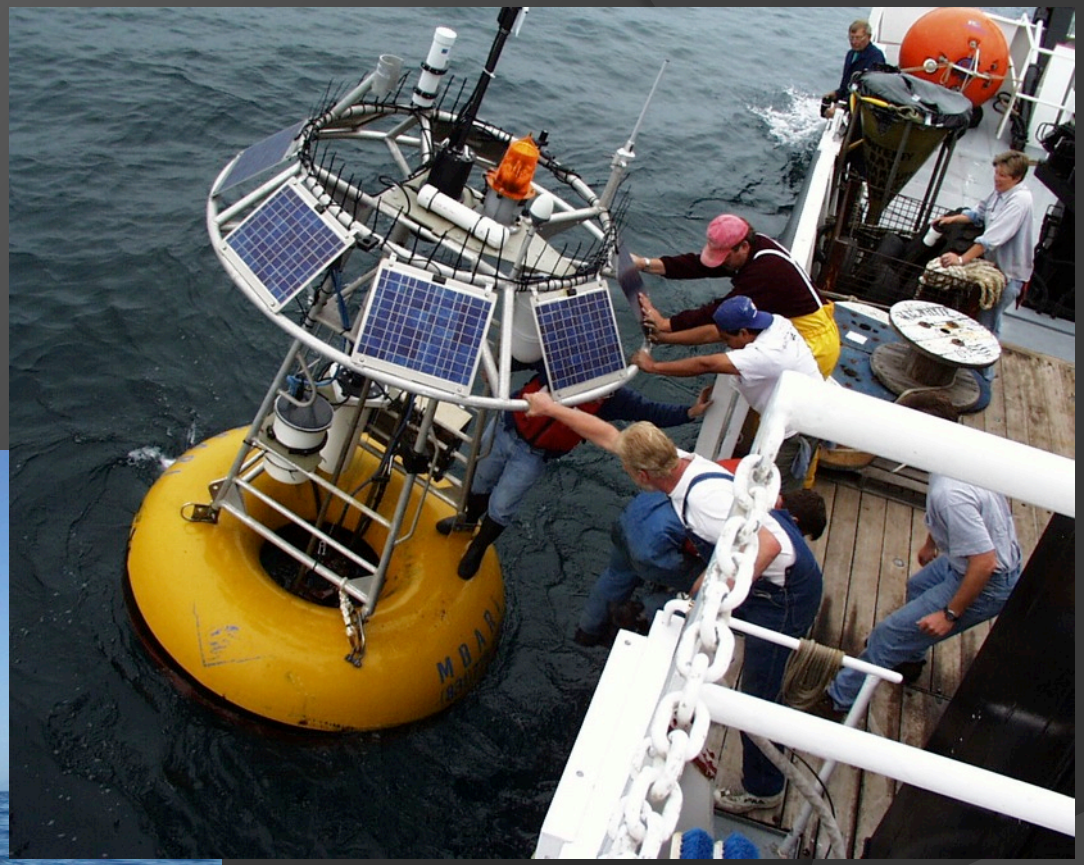
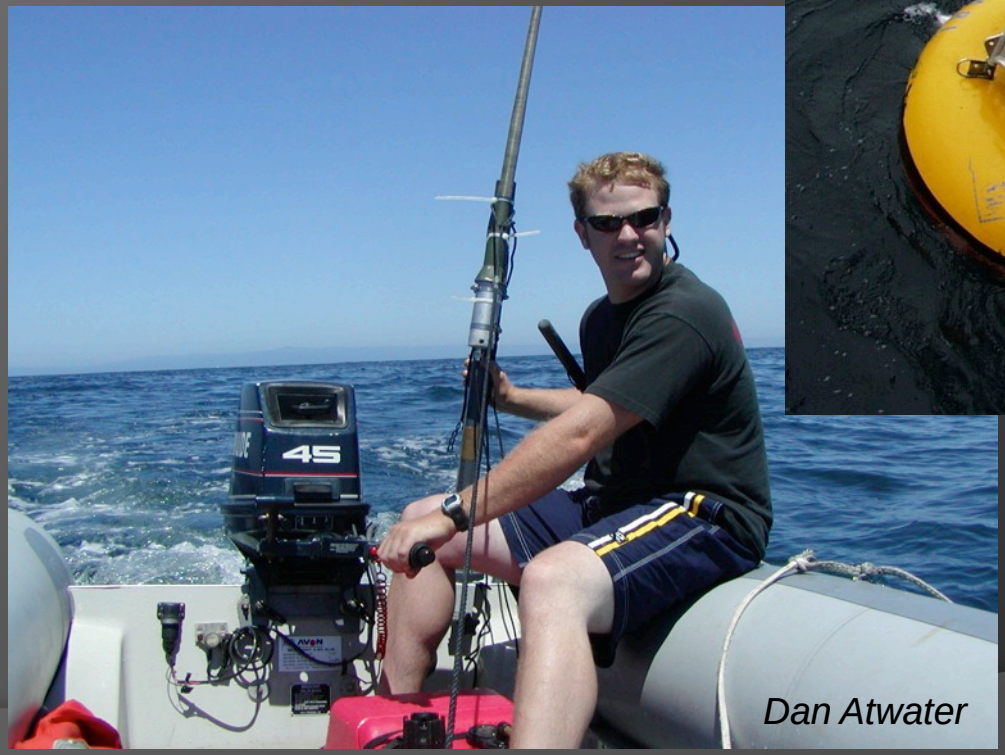
Calibration and Validation of Direction-Finding HF Radar Ocean Surface Current Measurements

Jeffrey D. Paduan
Naval Postgraduate School





Dan Atwater

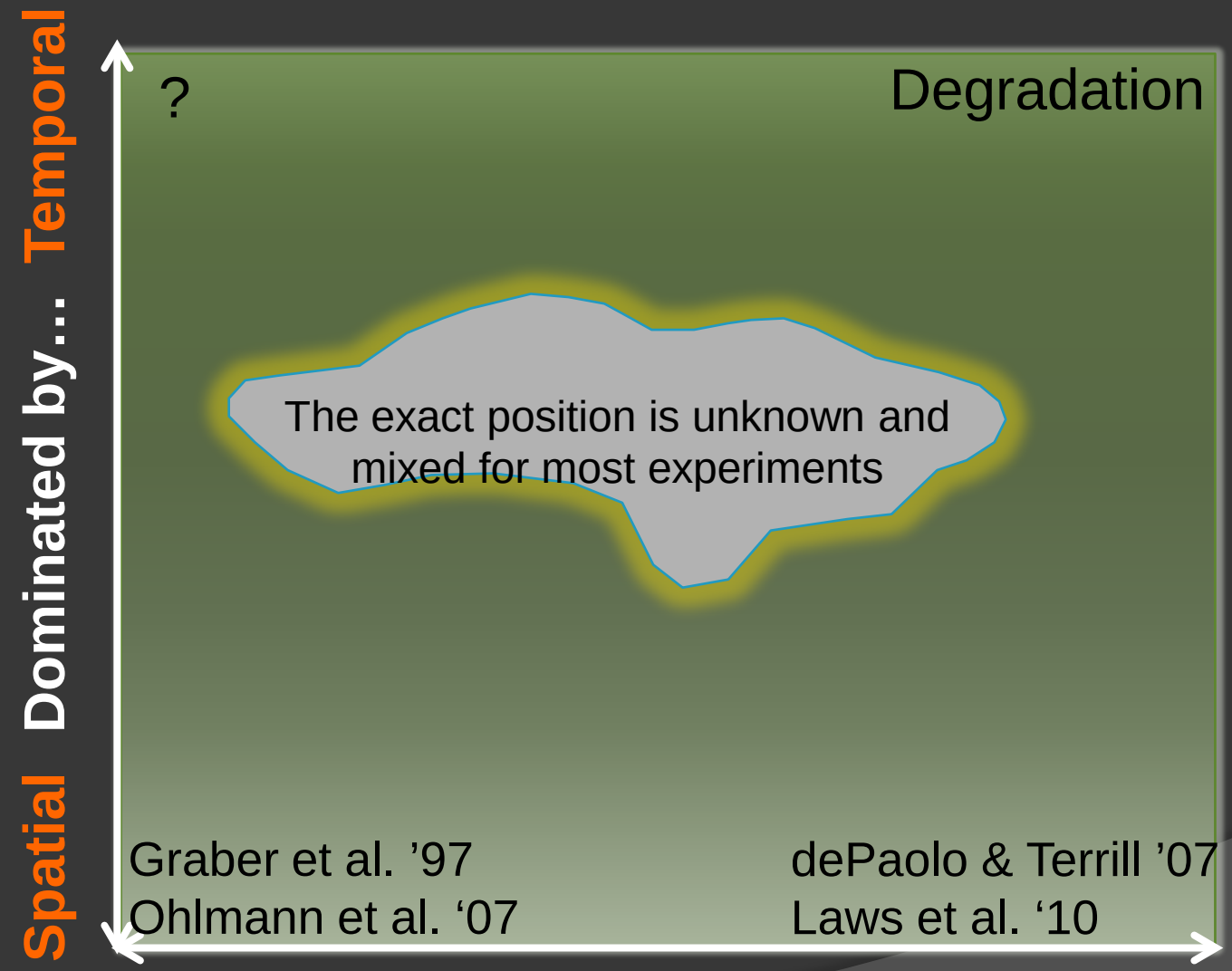
Calibration and Validation of Direction-Finding HF Radar Ocean Surface Current Measurements

Comments here are (mostly) restricted to direction-finding systems and, in particular, to the CODAR SeaSonde system

All systems have “CAL-VAL” requirements and many of them overlap

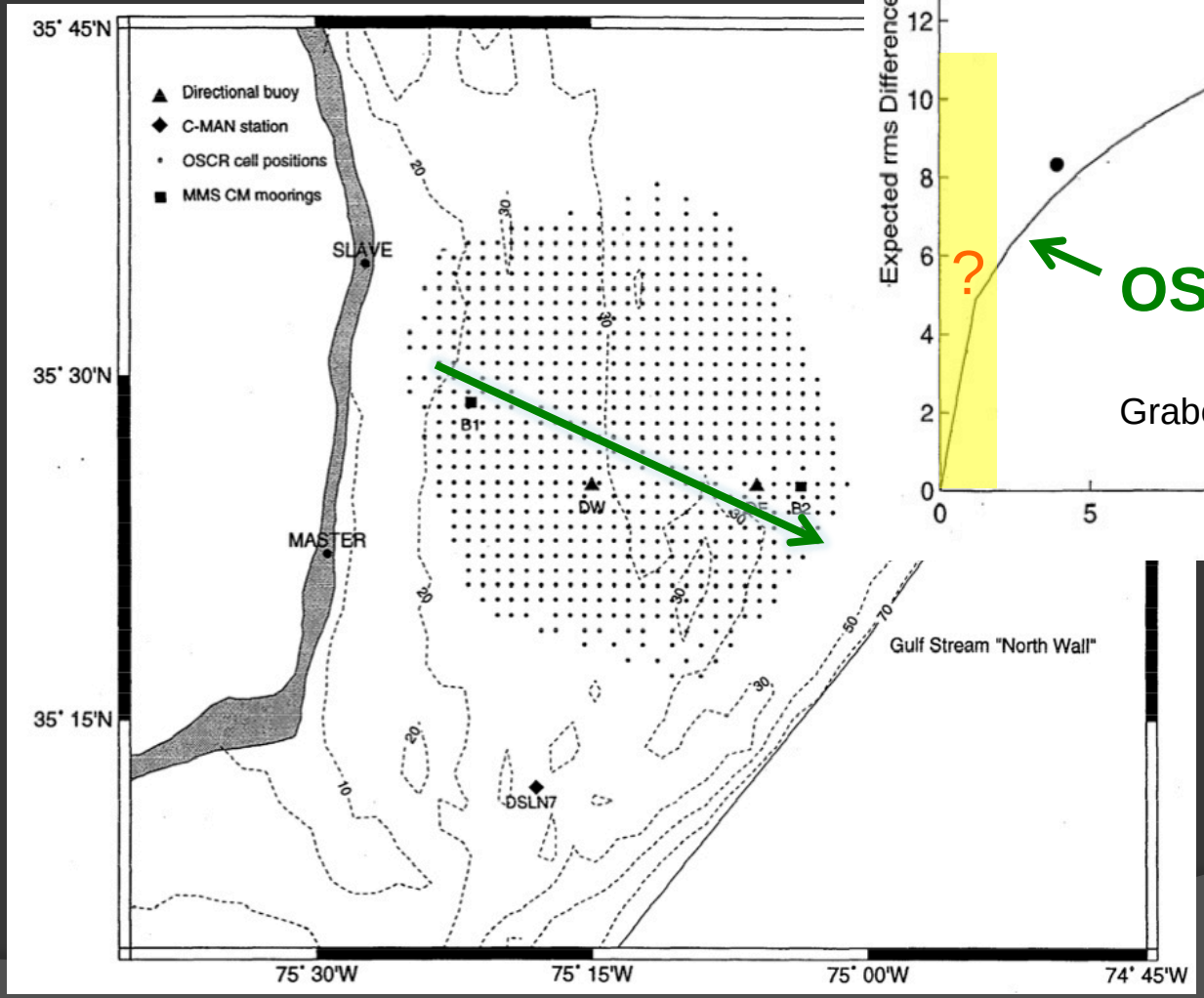
All systems have “CAL-VAL” requirements and many of them overlap

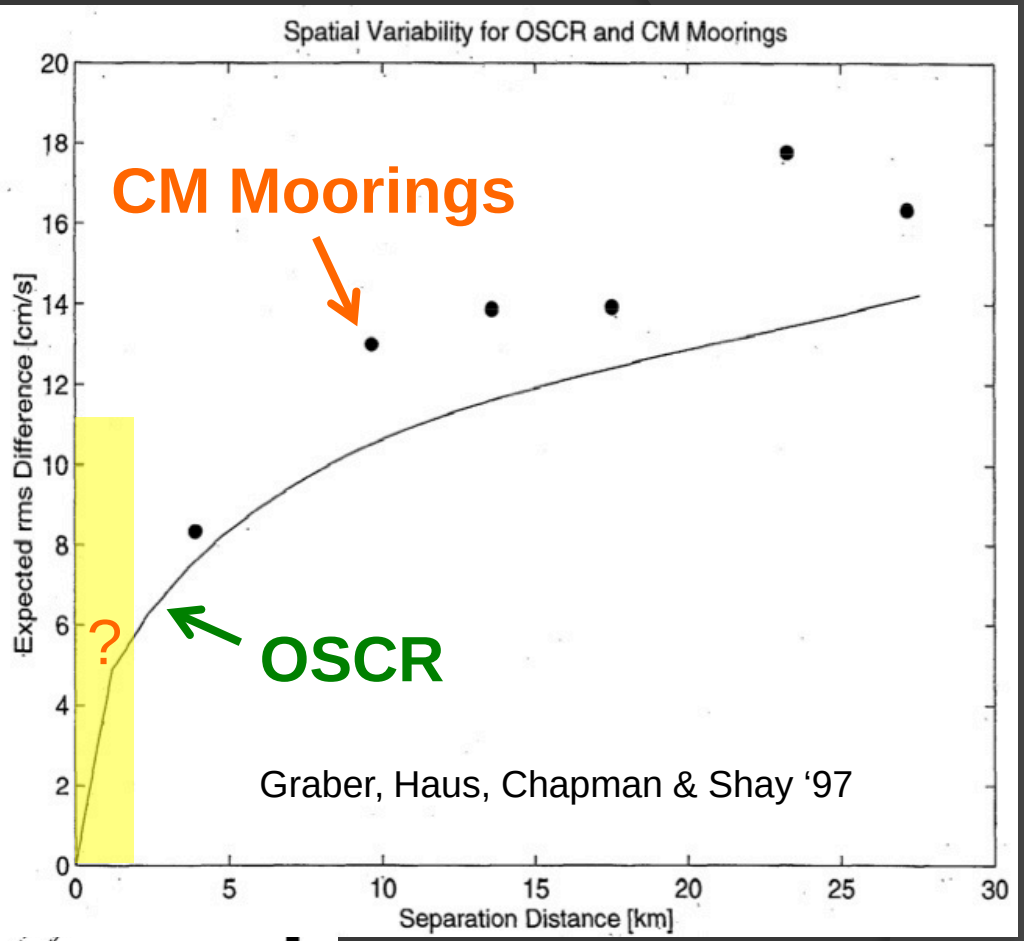
Think of the CAL-VAL problem as the need to identify and quantify errors in the measurements



