C-band scatterometers inter-calibration: from ERS-1 to Metop-B

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Introduction - Motivation

- Continuity and consistency of the scatterometer data
  - Need of cross-calibration
- ERS-1/AMI, ERS-2/AMI, Metop-A/ASCAT and Metop-B/ASCAT: active C-band real aperture radars
  - Similar instruments and orbits
  - Missions
    - ERS-1: 1991 - 2000 and ERS-2: 1995 - 2011
    - Metop-A: 2006 - and Metop-B: 2012 -
  - Tandem missions
    - ERS-1/ERS-2 : from August 17, 1995 to June 03, 1996
    - Metop-A/Metop-B: since 2012
  - Missions overlap
    - ERS-2/Metop-A: between 2006 and 2011
- Opportunity for cross-comparison
- Use of natural targets (rainforest, sea ice, ocean)

Methodology

- Assumption: differences in σ_0 are due to differences in antenna gain
- Model-based methods
  - Comparison of the measured σ_0 to the simulated σ_0 gives a model bias
    - $Bias_m = E[{\sigma_0}^{meas}/{\sigma_0}^{sim}]$
  - Comparison of the Model bias of scatt-1 to the model bias of scatt-2
    - Bias $= {Bias_m}^{scatt-1}/{Bias_m}^{scatt-2}$
- The comparison is performed WVC by WVC
- The dataset used:
  - ERS-1/ERS-2 : tandem mission (March 20 1996 - June 03 1996)
  - ERS-2/ASCAT-A : mission overlap (December 2008)
  - ASCAT-A/ASCAT-B: tandem mission (January 2013)

Inter-calibration over the Rainforest - Methodology

- The rainforest is assumed to be (at C-band frequency)
  - Homogeneous
    - Spatial masking to remove inhomogeneous areas
  - Stable in time
    - Spatial masking to remove unstable areas
  - Isotropic

$\Rightarrow$ The backscatter depends only on incidence angle θ

- The incidence angle dependence can be removed by using the parameter γ_0

$$\gamma_0 = \sigma_0 / cos(\theta)$$

- Comparison of gamma naught after application of the mask and averaging for each beam and incidence angle.

$$Bias(\theta) = E[{\gamma_0}^{scatt-1} / {\gamma_0}^{ref}] / E[{\gamma_0}^{scatt-2} / {\gamma_0}^{ref}]$$

Inter-calibration over the Rainforest - Masking

Amazonas $[15^oS, 5^oN], [75^oW, 55^oW]$

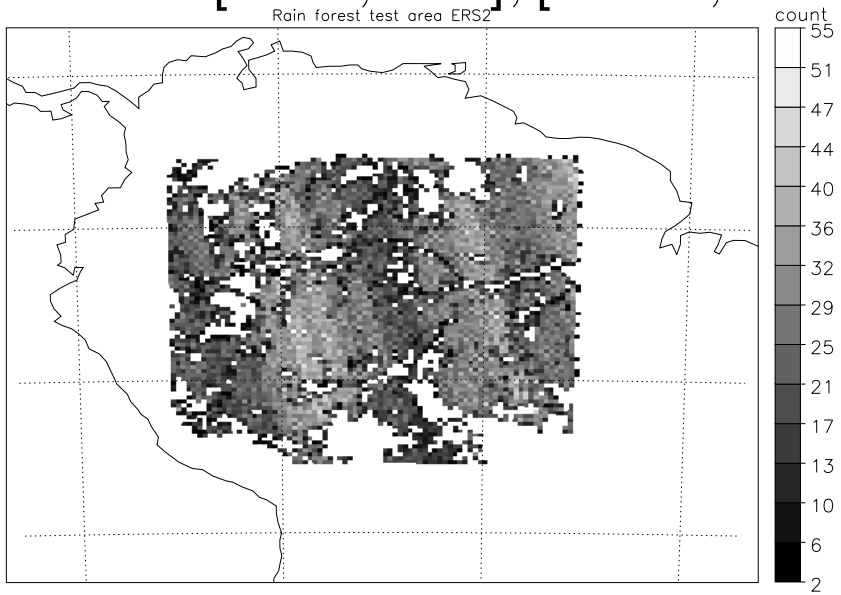


Figure: Rainforest selected data

- Region of interest: Amazonas $[15^oS, 5^oN], [75^oW, 55^oW]$
- The masking excludes areas with very low or very high γ_0 and high variance
  - e.g.,rivers, urban areas ...
- The mask favors areas with homogeneous vegetation type

Inter-calibration over Sea ice - Methodology

- σ_0 triplets over ice lie on a line $\Rightarrow$ isotropic scattering
- Sea ice line model depends only on incidence angle θ and geophysical parameter a (De Haan 2001)

$$\sigma_0{}^{sim}(\theta, a) = \overline{\sigma_0}(\theta) + a\sigma_0{}^{ice}(\theta)$$

where $\overline{\sigma_0}$ and $\sigma_0{}^{ice}$ are tabulated.

