REQUIREMENT ON ANTENNA ISOLATION FOR OPERATIONAL USE OF C-BAND DUAL-POLARIZED SAR IN FUTURE CONSTELLATION MISSIONS

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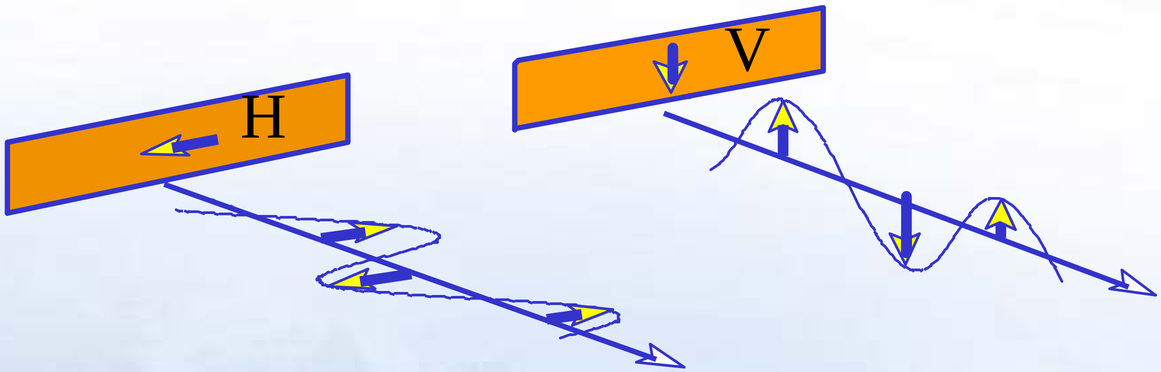
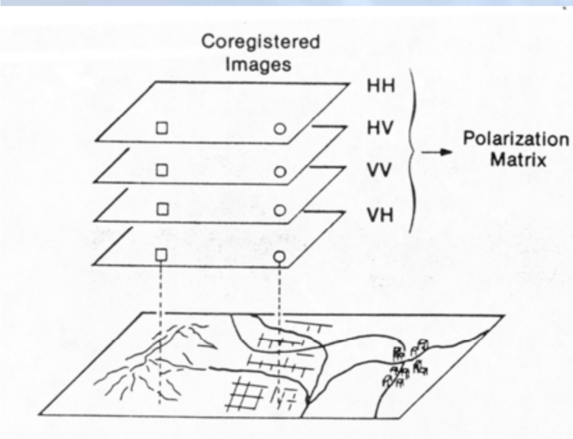
OUTLINE:

- ✦ SAR imaging with a dual-polarized antenna
- ✦ Antenna cross-talk calibration
- ✦ Antenna isolation of current satellite SARs
- ✦ Impact of low C-band antenna isolation on maritime surveillance applications:
  - ➢ ship detection
  - ➢ wind speed measurement
- ⇨ Requirement on C-band dual-polarized antenna isolation for successful radar constellation missions

SAR imaging with a Dual-Polarized Antenna





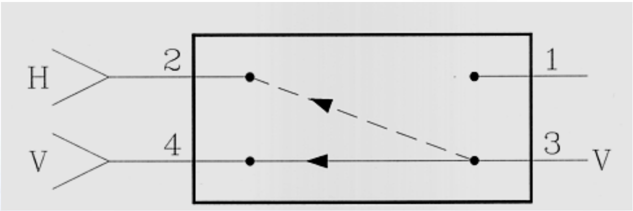
Quad-Pol: (HH,HV,VH,VV)

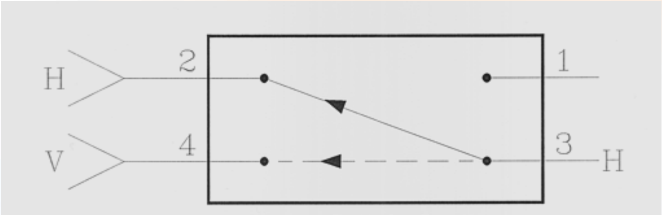
Polarization Synthesis

- Dual-Pol: HH-HV& VV-VH
- Single-Pol: HH, HV or VV

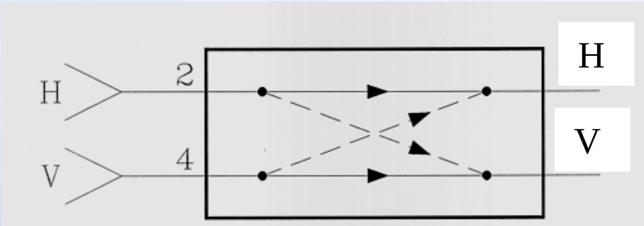
σ°_{TR}

Antenna Cross-talk (Isolation)





Antenna cross-talk at transmission



Antenna cross-talk at reception

- Each polarization measurement is contaminated with target backscattering that occurs at the other polarizations

➩ V_{HH}= func(HH, HV, VH, VV, radar & antenna parameter)

Measured **Versus** Pure **Voltage:** **Polarimetric Calibration**

☛ Quad-pol measurement **required** V_{HH}, V_{HV}, V_{VH} and V_{VV}

CALIBRATION

↓

Pure (HH,VV,HV,VH) from distorted measurements

☛ **Touzi-Livingstone General** polarimetric SAR **Model**:

$$[V] = K \cdot \frac{n_{az}\rho_{az}}{R^2} \cdot [D_r]^T \cdot [g_r(\theta)]^T \cdot [S] \cdot [g_t(\theta)] \cdot [D_t]$$

- [D]: Distortion matrix [g(θ)]: Antenna distortion matrix

➢ R. Touzi, C.E. Livingstone, et al., Antenna Gain and Phase Patterns for **Calibration** of Polarimetric SAR Data; *IEEE TGRS*, 1993

