Alessio Di Simone

Tutor: Daniele Riccio

XXIX Cycle - III year presentation

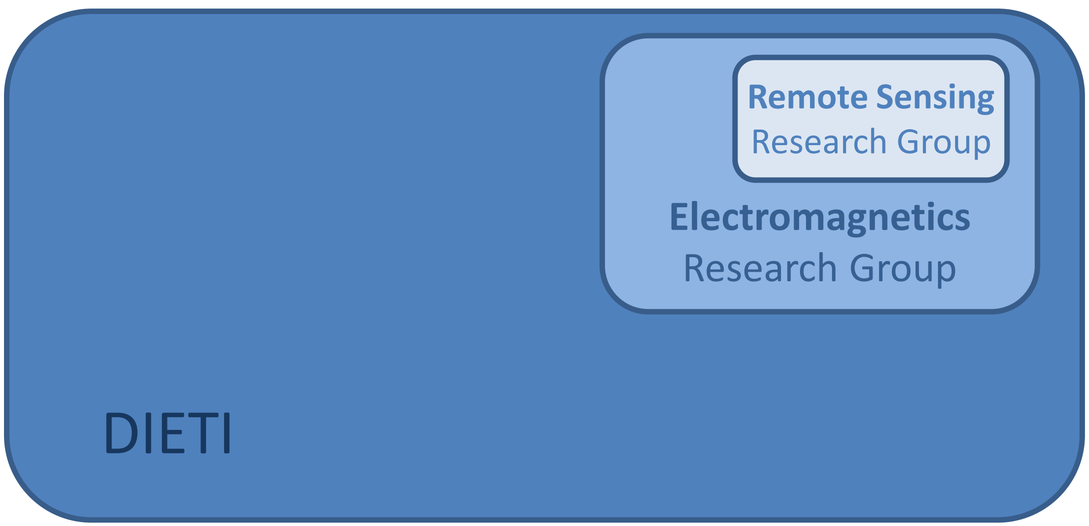
Scattering Models in Remote Sensing

Application to SAR Despeckling and Sea Target Detection from GNSS-R Delay-Doppler Maps

Università degli Studi di Napoli Federico II

My personal background

- MSc in **Telecommunications Engineering** – Università di Napoli Federico II
- **Fellowship** – MIUR – FSG research program "Sistemi di telecomunicazione innovativi a larga banda anche con impiego di satelliti per utenze differenziate in materia di sicurezza, prevenzione e intervento in caso di catastrofi naturali”



My personal background

- Training activities:

	Credits year 1								Credits year 2								Credits year 3								
	1 bimonth	2 bimonth	3 bimonth	4 bimonth	5 bimonth	6 bimonth	**Summary**	Check	1 bimonth	2 bimonth	3 bimonth	4 bimonth	5 bimonth	6 bimonth	**Summary**	Check	1 bimonth	2 bimonth	3 bimonth	4 bimonth	5 bimonth	6 bimonth	**Summary**	Check	**Total**
Modules	0	3	3	6	3	10	**25**	20-40	0	3	7	0	0	0	**10**	10-20	0	0	0	0	0	0	**0**	0-10	**35**
Seminars	1.2	0.9	0	1	1	0.9	**5**	5-10	2.9	1.3	0	0	0.4	0.7	**5.3**	5-10	0	0.6	0	0	0	0	**0.6**	0-10	**10.9**
Research	7	5	7	3	6	2	**30**	10-35	7.1	5.7	3	10	9.6	9.3	**44.7**	30-45	10	9.4	10	10	10	10	**59.4**	40-60	**134.1**
	8.2	8.9	10	10	10	12.9	**60**		10	10	10	10	10	10	**60**		10	10	10	10	10	10	**60**		**180**

- Experience abroad:

4-month stay (June-September 2016, 3° year of PhD) at the Universitat Politècnica de Catalunya-BarcelonaTech, Signal Theory and Communications Department working on sea target detection using GNSS-R data (part of this presentation) in collaboration with the Passive Remote Sensing Group led by Adriano Camps.

Outline

PART I

- Introduction
  - Synthetic Aperture Radar (SAR)
  - Why SAR despeckling?
- Proposed Scattering-Based Despeckling Approach
  - SB-PPB
  - SB-SARBM3D
- Experimental Results

PART II

- Why ship/ice detection?
- Why Global Navigation Satellite System-Reflectometry (GNSS-R)?
  - GNSS-R vs. SAR, Optical, Automatic Identification System (AIS)
  - Revisit Time
- Sea Target Detection from GNSS-R delay-Doppler Maps (DDM)
  - Algorithm Rationale
- Experimental results on UK TDS-1 data

Comments and Conclusions

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Comments and Conclusions

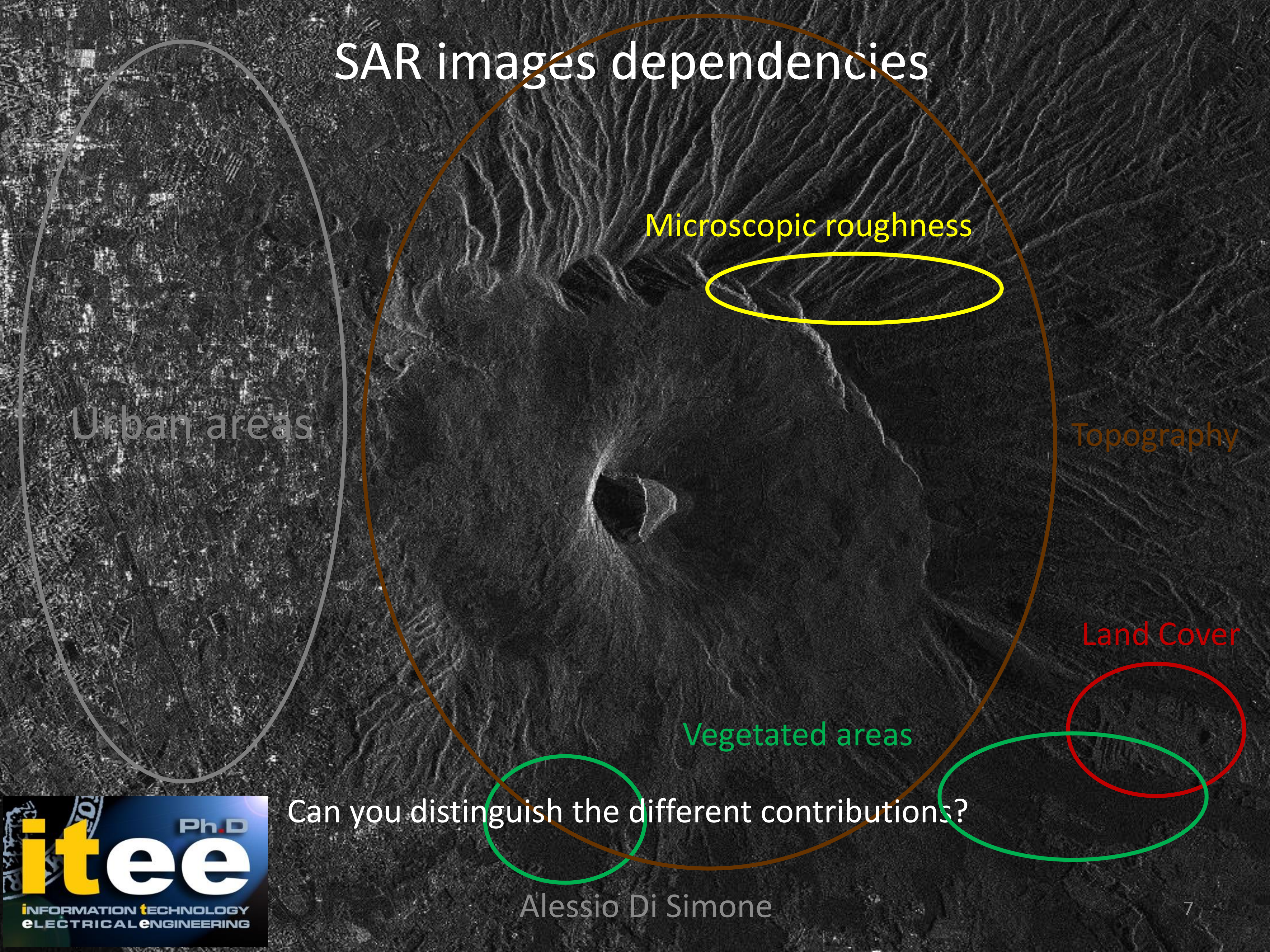
SAR images dependencies

Unknown parameters

SAR Image dependencies	Electromagnetic parameters	Geometric parameters
Surface parameters	• Dielectric constant (complex)	• Roughness • Topography (slopes)
Sensor parameters	• Polarization • Operating frequency	• Look angle • Resolution

Known parameters

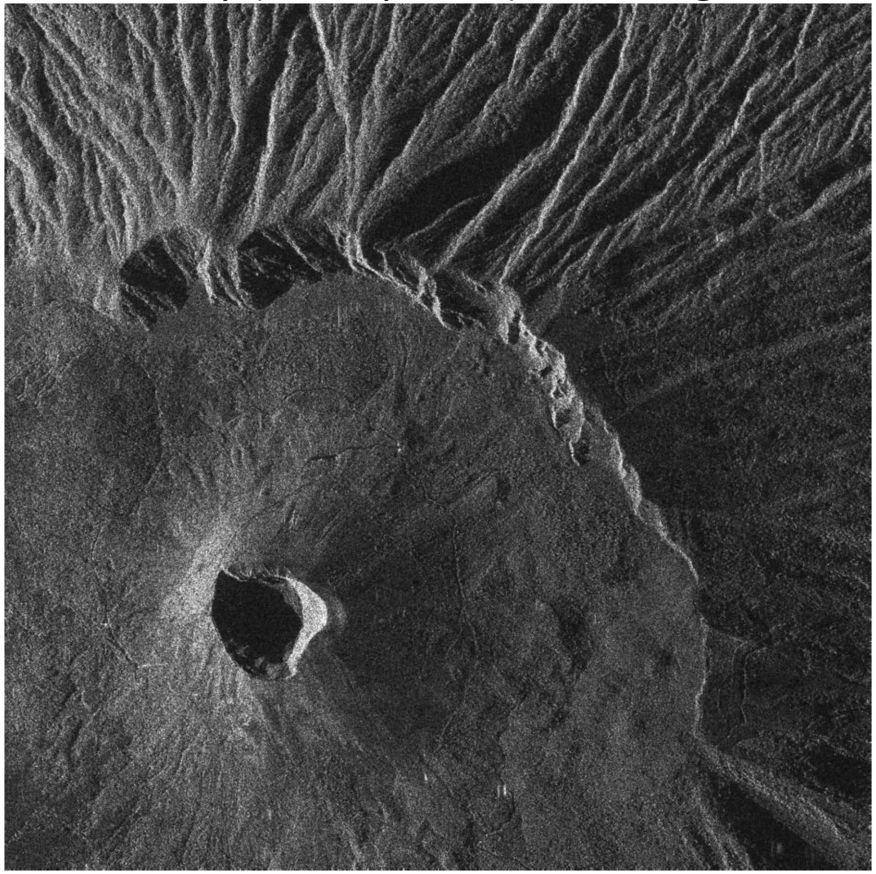
SAR images dependencies



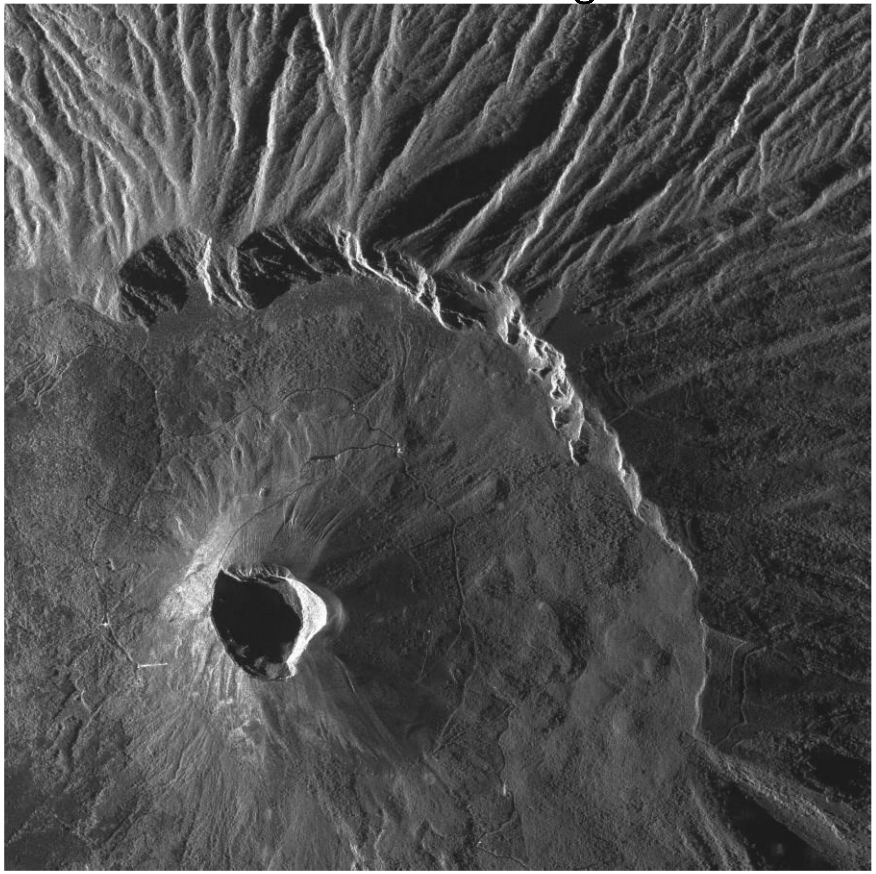
Can you distinguish the different contributions?

SAR Images Despeckling: a desiderable result

Noisy (with speckle) SAR Image



"Clean" SAR Image



Objective: remove (reduce) speckle in SAR imagery

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Comments and Conclusions

Scattering-Based SAR Images Despeckling

- How can we take into account for the different colors?
  - ✓ The answer is straightforward… by taking into account for scattering phenomena.
- Electromagnetic scattering concepts can be «injected» in the SAR despeckling pre-processing step like a kind of a priori information.

👍 More physical-based despeckling approaches can be developed.

👍 Thanks to the a priori information, presumibly better perfomance results could be obtained.

👎 Scattering model(s) needed

👎 Some a priori information is needed.

