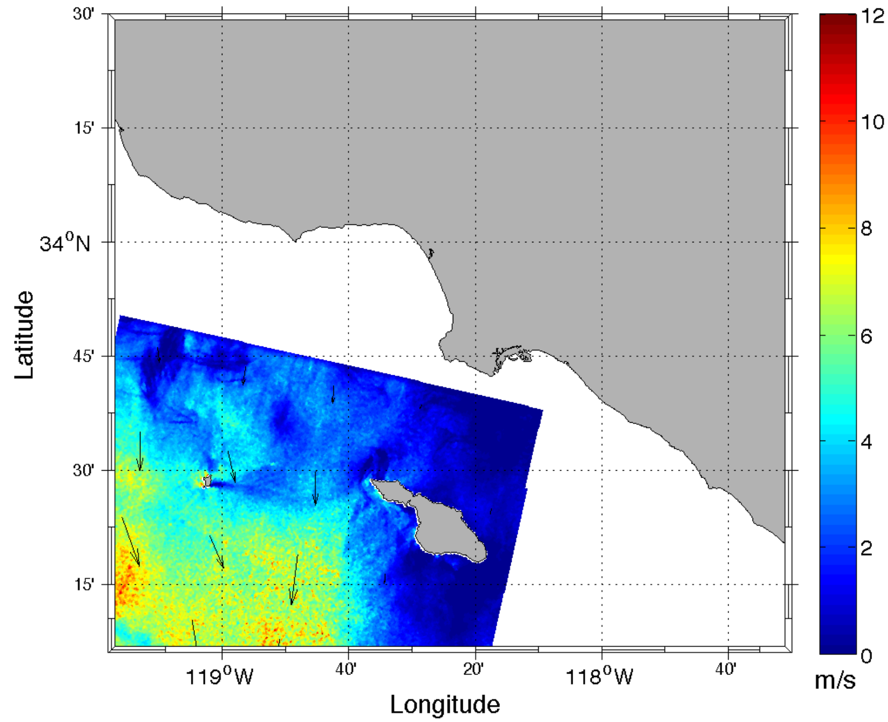
UAVSAR –Overview, April 16



Envisat ASAR – April 16, 11:11



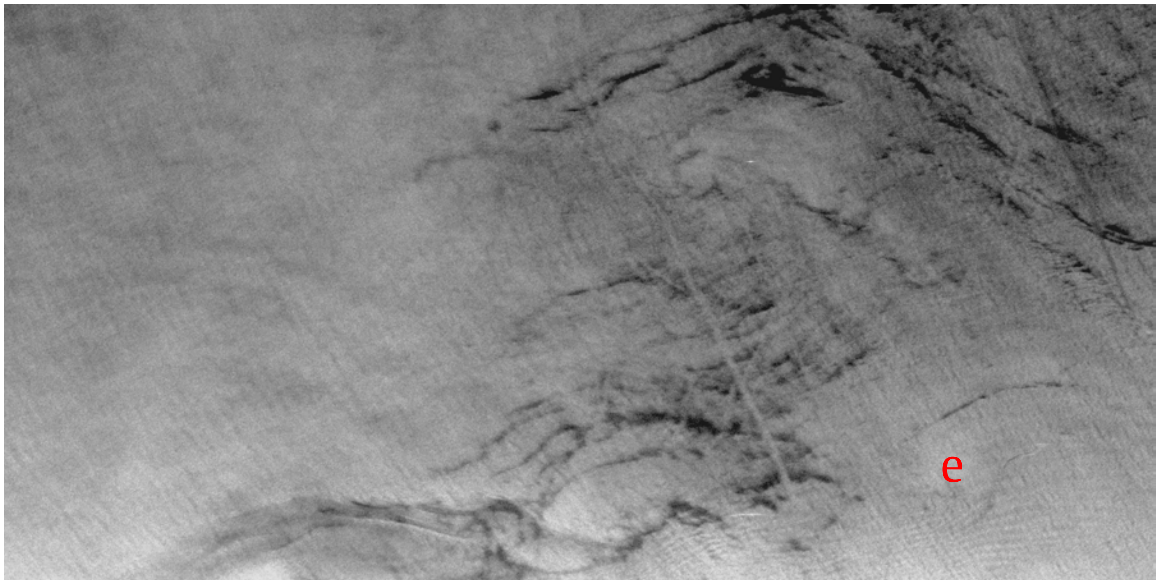
SAR-derived Wind Speed