Calibration of the Convair-580 X and C-band SAR at CCRS since 1990

- Active (ARC) and passive calibrator (CR) + natural target

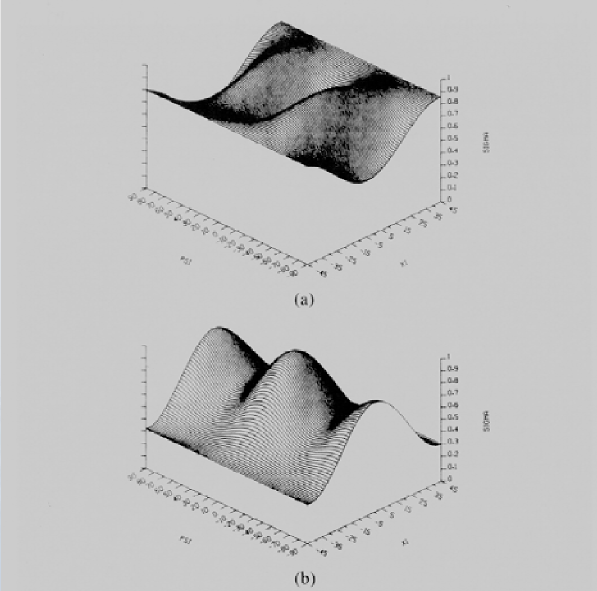


Fig. 8. Co-polarized signatures of shrubs. (a) Before calibration. (b) After calibration.

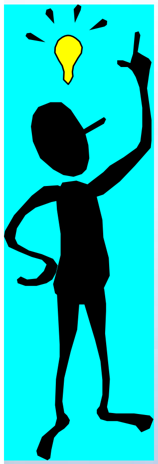
☛ **influence** RADARSAT2 system design

⇨ Antenna isolation from -20dB (orig. requirement) to -32dB (Thanks to **Tony Luscombe** MDA)

Dual-Polarization Antenna Isolation of Satellite SAR

- CEOS Antenna isolation Requirement: **-25 dB** (CEOS2007)
- Envisat (**2002**): **actual** isolation **-35 dB (**Torres CEOS02)
- ALOS (2006): **actual** cross-pol isolation **-35 dB** (☛ Touzi & Shimada *IEEE TGRS* 2009)
- TerraSAR (2007): requirement -25 dB; **actual** -30 dB (☛ A. Moreira)
- Radarsat2 (2007): **actual** isolation **-32 dB** (A. Luscombe CEOS 2008)
- Sentinel-1 (2012): **Expected** isolation **-35 dB** (☛ E. Attema and P. Snoeij)
- RCM (2012): **Expected** antenna isolation **-28 dB** (☛ **Not finalized)**

Impact of Low Antenna Isolation on Ship Detection



- **Cross-talk cannot be removed from single and dual-polarization measurements**
  - **"Pure" polarization measurement HH, HV and VV**

- **Minimum requirement on antenna isolation ⇨ Frequency dependent**
  - **Applications Requirements at various frequency (P, L, C, and X)**
  - **Technology advance in Antenna, T/R, switch Design**

- ⇨ **Impact of low antenna isolation on key applications using multi-frequency polarimetric SAR data**

Impact of C-band Low Antenna Isolation on Maritime Surveillance Applications

- **Calibrated Quad-pol RADARSAT 2 are used**
  - **Cross-pol isolation better than -50 dB (Luscombe CEOS08)**
- **HV is the most affected polarization**
- **HV Key applications: Ship detection and Wind speed measurements**
- **Simulated HV for antenna isolation of -20dB, -26 dB, -30 dB, and -35 dB**
- **Identification of the minimum requirement on antenna isolation**

Can. J. Remote Sensing, Vol. 30, No. 3, pp. 552–559, 2004

Research Note / Note de recherche

Ship detection and characterization using polarimetric SAR

R. Touzi, F.J. Charbonneau, R.K. Hawkins, and P.W. Vachon

Abstract. Polarimetric information is investigated for ship detection and characterization at operational satellite synthetic aperture radar (SAR) incidence angles (20°–60°). It is shown that among the conventional single-channel polarizations (HH, VV, or HV), HV provides the best ship–sea contrast at incidence angles smaller than 50°. Furthermore, HH polarization permits the best ship–sea contrast at near-grazing incidence angles. The wave polarization anisotropy is used for optimal information extraction from polarimetric SAR data. It is shown that fully polarimetric information permits a significant improvement in the ship–sea contrast for relatively calm wind conditions, in comparison with conventional (i.e., scalar) single-channel polarizations (i.e., HH, VV, or HV). For rougher sea conditions, the effectiveness of polarimetric tools may be significantly degraded. Ship characterization is also investigated using the symmetric scattering characterization method (SSCM). Identification of ship targets with significant symmetric scattering can provide a useful ship pitch angle estimate under certain conditions.

Résumé. L'apport de l'information polarimétrique à la détection et la caractérisation des bateaux est étudiée. Parmi les polarisations conventionnelles HH, VV, et HV, la polarisation HV permet le meilleur contraste bateau-mer aux angles d'incidence plus petits que 50°. HH donne les meilleurs résultats aux incidences rasantes. L'anisotropie de polarisation a été utilizée pour l'extraction optimale de l'information polarimétrique. La polarimétrie permet une grande amélioration du contraste bateau–mer dans des conditions de mer et vents relativement calmes. L'efficacité de la polarimétrie est réduite quand la mer est agitée. La méthode SSCM a été testée pour la caractérisation de bateaux. Elle a même permis une mesure de l'angle de tangage de bateaux dans certaines conditions.

Introduction

Ship detection and identification have many potential applications within the commercial, fishery, vessel traffic service, and military sectors. The importance of the transmit–receive antenna polarizations on ship detectability is now well understood. Better ship–sea contrast is obtained with HH polarization, whereas VV polarization provides more information on the sea surface conditions (Vachon et al., 1997; Eldhuset, 1996; Rey et al., 1993). Future satellite synthetic aperture radars (SARs) will offer various polarization channels, and as such will be able to provide additional information that will permit better characterization of the illuminated targets. For example, the environmental satellite advanced synthetic aperture radar (ENVISAT ASAR) (Zink et al., 2001) allows simultaneous measurement of two polarization channels (chosen from among the four linear polarizations: HH, VV, HV, and VH) in the alternating polarization mode. Furthermore, RADARSAT-2 (Luscombe et al., 2000) and ALOS-PALSAR (Ito et al., 2001) will be fully polarimetric SARs. With these upcoming polarimetric missions, it is important to assess the ship–sea contrast improvement that can be obtained by using the additional polarization information. On the other hand, it is well known that fully polarimetric data have a strong potential for characterization of target backscattering (Cloude and Pottier, 1996; Touzi et al., 1992a; Touzi and Charbonneau, 2002). Such information might be helpful for ship identification and for estimating ship orientation (i.e., pitch and roll).