Super-Grid Spatial

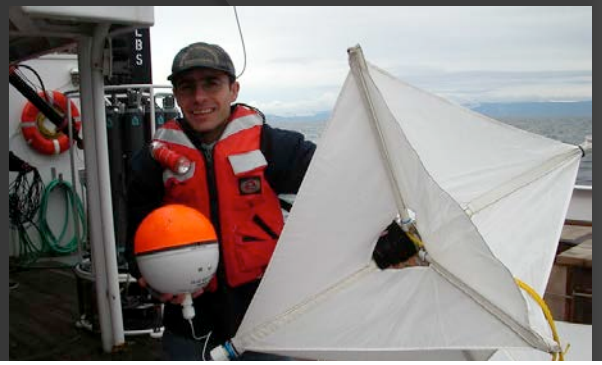
Ocean conditions vary from place to place

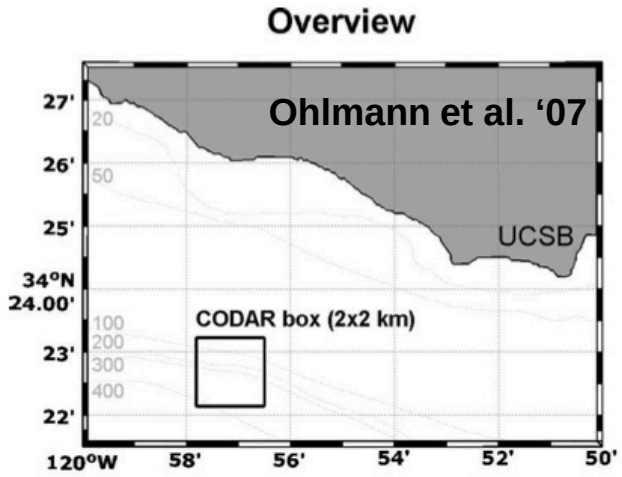


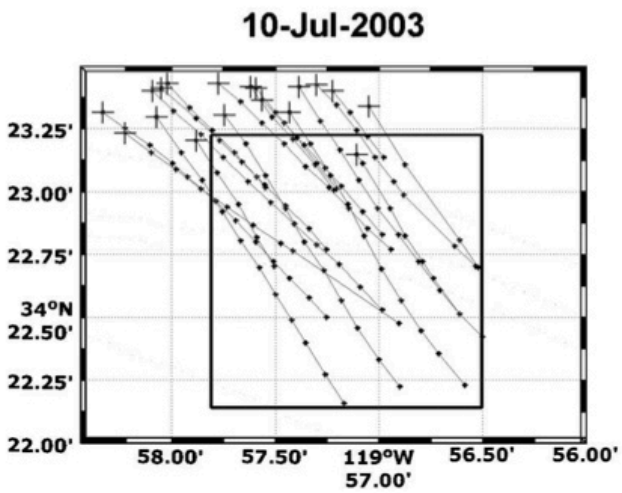


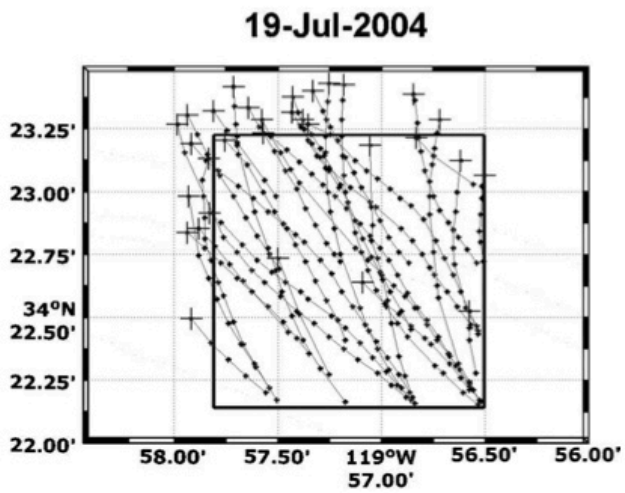
Sub-Grid Spatial

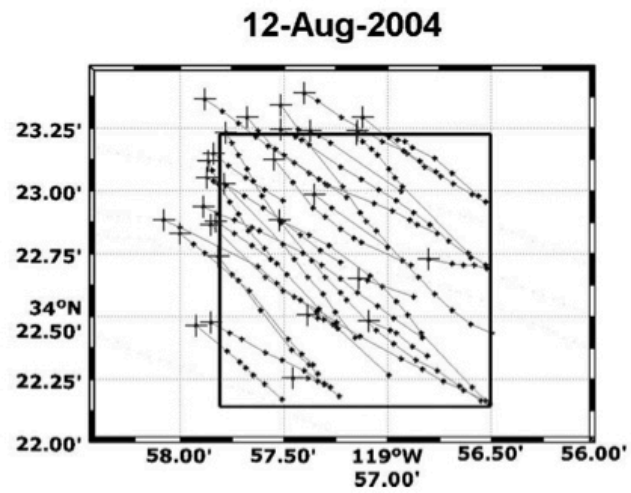
"Catch-and-release" drifter experiments conducted by Carter Ohlmann and others

