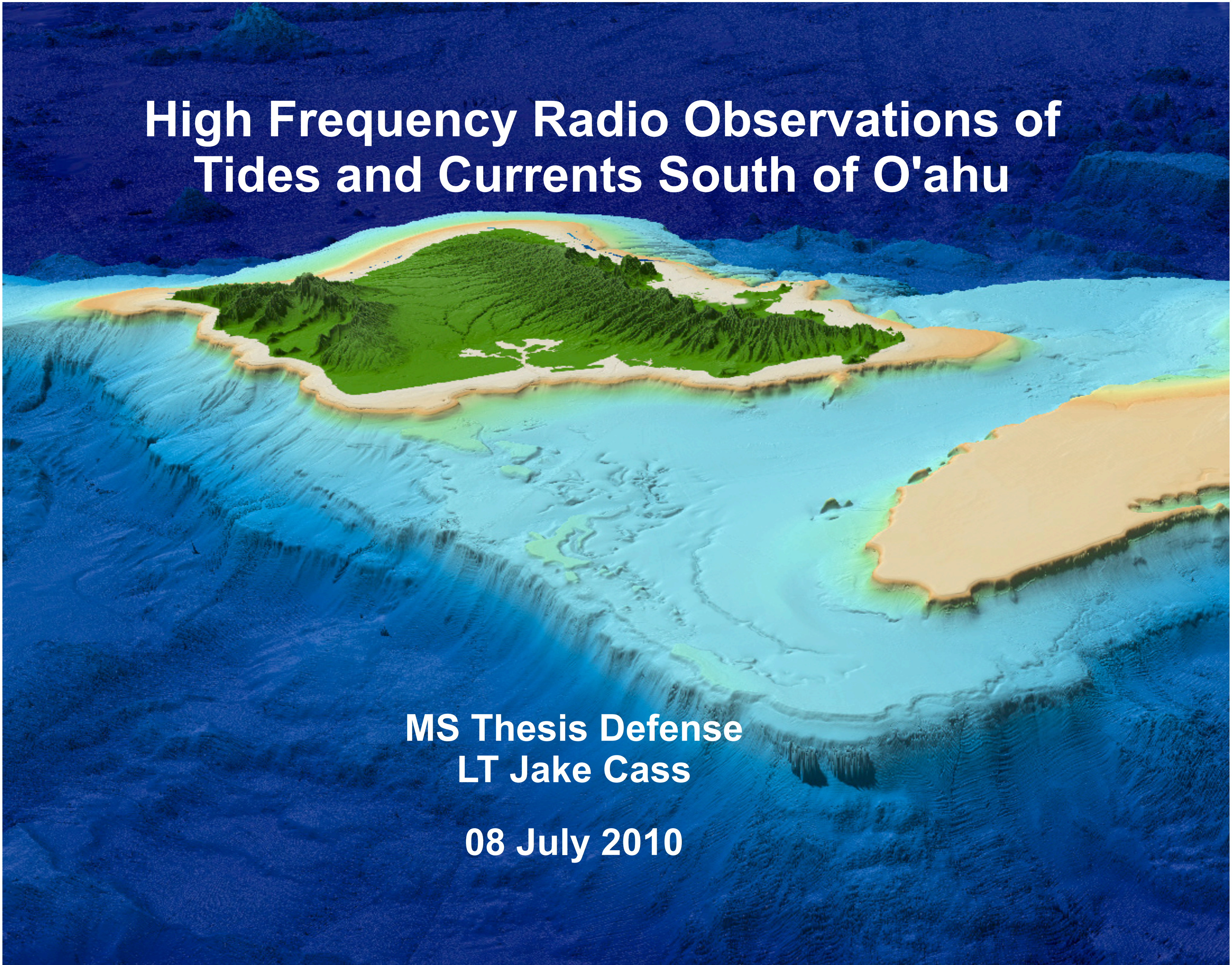


High Frequency Radio Observations of Tides and Currents South of O'ahu

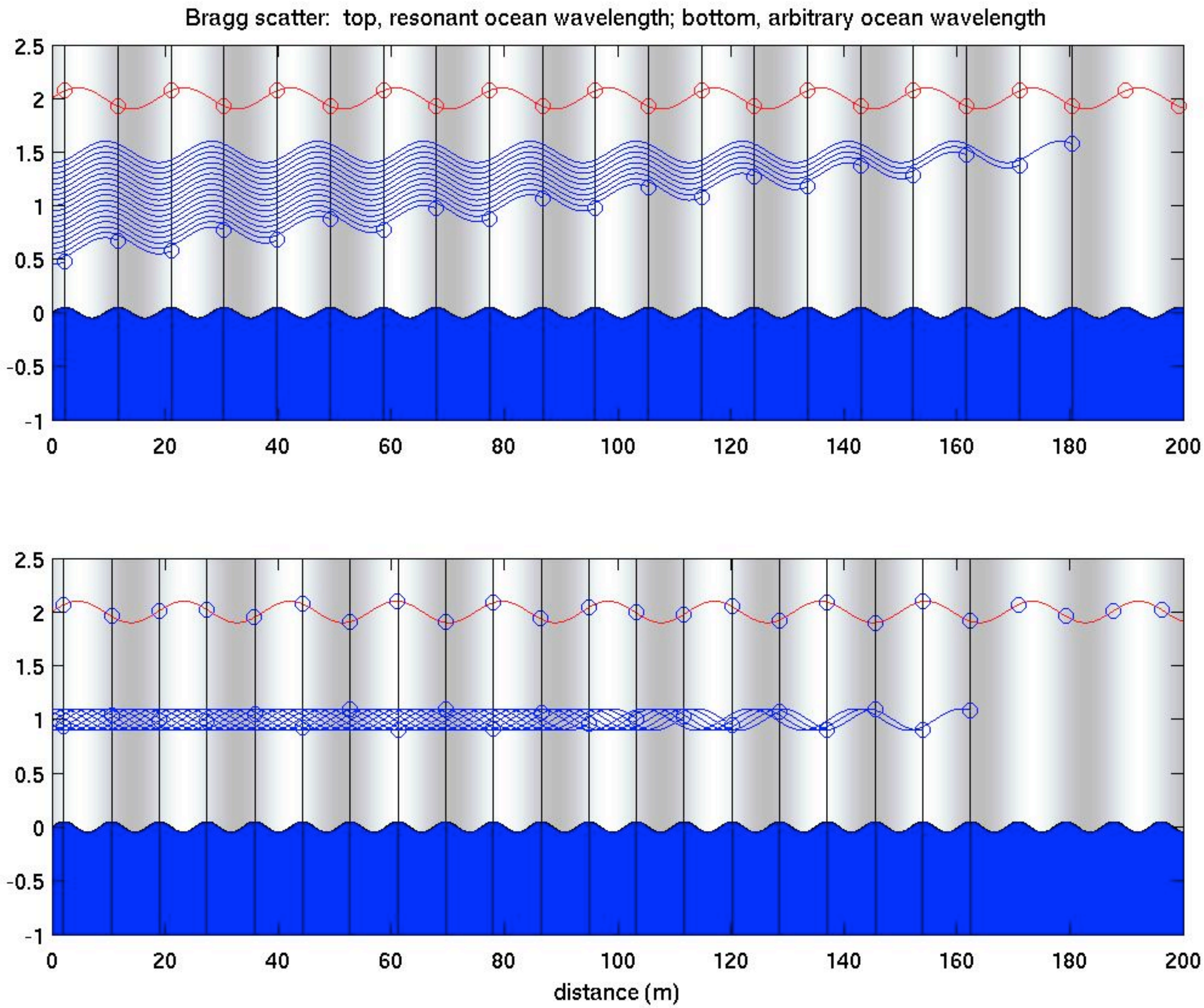
MS Thesis Defense
LT Jake Cass

08 July 2010

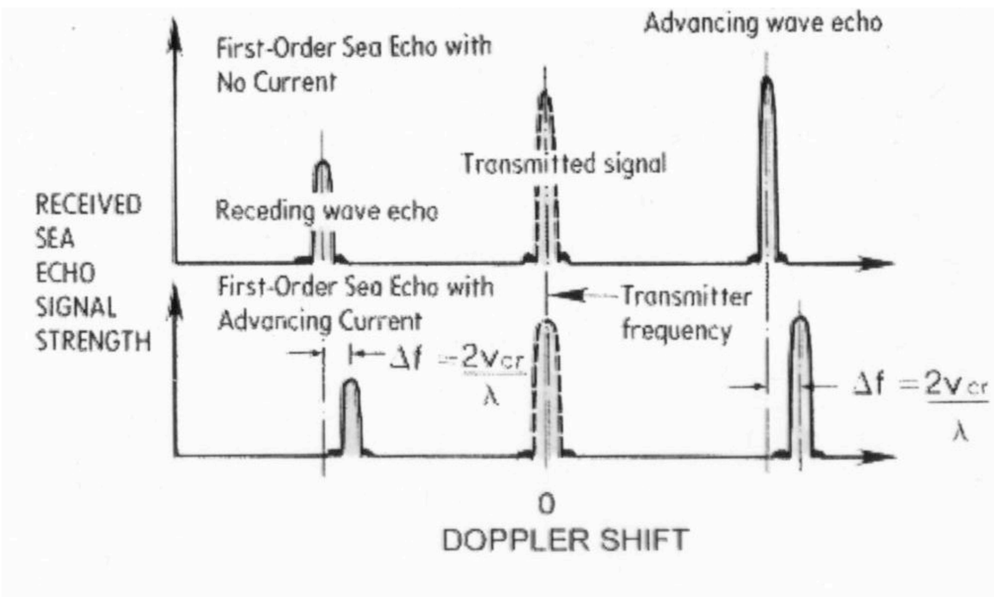
Outline

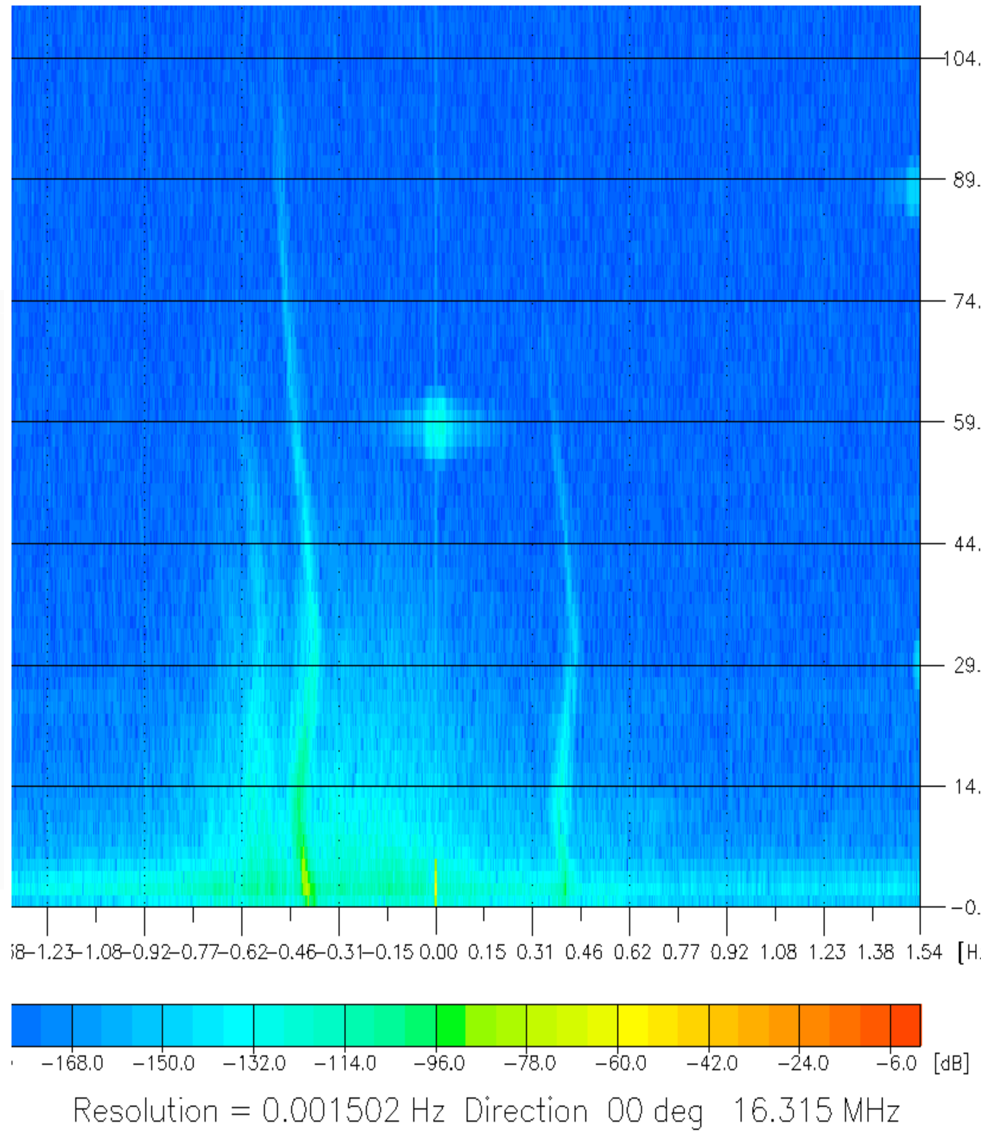
- HFR operating principles
- Site description and quality assessment
- Spectral tour of observations
  - Low frequency currents
  - Near inertial currents - island trapped waves?
  - Tides and comparison with existing models
  - Samoan and Chilean tsunami
- Conclusions
- Questions

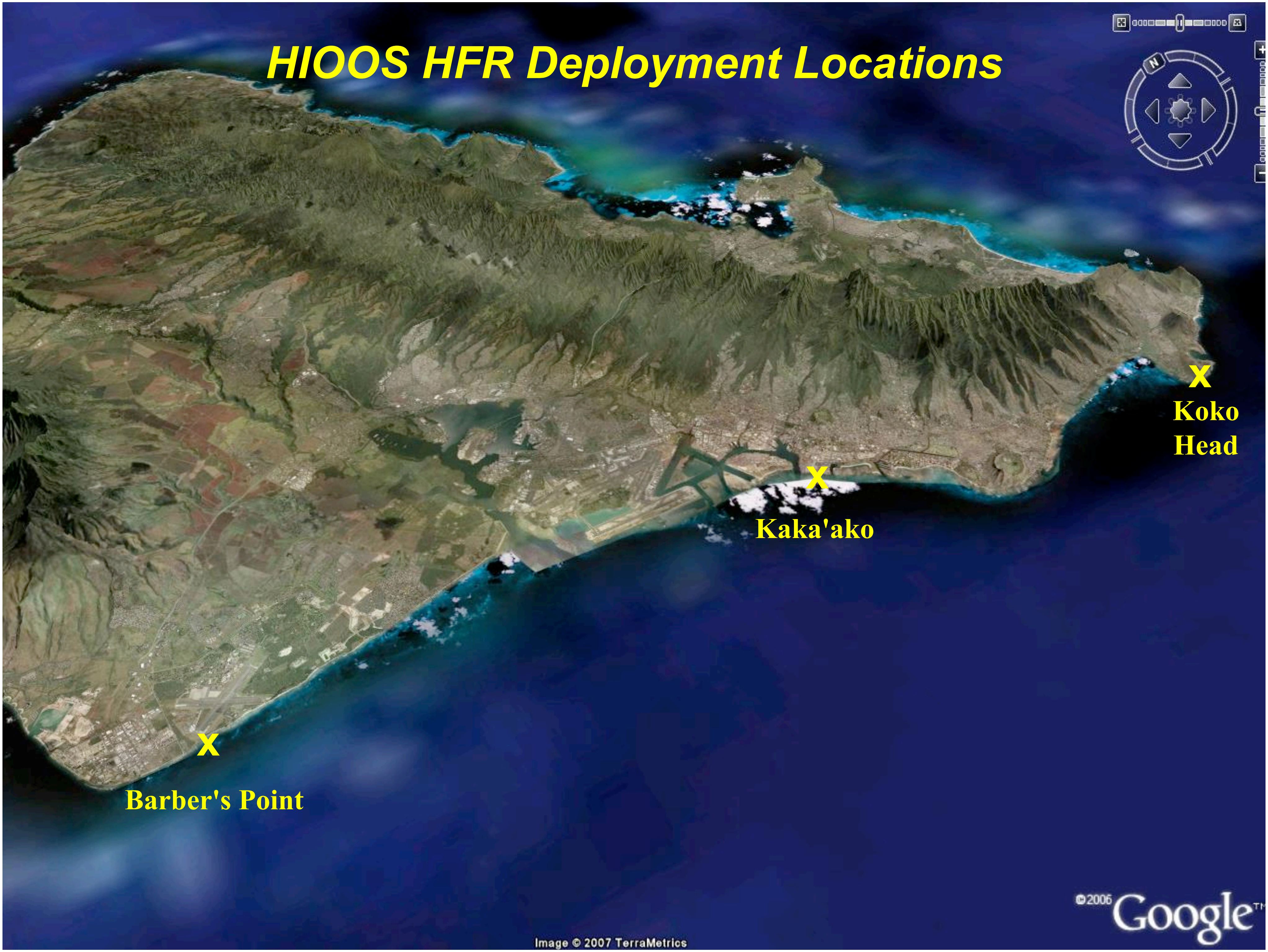
Operating Principle



Backscattered signal is doppler shifted by wave speed and radial current

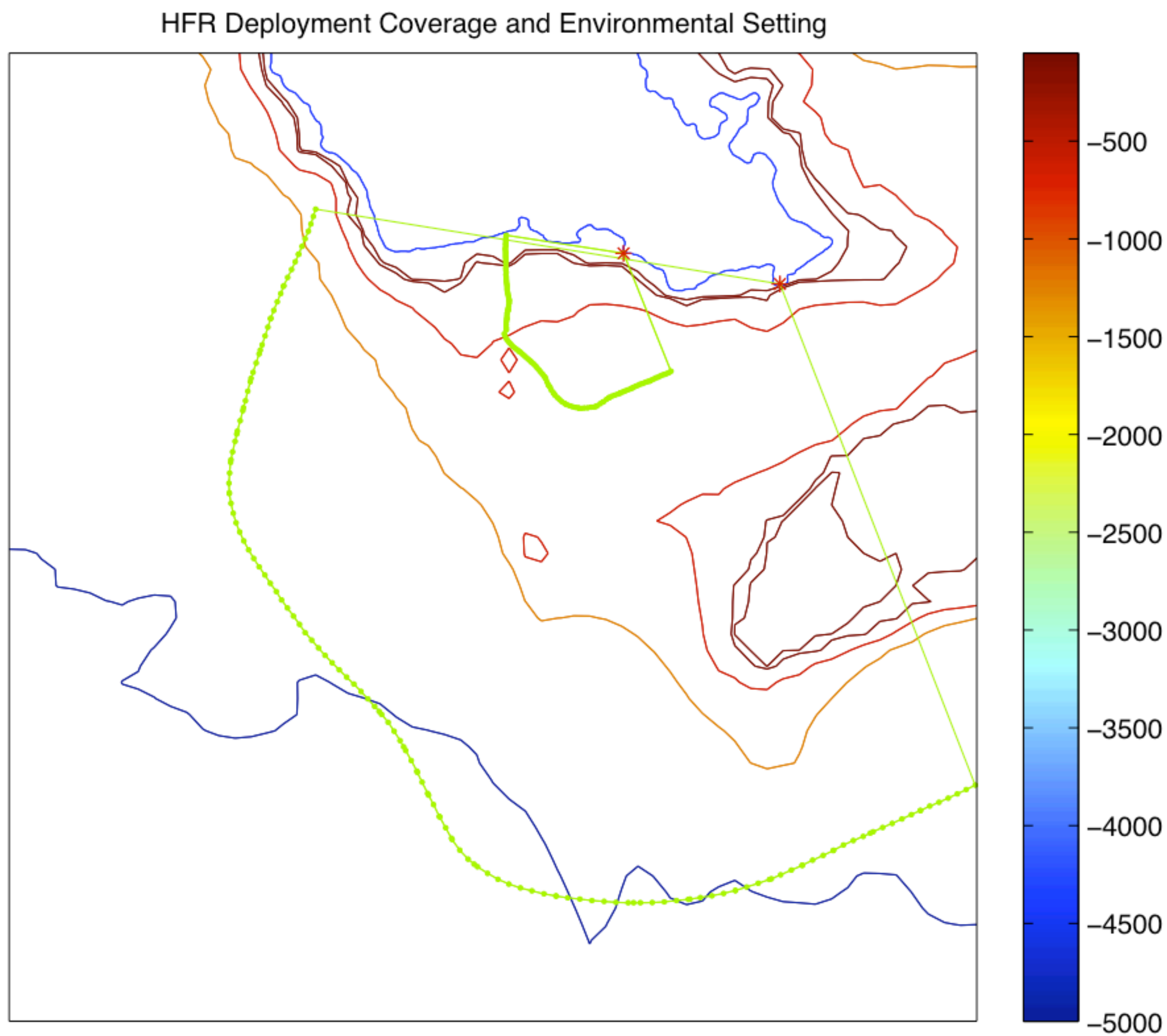





HIOOS HFR Deployment Locations
Koko Head
Kaka'ako
Barber's Point
Image © 2007 TerraMetrics
©2006 Google