In this study, ship detection and characterization are investigated using fully polarimetric SAR data. Data acquisition and calibration are described, and ship–sea contrast is analyzed for conventional single-channel polarizations (HH, VV, or HV) at operational satellite SAR incidence angles (20°–60°). The wave polarization anisotropy, introduced by Touzi (2000), is also investigated. Ship–sea contrast improvement is then discussed as a function of the SAR illumination angle and wind conditions. Ship identification and characterization are investigated with reference to available ground-truth data collected during SAR data acquisition. The symmetric scattering characterization method (SSCM), which was introduced by Touzi and Charbonneau (2002), is used for high-resolution characterization of ship scattering. Lastly, the

Received 24 December 2002. Accepted 13 January 2004.

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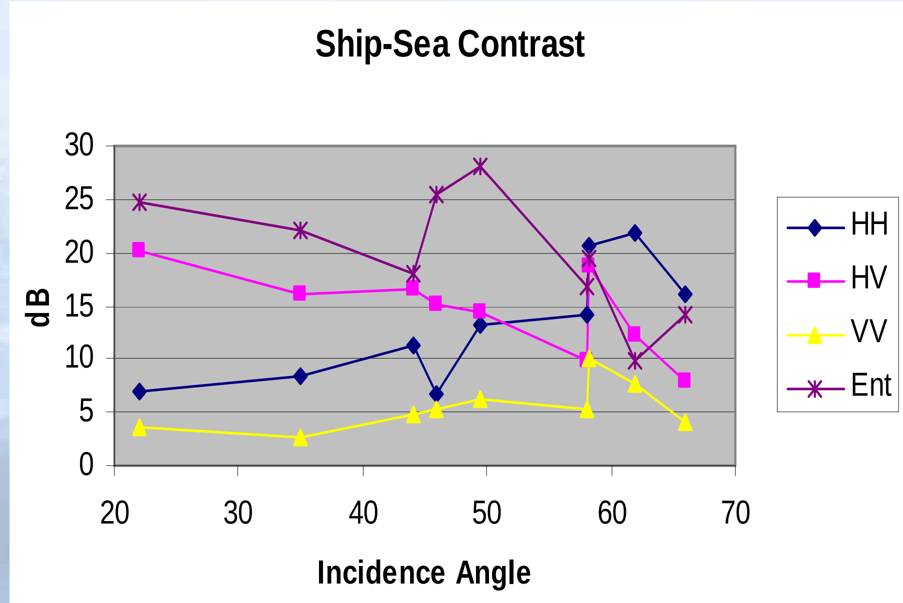
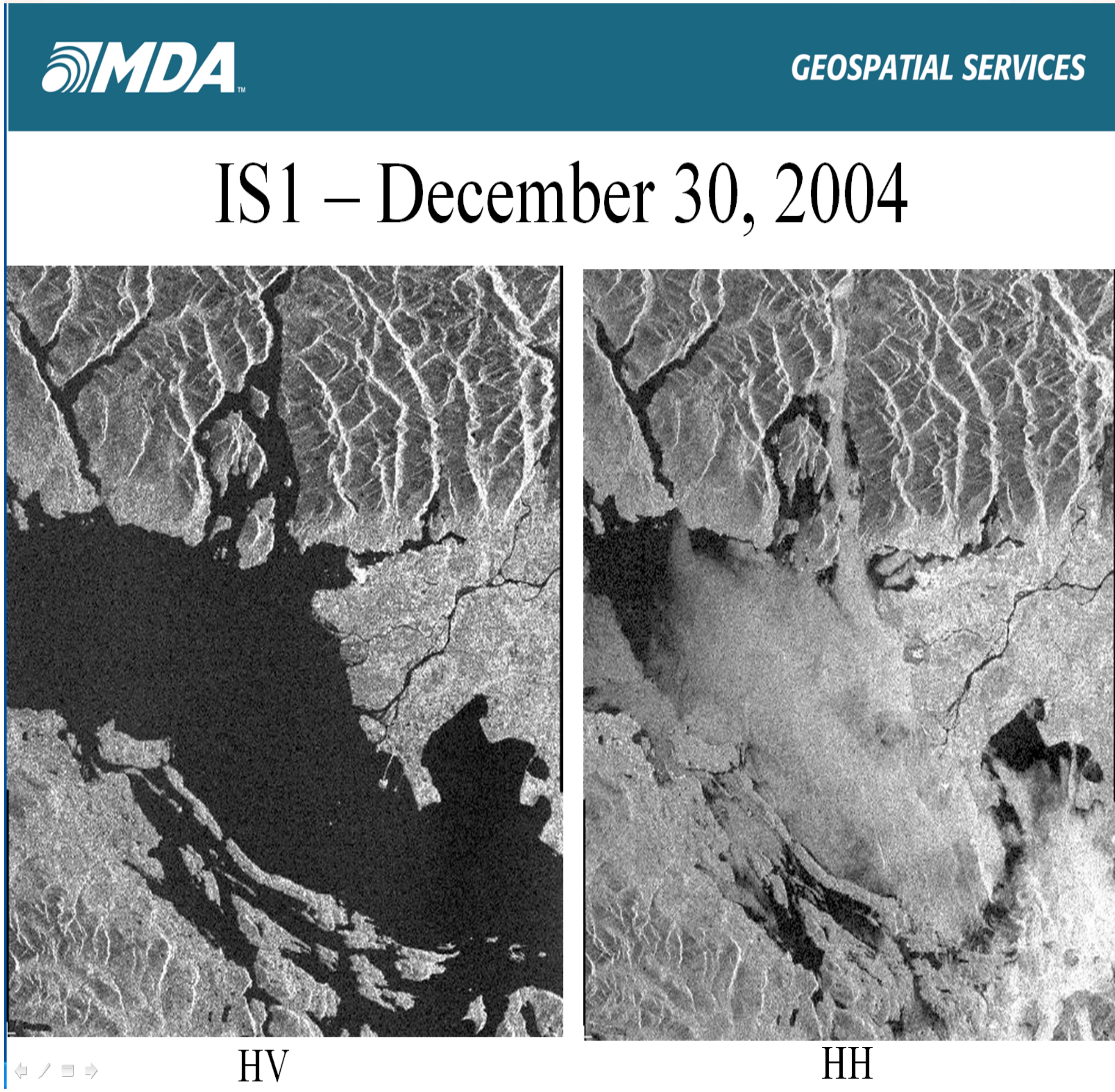
Ship	Size (ft)	Estimated RCS (dBm^2)			
		Incidence Angles			
		25°	35°	45°	55°
M/V Anne S Pierce	116	31	32	33	34
M/V Arctic Pride	60	24	25	26	27
HMCS Ville de Québec	436	44	45	46	47