- A simulated σ_0 is computed using the ice model and compared to the measured σ_0

$$Bias_m(\theta) = E[\sigma_0{}^{meas}(\theta)/\sigma_0{}^{sim}(\theta)]$$

- The bias between the two instruments is the difference between the two model biases

$$Bias(\theta) = Bias_m^{scatt-1}(\theta)/Bias_m^{scatt-2}(\theta)$$

Inter-calibration over Sea ice - Masking

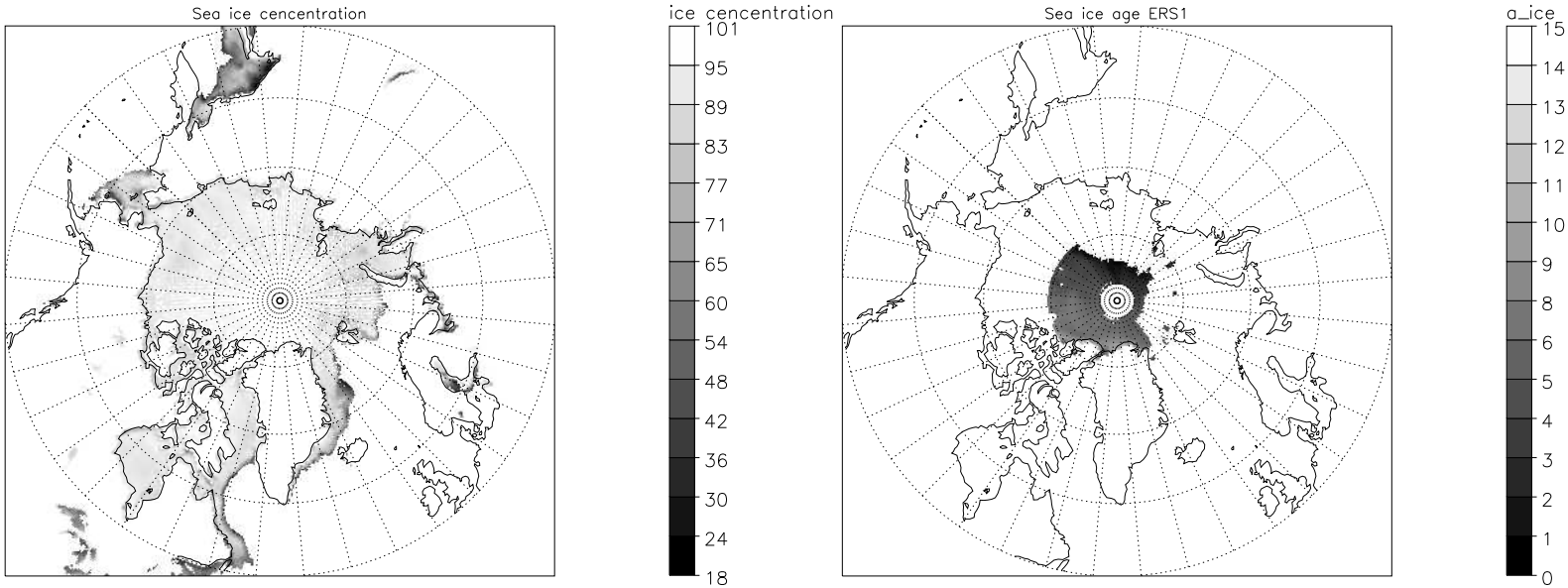


Figure: IFREMER ice concentration (left), ERS-1 selected data (right) - from March 20 to June 03 1996

- IFREMER SSM/I sea ice concentration product is used to select region with concentration $\geq$ 90 %
- Only regions with ice age parameter $a > 0$ are kept
- Backscatter triplets with distance to ice line model > 1 dB are rejected

Cross-comparison over Ocean - Methodology

- σ_0 triplets measured on the sea lie on a surface of a cone
- The mathematical representation of this cone is the C-band Geophysical Model function (GMF)

$$\sigma_0(\theta, V, \phi) = B_0(\theta, V)[1 + B_1(\theta, V)cos\phi + B_2(\theta, V)cos2\phi]^{1.6}$$

where V is the wind speed and ϕ is the wind direction

- A simulated σ_0 is computed using NWP winds and the CMOD5 GMF and then compared to the measured σ_0
- Ocean calibration in z-space: $z = (\sigma_0)^{0.625}$ (Stoffelen 1998)

