UAVSAR Polarimetric Calibration

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Overview of Talk

1. Summary of hardware events and calibration changes.
2. SAR Performance over Time
   - Noise-Equivalent σ_0 (NESZ).
   - Resolution estimated at corner reflectors.
3. Radiometric and Phase Calibration
   - Performed within UAVSAR processor: jurassicprok.
   - Estimated using point-targets and distributed targets.
   - Periodically check / update using engineering flights.
4. Cross-talk Calibration
   - Runs as part of post-processing kit.
   - Requires radiometric and phase calibration to be applied already.
   - Estimated using the data itself for each flight line.
5. Temporal Stability of Calibration Parameters

Summary of Hardware Events / Calibration Changes

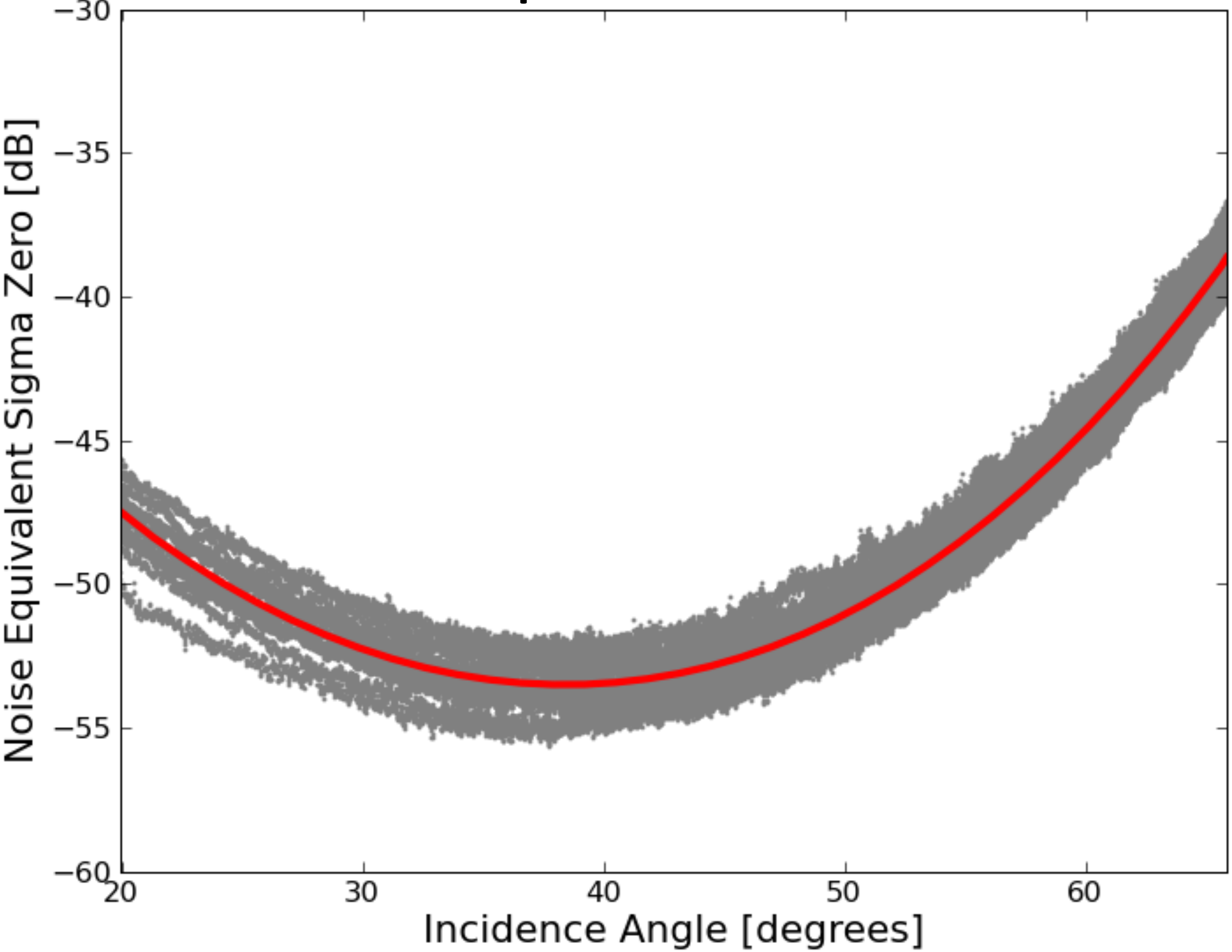
Start Date	Event	Effect
4/23/2009	Ka-band / L-band pod swap	Changed L-band calibration
4/8/2011	L-band antenna switch	New calibration; change in NESZ.
4/19/2011	Updated beam table	Updated L-band calibration
6/14/2011	L-band calibration change*	Updated calibration (~ 1dB change)
8/15/2012	Ka-band / L-band pod swap	Changed L-band calibration
1/2/2013	Antenna re-installed in pod; accidental cable short.	Very noisy data due to cable short.
3/2/2013	Cable short repaired.	Changed L-band calibration