Scattering-Based SAR Images Despeckling: Scattering Model(s)

Urban area

- Multiple bounce scattering
- Layover
- Shadowing

Vegetated area

- Volume scattering

Unvegetated area

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

Different scenarios $\Rightarrow$ Different scattering models

Scattering-Based SAR Images Despeckling: Scattering Model

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

Scattering-Based SAR Images Despeckling: Scattering Model

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

Scattering-Based SAR Images Despeckling: Scattering Model

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

Fractal Surface Model

(Fractal) Scattering Model

SAR Image Model

Scattering-Based SAR Images Despeckling: Scattering Model

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

Fractal Surface Model

$$\Pr\{z(x,y) - z(x',y') < \bar{\zeta}\} = \frac{1}{\sqrt{2\pi}T^{(1-H)}\tau^{H}} \int_{-\infty}^{\bar{\zeta}} \exp\left(-\frac{\zeta^2}{2T^{2(1-H)}\tau^{2H}}\right) d\zeta$$

T: Topothesy
H: Hurst coefficient

$$\tau = \sqrt{(x-x')^2 + (y-y')^2}$$

Scattering-Based SAR Images Despeckling: Scattering Model

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

Fractal Surface Model

$$\Pr\{z(x,y) - z(x',y') < \bar{\zeta}\} = \frac{1}{\sqrt{2\pi}T^{(1-H)}\tau^{H}} \int_{-\infty}^{\bar{\zeta}} \exp\left(-\frac{\zeta^2}{2T^{2(1-H)}\tau^{2H}}\right) d\zeta$$

(Fractal) Scattering Model

$$\sigma_{mn}^{0} = 2\pi 8k^4 cos^4\theta |\beta_{mn}|^2 \frac{S_0}{(2k\sin\theta)^{2+2H}}$$

σ_{mn}^{0}: Backscattering coefficient
k: Propagation constant
θ: Local incidence angle
β_{mn}: Reflection coefficient
S_0: Spectral amplitude

Scattering-Based SAR Images Despeckling: Scattering Model

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

Fractal Surface Model

$$\Pr\{z(x,y) - z(x',y') < \bar{\zeta}\} = \frac{1}{\sqrt{2\pi}T^{(1-H)}\tau^{H}} \int_{-\infty}^{\bar{\zeta}} \exp\left(-\frac{\zeta^2}{2T^{2(1-H)}\tau^{2H}}\right) d\zeta$$

(Fractal) Scattering Model

$$\sigma_{mn}^{0} = 2\pi 8k^4 cos^4\theta |\beta_{mn}|^2 \frac{S_0}{(2k\sin\theta)^{2+2H}}$$

SAR Image Model

$$I = G\Delta x \Delta r \frac{\sigma_{mn}^{0}}{\sin\theta}$$

G: Calibration constant
Δx: Azimuth SAR resolution
Δr: Slant range resolution

Scattering-Based SAR Images Despeckling: Scattering Model

- Single-bounce scattering
- Sub-surface scattering
- Layover
- Shadowing

SAR Image Model

$$I = G\,\Delta x \Delta r\, 2\pi 8k^4 |\beta_{mn}|^2 S_0 \frac{\cos^4\theta}{(2k)^{2+2H}(\sin\theta)^{3+2H}}$$

- G: Calibration constant
- $\Delta x \Delta r$: Sensor resolution
- $|\beta_{mn}|^2$: Land cover
- $S_0 \frac{\cos^4\theta}{(2k)^{2+2H}(\sin\theta)^{3+2H}}$: Roughness (microscopic and macroscopic)

$$\beta_{hh} = \frac{\cos\vartheta - \sqrt{\varepsilon_r - \sin^2\vartheta}}{\cos\vartheta + \sqrt{\varepsilon_r - \sin^2\vartheta}};$$

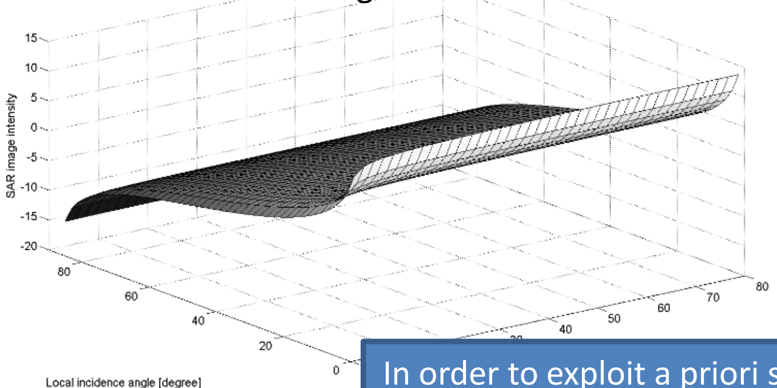
$$\beta_{vv} = (\varepsilon_r - 1)\frac{\sin^2\vartheta - \varepsilon_r(1+\sin^2\vartheta)}{\left[\varepsilon_r\cos\vartheta + \sqrt{\varepsilon_r - \sin^2\vartheta}\right]^2}$$

$$S_0 = 2^{2H+1}\Gamma^2(1+H)\sin\pi H\, T^{2(1-H)}$$

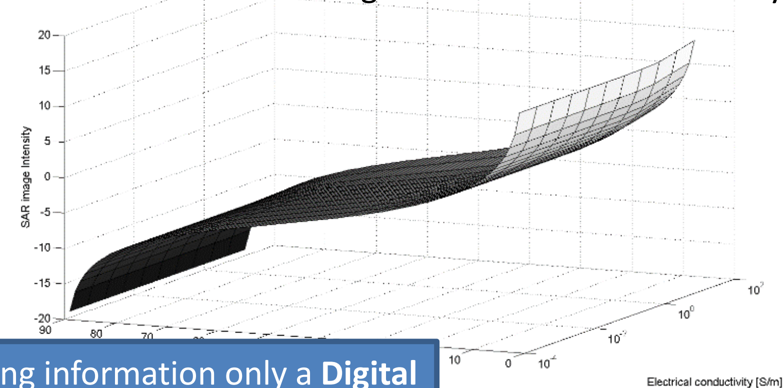
Scattering-Based SAR Images Despeckling: A Priori Scattering Information

$$\sigma_{mn}^{0} = 2\pi 8 k^{4} cos^{4}\theta |\beta_{mn}|^{2} \frac{S_0}{(2k \sin\theta)^{2+2H}}$$

Local Incidence Angle vs. Dielectric Constant

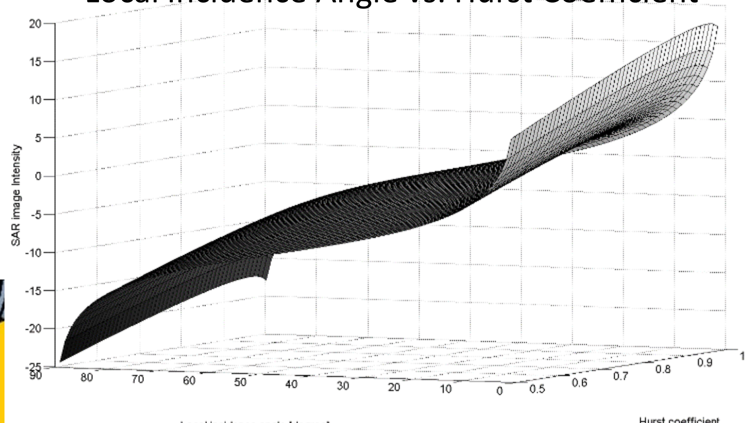


Local Incidence Angle vs. Electrical Conductivity

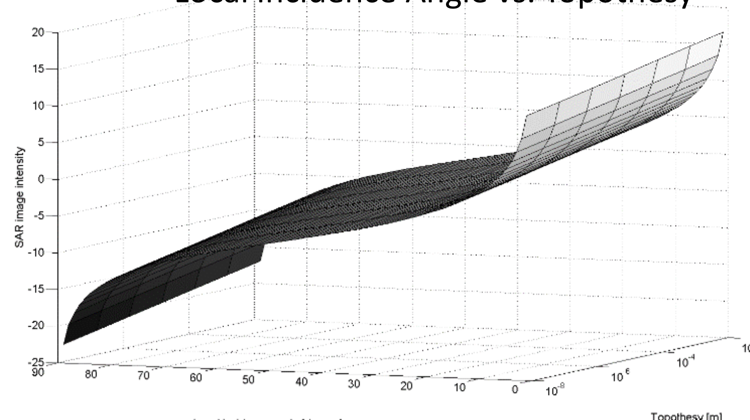


In order to exploit a priori scattering information only a **Digital Elevation Model (DEM)** of the illuminated surface is required.

Local Incidence Angle vs. Hurst Coefficient



Local Incidence Angle vs. Topothesy



INFORMATION TECHNOLOGY ELECTRICAL ENGINEERING

Scattering-Based Probabilistic Patch-Based filter

Probabilistic Patch-Based (PPB) filter

$$\hat{\sigma}_s^{WMLE} = \frac{\sum_{t\in\Omega} w_{s,t} A_t^2}{\sum_{t\in\Omega} w_{s,t}}$$

Non-iterative PPB

$$w_{s,t}{}^{(non-it.\,PPB)} \triangleq p(\sigma_{\Delta s} = \sigma_{\Delta t} | A)^{\frac{1}{h}}$$

$$w_{s,t}{}^{(non-it.\,PPB)} = \exp\left[-\sum_k \frac{1}{\tilde{h}} \ln\left(\frac{A_{s,k}}{A_{t,k}} + \frac{A_{t,k}}{A_{s,k}}\right)\right]$$

Iterative PPB

$$w_{s,t}{}^{(it.\,PPB,i)} \triangleq p\left(\sigma_{\Delta s} = \sigma_{\Delta t} | A, \hat{\sigma}^{i-1}\right)^{\frac{1}{h}}$$

$$w_{s,t}{}^{(it.\,PPB,i)} = \exp\left[-\sum_k \left(\frac{1}{\tilde{h}} \ln\left(\frac{A_{s,k}}{A_{t,k}} + \frac{A_{t,k}}{A_{s,k}}\right) + \frac{L}{T_{fil}} \frac{\left|\hat{\sigma}_{s,k}^{i-1} - \hat{\sigma}_{t,k}^{i-1}\right|^2}{\hat{\sigma}_{s,k}^{i-1} \hat{\sigma}_{t,k}^{i-1}}\right)\right]$$

Scattering-Based PPB (SB-PPB) filter

$$\hat{\sigma}^0 = 2\pi 8 k^4 S_0 |\beta_{mn}|^2 \frac{\cos^4\theta}{(2k\sin\theta)^{2+2H}}$$

$$w_{s,t}^{SB-PPB\ non-it.} \triangleq p(\sigma_{\Delta s} = \sigma_{\Delta t} | A, \hat{\sigma}^0)^{\frac{1}{h}}$$

$$w_{s,t}^{SB-PPB\ non-it.} = \exp\left[-\sum_k \left(\frac{1}{\tilde{h}} \ln\left(\frac{A_{s,k}}{A_{t,k}} + \frac{A_{t,k}}{A_{s,k}}\right) + \frac{L}{T_{fil}} \frac{\left|\hat{\sigma}_{s,k}^0 - \hat{\sigma}_{t,k}^0\right|^2}{\hat{\sigma}_{s,k}^0 \hat{\sigma}_{t,k}^0}\right)\right]$$

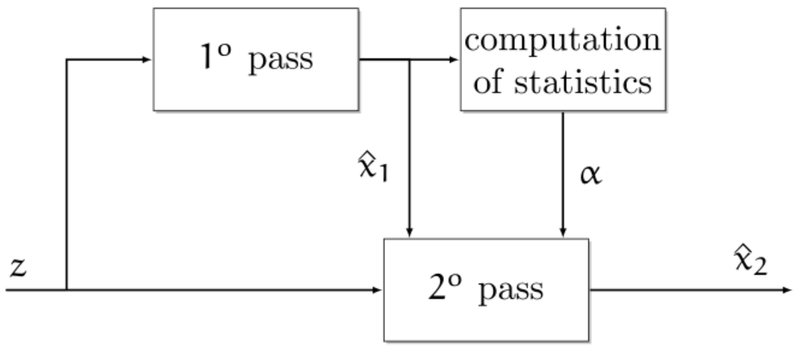
$$= w_{s,t}^{PPB\ non-it} \cdot \exp\left(-\sum_k \frac{L}{T_{fil}} \frac{\left|\hat{\sigma}_{s,k}^0 - \hat{\sigma}_{t,k}^0\right|^2}{\hat{\sigma}_{s,k}^0 \hat{\sigma}_{t,k}^0}\right)$$

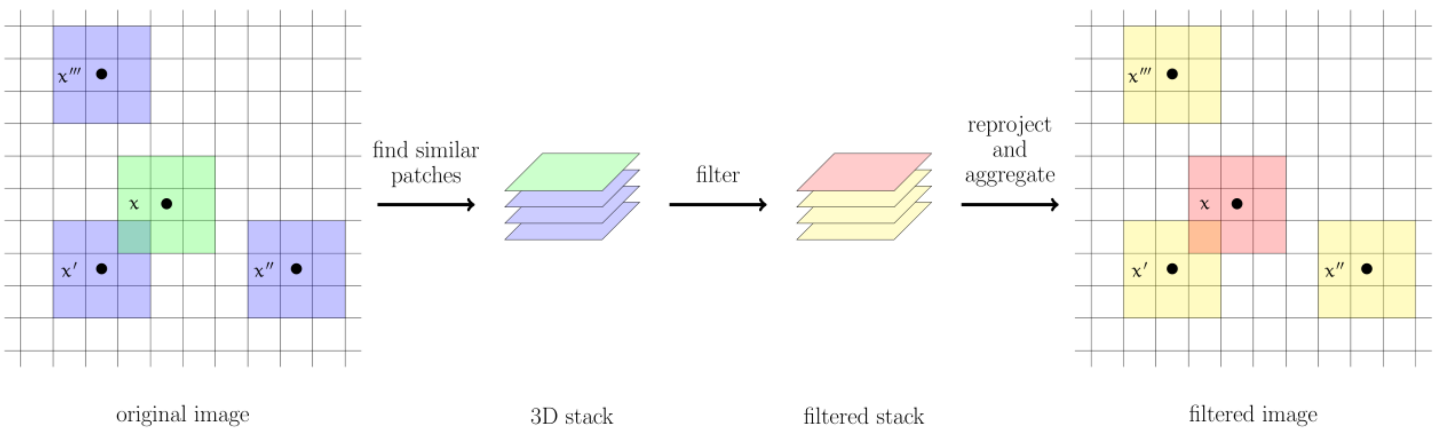
Thanks to the a priori scattering information, iterations can be avoided

Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D. "Scattering-Based Non-Local Means SAR Despeckling," *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54, no. 6, pp. 3574-3588, Jun. 2016. doi: 10.1109/TGRS.2016.2520309

Scattering-Based SAR Block-Matching 3-D filter

SAR-Block-Matching 3-D (SARBM3D)