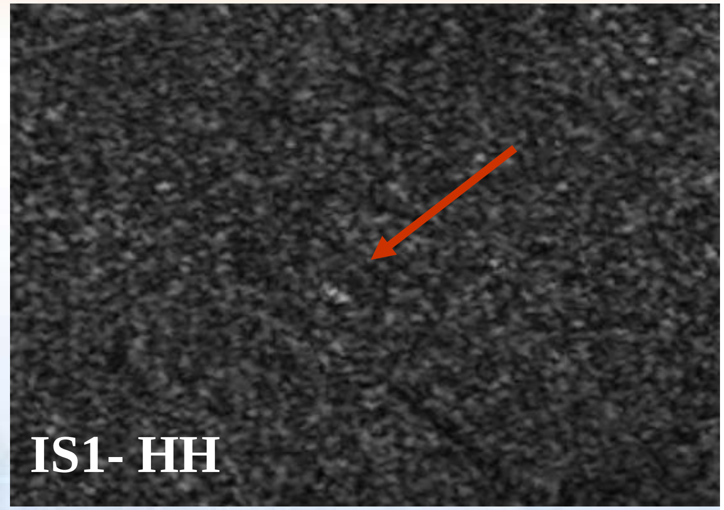


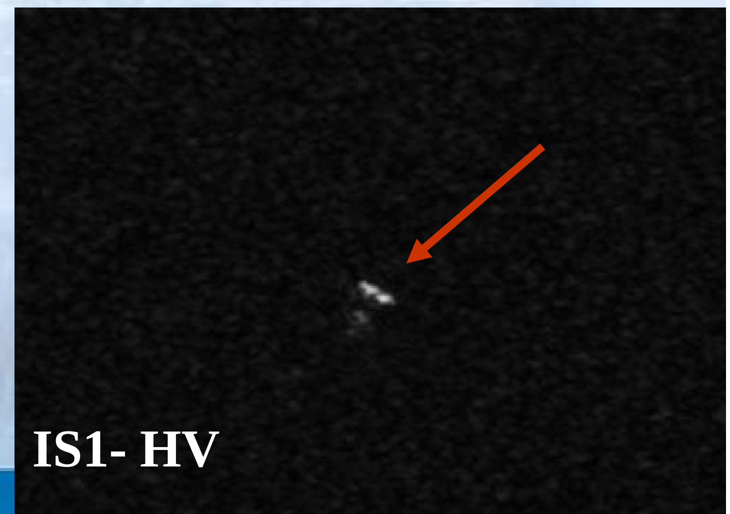
☛ HV better than HH and VV for inc. ang. 20° -45°.

☛ Quad-Pol ⇨ **Best** contrast (Touzi Entropy)

ASAR ➩ -35 dB antenna isolation
IS1 14.3˚ - 22.2˚– Dec. 30, 2004
☛ G. Staples et al. ASAR 2007



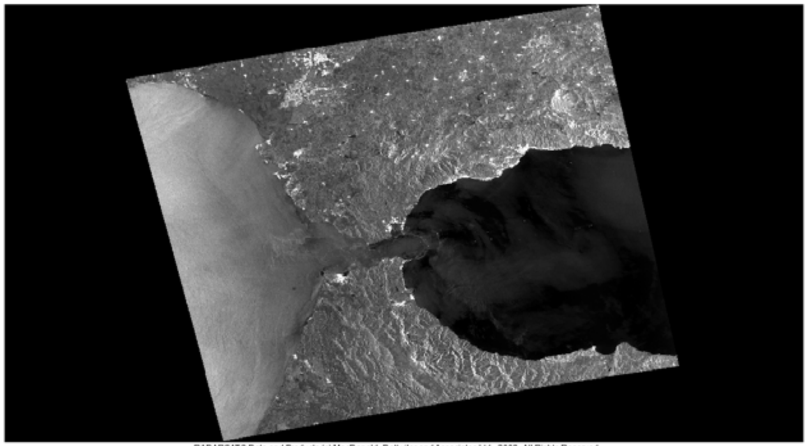




Radarsat 2 ⇨ -32 dB antenna isolation

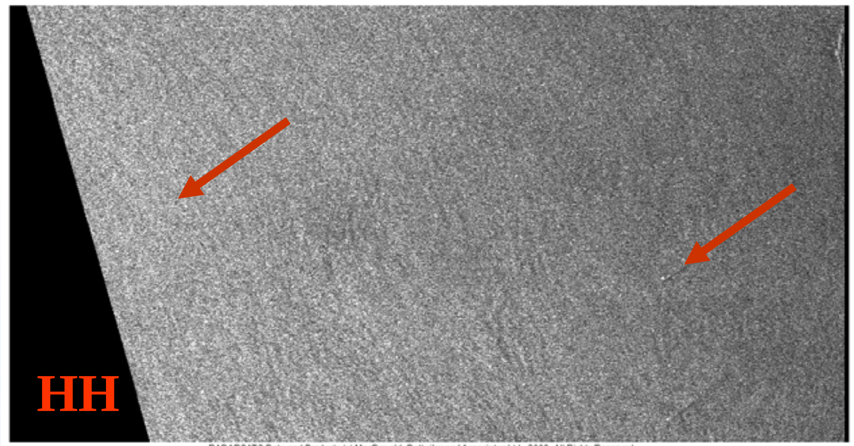
ScanSAR Narrow, Inc. Ang. 20-46°, 300x300km