* Retroactively applied to data starting in September 2012

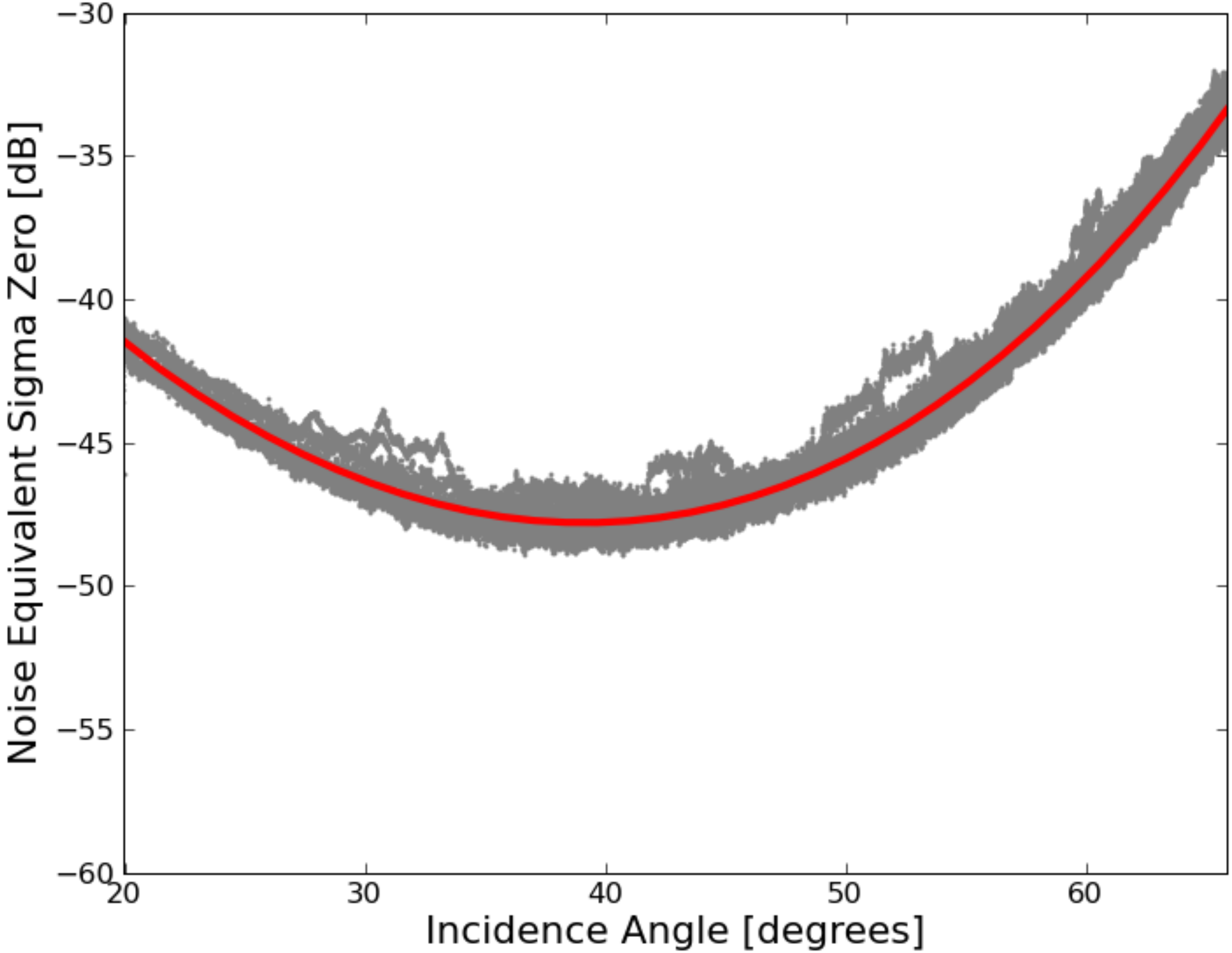
SAR Performance

- We have tracked the noise-equivalent σ_0 over time and have found two regimes:
  - One for time period up to 2011-04-07
  - Another for after 2011-04-07
  - *The difference is due to an antenna change.*
- The range and azimuth resolutions as estimated by corner reflectors have been extremely stable over time.