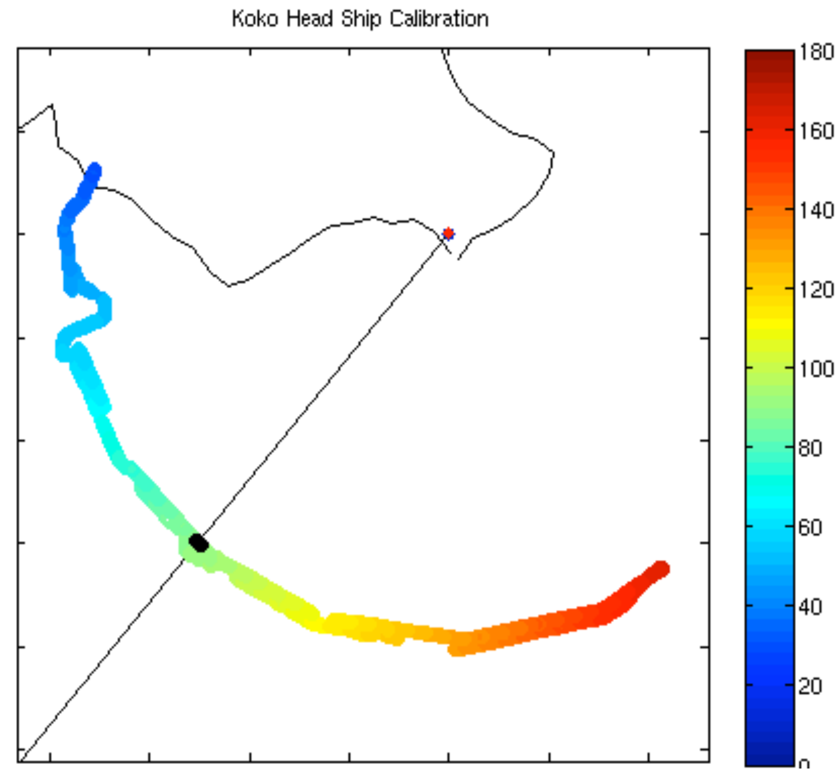
Koko Head (14)
Frequency - 16.315 MHz
Working Range - >90 km
Bragg Wavelength - 9.1875 m
Range Resolution -1.5 km
Velocity Resolution - 2.55 cm/s
Azimuthal Resolution ~ 8°

Kaka'ako Park (5)
Frequency - 27.3 MHz
Working Range - ~30 km
Bragg Wavelength - 5.49 m
Range Resolution -0.6 km
Velocity Resolution - 1.5 cm/s
Azimuthal Resolution ~ 10°



HFR Deployment Coverage and Environmental Setting
−500
−1000
−1500
−2000
−2500
−3000
−3500
−4000
−4500
−5000

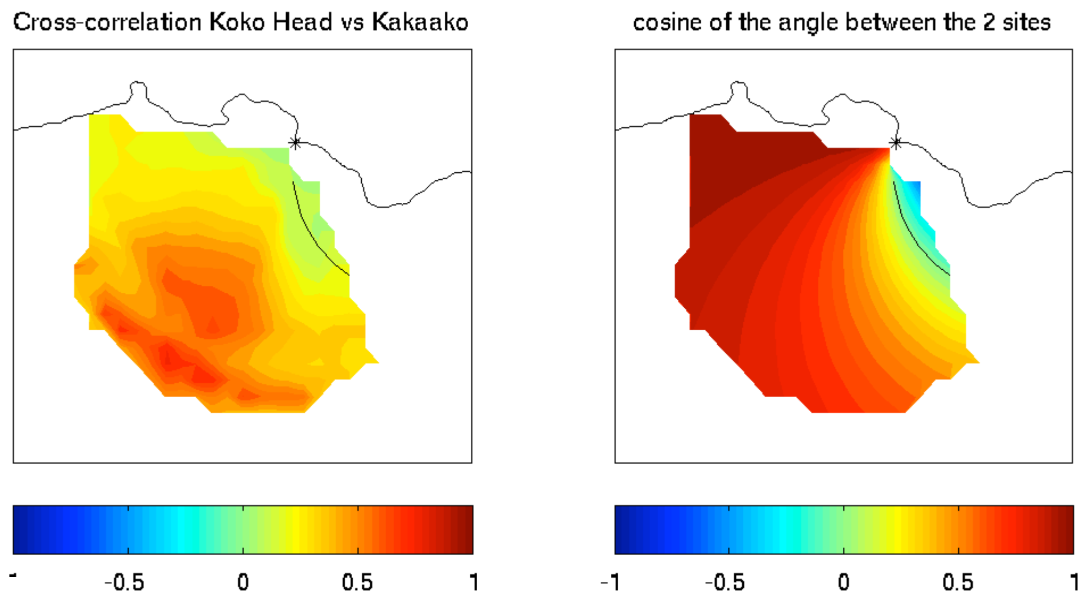
Quality Assessment – Shipboard Beamforming Calibration



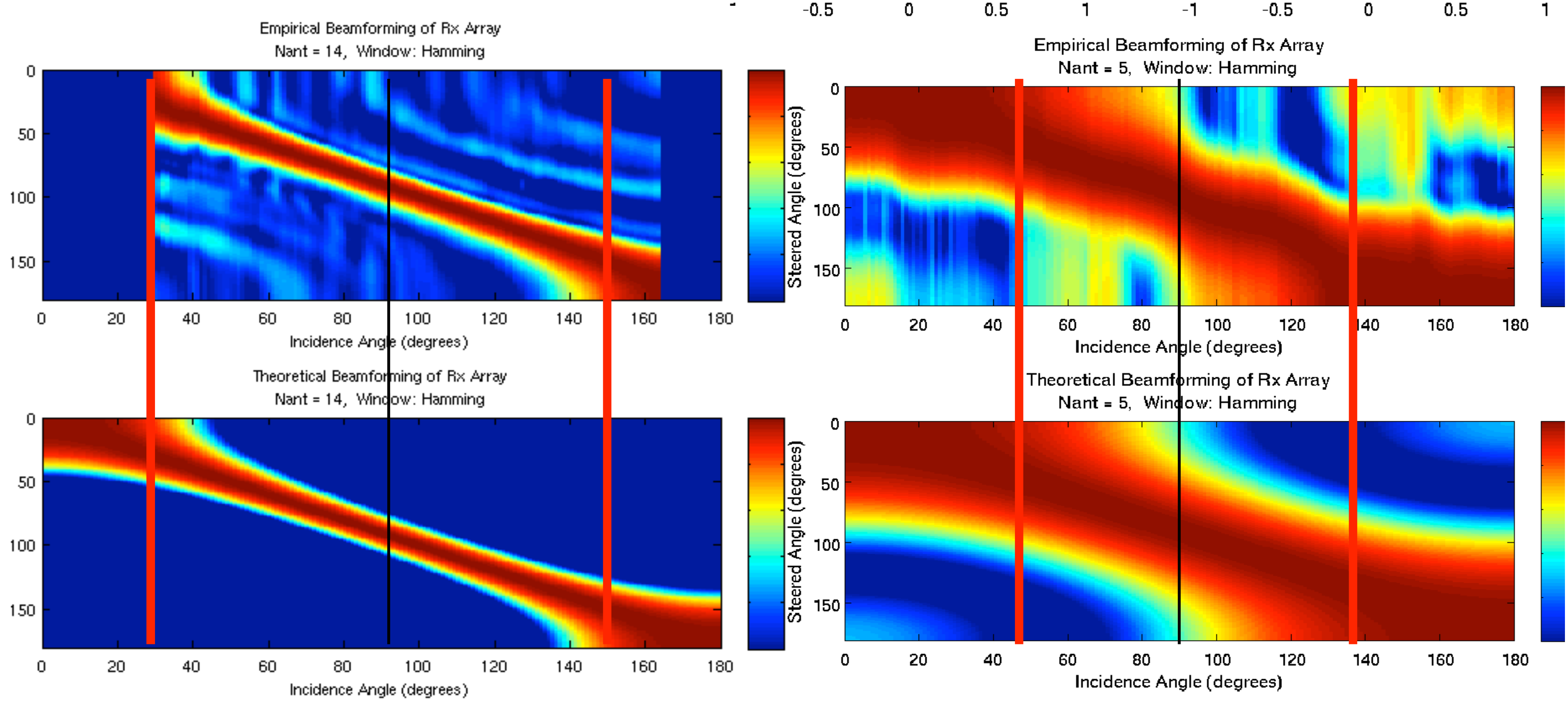
Beamforming analysis by Tyson Hilmer

Quality Assessment

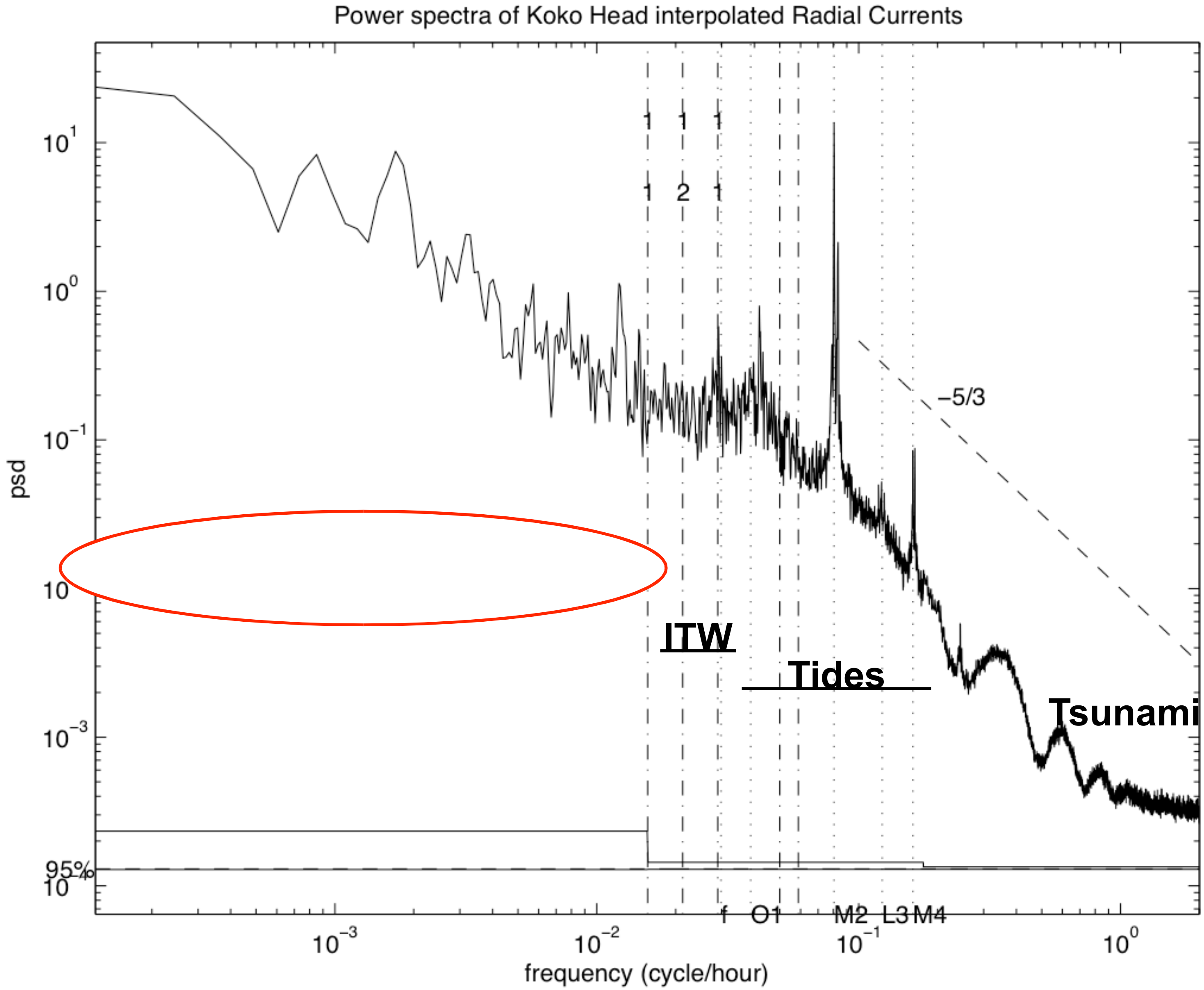
– Cross Correlation between sites



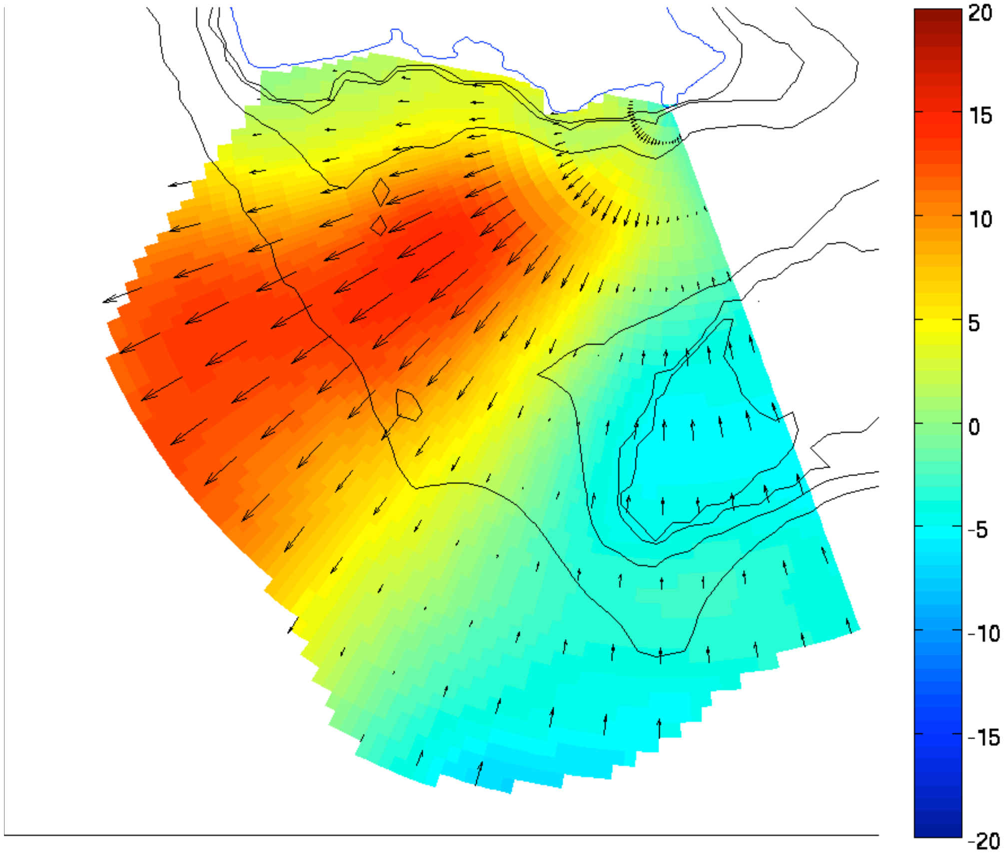
– Observed and Theoretical Beam Forming during ship calibration (by Tyson Hilmer)