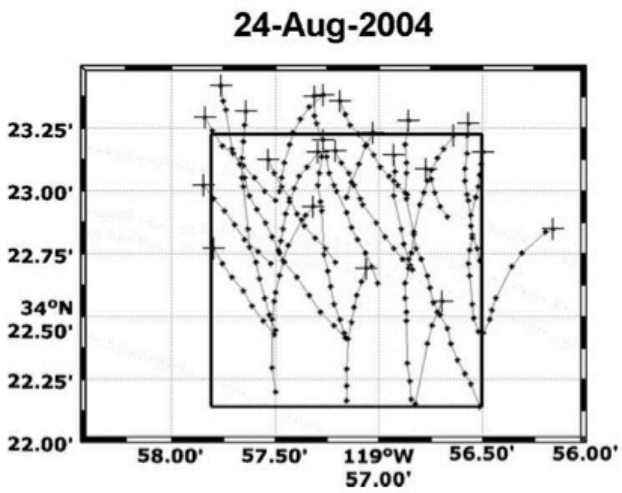


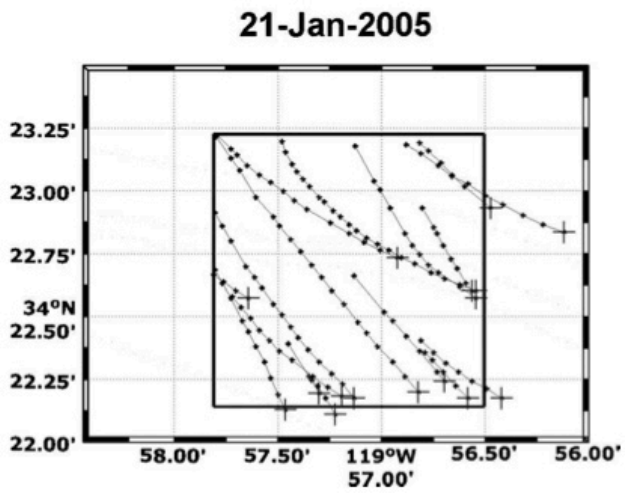






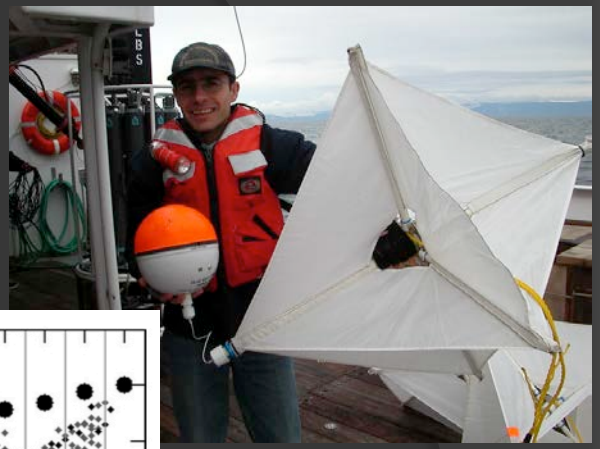


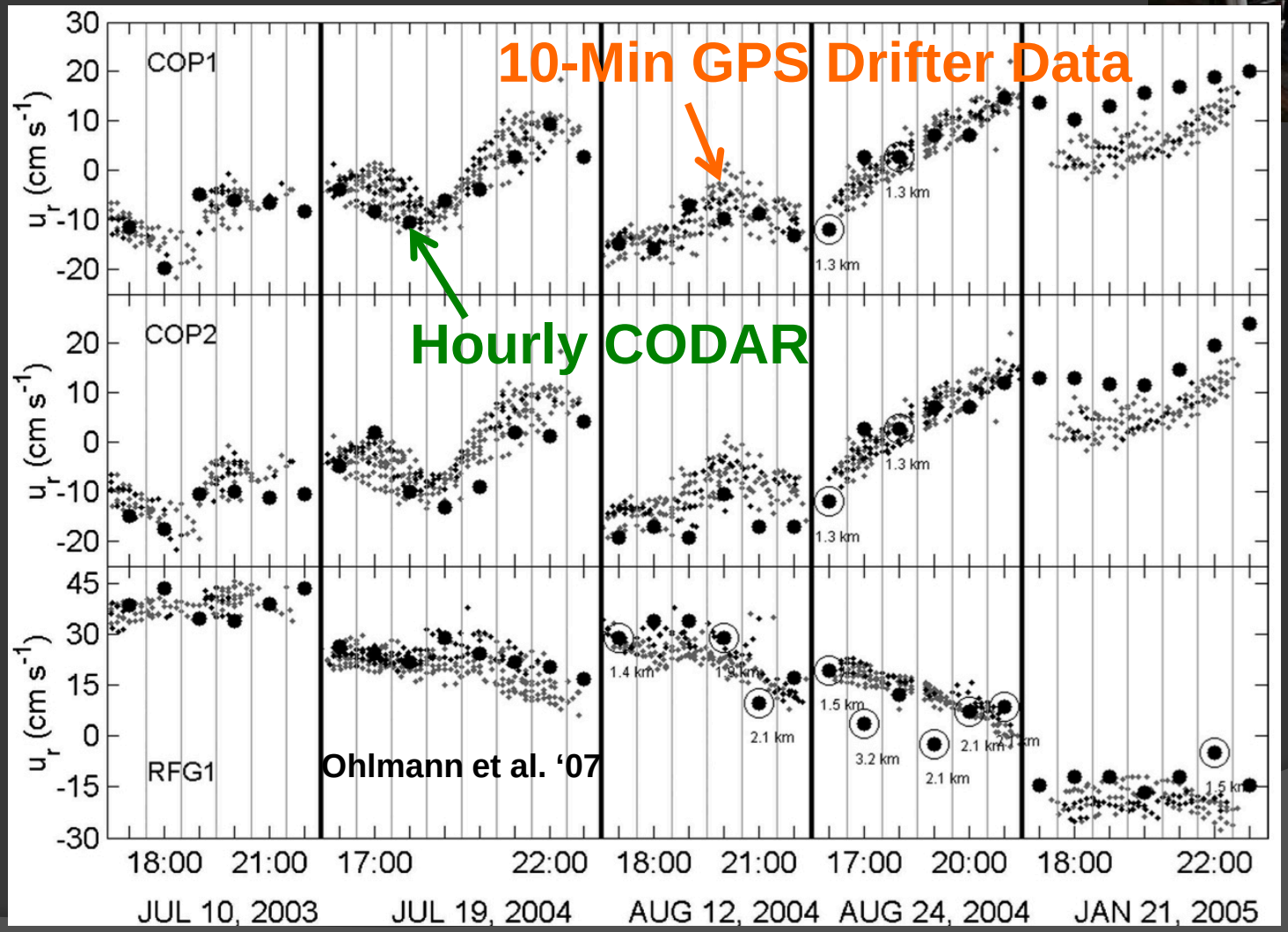


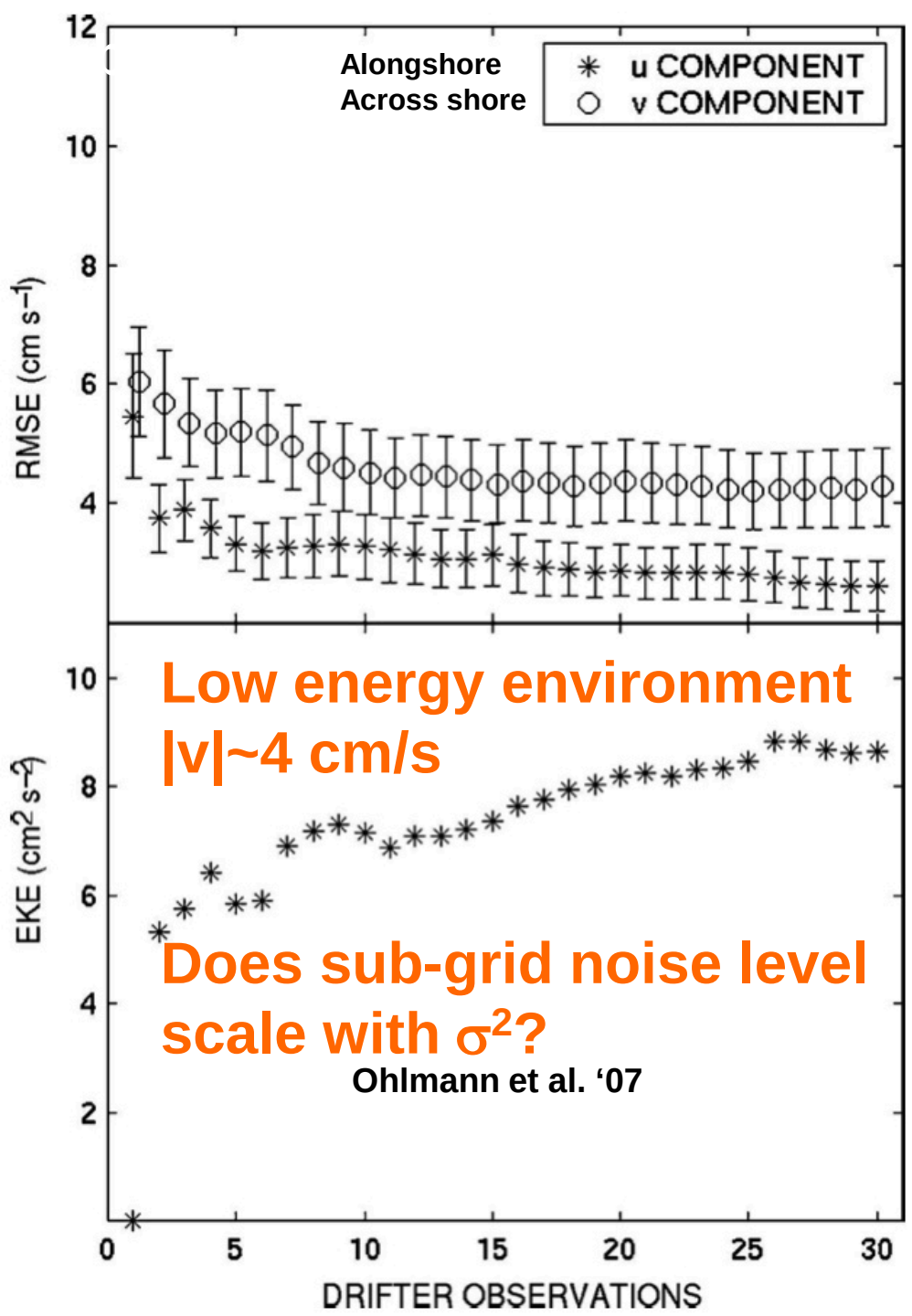


Sub-Grid Spatial

"Catch-and-release" drifter experiments conducted by Carter Ohlmann and others

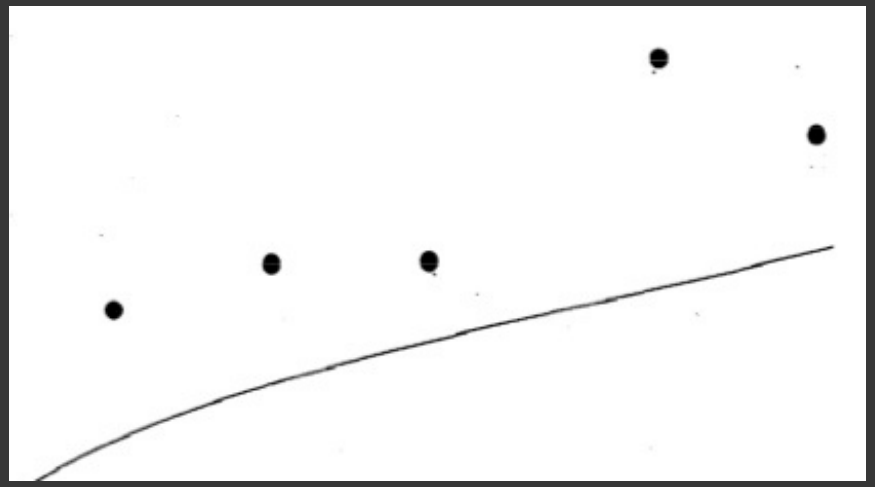






Ohlmann shows very clearly that averaging sub grid scale velocity variability improves the rms comparisons between HF radar and drifter mean velocities

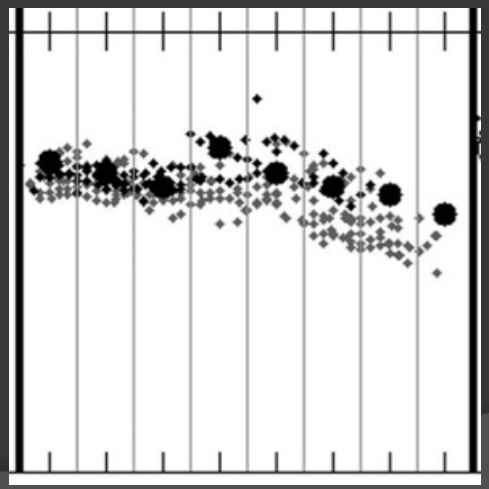
After about 15 independent drifter observations the variance and the rms difference values reach plateaus

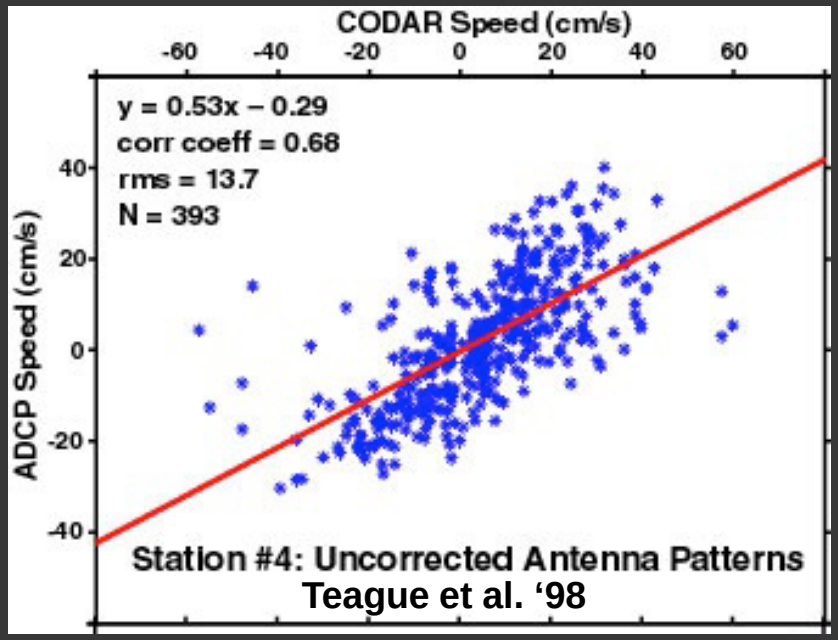


OK so,

Graber et al. (97) and Ohlmann et al. (07) showed that mismatched spatial sampling can explain a large part of the error

What about the instrument-induced error?



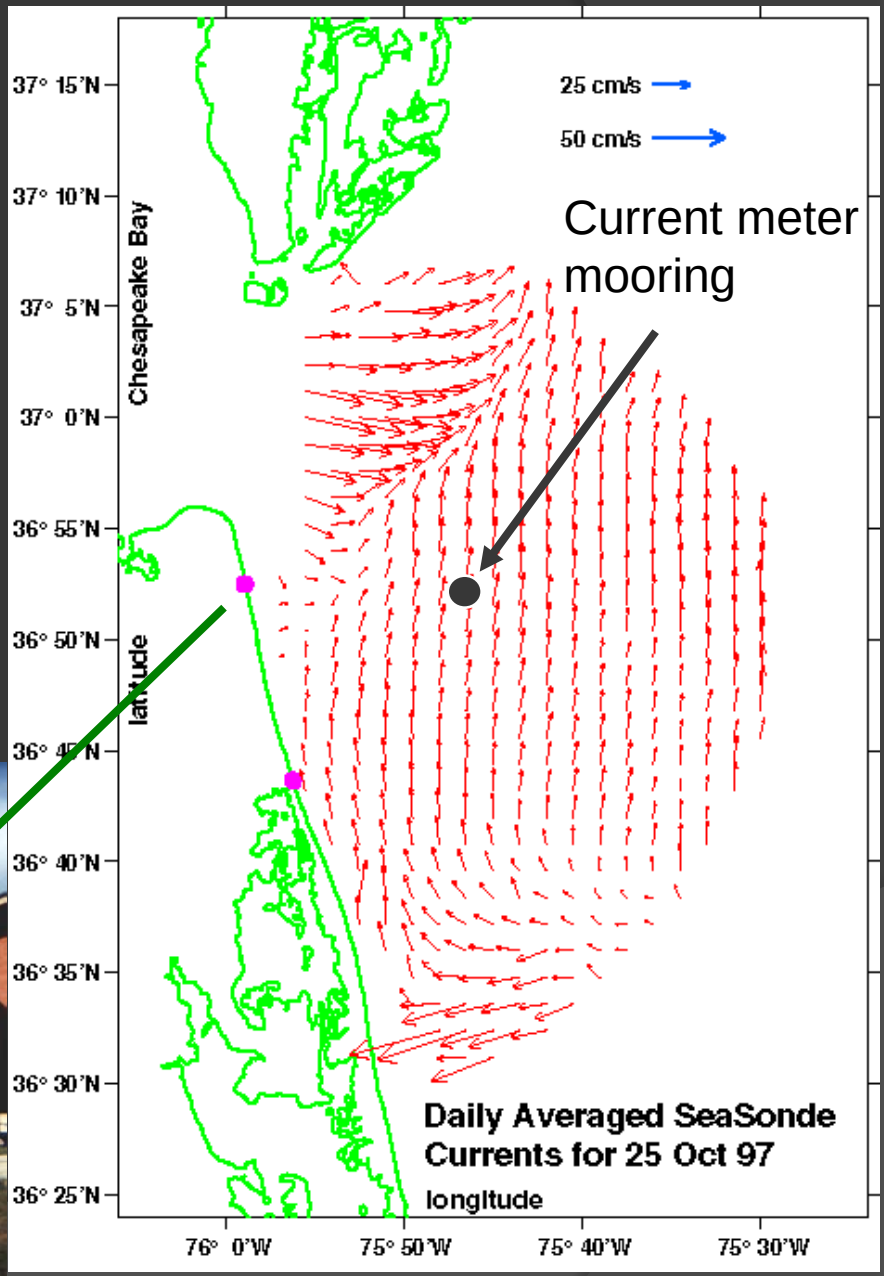


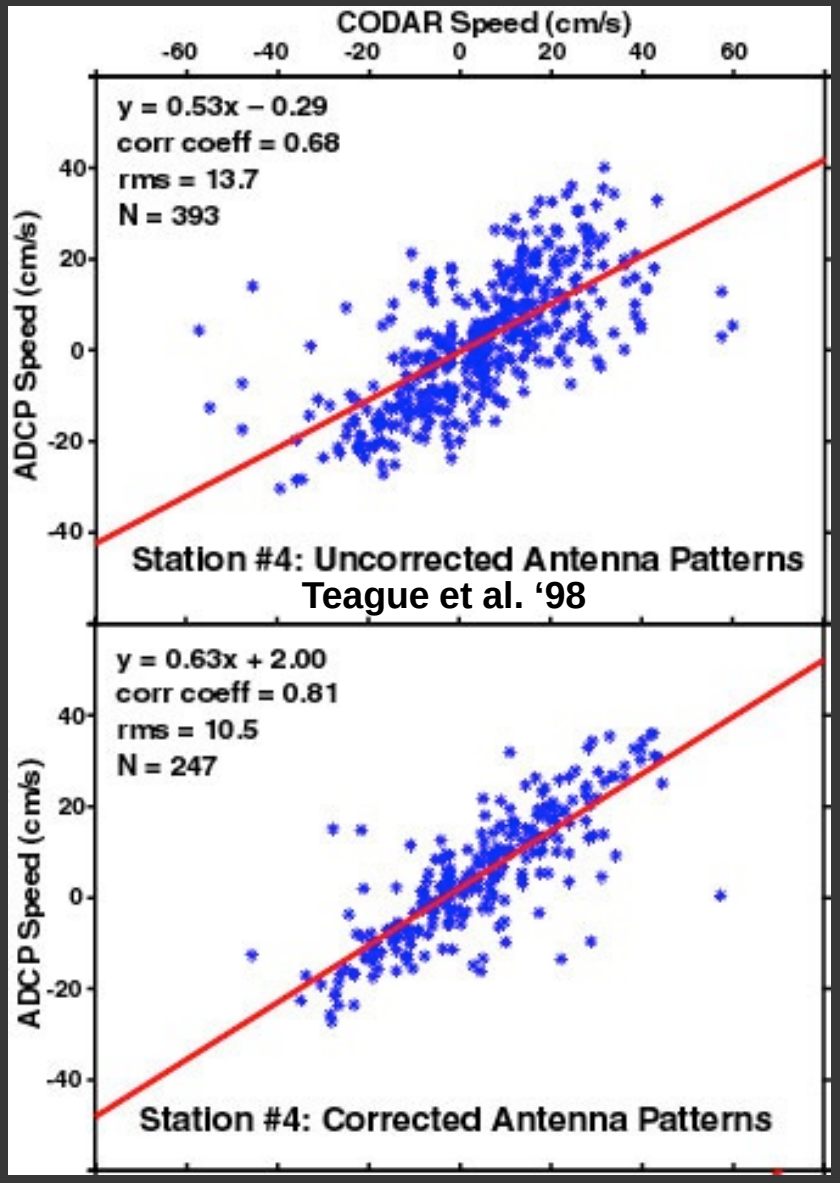
Graber et al. (97) and Ohlmann et al. (07) showed that mismatched spatial sampling can explain a large part of the error

What about the instrument-induced error?

In that arena it is useful to look at radial-to-radial speed comparisons, which eliminate the mapping errors

COPE-3 (1997)