NESZ Up to 2011-04-07

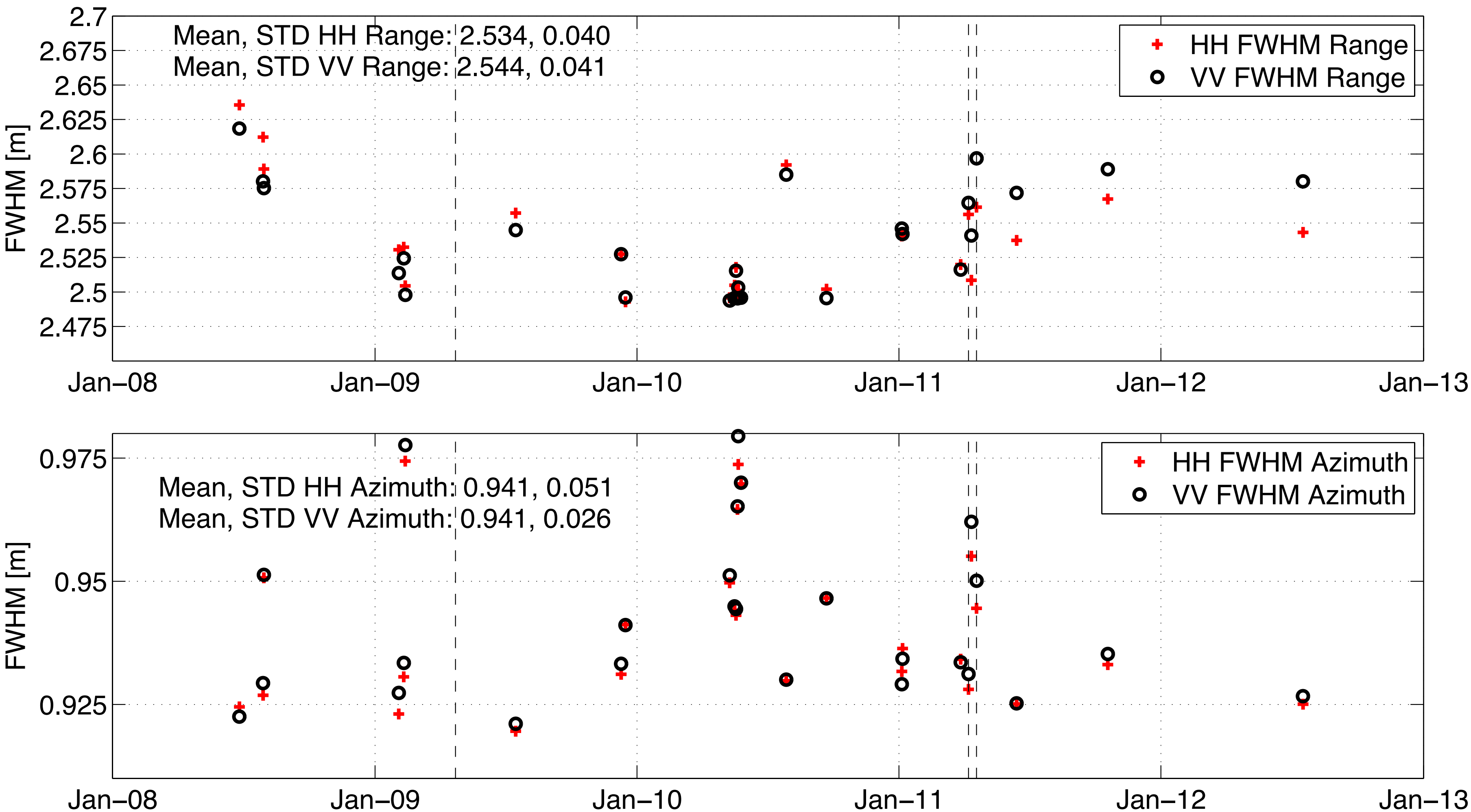


NESZ After 2011-04-07



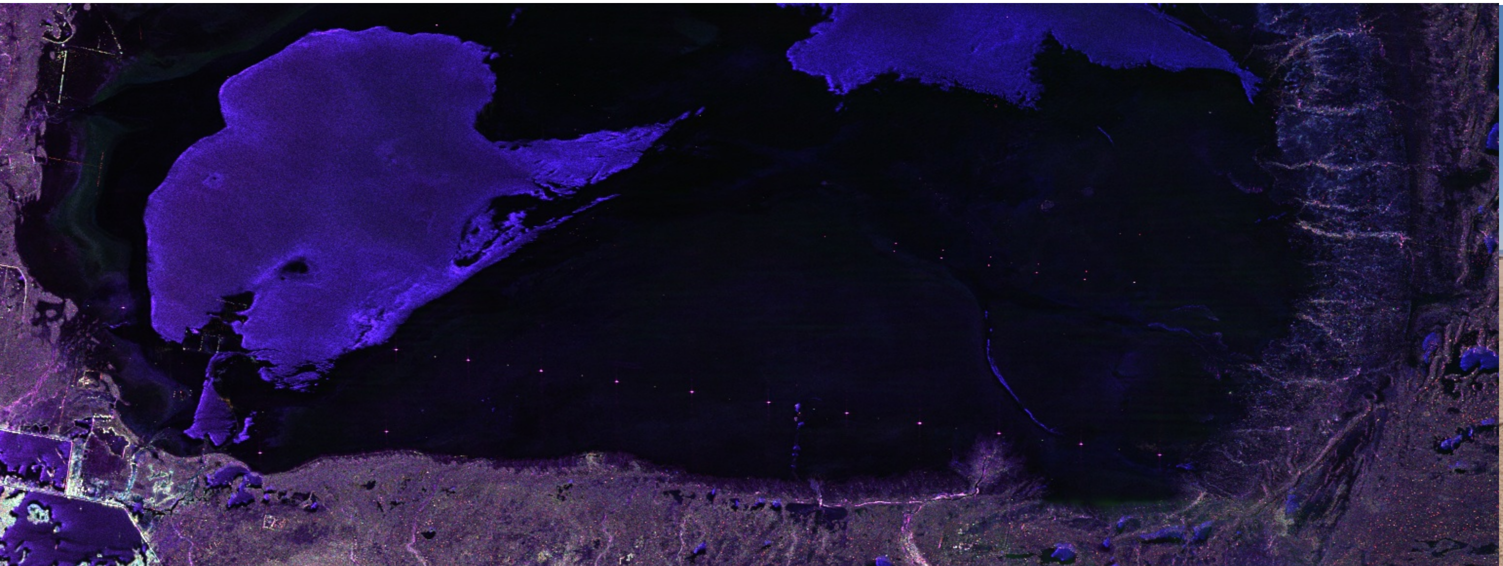
Range and Azimuth Resolution

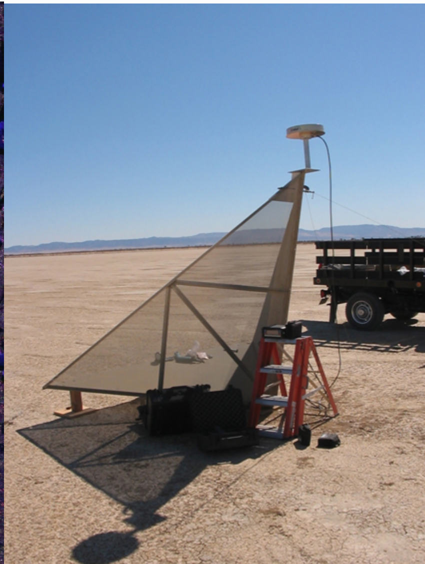
Full Width at Half Max of Corner reflectors



Radiometric / Phase Calibration

- Antenna pattern correction performed within the processor.
- The radiometric and phase calibration is performed within the processor via pre-computed parameters:
  - Per-channel gain bias (HH,HV,VH,VV). (corner reflectors)
  - HH-VV phase bias polynomial fit to incidence angle. (corner reflectors)
  - HV-VH phase bias polynomial fit to incidence angle. (distributed targets)
- Corner reflector array in dry lake bed in Rosamond, CA.
  - 23 corner reflectors (side length = 2.4 meters).
  - Position of CR measured very accurately with differential GPS.