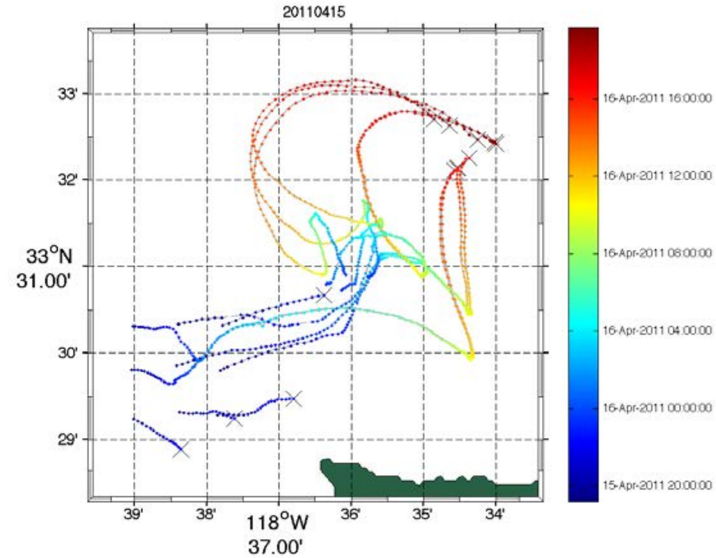
Jochen Hortsmann

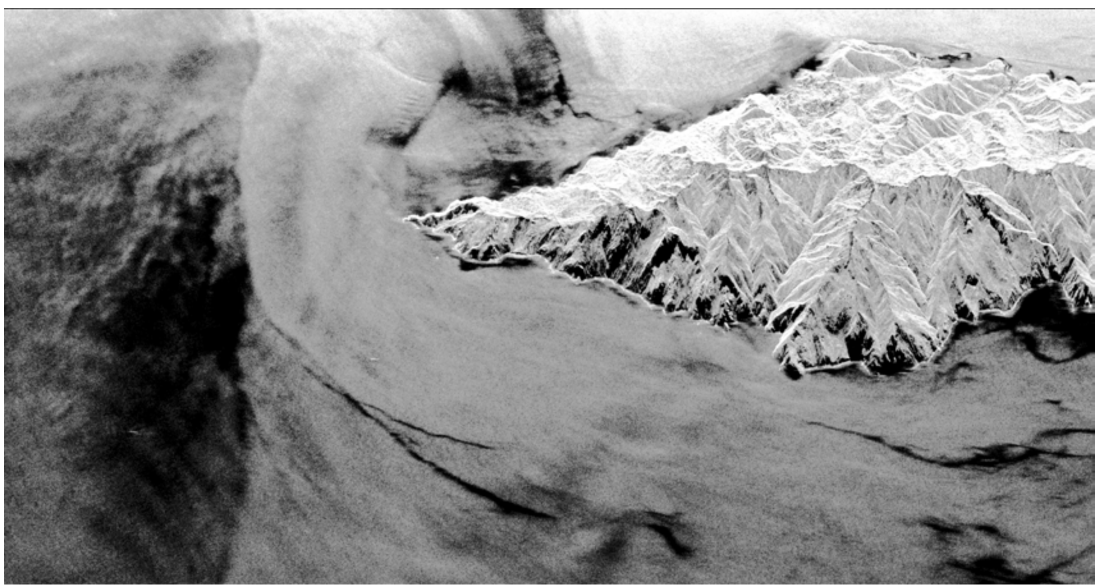
•Provides an additional repeat track – detected larger eddy, fronts, but not smaller, sampled eddy