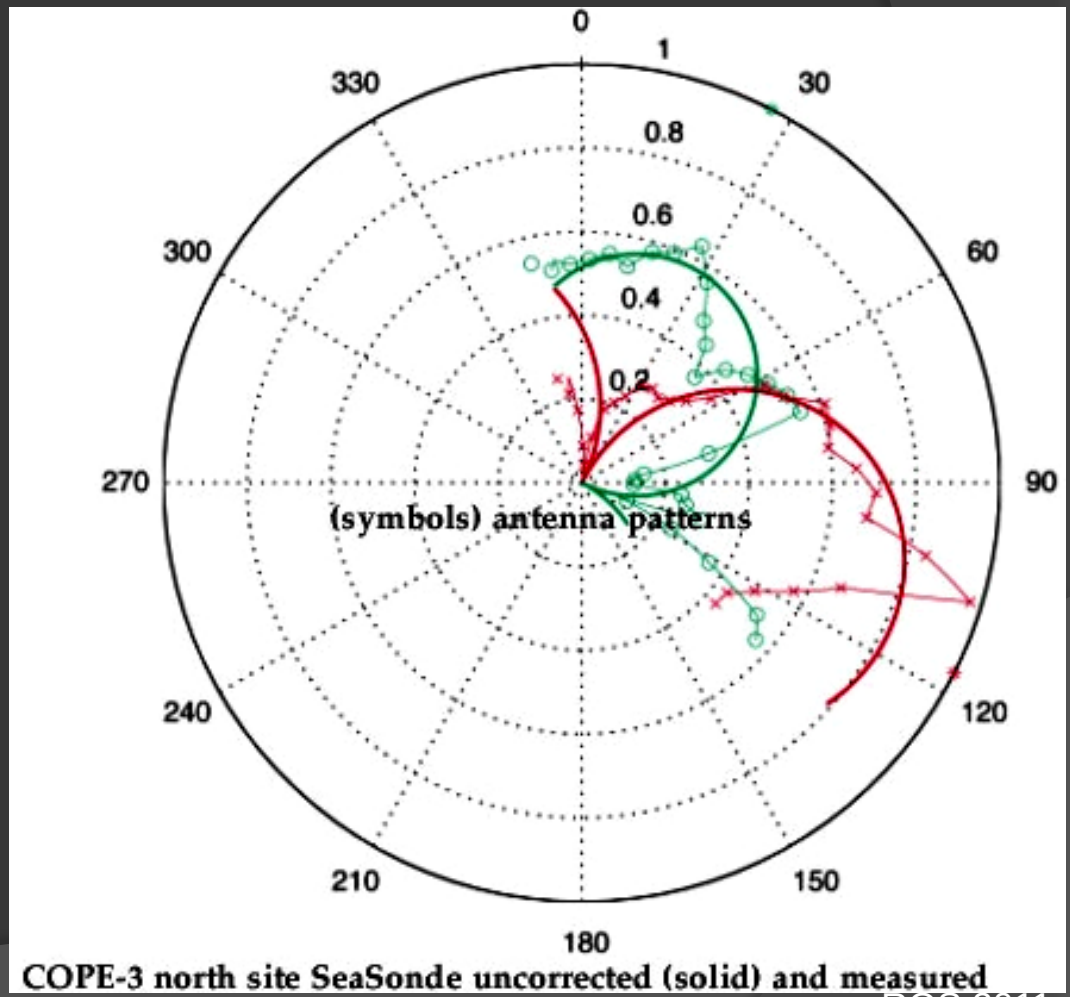


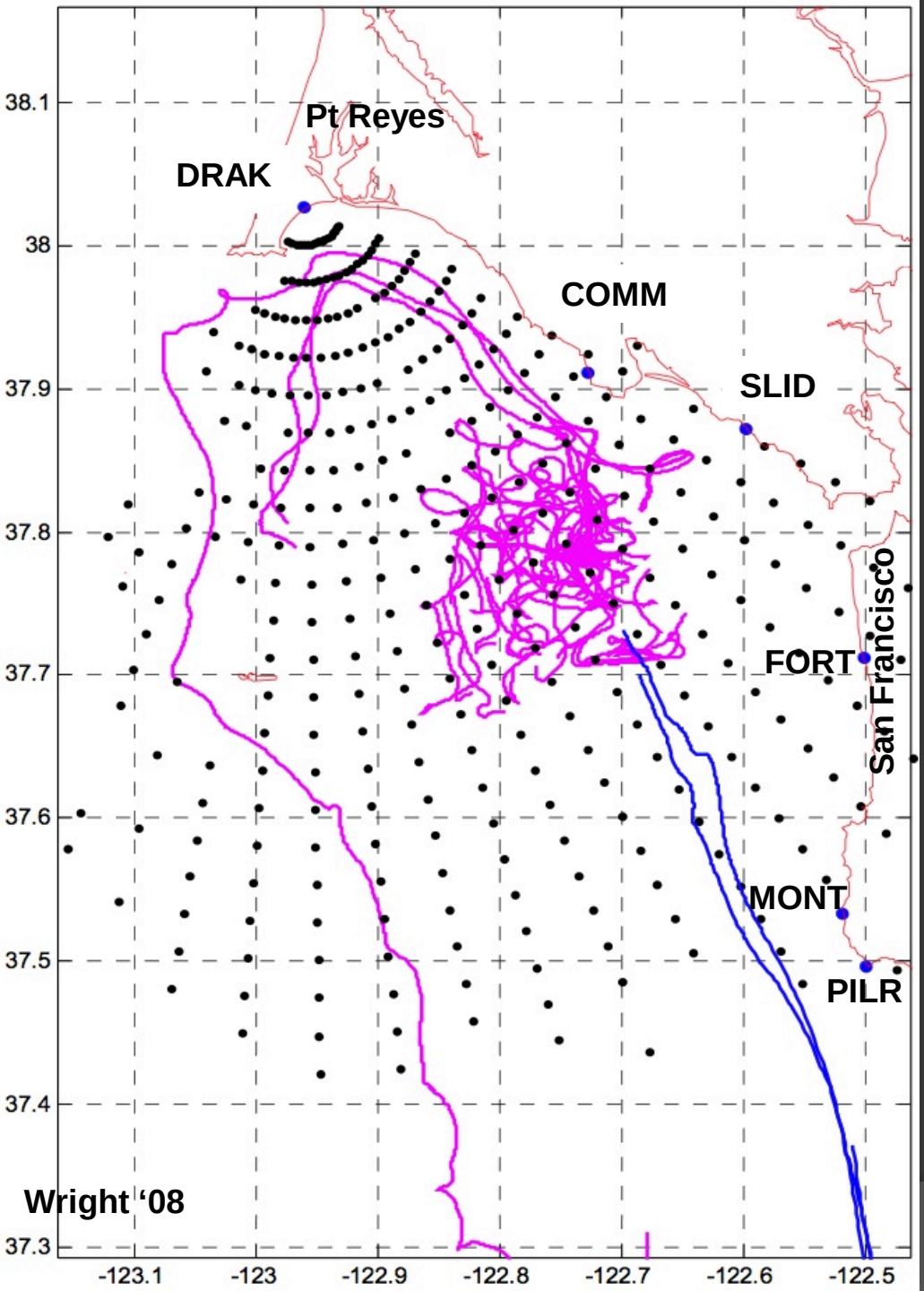


16% better with calibrated patterns (for this case and this grid point)

Direction finding systems depend on knowing the angular response pattern for each co-located antenna element

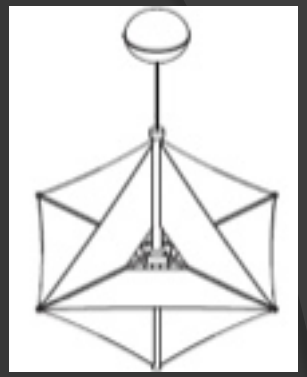
For the SeaSonde system, that is two loops and a monopole element; the loops(theoretically) have a cos(□) response





April 2008 drifter experiment

32 drifters



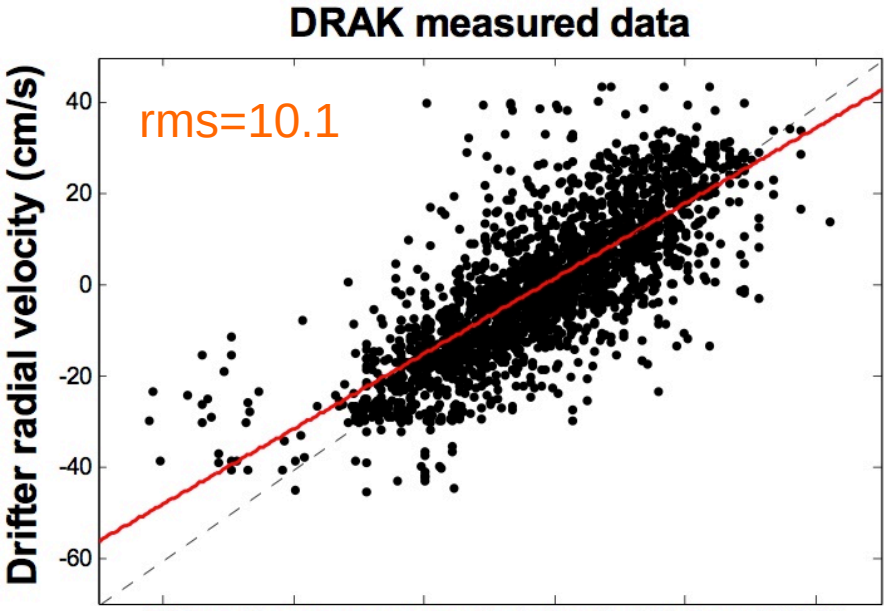
2 vessels

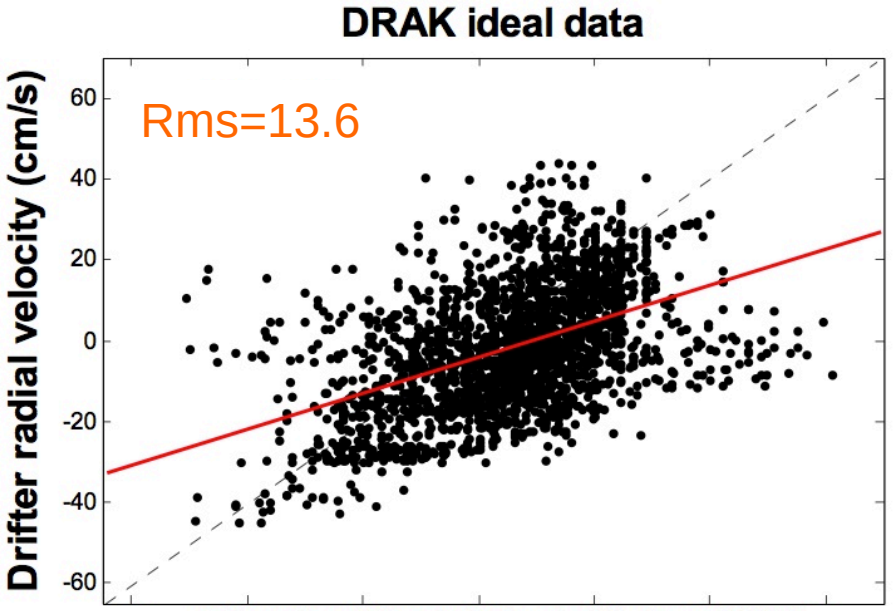
R/V John Martin

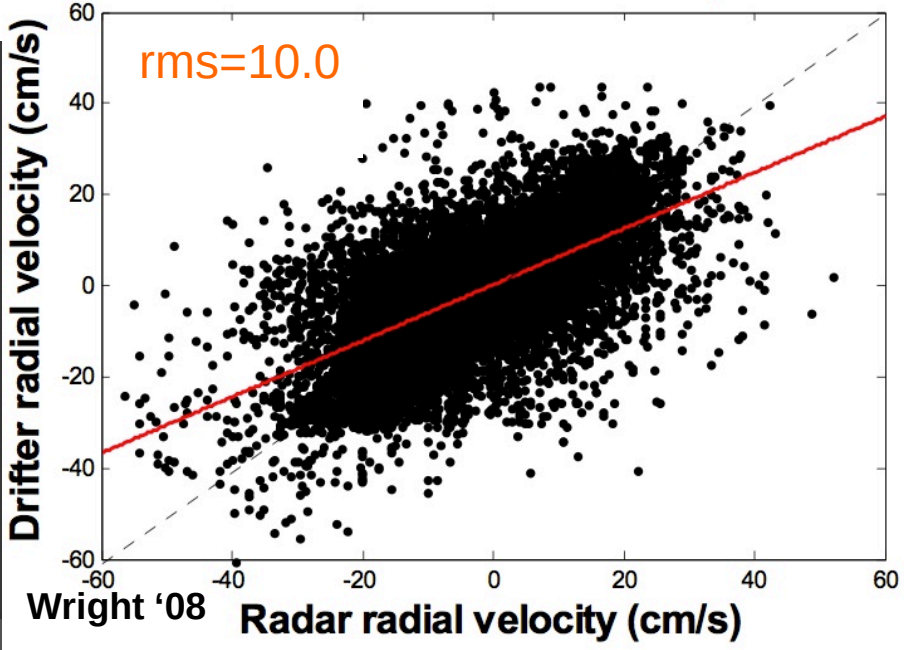
R/V Mussel Point

and zero wind!