Scattering-Based SAR Block-Matching 3-D filter

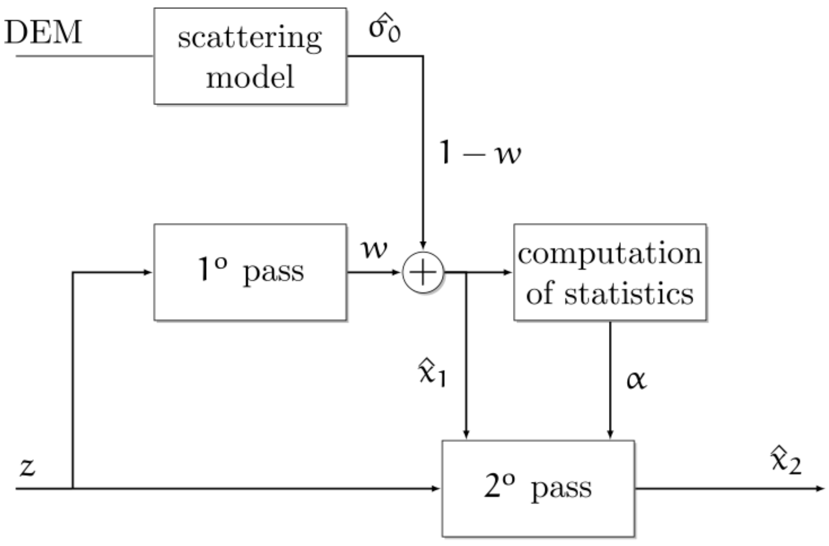
Scattering-Based SARBM3D (SB-SARBM3D)

$$\hat{\sigma}^0 = 2\pi 8 k^4 S_0 |\beta_{mn}|^2 \frac{\cos^4\theta}{(2k\sin\theta)^{2+2H}}$$

$$\hat{x}_{1,SB-SARBM3D} = f\left(\hat{x}_{1,SARBM3D}, \hat{\sigma}^0\right)$$

$$\hat{x}_{1,SB-SARBM3D}(s) = w(s)\hat{x}_{1,SARBM3D}(s) + (1 - w(s))\hat{\sigma}^0(s)$$

$$w(s) = \begin{cases} 1 - \dfrac{r_I(s)}{r_\vartheta(s)} & if\ r_I(s) \le r_\vartheta(s) \\ 1 - \dfrac{r_\vartheta(s)}{r_I(s)} & if\ r_\vartheta(s) < r_I(s) \end{cases}$$



Di Martino, G.; **Di Simone, A.**; Iodice, A.; Poggi, G.; Riccio, D.; Verdoliva, L. "Scattering-Based SARBM3D," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 9, no. 6, pp. 2131-2144, Jun. 2016.
doi: 10.1109/JSTARS.2016.2543303

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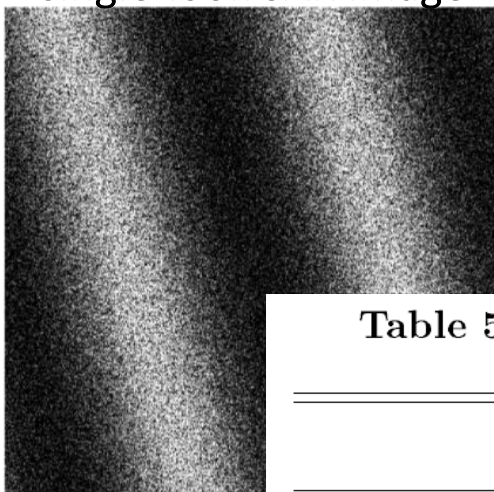
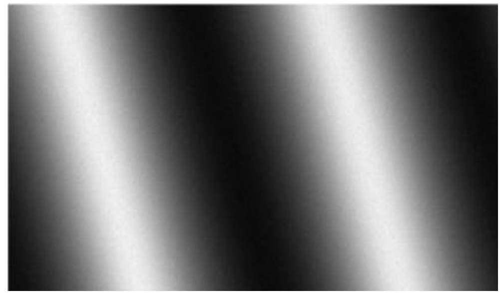
Comments and Conclusions

Scattering-Based SAR Images Despeckling: Experimental Results

single-look SAR image



512-look reference SAR image



PPB 4-iterative

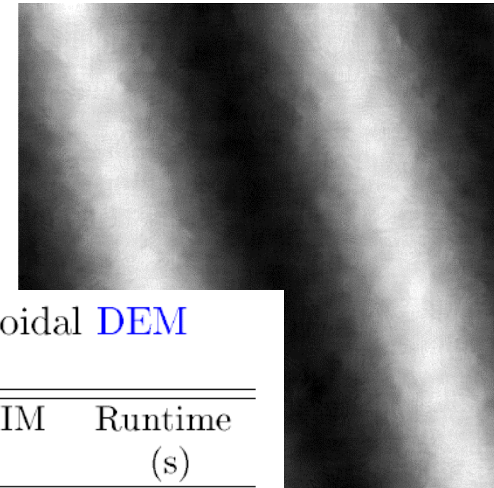
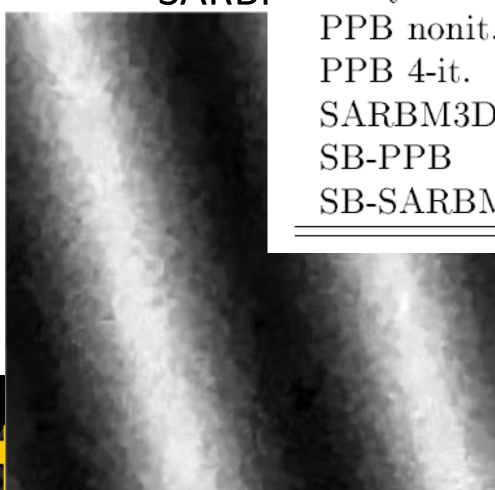


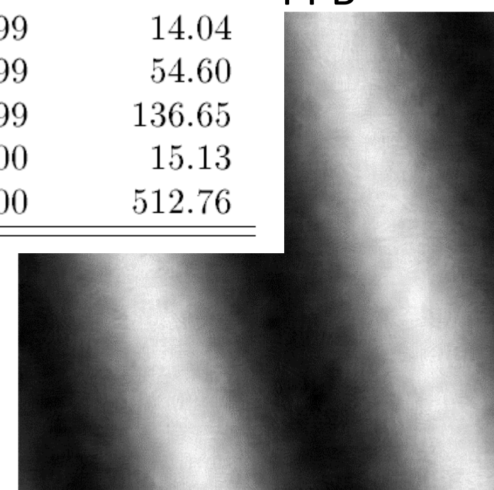
Table 5.1. Performance parameters for the sinusoidal DEM

	MoI	VoR	SNR	C_x	MSSIM	Runtime (s)
Reference	1.000	0.997	∞	0.860	1.000	-
Noisy	1.000	-	-3.693	1.572	0.970	-
PPB nonit.	0.998	0.819	17.192	0.848	0.999	14.04
PPB 4-it.	0.999	0.820	16.921	0.852	0.999	54.60
SARBM3D	0.985	0.858	16.045	0.862	0.999	136.65
SB-PPB	0.998	0.823	17.286	0.849	1.000	15.13
SB-SARBM3D	0.986	0.993	19.155	0.852	1.000	512.76

SARBI

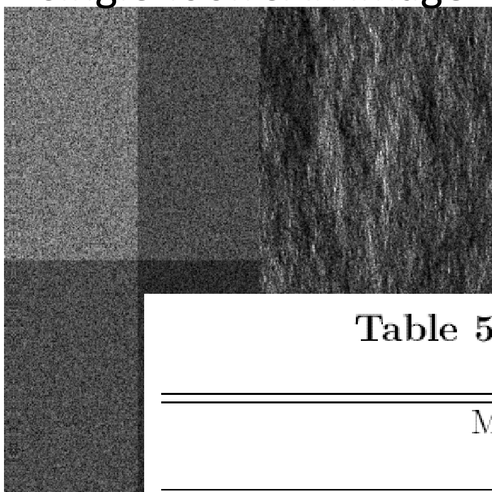


PPB

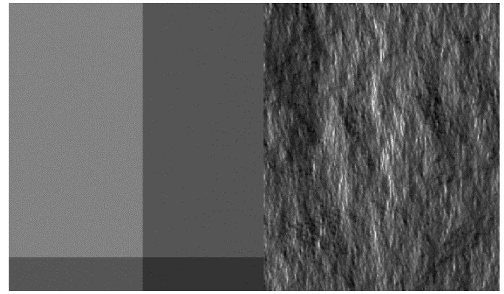


Scattering-Based SAR Images Despeckling: Experimental Results

single-look SAR image



512-look reference SAR image



PPB 4-iterative

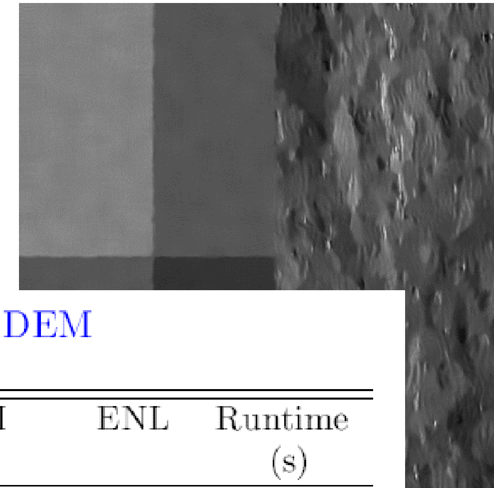
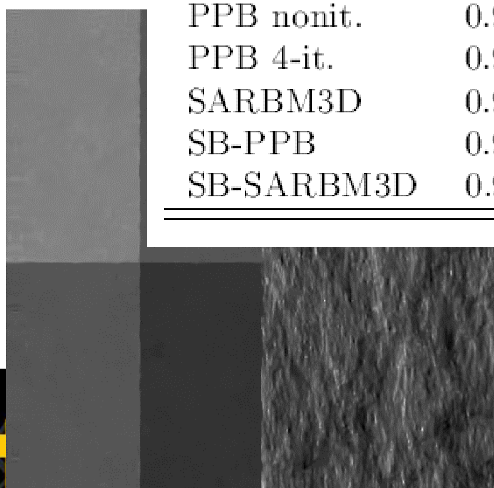
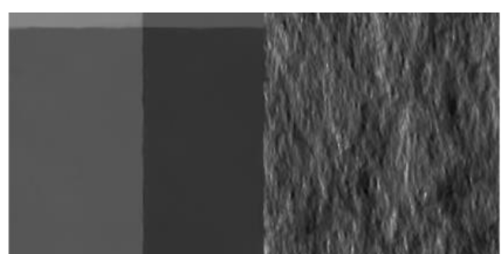
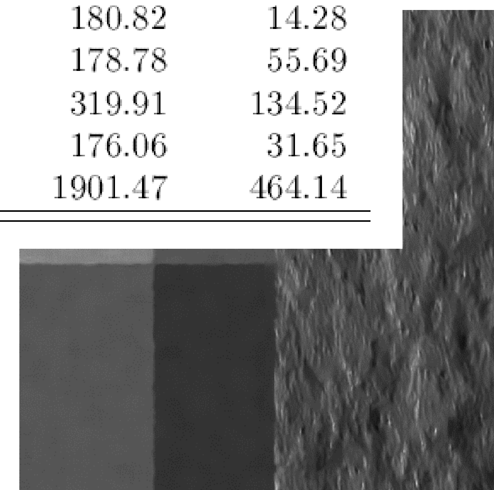


Table 5.3. Performance parameters for the mixed DEM

	MoI	VoR	SNR	C_x	ES	MSSIM	ENL	Runtime (s)
Reference	1.000	1.003	∞	1.899	0.000	1.000	503.79	-
Noisy	0.997	-	-1.874	2.777	0.025	0.965	0.98	-
PPB nonit.	0.966	1.104	4.583	0.861	0.291	0.989	180.82	14.28
PPB 4-it.	0.979	0.943	6.365	1.569	0.092	0.993	178.78	55.69
SARBM3D	0.967	0.724	6.919	1.778	0.060	0.995	319.91	134.52
SB-PPB	0.978	0.817	7.457	1.625	0.101	0.995	176.06	31.65
SB-SARBM3D	0.963	0.892	7.813	1.390	0.075	0.996	1901.47	464.14

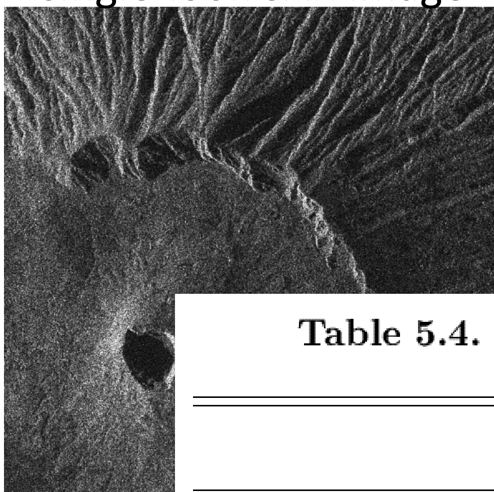




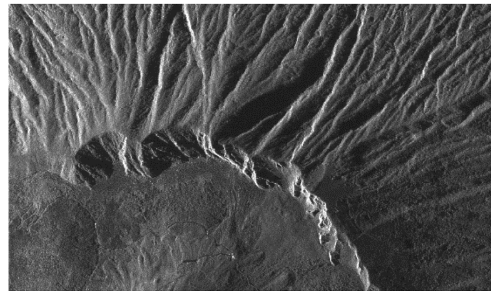


Scattering-Based SAR Images Despeckling: Experimental Results

single-look SAR image



42-look reference SAR image



PPB 4-iterative

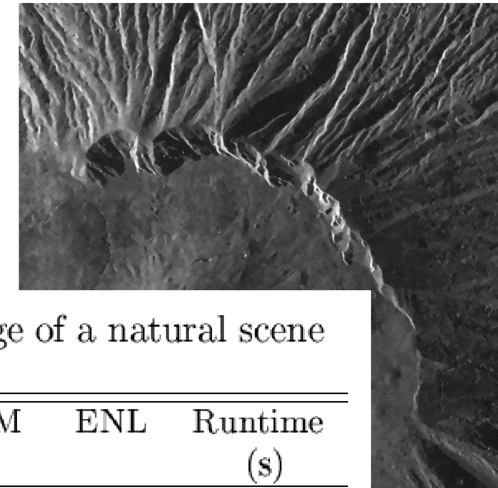
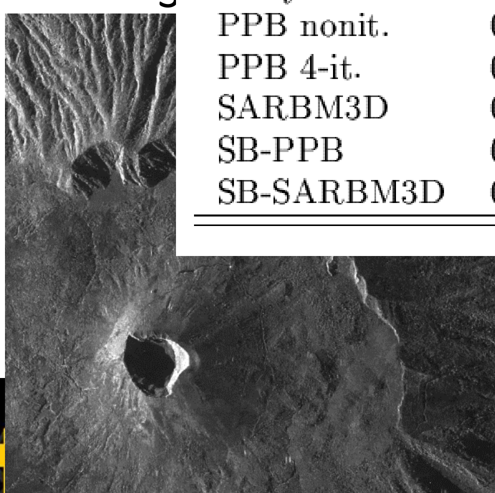
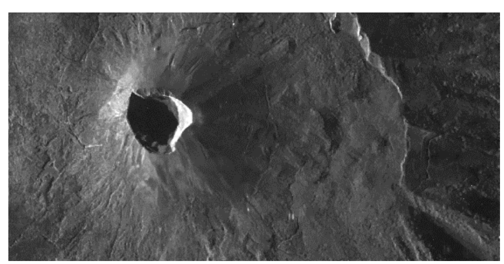


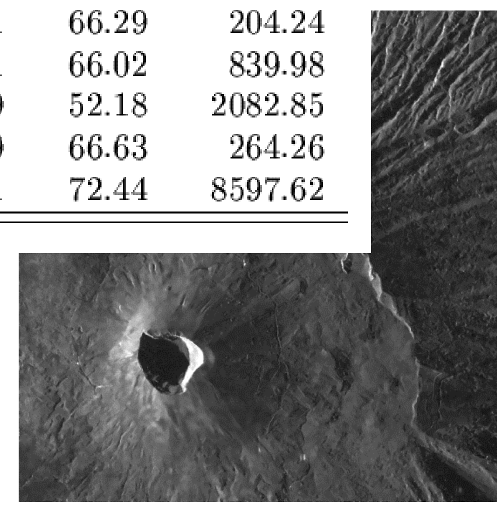
Table 5.4. Performance parameters for the actual image of a natural scene