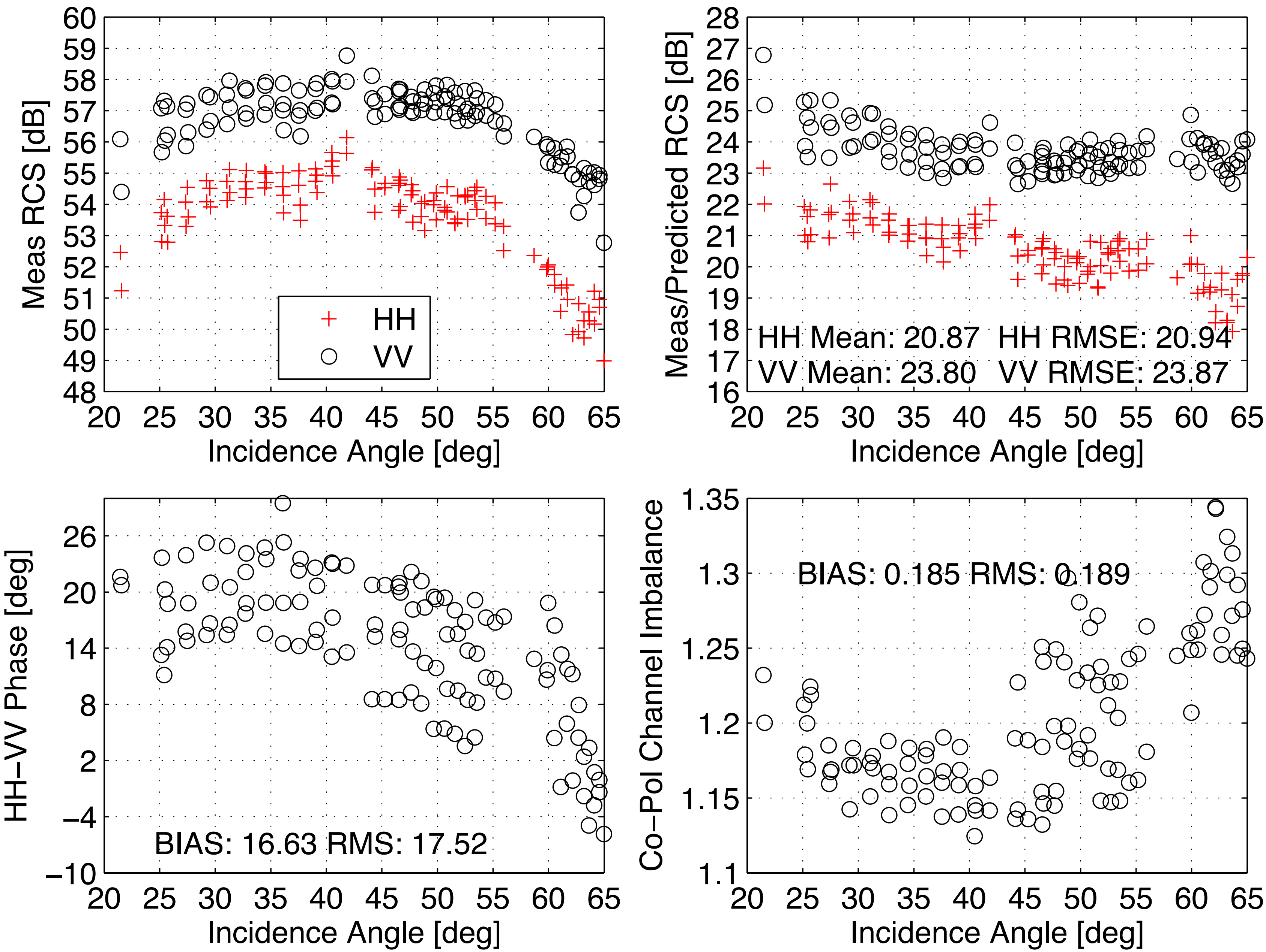




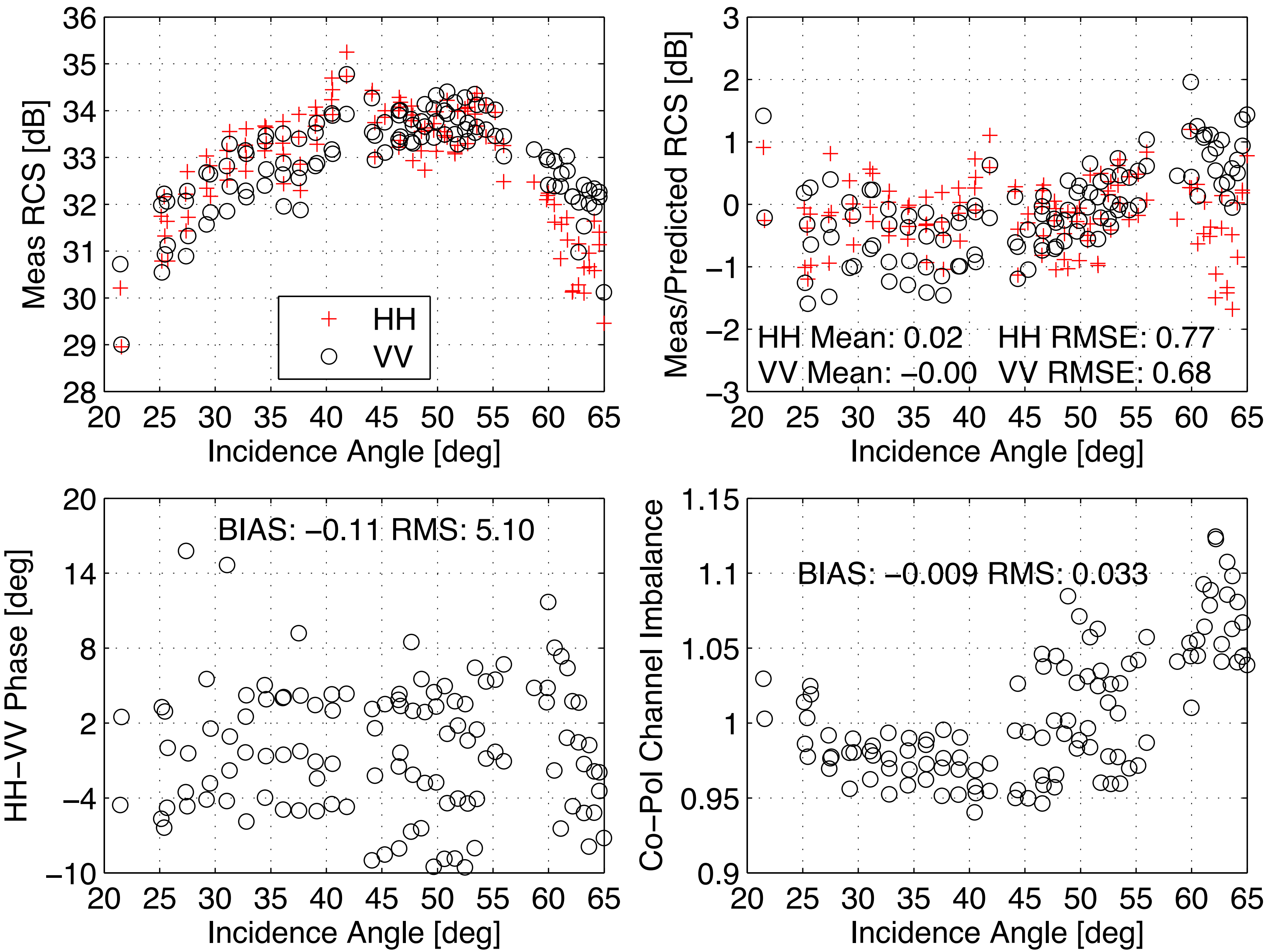
Corner Reflector Calibration Estimation

1. For each imaged corner reflector (CR) we:
   - Compute predicted normalized radar cross-section (σ_0) using analytical expression.
   - Compute observed σ_0 via oversampling and integration for HH and VV channels.
   - Compute observed HH-VV phase at CR peak.
2. Collect this data over typically 8 flight-lines covering the range swath of UAVSAR.
   - From these data we generate the radiometric and phase calibration parameters.