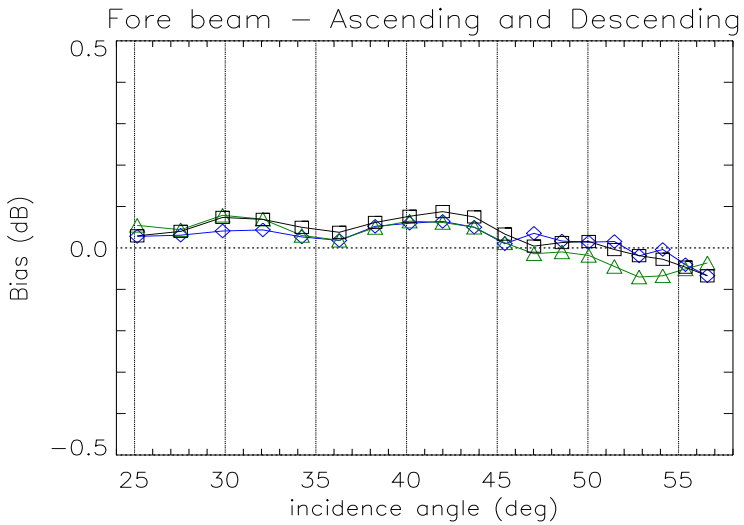
$$Bias_m(\theta) = E[z^{meas}(\theta)/z^{sim}(\theta)]$$

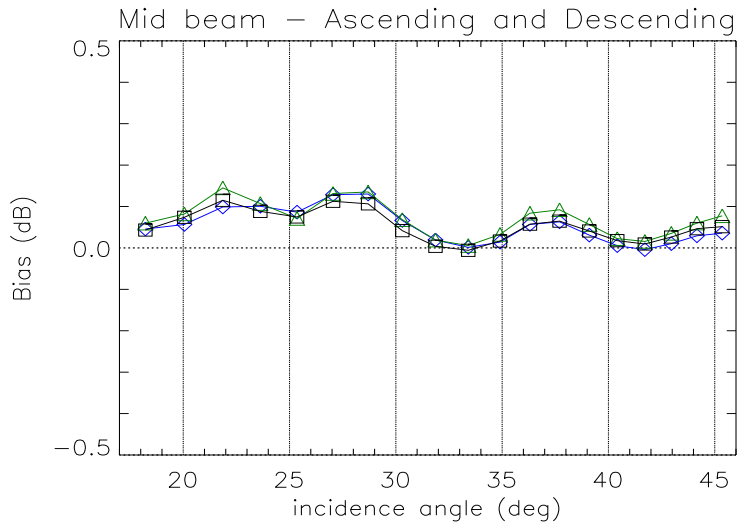
- The bias between the two instruments is the difference between the two model biases

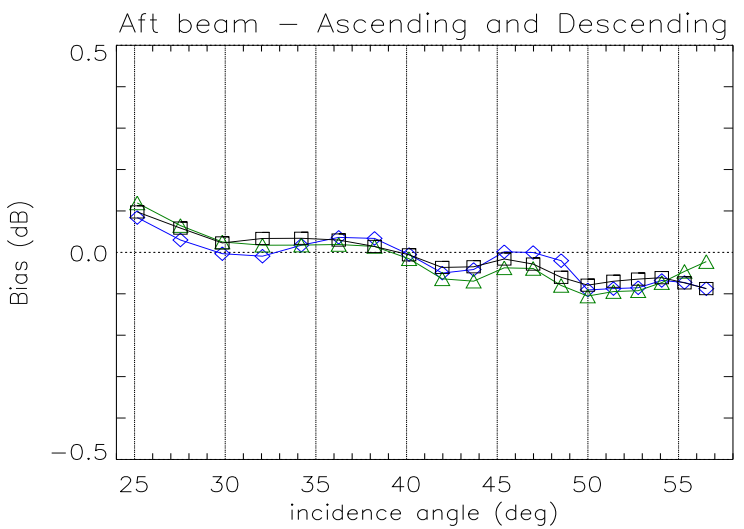
$$Bias(\theta) = Bias_m^{scatt-1}(\theta)/Bias_m^{scatt-2}(\theta)$$