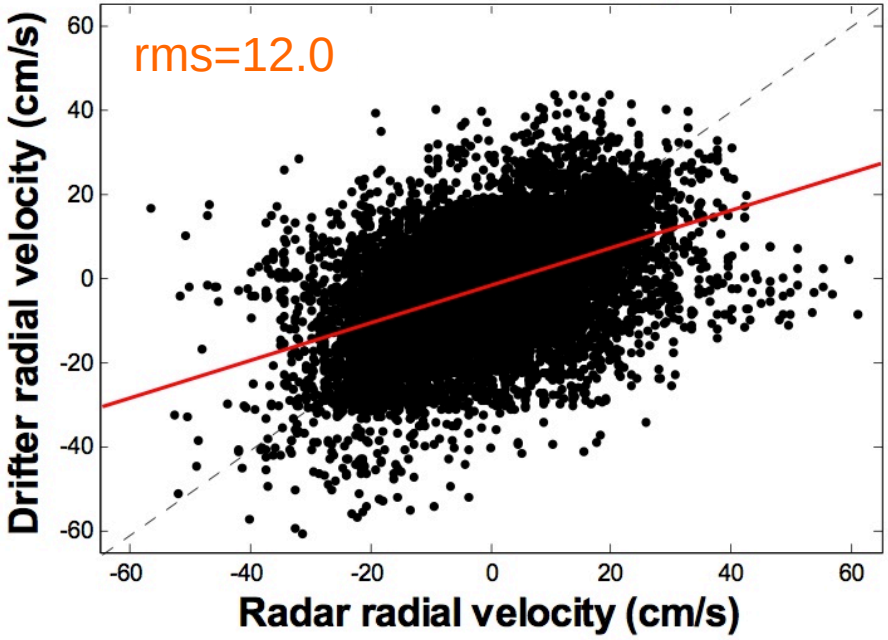
April 2008 drifter experiment



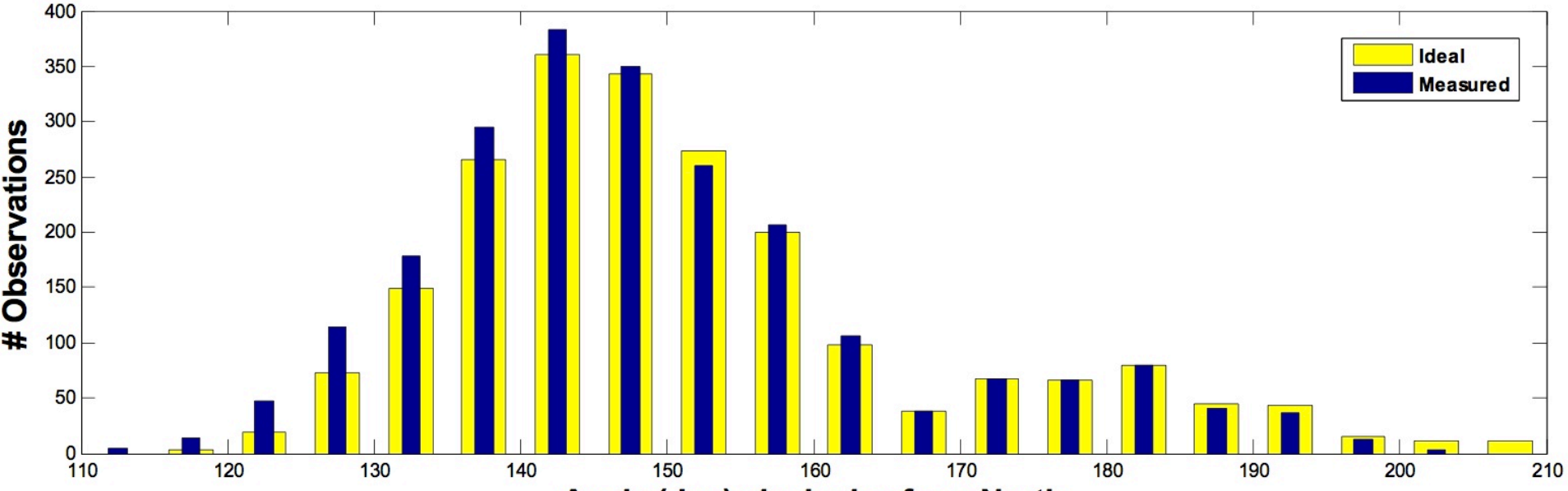


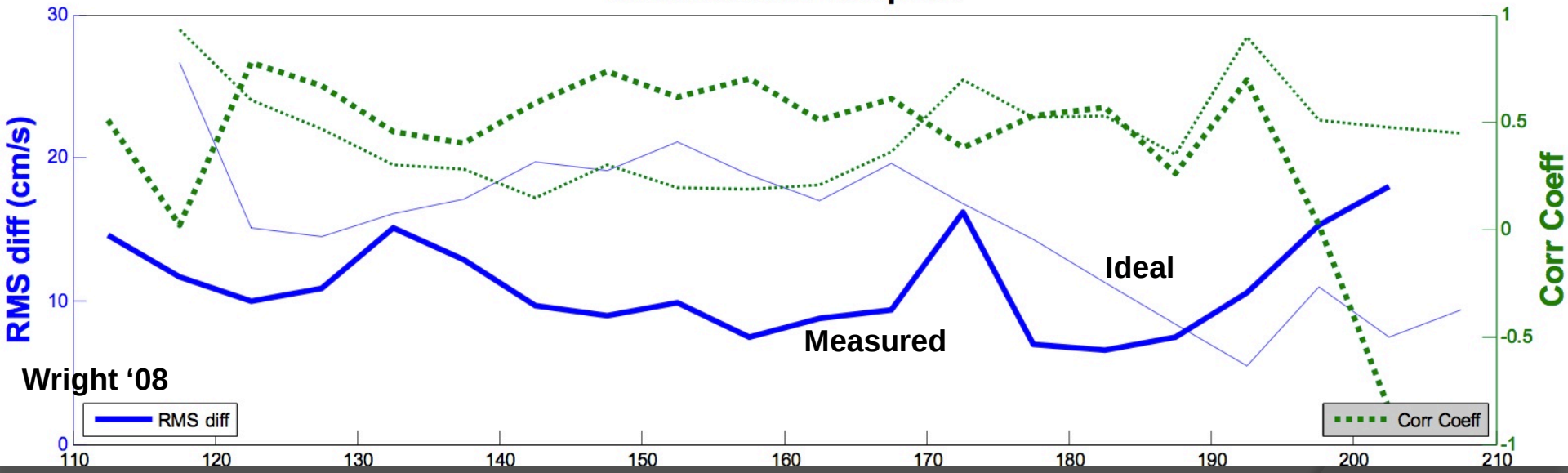


Wright '08



April 2008 drifter experiment

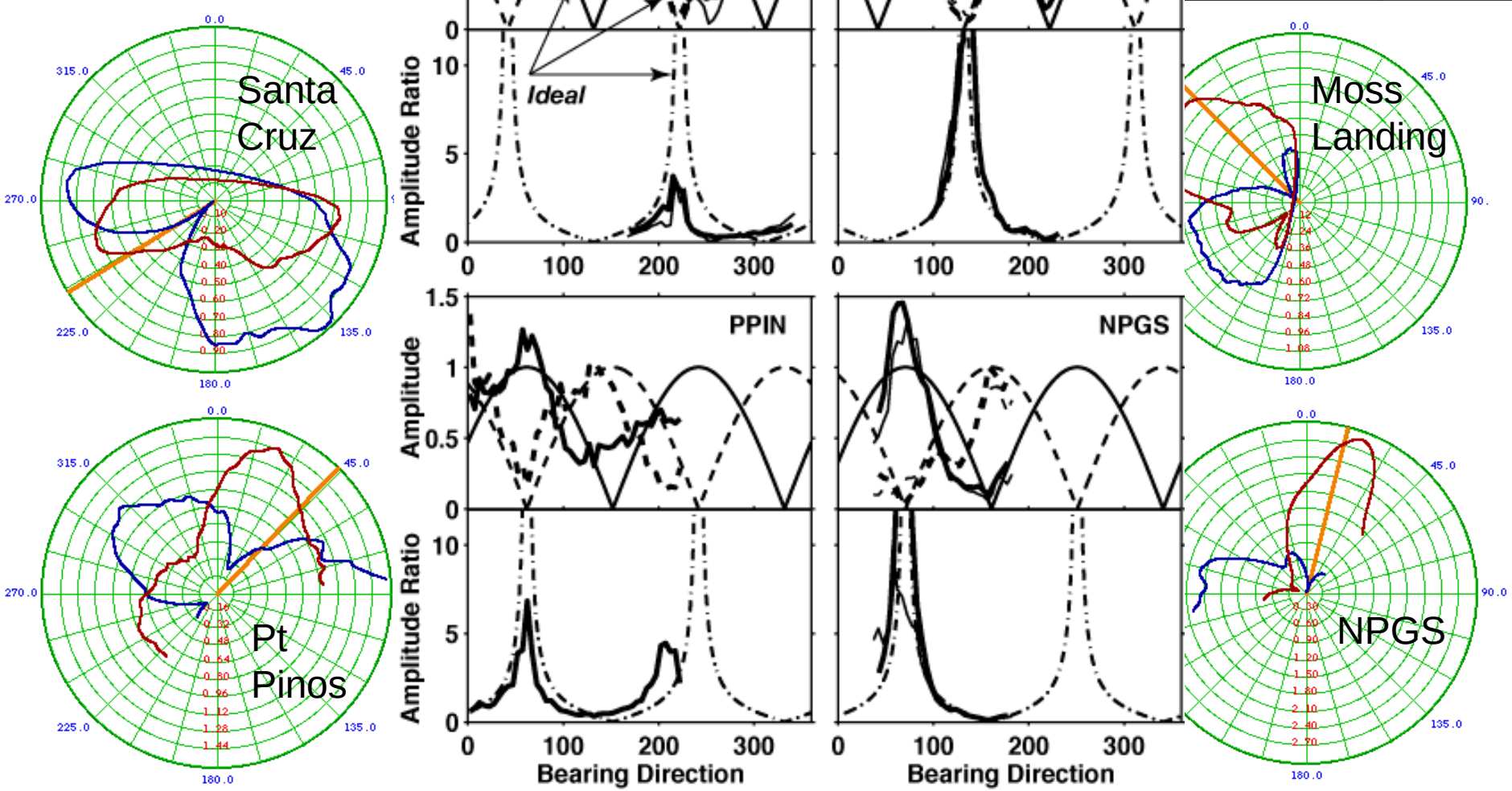




Antenna calibration is accomplished by moving a transponder slowly around an arc ~1 km from the radar site; GPS position and time must also be recorded

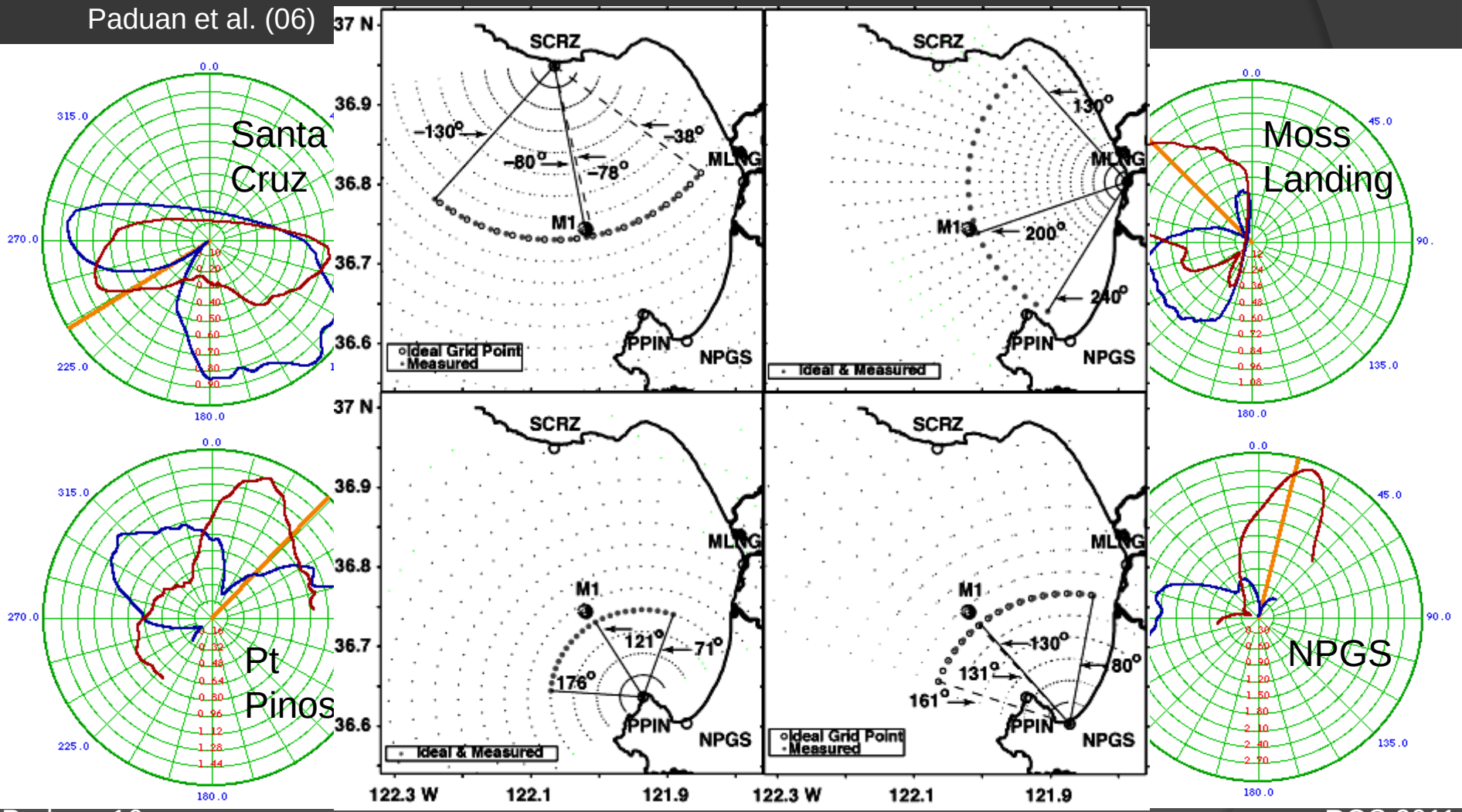
Paduan et al. (06)

~Stable after one year, which was illustrated earlier by Kohut & Glenn (03)



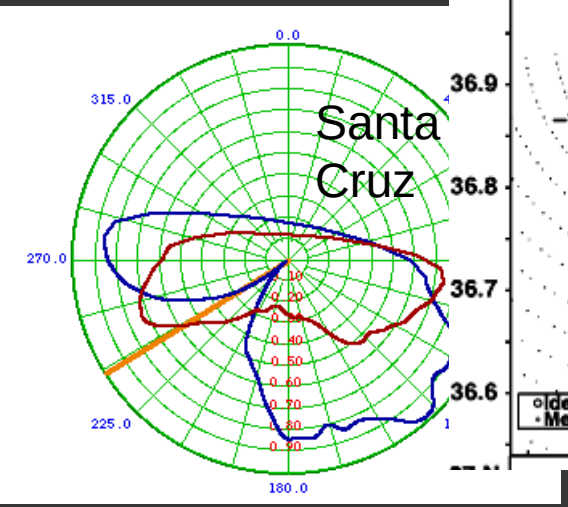
Validation tests against moored ADCP currents can also indicate whether there are errors in the direction finding due, presumably, to the distortions in the antenna patterns;
However, it is impractical to cover many different angles

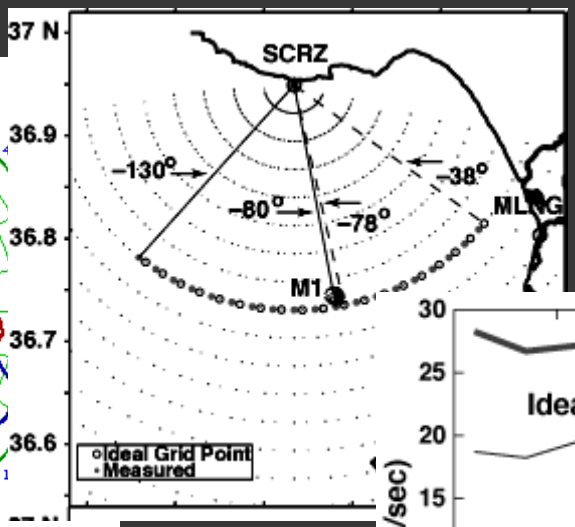
Paduan et al. (06)



Validation tests against moored ADCP currents can also indicate whether there are errors in the direction finding due, presumably, to the distortions in the antenna patterns;
However, it is impractical to cover many different angles

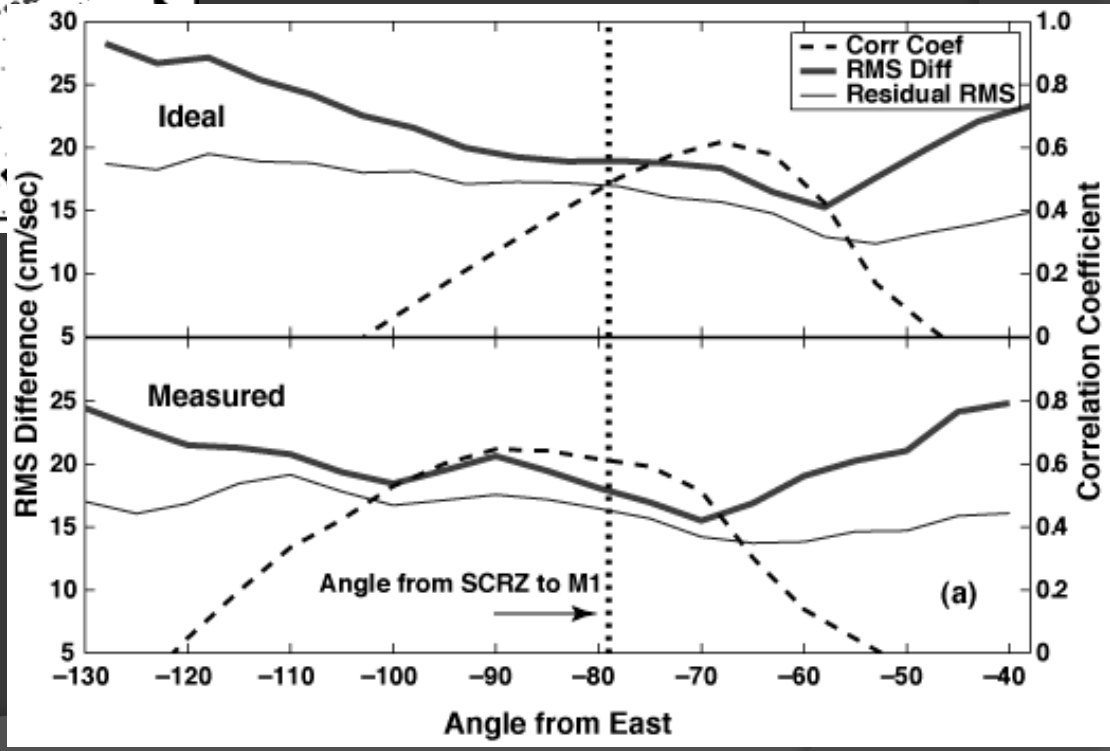
Paduan et al. (06)

