High Frequency Radio Oceanography

Pierre Flament

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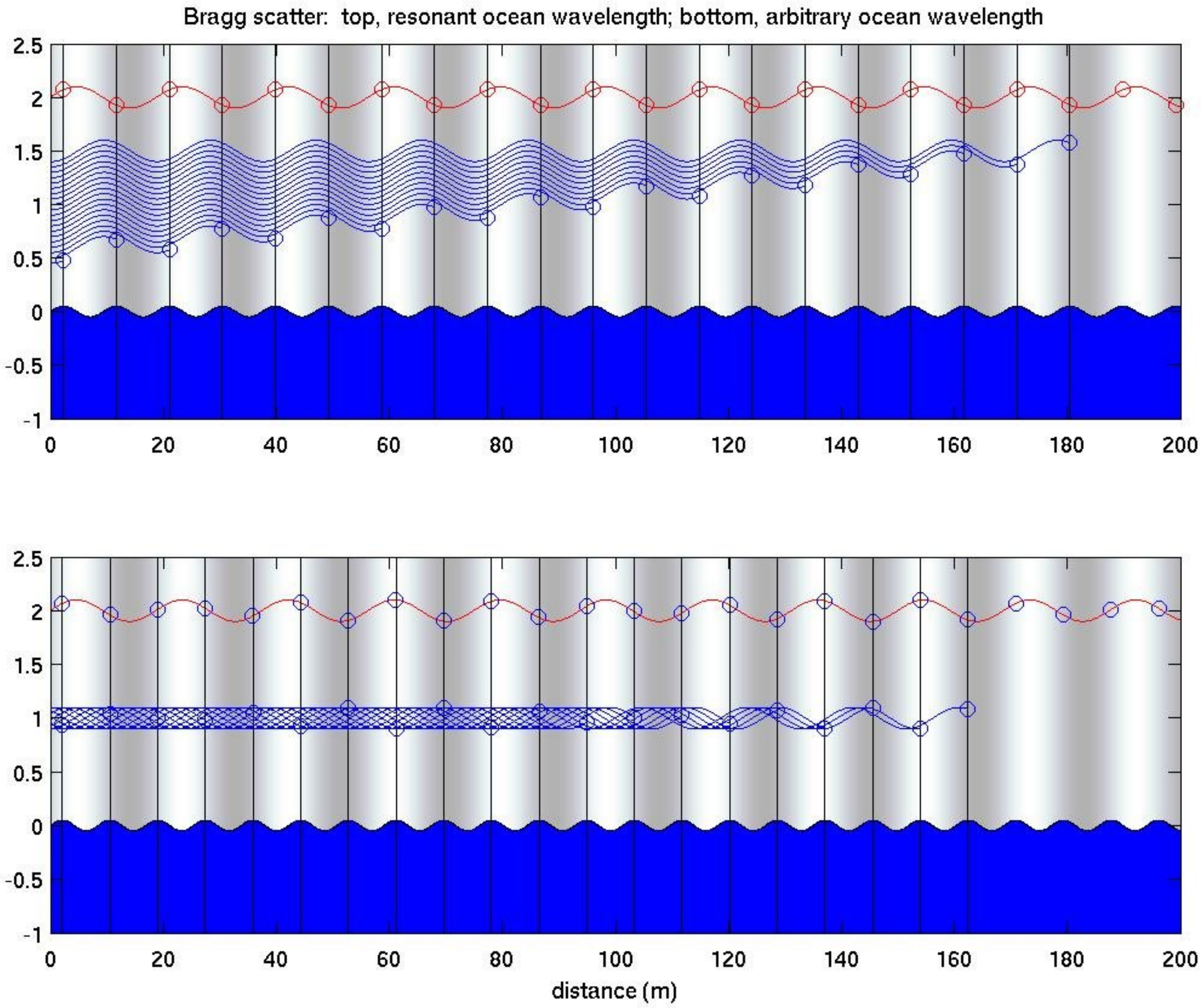
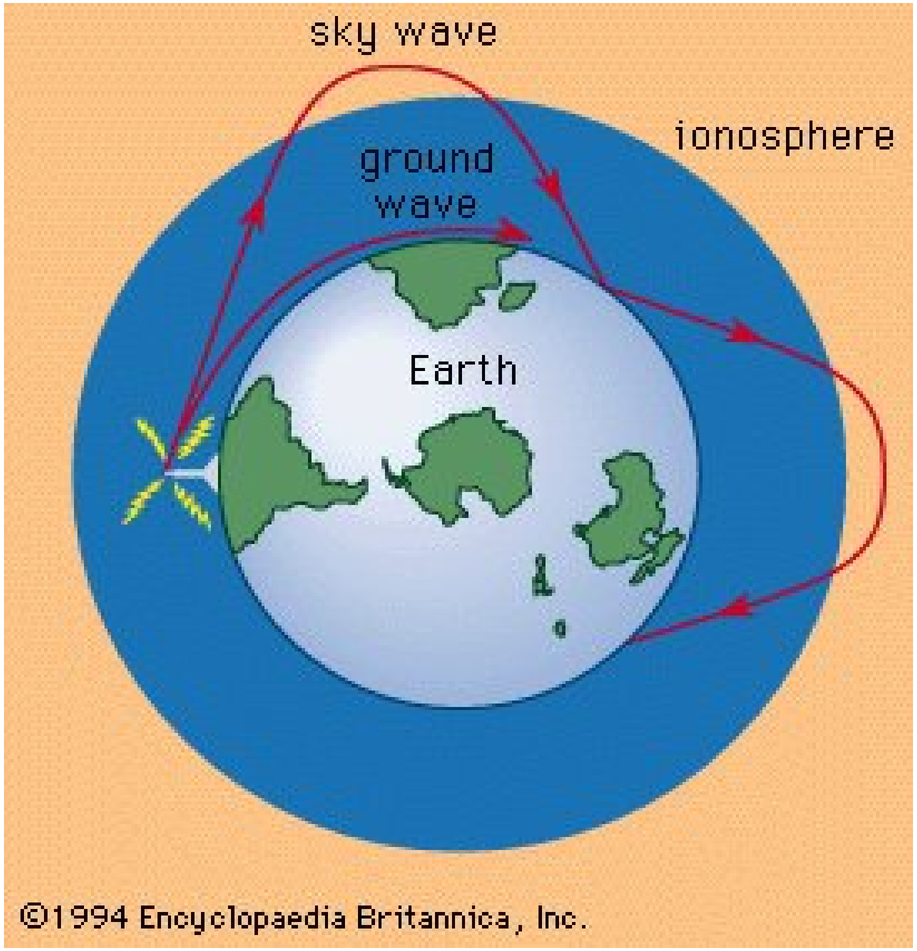
Bragg-scattering from a water surface



Over-the-horizon propagation by ground wave over conductive ocean



UH High Frequency Doppler Radio system specifications

Modulation	FMCW linear chirp
Operating Frequency Range	from 3 MHz to 30 MHz
Transmitted RF-Power	typically 3-5 W, max. 50 W
Range, ocean currents	100 km/ 50 NM @ 16 MHz
	260 km/ 140 NM @ 8 MHz
Range, targets	max. 260 km/ 140 NM (noise-limited)
Range Resolution	depends on bandwidth c/2B 1.5 km @ 100 kHz, 150 m at 1 MHz (voice 3 kHz)
Azimuthal Resolution	better than 2 degrees

Past: Adriatic (ONR), Oahu (NSF), Tehuantepec (CONACyT, NSF)

Present: Philippines (ONR, MARFORPAC), Oahu (NOAA/DHS)

Receiving Array 8 MHz range 260 km

Koko head range 110 km @ 16 MHz

Kaka'ako range 40 km @ 27 MHz

RANGE

$$\Delta x = c / 2B$$

B = 150 kHz -> Δx = 1 km

B = 1.5 MHz -> Δx = 100 m

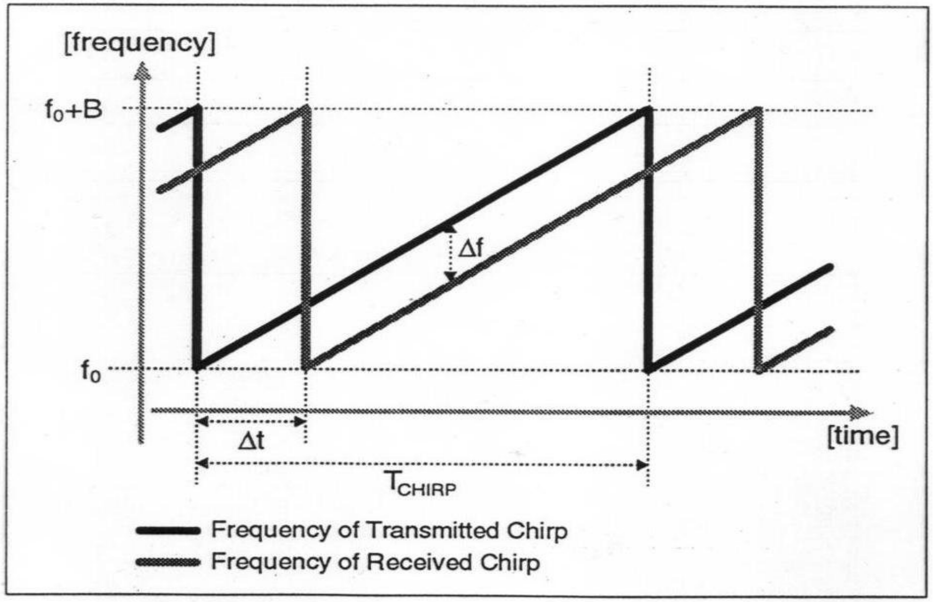


Figure 2: Range resolution using a frequency chirp.

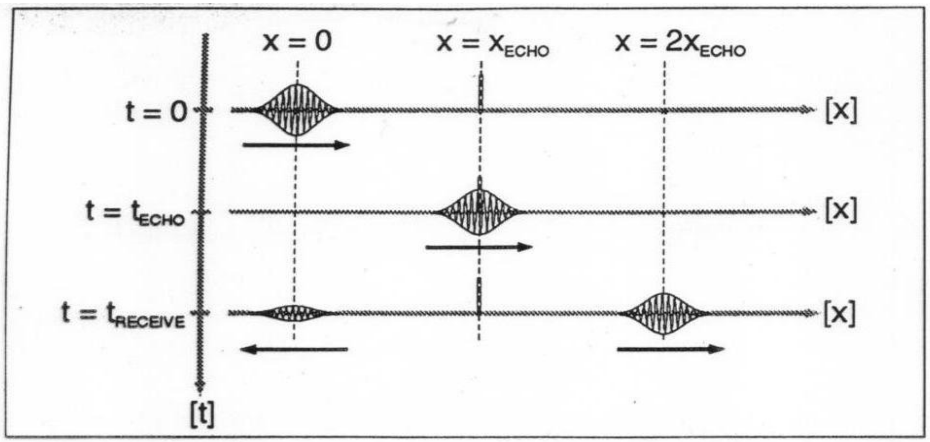
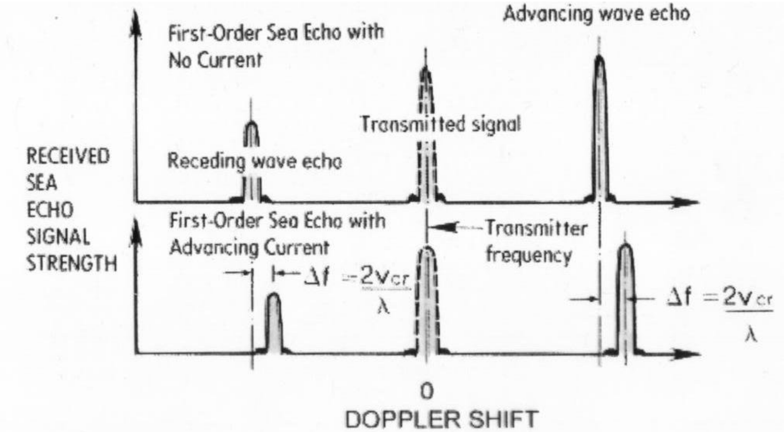
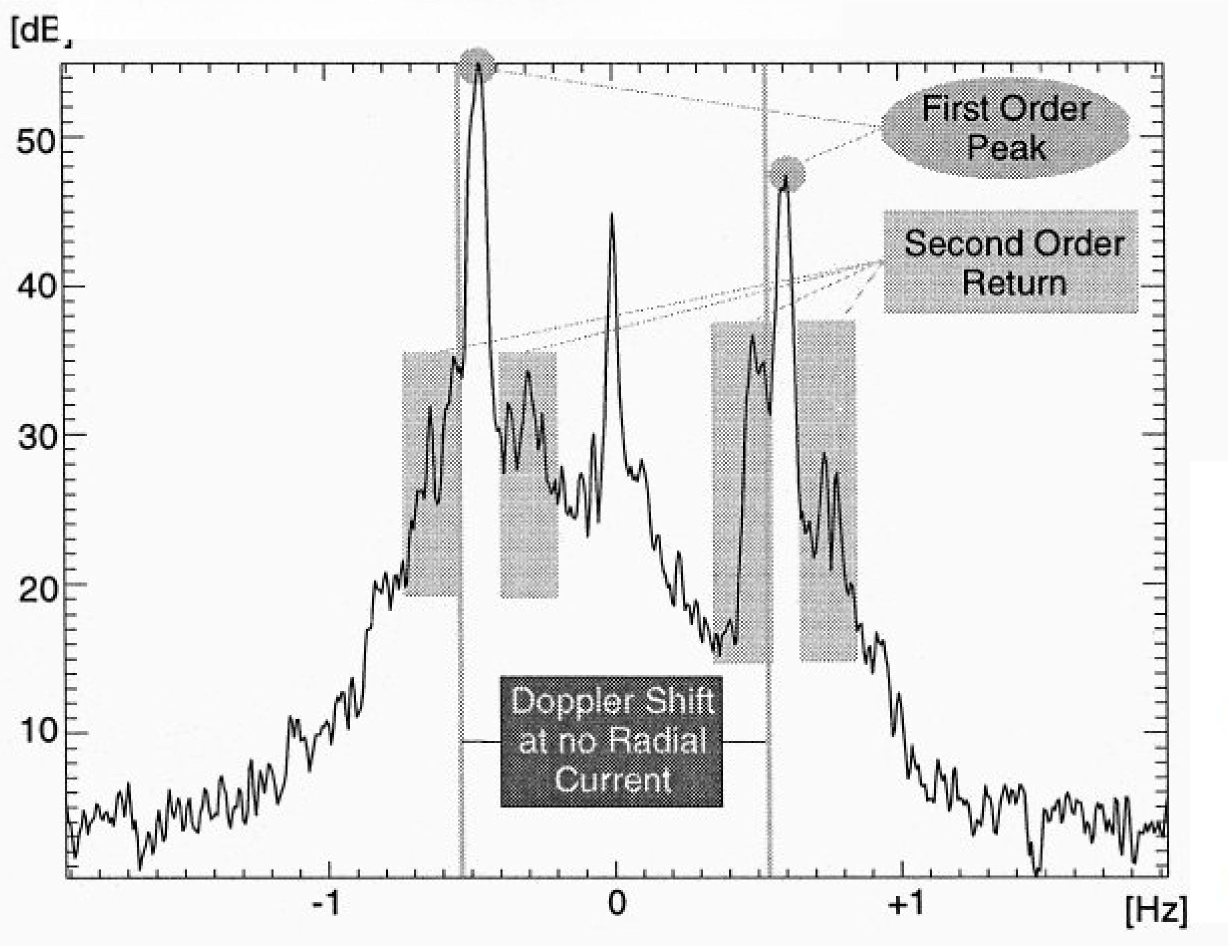


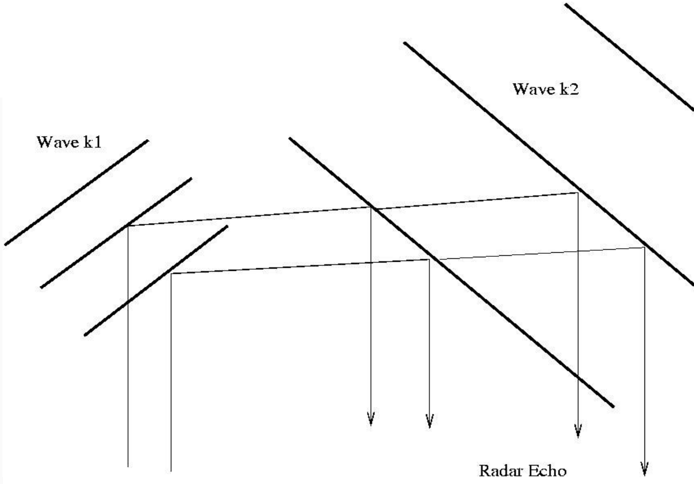
Figure 1: Range resolution using pulses.

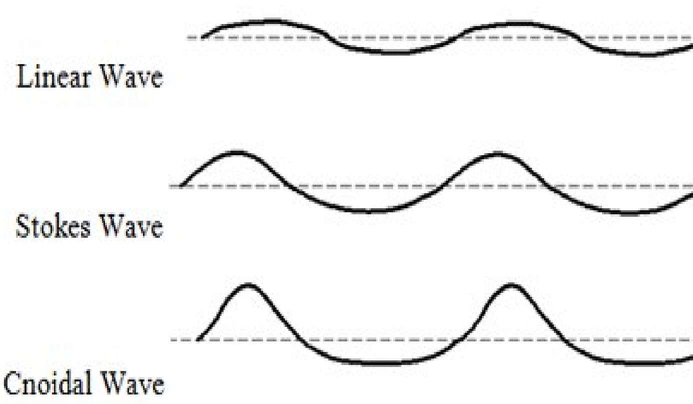


C = (gL/2π)^1/2

- Surface currents
- Wave spectrum
- Wind direction







8.25 MHz, 260 km @ 2.5 W TX power

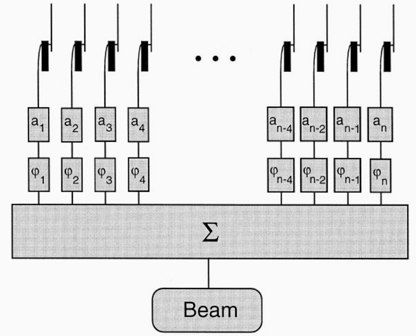
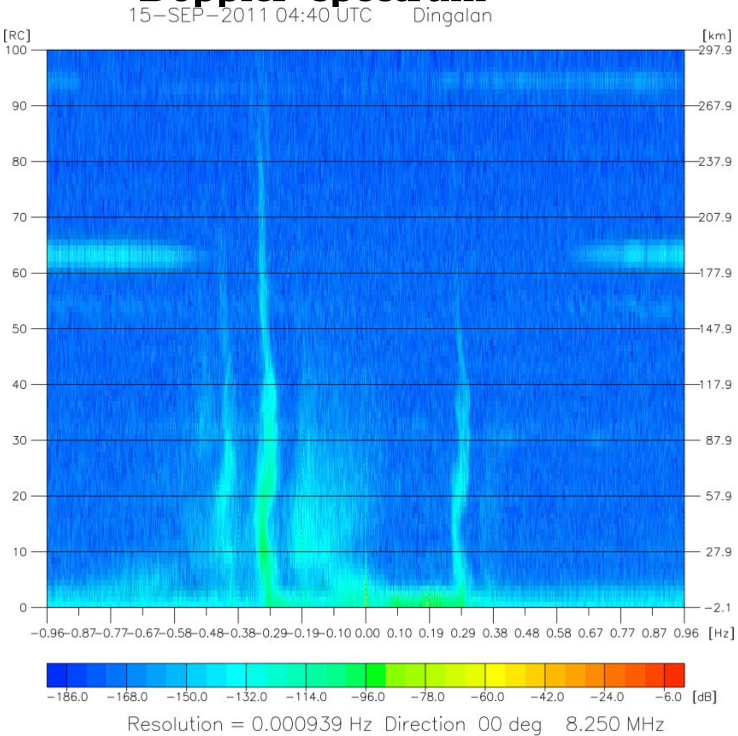
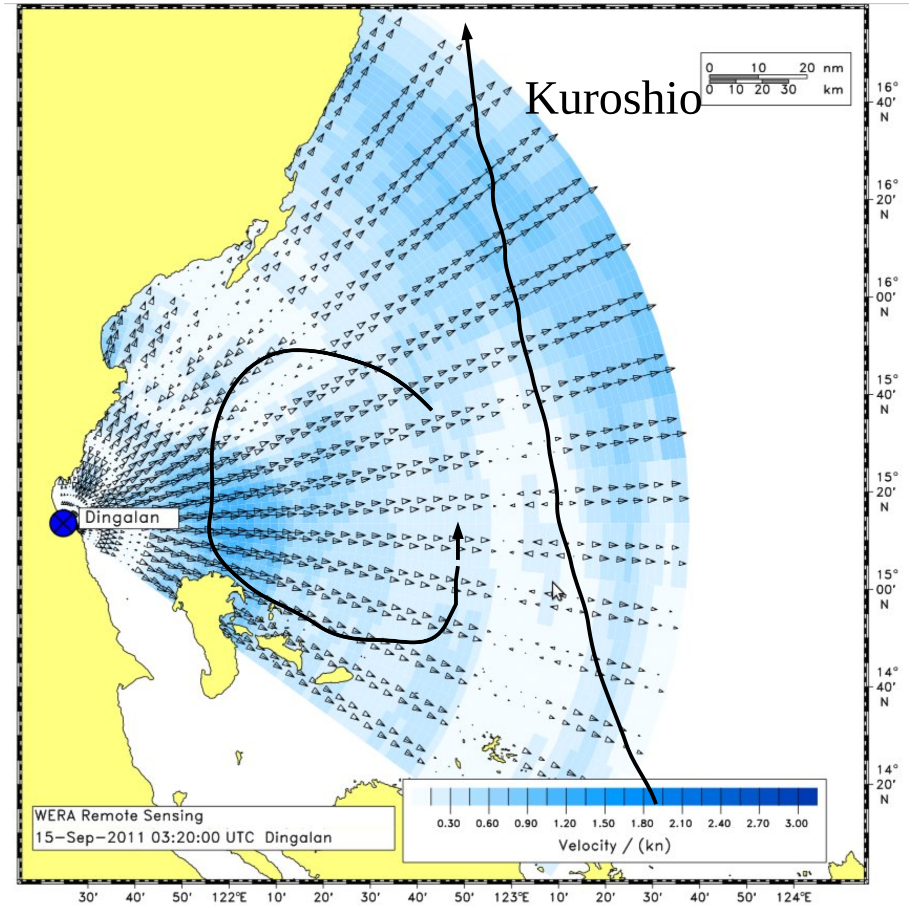


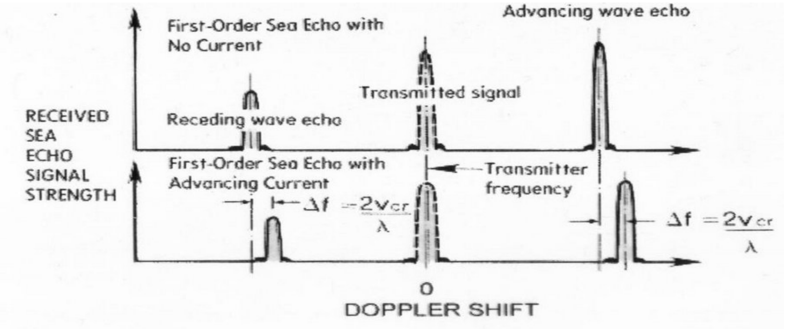
Fig. 10. Principle of beamforming. After weighing by a_i and phase shifting by φ_i the signals of n receive antennas are added.