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



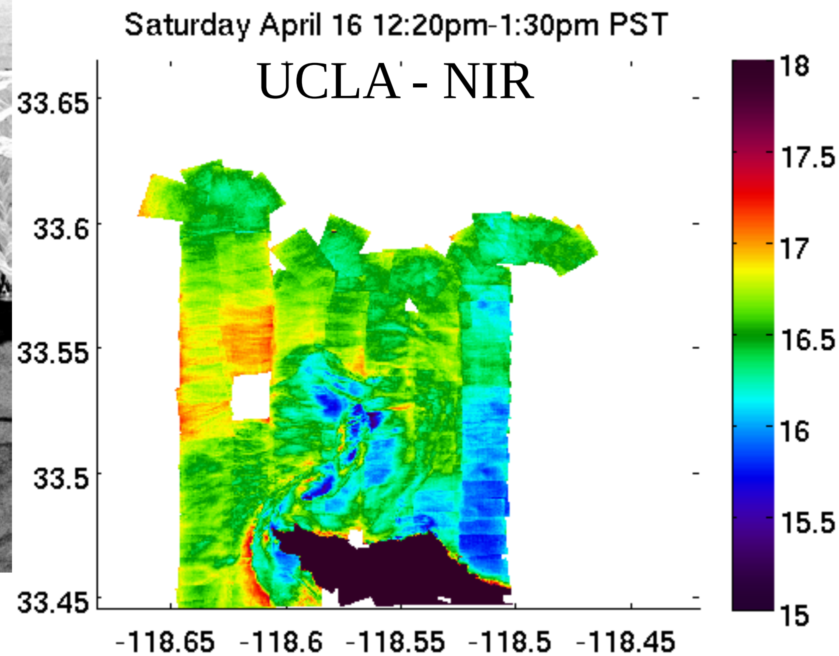
UCSB Drifters



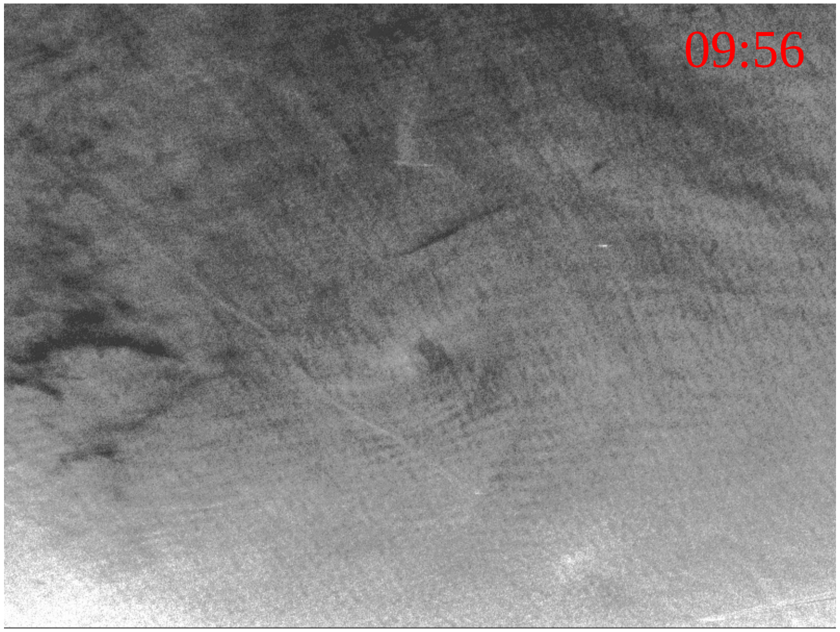


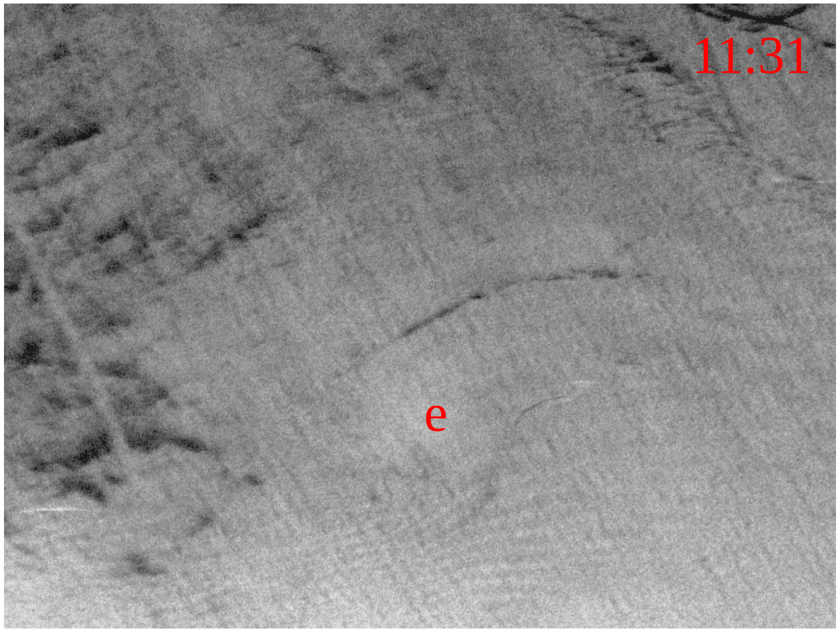
~1 deg C° gradient

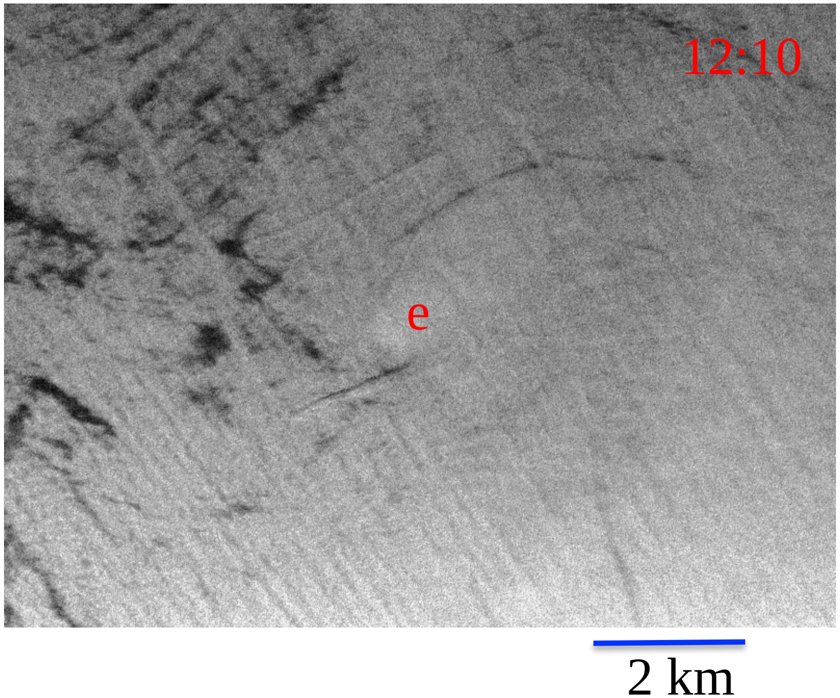