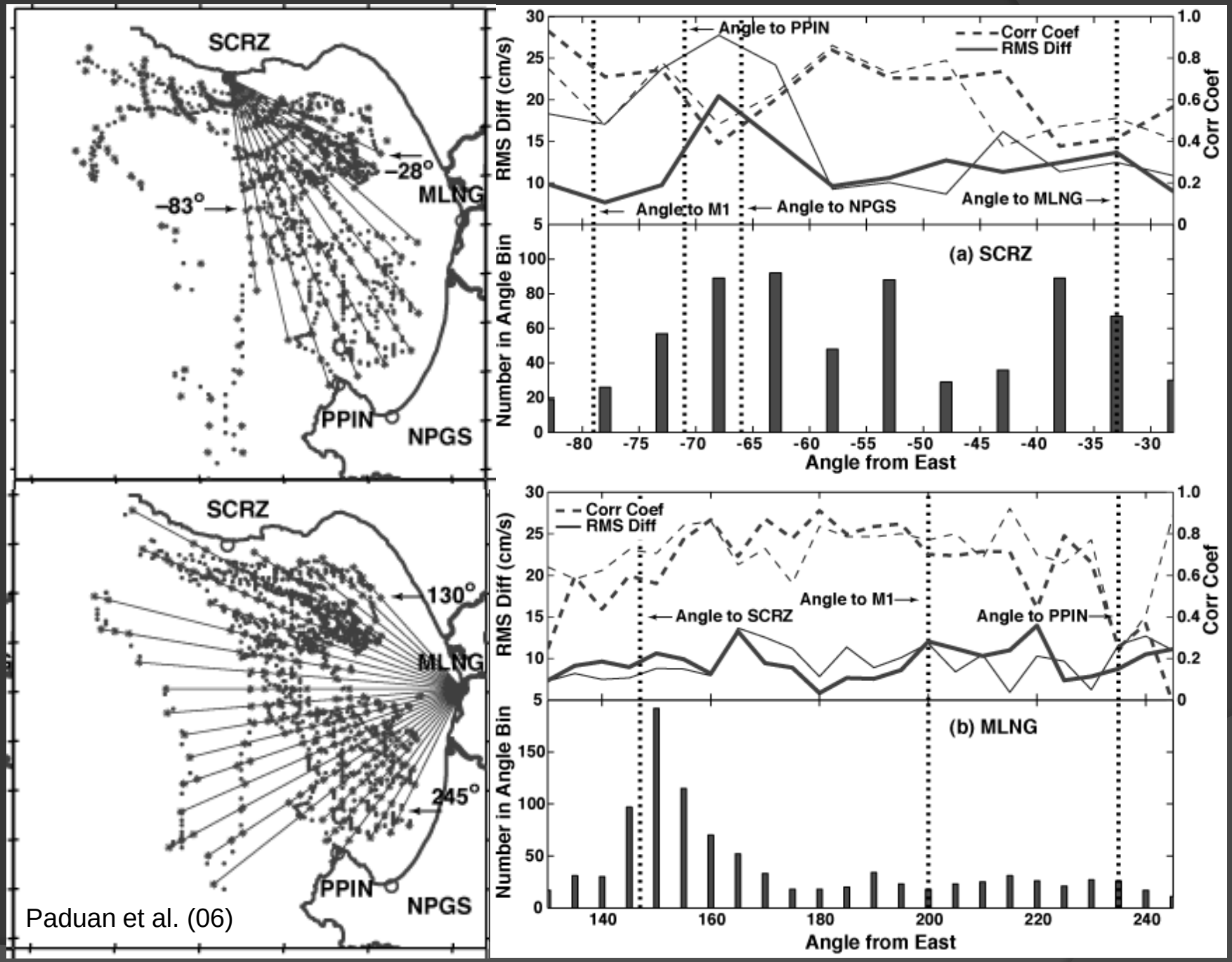




RMS difference and correlation between radar-derived and ADCP radial currents can be computed for all angle bins on the same range cell (arc)

If the minimum RMS difference and maximum correlation do not fall on the angle bin for the mooring location, then the HF radar direction-finding algorithm is likely to be placing the radar observations in the wrong location

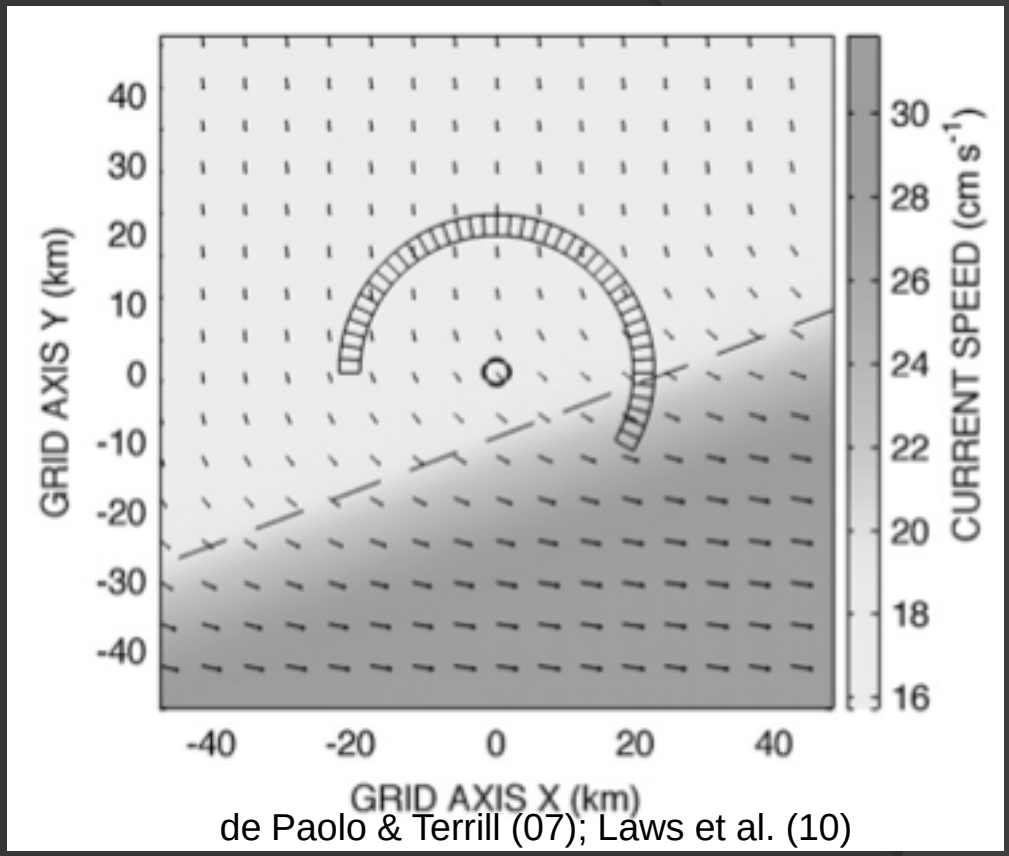




Paduan et al. (06)

Simulations: use simulated Doppler back-scatter spectra– for first-order, Bragg returns only–with a range of surface current patterns and a range of antenna distortion patterns.

The simulated backscattered electromagnetic amplitude from the sea surface is given by:



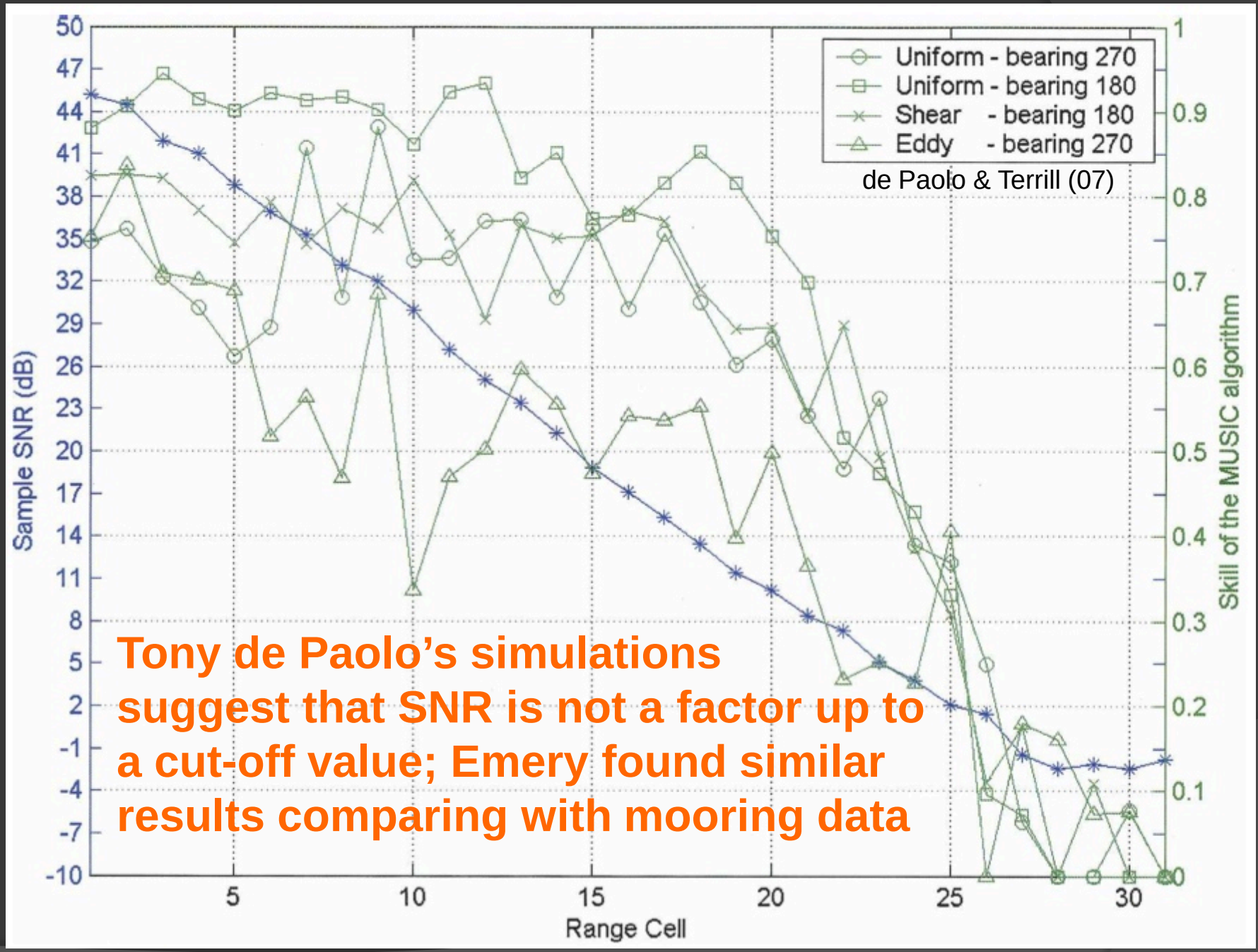
de Paolo & Terrill (07); Laws et al. (10)

$$E = \gamma \exp(i\omega_r t)[A_+ \exp(-i\Delta\omega_- t) + A_- \exp(-i\Delta\omega_+ t)]$$

$$\Delta\omega_\pm = \omega_c \pm \omega_B$$

Amplitudes are zero-mean, Gaussian random variables whose variances are proportional to the spectral energy of the resonant waves. The wave spectra are assumed to follow the cardioid function of the equilibrium waves:

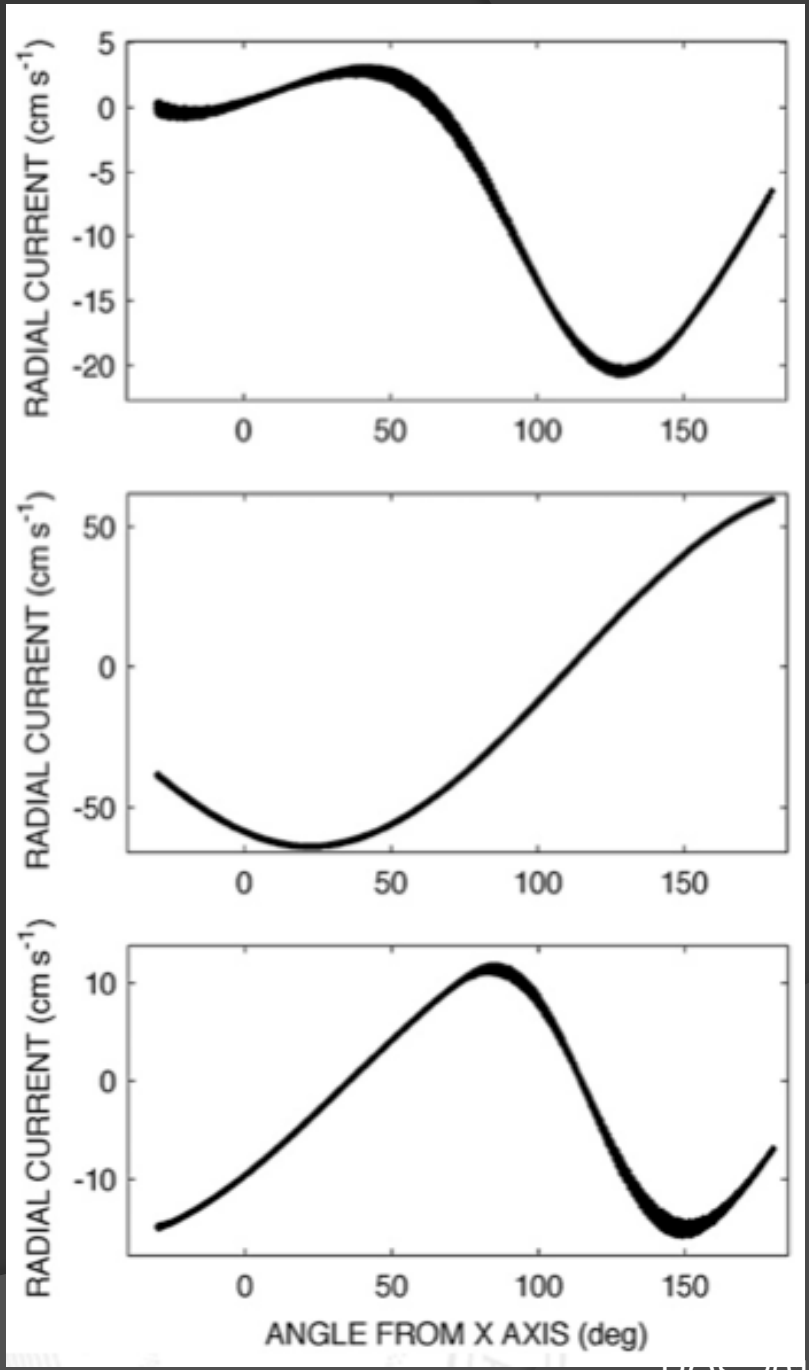
$$G(\theta_r, \theta_w) = \alpha + (1-\alpha)\cos^4\left(\frac{\theta_r - \theta_w}{2}\right)$$


Uniform - bearing 270
Uniform - bearing 180
Shear - bearing 180
Eddy - bearing 270
de Paolo & Terrill (07)
Sample SNR (dB)
Skill of the MUSIC algorithm
Range Cell
50
47
44
41
38
35
32
29
26
23
20
17
14
11
8
5
2
-1
-4
-7
-10
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
5
10
15
20
25
30
Tony de Paolo's simulations suggest that SNR is not a factor up to a cut-off value; Emery found similar results comparing with mooring data