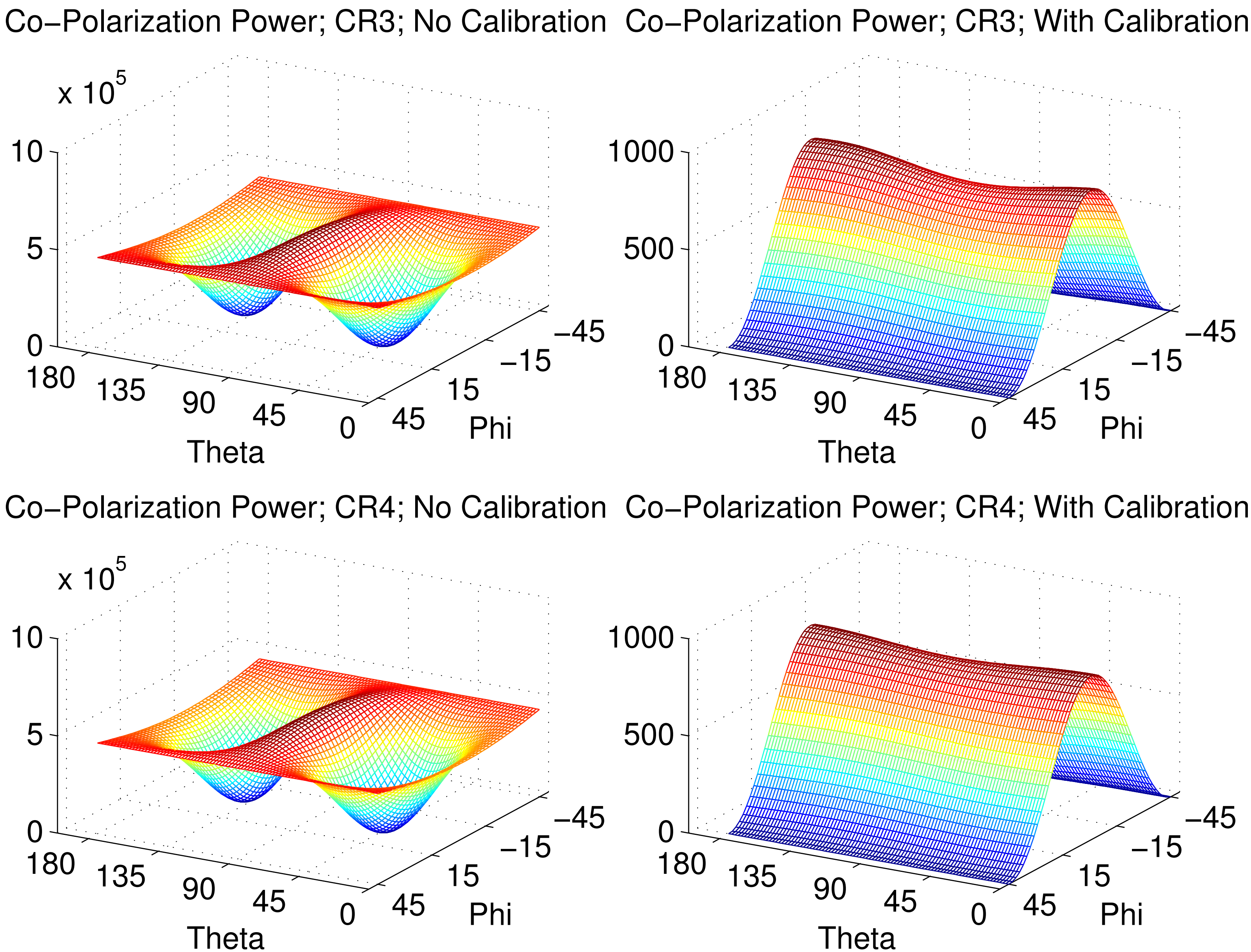
No Radiometric or Phase Calibration Applied



With Radiometric and Phase Calibration Applied



Co-Polarization Signatures of Corner Reflectors



Cross-Talk Calibration

- We use a fully general distortion model:
  - 4 complex parameters that link polarizations (u,v,w,z)
  - 1 complex parameter for the HV/VH channel balance (α)
  - 1 complex parameter for the HH/VV channel balance (k) – assumed to be 1 via corner reflector analysis.
- We use Ainsworth et al. method for cross-talk parameter estimation.
  - Data driven algorithm using local window to compute observed polarimetric covariance matrix (C).
  - Remove pixels with large hh-hv correlation and very bright pixels.
  - Use a large window (~40,000 pixels) for computation of C.
  - Rather CPU intensive, we use domain decomposition to perform parallel processing.

Cross-Talk Calibration Algorithm

Fully general formulation:

$$\begin{pmatrix} O_{hh} & O_{hv} \\ O_{vh} & O_{vv} \end{pmatrix} = Y \begin{pmatrix} k & w \\ ku & 1 \end{pmatrix} \begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix} \begin{pmatrix} \alpha k & \alpha kz \\ v & 1 \end{pmatrix} + \begin{pmatrix} N_{hh} & N_{hv} \\ N_{vh} & N_{vv} \end{pmatrix}$$

Assume radiometric and phase calibration:

With k=1/√α; Y=1:

$$\begin{pmatrix} O_{hh} \\ O_{vh} \\ O_{hv} \\ O_{vv} \end{pmatrix} = D \begin{pmatrix} S_{hh} \\ S_{vh} \\ S_{hv} \\ S_{vv} \end{pmatrix} \qquad D := \begin{pmatrix} 1 & w\sqrt{\alpha} & v/\sqrt{\alpha} & vw \\ u & \sqrt{\alpha} & uv/\sqrt{\alpha} & v \\ z & wz\sqrt{\alpha} & 1/\sqrt{\alpha} & w \\ uz & z\sqrt{\alpha} & u/\sqrt{\alpha} & 1 \end{pmatrix}$$