3 km



UAVSAR, Sampled Eddy (16e) – April 16



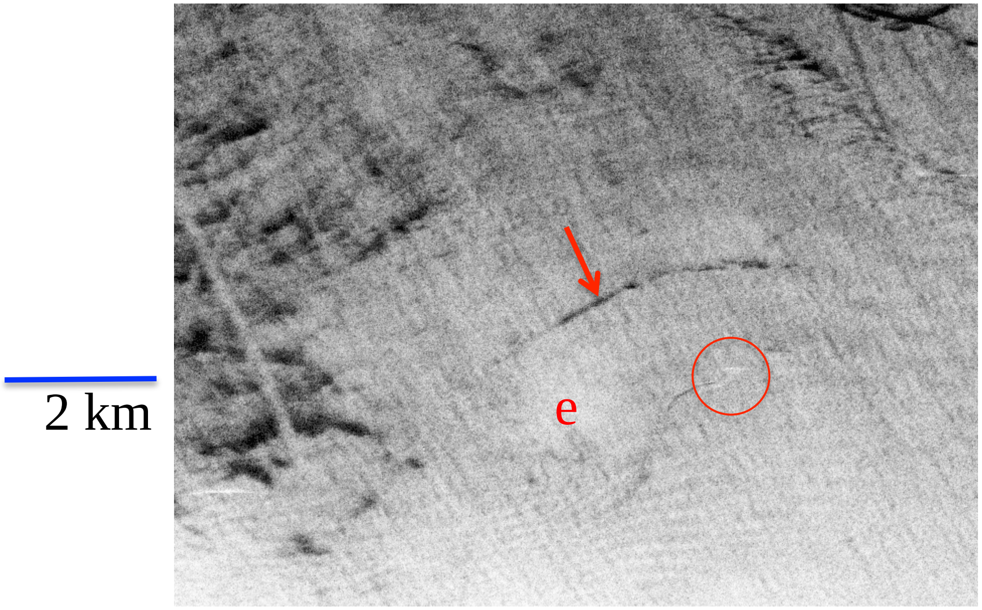




- **Eddy has weak SAR signature, location based on NRL IR**

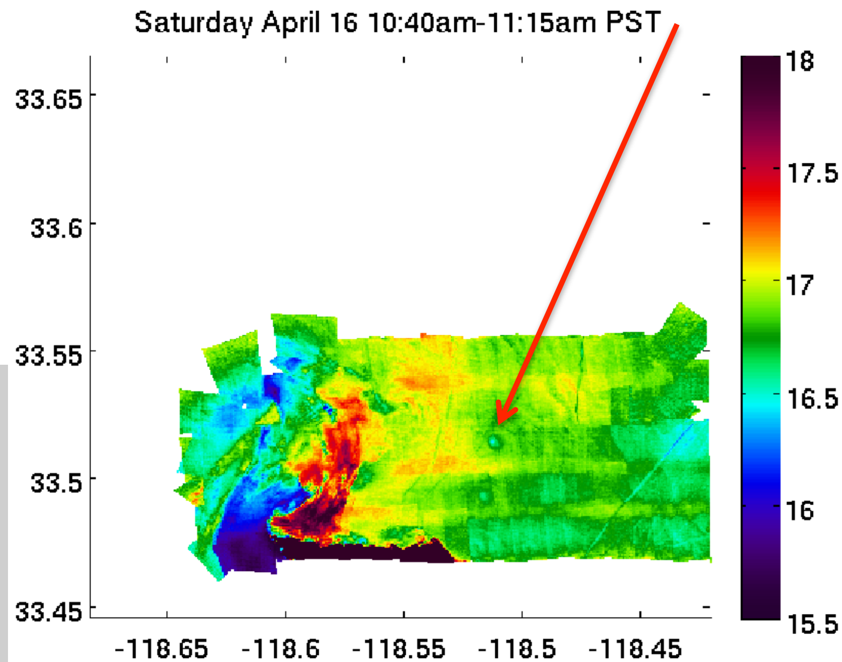
- **Due to recent formation and/or small size/ reduced energetics?**