Doppler spectrum



Radial Current





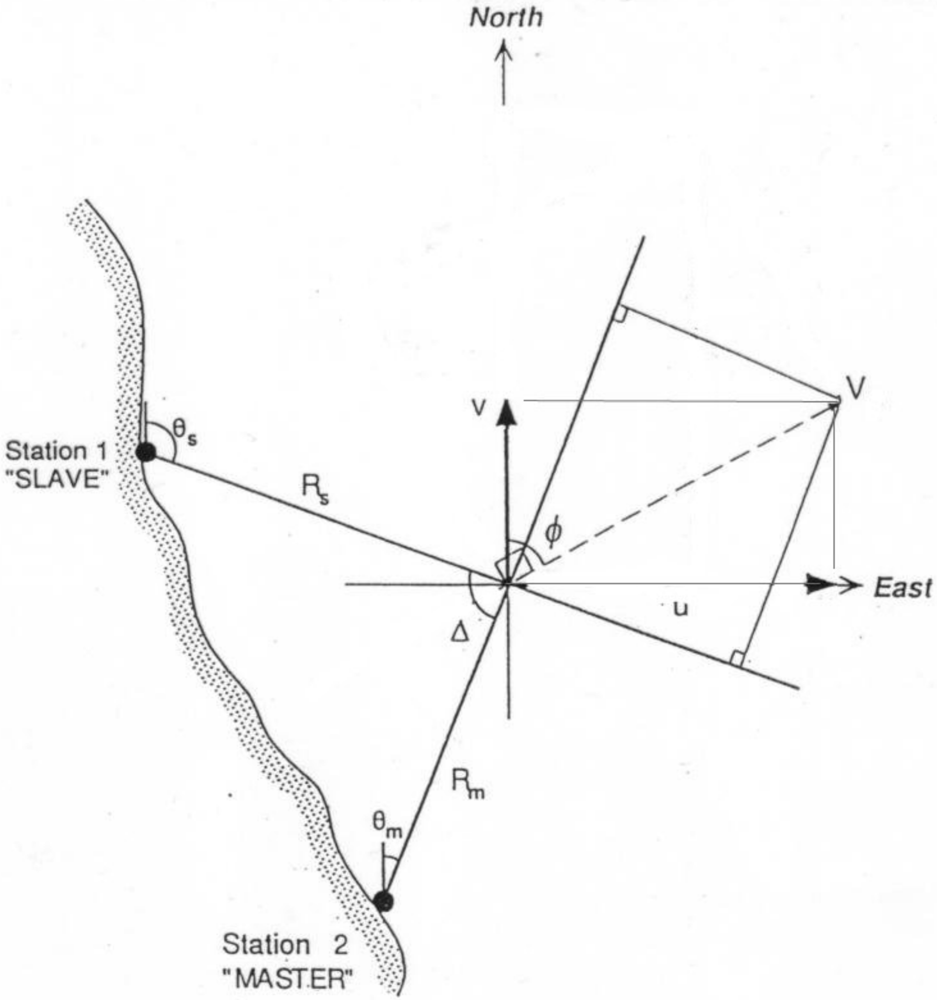
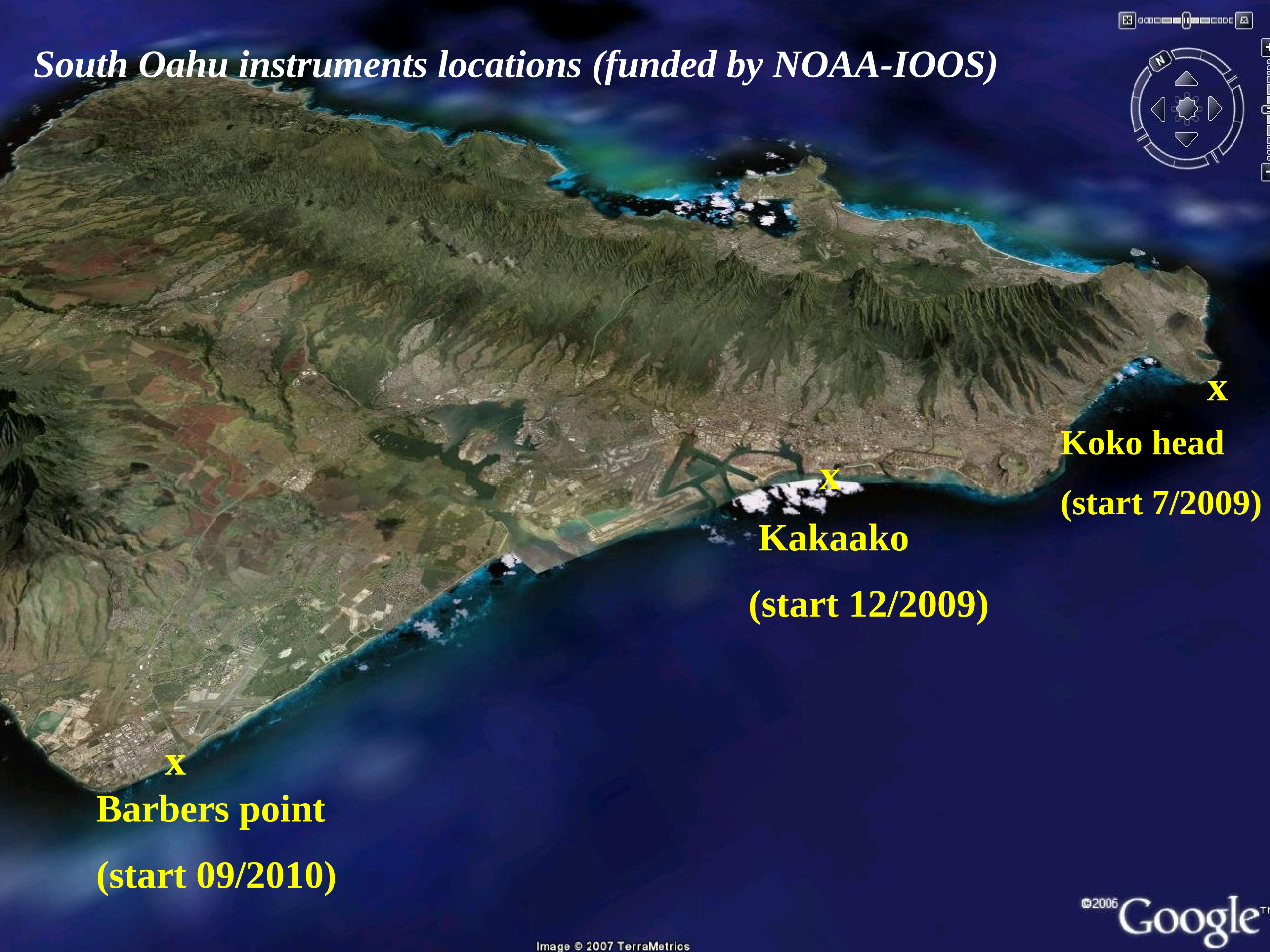


Figure 2. Schematic for determining the resulting vector current from velocity components of two intersecting radials.

South Oahu instruments locations (funded by NOAA-IOOS)



Kaena ridge

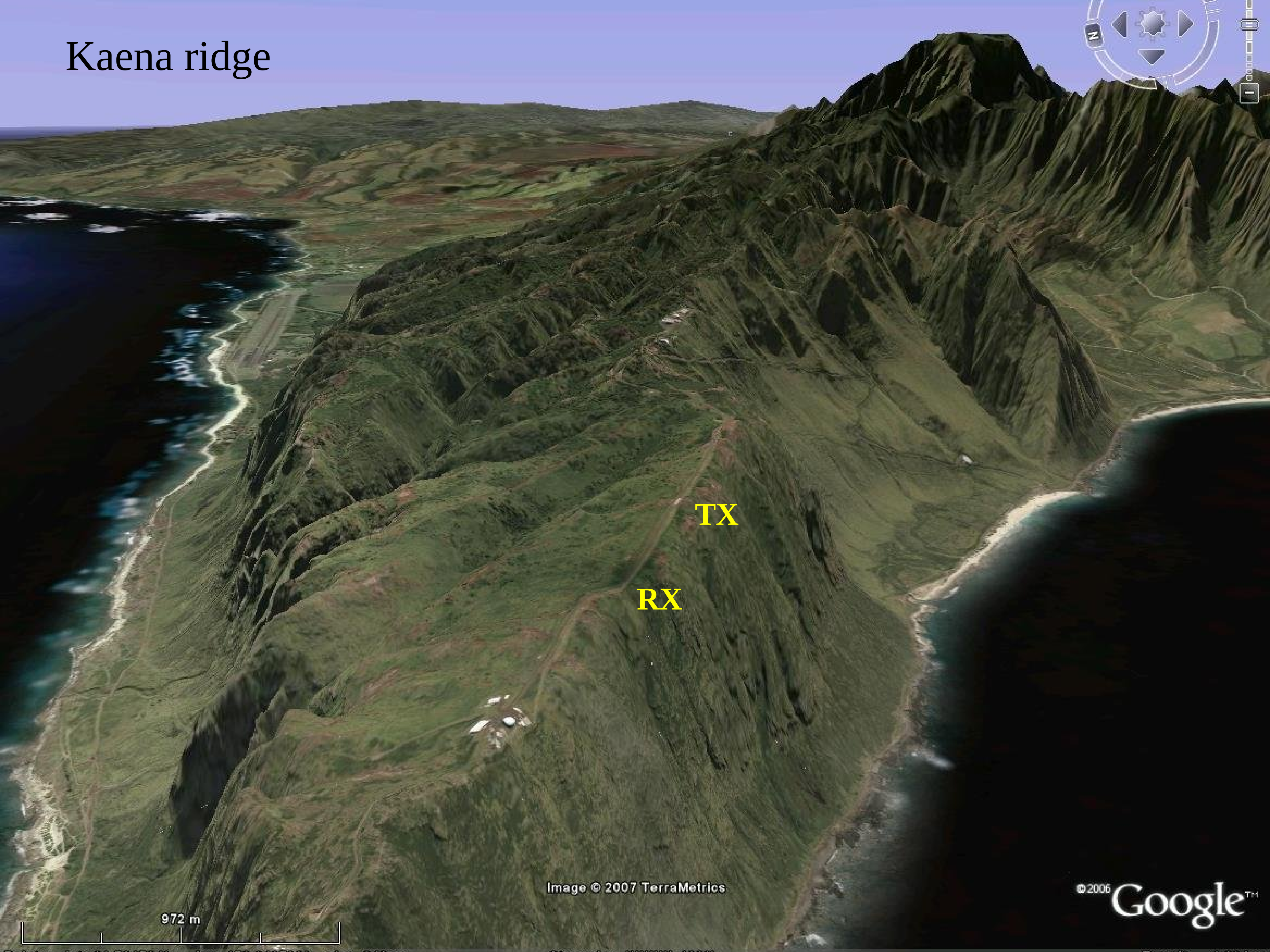


Image © 2007 TerraMetrics

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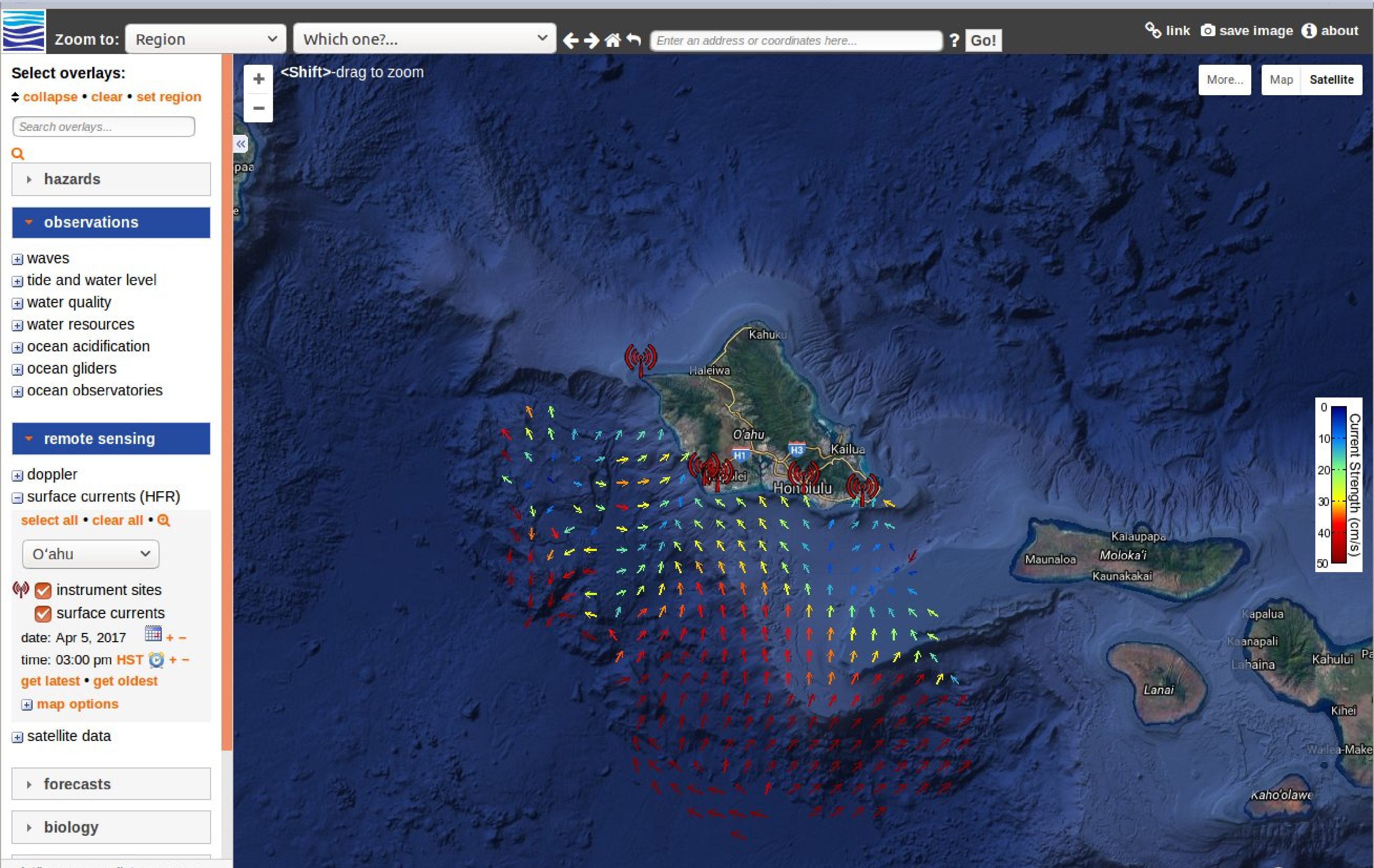
PacIOOS Voyager

PacIOOS
PACIFIC ISLANDS OCEAN OBSERVING SYSTEM

http://www.pacioos.org/



Zoom to: Region

Which one?...

Select overlays:

surface currents (HFR)

O‘ahu

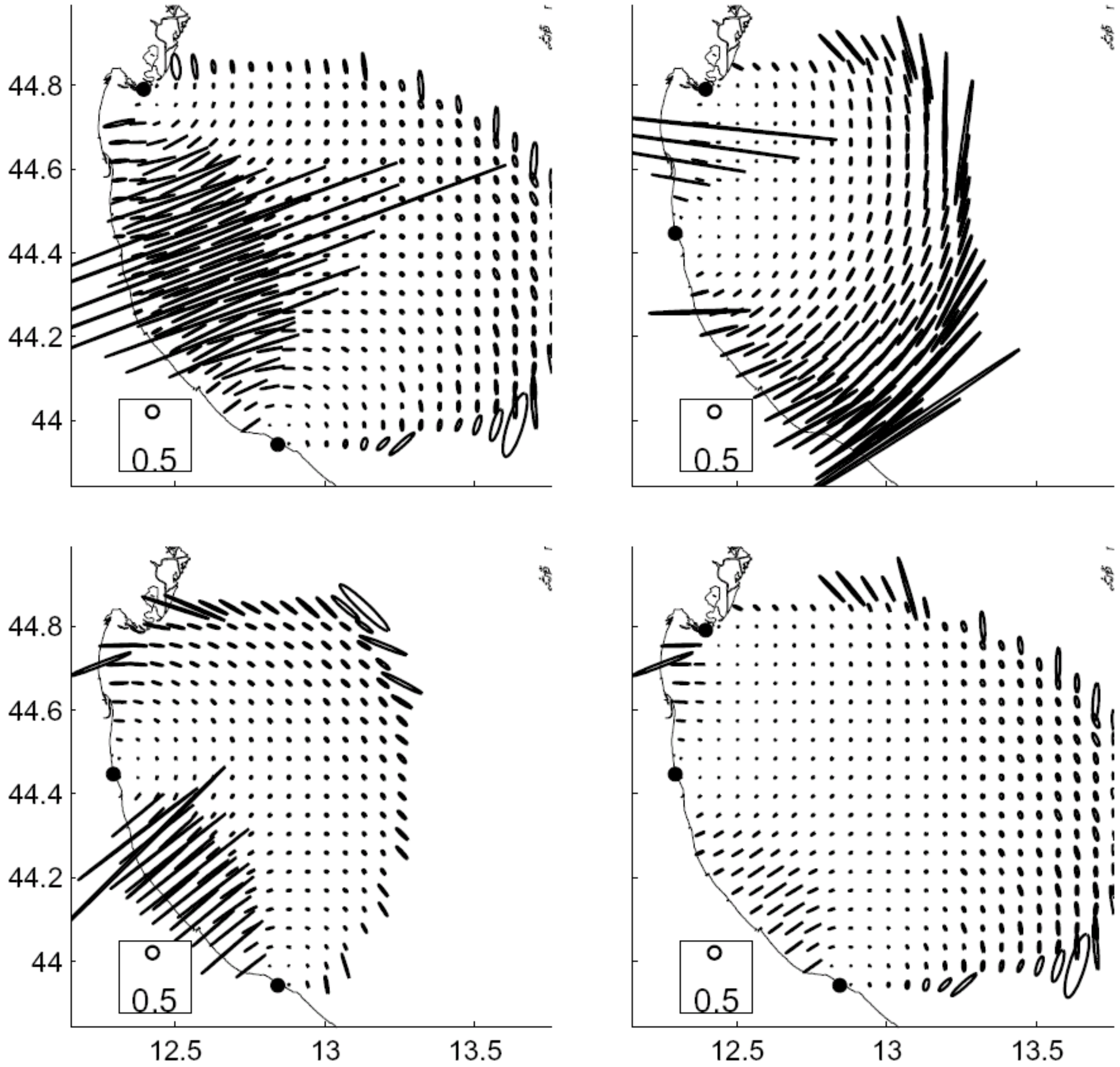
☑ instrument sites

☑ surface currents

date: Apr 5, 2017

time: 03:00 pm HST

Geometric Dilution Of Precision



Tides in the Kauai Channel and their Interactions with Mesoscale Currents

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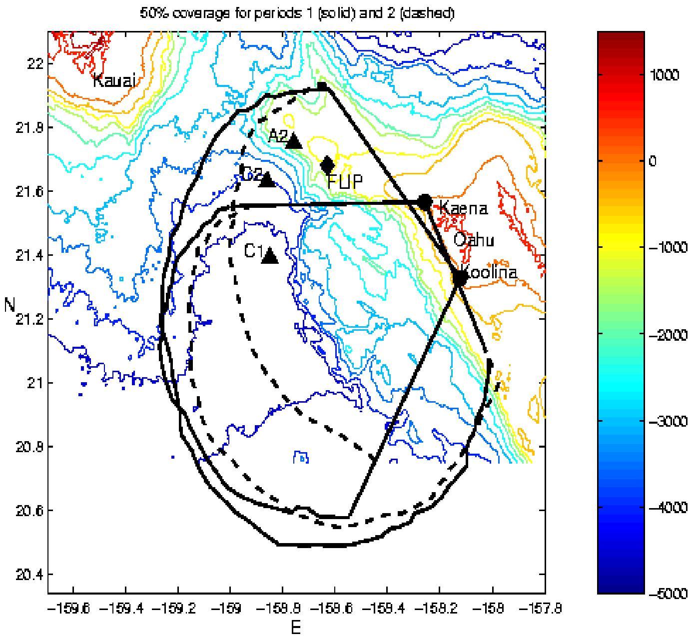
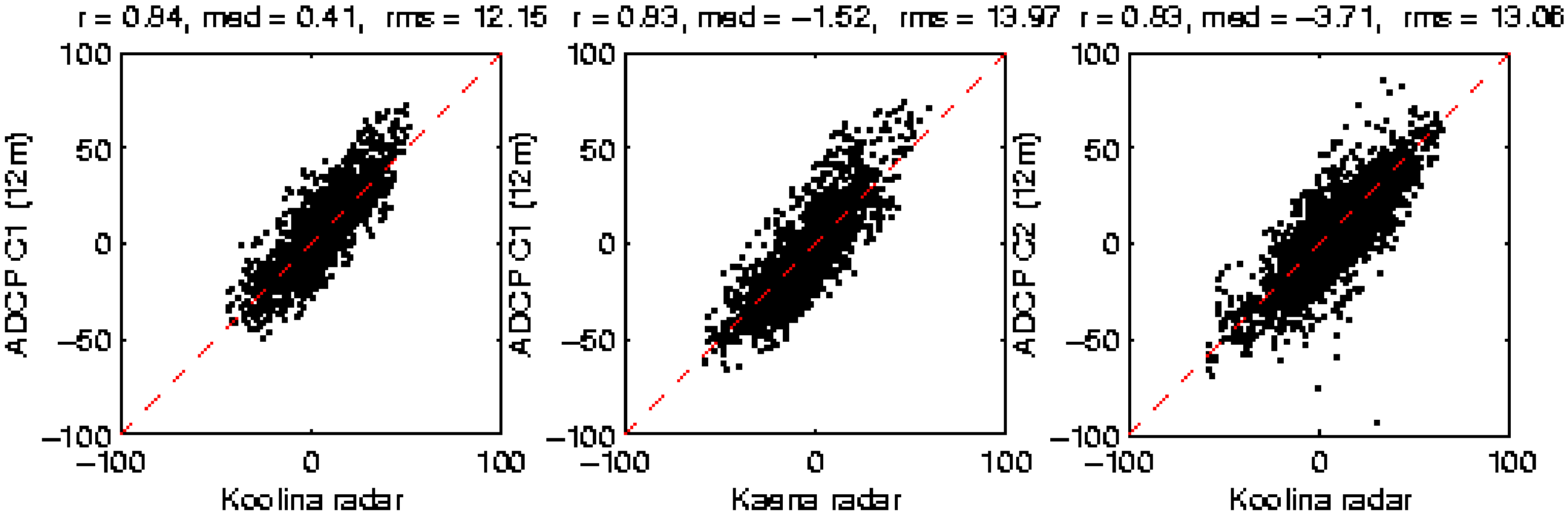
[1]Department of Oceanography, School of Ocean and Earth Science and Technology, University of Hawaii, Honolulu, HI 96822, USA.