ERS-1/ERS-2 inter-calibration

Rainforest / Sea ice / Ocean



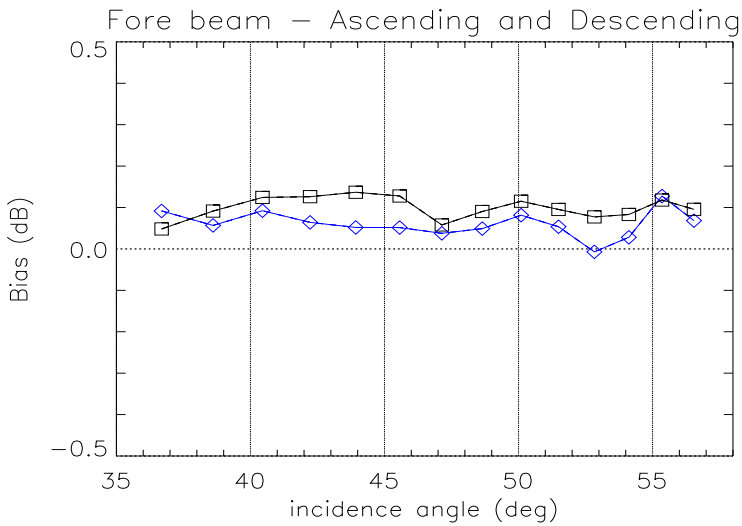


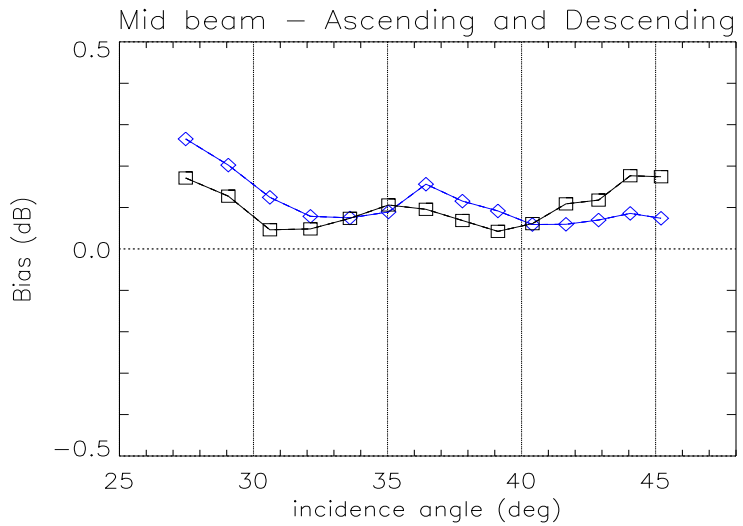


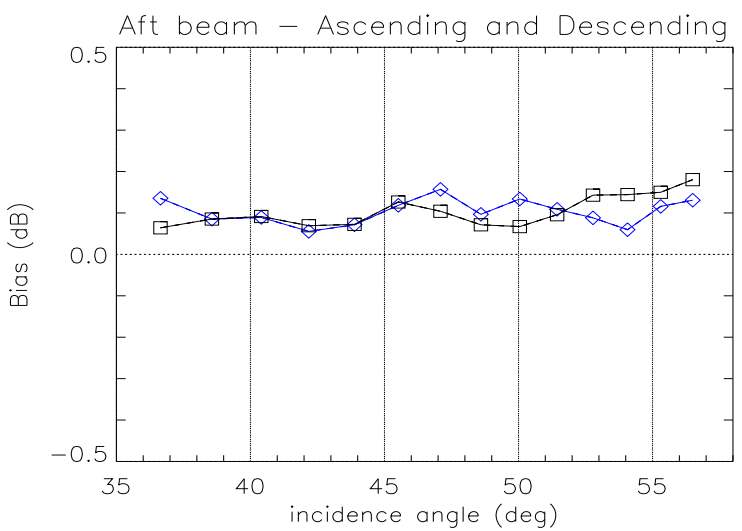
- Three methods consistent results
- Fore/Aft bias around 0
- Mid bias positive
- $Bias_{max} = 0.13$ dB