- **Flow fields still derivable from surrounding patterns.**



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

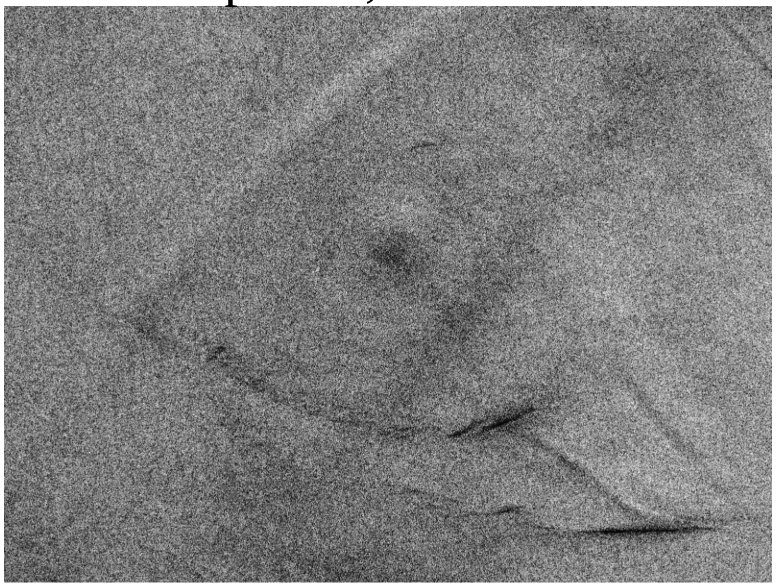
Eddy center= ~118.515, 33.52



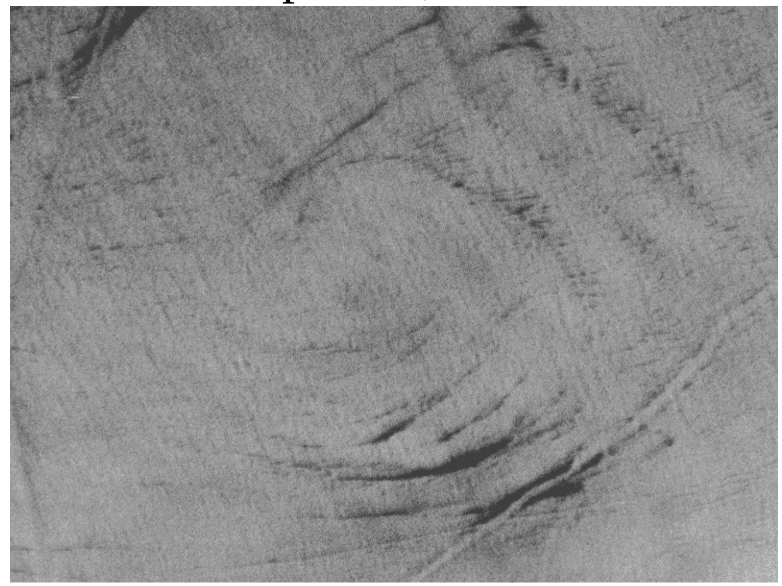
- 2nd boat, Never Satisfied, seen in both SAR and NRL IR at ~11.30
- Surfactant line shows SST differences
- Microlayer sampling for surfactants