Hawaiian Ocean Mixing Experiment

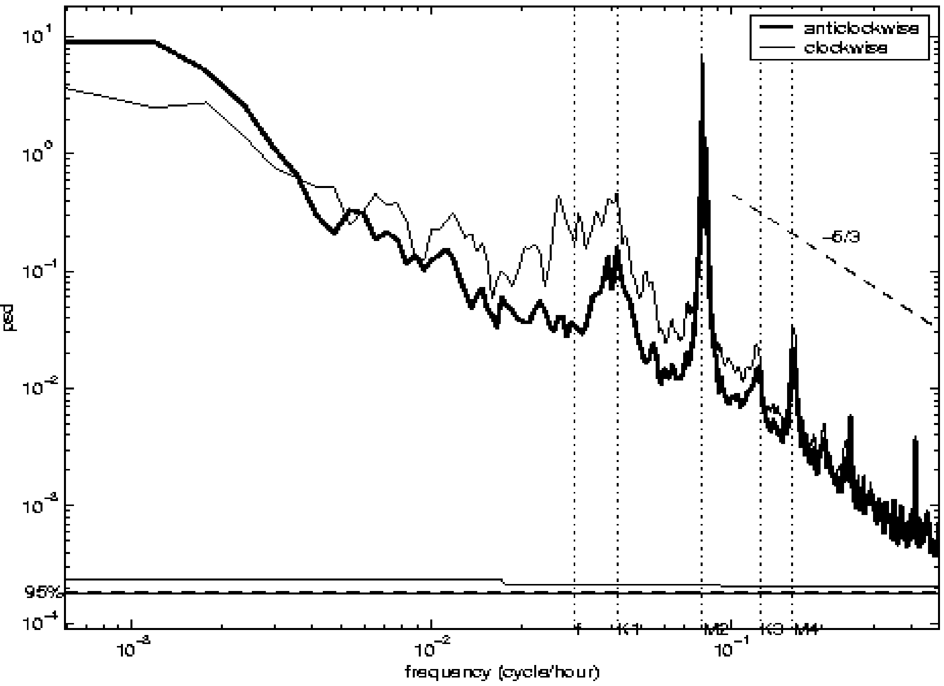
Validation:
High Frequency Radar Currents
(16 Mhz, 1 m)
vs.
Acoustic Doppler Current meters
(300 kHz, 12 m)

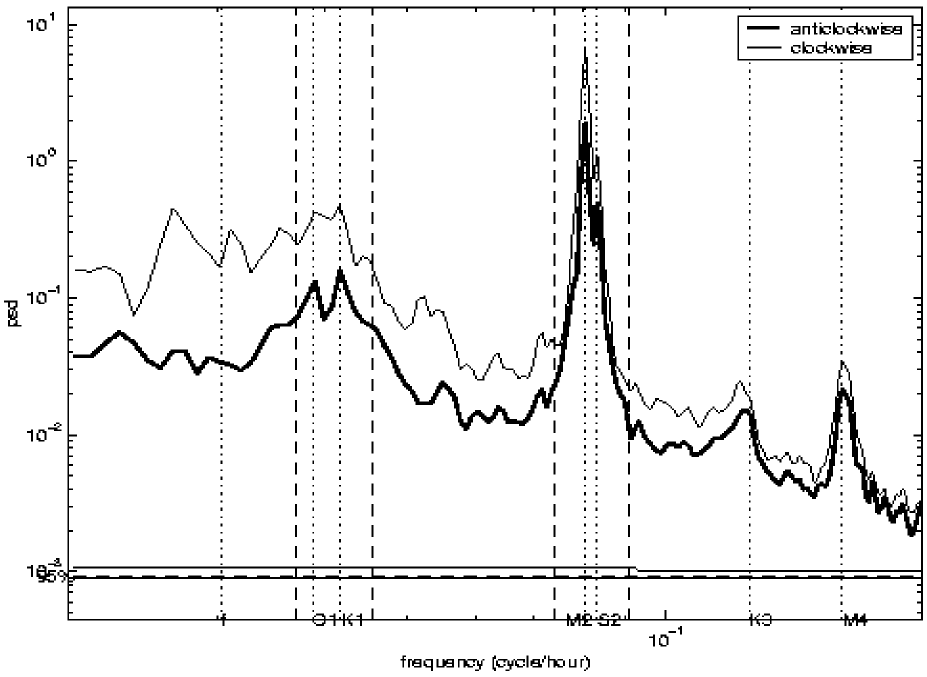




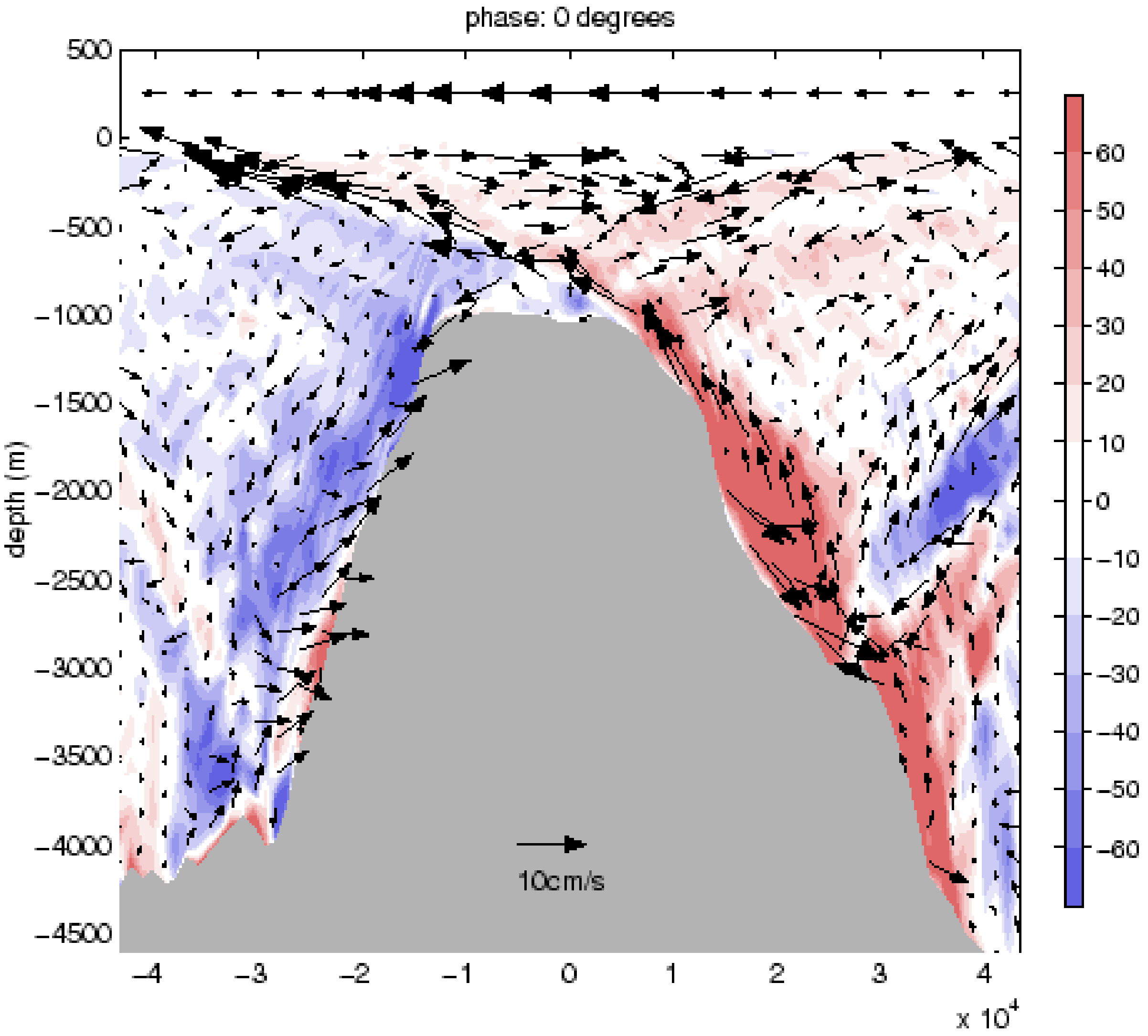
Temporal spectra:

- tides and harmonics
- inertial motions
- mesoscale currents

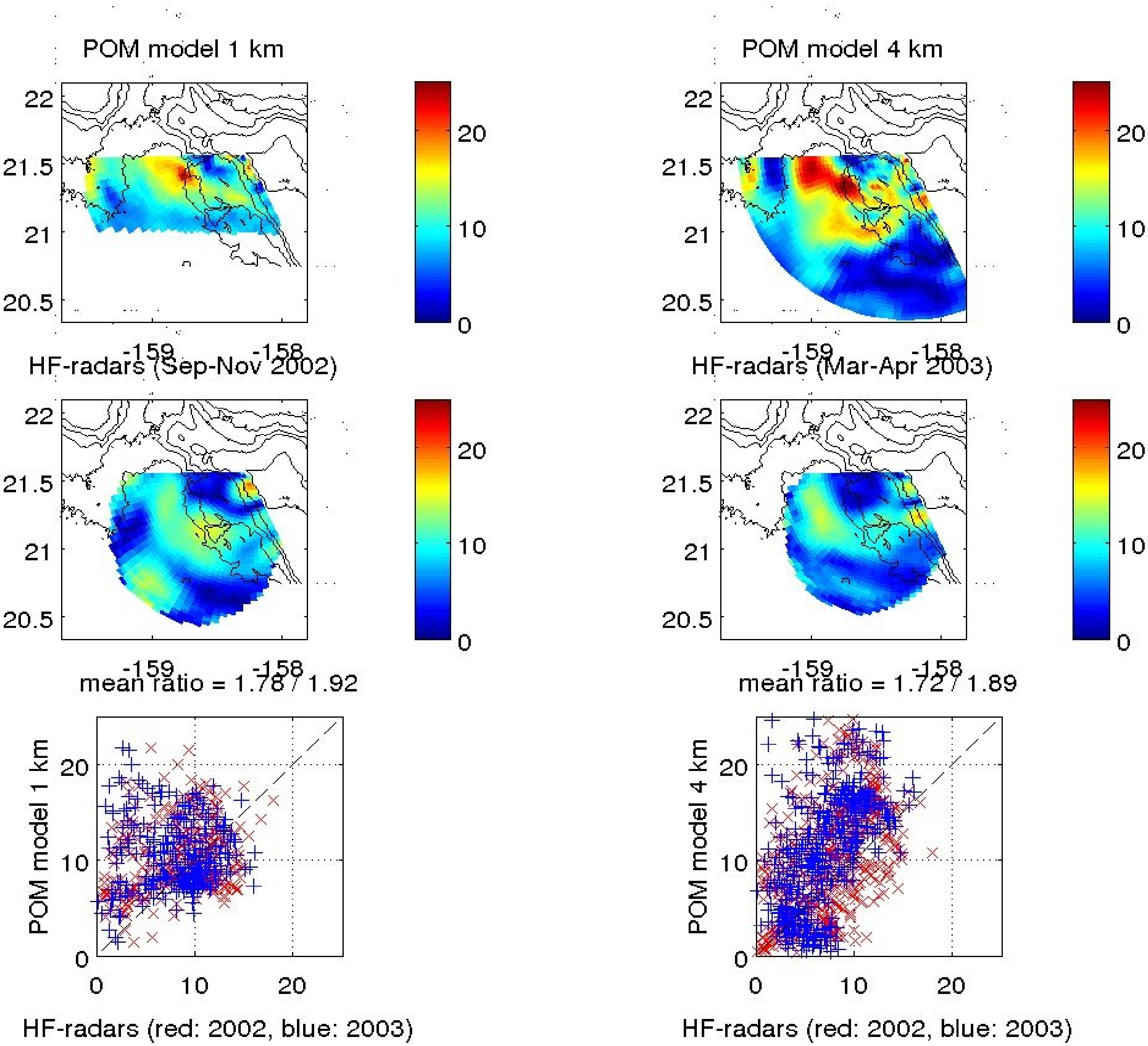

Power spectra averaged over grid points with 100% time coverage for period 1


Power spectra averaged over grid points with 100% time coverage for period 1

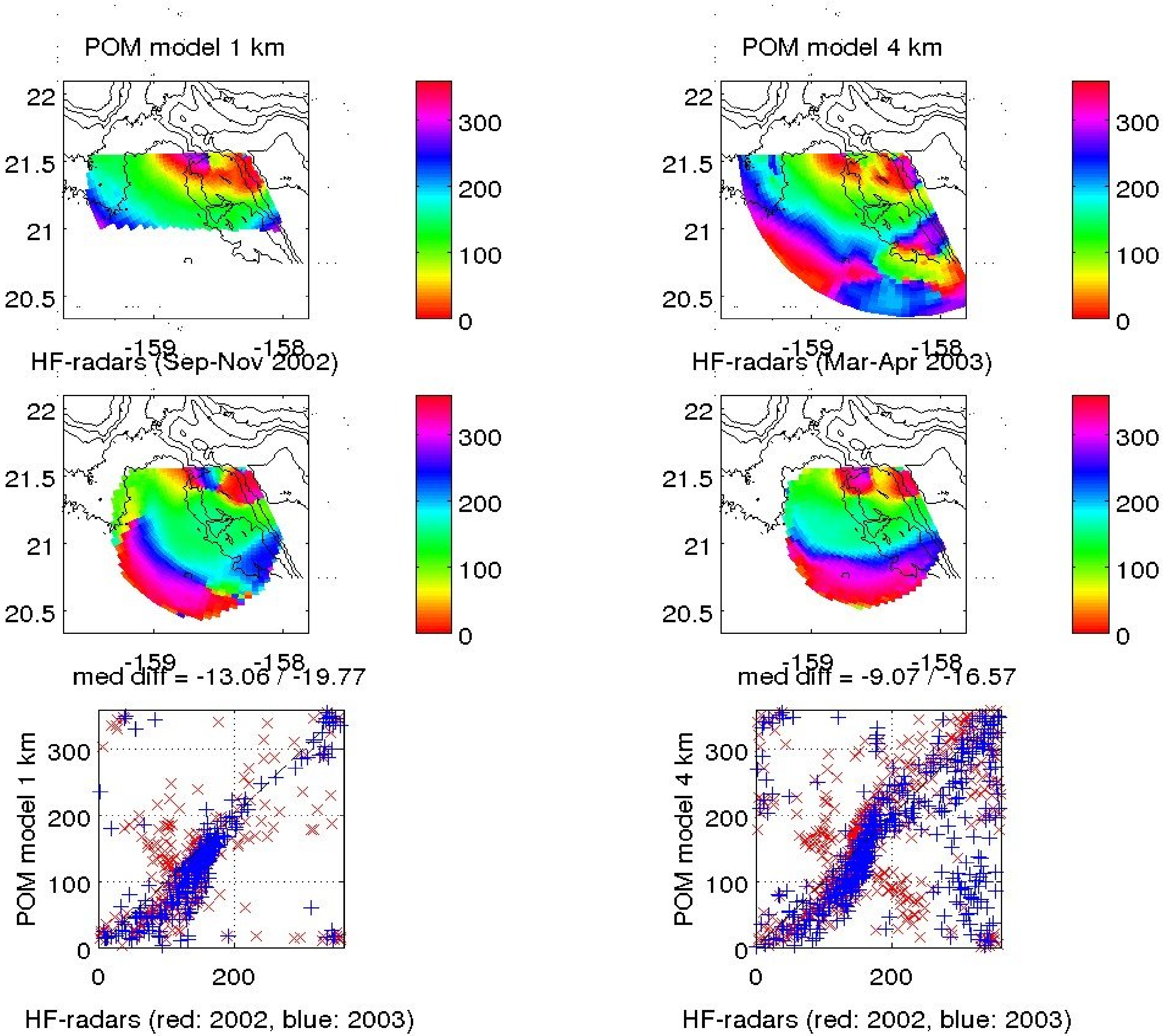
Barotropic and baroclinic M2 currents from POM (Merrifield and Holloway, 2002)



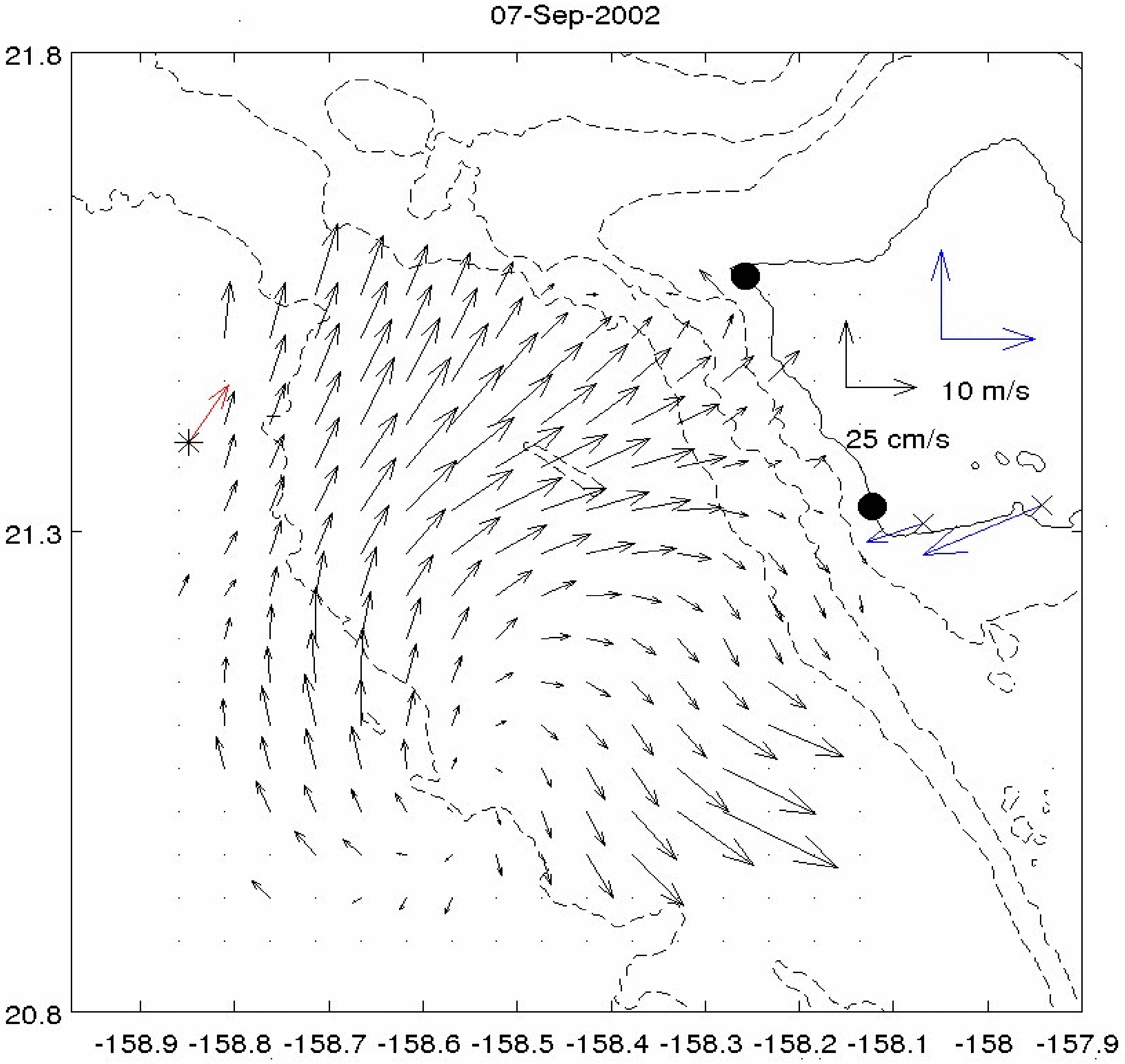
M2 amplitude for Kaena radial currents from harmonic analysis



M2 phase for Kaena radial currents from harmonic analysis



Low-pass filtered currents (period 1)



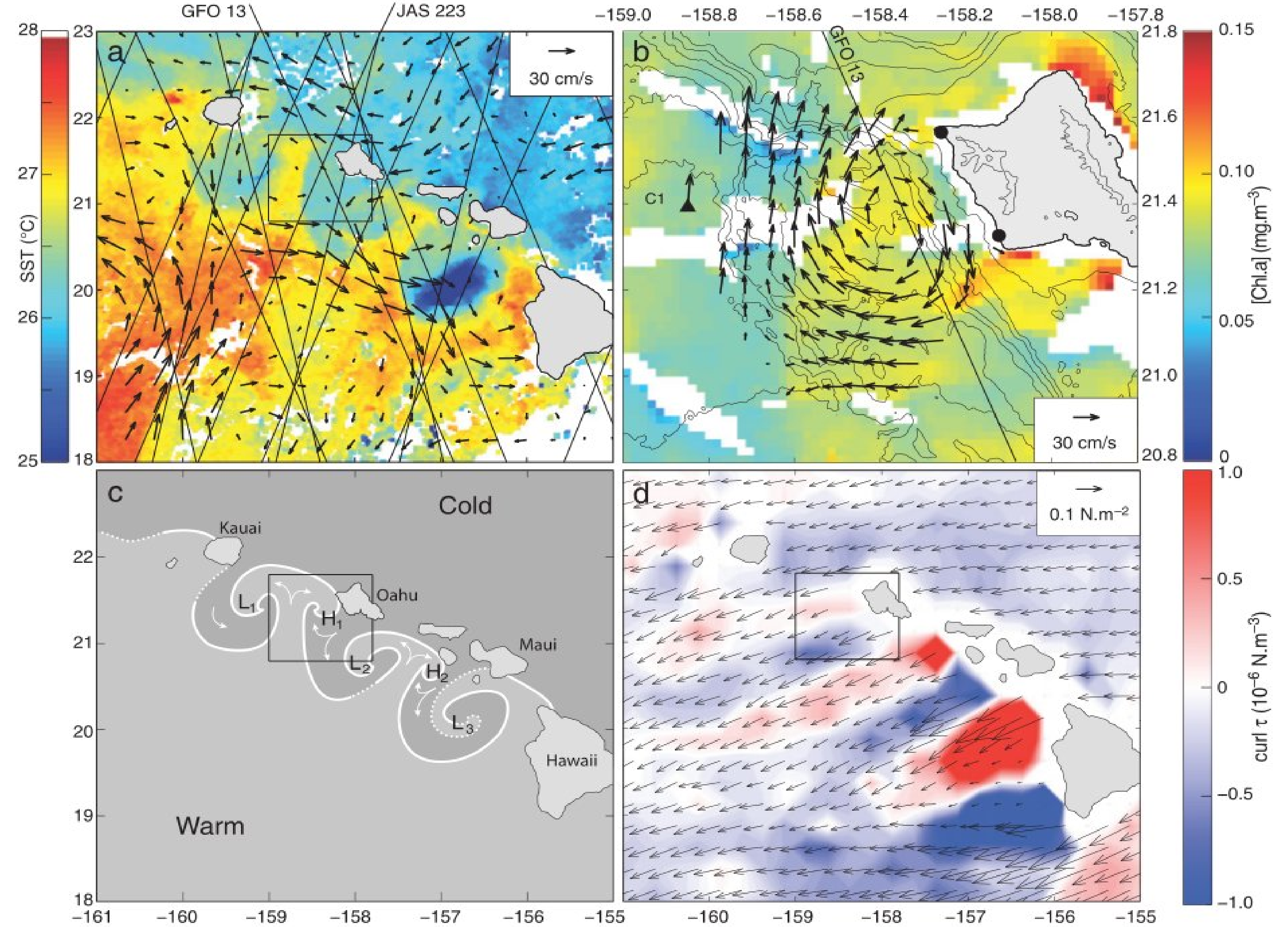


FIG. 1. (a) Altimetric surface geostrophic currents for 23–30 Oct 2002, overlaid on a composite SST image from *Aqua* and *Terra* MODIS for 26 Oct. The tracks of the *Jason-1*, *European Remote Sensing Satellite-2* (*ERS-2*), *GFO*, and Ocean Topography Experiment (TOPEX)/Poseidon altimeters are shown as black lines. (b) Subinertial surface currents for 27 Oct from HFRs (marked by black bullets) and from ADCP C1 (12-m-depth bin, marked by a black triangle), overlaid on chlorophyll-*a* concentration from *Aqua* MODIS at 2355 UTC 26 Oct. Bathymetry is contoured every 500 m. (c) Conceptual sketch of the main SST and circulation features (H: anticyclones, L: cyclones). (d) Wind stress and curl from QuikSCAT at 25-km resolution, averaged over 23–30 Oct. The coverage of (b) is outlined in (a),(c), and (d).