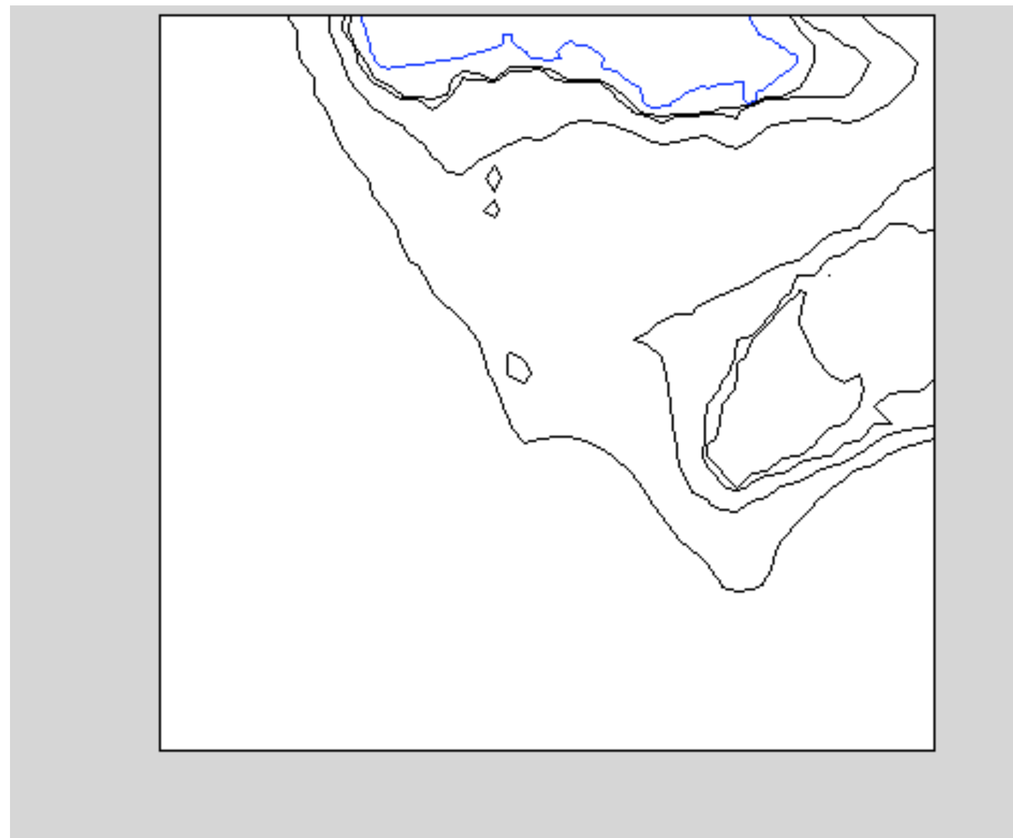


Spectral tour of observations

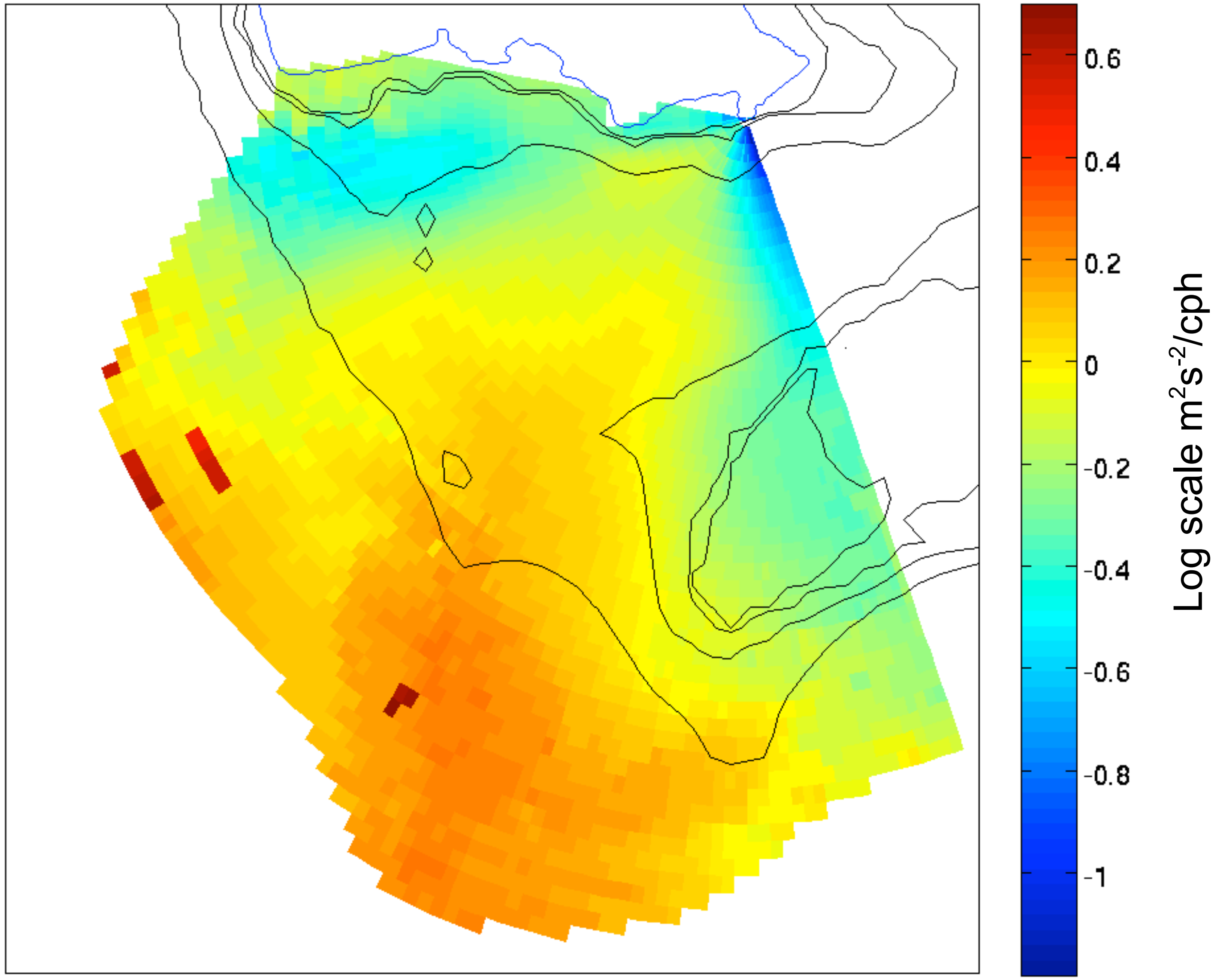


Low Frequency - Radial Currents (cm/s)



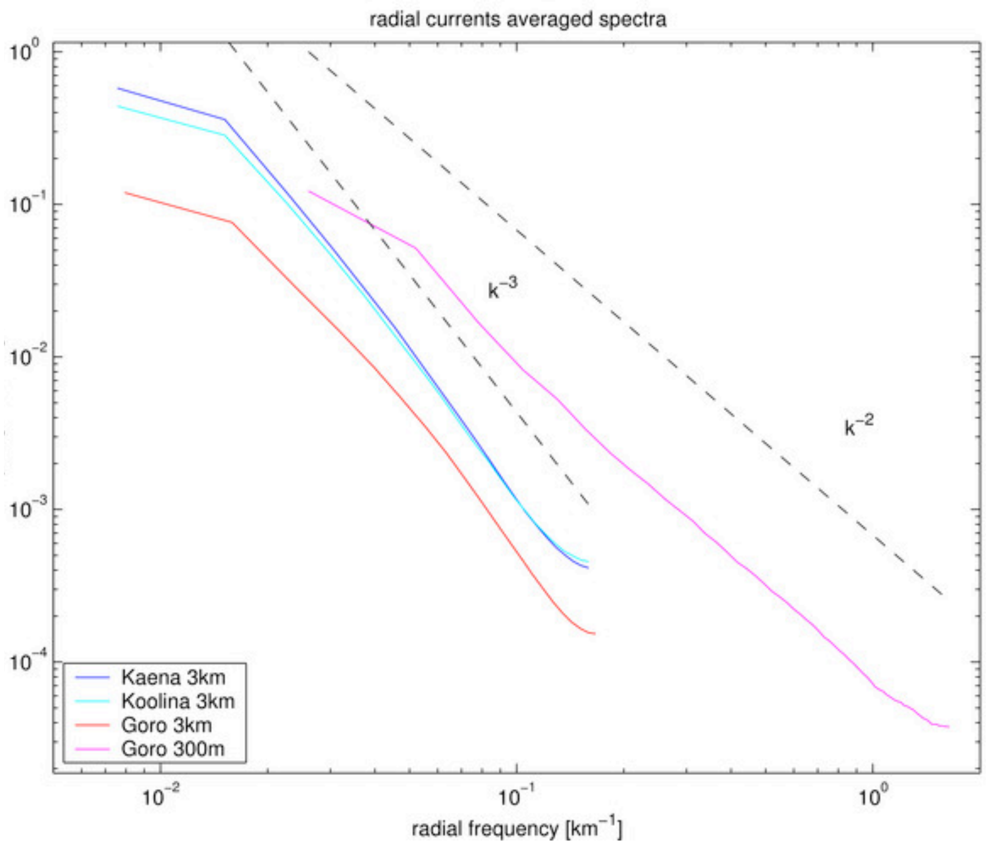


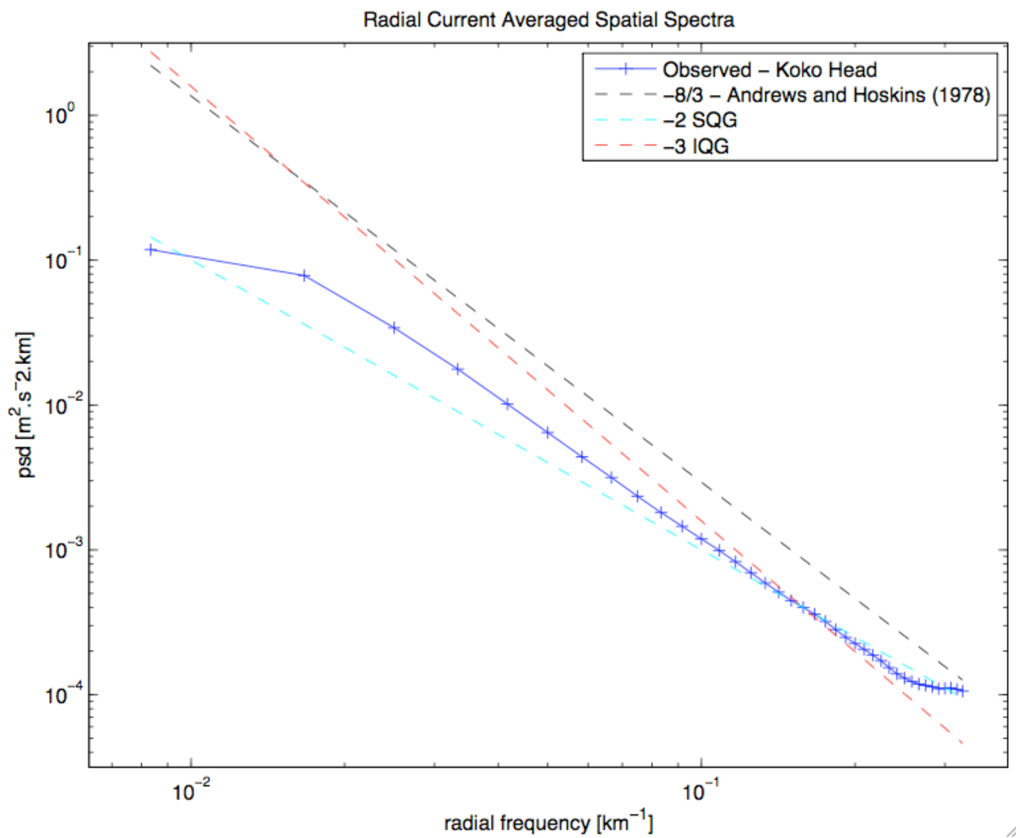
Mesoscale Eddy Energy



frequency band
[1/90 day:1/7day]

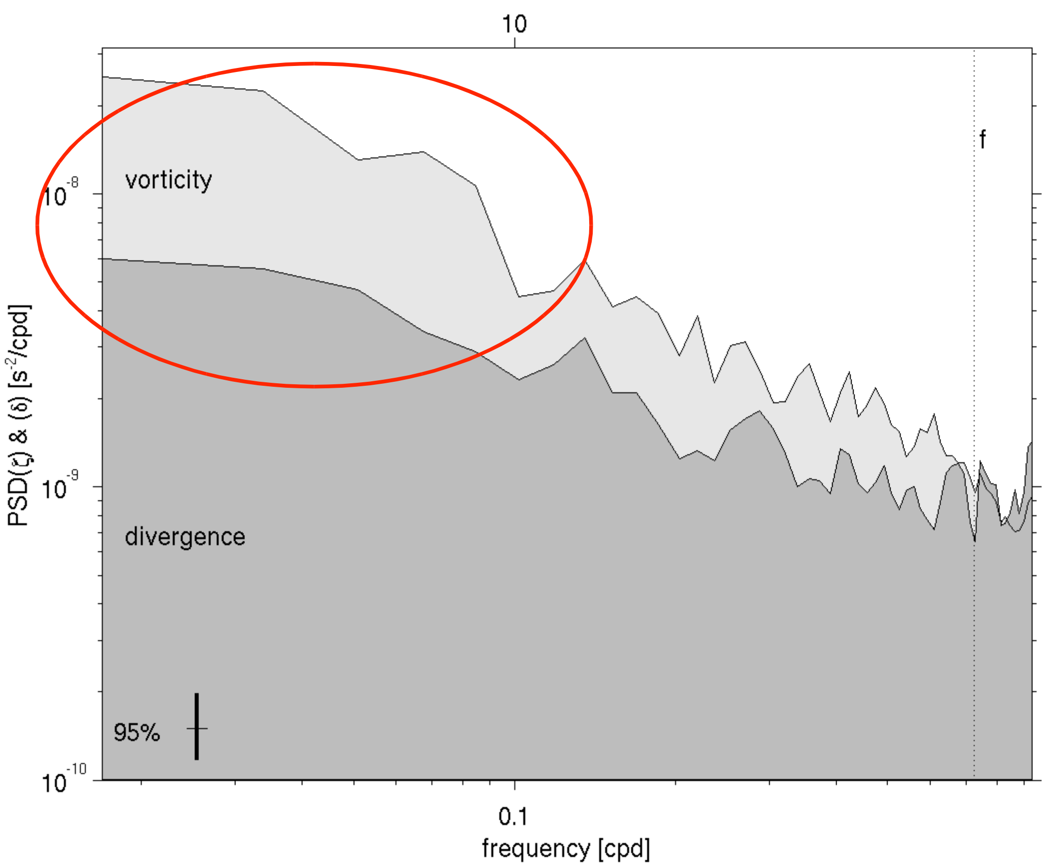
Spatial Spectrum





Previous HFR deployments: Chavanne

Assume sub-inertial currents are geostrophic and non-divergent



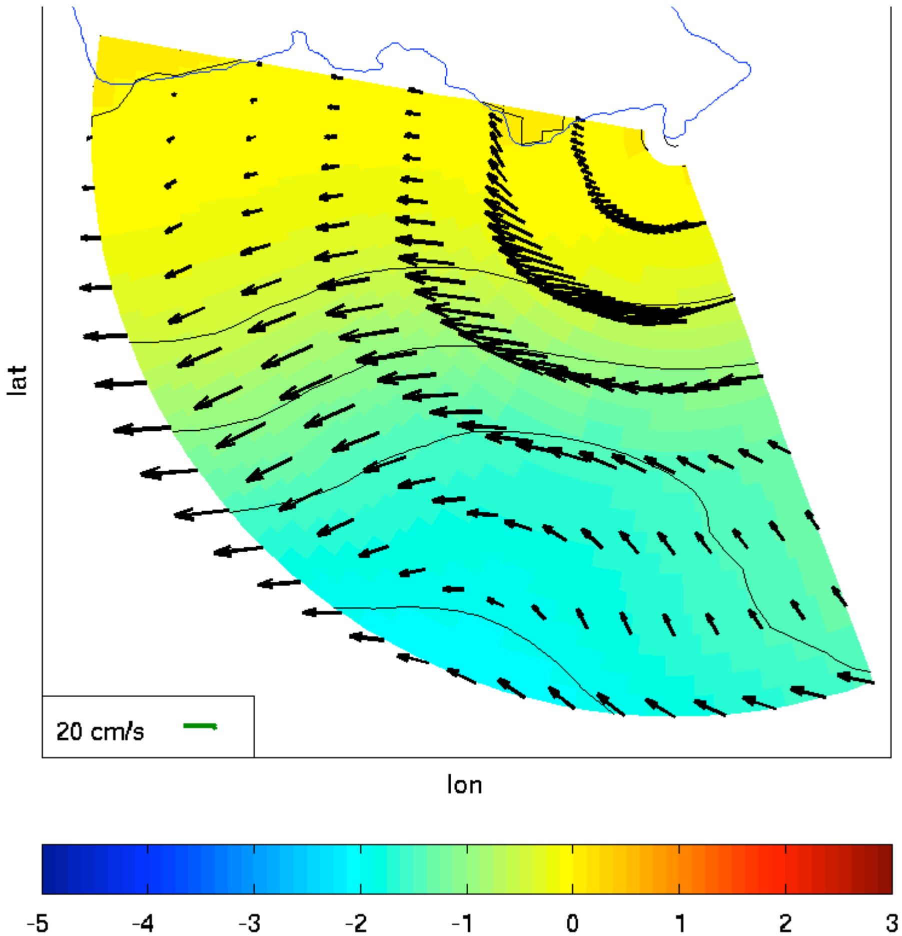
Chavanne et al. 2010

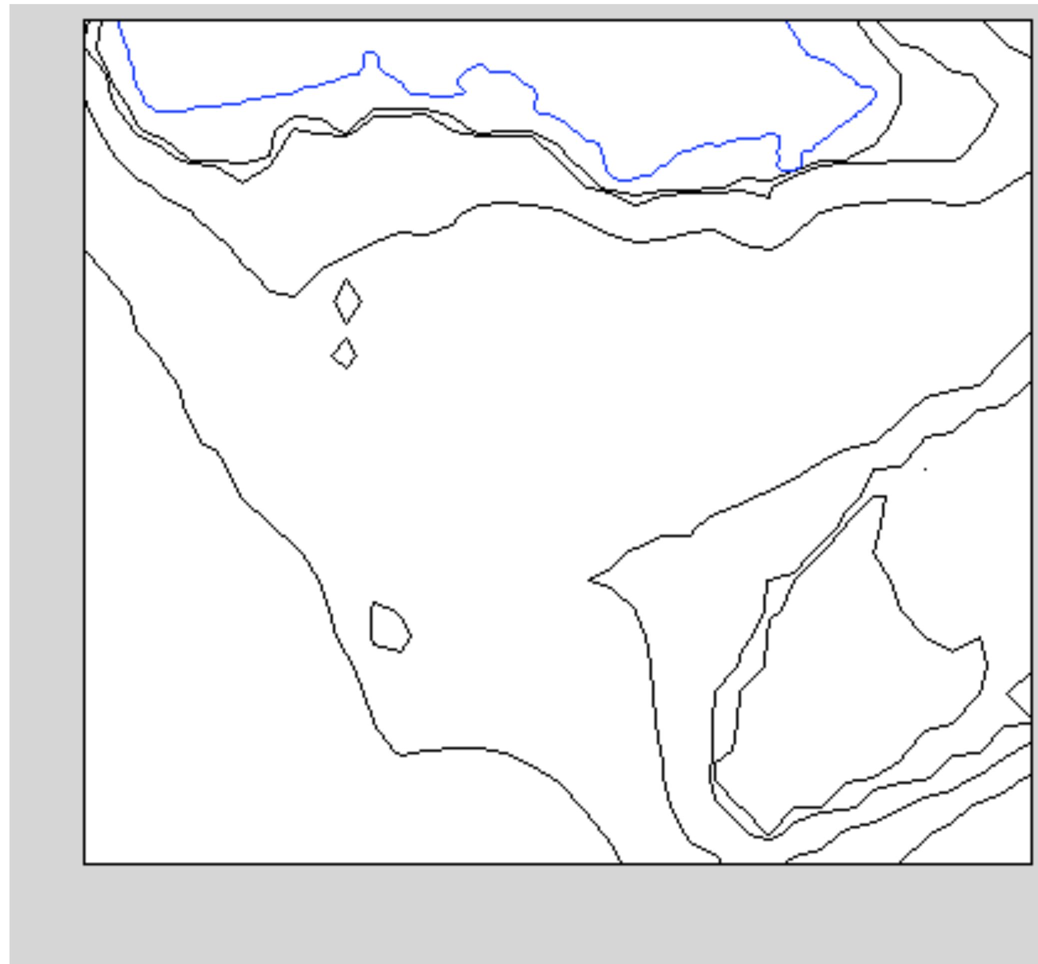
Enforce no-flow through the coast as a boundary condition, and require non-divergence at all grid cells