ASCAT-A/ERS-2 inter-comparison - right swath

Rainforest / Sea ice / Ocean



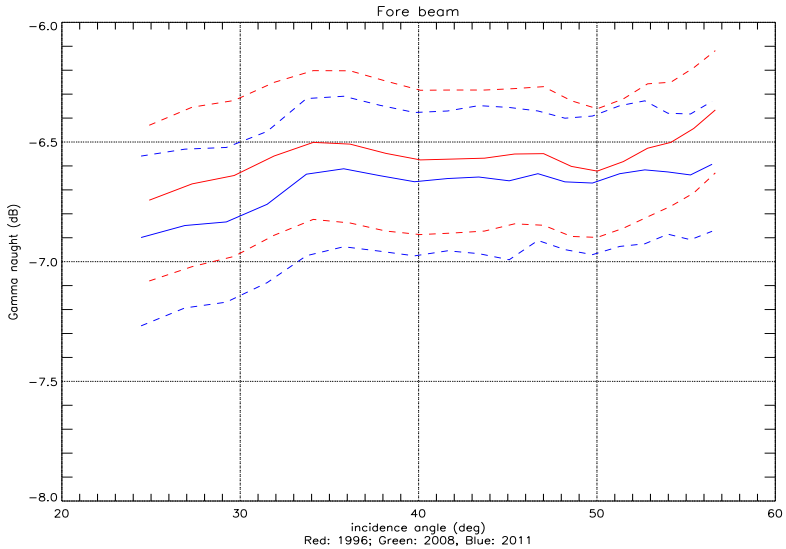


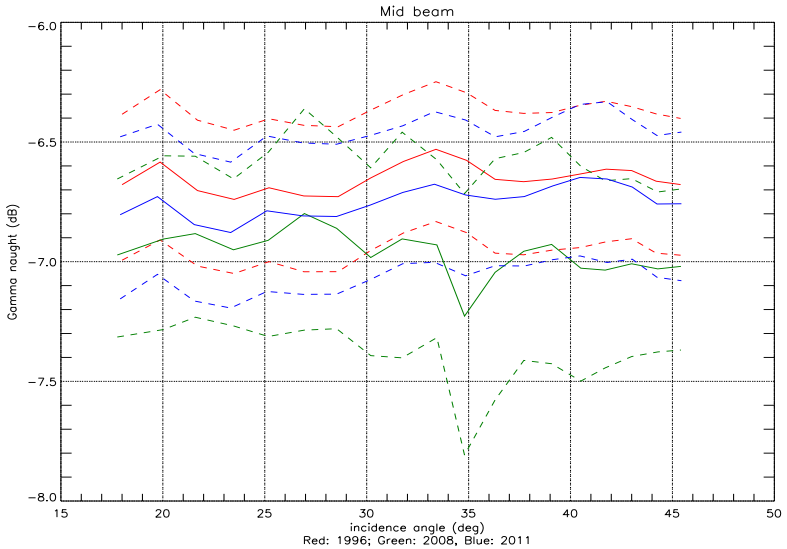


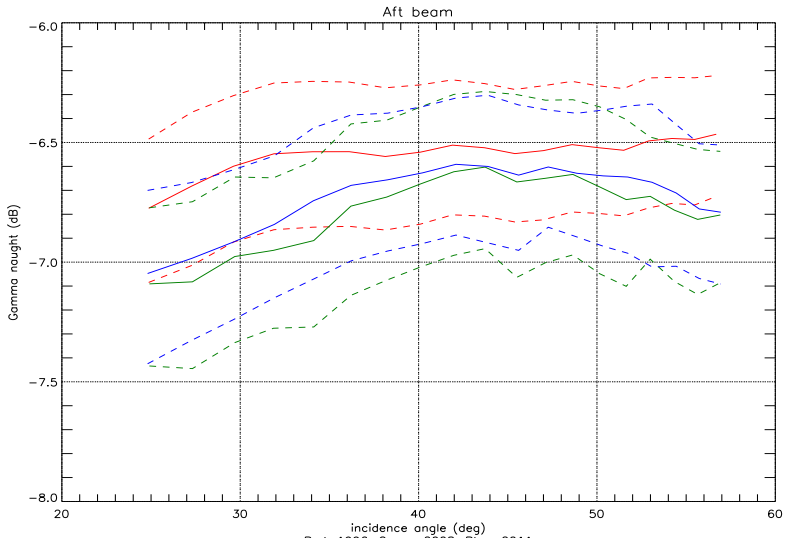
- Methods less consistent
- ERS-2 regional coverage
  - noisy
  - Rainforest excluded
- Systematic positive bias ≈ 0.1 dB
- $Bias_{max} = 0.26$ dB