DEFENCE RD DÉFENSE R-2, Gibraltar, 15Aug2008, SCNA, HH UNCLASSIFIED



UNCLASSIFIED Canada

DEFENCE RD DÉFENSE R-2, Gibraltar, 15Aug2008, HH UNCLASSIFIED



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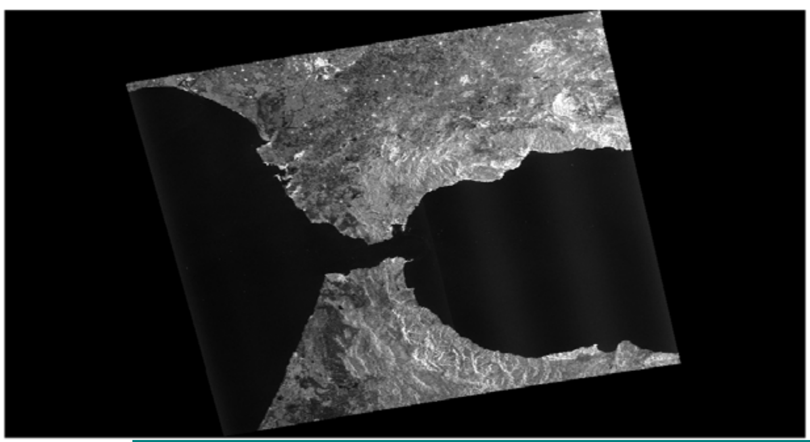
DEFENCE RD DÉFENSE R-2, Gibraltar, 08Aug2008, SCNA, HV UNCLASSIFIED



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DEFENCE RD DÉFENSE R-2, Gibraltar, 15Aug2008, SCNA, HV UNCLASSIFIED

Canada

SAR Model for Simulation of Cross-Pol Contamination

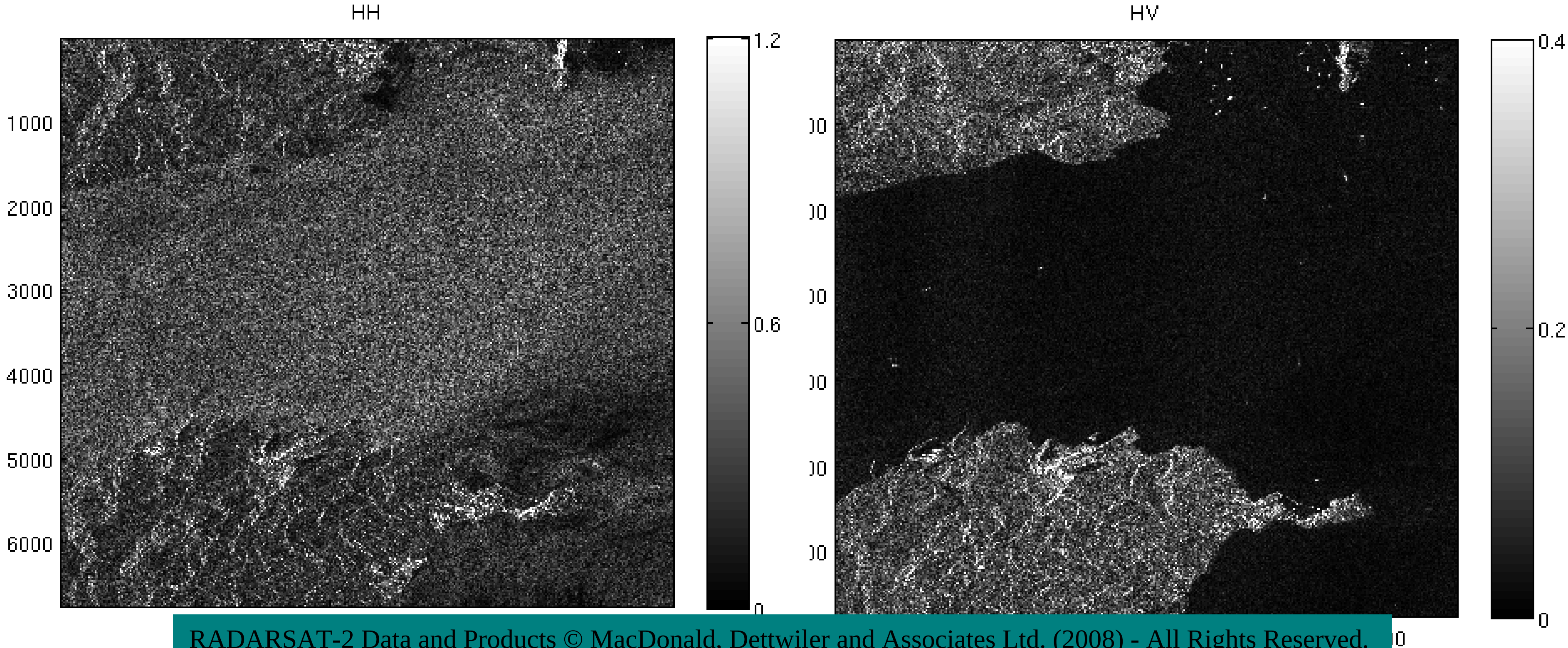
$$\begin{bmatrix} V_{hh} & V_{vh} \\ V_{hv} & V_{vv} \end{bmatrix} = Ae^{j\phi} \begin{bmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{bmatrix}^T \begin{bmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{bmatrix} \begin{bmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{bmatrix}$$

- Assumption: Symmetric system $\delta_1 = \delta_3$ $\delta_2 = \delta_4$

$$\begin{bmatrix} V_{hh} & V_{vh} \\ V_{hv} & V_{vv} \end{bmatrix} = Ae^{j\phi} \begin{bmatrix} 1 & \delta_3 \\ \delta_2 & f_1 \end{bmatrix}^T \begin{bmatrix} S_{hh} & S_{vh} \\ S_{hv} & S_{vv} \end{bmatrix} \begin{bmatrix} 1 & \delta_3 \\ \delta_2 & f_2 \end{bmatrix}$$