	MoI	VoR	SNR	C_x	ES	MSSIM	ENL	Runtime (s)
Reference	1.000	1.312	∞	1.054	0.000	1.000	19.70	-
Noisy	1.000	-	-1.470	1.795	0.600	0.962	0.93	-
PPB nonit.	0.980	1.077	4.437	0.784	0.455	0.991	66.29	204.24
PPB 4-it.	0.984	1.026	5.747	0.902	0.357	0.991	66.02	839.98
SARBM3D	0.970	0.607	5.131	1.052	0.293	0.989	52.18	2082.85
SB-PPB	0.997	0.728	3.861	1.075	0.555	0.989	66.63	264.26
SB-SARBM3D	0.973	0.818	5.139	0.958	0.237	0.991	72.44	8597.62

S

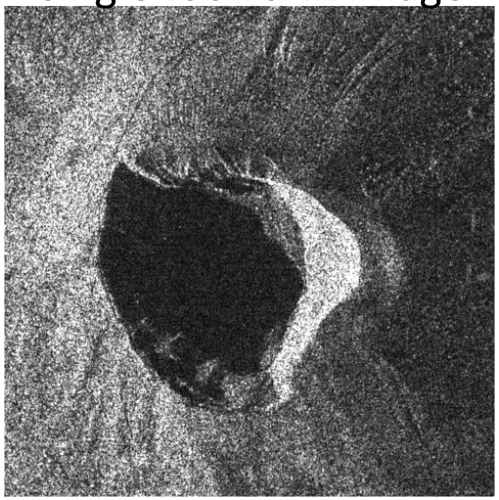




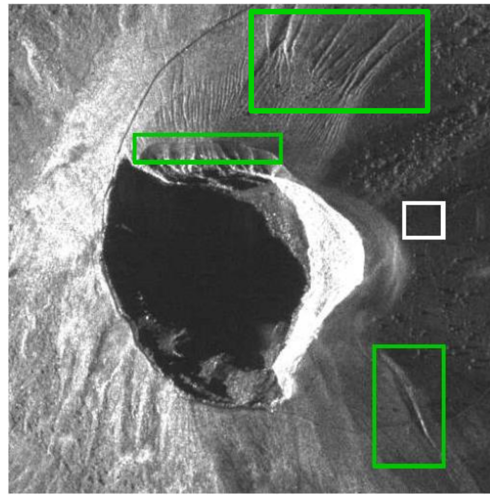


Scattering-Based SAR Images Despeckling: Experimental Results

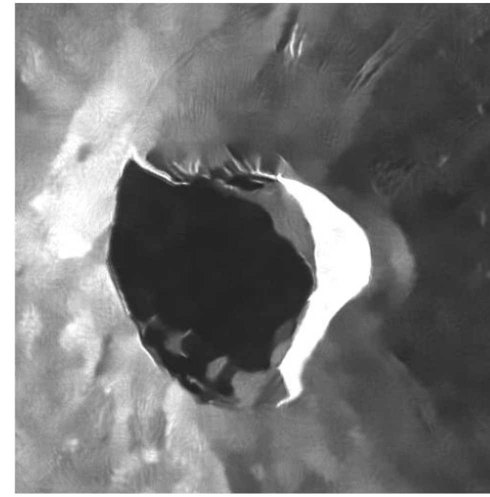
single-look SAR image



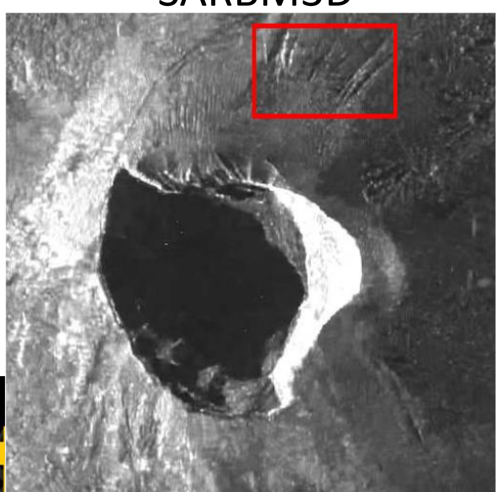
42-look reference SAR image



PPB 4-iterative



SARBM3D



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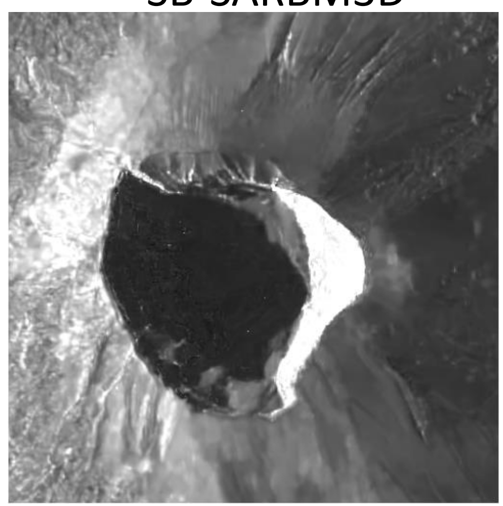

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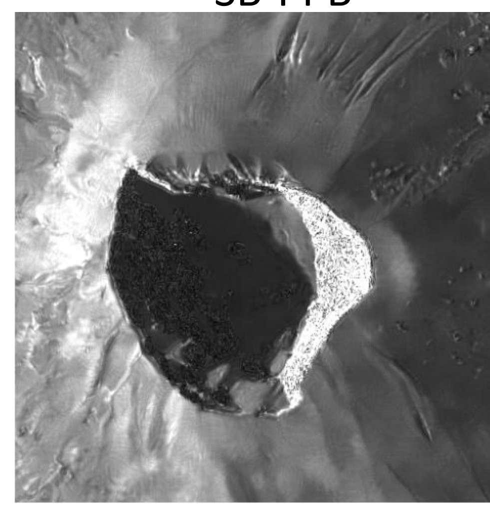

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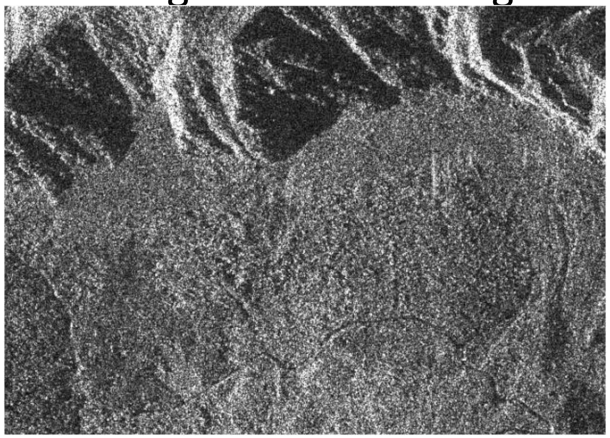
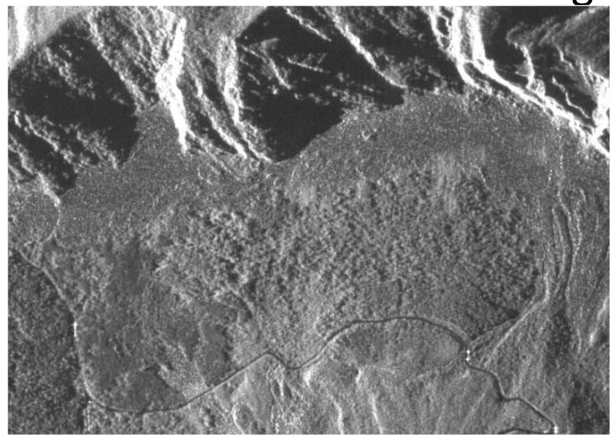
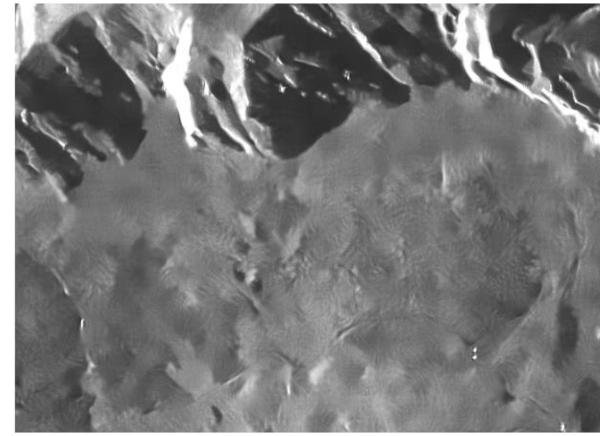


42-look reference SAR image



PPB 4-iterative



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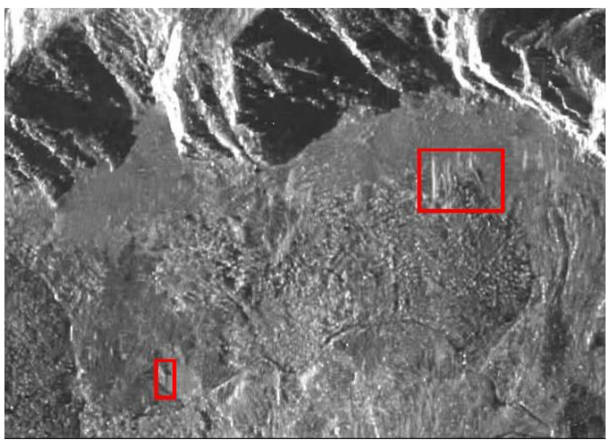

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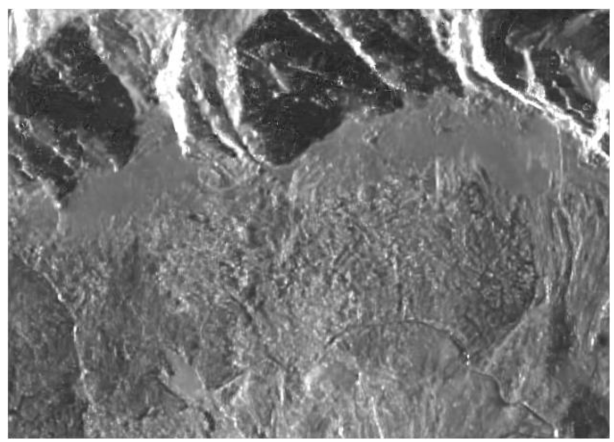

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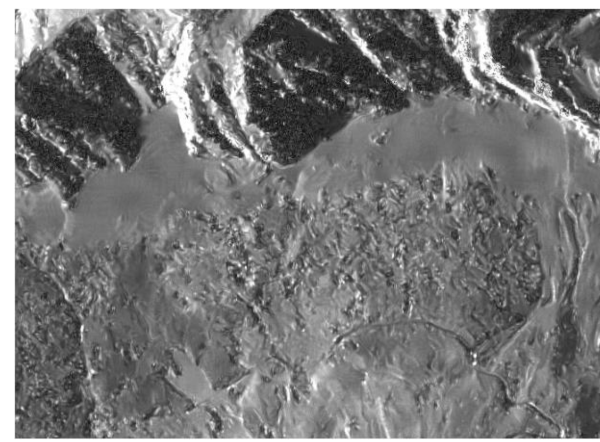

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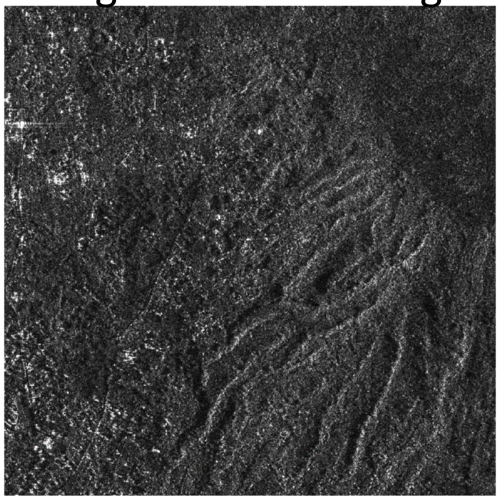
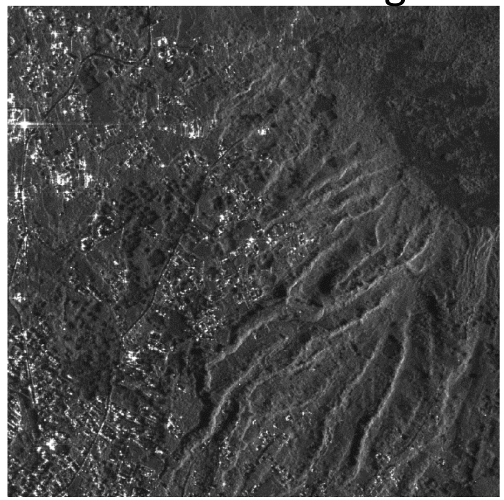
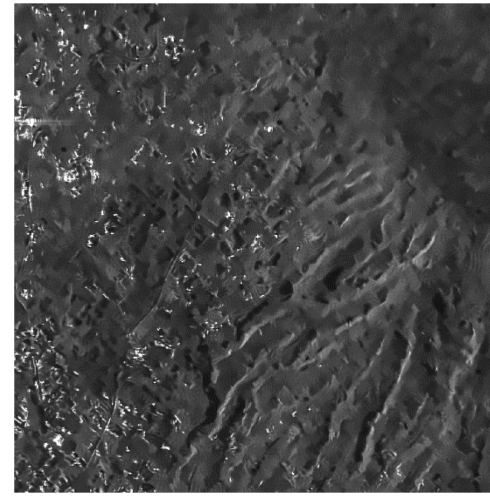
single-look SAR image