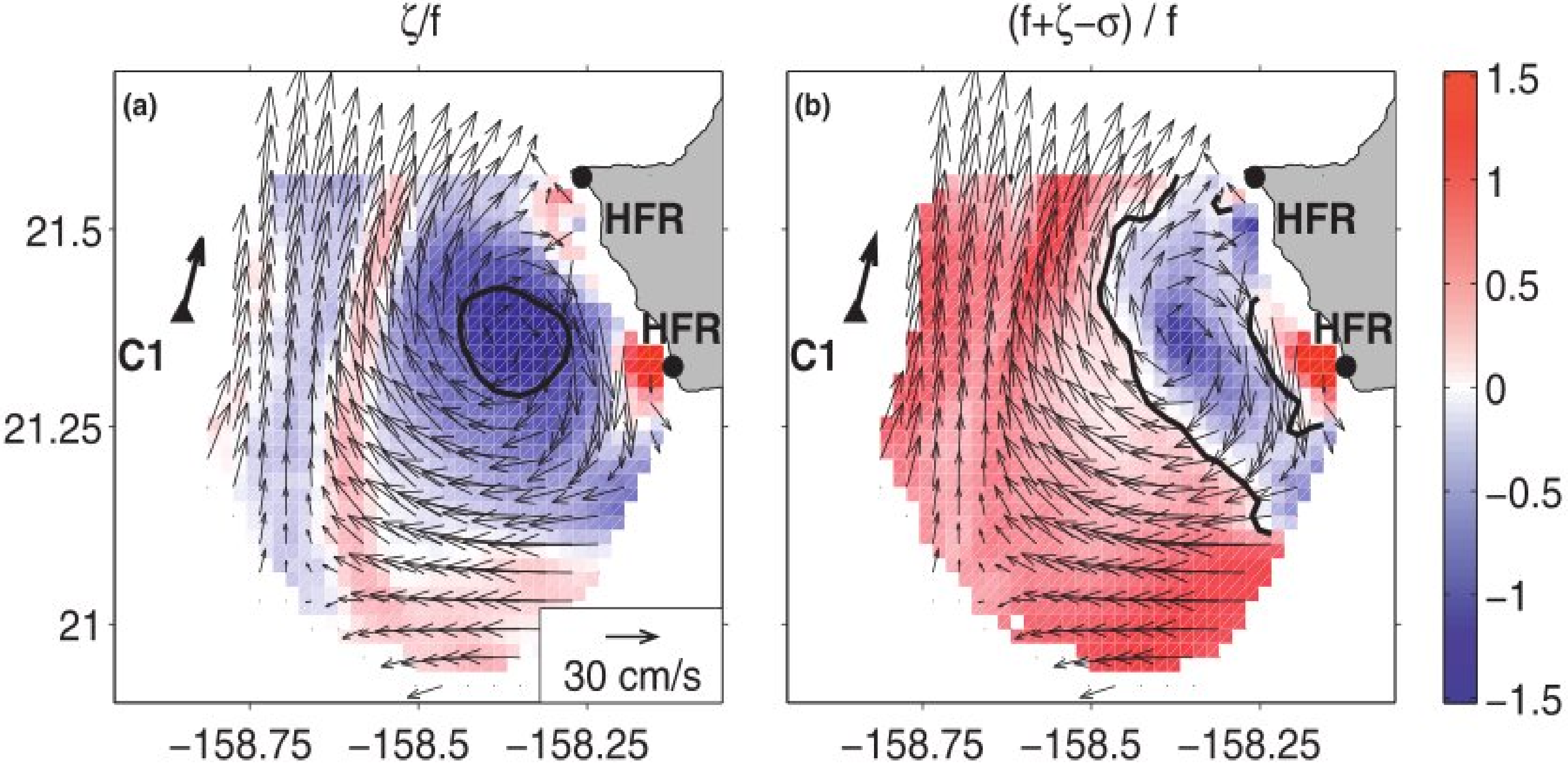
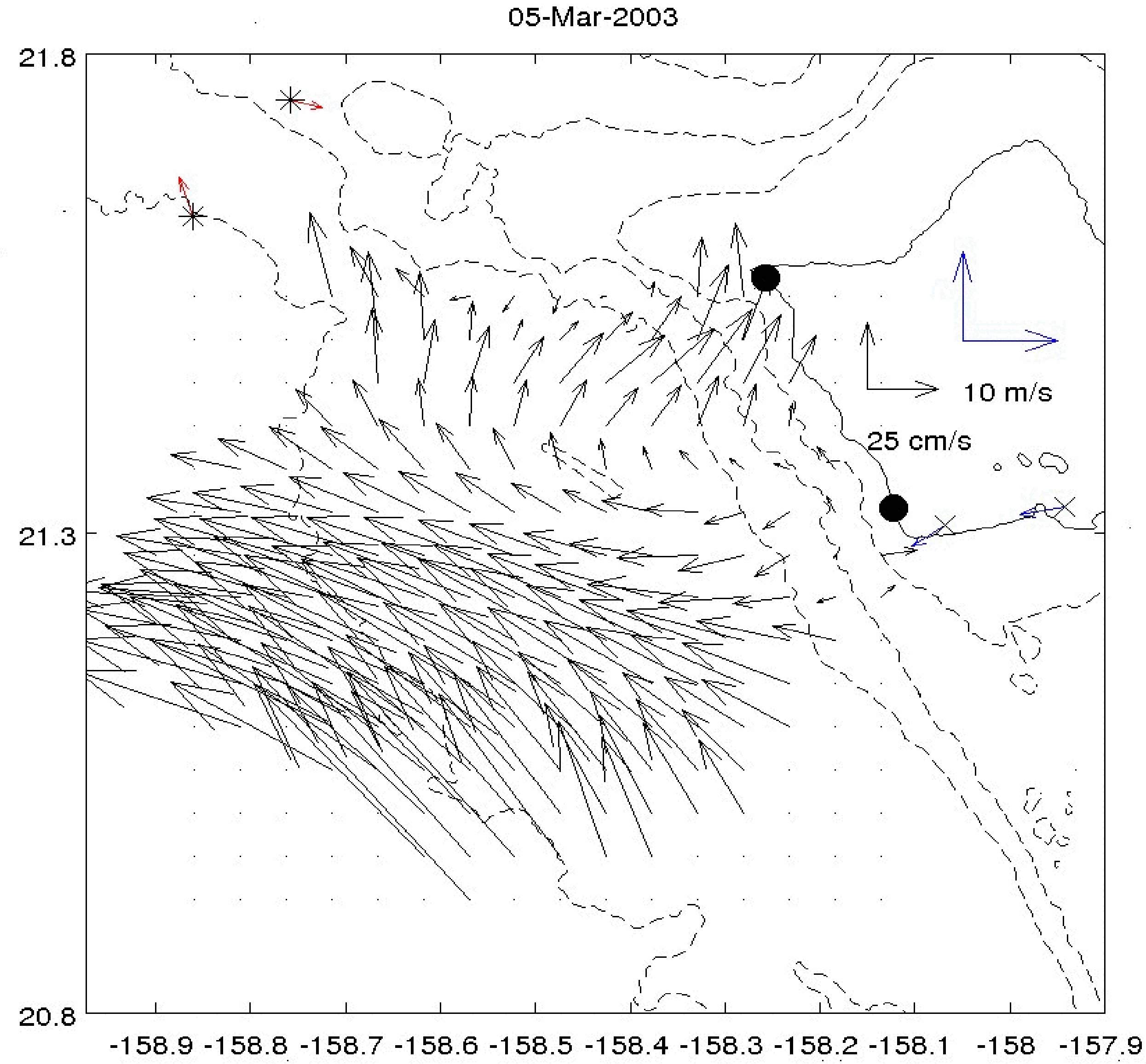


FIG. 7. Instability criteria at extremum of vorticity on 26 Oct 2002: (a) relative vertical vorticity ζ, normalized by f, with the inertial instability criterion $\zeta/f < -1$ shown by a black contour and (b) absolute vorticity $f + \zeta$ minus strain σ, normalized by f, with the ageostrophic anticyclonic instability criterion $f + \zeta - \sigma < 0$ shown by a black contour.

Low-pass filtered currents (period 2)



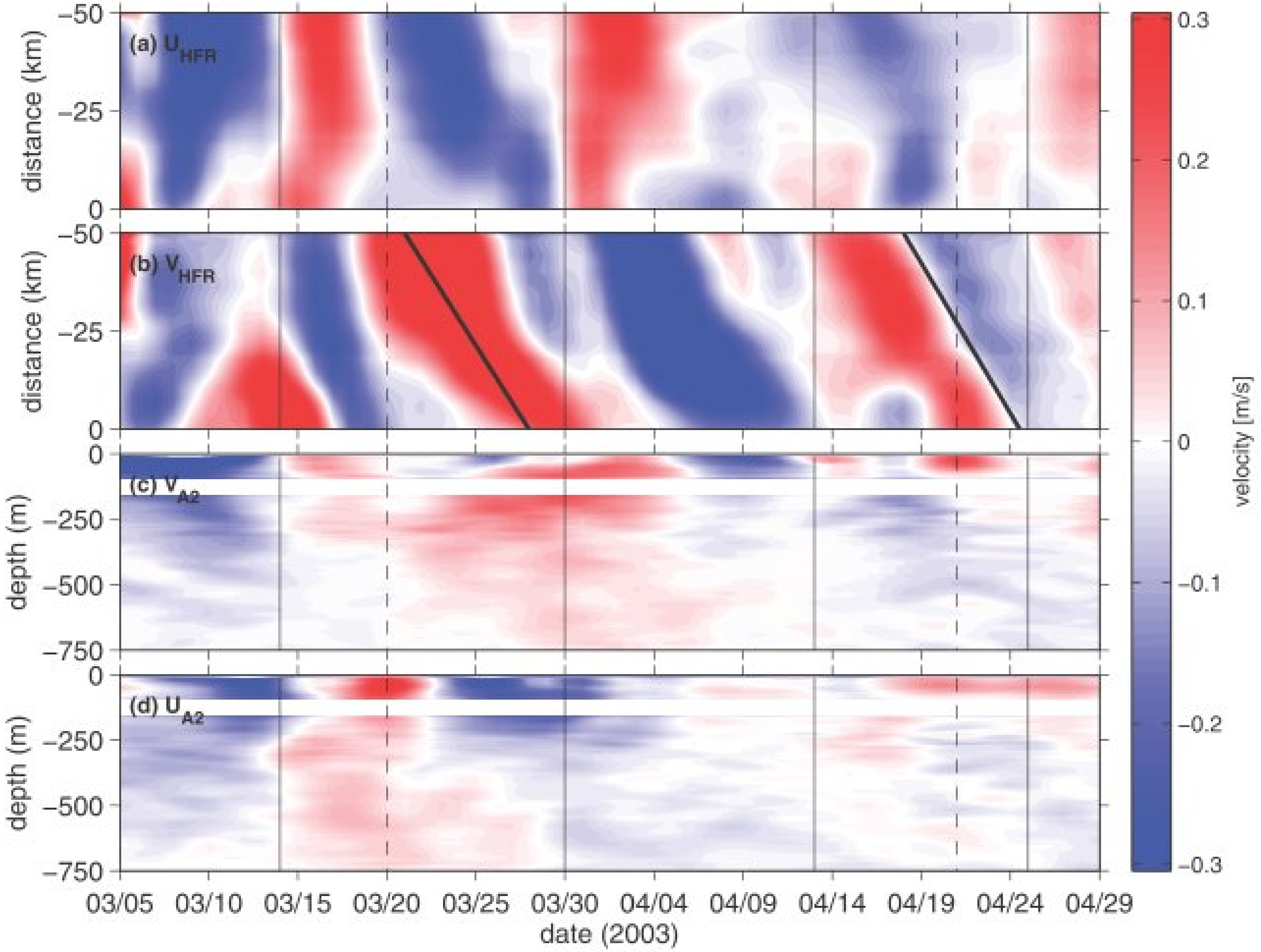


FIG. 2. Time series of (a),(b) surface current anomalies as a function of distance along the transect shown in Fig. 1, and (c),(d) current anomalies at mooring A2 as a function of depth, decomposed in (a),(d) along-transect *U* and (b),(c) across-transect *V* components. The mean currents from 5 Mar to 29 Apr were subtracted. The vertical dashed lines indicate the times of the snapshots shown in Fig. 1, and the vertical solid lines indicate the intervals of the periods of the analysis. The slanted bold lines represent the phase propagation inferred from the RTs.

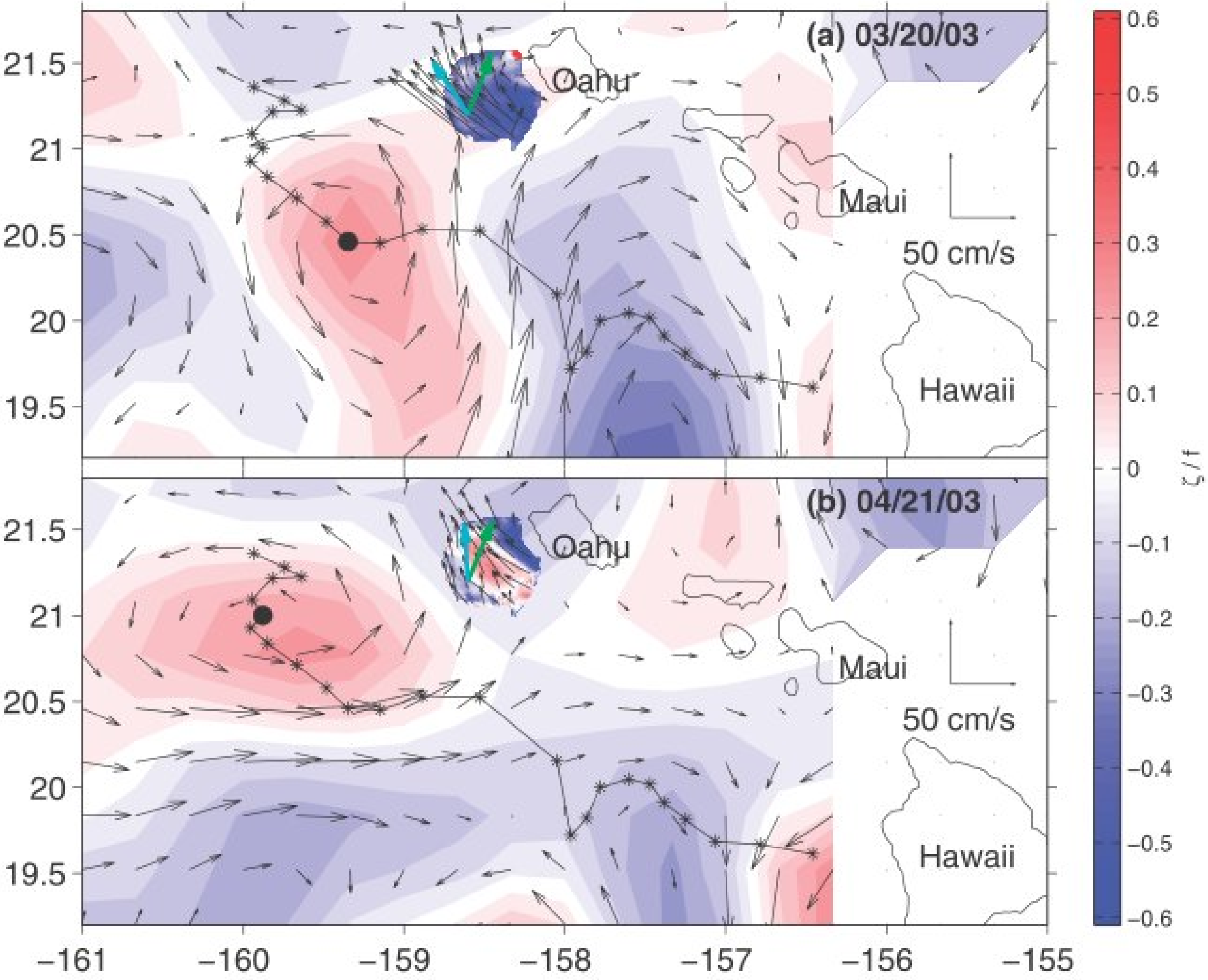
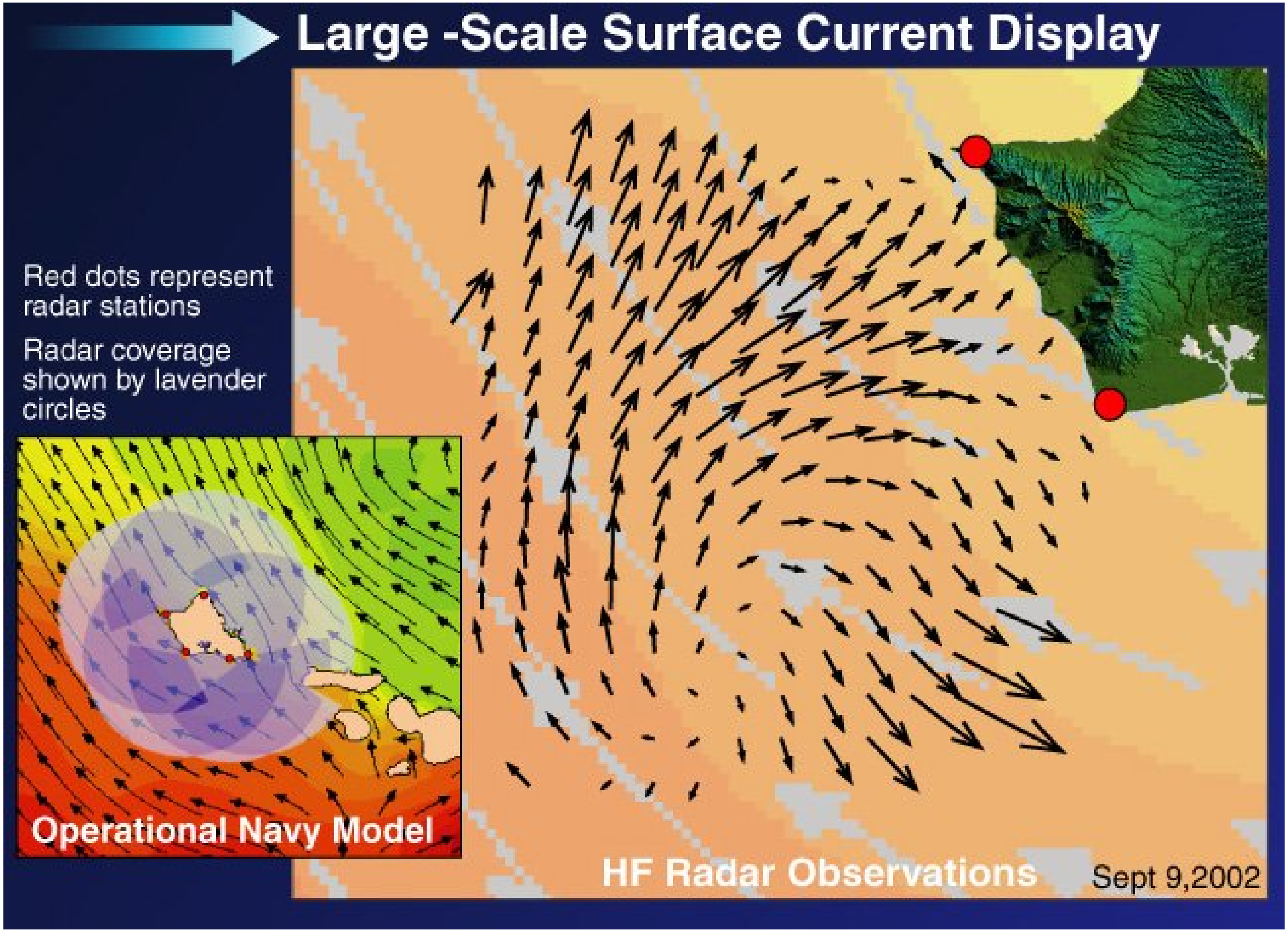
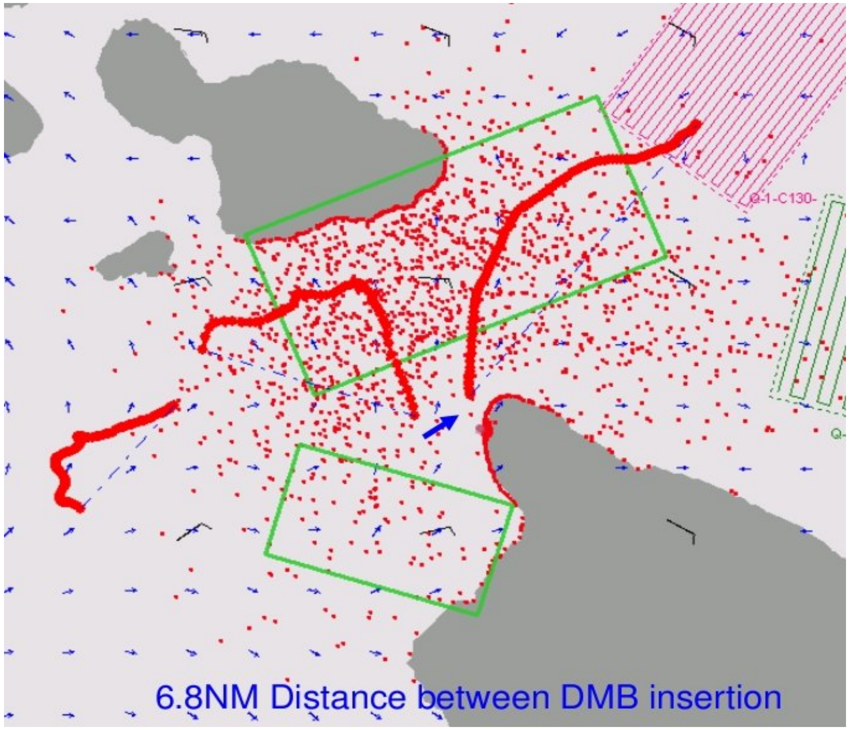


FIG. 5. Weekly averaged geostrophic currents from altimetry, centered on (a) 20 Mar and (b) 21 Apr 2003. The VRWs, absent from the gridded altimetric observations but resolved by the HFRs, are superimposed. Vorticity is normalized by *f*. The green arrows indicate the direction of phase propagation inferred from the RTs, and the cyan arrows indicate the group velocity inferred from the dispersion relation of VRWs. The track of the cyclone center is shown in black, with stars every 7 days, and the black bullets indicate the center's position at the times of the snapshots.