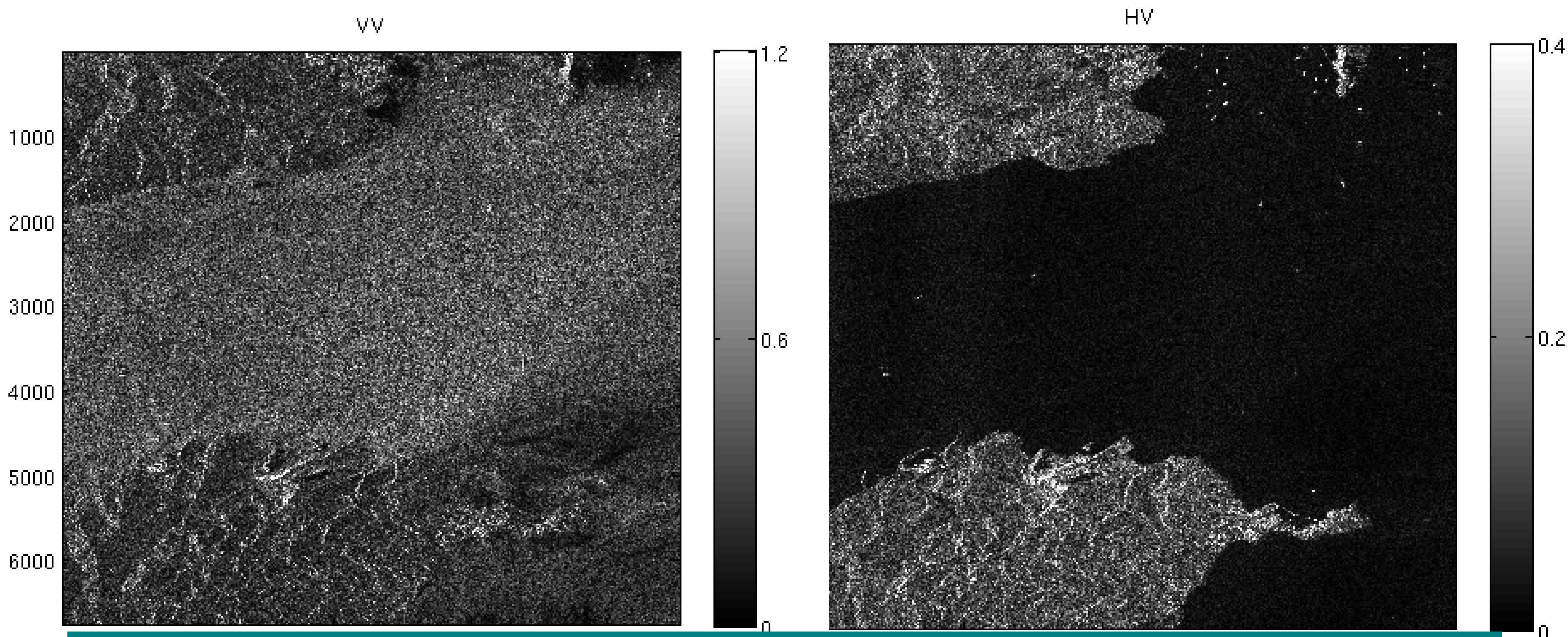
- Assumption 2: $\delta_2 = \delta_3$
- Radarsat2 Channel imbalance typical value f_1=0.1 dB and f_2=0.5 dB (Merci Tony Luscombe)
- Channel imbalance variations with incidence angle ignored (do not affect significantly the results)

Radarsat 2 HH and HV (no cross- talk) Gibraltar July 2008 FQ4 (22°-24°)



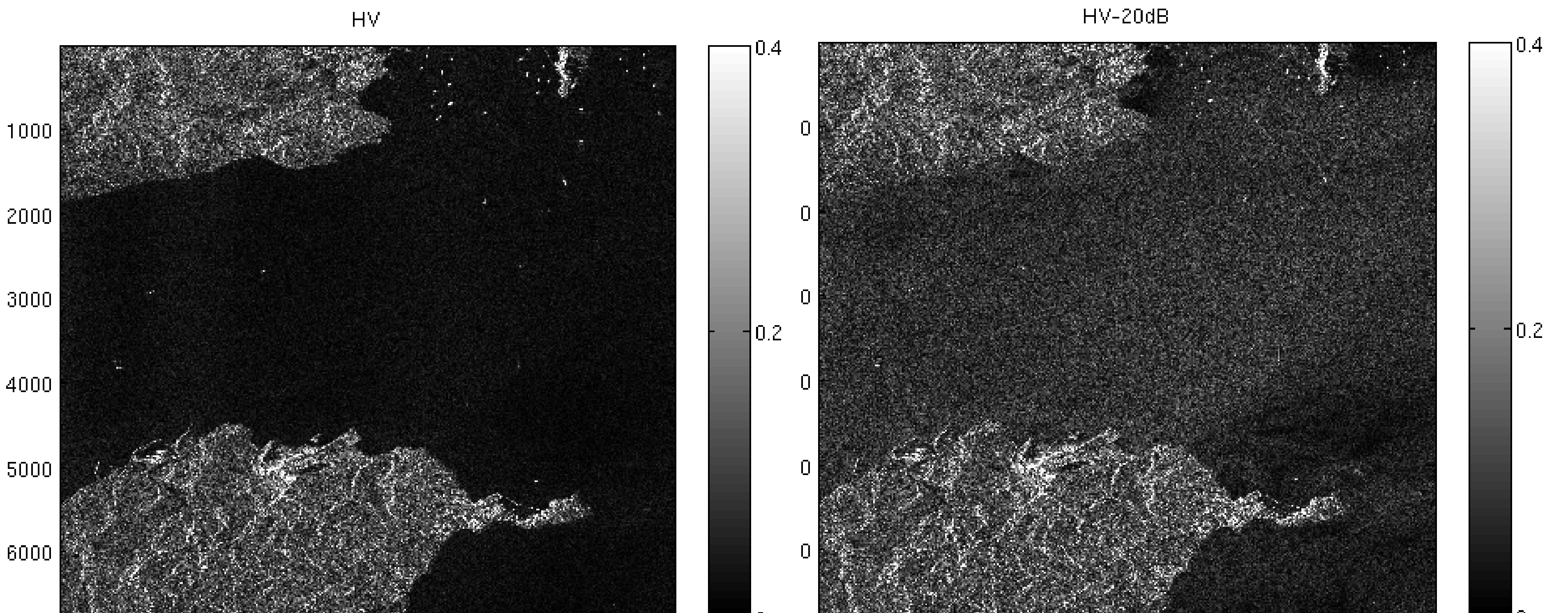
- HV enhances ships
- Ships can hardly be seen with HH