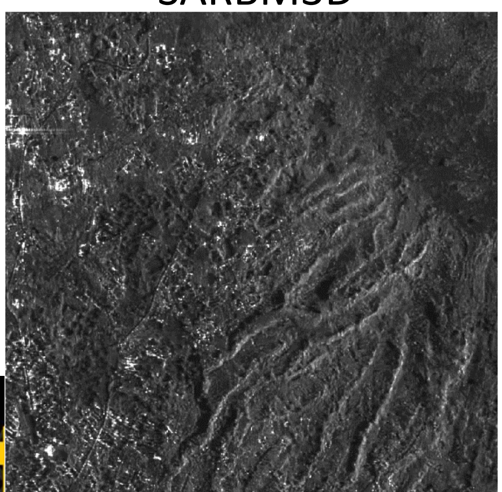
42-look SAR image



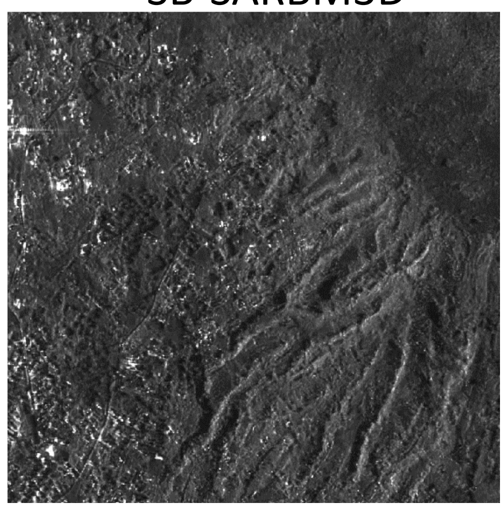
PPB 4-iterative



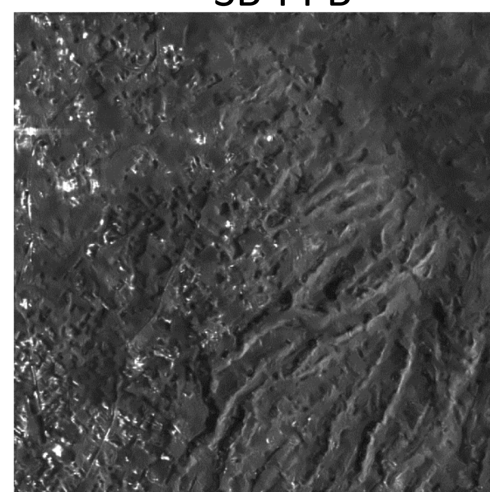
SARBM3D



SB-SARBM3D



SB-PPB



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Comments and Conclusions

Globalization has its effects…

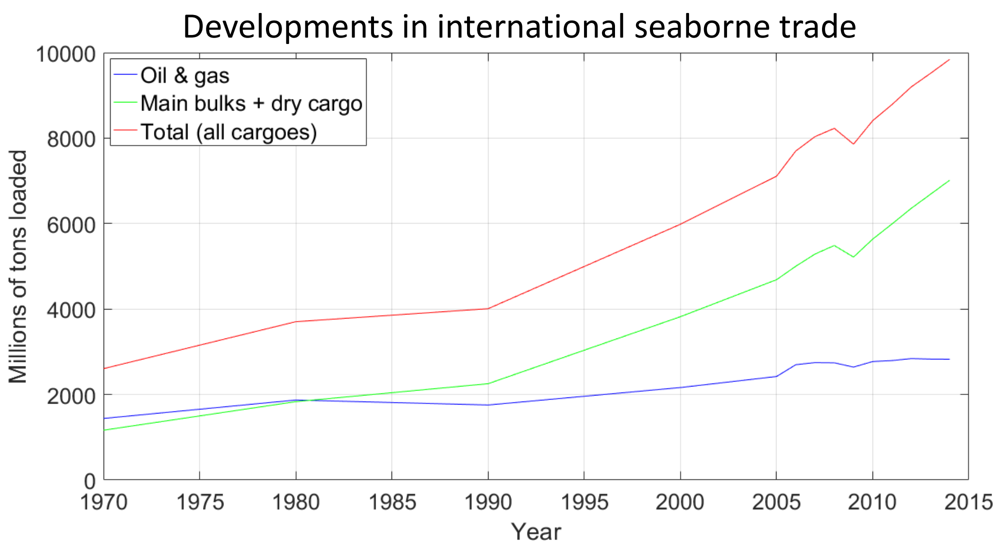
Global seaborne shipments have increased 3.4% in 2013-2015.

9.84 billion tons over the world sea and oceans in 2015.

Global imports increased of 3.5 times more than in the ‘70s in developing countries.

World commercial fleet consists of 89,464 vessels with a total tonnage of 1.75 billion dwt.

World fleet grew by 3.5% in 2015 - the lowest annual growth rate in over a decade.



Oil & gas: + 96%
Main bulks + dry cargo: + 502%
Total (all cargoes): + 278%

Source: Review of Maritime Transports 2015. United Nations Conference on Trade and Development (UNCTAD)

Human decisions have their impacts…

Understanding the thickness and extent of sea ice on a global scale is critical for studying climate change.

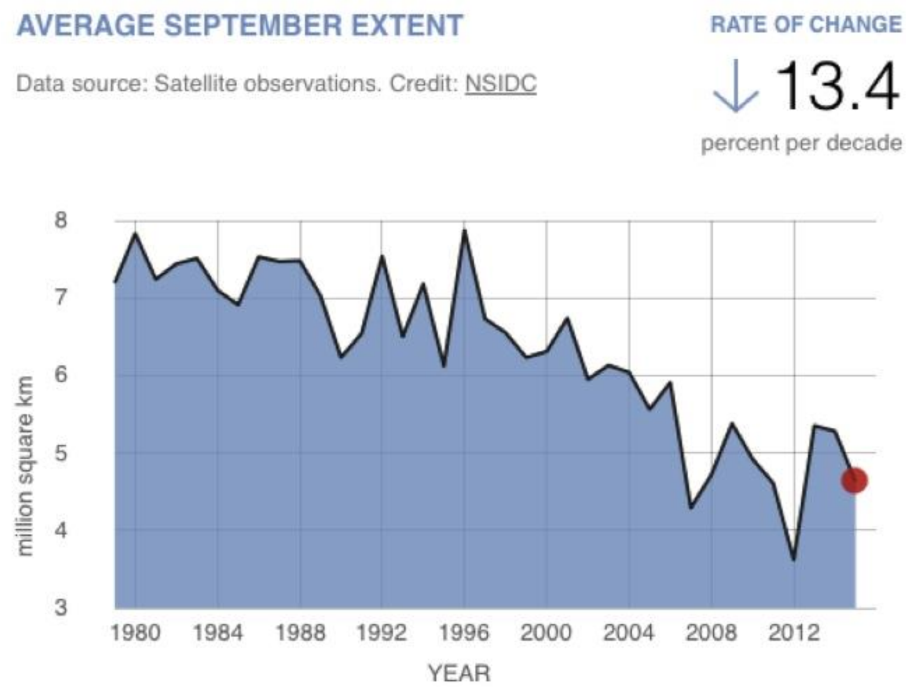
In 2016 Arctic sea ice wintertime extent hits another record low.

Sea ice plays a key role in the exploration of oil and gas fields and the worldwide sea trade.

The determination of sea ice extents serves as a validation tool in cryosphere modeling studies.

Icebergs dramatically affect maritime security and traffic.

Ice melting may open new commercial routes (i.e. Arctic)



Source: National Snow and Ice Data Center (NSIDC)

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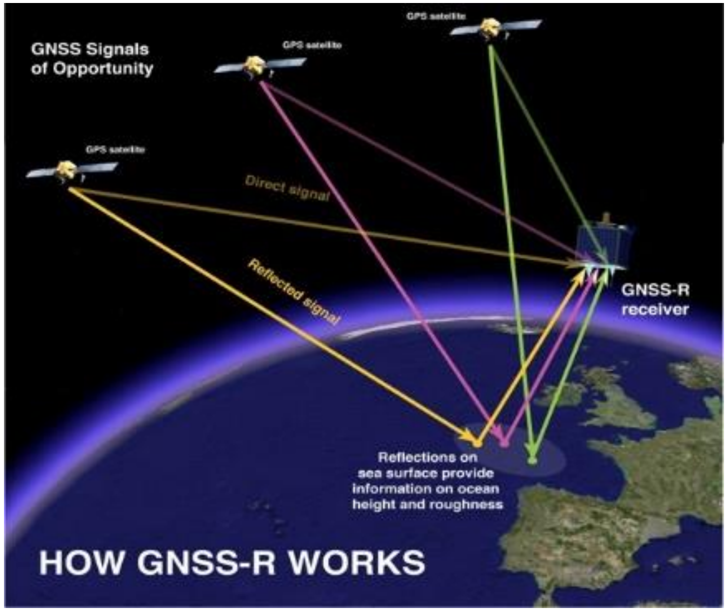
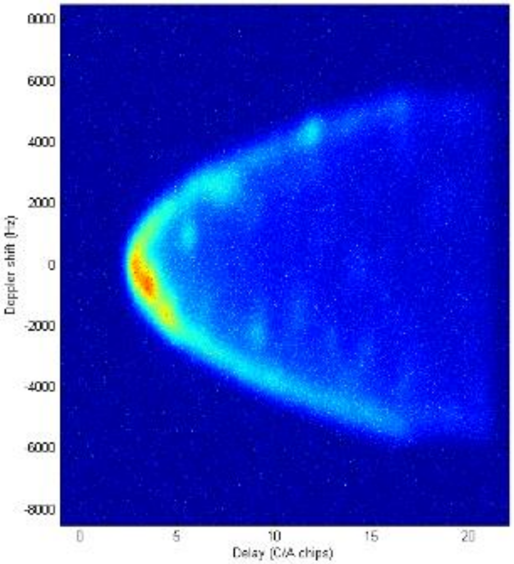
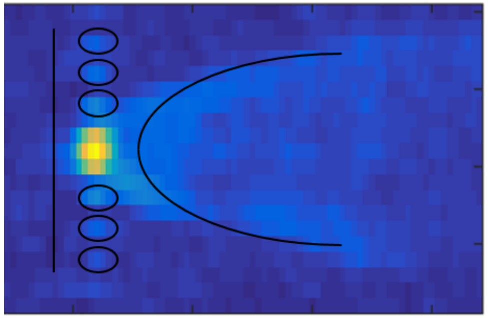
Global Navigation Satellite System-Reflectometry

- Recently remote sensing approach based on the measurements of the Earth' surface reflected GNSS signals.
- Due to the low signal-to-noise ratio (SNR), a region surrounding the specular reflection point (glistening zone) dominates the scattered signal.
- A delay-Doppler Map (DDM) of the glistening zone is computed by cross-correlating the received signal with a replica of the GNSS signal for a set of different time lags and different carrier frequency offsets.
- Geophysical parameters (e.g. wind speed) can be inferred from GNSS observables, e.g., DDM.







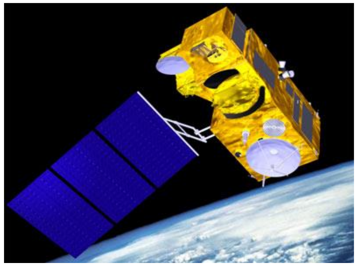
Why sea target detection from GNSS-R?

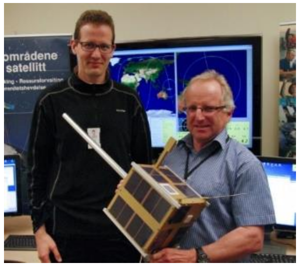
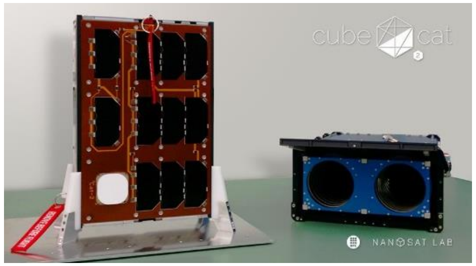
	Pros	Cons
Automatic Identification System (AIS)	• Accurate information (ship name, position, speed, course, IMO, MMSI). • Very high update rate (from 3 minutes for anchored or moored vessels, to 2 seconds for fast moving or maneuvering vessels). • Global coverage (Satellite AIS).	• Vulnerable (e.g. spoofing) • Required on board of ships with gross tonnage of 300 or more, and all passenger ships regardless of size. • Non-cooperative ships cannot be tracked
Synthetic Aperture Radar (SAR)	• Independence on cloud & illumination conditions. • Very high spatial resolution (up to 1 m)	• Cost and size $\uparrow$ • Sensitive to sea state + speckle $\Rightarrow P_{fa} \uparrow$ • Limited revisit time
Optical	• Very high spatial resolution (up to 0.5m) • Suited to hyperspectral imaging • Easy to interpret (no expert user needed)	• Sensitive to cloud & illumination conditions + sea clutter $\Rightarrow P_{fa} \uparrow$ • Limited revisit time • The large amount of data prevent the use in real time.

GNSS-R	• Independence on cloud & illumination conditions.
	• Bistatic system
	  • Ability of counter the attack of anti-radiation missiles
	  • Compact, low-power, light-weight and cheap
	    • **Very low revisit time**
		• Low spatial resolution (order of km)
		• Not yet extensively study and assessed.

Remote sensing with improved revisit time!

GNSS-R and nanosat constellations



	Sentinel-3A	Sentinel-1B	AISSat-1	^{3}Cat-2
Spacecraft class	Large satellite	Large satellite	CubeSat	6-Unit CubeSat
Payload instrument	Spectrometer, radiometer, SAR altimeter	C-band SAR	VHF antenna, onboard computer	Dual-band altimeter, multi-frequency, multi-constellation, dual-polarization GNSS-Reflectometer
Total mass	1,250 kg	2,300 kg	6 kg	7.1 kg
Dimensions	390 x 220 x 220 cm^3	390 x 260 x 250 cm^3	20 x 20 x 20 cm^3	10 x 24.3 x 34 cm^3
Power consumption	2,300 W	4,400 W	9 W	5.46 W
Launch date	February 16^{th}, 2016	April 25^{th}, 2016	July 12^{th}, 2010	August 15^{th}, 2016
Total cost	305,000,000 €	270,000,000 €	3,500,000 €	750,000 €

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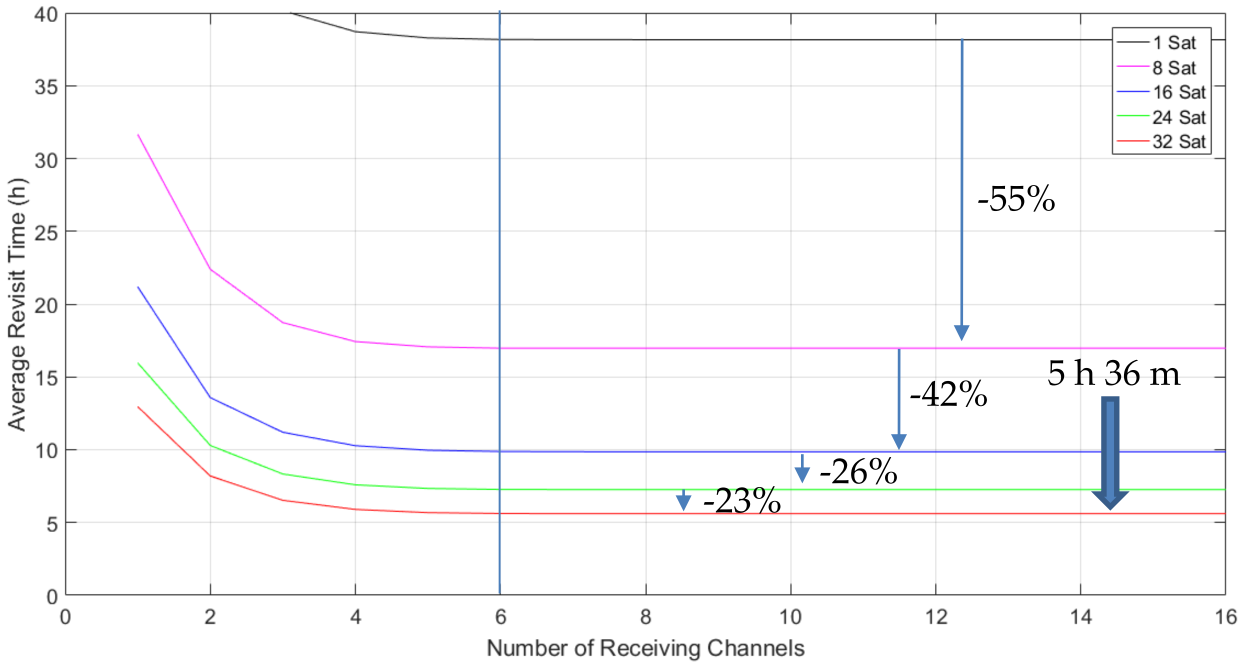
Revisit Time of GNSS-R constellations

- Three realistic scenarios defined.
- Mission simulations performed using AGI-STK® Suite.
- Specular point position and glistening zone computed with spatial resolution of 1° x 1°.
- Mean, median and standard deviation of revisit time estimated as a function of number of tracking channels for different constellation subsets size.