UAVSAR – 5 km Eddy to East

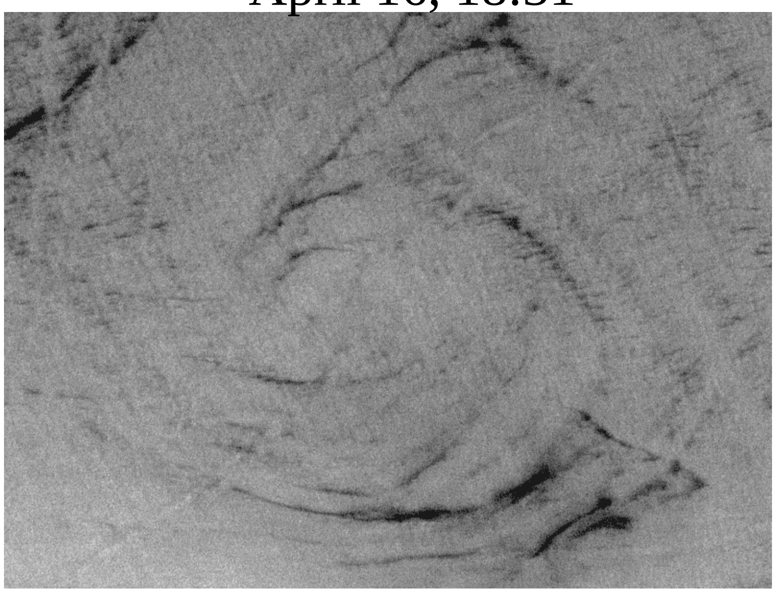
April 15, 16:50



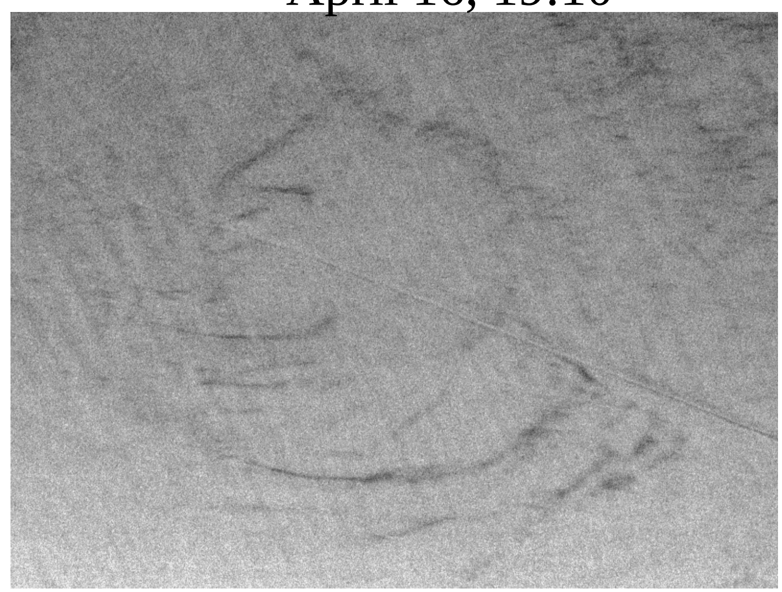
April 16, 16:56



April 16, 18:31



April 16, 19:10



2 km

•Derive rotational velocity field

Summary

- Coordination difficult and critical to sample sub-mesoscale 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.

- Nex field campaign potentially in September 2012 and potentially with AIRSWOT and also hopefully for a larger eddy

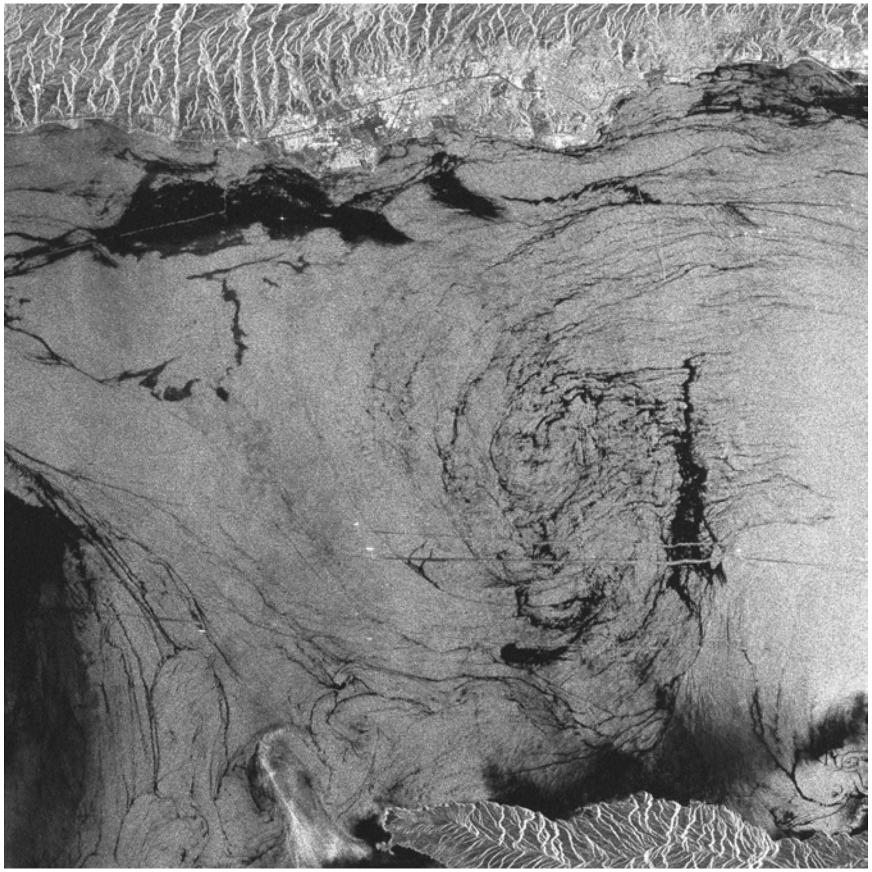
- Surfactant lines indicate convergent/divergent vertical cells within eddy or filaments

- Repeat coverage enables feature tracking for surface current flow and rotational velocity, to help determine energetics