Radarsat 2 VV, and HV (no cross- talk)



- HV enhances ships
- Ships can hardly be seen with VV

HV versus Corrupted HV (-20 dB)



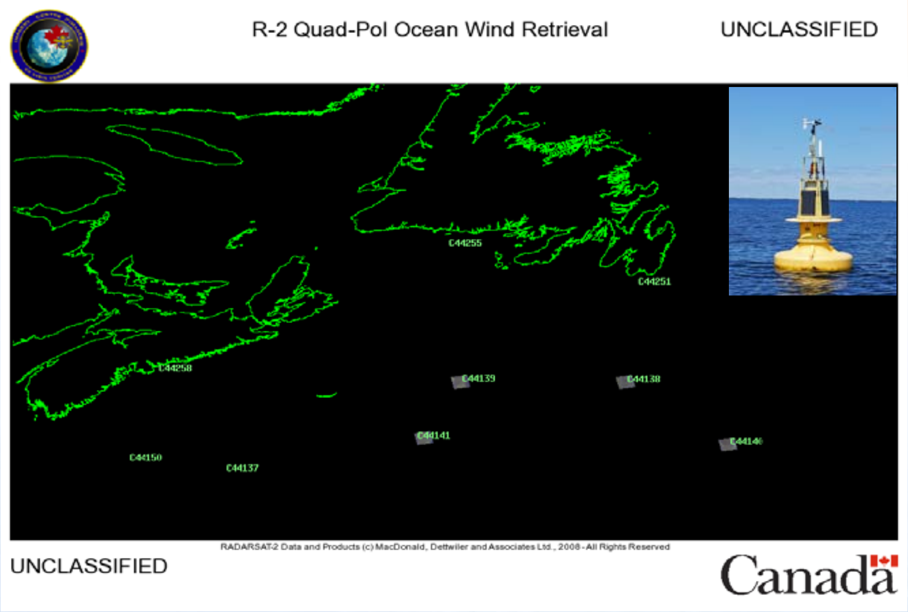
- -20dB cross-talk ➩ HV **contaminated** with HH and VV
- ➩ Ships can hardly be discriminated with HV (-20dB)
- HH&VV contamination **cannot be removed** from HV(-20dB)

Ship- Sea Contrast -20dB and -26dB FQ4 (22°-24°)

- HV(-20dB): Contrast ship/sea 12 dB lower
- HV(-26dB): Contrast ship/sea 7 dB lower

☛ **Contaminated** HV is **not efficient** ship detection

Impact of C-band Antenna Low Isolation on Cross-pol Wind Retrieval



New P. Vachon's model (Oper. of SAR Winds Workshop 2009) :

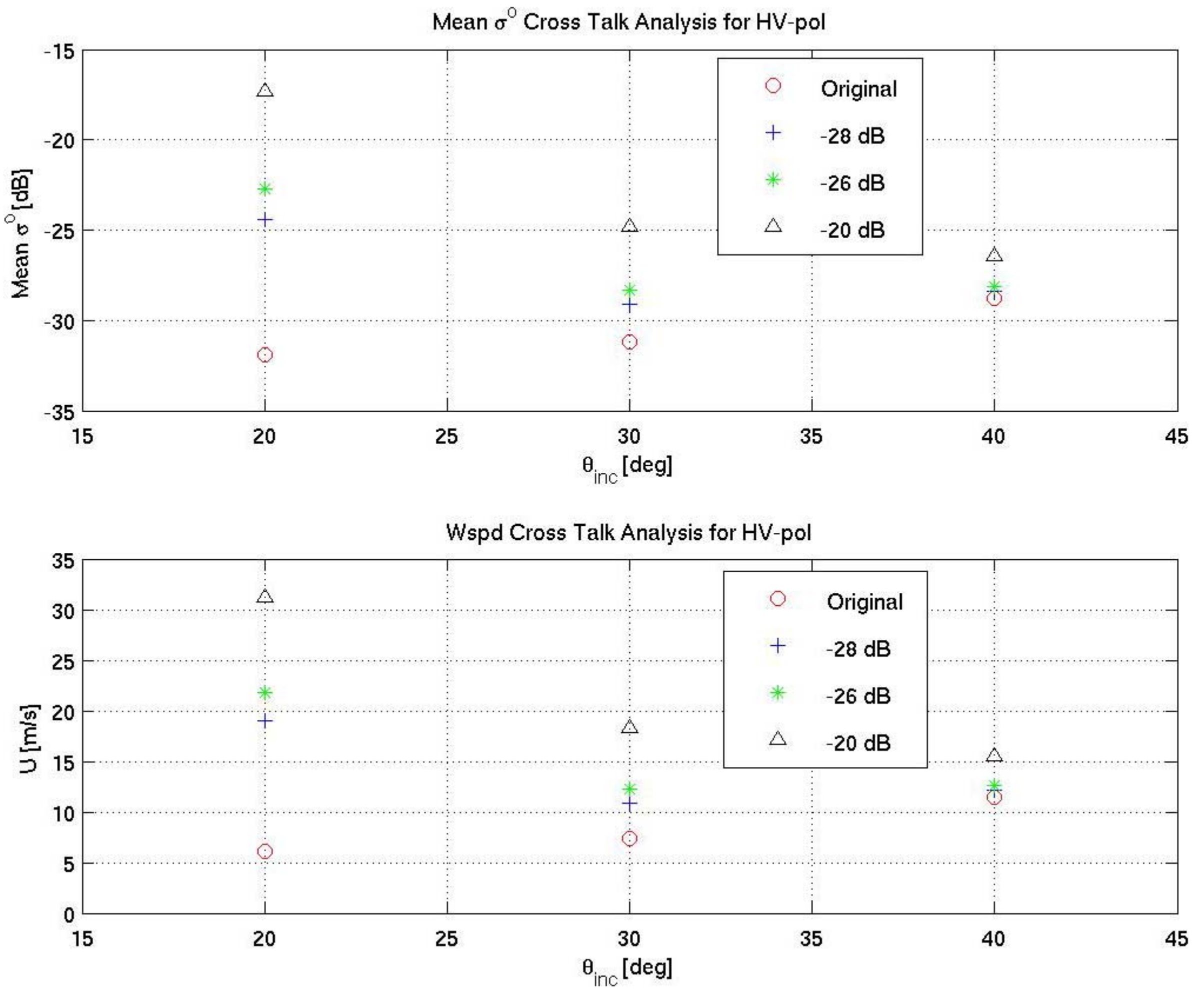
- HV ☛ accurate wind speed measurement
- Wind speed retrieval **independent** of **wind direction** and **incidence angle**