	Scenario 1	Scenario 2	Scenario 3
Altitude [km]	500	500	500
Inclination [degree]	98°	98°	98°
Orbit type	Circular	Circular	Circular
Number of GNSS-R satellites	up to 32	up to 32	up to 32
Number of parallel channels	up to 16	up to 16	up to 16
GNSS systems tracked	**GPS**	**GPS, Galileo**	**GPS, Galileo, Glonass, BeiDou-2**

Revisit Time of GNSS-R constellations



Scenario 1	
Altitude [km]	500
Inclination [degree]	98°
Orbit type	Circular
Number of satellites	32
Number of parallel channels	16
GNSS systems tracked	GPS

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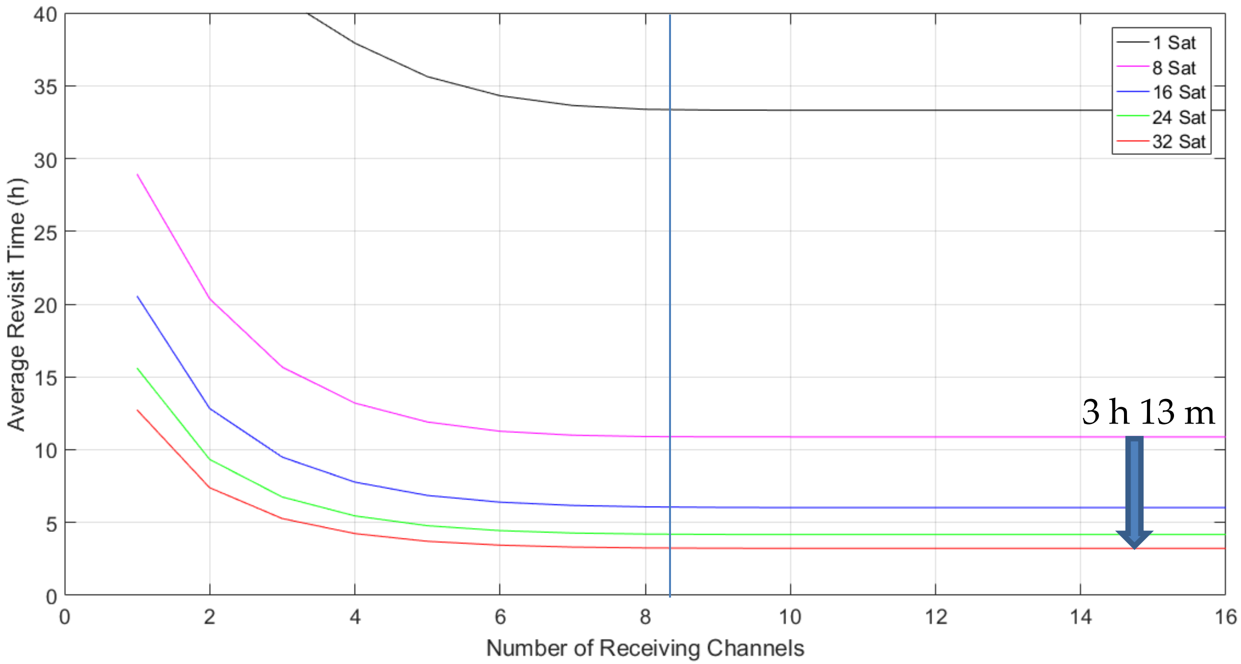
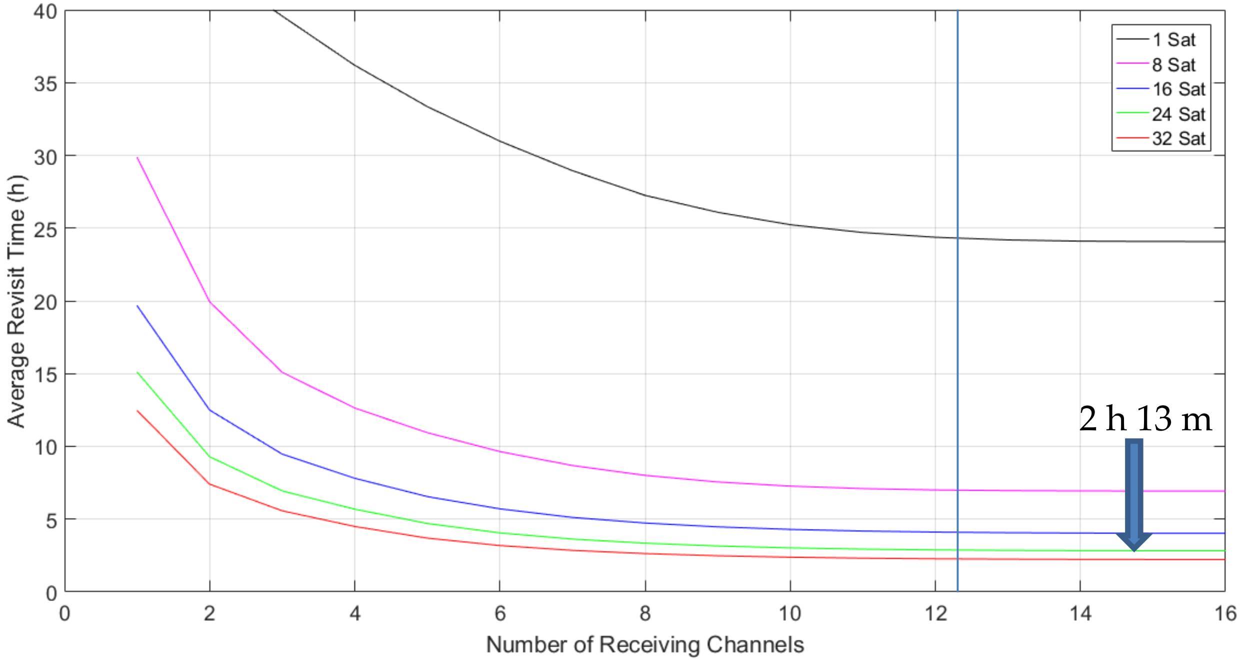
Revisit Time of GNSS-R constellations



Scenario 2	
Altitude [km]	500
Inclination [degree]	98°
Orbit type	Circular
Number of satellites	32
Number of parallel channels	16
GNSS systems tracked	GPS, Galileo

Revisit Time of GNSS-R constellations



Scenario 3	
Altitude [km]	500
Inclination [degree]	98°
Orbit type	Circular
Number of satellites	32
Number of parallel channels	16
GNSS systems tracked	GPS, Galileo, Glonass, BeiDou-2

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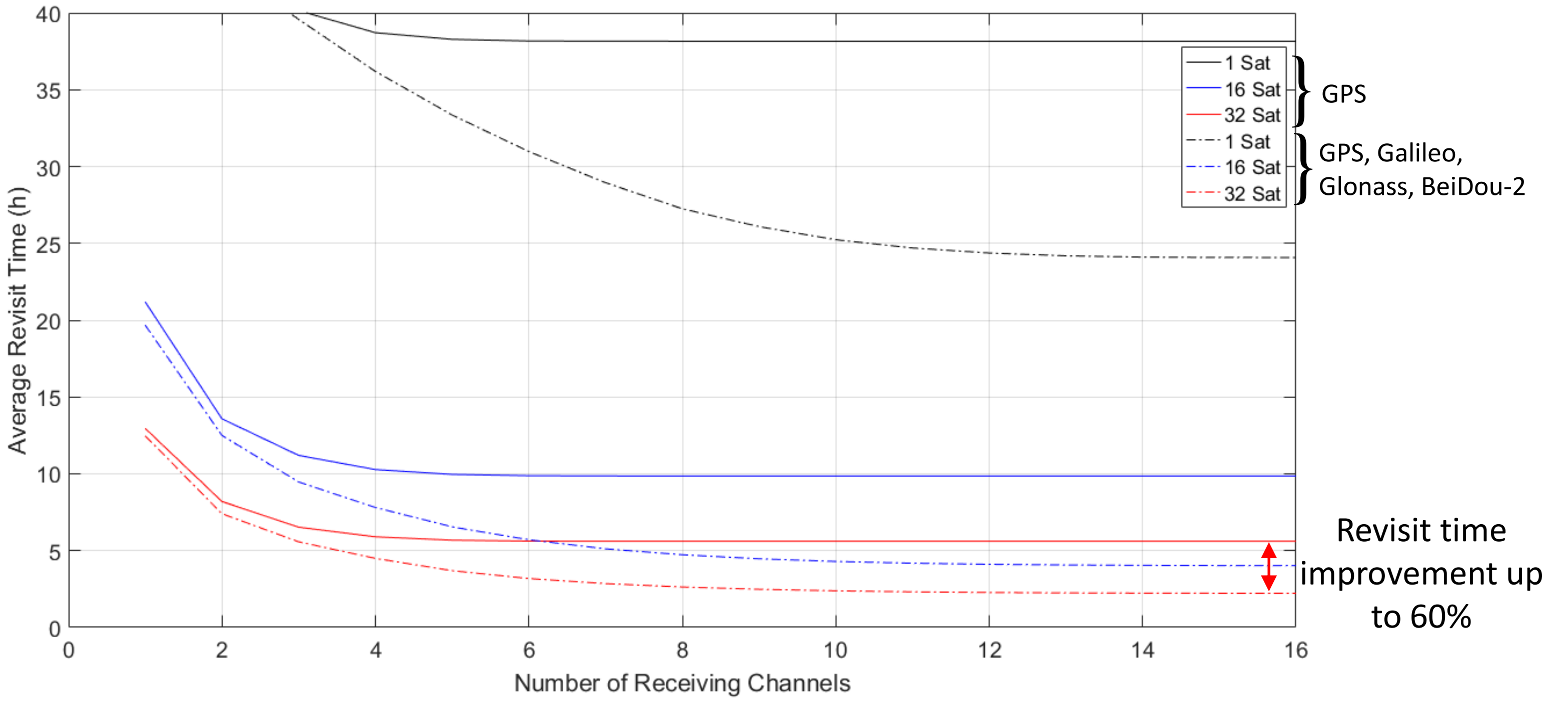
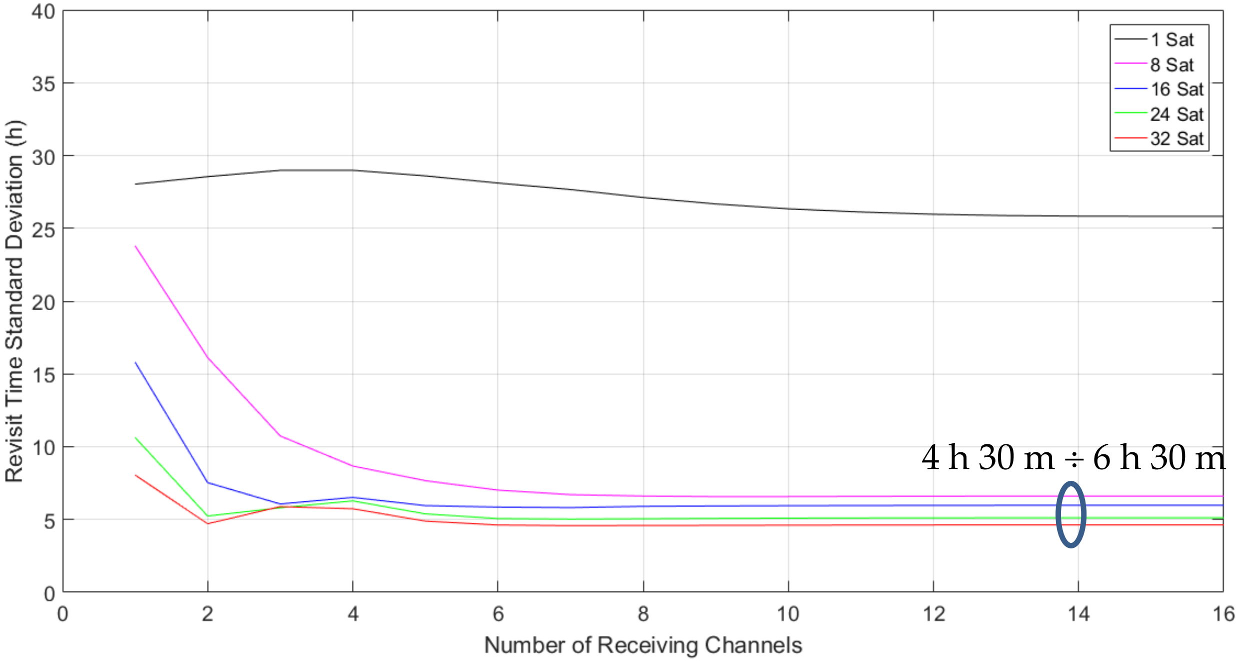
Revisit Time of GNSS-R constellations



Revisit Time of GNSS-R constellations



Scenario 3	
Altitude [km]	500
Inclination [degree]	98°
Orbit type	Circular
Number of satellites	32
Number of parallel channels	16
GNSS systems tracked	GPS, Galileo, Glonass, BeiDou-2