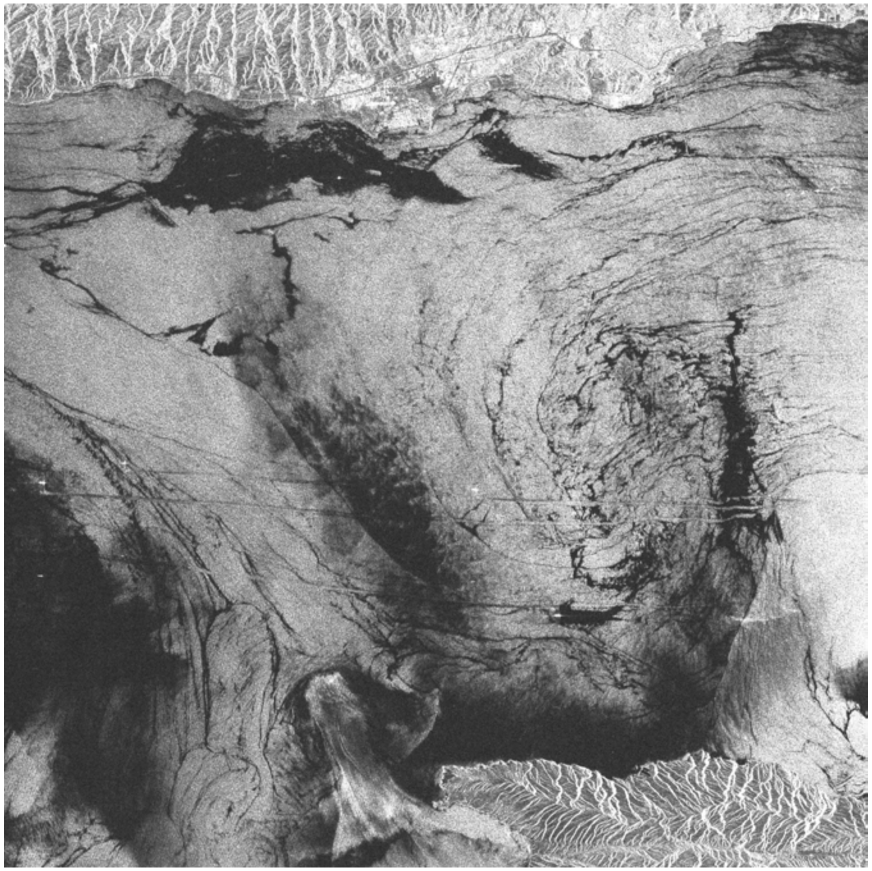
- Will compare satellite and aircraft SST and SAR for velocity fields.

Rpeat SAR Imaging from Satellite

Envisat ASAR Oct 8, 2006, 1810Z



ERS2 SAR Oct 8, 2006, 1838Z



Recurring Eddy in Santa Barbara Channel

if flow is 0.2 m/s • 28 minutes = 336 meters ~ 13 pixels

Varying Winds Impact Rapid Repeat Eddy Imaging

RADARSAT - 27Jan02- 02Z

Afternoon winds

RADARSAT-27Jan02-14Z

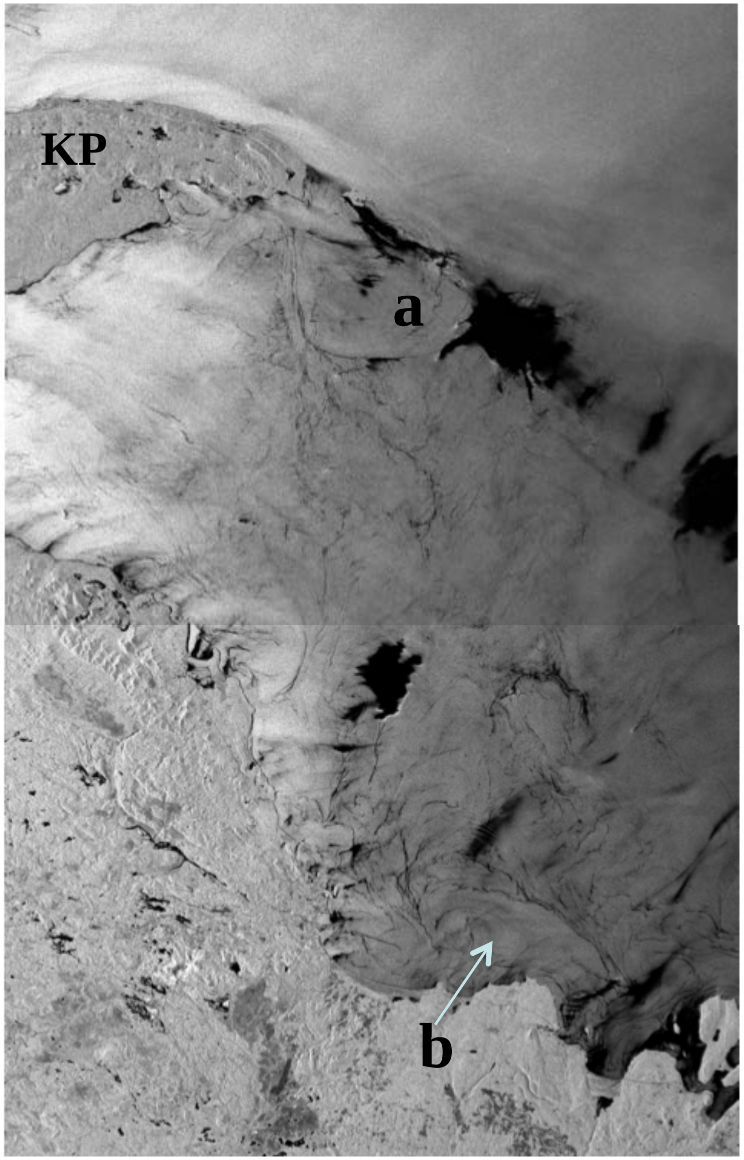
Morning winds

•Difficult to determine eddy rotational speed due to varying surface roughness.