Calibration Matrix:

$$E = D^{-1} = \frac{1}{(uv-1)(vz-1)} \begin{pmatrix} 1 & -w & -v & vw \\ -u/\sqrt{\alpha} & 1/\sqrt{\alpha} & uv/\sqrt{\alpha} & -v/\sqrt{\alpha} \\ -z\sqrt{\alpha} & wz\sqrt{\alpha} & \sqrt{\alpha} & -w\sqrt{\alpha} \\ uz & -z & -u & 1 \end{pmatrix}$$

SLC HH, HV, VH, VV channels (no cross-talk calibration)

Construct observed polarimetric covariance matrix over window: $C_{ij} = \langle O_i O_j^* \rangle$

Iterative parameter estimation (*)

Cross-talk parameter estimates: (u, v, w, z, α)

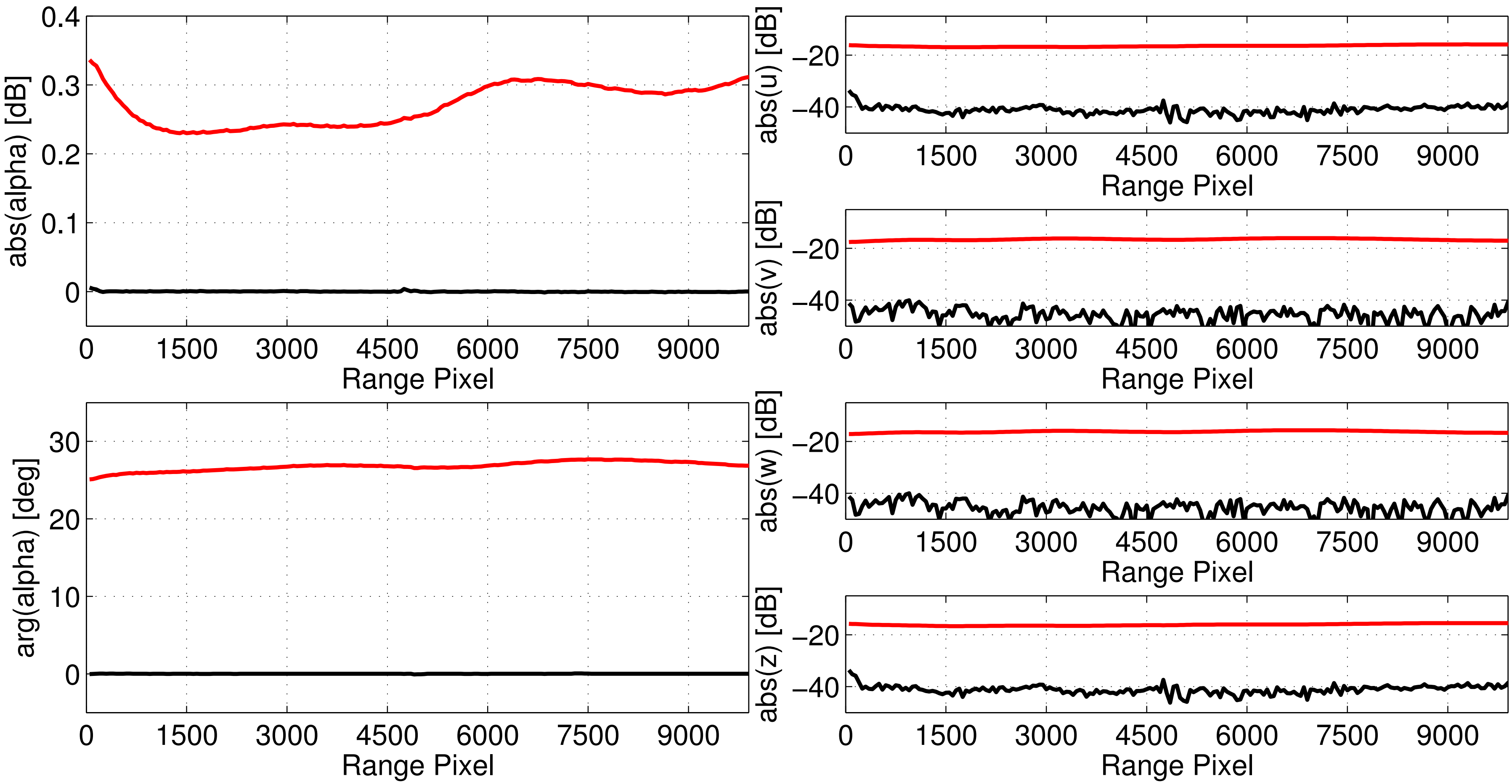
Cross-Talk Removal

Cross-Talk Calibrated SLC HH, HV, VH, VV channels

(*) T.L. Ainsworth, L. Ferro-Famil, and Jong-Sen Lee. Orientation angle preserving a posteriori polarimetric sar calibration. IEEE Transactions on Geoscience and Remote Sensing, 44(4):994–1003, April 2006.

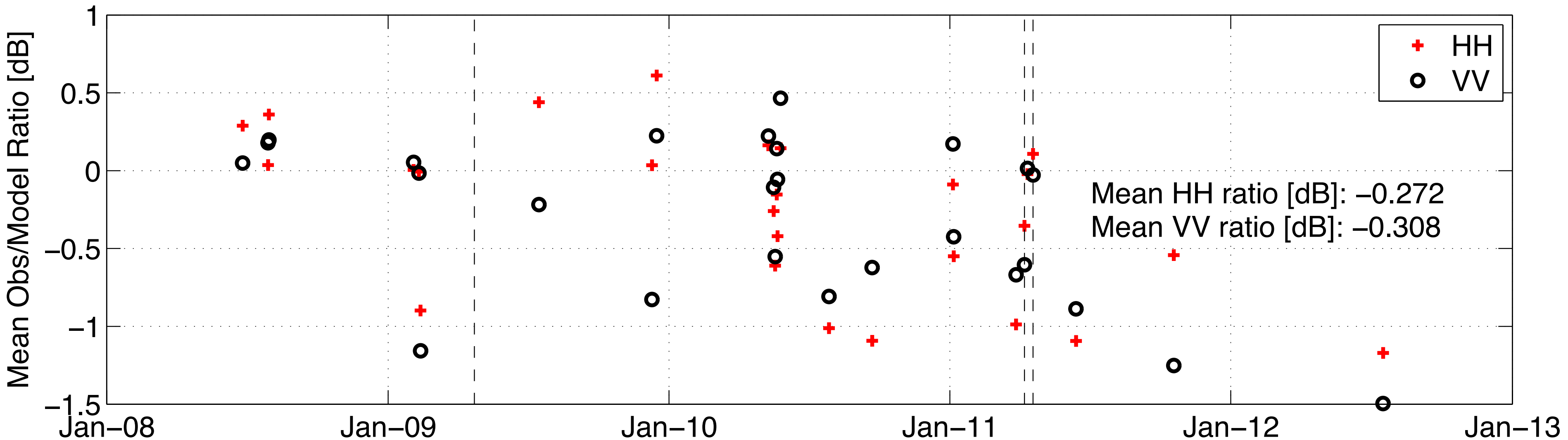
Red: Estimated cross-talk parameters as a function of range
Black: Residual estimated cross-talk parameters