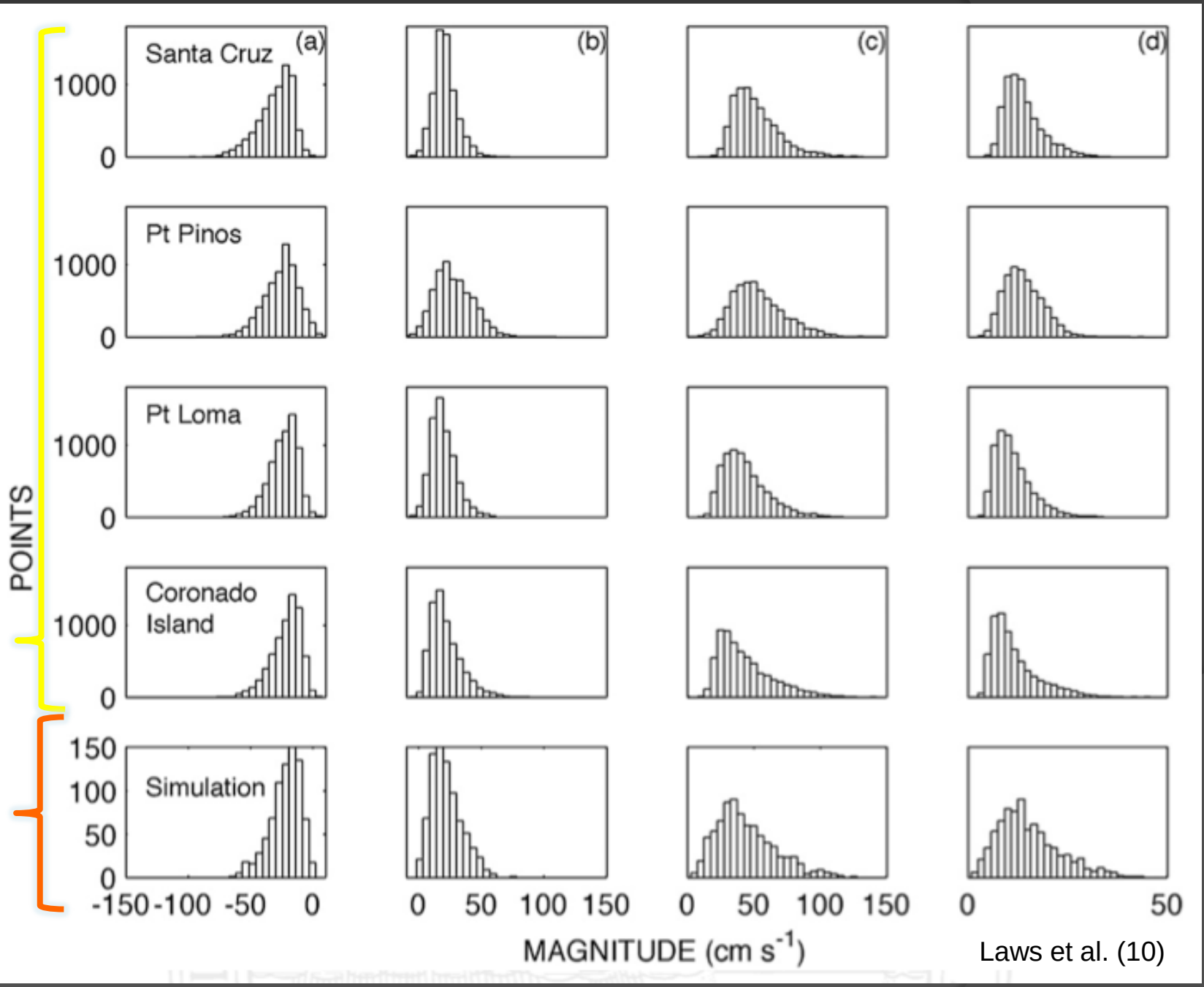
Laws et al. (10) used range of current scenarios can be created by superposing a downwind current at 3% of the wind speed with a linear sheared flow

Varying the wind direction and shear magnitude leads to a range of Doppler parameters statistically similar to those found at several U.S. West Coast HF radar sites

Each simulated case is formatted to be read and processed by Codar's standard radial processing software



Observed and simulation statistics around a range arc



Observed

Simulated

Laws et al. (10)

The reference case-Ideal Antenna Pattern Simulation

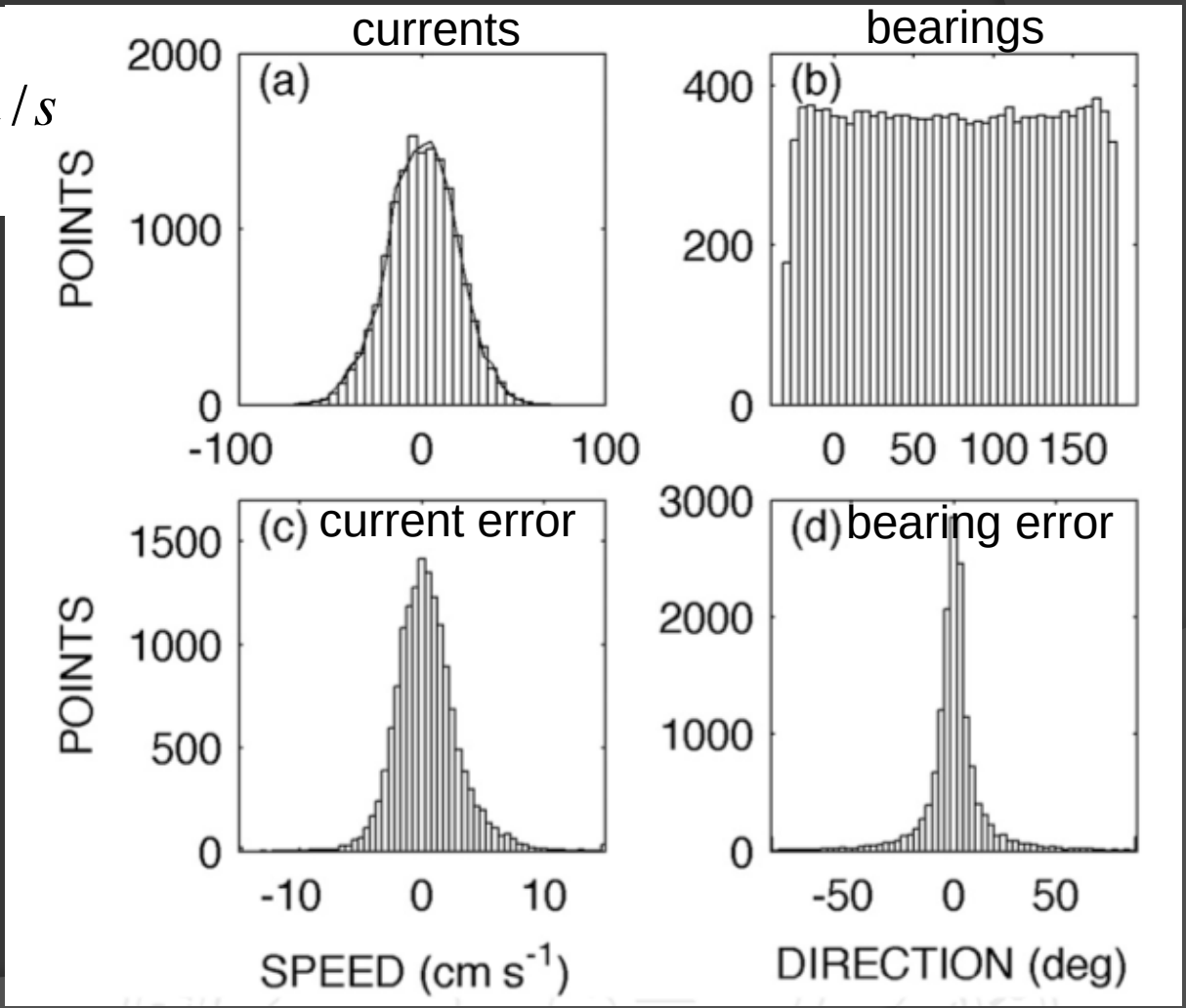
Parameters mimicked a 12.15 MHz SeaSonde configuration for which the velocity (Doppler) resolution is:

$$\Delta v = \frac{\lambda_r}{2T} = \frac{c}{2n\Delta t f_r} = 4.82 cm/s$$

Laws et al. (10)

RMS Current Error is 2.9 *cm/s* i.e., slightly better than the velocity precision

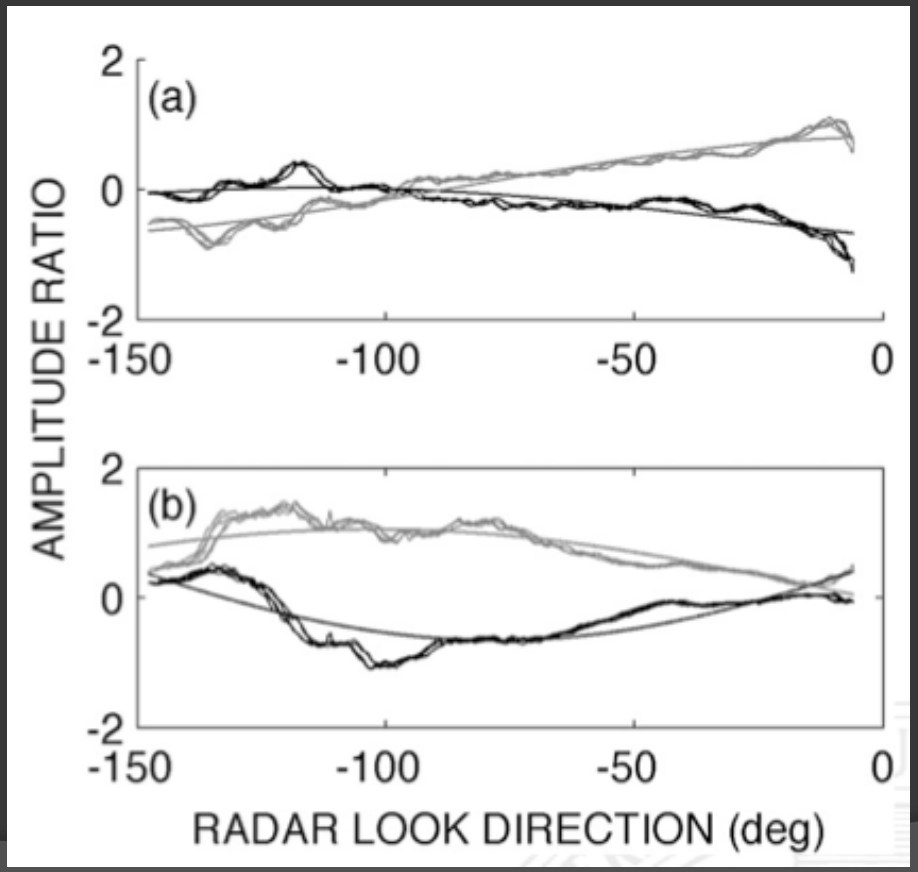
Next, effects of antenna pattern distortions can be investigated



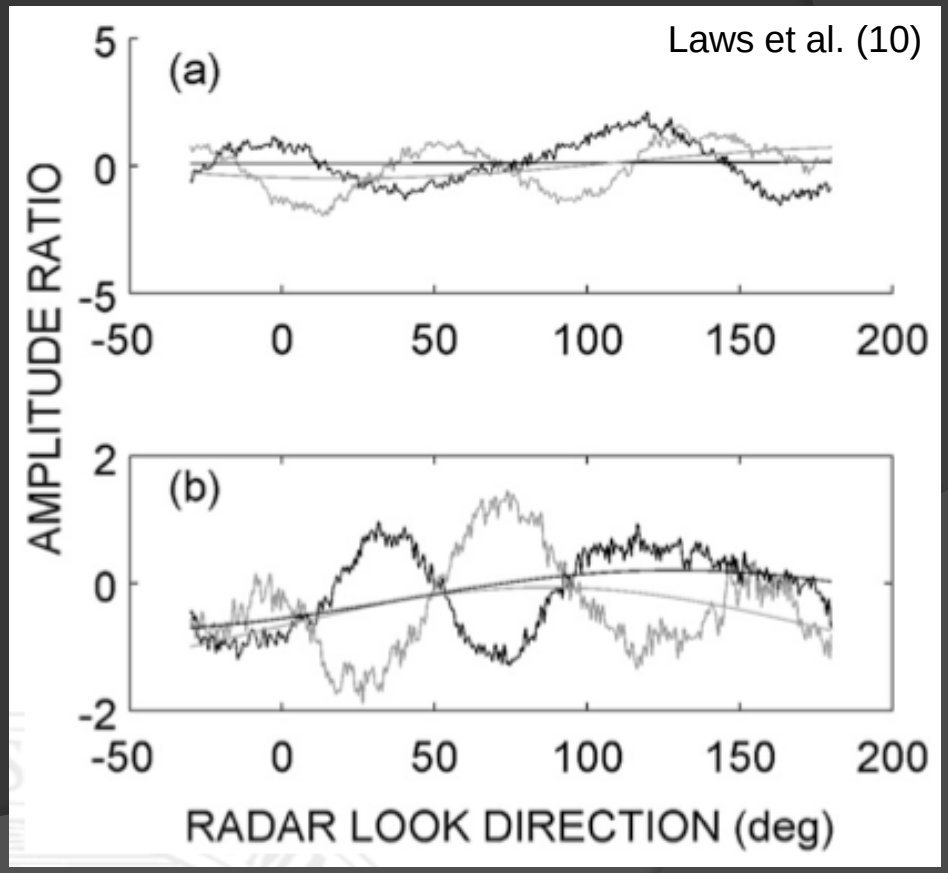
How distorted is *your* pattern?

A single pattern distortion parameter can be created by comparing the RMS difference between the observed pattern and a “mildly distorted” cosine function

Modest Distortion

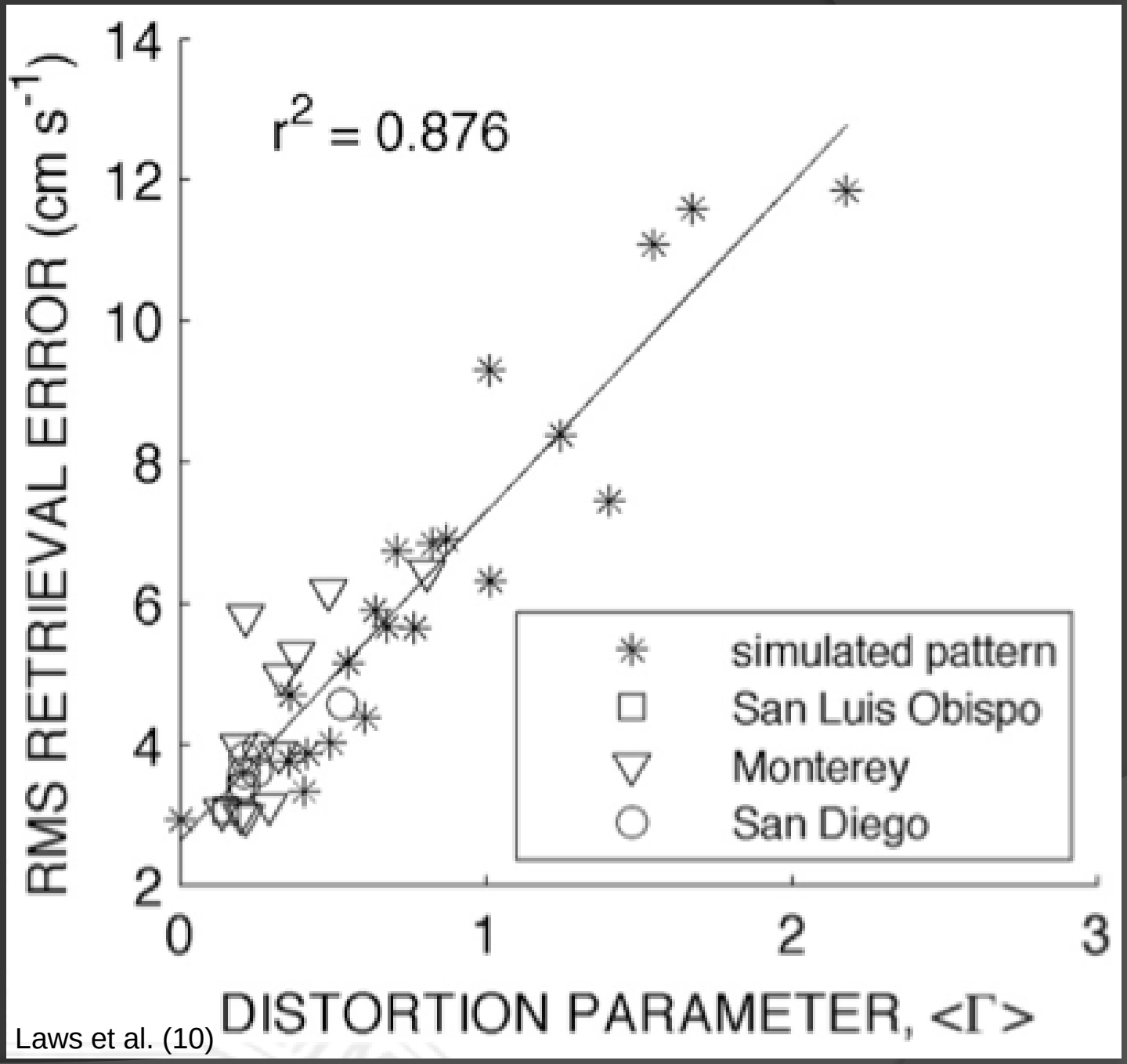


Severe Distortion



Hundreds of simulations for 40 different observed antenna patterns and for simulated antenna patterns