ERS-2 stability

1996 / 2008 / 2011



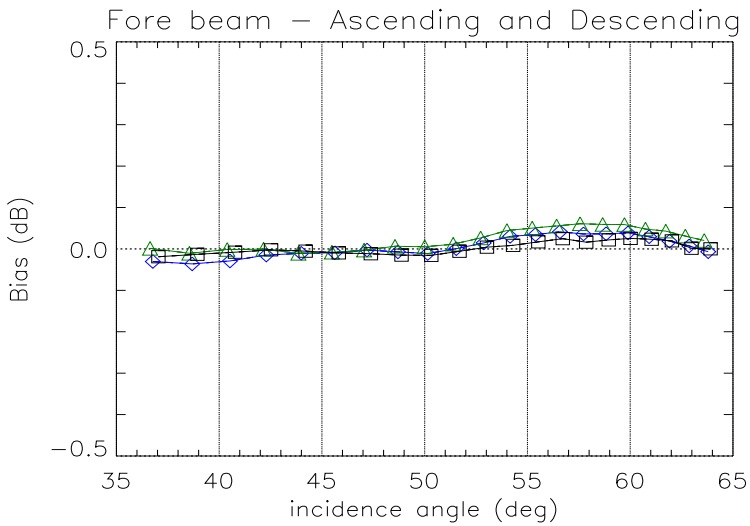


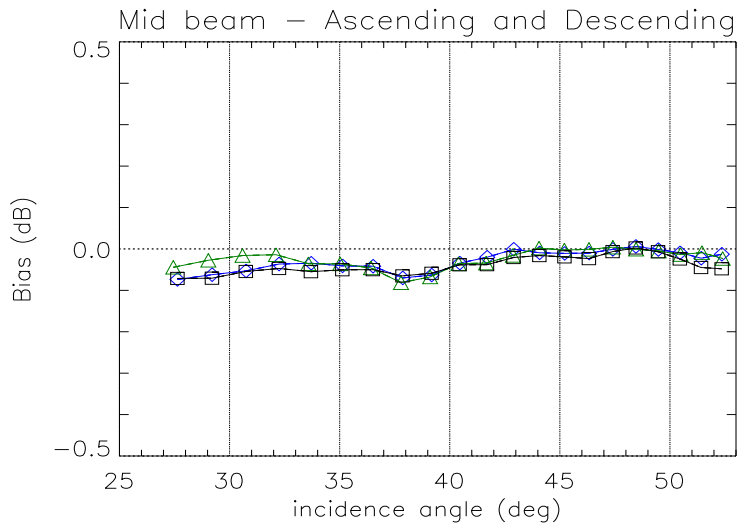


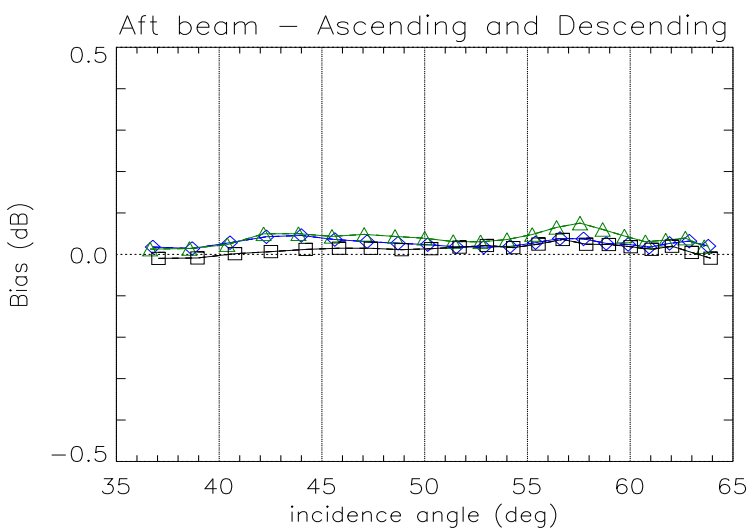
- γ_0 over the rainforest
- 2008: regional scenario/high standard deviation
- Offset $\approx$ 0.12 dB
- Can explain the ASCAT/ERS-2 bias (same order of magnitude)

ASCAT-A/ASCAT-B inter-calibration - right swath

Rainforest / Sea ice / Ocean







- Methods very consistent
- No systematic offset
- $|Bias_{right}| < 0.060/0.090/0.075$ dB
- $|Bias_{left}| < 0.092/0.083/0.051$ dB

Estimation of the variance - Procedure

The bias is the ratio of the two model biases $bias_{m1}$ and $bias_{m2}$

$$Bias = \overline{bias_{m1}} / \overline{bias_{m2}}$$

- We need to assess the variance of this bias
- Monte Carlo method is used to estimate the mean and variance

	ERS-1/ERS-2		ERS-2/ASCAT		ASCAT-1/ASCAT-B	
Beam	Mean (dB)	Std error (dB)	Mean (dB)	Std error (dB)	Mean (dB)	Std error (dB)
Fore	0.028	0.018	0.092	0.034	0.009	0.010
Mid	0.049	0.013	0.166	0.027	-0.025	0.008
Aft	-0.024	0.021	0.128	0.030	0.026	0.010

Table: Mean and standard error of the bias

- The values shown are averaged over incidence angles for ascending/descending passes
- Only values for ocean calibration are shown (others are roughly similar)

Maximum likelihood estimation of the bias

- We have three biases, each from the three methods
- The biases are assumed to be Gaussian and independent
- We want the best estimate of the average bias $bias^*$ from our set of estimators with different means $bias_i$ and variances σ_i^2

The likelihood function of $bias^*$ is defined as

$$L(bias^*) = \prod_{i=1}^{n} p(bias_i|bias^*) = \prod_{i=1}^{n} \frac{1}{\sqrt{2\pi}\sigma_i} \exp(-\frac{(bias_i - bias^*)^2}{2\sigma_i^2})$$