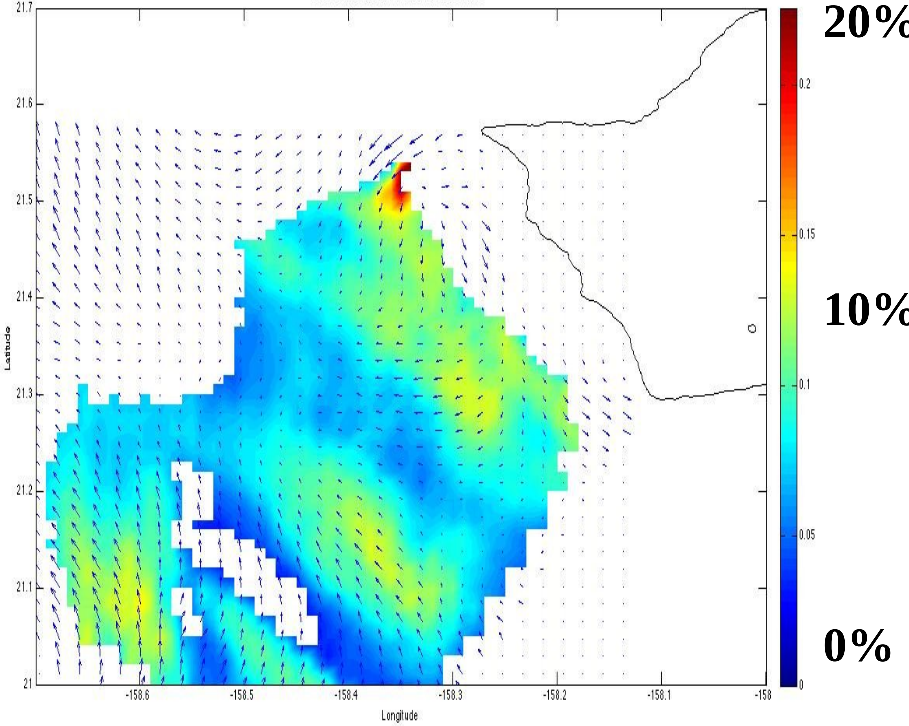
Motivation: a comparison with Navy Operational Model...



Used “Lyapunov Exponents” (exponential rate of separation of fluid particles) to quantify stretching $\lambda(\mathbf{x},t,\delta_o, \delta_f) = (1/\tau)\log(\delta_f/\delta_o)$



% stretching/day



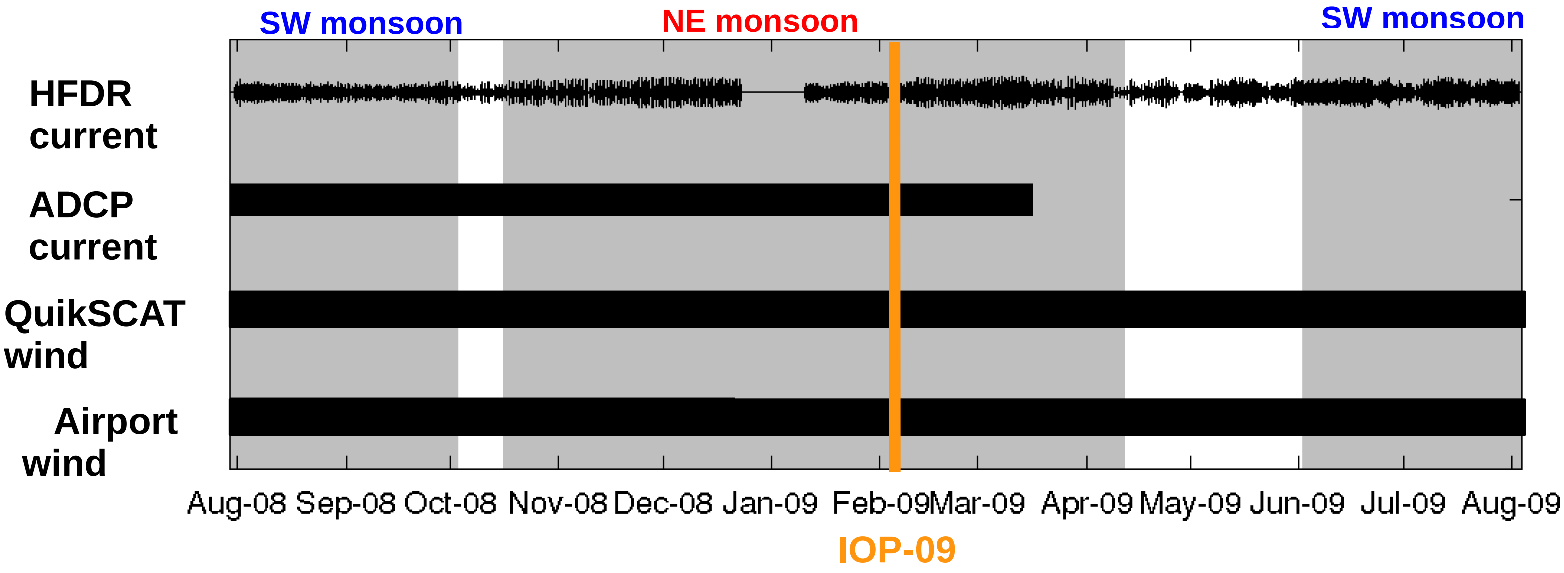
Lt. Victoria Futch, M.Sc. thesis, 2009

Low frequency flow in Panay Strait
Ph.D. dissertation
Charina Repollo, U.P. Diliman

- **characterize the dominant surface and subsurface flows**
- **assess the wind contribution on the onset and growth of cyclonic eddy**
- **describe the influence of eddy on biology**

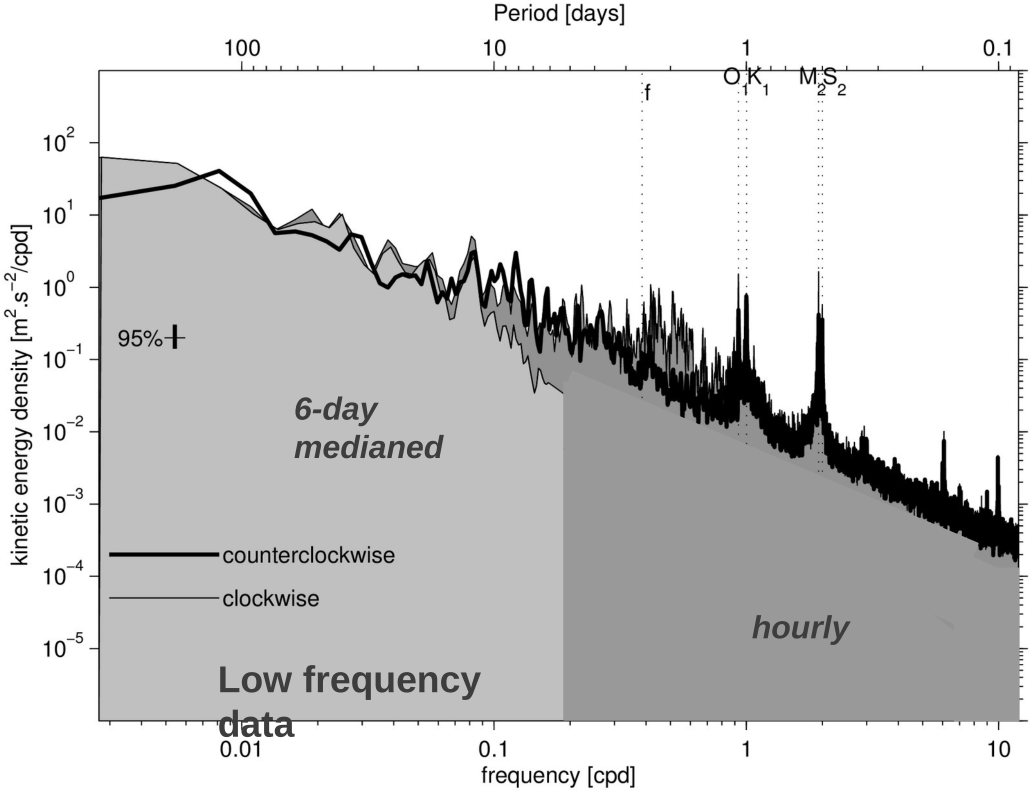

UP DILIMAN
MARINE SCIENCE INSTITUTE
RADIO OCEANOGRAPHY PROJECT
DO NOT ENTER
BAWAL MAGSULOD ROGYA
SALAMAT GID...

Data



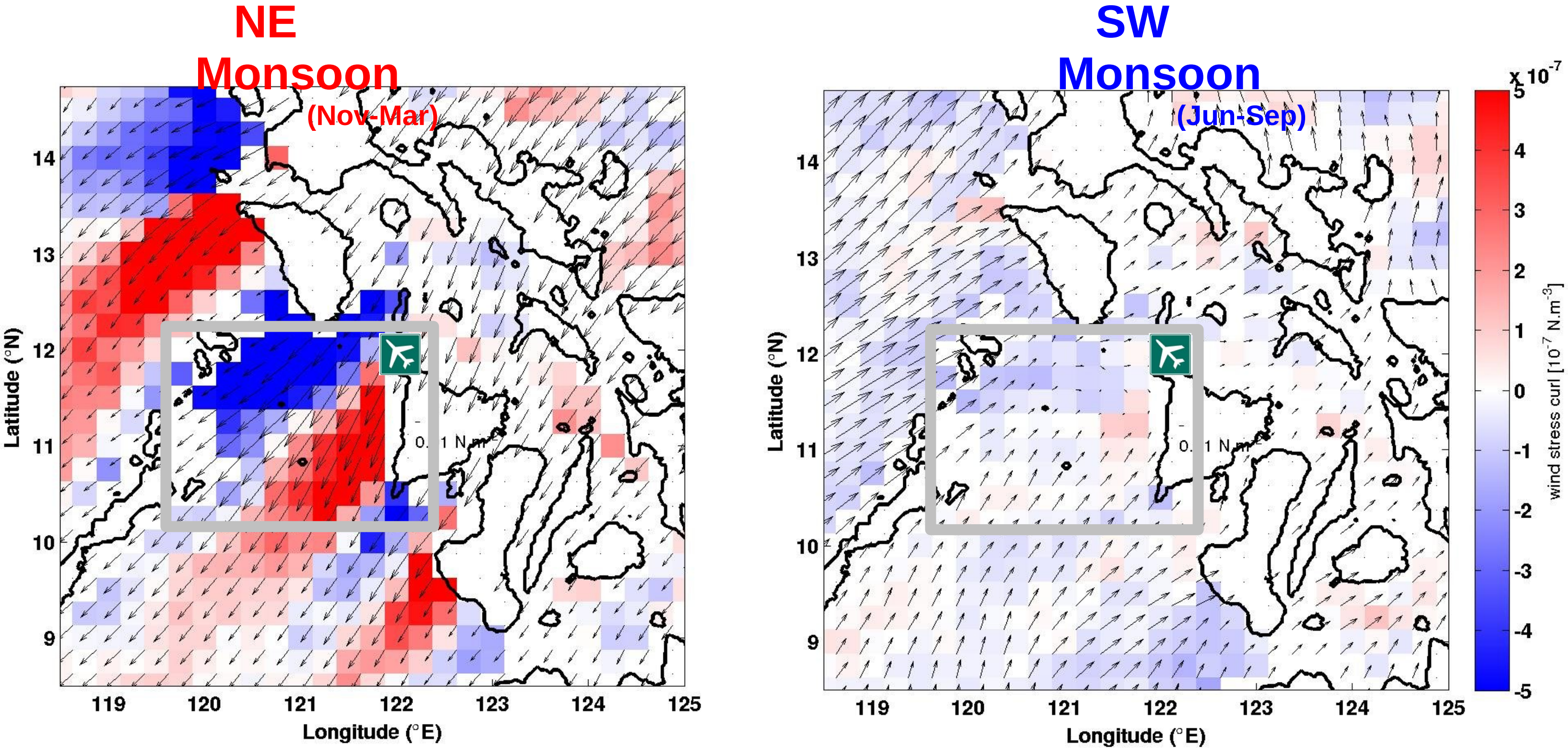
Low-frequency time series obtained by

- **removing the tides (*t-tide*)**
- **6-day running median**



Wind stress and curl

QuikSCAT



NE Monsoon (Nov-Mar)

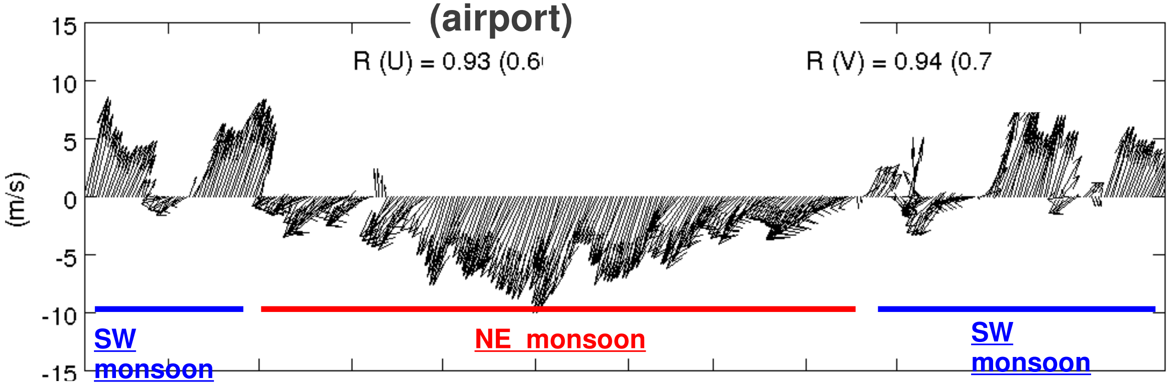
SW Monsoon (Jun-Sep)

Pronounced seasonal cycle

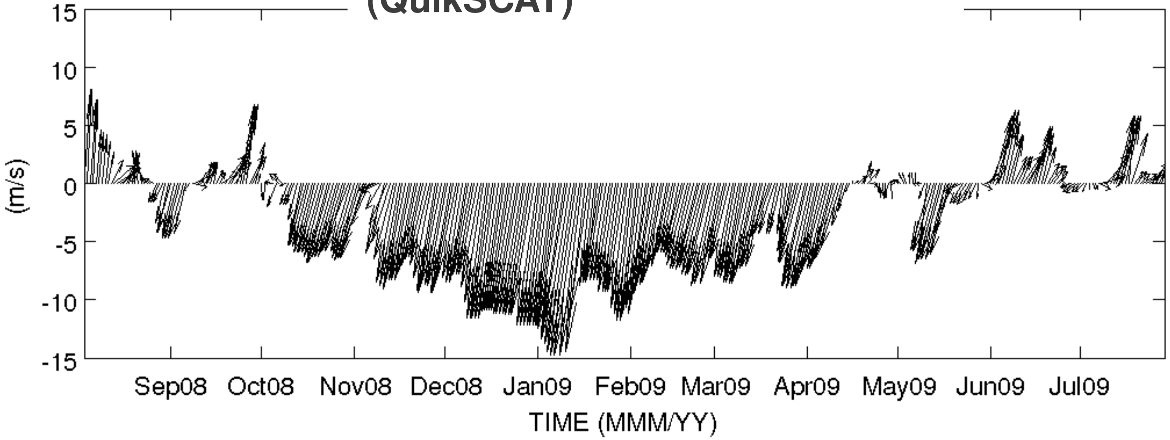
- **NE monsoon, positive wind stress curl in the lee of Panay Island**
- **absent during SW monsoon**

Local

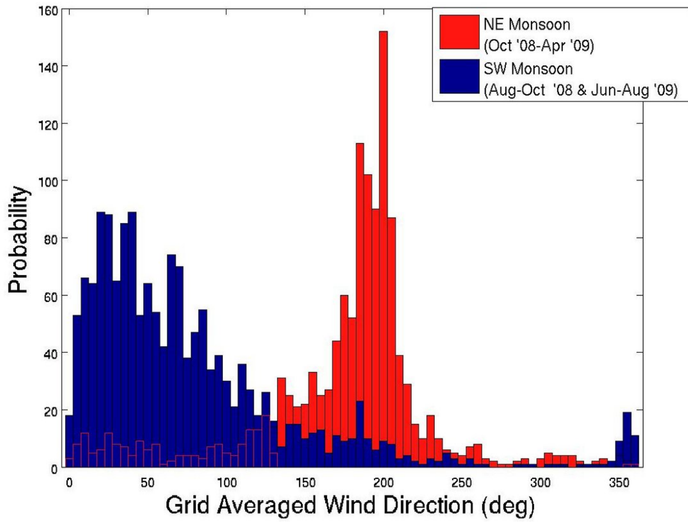
observed wind (airport)

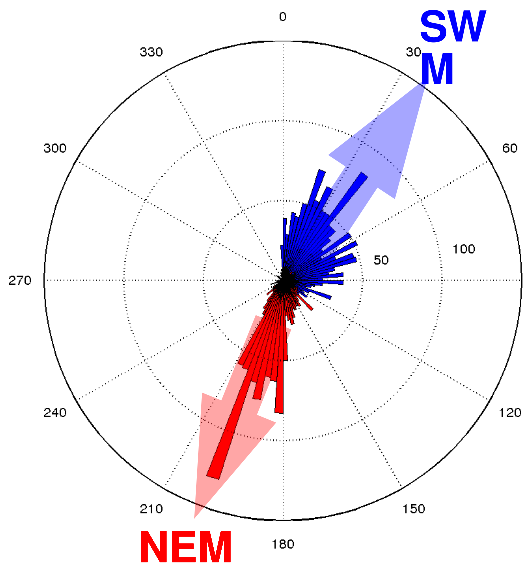


satellite-derived wind (QuikSCAT)