Note that none of the observed patterns fell within the largest distortion values

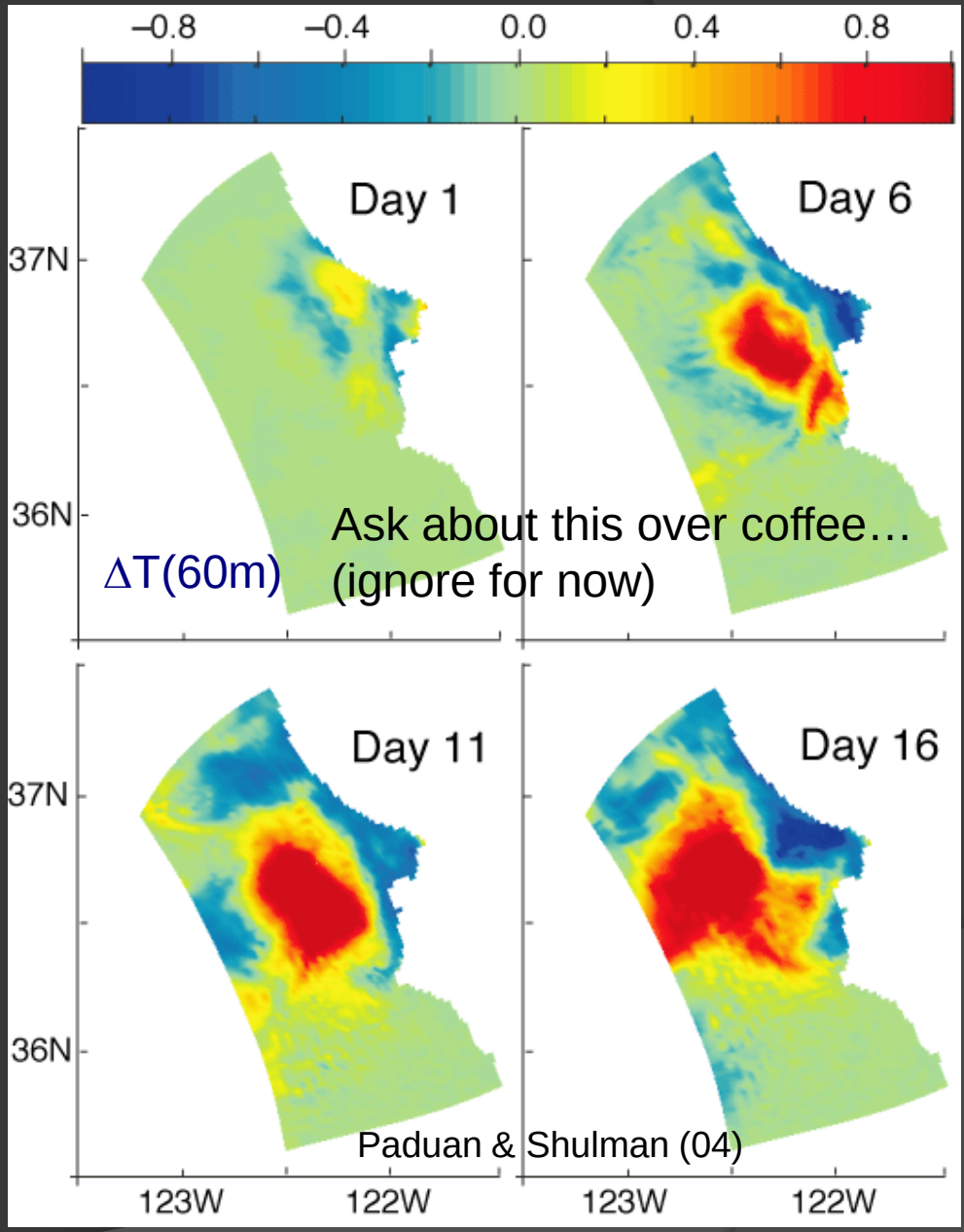


Laws et al. (10)

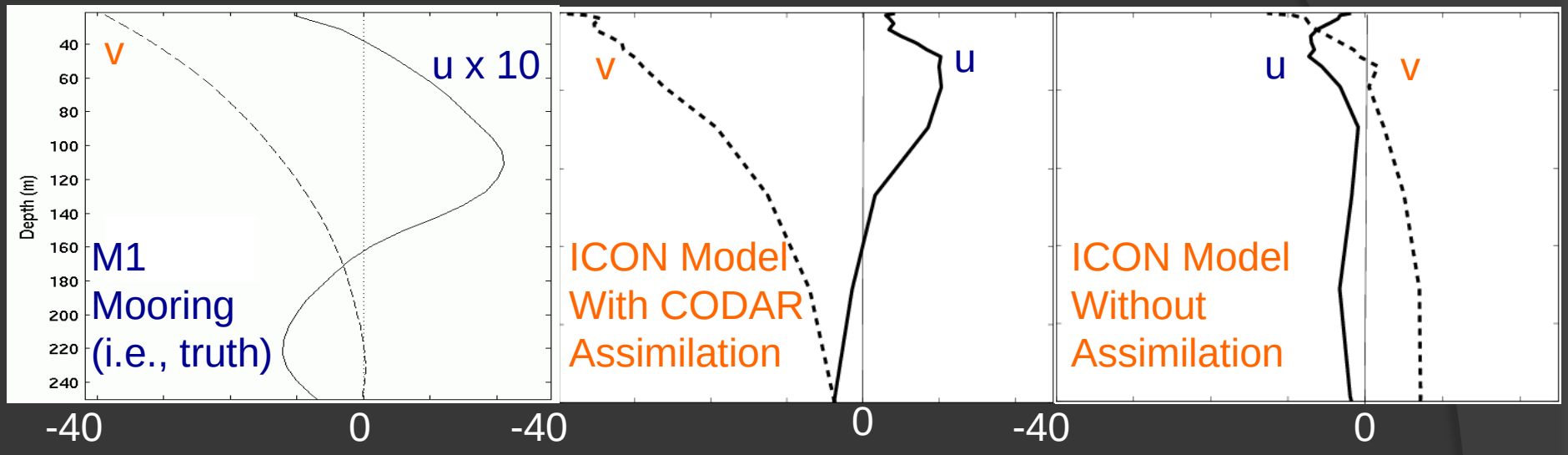
Why are error descriptions so important?

Besides the obvious reasons, modelers need the error-error covariance functions to assimilate HF radar-derived surface current fields

Or do they?

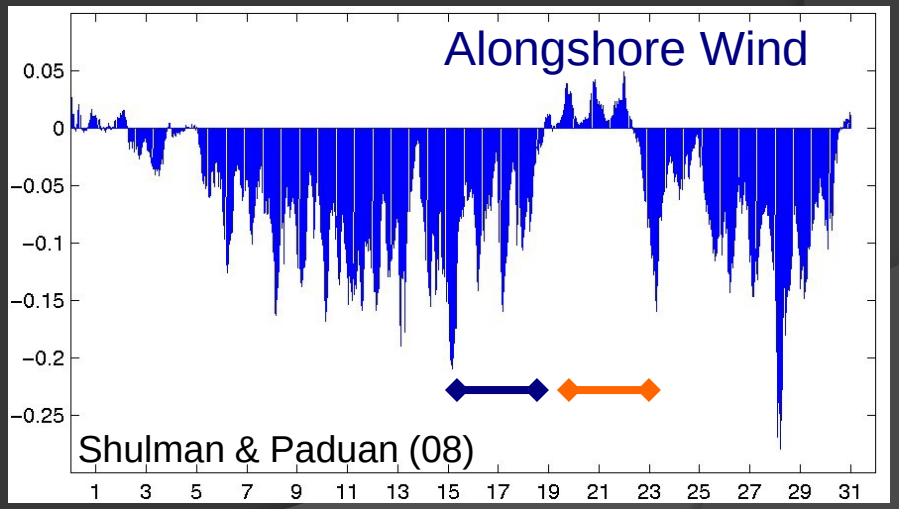


AOSN-II Aug-Sep 2003

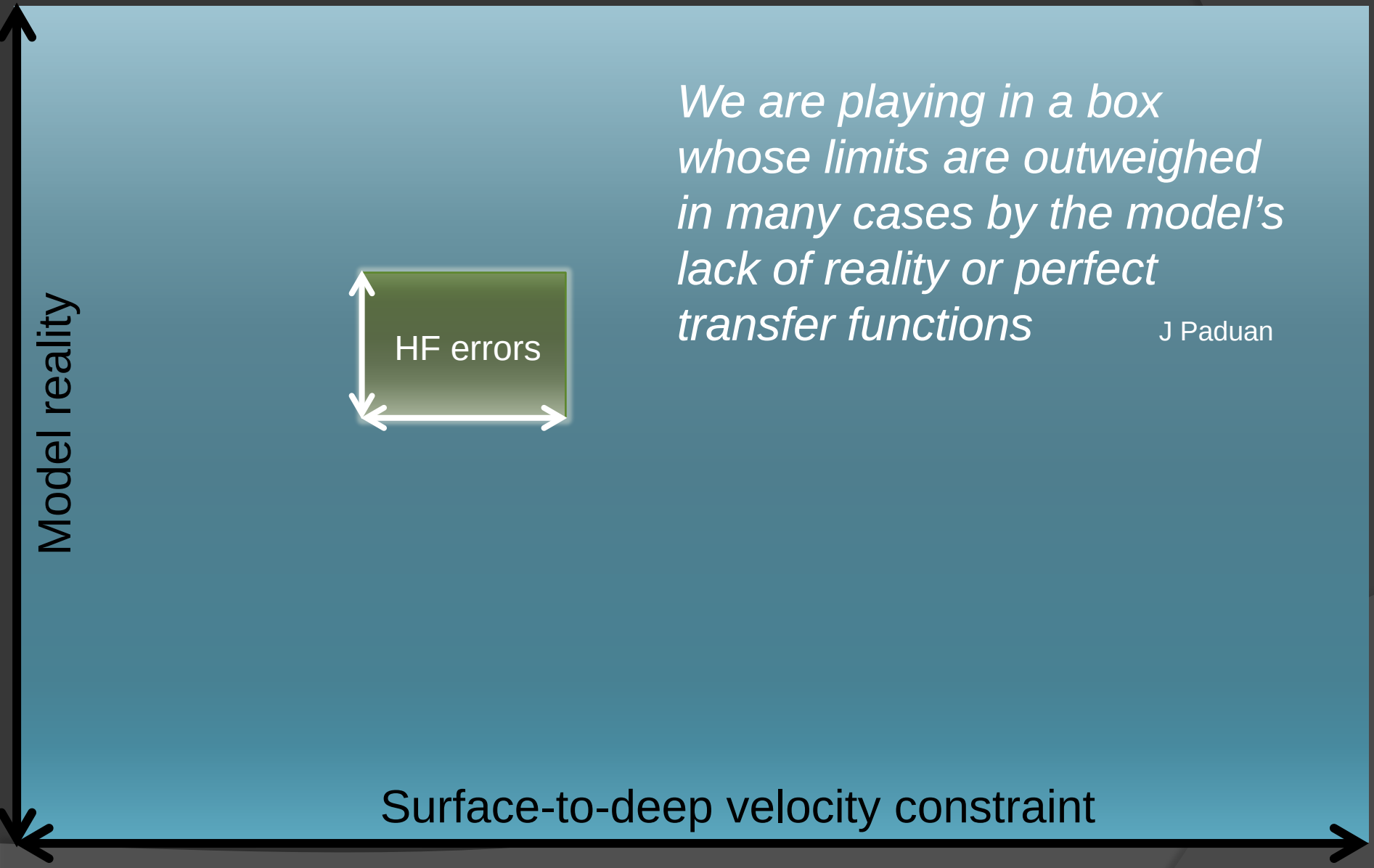


Data assimilation of surface current fields has been shown on many occasions to benefit the models down to depths ~100m

True <u>even though we have not yet provided accurate error covariance functions</u>



What does the modelers CAL-VAL diagram look like?



We are playing in a box whose limits are outweighed in many cases by the model's lack of reality or perfect transfer functions

J Paduan

Conclusions

- Validation and calibration of HF radar-derived surface currents has been going on for some time
  - A good deal of the error is attributed to environmental variations, which lead to sampling discrepancies
  - Instrument error in CODAR-type systems can be reduced somewhat (~20%) by using measured antenna patterns
    - Error appears to scale with antenna distortion
- Modelers should just get on with assimilating the data even though full statistics are unknown

Kohut, J. T. and S. M. Glenn. 2003. Calibration of HF radar surface current measurements using measured antenna beam patterns. *J. Atmos. Ocean. Tech.*, **20**, 1303-1316.

de Paolo, T. and E. Terrill, 2007: Skill Assessment of Resolving Ocean Surface Current Structure Using Compact-Antenna-Style HF Radar and the MUSIC Direction-Finding Algorithm. *J. Oceanic and Atmos. Tech*., **24**, 1277-1300.

Laws, K., J.D. Paduan, and J. Vesecky, 2010: Estimation and assessment of errors in high-frequency radar ocean current measurements. *J. Oceanic and Atmos. Tech*., **27**, 10.1175/2009JTECHO658.1.

Ohlmann, C., P. White, L. Washburn, E. Terrill, B. Emery, and M. Otero, 2007: Interpretation of Coastal HF Radar–Derived Surface Currents with High-Resolution Drifter Data, *J. Oceanic and Atmos. Tech*., **24**, 666-680.

Paduan, J.D., K.C. Kim, M.S. Cook, and F.P. Chavez, 2006: Calibration and validation of direction-finding high frequency radar ocean surface current observations. *IEEE J. Oceanic Engin*., 10.1109/JOE.2006.886195, 862-875.

Paduan, J.D., and I. Shulman, 2004: CODAR data assimilation in the Monterey Bay area. *J. Geophys Res.*, **109**, C07S09, doi: 10.1029/2003JC001949.

Shulman, I. and J.D. Paduan, 2008: Assimilation of HF radar-derived radials and total currents in the Monterey Bay area, *Deep-Sea Res. II*, doi:10.1016/j.dsr2.2008.08.004.

Teague, C.C., D.M. Fernandez, K.E. Laws, **J.D. Paduan**, and J.F. Vesecky, 1998: Comparison of multifrequency phased-array and direction-finding HF radar systems during COPE-3. *Proceedings, IEEE Inter. Geoscience and Remote Sensing Symposium*, Seattle, July 1998, paper A08-10.

Wright, G., 2008: Validation of high frequency radar used in ocean surface current mapping via in-situ drifting, M.S. Thesis, Naval Postgraduate School, Monterey, CA, September, 110pp.