$$\eta = \frac{f}{g} \int_{\theta_0}^{\theta} r u_r \, d\theta$$

$$u_\theta = \frac{g}{f} \frac{\partial \eta}{\partial r}$$

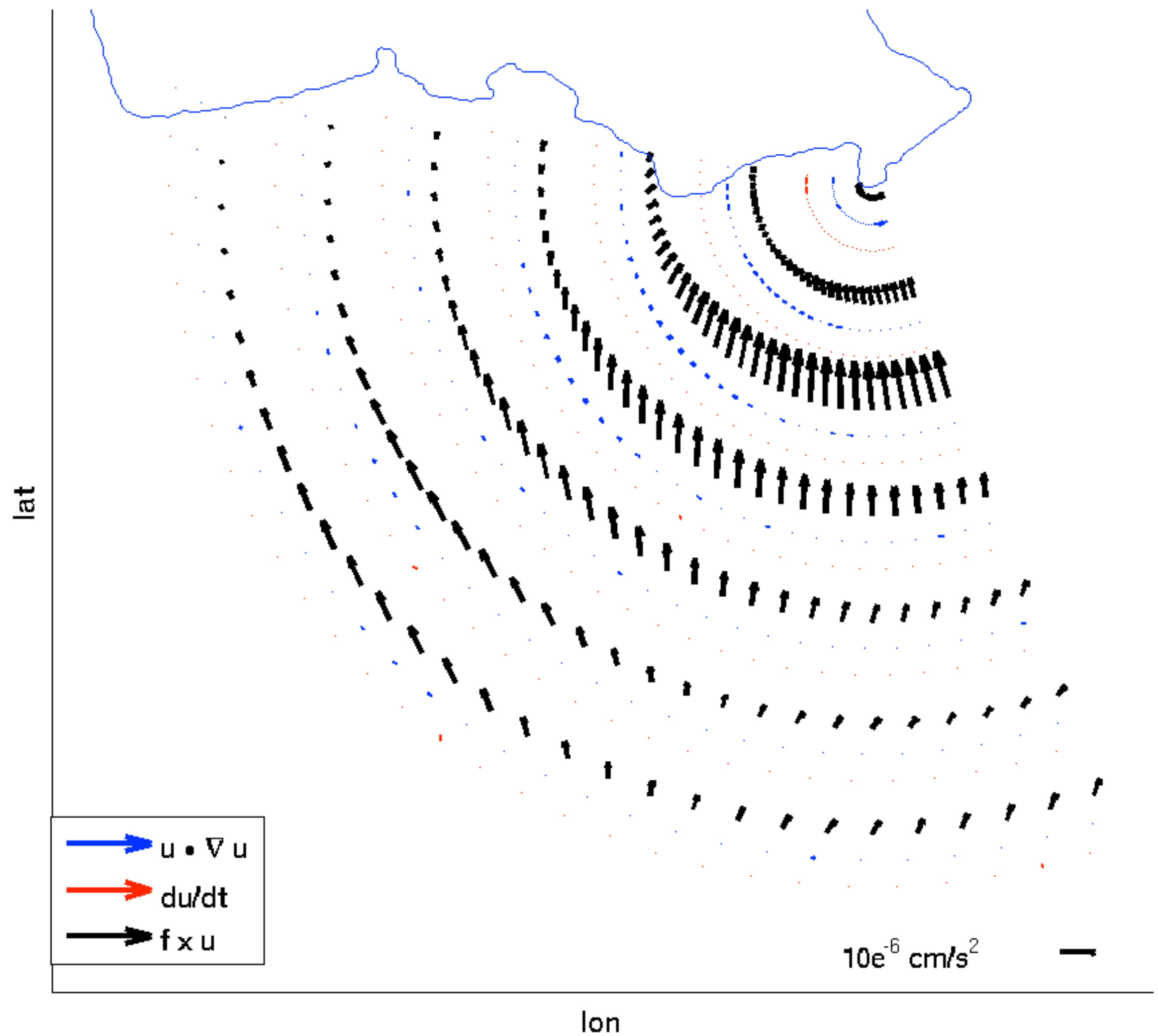
Inferred Vector Currents



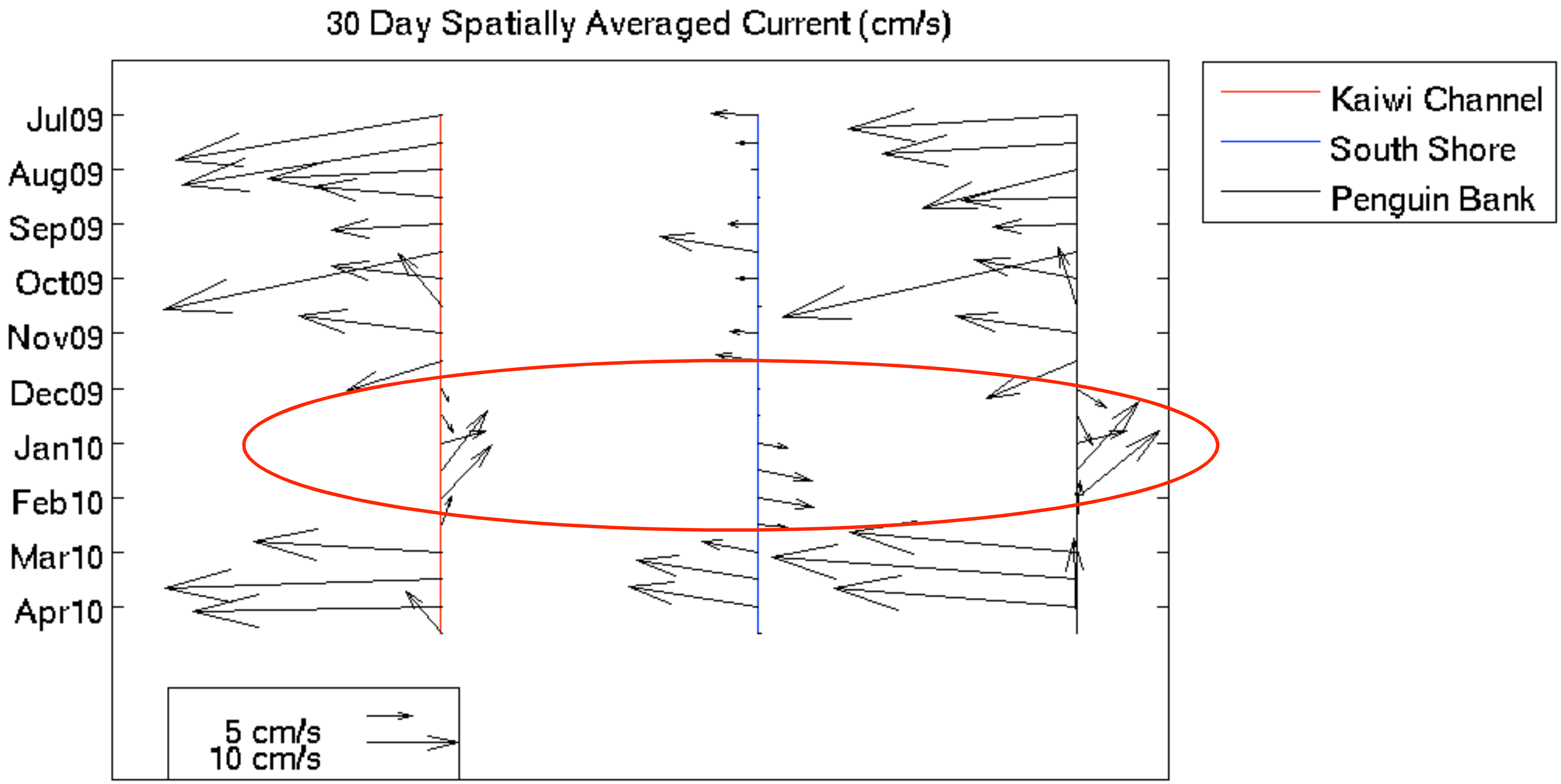


Color scale is geostrophic height (cm)

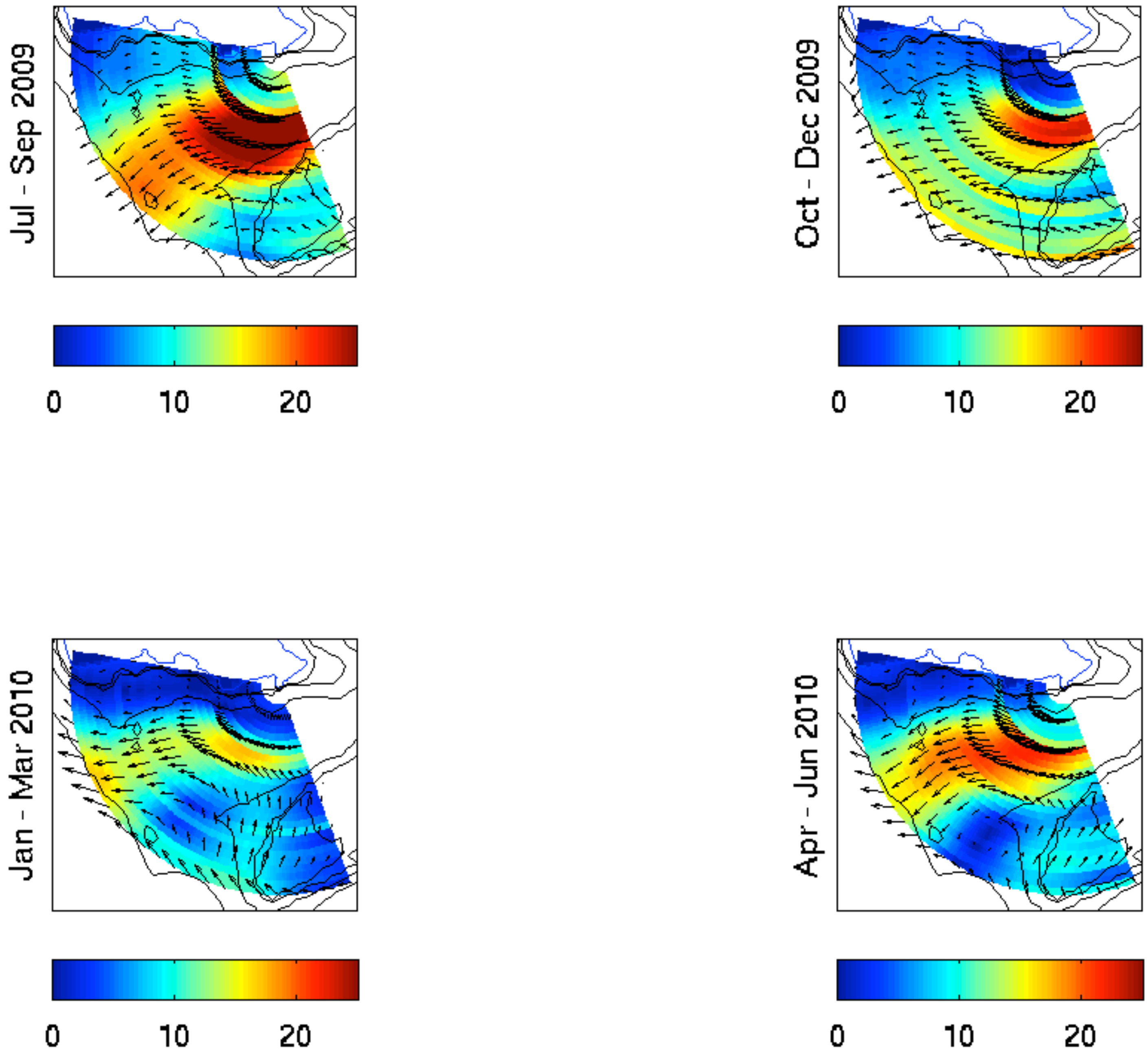
Importance of Geostrophy?



Spatial Averages

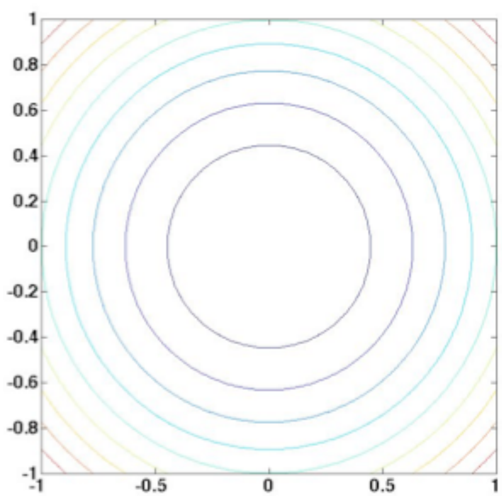


Wind Driven/Gyre Scale Currents (cm/s)