Cross-pol Wind Retrieval as a Function of Antenna Isolation and Incidence Angle
FQ2, FQ10 and FQ20

FQ2: 19.7°-20.7°

- HV(-20dB):
  - Δσ°: **15 dB**
  - Δv= **25m/s**
- HV(-28 dB):
  - Δσ°: **8 dB**
  - Δv=**12m/s**

☛ **Contaminated** HV **not efficient** for wind speed retrieval



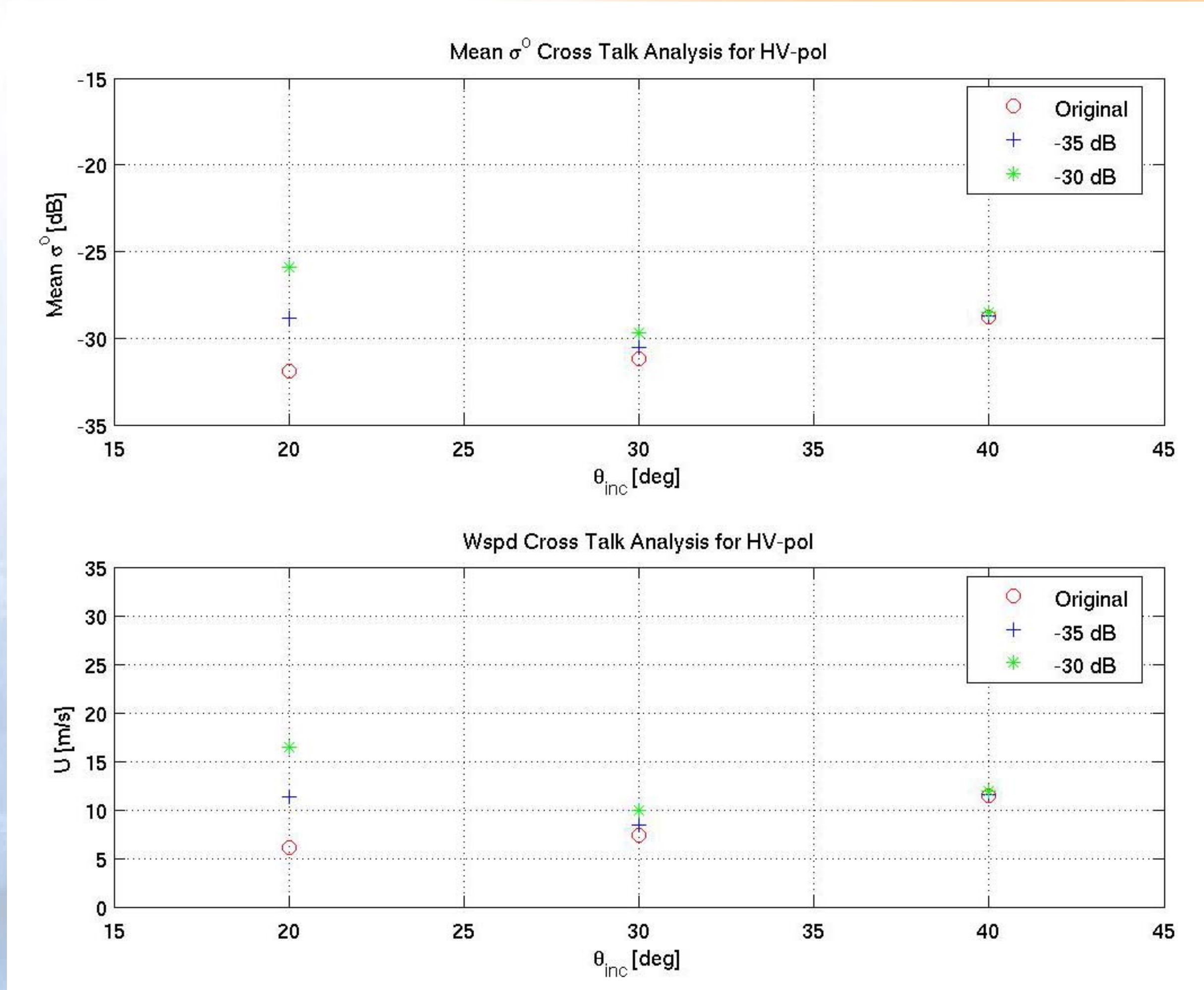
Minimum Requirement on C-band Antenna Isolation For Successful Dual-Polarization SAR Constellation Missions

Ship- Sea Contrast
FQ4 (22°-24°)

- HV(-30dB): Contrast ship/sea 3 dB lower than pure HV
- HV(-35dB): Contrast ship/sea 1 dB lower than pure HV

Cross-pol Wind Retrieval

FQ2, FQ10 and FQ20



- -30dB: $\Delta\sigma°$: **6 dB** Δv= **7m/s**
- -35dB: $\Delta\sigma°$: **3 dB** Δv= **5m/s**

Minimum Requirement on C-band Antenna Isolation

- Actual CEOS requirement (-25 dB) too low
  - ☛ $\Delta\sigma°$= 8 dB error on HV ocean due to VV and HH contamination (at 20°)
  - ☛ Δv=15m/s error in wind speed measurement (at 20°)
  - ☛ Contrast ship/sea: 7 dB lower than pure HV (at 23°)
- Minimum Requirement on Future C-band SAR Constellations: -35 dB

➢ Realistic: Envisat was designed in 1998 with -35 dB antenna isolation

⇨ Meeting the requirement in term of HV purity for operational use of SAR Constellations in maritime surveillance (ship and iceberg detection, wind-speed measurement), ice classification and others

☛ Similar study is being conducted at L-band using polarimetric ALOS

☛ Calibrated Polarimetric TerraSAR data are required to conduct the study at X-band.