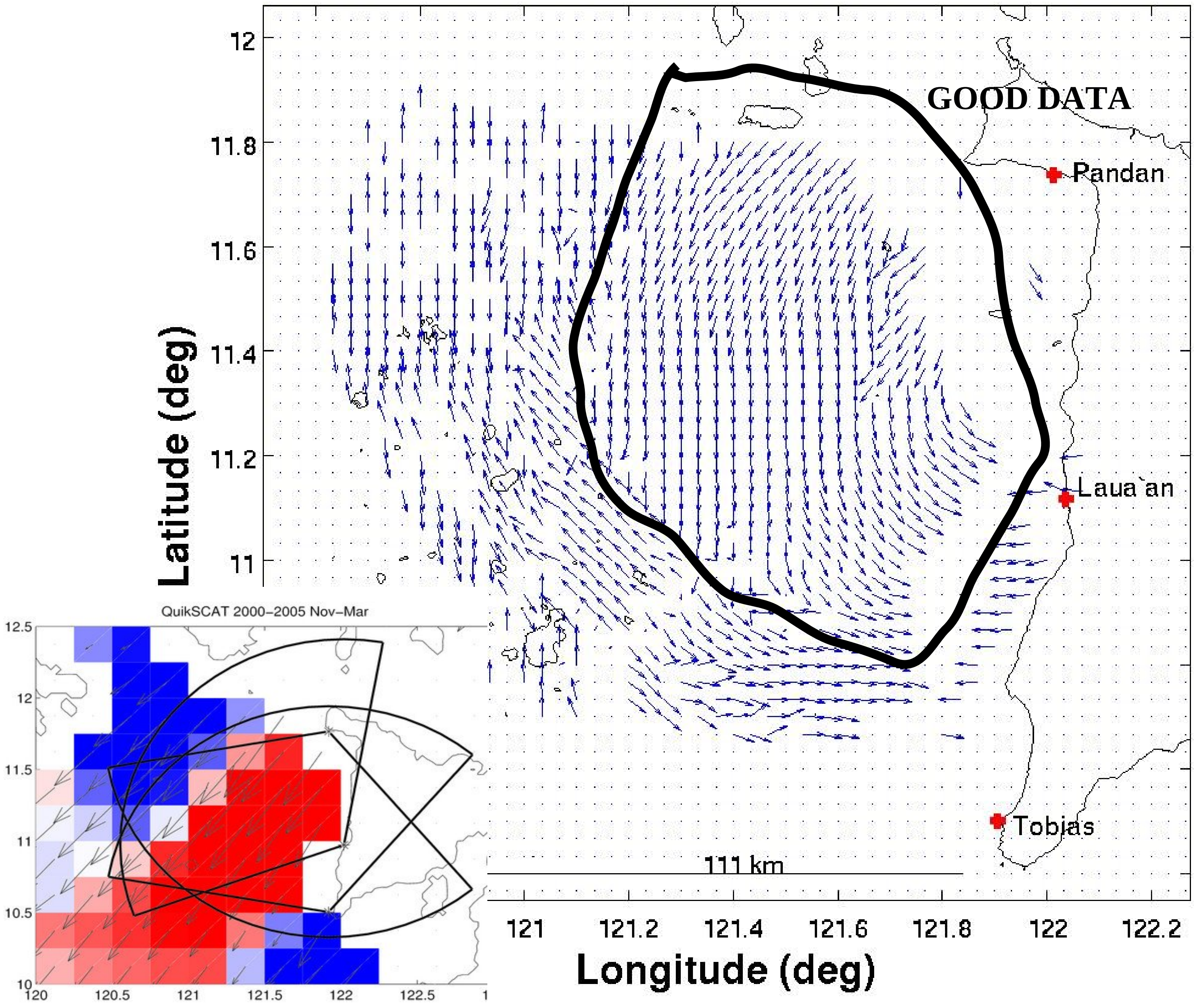
HFDR wind direction



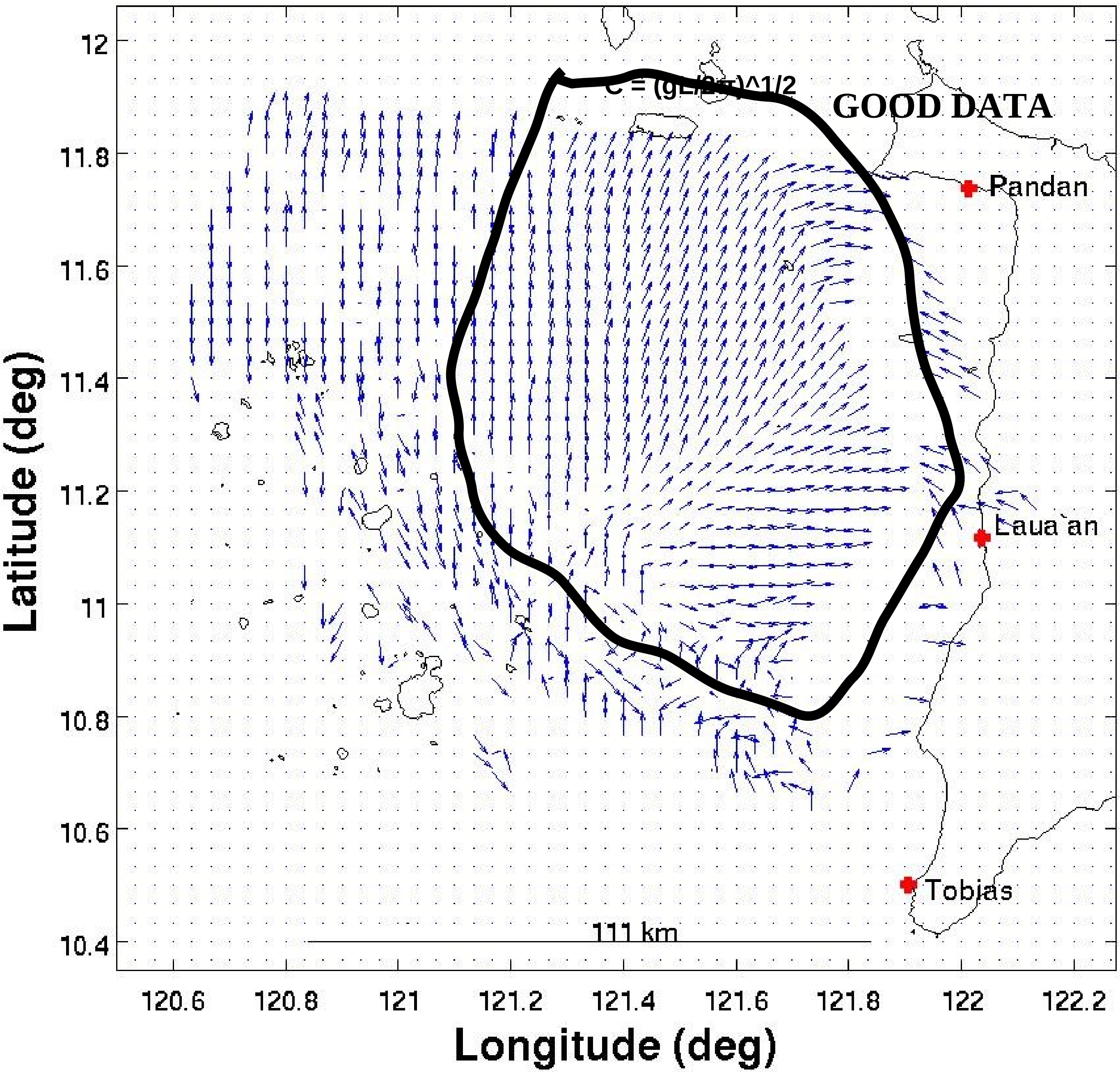


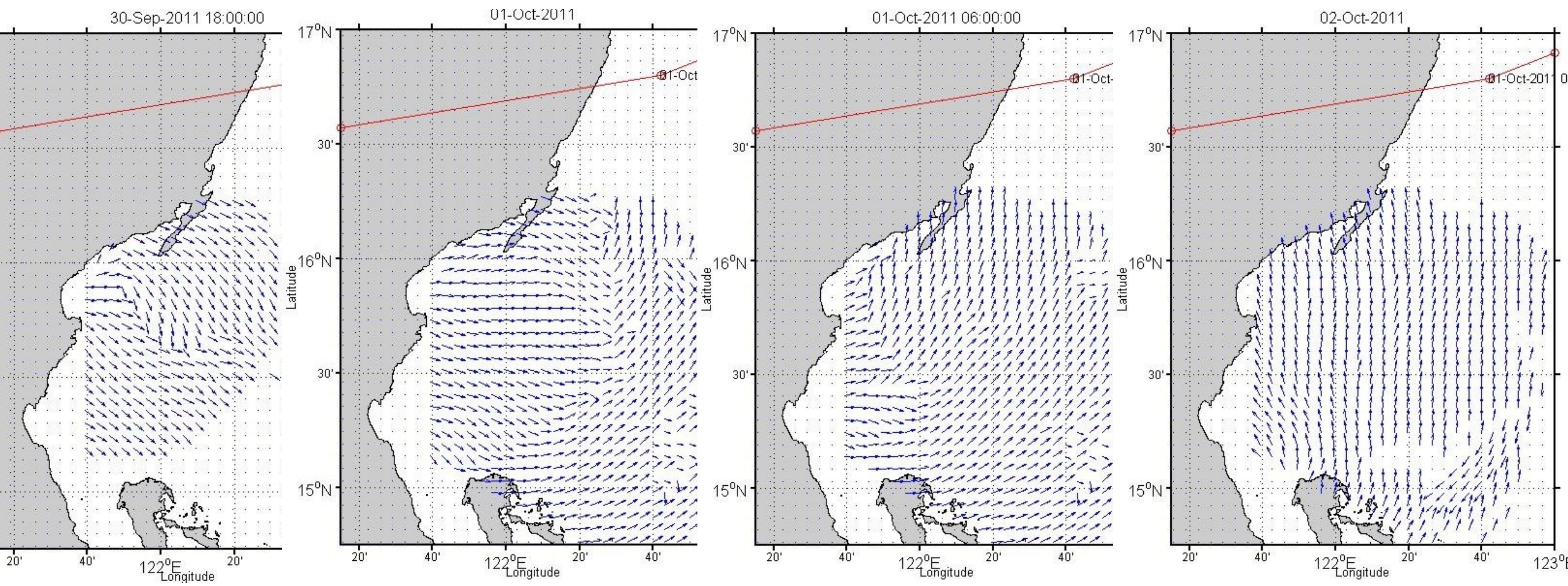
- Observed and satellite-derived winds well-correlated
- Persistent northeasterly wind Oct - April
- Variable southwesterly wind May - Sep
- Well-defined transition periods, October and April

NE Monsoon

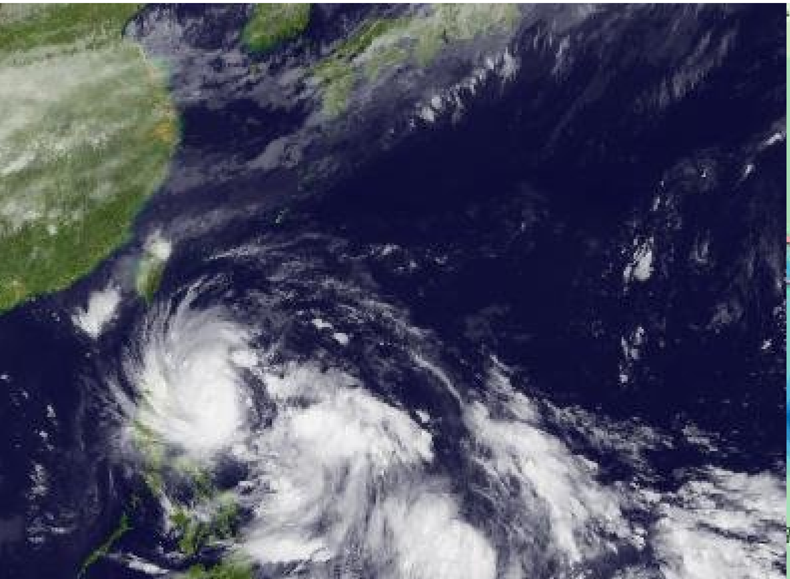

GOOD DATA
Pandan
Laua`an
Tobias
111 km
12
11.8
11.6
11.4
11.2
11
Latitude (deg)
121
121.2
121.4
121.6
121.8
122
122.2
Longitude (deg)
QuikSCAT 2000–2005 Nov–Mar
12.5
12
11.5
11
10.5
10
120
120.5
121
121.5
122
122.5
1

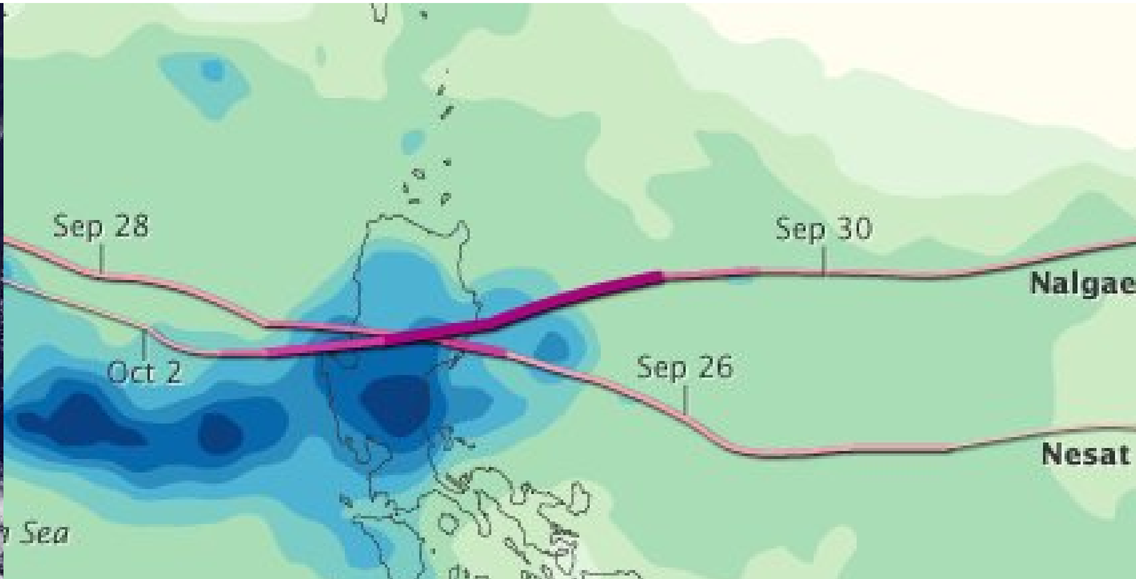
SW Monsoon


C = (gL/2π)^1/2
GOOD DATA
Pandan
Laua`an
Tobias
111 km
Latitude (deg)
12
11.8
11.6
11.4
11.2
11
10.8
10.6
10.4
Longitude (deg)
120.6
120.8
121
121.2
121.4
121.6
121.8
122
122.2

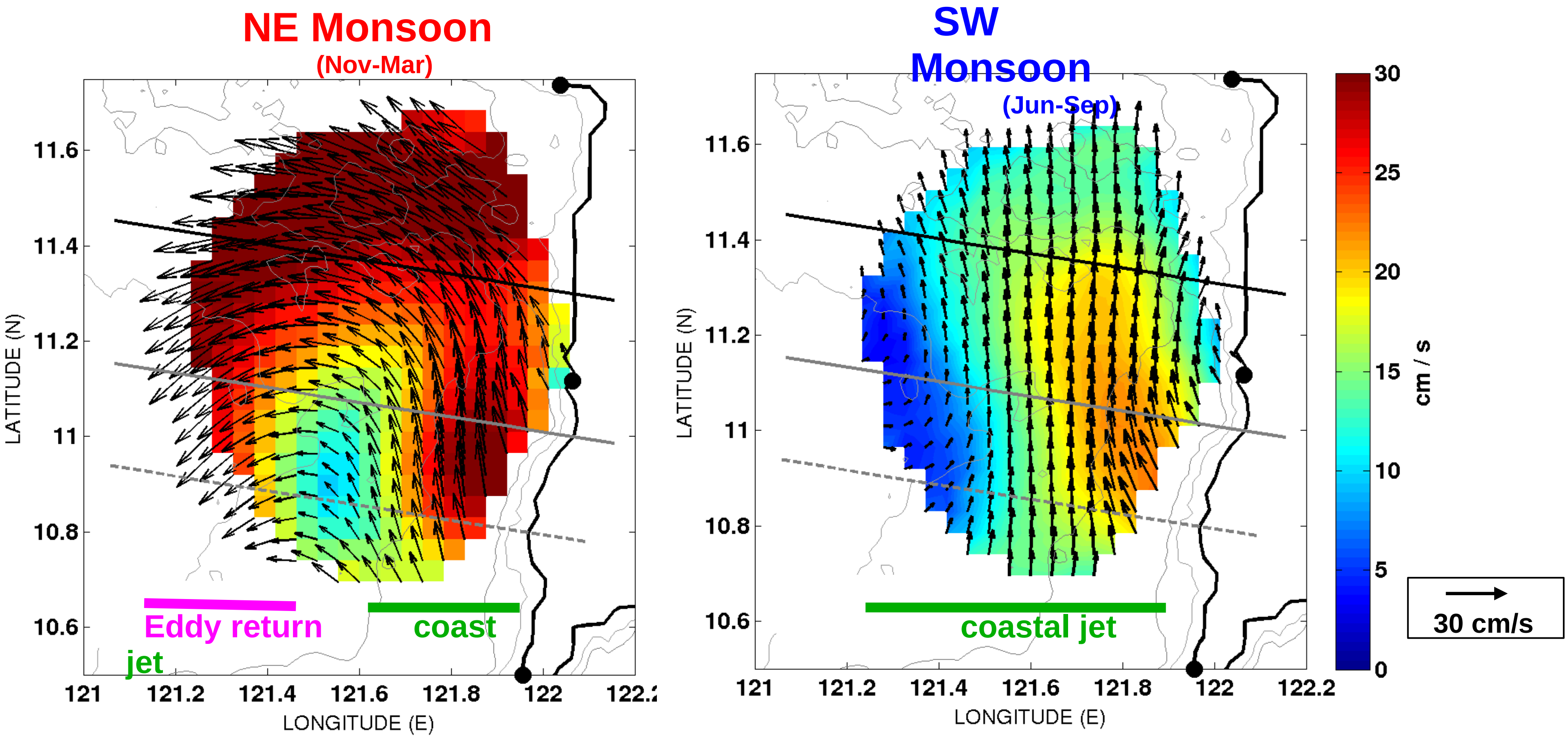


Wind direction from HF radar during passage of typhoon Nalgae





Surface flow (HFDR)



NE Monsoon

(Nov-Mar)

SW Monsoon

(Jun-Sep)

Eddy return jet

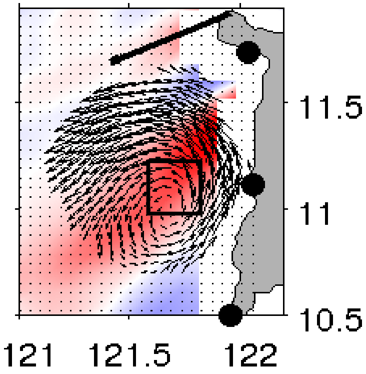
coast

coastal jet

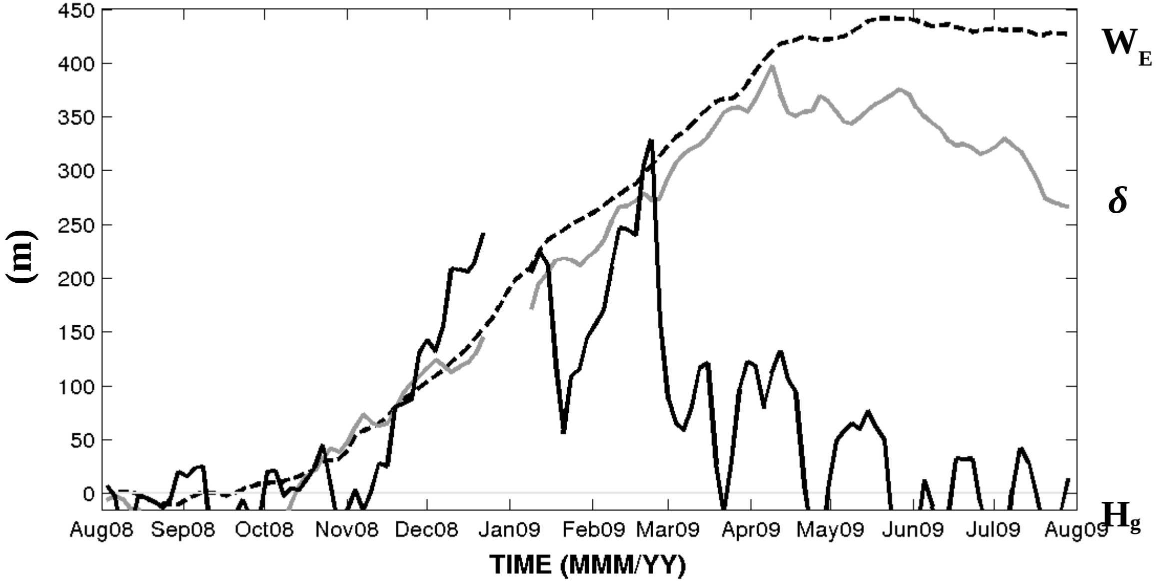
30 cm/s

- coastal jet – northward alongshore flow from the coast to the center of the eddy
- eddy – southward return flow from the center of the eddy to the west

- **Time integral**



Cumulative effect of wind stress curl generates divergence, permanently lifting the thermocline and increases vorticity



W_E - wind stress curl

δ - divergence

H_g - vorticity

- - - -	$\int_0^T W_E$	**(COAMPS)**	**W_E – Ekman pumping velocity**
▬	$H_E \int_0^T \delta$	**(HFDR)**	**H_E – Ekman depth, best fit = 32 m**
▬	H_g	**(HFDR)**	**H_g – thermocline height**

$$H_G = \frac{\zeta f L_G^2}{g'}$$

ζ - vorticity

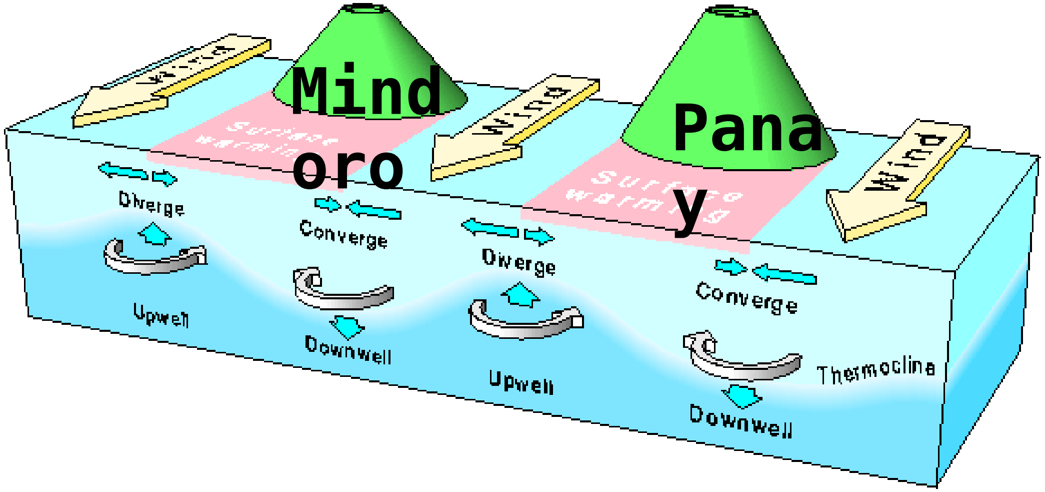
f - Coriolis parameter

L_G - radius the eddy, best fit=100km

g' - reduced gravity

Conclusions

- **Conceptual diagram showing Ekman pumping in the lee of islands**
  1. **wind intensifies between islands**
  2. **wind stress variations form positive wind stress curl in the lee of Panay**
  3. **induces divergent surface currents**
  4. **which in turn uplift thermocline**
  5. **pressure gradient spins-up eddy in geostrophic balance**

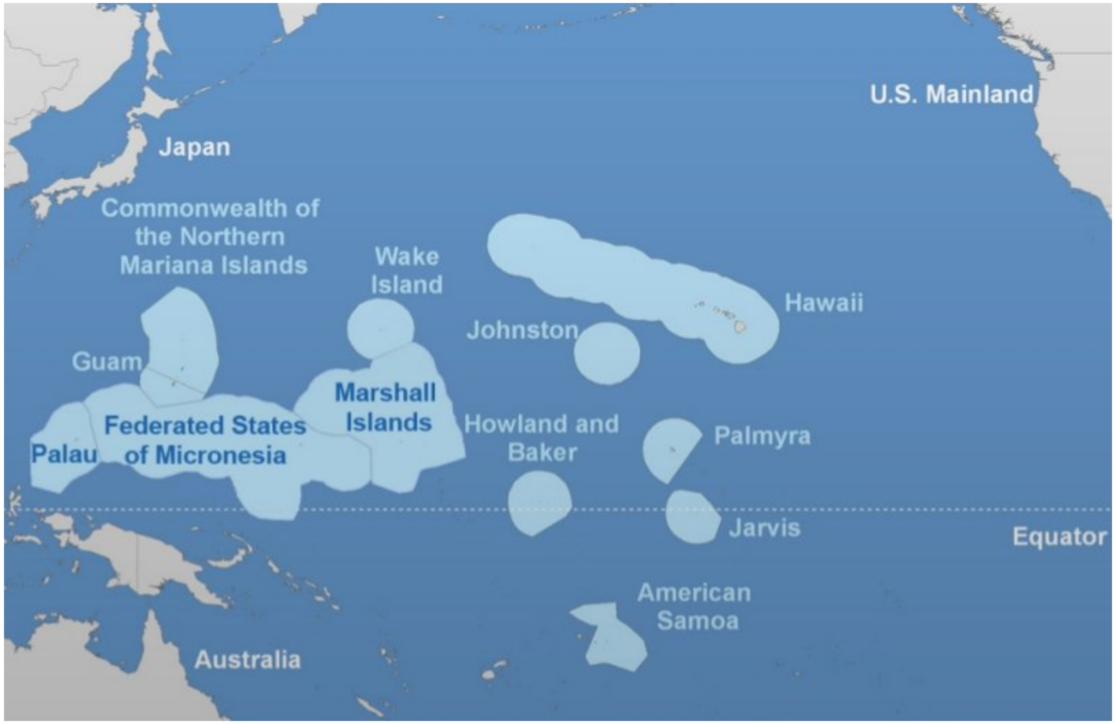


- **robust mechanism of cumulative wind stress curl to eddy kinetic energy**

3. Technology development: low-cost High Frequency Radar

DESIGN AND PRODUCTION OF A LOW-POWER LOW-COST HIGH FREQUENCY DOPPLER RADIO SCATTEROMETER FOR COASTAL ZONE OCEANOGRAPHY

Motivations: coverage of the Pacific Island Ocean Observing Syste



Needed: ~ 60 HFR, population ~ 2M, $3.6/head
Compare: US West Coast: ~ 80 HFR, population ~40M, $0.25/head

Motivations:

Notion: commodity pricing of oceanographic instrumentation (Mark Abbott, 2001); *cost of instrument << cost of staff*

Year	**150 kHz ADCP**	**1 year MSc tech**	**4-channel HFR**	**HFR/ tech**	**ADCP/ tech**
1990	150	135	200	1.50	1.10
2000	50	135	155	1.15	0.37
2010	20	135	120	0.89	0.15
1990/2010	**7.5**	**1**	**1.7**		

(USD inflation corrected using http://www.bls.gov/data/inflation_calculator.htm)

Objectives/achievements:

- simplified chirped FMCW HF radar (phased antenna array)
- open-source open-design freely available

- outsourced production (batches of 40 produced in < 6 months)
- minimized cost (non-profit non-subsidized, 60% hardware & 40% testing, support)

  $48,000 8-channels 50 W RF (MK-II rack-mounted, 2012)