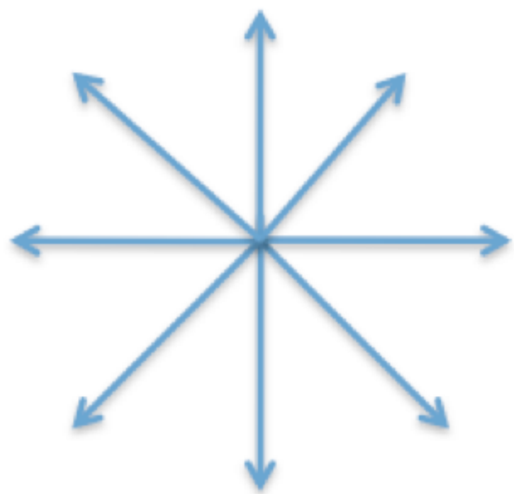


Velocity Gradient Tensor

•Vorticity – Pure Rotation

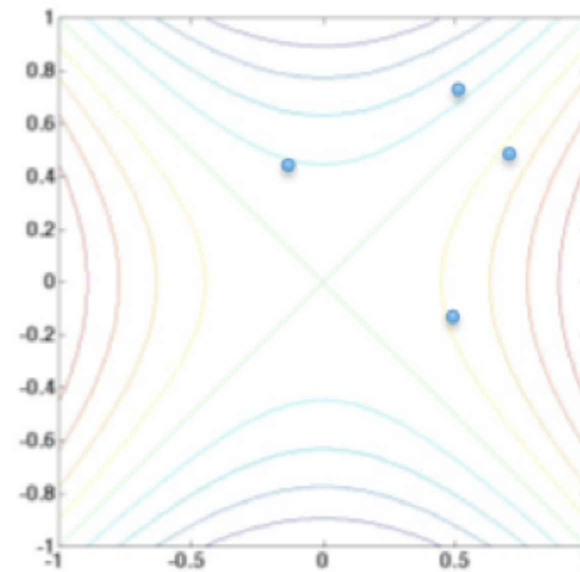


•Symmetric Divergence



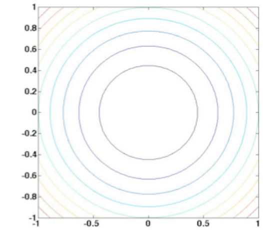
Divergence = 0

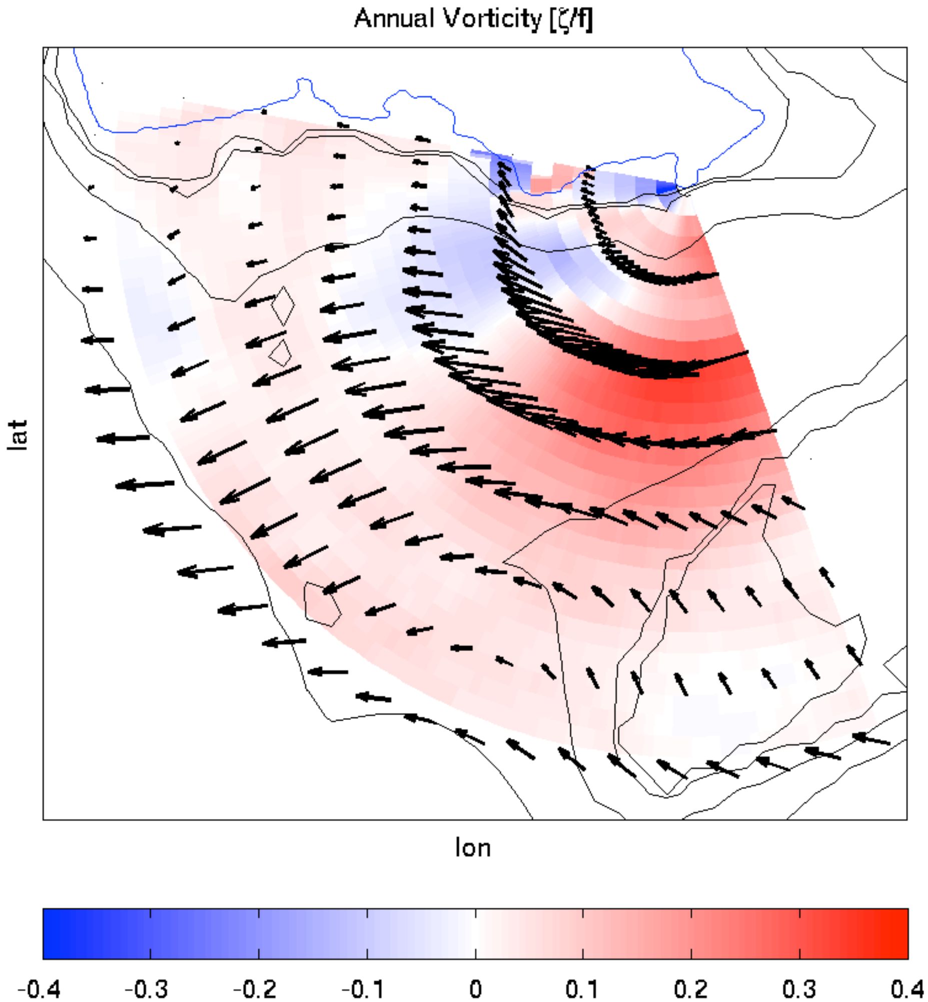
•Non-Divergent Strain

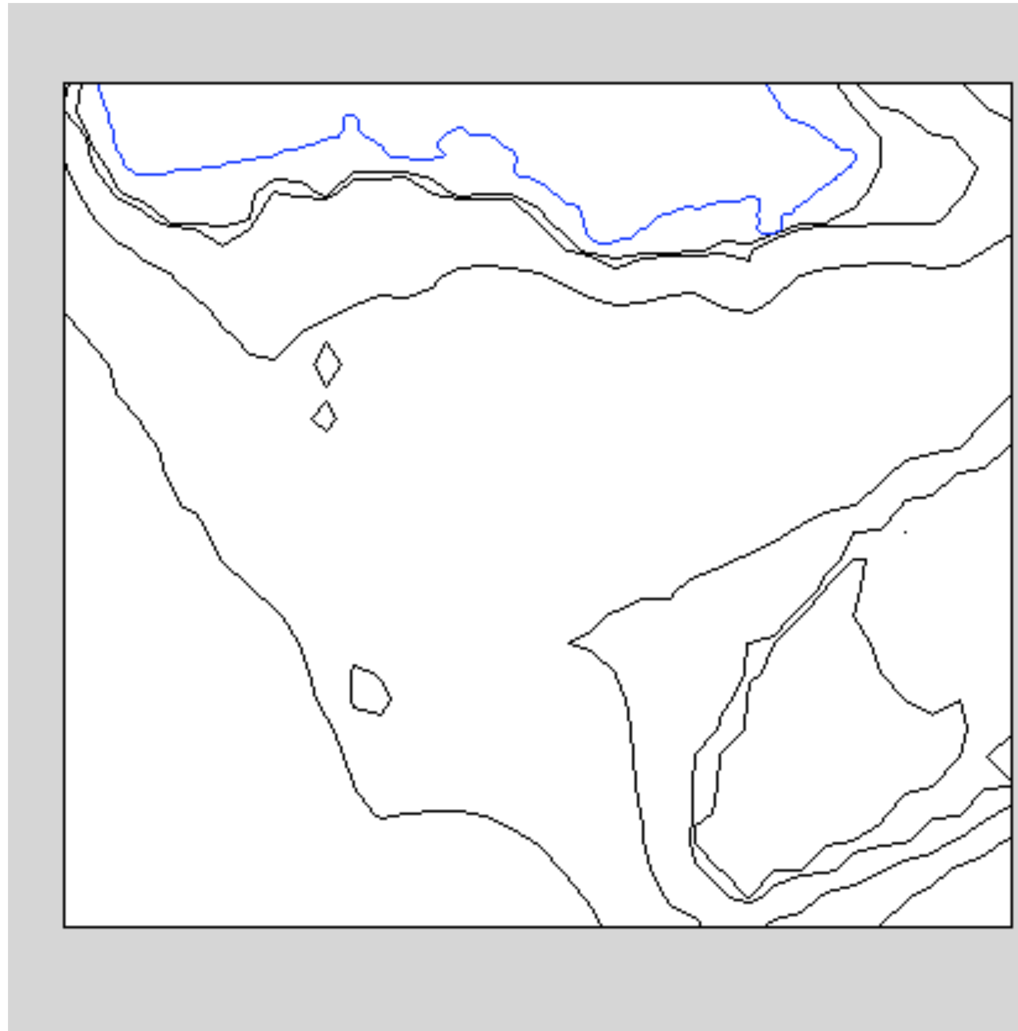


Streamline figures from Futch 2009

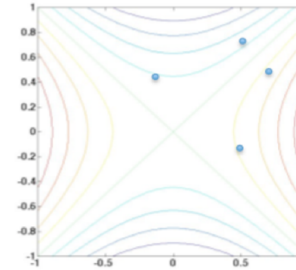
Vorticity (ζ/f)

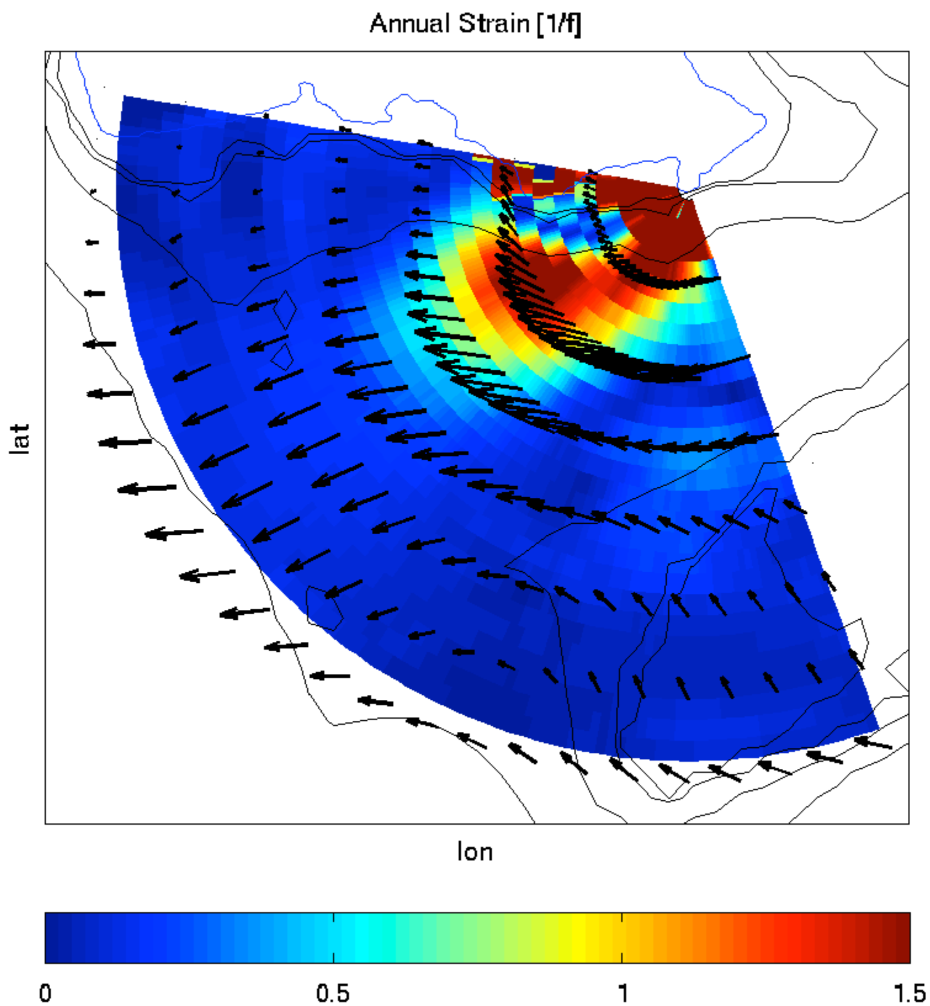


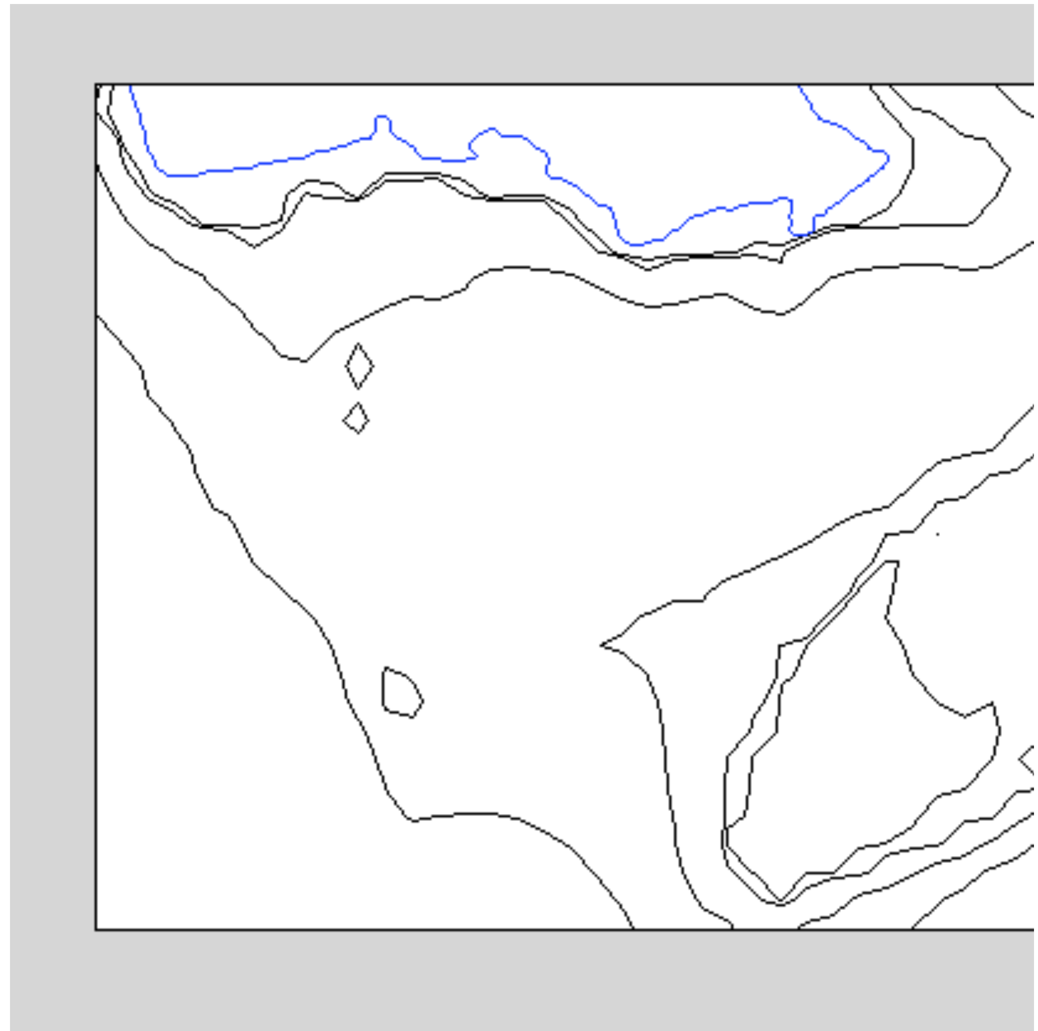




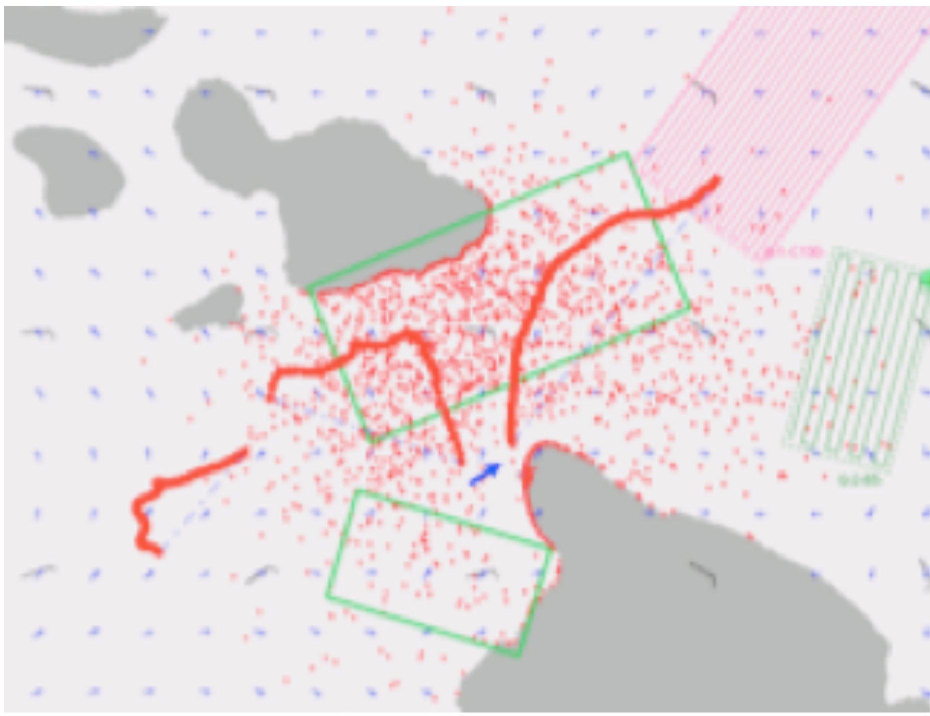
Strain (1/f)