Lake Superior – Small-Scale Eddies Associated with Coastal Current

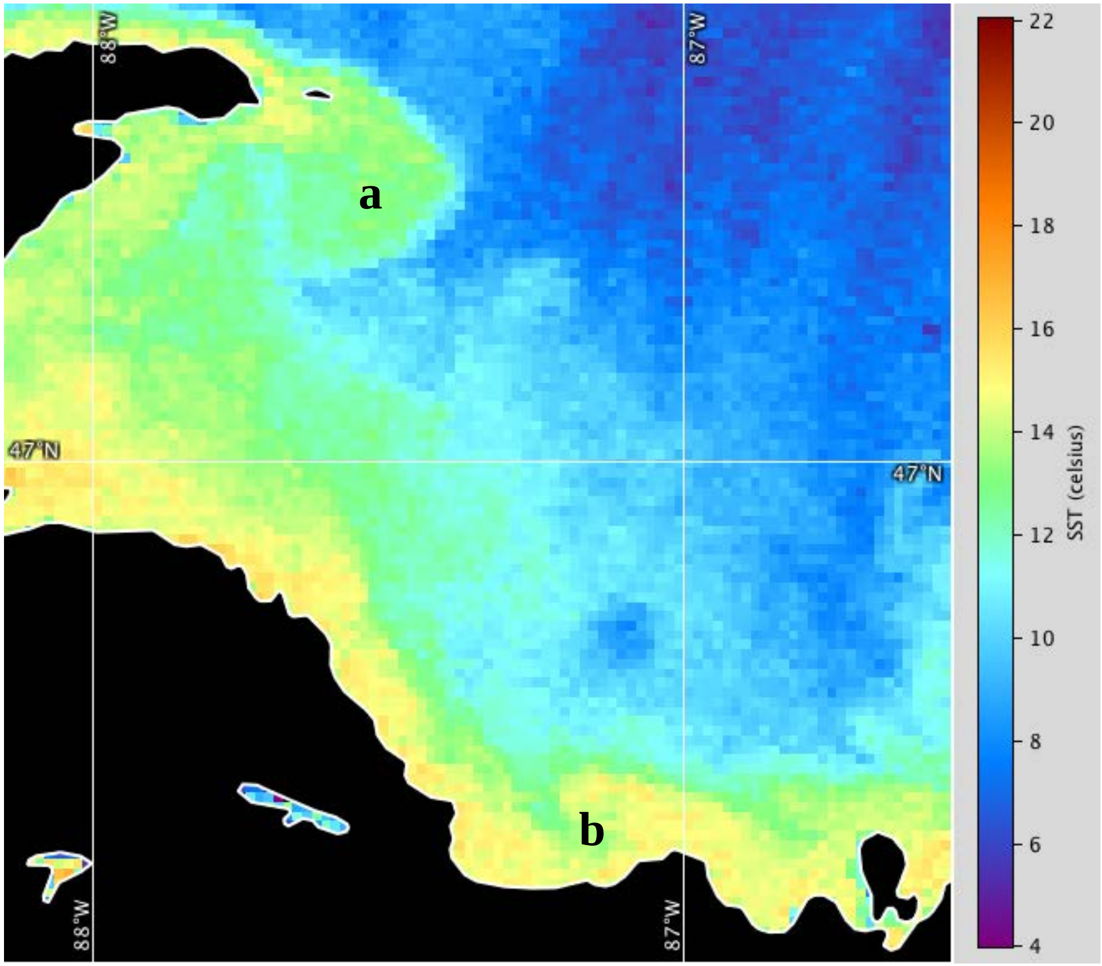
From McKinney[1], Holt[2], White[1], Matsumoto[1], Small eddies observed in Lake Superior using SAR and sea surface temperature data, J. Great Lakes Research, resubmitted 2012, U. Minnesota[1], Jet Propulsion Laboratory[2]

ERS-1 SAR



05 August 1992, 0358UTC

AVHRR SST



05 August 1992, 0943UTC

•Anticyclonic eddy (a) shedding off Keweenaw Peninsula (KP), diameter 19 km, and smaller cyclonic eddy (b), diameter 17 km, both associated with sharp thermal gradient that forms in Lake Superior during the summer months.
•Indicative of enhanced coastal current variability.