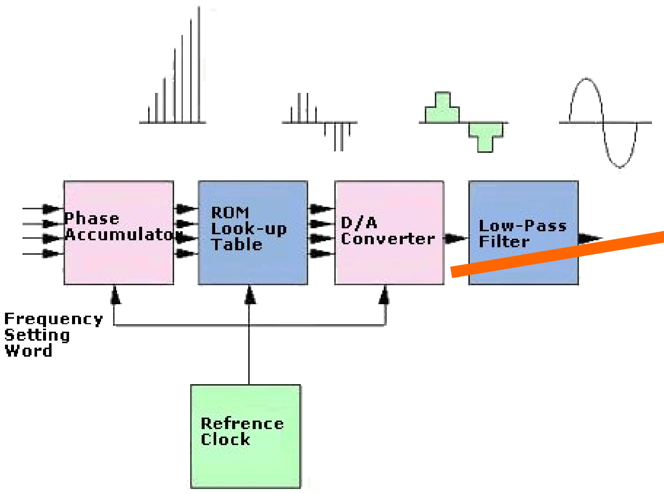
  $36,000 8-channels 50 W RF (MK-III all-in-one, 2017)
  $25,000 4-channels 10 W RF (MK-IV compact, expected 2021)

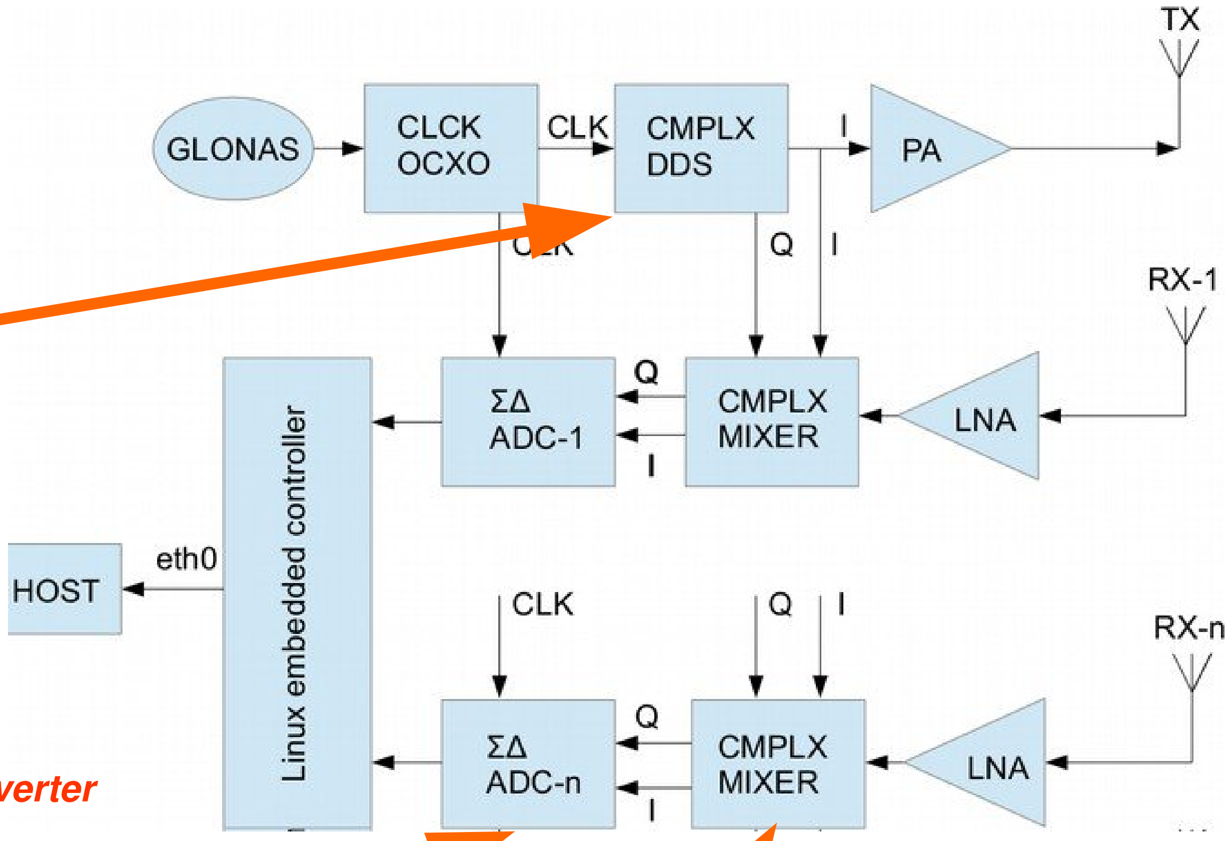
- scales to arbitrary number of channels (∞!) $36,000 for each additional 8-channels
- minimized power consumption

  300 W DC for 8-channel 50 W RF
  120 W DC for 4-channel 10 W RF

- solar/wind/fuel cell operation by default (24-48 V DC supply thorough)
- distributed through partnerships with research institutes (share of intellectual products)
- 20 MK-II built (2012): Hawaii (7), Mexico (10), France (2)
- 40 MK-IIIz built (2017): Woods Hole (6), Mexico (17), Quebec (2), Philippines (2), Taiwan (4/6), France (1)
- 60 MK-IIIb built (2021): Woods Hole (5), Taiwan (21/43)

MK-III architecture



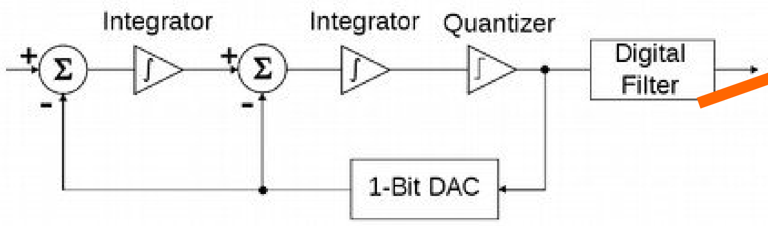


IQ Direct Digital Synthesizer

(Analog Devices AD9854)

Delta-sigma Analog-Digital converter

(Texas Instrument ADS1278)

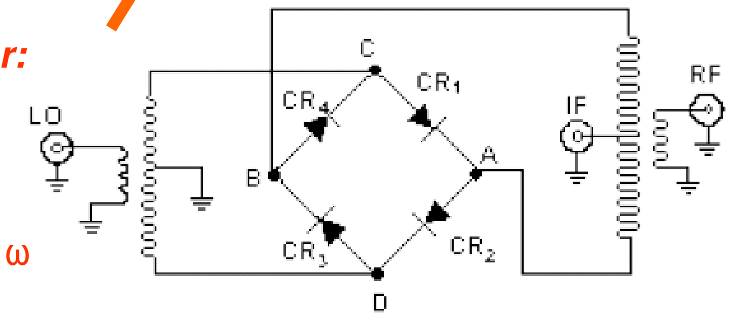


Double-Balanced Mixer/quadrature detector:

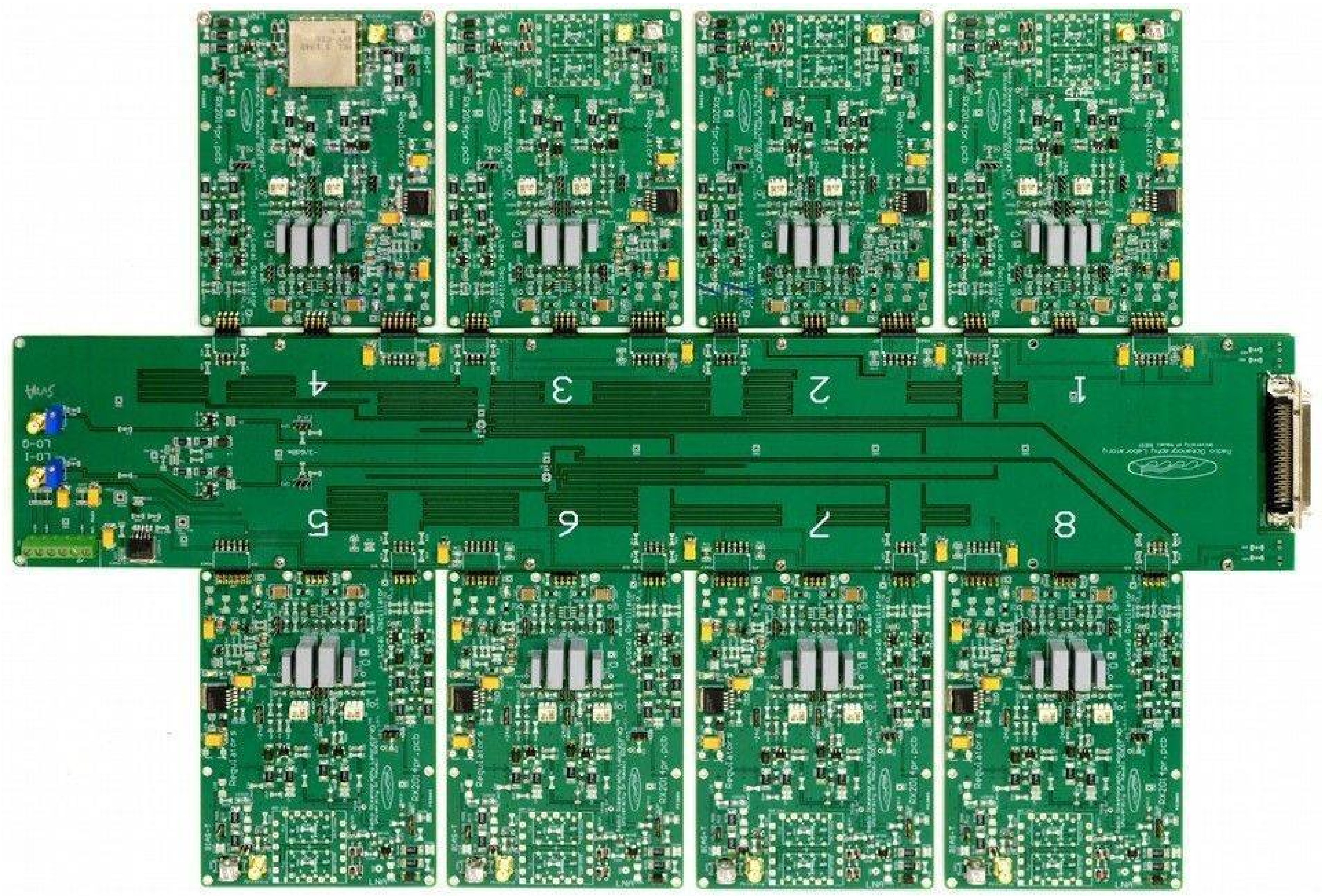
I: $2 \sin x \sin y = \cos (x-y) - \cos (x+y)$

Q: $2 \sin x \cos y = \sin (x-y) + \sin (x+y)$

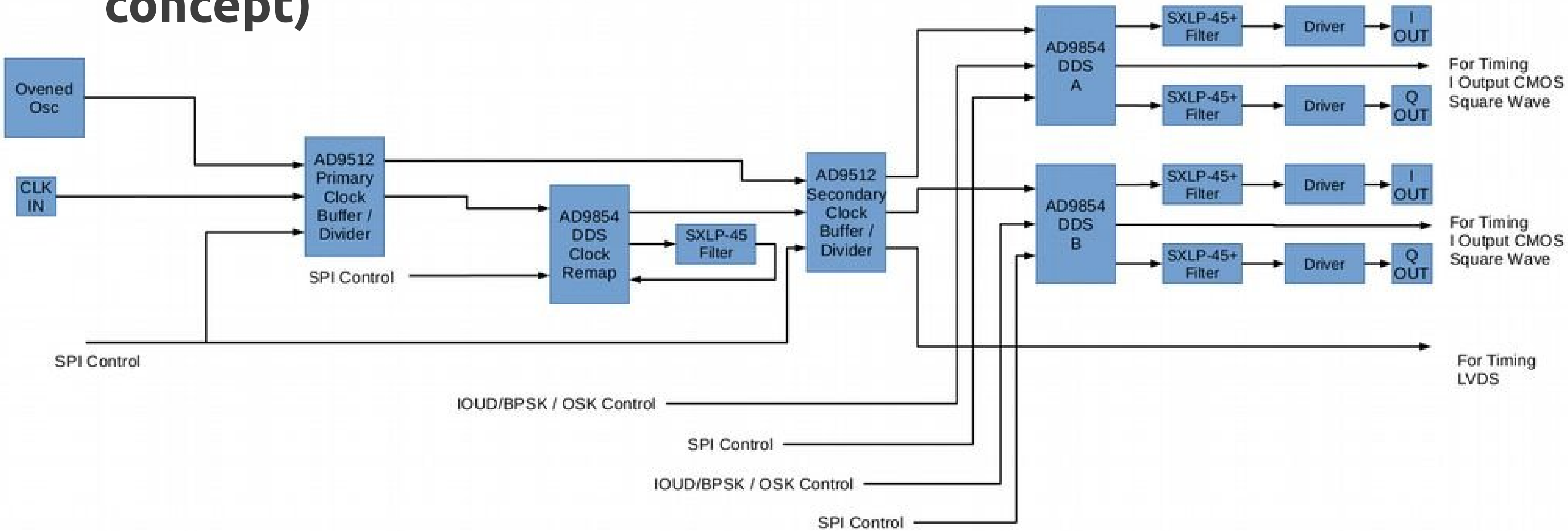
if $x = (\omega + \Delta \omega) t$ **and** $y = \omega t$ **then** $x-y = \Delta \omega t$



University of Hawaii 8-antenna complex homodyne receiver



D-Tacq Solutions radar/sonar signal generator (UH concept)



Ovened Osc

CLK IN

AD9512 Primary Clock Buffer / Divider

SPI Control

AD9854 DDS Clock Remap

SXLP-45 Filter

AD9512 Secondary Clock Buffer / Divider

AD9854 DDS A

AD9854 DDS B

SXLP-45+ Filter

Driver

I OUT

Q OUT

For Timing I Output CMOS Square Wave

For Timing LVDS

SPI Control

IOUD/BPSK / OSK Control

SPI Control

IOUD/BPSK / OSK Control

SPI Control

MK-II: 20 built (2012)

MK-III: 40 built (2017), 60 built (2021)

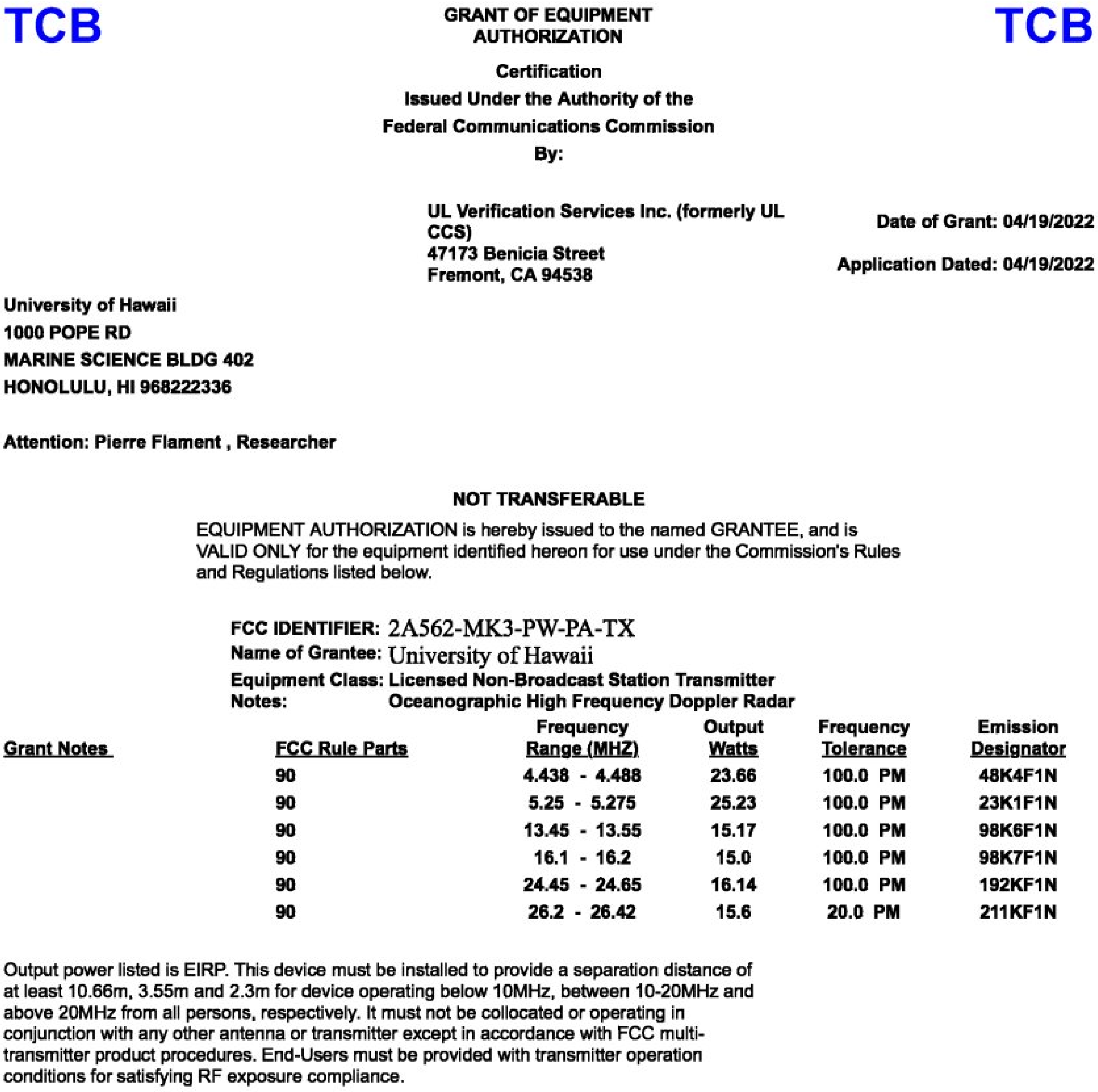
6. Antenna design

The transmit antennas are normal-mode helical monopoles (Kraus, J.D., “The Helical Antenna”, *Proc. I.R.E.* 1949 pp. 263-272). They consist of an AWG-16 vertical wire of length λ/4 wound over a mast of height λ/8 and diameter λ/300, a 3-loop tuning air-coil, and a network of 4 underground radials of length λ/4 (λ is the electromagnetic wavelength). The air-coil diameter is adjusted to achieve resonance using a standard commercial VSWR meter.

2022:

FCC Part 90

Certification approval by UL



TCB

TCB

GRANT OF EQUIPMENT AUTHORIZATION

Certification
Issued Under the Authority of the
Federal Communications Commission
By:

UL Verification Services Inc. (formerly UL CCS)
47173 Benicia Street
Fremont, CA 94538

Date of Grant: 04/19/2022

Application Dated: 04/19/2022

University of Hawaii
1000 POPE RD
MARINE SCIENCE BLDG 402
HONOLULU, HI 968222336

Attention: Pierre Flament , Researcher

NOT TRANSFERABLE

EQUIPMENT AUTHORIZATION is hereby issued to the named GRANTEE, and is VALID ONLY for the equipment identified hereon for use under the Commission's Rules and Regulations listed below.

FCC IDENTIFIER: 2A562-MK3-PW-PA-TX
Name of Grantee: University of Hawaii
Equipment Class: Licensed Non-Broadcast Station Transmitter
Notes: Oceanographic High Frequency Doppler Radar

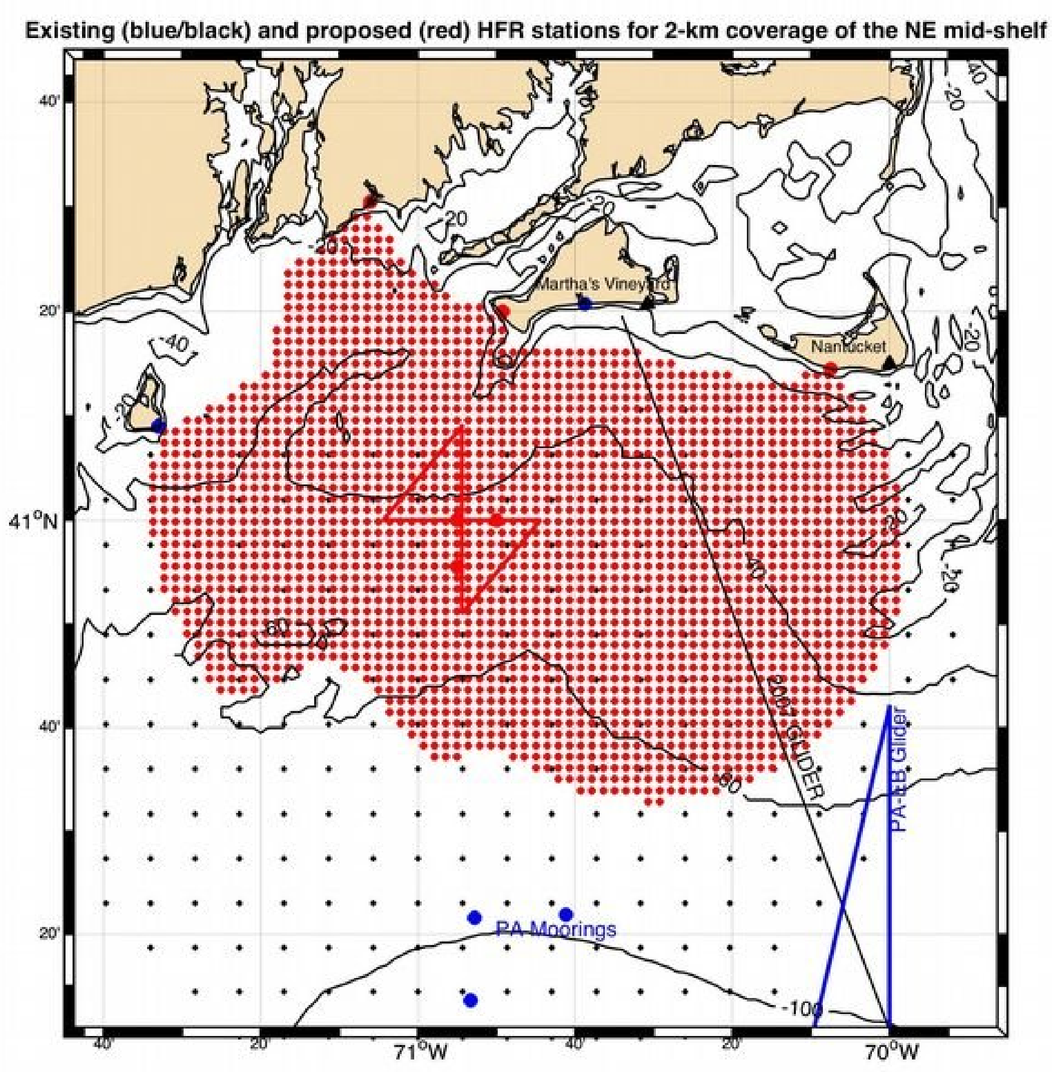
Grant Notes	FCC Rule Parts	Frequency Range (MHZ)	Output Watts	Frequency Tolerance	Emission Designator
	90	4.438 - 4.488	23.66	100.0 PM	48K4F1N
	90	5.25 - 5.275	25.23	100.0 PM	23K1F1N
	90	13.45 - 13.55	15.17	100.0 PM	98K6F1N
	90	16.1 - 16.2	15.0	100.0 PM	98K7F1N
	90	24.45 - 24.65	16.14	100.0 PM	192KF1N
	90	26.2 - 26.42	15.6	20.0 PM	211KF1N

Output power listed is EIRP. This device must be installed to provide a separation distance of at least 10.66m, 3.55m and 2.3m for device operating below 10MHz, between 10-20MHz and above 20MHz from all persons, respectively. It must not be collocated or operating in conjunction with any other antenna or transmitter except in accordance with FCC multi-transmitter product procedures. End-Users must be provided with transmitter operation conditions for satisfying RF exposure compliance.