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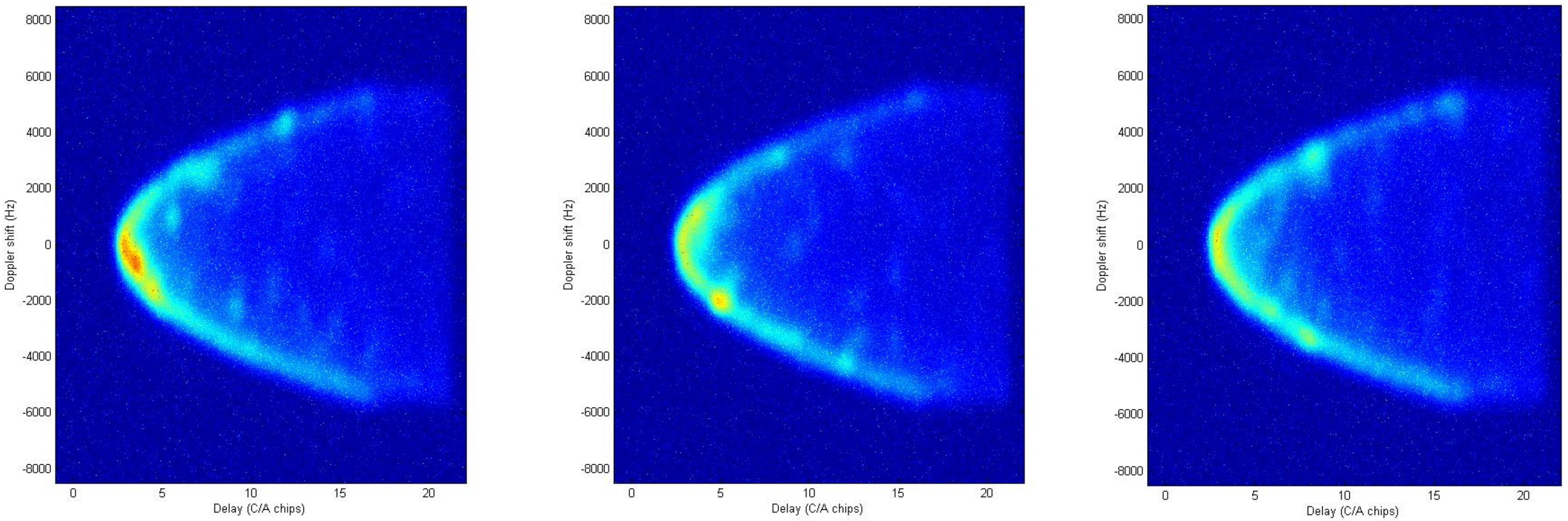
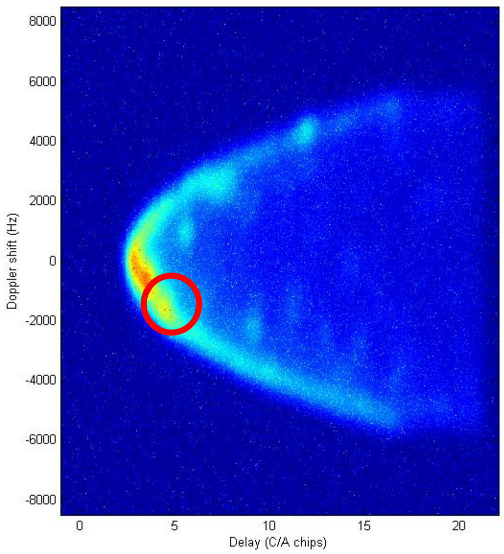
Sea Target Detection from GNSS-R DDM



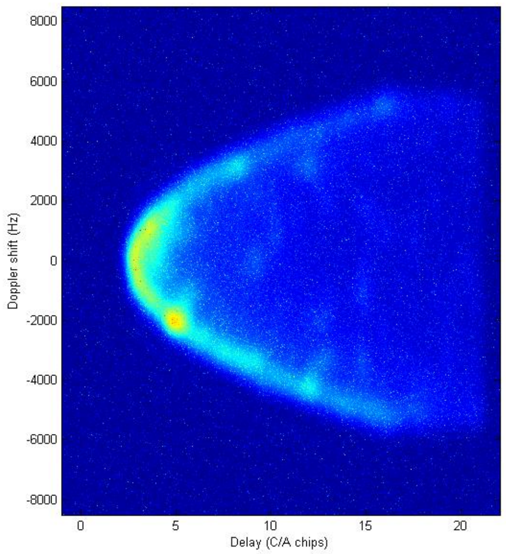
Targets?

Sea Target Detection from GNSS-R DDM

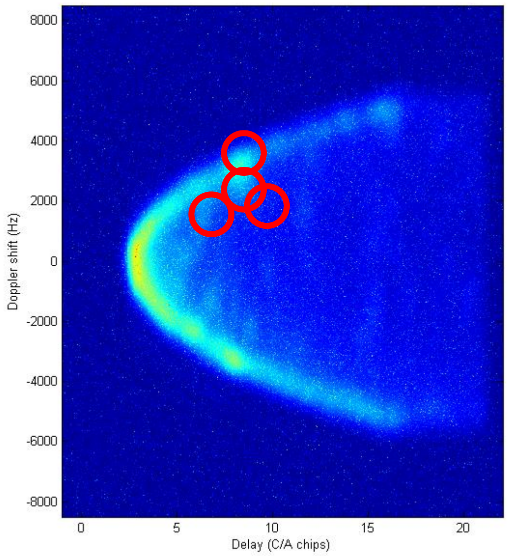
One target



No Target

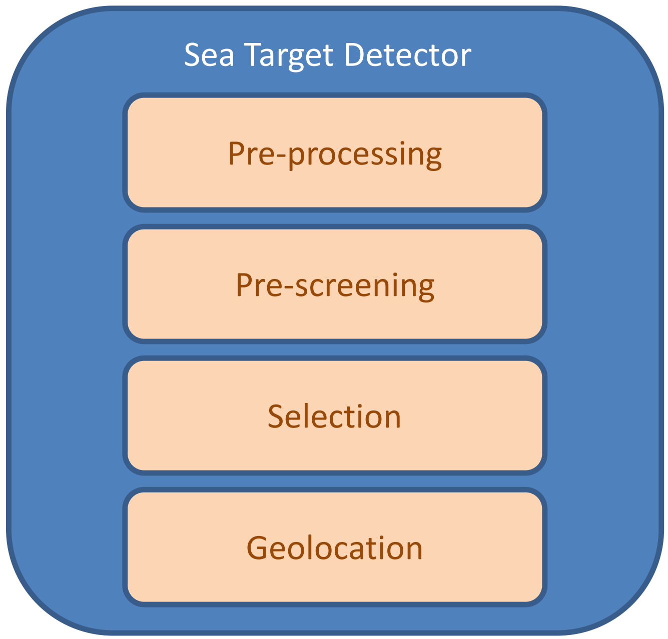


Four targets

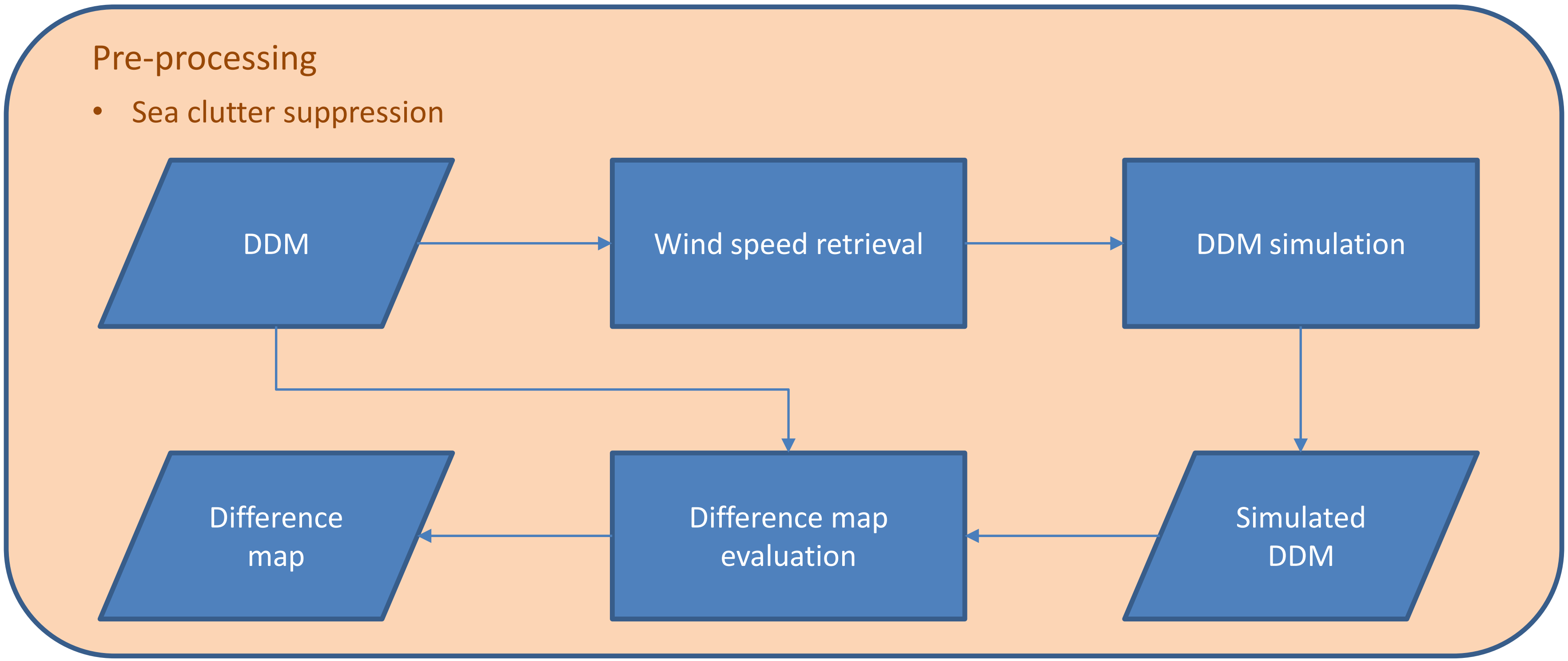


Sea Target Detection from GNSS-R DDM

Simulation study performed by using the actual spaceborne GNSS-R mission simulator developed by UPC-BarcelonaTech: GEROS-SIM (http://www.tsc.upc.edu/rslab/gerossim).

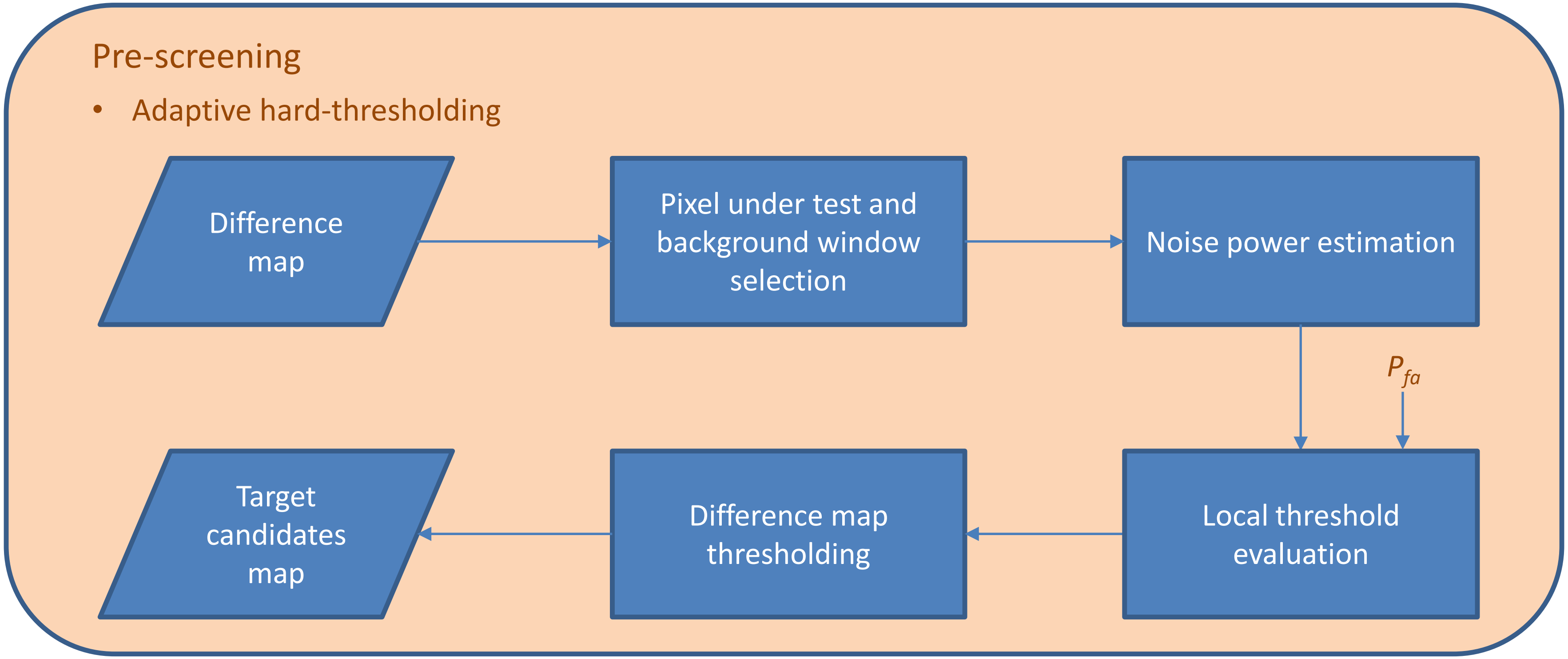


Proposed Sea Target Detector from GNSS-R DDM



Di Simone, A.; Park, H.; Riccio, D.; Camps, A. "Sea Target Detection using Spaceborne GNSS-R Delay-Doppler Maps: Theory and Experimental Validation using TDS-1 Data," *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (under review).*

Proposed Sea Target Detector from GNSS-R DDM



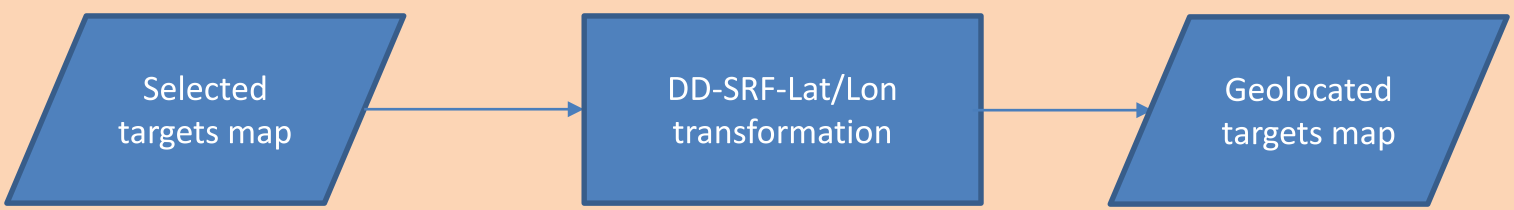
Proposed Sea Target Detector from GNSS-R DDM

Selection

- False alarms reduction

Geolocation

- From Delay-Doppler to latitude-longitude



Proposed Sea Target Detector from GNSS-R DDM: Performance Evaluation

y: observed DDM sample
s: target echo
c: sea clutter
n: thermal noise
k: number of DDM "snapshots" incoherently averaged

$$\begin{cases} H_1 : y = s + c + n \\ H_0 : y = c + n \end{cases} \qquad \begin{matrix} n \sim \chi^2(k) \\ k \gg 1 \end{matrix} \quad \Rightarrow \quad n \sim N(\mu_n, \sigma_n).$$

- Noise compensation

$$y' = y - \mu_n \qquad \begin{cases} H_1 : y' = s + c + n \\ H_0 : y' = c + n \end{cases} \qquad n \sim N(0, \sigma_n),$$