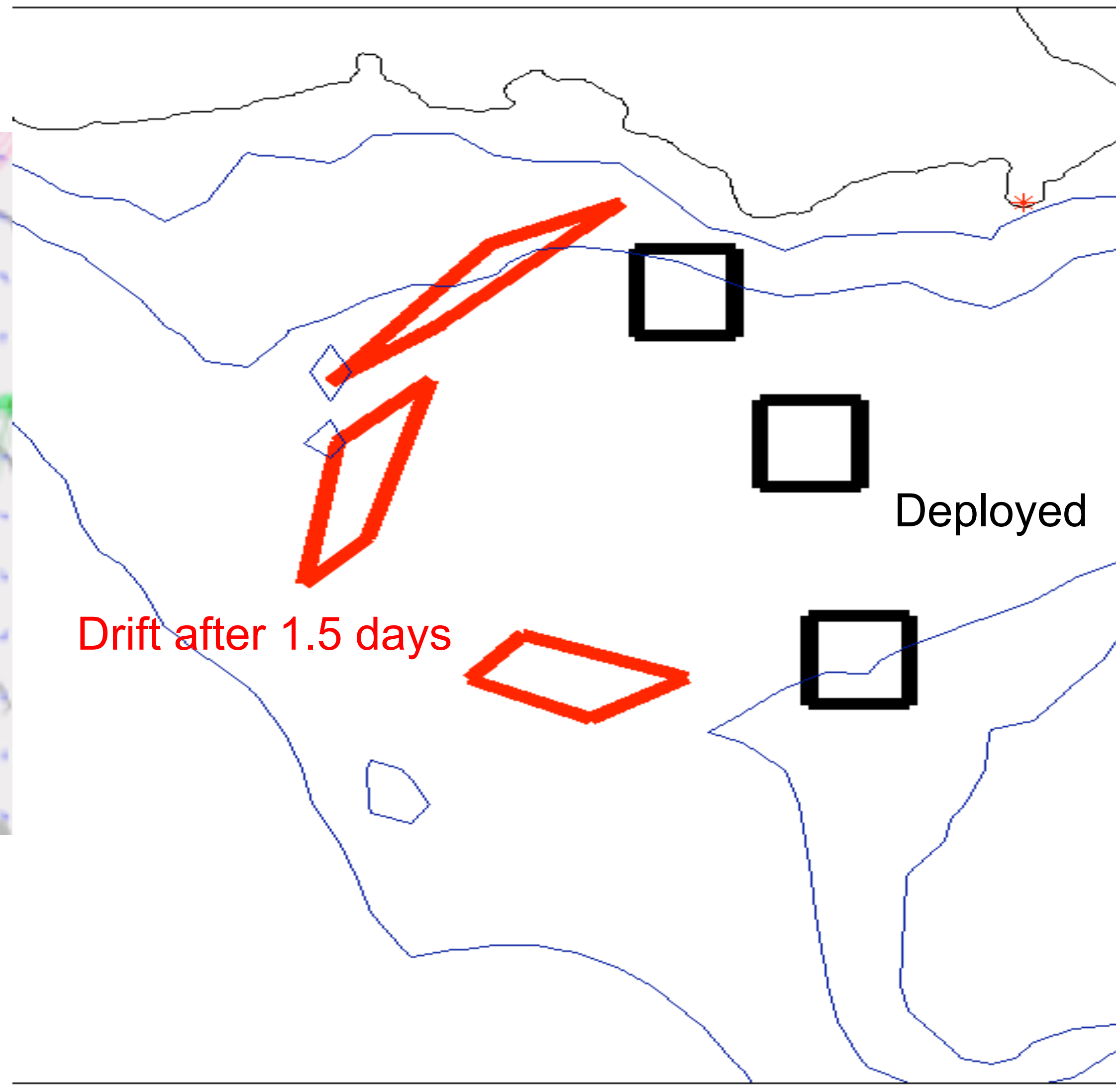






Applicability to CG missions

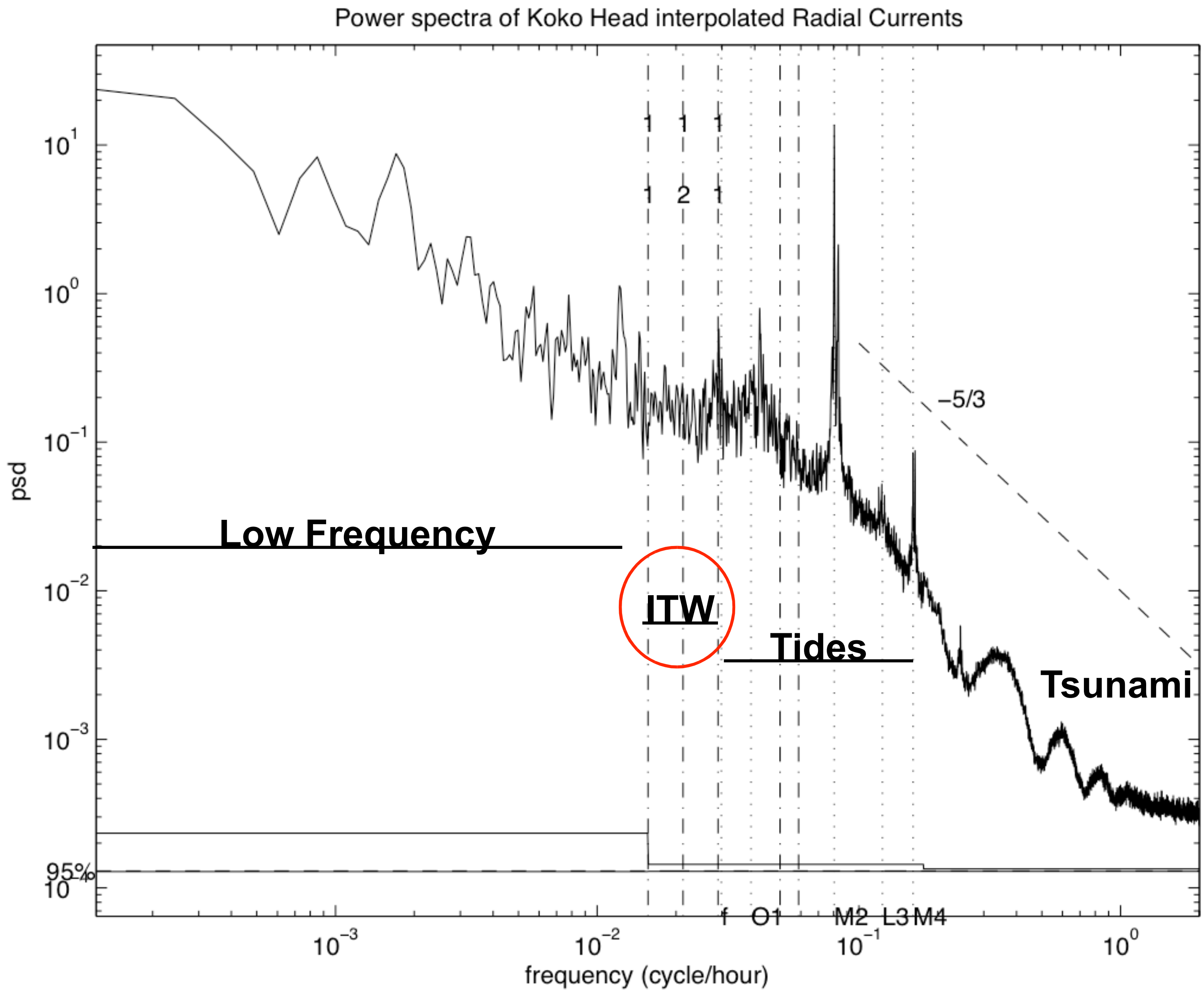


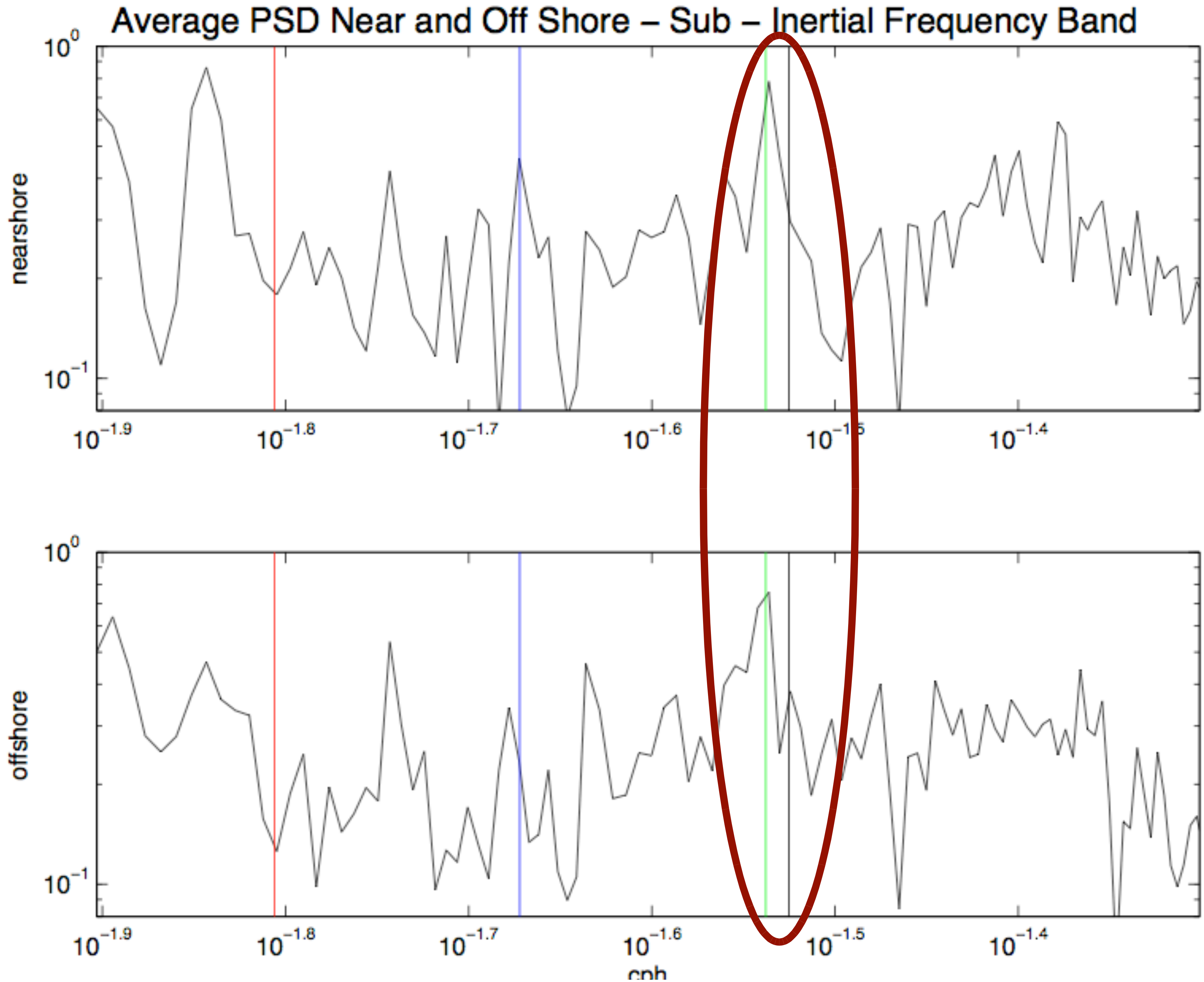


Low frequency wrap-up

- Seasonal inversion of flow
- Mesoscale energy
- By assuming non-divergence, vectors were inferred
- Inferred vectors reveal
  - jet-like flow through Ka'iwi Channel
  - persistent cyclonic flow near Penguin Bank
  - elevated areas of strain/vorticity along steep ridges

Spectral tour of observations

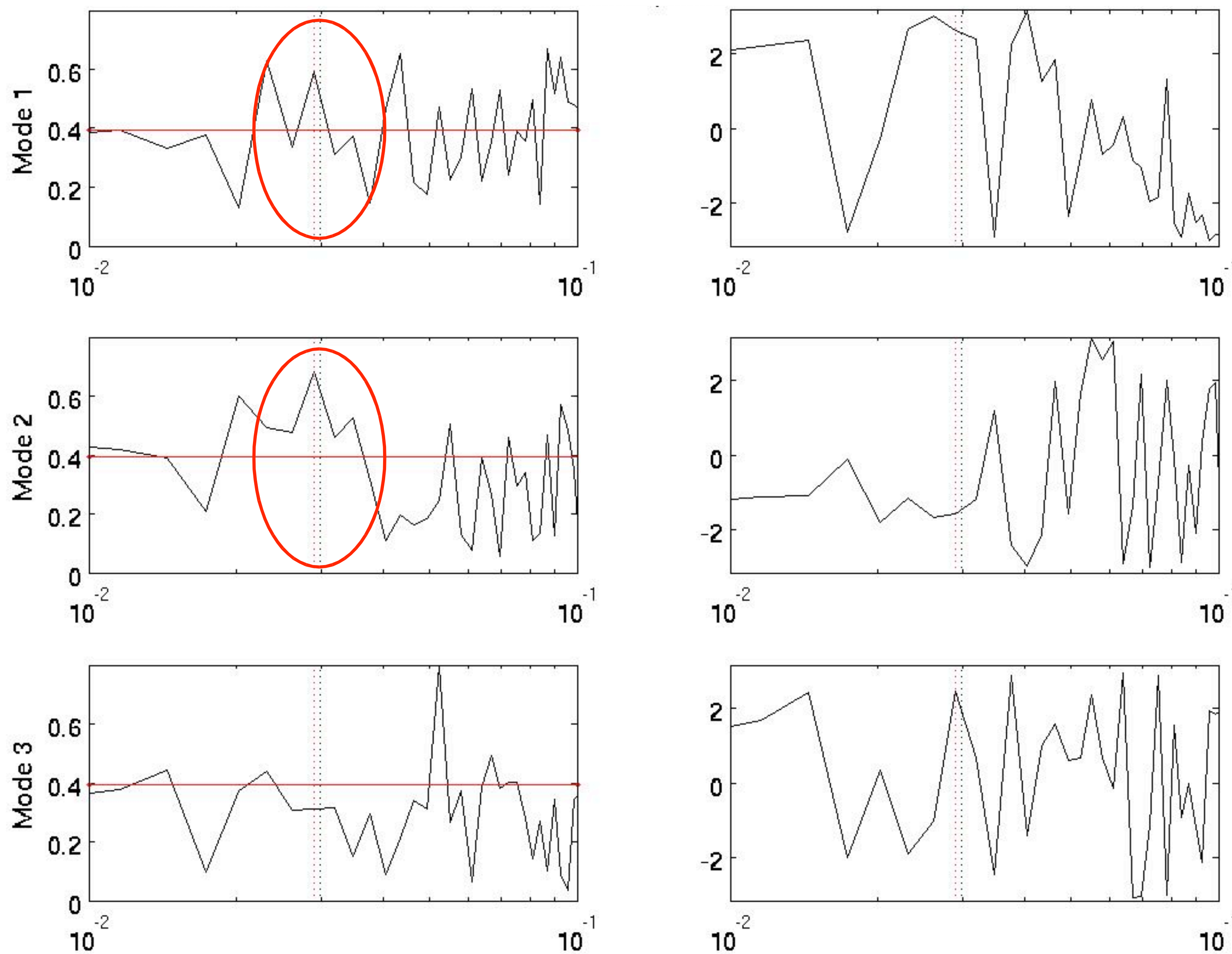




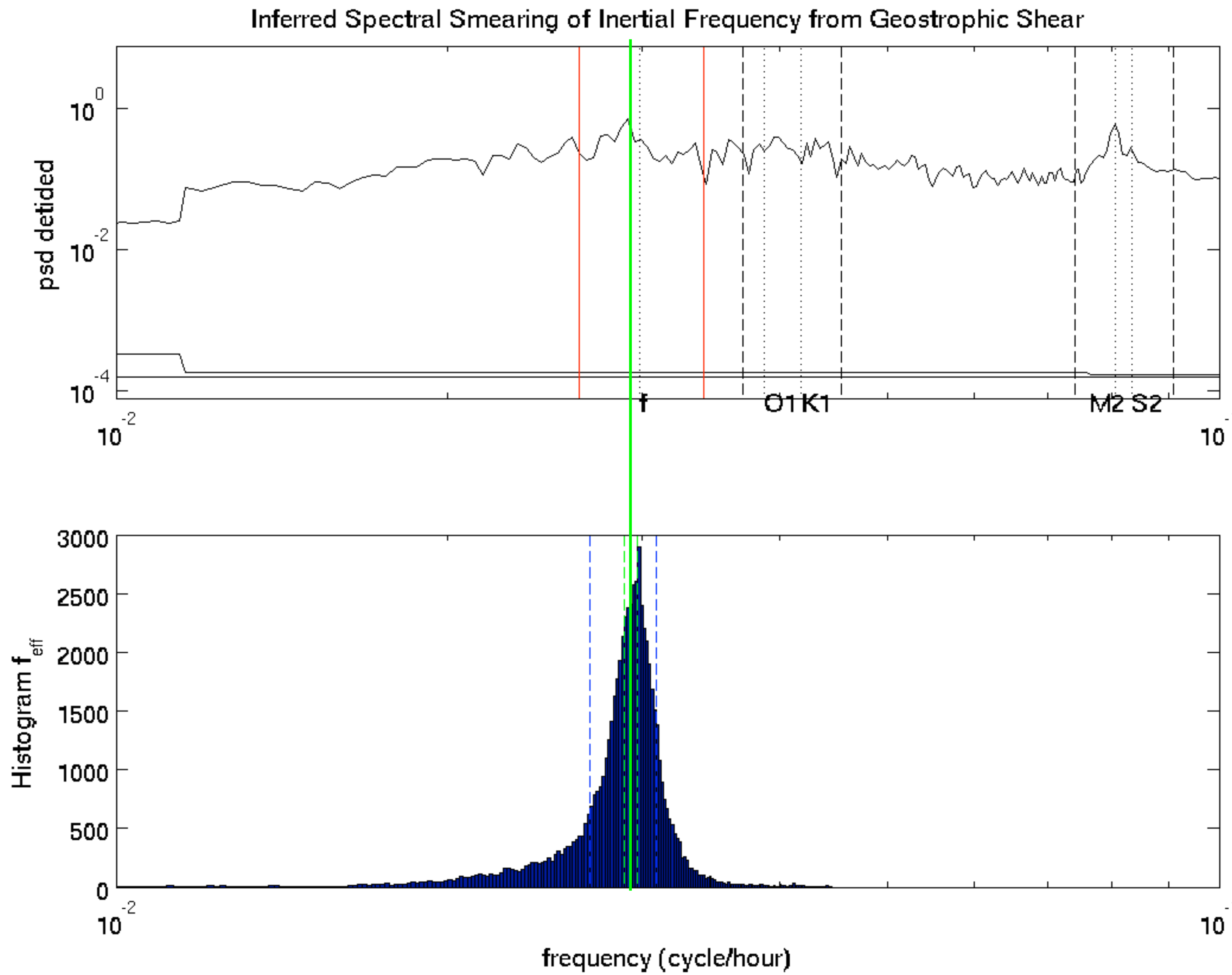
Average PSD Near and Off Shore – Sub – Inertial Frequency Band
nearshore
offshore
10^0
10^-1
10^-1.9
10^-1.8
10^-1.7
10^-1.6
10^-1.5
10^-1.4
cph

Coherence Function - Phase Spectra

Eigenmodes of Band Passed HFR with Honolulu Sea Level



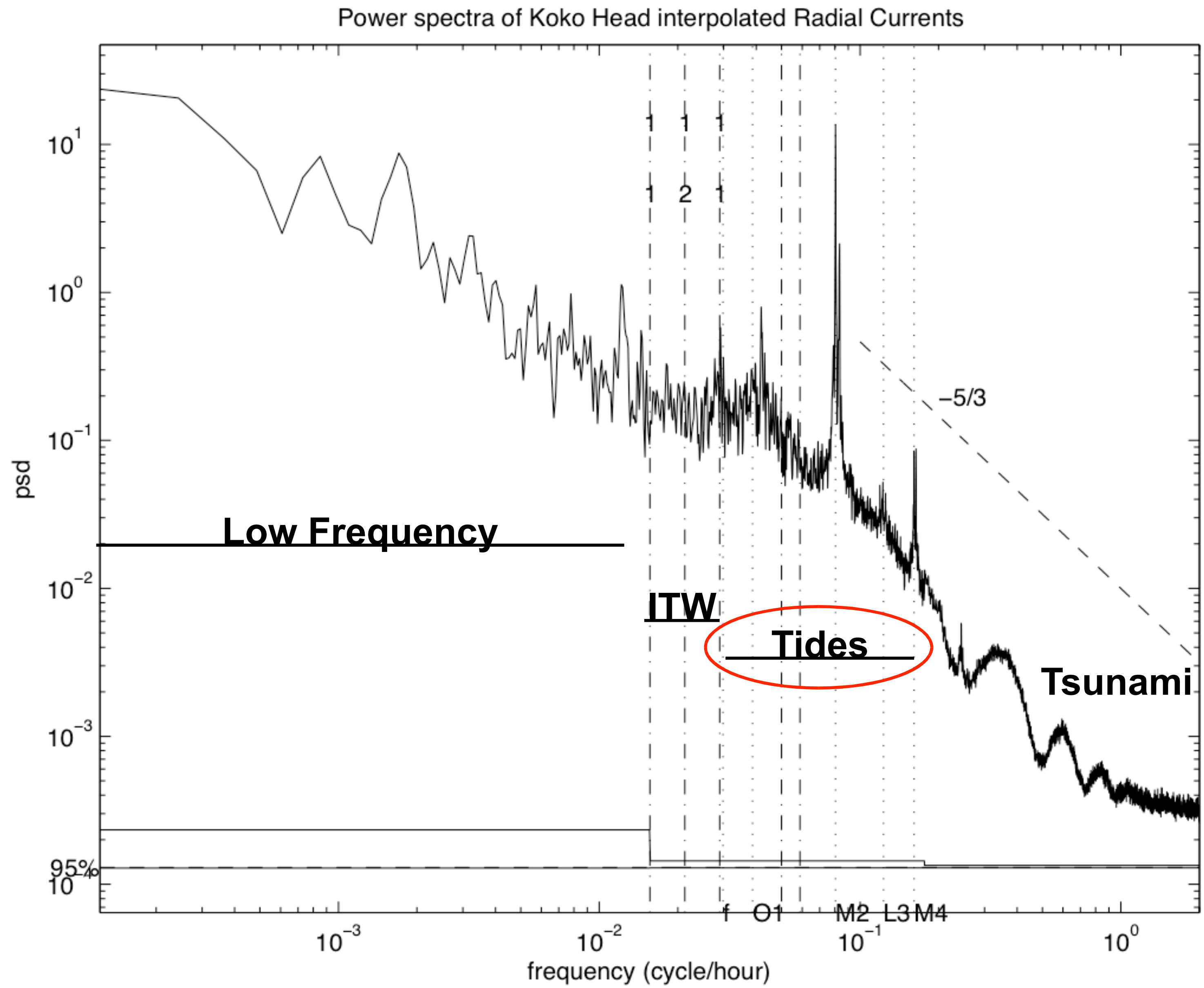
Broadening of the Inertial Peak



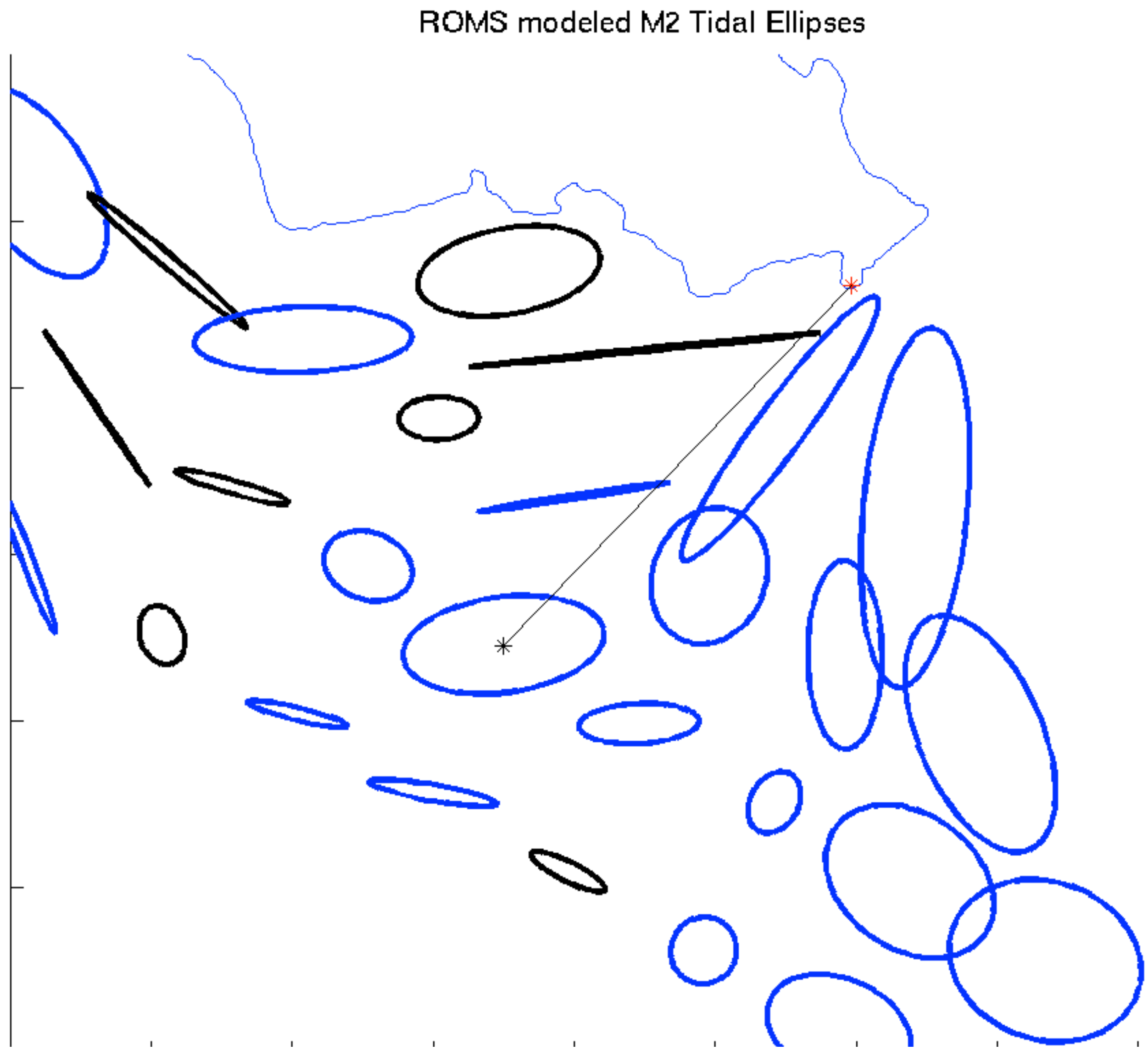
ITW wrap-up

- Gravest mode ITW very near inertial frequency
- Coherence between HFR and SL record suggest ITW
- Smearing of inertial peak due to local vorticity wider than f-ITW
- Longer records and multiple radars would allow spatial lagged-correlation and infer propagation of ITW