The $bias^*$ value which maximizes the likelihood function is given by

$$bias^* = \frac{\sum \frac{bias_i}{\sigma_i^2}}{\sum \frac{1}{\sigma_i^2}}$$

Validation of the MLE bias estimate

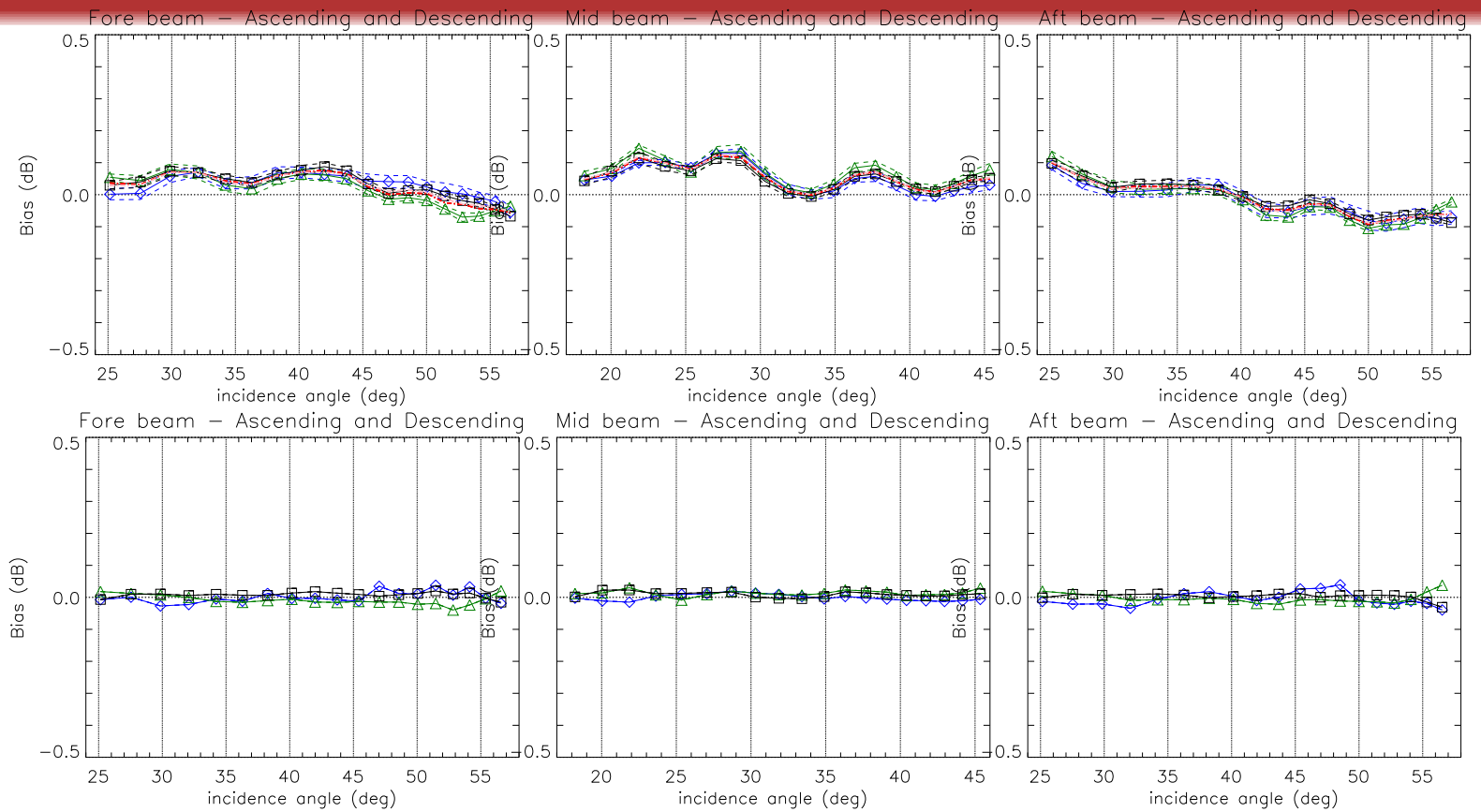


Figure: ERS-1/ERS2 inter-calibration, Blue: Ocean, Black: Sea ice, Green: Rainforest, Red: MLE - Fore (left), Mid (center), Aft (right)

- $Bias_{RMS}$ before: 0.02 dB
- $Bias_{RMS}$ after: 0.003 (MLE)
- $Bias_{RMS}$ after: 0.006 (RF)/0.006 (ice)/0.007 (ocean)