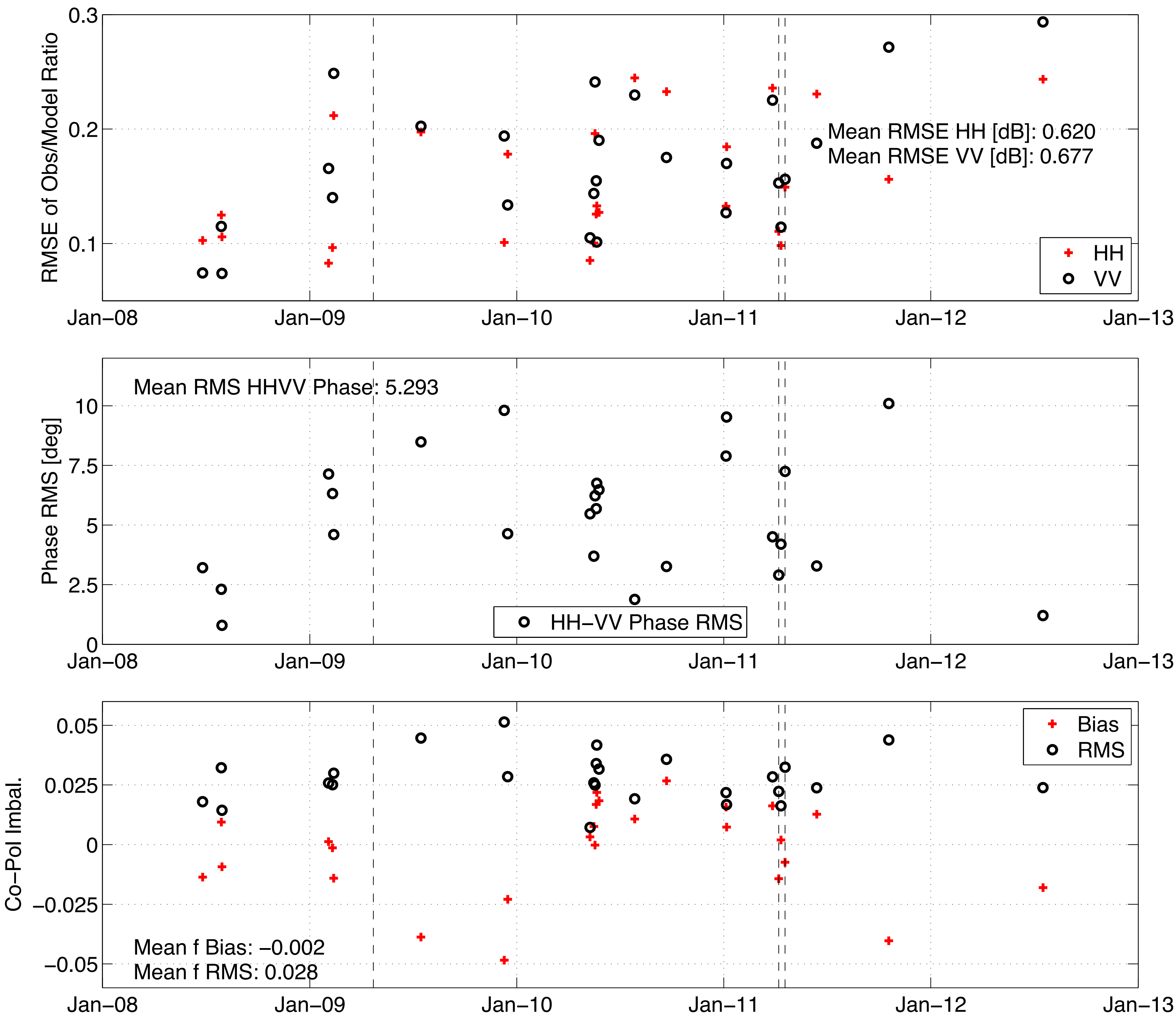
- u,v,w,z about -15 dB before cross-talk calibration.
- After cross-talk calibration, residual cross-talk parameters are estimated to be ~ -40 dB.
- Leaked power is proportional to cross-talk parameters squared.



Temporal Stability of Calibration Parameters

Here is a subset of all the Rosamond engineering flights taken up to end of 2012
-Each point represents an engineering flight over Rosamond.
-Dashed lines represent change in calibration parameters.
Here we show the mean observed / model ratio in dB for each flight over the Rosamond CR array.
On the next slide we show the RMS error in radiometeric calibration and phase calibration
Note that other geophysical errors sources may be present (water, dirty CR, … etc).