Spectral tour of observations



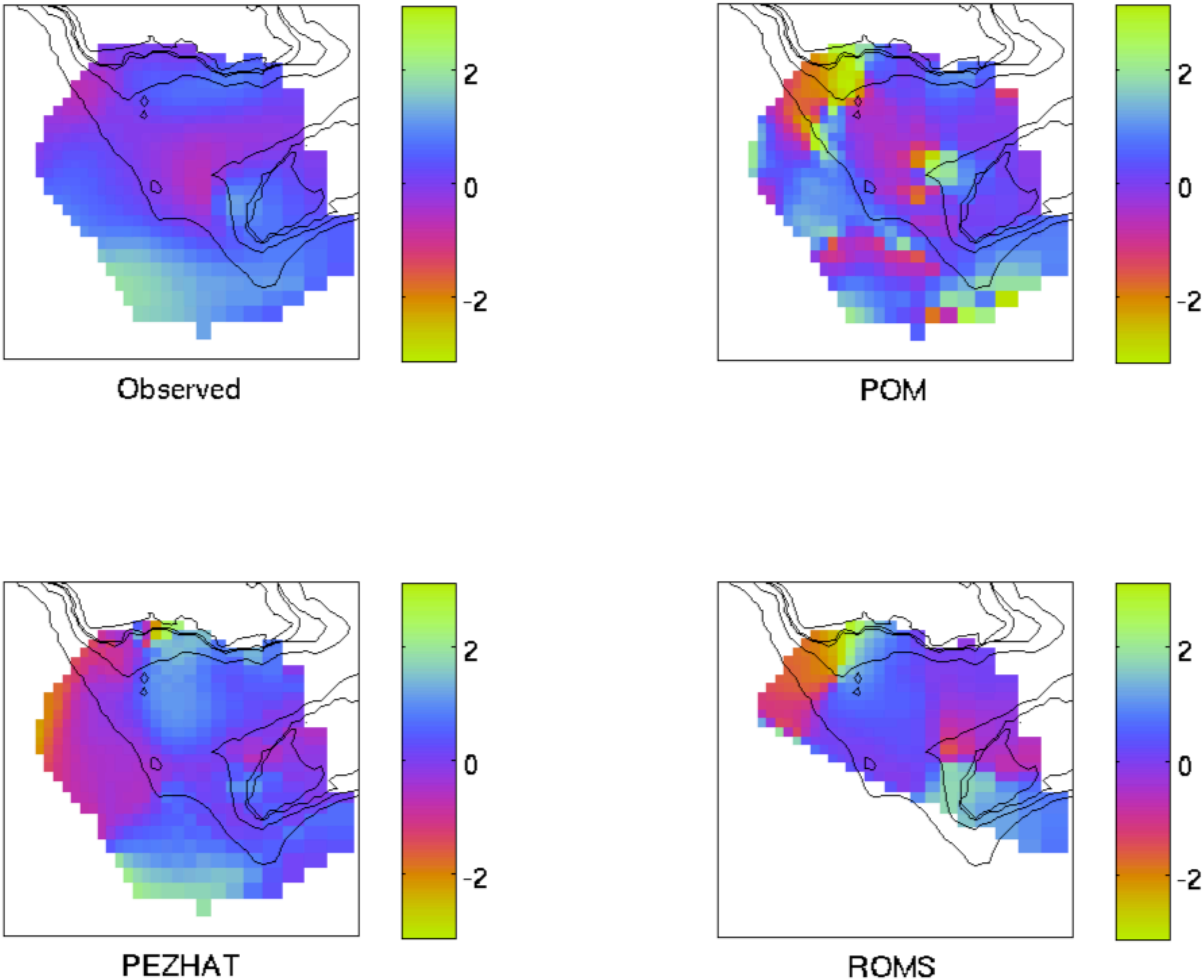
Tides



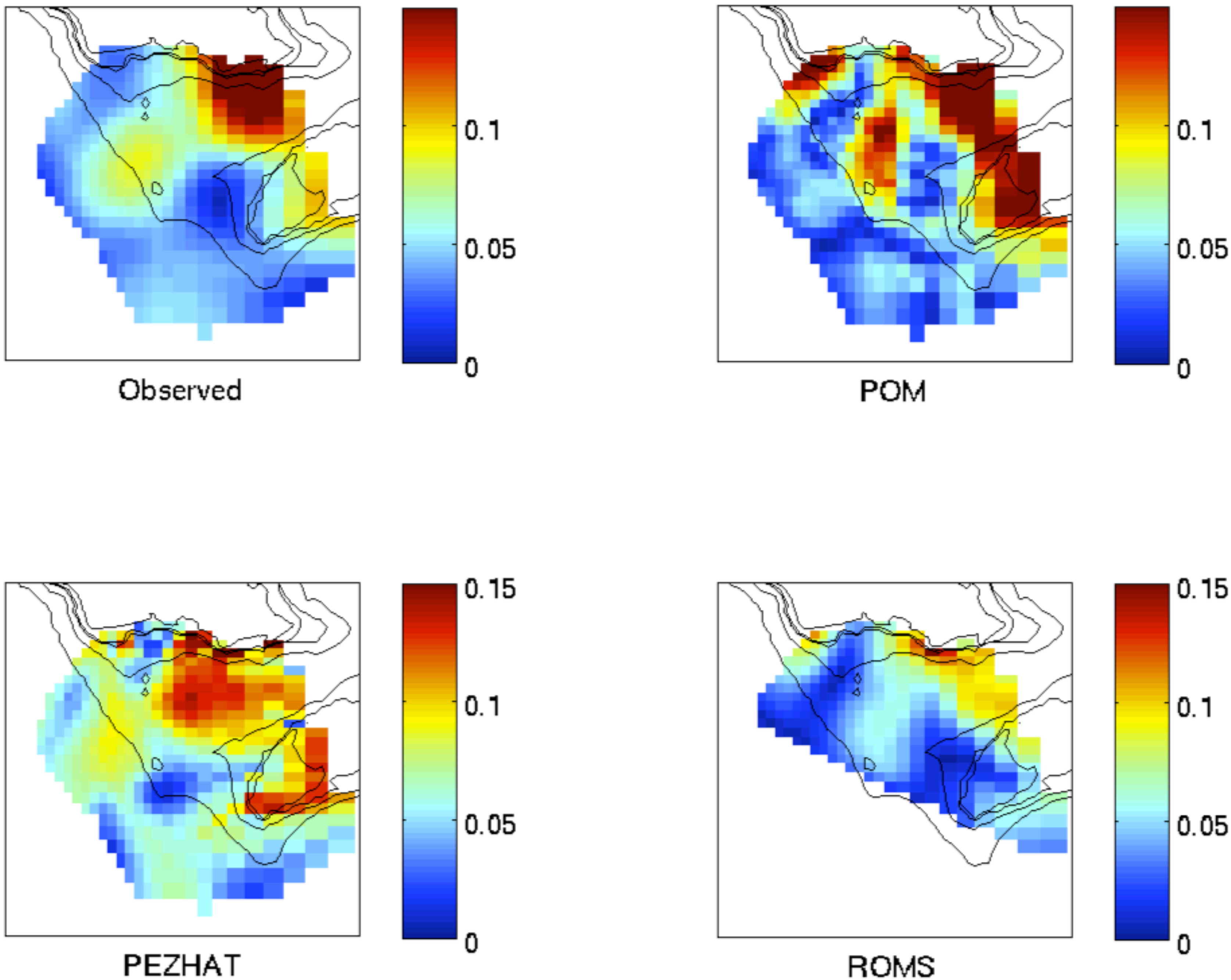
Model Descriptions

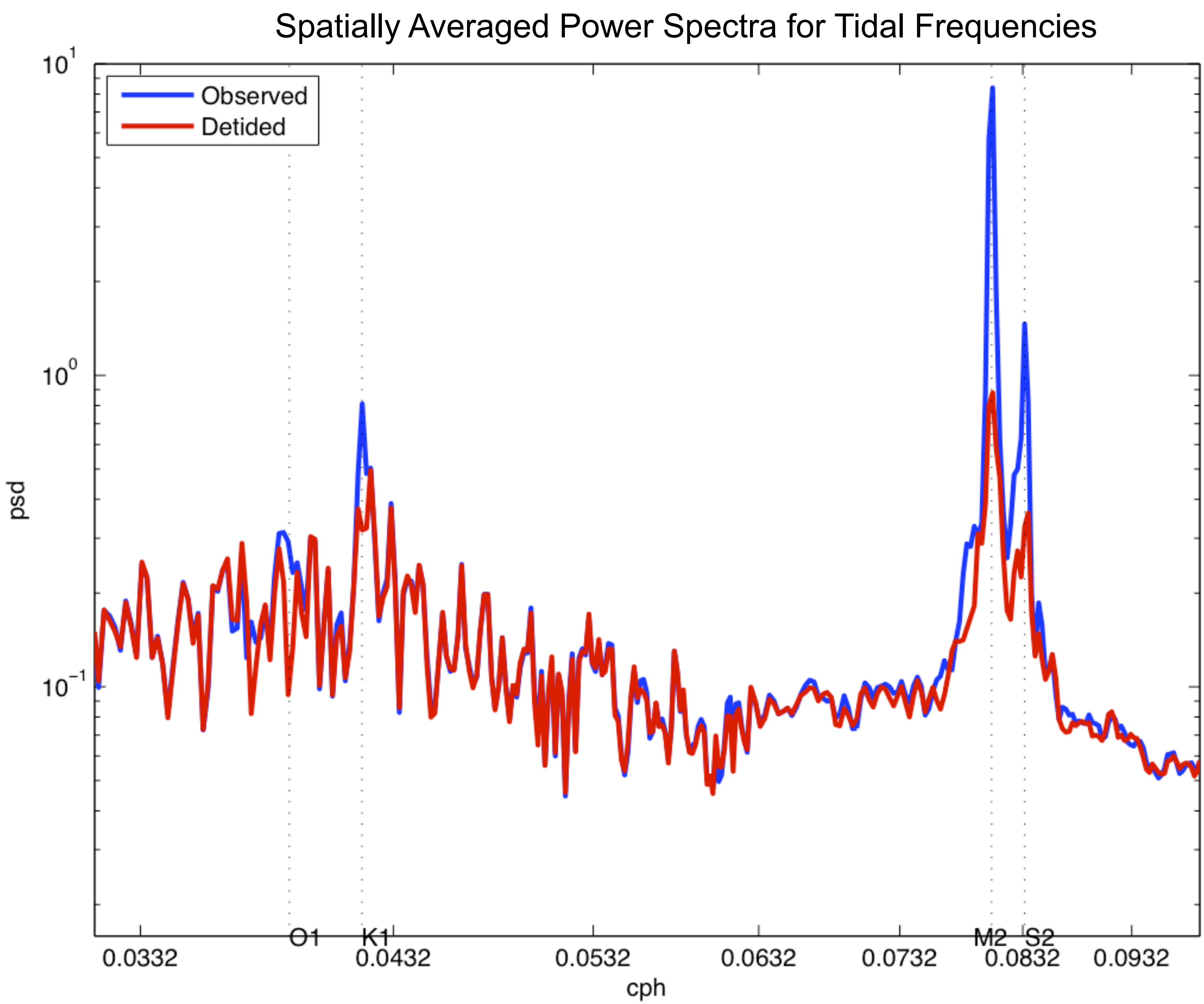
	Version	Δx	Δz	Integration Time	Stratification	Forcing	Data Assimilation
POM	Carter et al. 2008	~1 km	61 terrain following σ-levels	18 – M2 cycles (harmonic fit of last 6 cycles)	HOT 10 year mean	M2 barotropic velocity and elevation	N/A
PEZ-HAT	Zaron et al. 2009	2 km	60 z-levels evenly spaced	14 – M2 cycles (harmonic fit of last 3 cycles)	HOT 2 month mean during HOME HFR observations	Normal component of M2 transport	HOME HFR tidal harmonics
ROMS	Powell (HIOG)	~1.2 km	30 terrain following S-levels	T-tide harmonic analysis of 3 months (September – December '09)	Available data	Tide elevation and other available satellite data	WRF atmospheric model

M2 Phase (GMT)



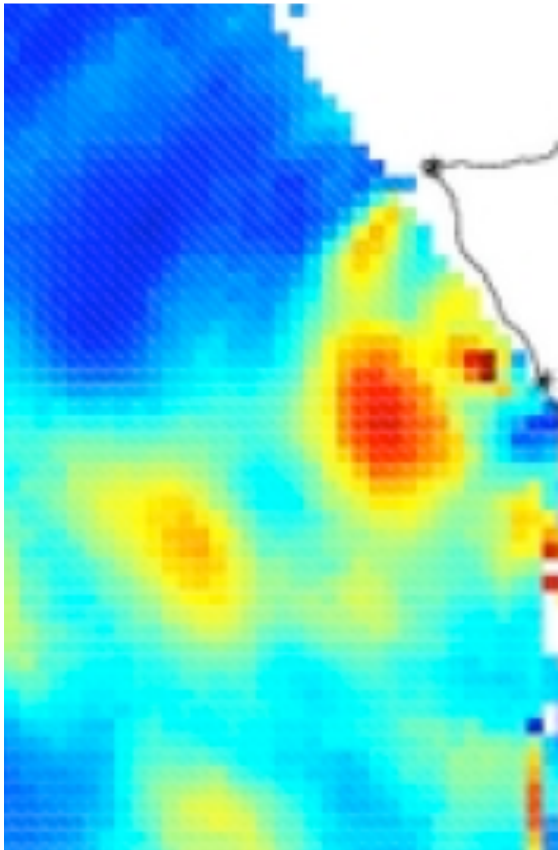
M2 Amplitude (m/s)

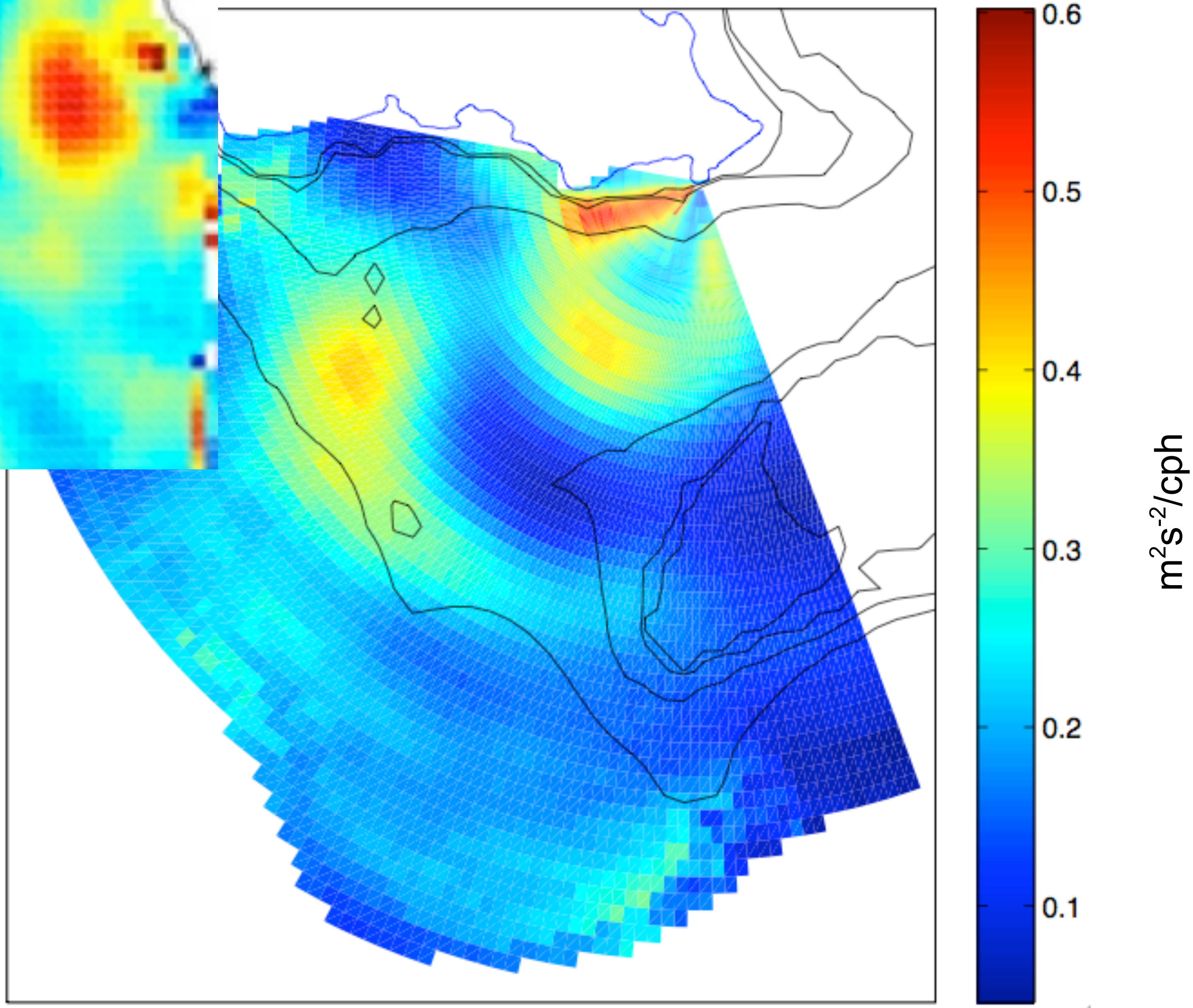




Spatially Averaged Power Spectra for Tidal Frequencies
Observed
Detided
psd
10^1
10^0
10^-1
O1
K1
M2
S2
0.0332
0.0432
0.0532
0.0632
0.0732
0.0832
0.0932
cph