Validation of the MLE bias estimate

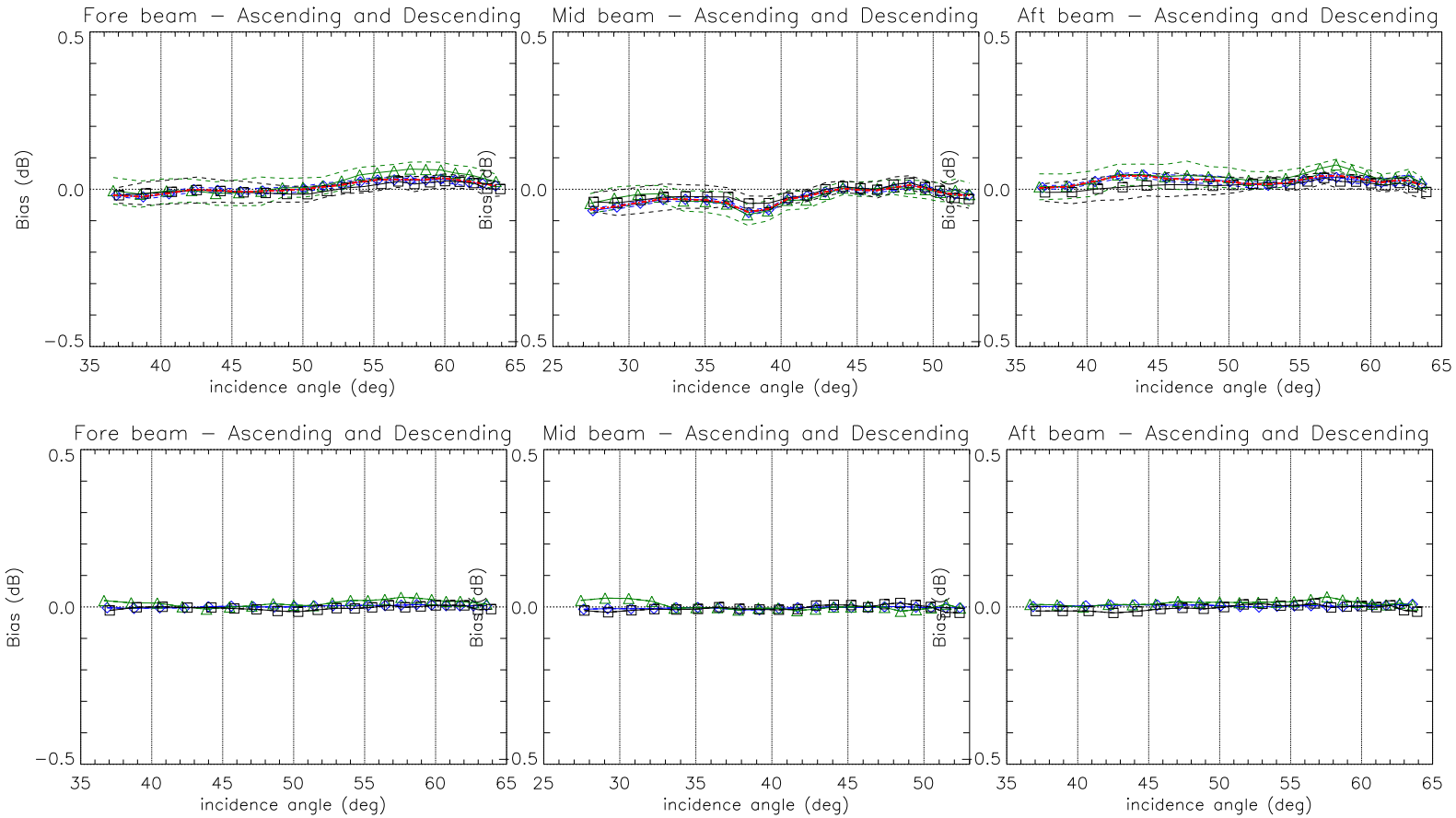


Figure: ASCAT-A/ASCAT-B inter-calibration, Blue: Ocean, Black: Sea ice, Green: Rainforest, Red: MLE - Fore (left), Mid (center), Aft (right)

- Maximum bias: 0.092 dB (before) / 0.032 dB (after)

Conclusions

- A methodology of inter-calibration for C-band scatterometers has been presented and applied to ERS-1, ERS-2, ASCAT-A and ASCAT-B
- The three methods provide consistent results with small standard error
- Discrepancy in ERS-2/ASCAT-A case due to the ERS-2 poor coverage
- ERS-1/ERS-2: need inter-calibration (max bias = 0.13 dB)
- ERS-2/ASCAT-A: need inter-calibration (max bias = 0.26 dB)
- ERS-2 offset could explain the bias between ERS-2 and ASCAT-A (same order of magnitude)
- ASCAT-A/ASCAT-B: very well calibrated (within 0.09 dB), a finer inter-calibration can be achieved using these methods
- The results should be compared to the transponders calibration