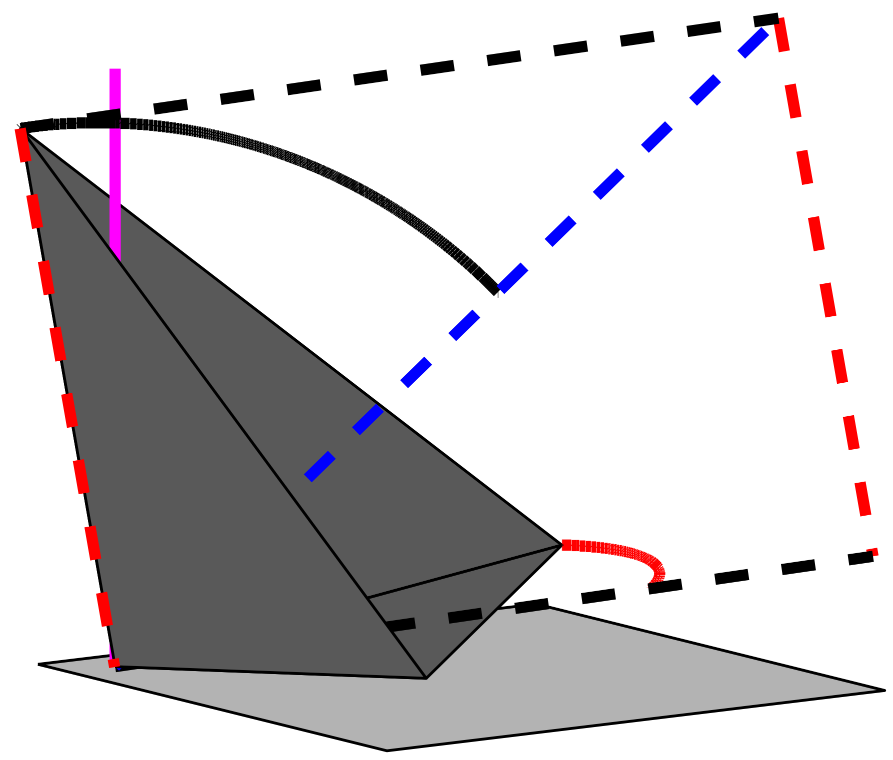

RMSE of Obs/Model Ratio
0.3
0.2
0.1
Mean RMSE HH [dB]: 0.620
Mean RMSE VV [dB]: 0.677
HH
VV
Jan–08
Jan–09
Jan–10
Jan–11
Jan–12
Jan–13
Phase RMS [deg]
Mean RMS HHVV Phase: 5.293
10
7.5
5
2.5
0
HH–VV Phase RMS
Co–Pol Imbal.
0.05
0.025
0
−0.025
−0.05
Bias
RMS
Mean f Bias: −0.002
Mean f RMS: 0.028

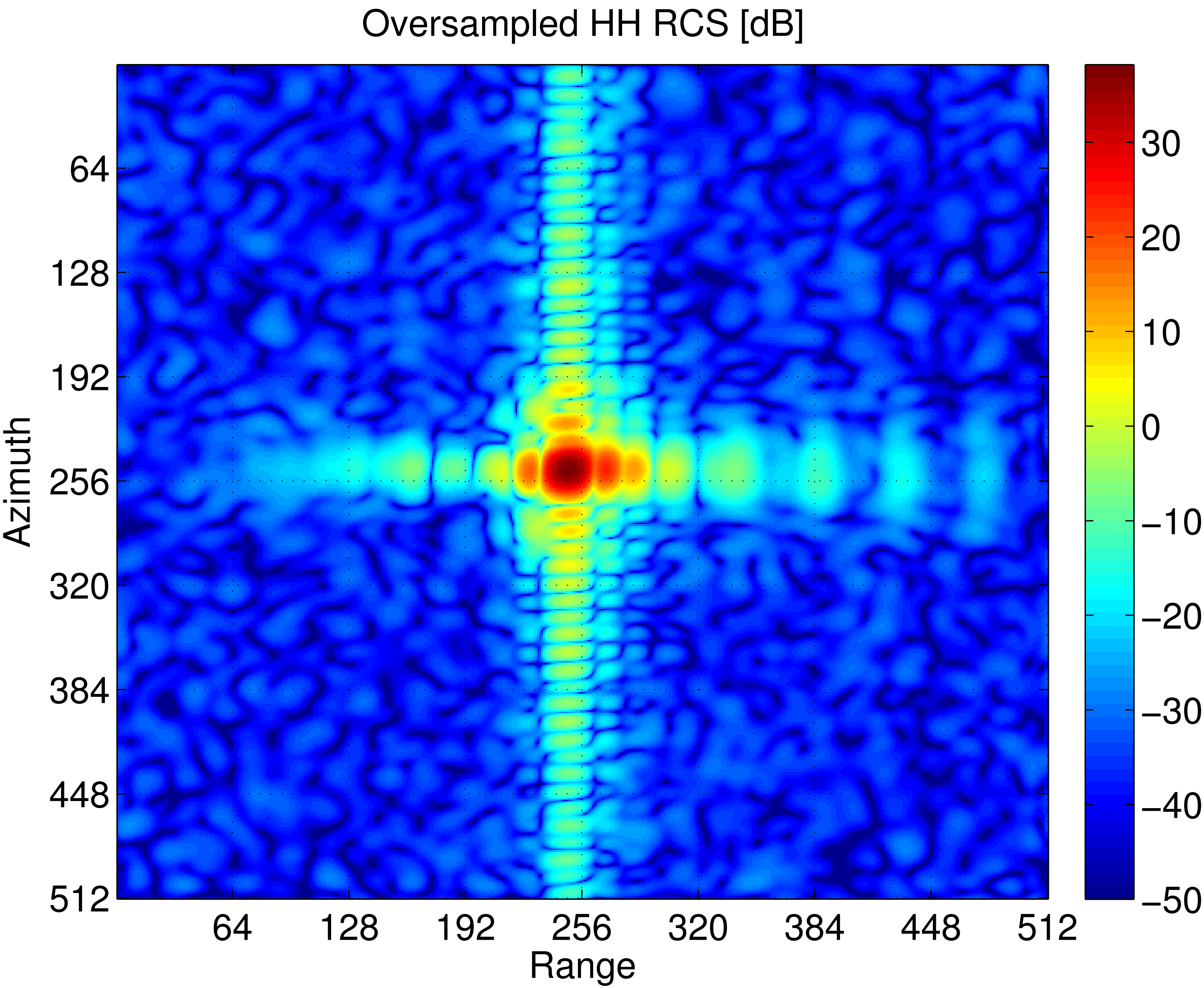
Summary

- Antenna change in spring 2011 caused:
  - Change in radiometric calibration.
  - Change in noise-equivalent sigma0.
- UAVSAR has provided well calibrated data for more than 3 years.

$$\sigma_{cr} = \frac{4\pi l^4}{\lambda^2}\left[P_x + P_y + P_z - \frac{2}{P_x+P_y+P_z}\right]^2, (P_x + P_y \geq P_z)$$

$$\sigma_{cr} = \frac{4\pi l^4}{\lambda^2}\left[\frac{P_x P_y}{P_x+P_y+P_z}\right]^2, \qquad (P_x + P_y \leq P_z)$$





Oversampled HH RCS [dB]
Azimuth
64
128
192
256
320
384
448
512
Range
64
128
192
256
320
384
448
512
30
20
10
0
−10
−20
−30
−40
−50