rent Semi Diurnal Energy





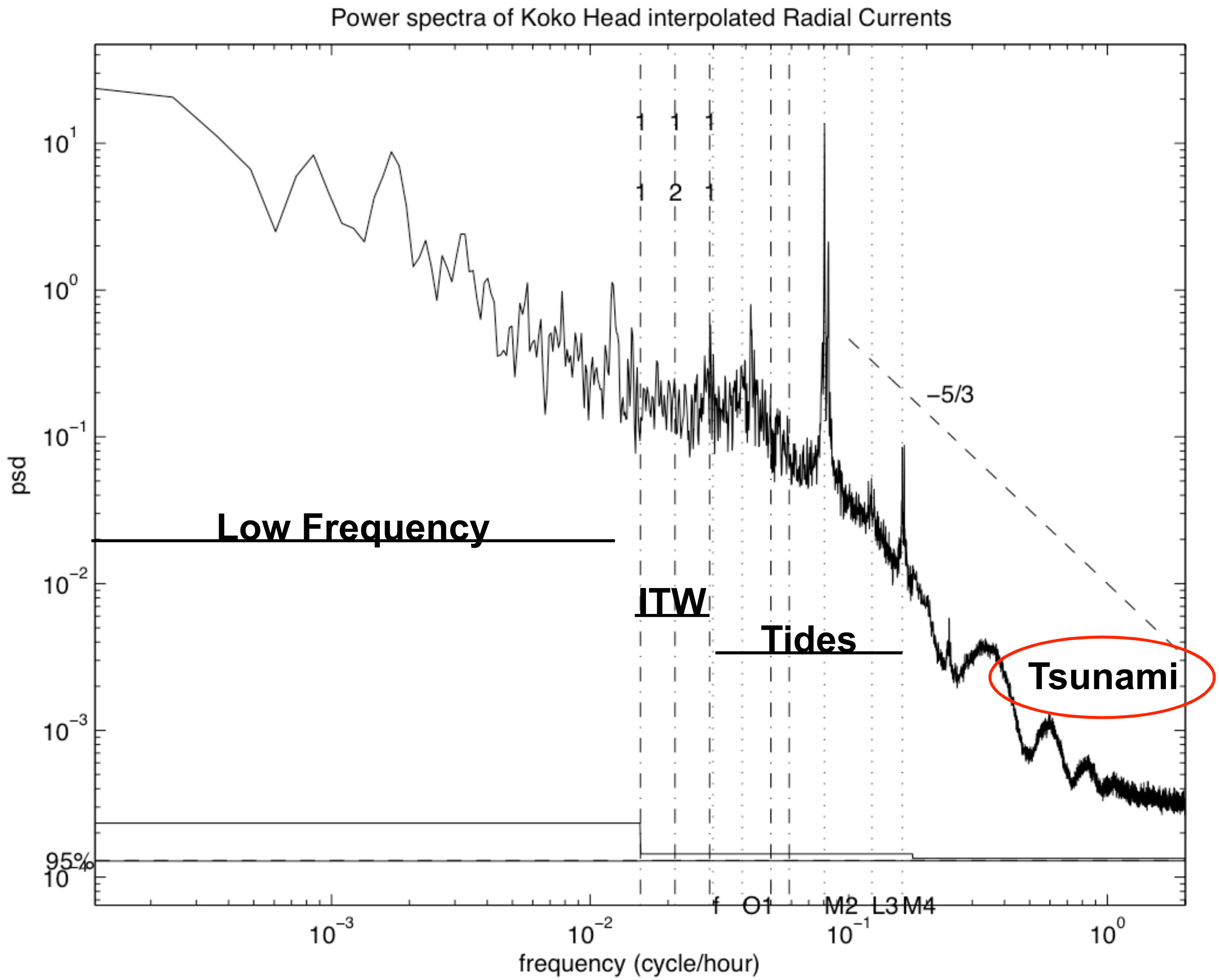
Chavanne
et al 2010b

frequency band
[N2+df,L2-df]

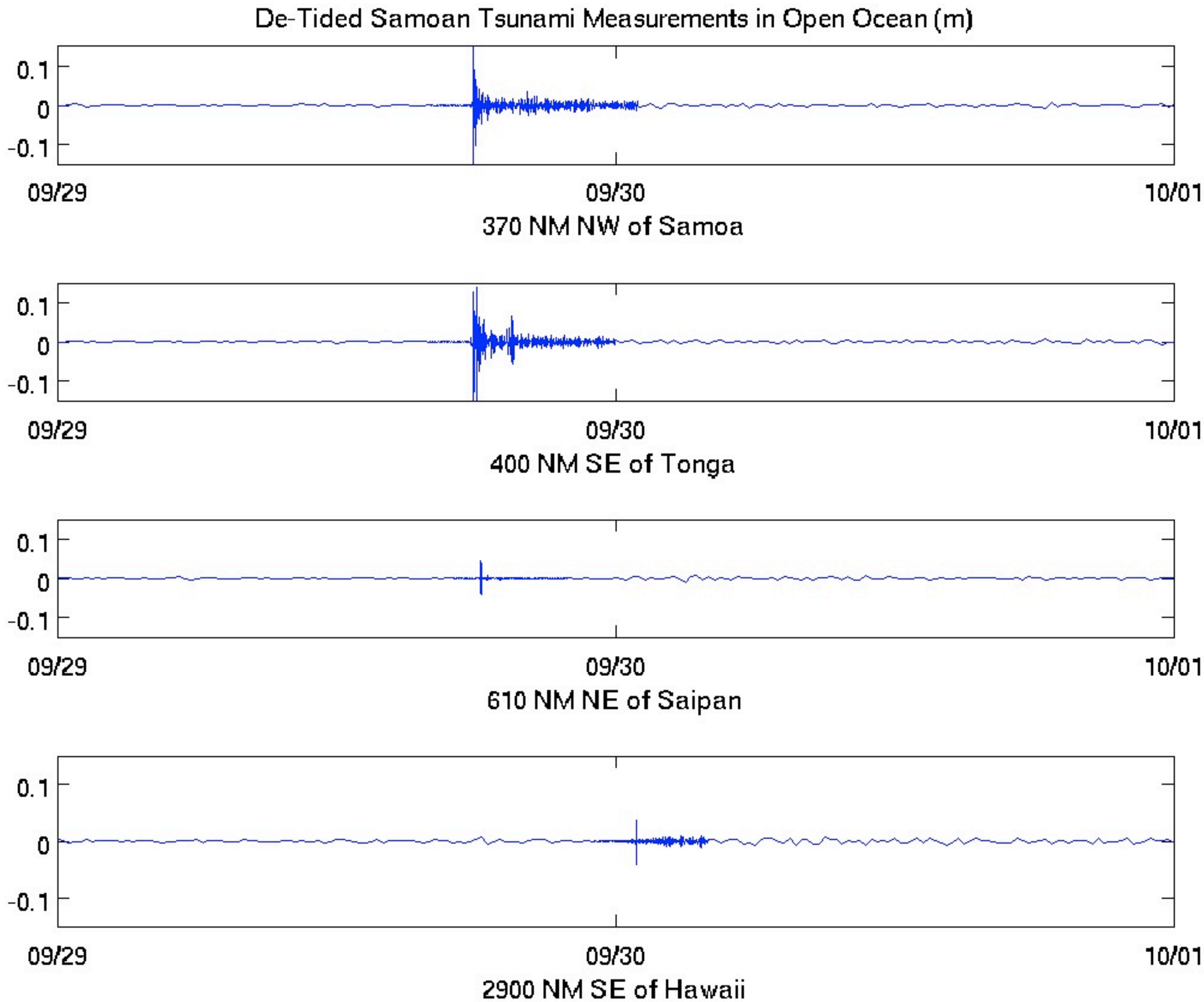
Tide Wrap-Up

- General agreement between tidal observations and models
- Significant incoherent tide may corresponds to internal tidal beams emanating from generation sites
- Apparent tidal beams appear to spatially align with similar analysis during HOME

Spectral tour of observations

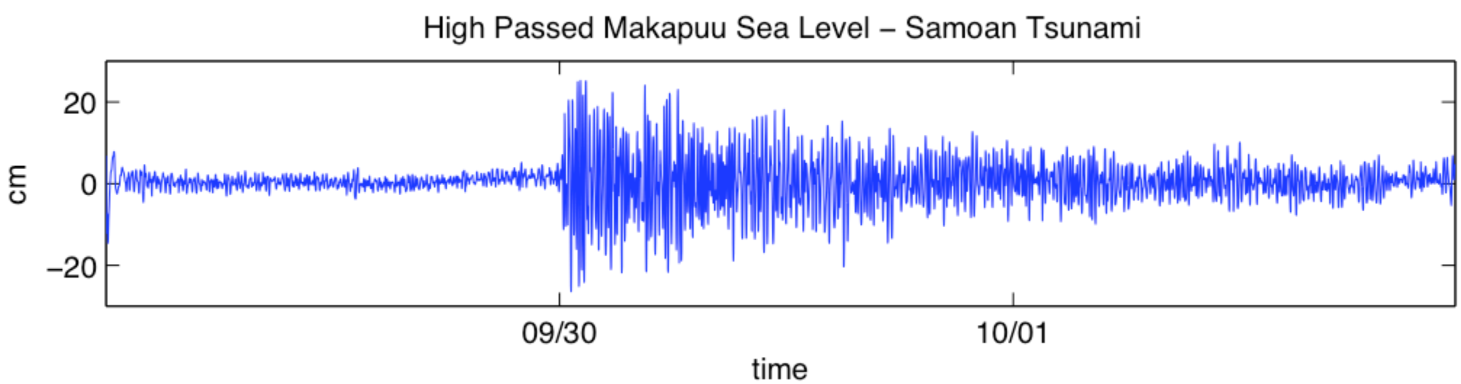


Tsunami observation

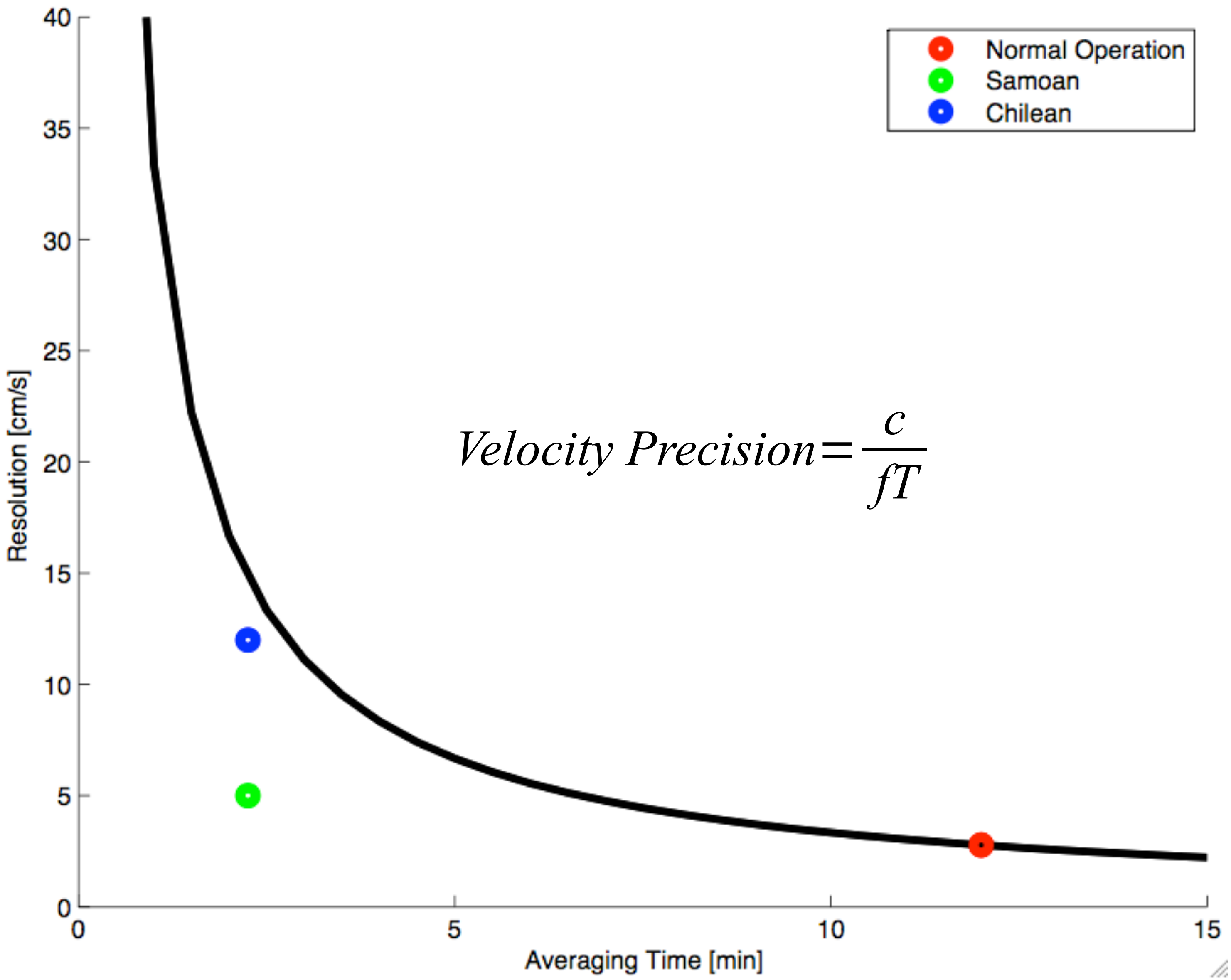


Expected currents from tsunami

	Open Ocean Period	Open Ocean Amplitude	Expected Current at Penguin Bank
Samoan	~10 min	~ 15 cm	~ 5 cm/s
Chilean	~10 min	35 cm	~12 cm/s

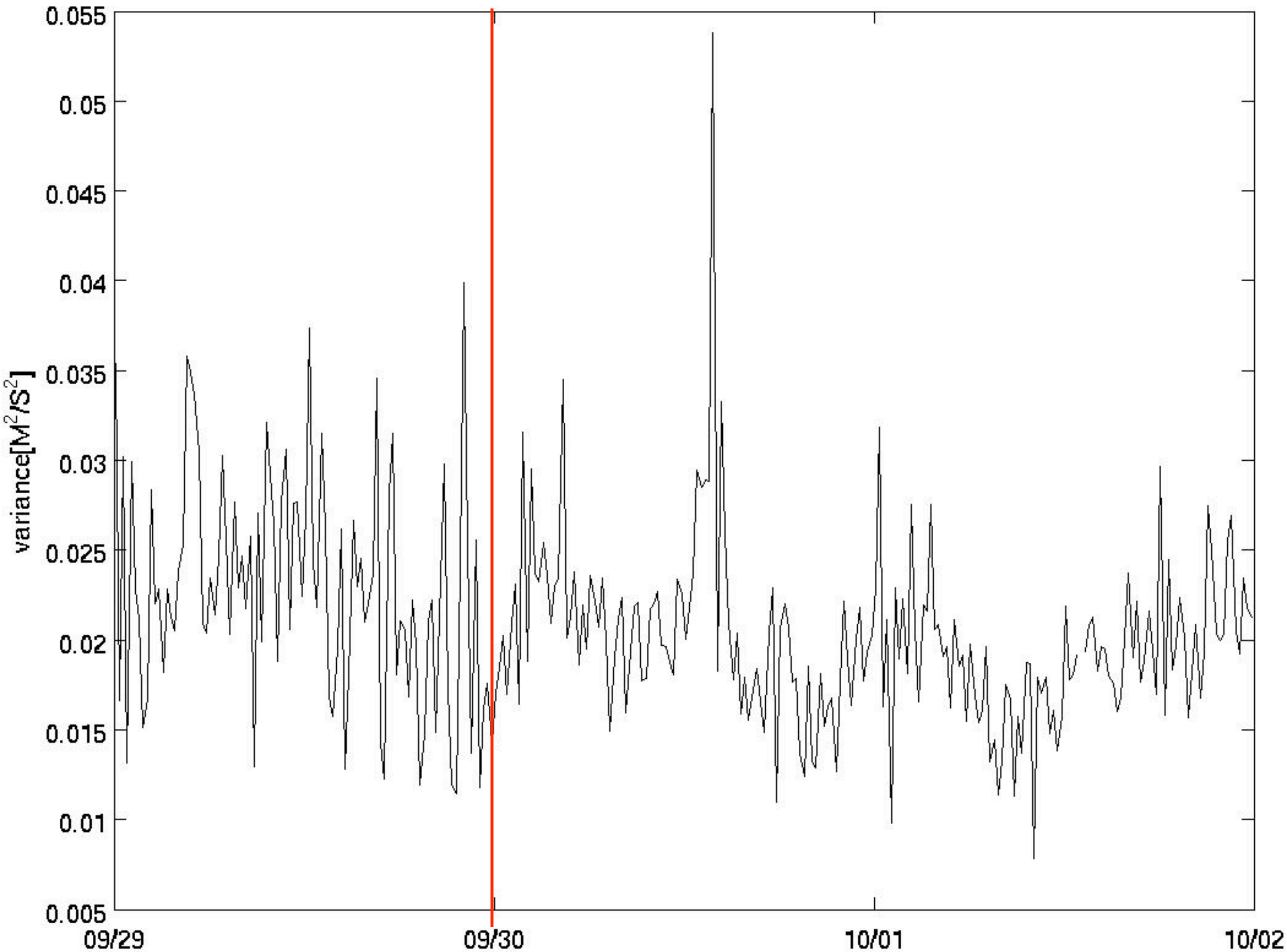


Shorter Averaging Time = Decreased Precision



$$Velocity\ Precision = \frac{c}{fT}$$

High-passed complex demodulation



Tsunami wrap-up

- Predicted expected currents
- Small magnitude of events necessitates creative analysis – subsampling and averaging
- Samoan event not detected with analysis techniques employed
- Processing of Chilean event pending

Conclusions

- Low frequency radial data used to infer vector currents
  - Jet-like flow through Ka'iwi Channel – seasonal inversion
  - Enhanced vorticity and strain along perimeter
- Tidal observations in one dimension explain large portion of deterministic process
  - Incoherent tidal energy
- ITW & small tsunamis difficult to detect
- Future Work:
  - Validate low freq assumptions - 2-site vectors and drifting buoys
  - Examine longer multiple-radars records for ITW
  - Extend tidal analysis to future sites to obtain rotary structure
  - Refine tsunami analysis

Acknowledgments and Mahalo

- UH
  - Pierre Flament, Glenn Carter, Brian Powell
  - RADLAB and other field work help
  - Classmates and teachers
  - Support Staff
- CG
  - Marine Science Program
  - Former shipmates
- Friends
- Family


Questions?