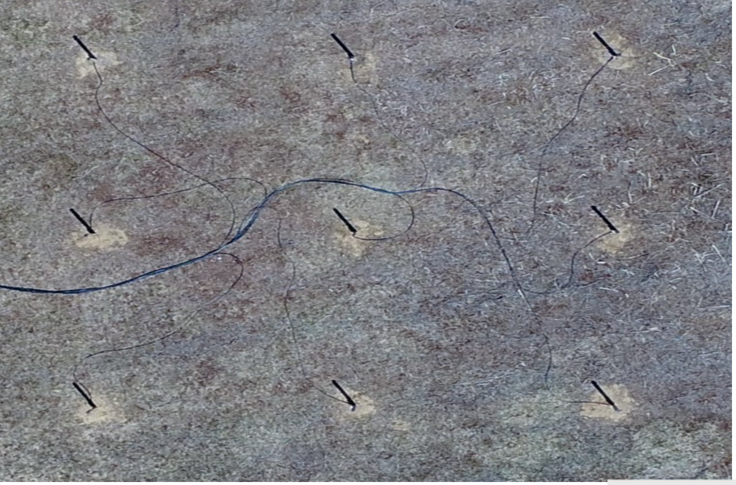
Submesoscale Dynamics over the Continental Shelf: Drivers and Implications for Across-Shelf Exchange

4 radars, 16 MHz

collaboration between U. Hawaii, Woods Hole and US Coast Guard



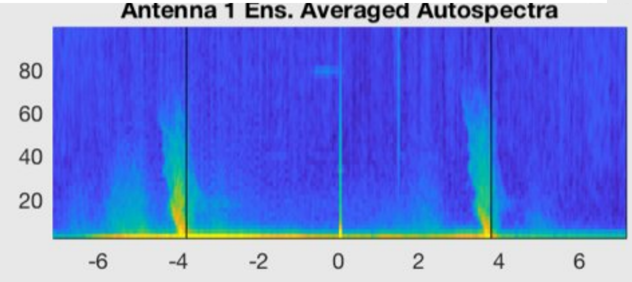
Existing (blue/black) and proposed (red) HFR stations for 2-km coverage of the NE mid-shelf

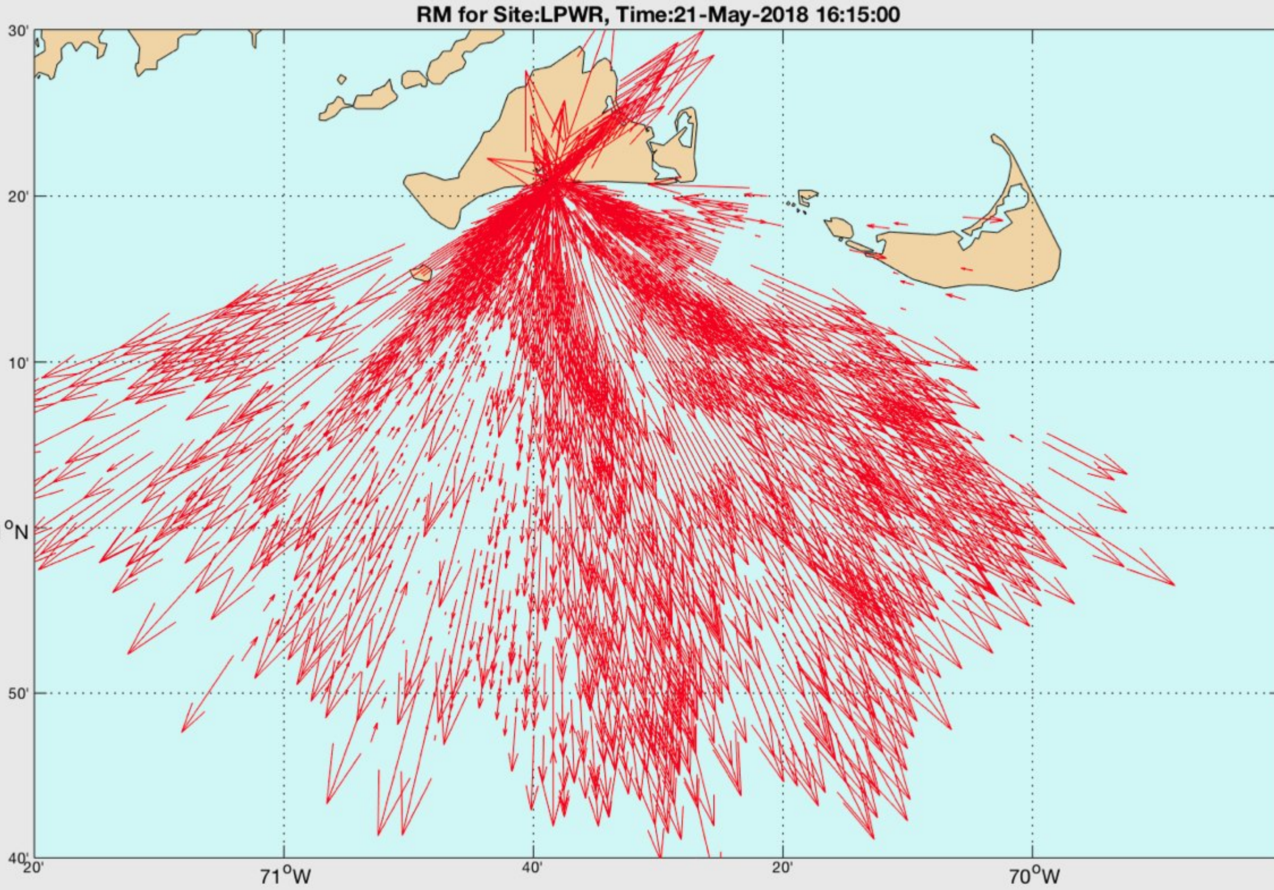


Woods Hole:

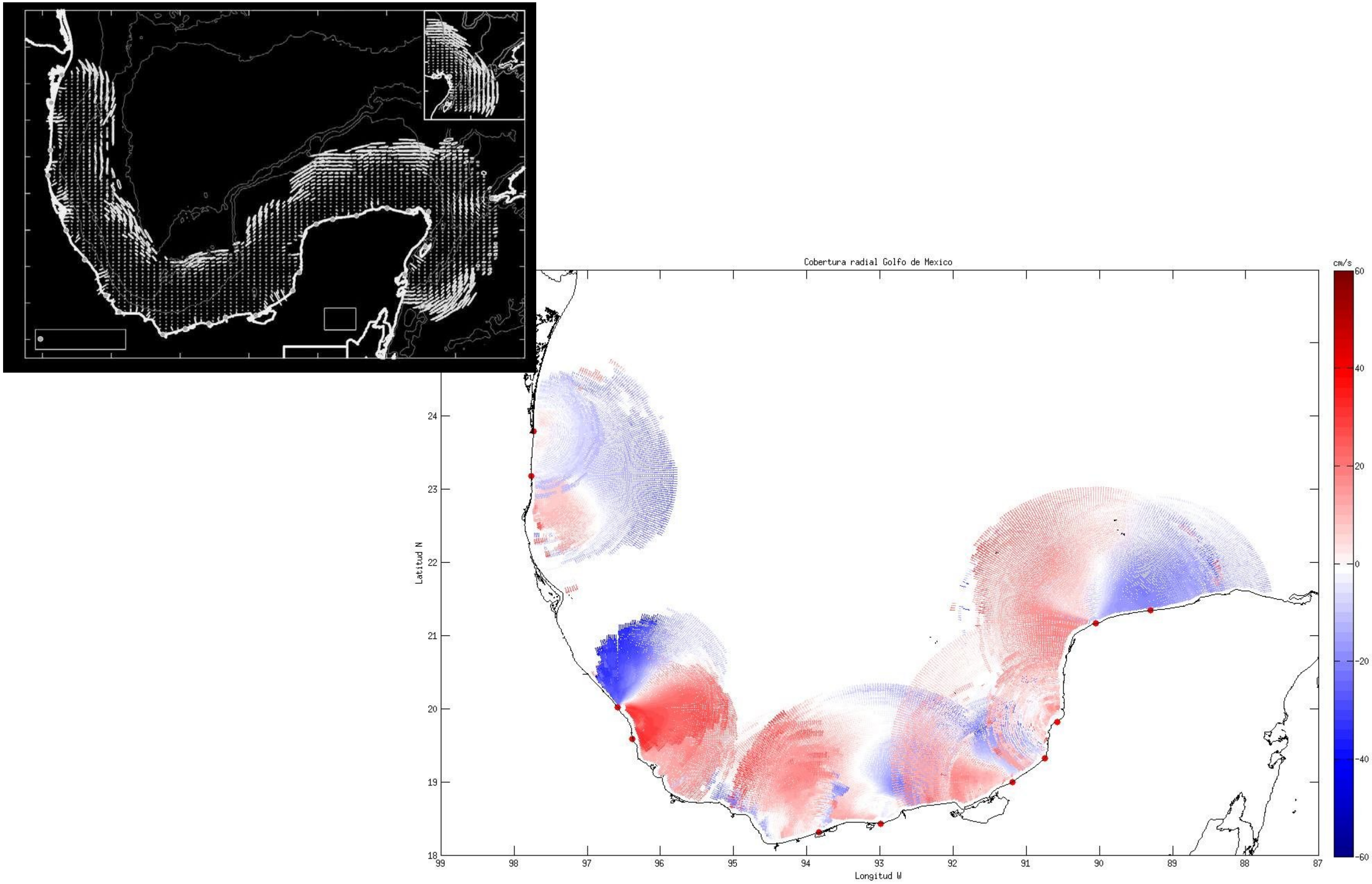
- **Martha's Vineyard**
- **Nantucket**

16.15 MHz, 15 W, 100 KHz
80 km range
(3^2-1) RX clusters

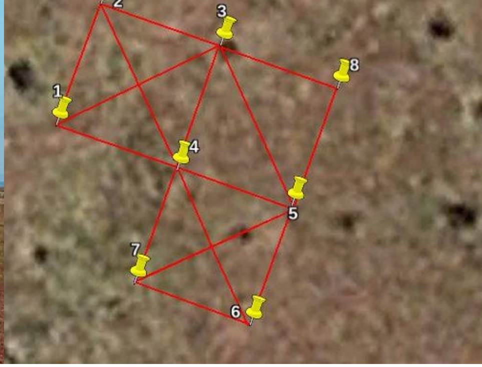




HF radar network for the Gulf of Mexico 15 radars, 6-8 MHz



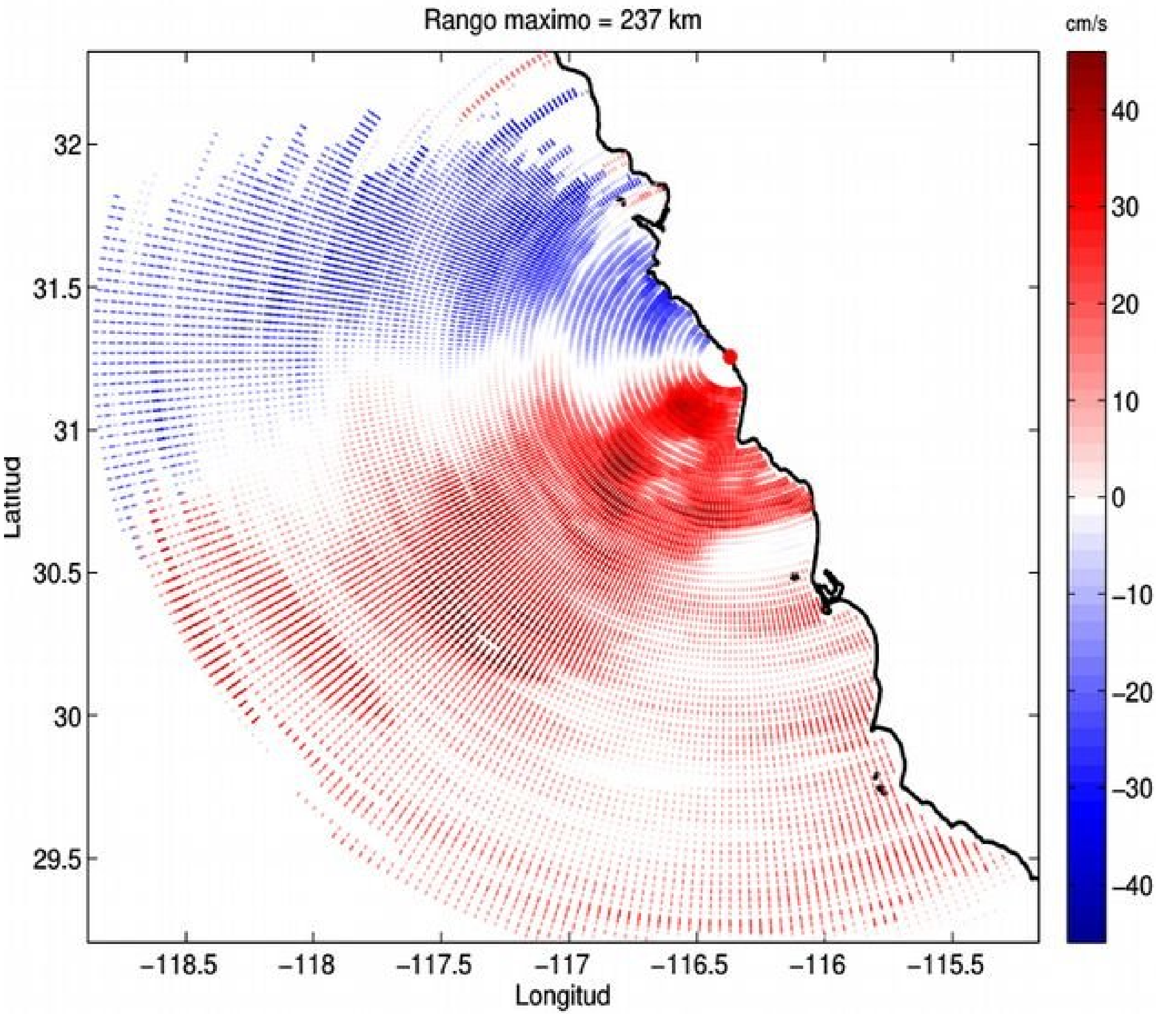
From: Hacia la creación de una red multinstitucional de radares oceanográficos para la medición de corrientes superficiales en el Golfo de México, Xavier Flores-Vidal, Pierre Flament et al., *Revista de la Universidad Juàrez Autónoma de Tabasco*, 2015



Baja California:

- Erendira
- San Quintin

8.25 MHz, 35 W, 50 Khz
240 km range
(3^2-1) direction finding cluster



A Surface Current Observing System for the Marianas

a collaboration between

University of Hawaiʻi, HI
University of Guam, GU
Northern Marianas College, CNMI (?)
Woods Hole Oceanographic Institution, MA

in the framework of the

Pacific Island Ocean Observing System (PacIOOS)

Pierre Flament, Johanna Saavedra,
University of Hawaiʻi at Manoa, School of Ocean and Earth Sciences and Technology

Atsushi Fujimura, University of Guam Marine Laboratory

tbd, Northern Marianas College, Department of Science

Anthony Kirincich, Ian Fernandez, WHOI, Department of Physical Oceanography

Objective:

Implement a permanent real-time surface current mapping of the Southern Marianas strait, combining High Frequency radar and numerical model assimilation

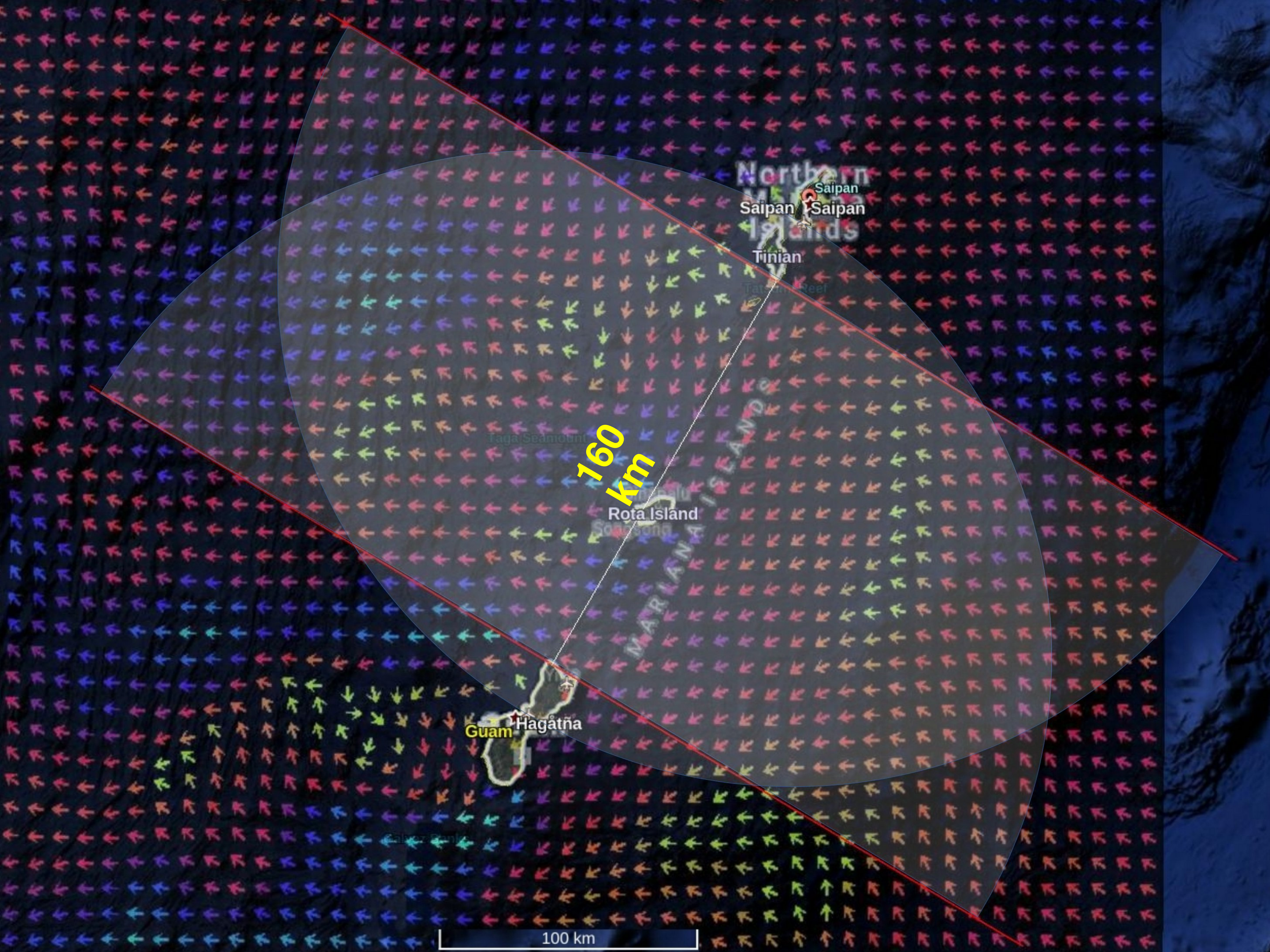
Complex physical environment, with a range of interacting processes:

- north equatorial current meandering and shedding eddies

- abrupt topography of trench coupling with barotropic and internal tides

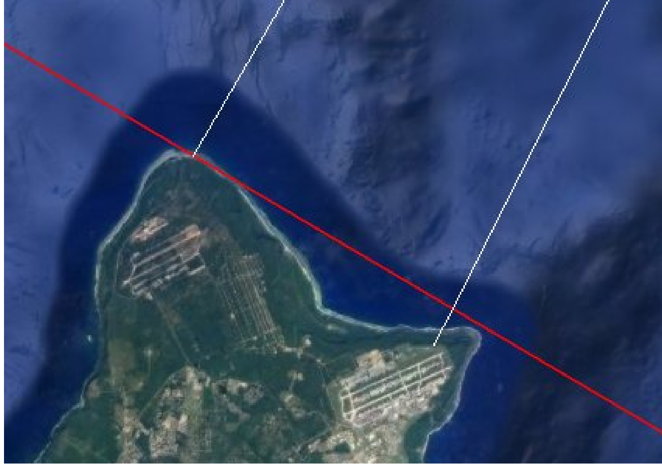
- strong atmospheric forcing through trades-monsoon-topography interactions

- intense sub-mesoscale activity associated with island-current interactions


Northern Mariana Islands
Saipan
Saipan
Saipan
Tinian
Tatsumi Reef
160 km
Taga Seamount
Rota Island
Songsong
MARIANA ISLANDS
Guam
Hagåtña
100 km

Site selection: Guam

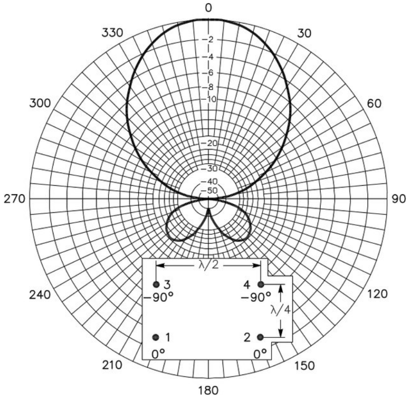
- unlikely: Pati point on N edge of Anderson AFB
- most practical: Ritidian point
- require 1 km between TX and RX



- antennas can be hidden in vegetation and do not require flat ground (here: TX in Panay, Philippines)

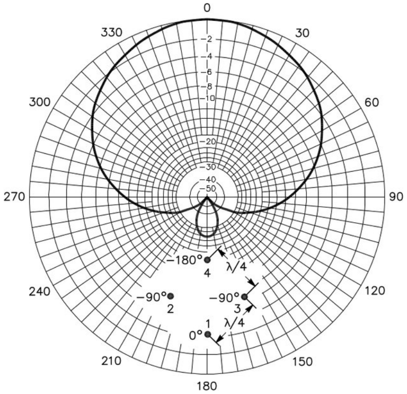
Guam-Ritidian, opt. 1

- both RX and TX in bushes near shoreline
- use rectangle configuration
- close location of TX and RX simplifies maintenance
- relative position of TX and RX is immaterial
- clarify respective control between USFW, USAF and local owner



Guam-Ritidian opt. 2

- only TX near shoreline
- use square configuration
- TX on USFWS/DoI land
- RX cliff-top, AAFB “North field”
- RX on USAF/DoD land
- best direct path rejection
- broader beam
- better azimuth coverage



Site selection: Tinian – NEED TO VISIT

Path forward

1. frequency allocation: apply for FCC permit

2. land use: apply for right-of-use and access
    - USFWS/DoI
    - USAF/DoD
    - local land owners
    - CNMI

3. construction: initiate procurement of missing components

4. explore telemetry options

The good news:

1. all radio components already procured through RCUH
   (recharge account)

2. all processing and upload to HFRNet will be done by WHOI
   (subcontract)

3. R&D effort for power plant shared with international partners