- Clutter suppression

$$d = y' - c \qquad \begin{cases} H_1 : d = s + n \\ H_0 : d = n \end{cases} \qquad n \sim N(0, \sigma_n), \quad \Rightarrow$$

$$P_{FA} = \Pr(d > T | H_0) = Q\left(\frac{T}{\sigma_n}\right)$$

$$T = \sigma_n Q^{-1}(P_{FA})$$

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_x^{+\infty} \exp\left(-\frac{u^2}{2}\right) du.$$

$$P_D = Q\left(Q^{-1}(P_{FA}) - SNR\right)$$

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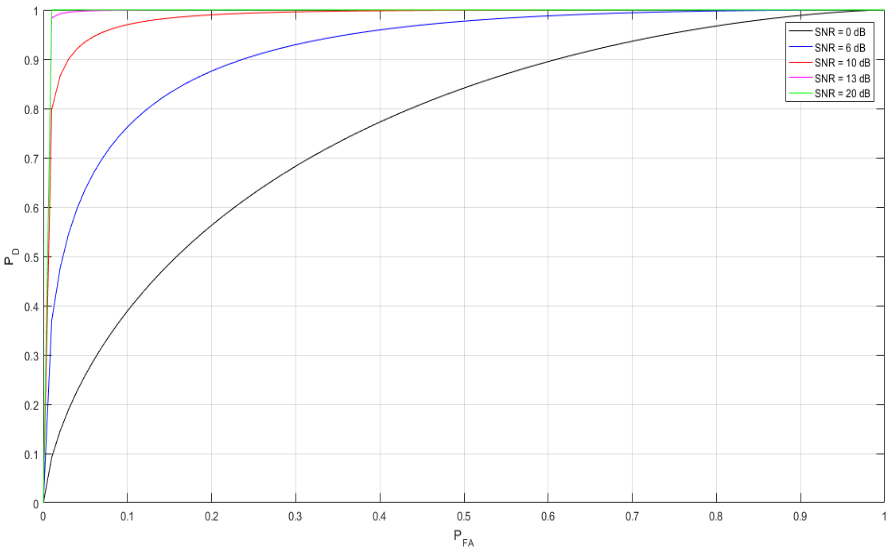
Proposed Sea Target Detector from GNSS-R DDM: Receiver Operating Curves

$$Q(x) = \frac{1}{\sqrt{2\pi}} \int_{x}^{+\infty} \exp\left(-\frac{u^2}{2}\right) du.$$

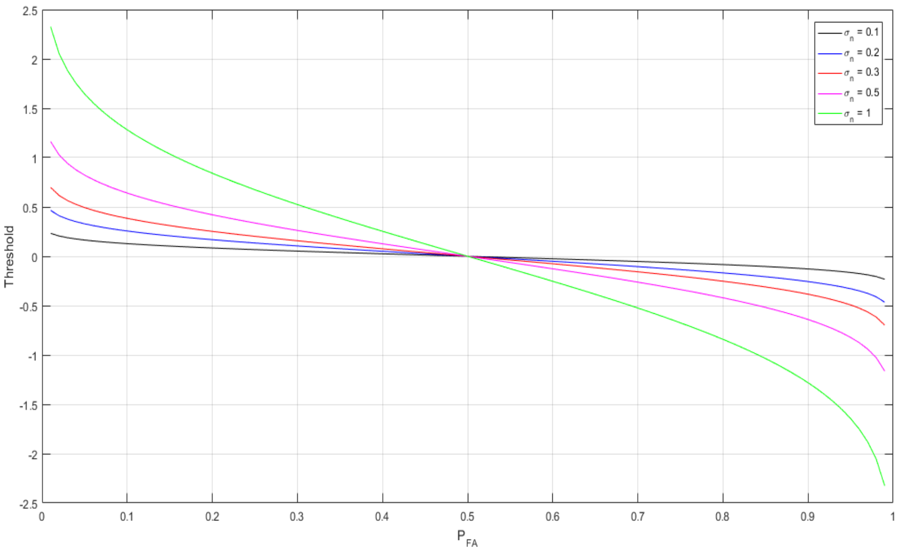
$$P_D = Q\left(Q^{-1}(P_{FA}) - SNR\right)$$

$$T = \sigma_n Q^{-1}(P_{FA})$$

ROC -1



ROC -2



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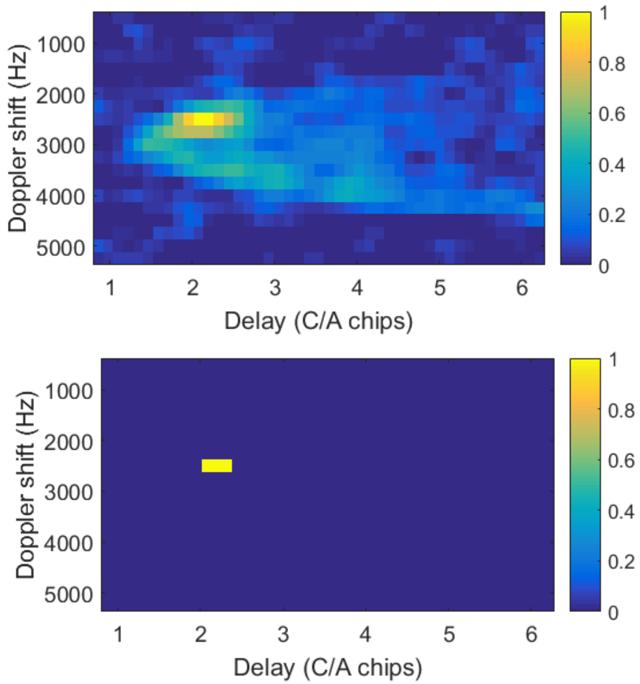
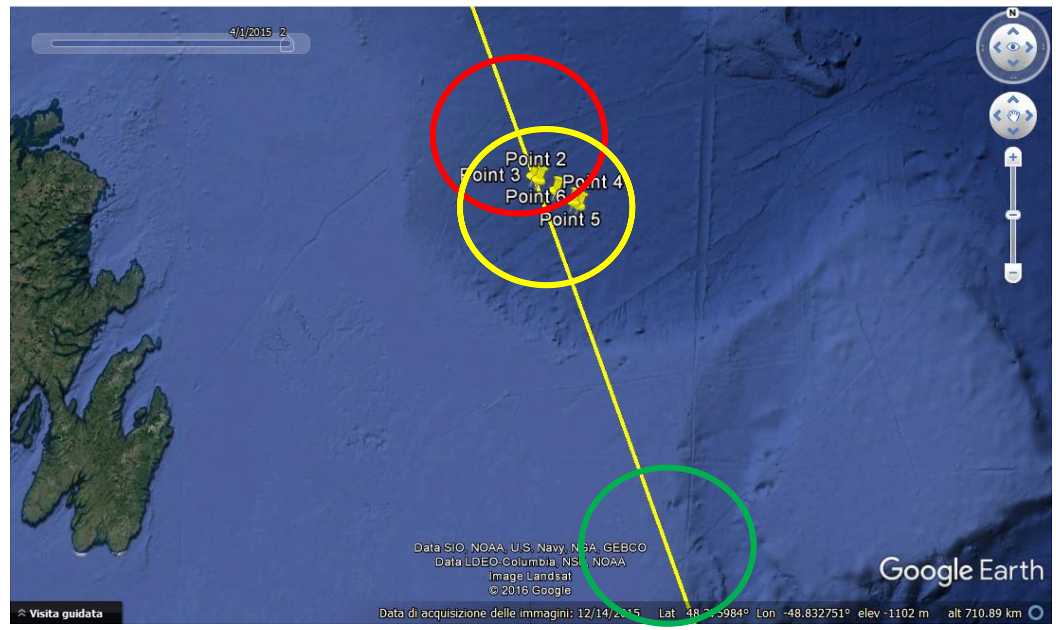
PART II

- Why ship/ice detection?
- Why Global Navigation Satellite System-Reflectometry (GNSS-R)?
  - GNSS-R vs. SAR, Optical, Automatic Identification System (AIS)
  - Revisit Time
- Sea Target Detection from GNSS-R delay-Doppler Maps (DDM)
  - Algorithm Rationale
- Experimental results on UK TDS-1 data

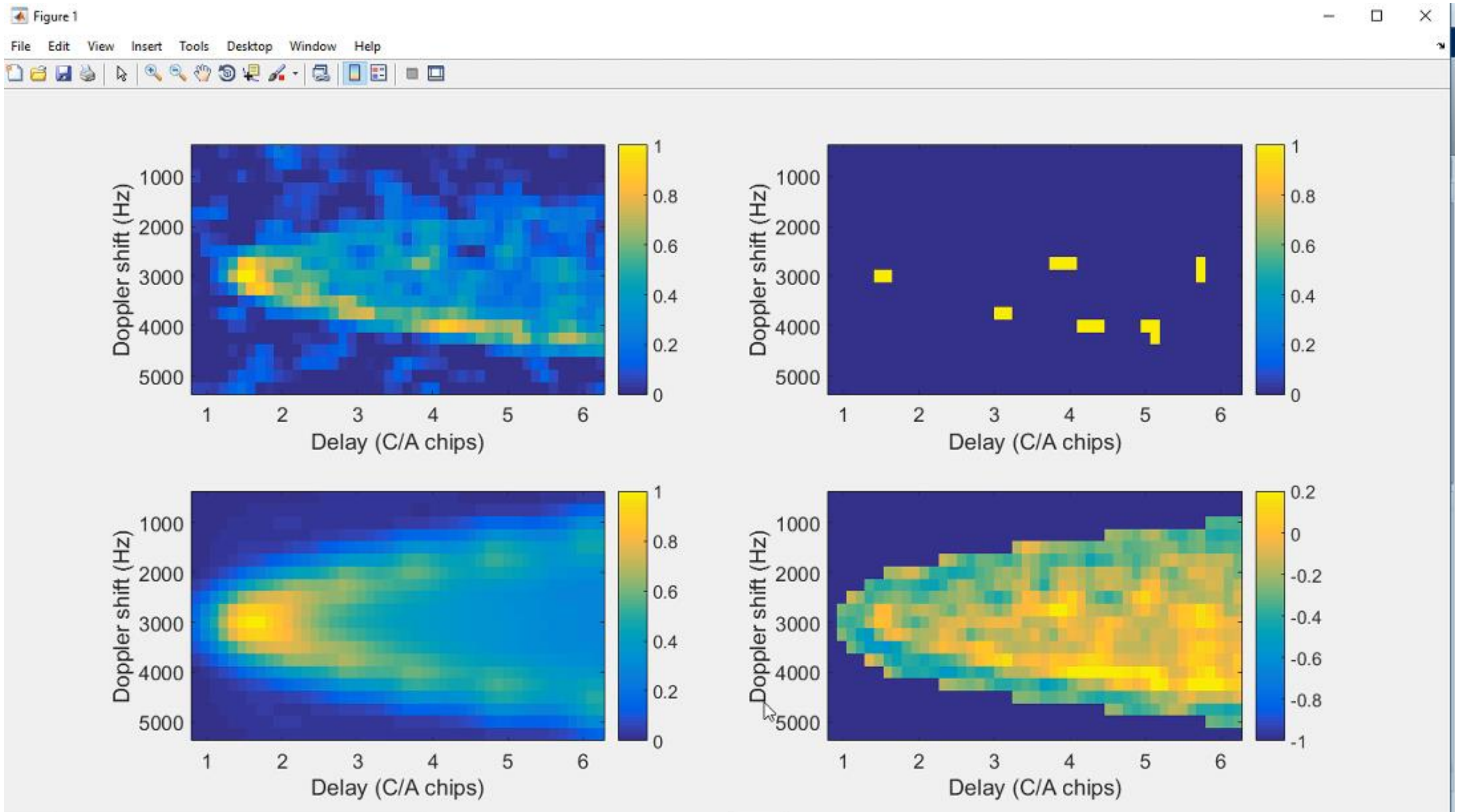
Comments and Conclusions

Experimental results on UK TDS-1 data





Experimental results on UK TDS-1 data



Outline

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Comments and Conclusions

Comments and Conclusions: SAR Despeckling

- Most state-of-the-art despeckling algorithms are based on pure geometrical and statistical concepts.
- More physical-based despeckling algorithms should take into account electromagnetic scattering phenomena.
- Thanks to the a priori information, scattering-based despeckling algorithms provides better (in some cases much better) performance w.r.t. state of the art.
- A priori information, namely DEM, is nowadays easily accessible also free of charge (see SRTM mission).
- The proposed scattering-based despeckling algorithms have been shown to overcome performances of the original filters both in terms of speckle reduction and edge preservation capability.
- Artifacts typical of nonlocal patch-based methods can be attenuated by exploiting a priori scattering information in the despeckling chain.
- Feasibility of retrieving the local incidence angle map from the SAR image is currently under investigation (this will avoid extra information requirements).

Comments and Conclusions: Sea Target Detection from GNSS-R DDM

- Ship/ice detection plays a key role in maritime surveillance and security.
- Remote sensing represents a competitive alternative to AIS especially for open ocean or non-cooperative sea traffic.
- SAR and optical, although greatly exploited in the maritime traffic monitoring, exhibit important limitations, especially concerning <u>the revisit time</u>.
- GNSS-R technology paves the way for <u>real-time sea target monitoring with cooperating constellations</u>.
- The revisit time of GNSS-R constellations can be reduced by increasing the constellation size, the number of parallel tracking channels, the GNSS stations tracked.
- <u>A sea target detection algorithm has been developed, and demonstrated with actual GNSS-R data for the first time</u>.
- Further validation will be performed with the upcoming <u>CYGNSS mission</u>.
- Detection performance improvements expected with GNSS-R multilook processing. More work is going on.

List of publications

International Conference Papers

[IC.1] **Di Simone, A.**; Riccio, D., “A New Perspective in Shape from Shading from SAR Images”, IEEE Graduate of the Last Decade (GOLD) Conference, Berlin, June 5-6, 2014.

[IC.2] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., "On shape from shading and SAR images: An overview and a new perspective," IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 2014, pp. 1333-1336, Quebec City, Canada, July 13-18, 2014.

[IC.3] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., “Polarimetry and Shape from Shading,” POLinSAR Conference, Frascati, January 26-30, 2015.

[IC.4] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., “SAR Shape from Shading in Suburban Areas,” Joint Urban Remote Sensing Event (JURSE), Lausanne, March 30 – April 1, 2015.

[IC.5] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., "Non-Local Means SAR Despeckling Based on Scattering," IEEE International Geoscience and Remote Sensing Symposium (IGARSS), 2015, pp. 3172-3174, Milan, Italy, July 2015.

[IC.6] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., “Estimation of the Local Incidence Angle Map from a Single SAR Image,” ESA Living Planet Symposium, 2016.

[IC.7] **Di Simone, A.**; Park, H.; Riccio, D.; Camps, A., “Ships and Ice Monitoring with Improved Revisit Time using GNSS-R Constellations,” 4th Federated and Fractionated Satellite Systems Workshop, Sapienza University, Rome, Italy, October 10-11, 2016.

List of publications

[IC.8] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., "A comparative sensitivity analysis of scattering-based despeckling algorithms," 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Fort Worth, Texas, USA, July 23-28, 2017 (submitted).

[IC.9] **Di Simone, A.**; Park, H.; Riccio, D.; Camps, A., "Ocean Target Monitoring with Improved Revisit Time using Constellations of GNSS-R Instruments," 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Fort Worth, Texas, USA, July 23-28, 2017 (submitted).

[IC.10] Lancheros, E.; Park, H.; Camps, A.; **Di Simone, A.**; Matevosyan, H.; Lluch, I.; Cote, J.; Pierotti, S., "Analysis of the Potential of Small Satellites to Cover the Sea Ice Data Products Gap," 2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), Fort Worth, Texas, USA, July 23-28, 2017 (submitted).

[IC.11] Franceschetti, G.; Wall, S.D.; Di Martino, G.; **Di Simone, A.**; Riccio, D., "A new convenient tool for ice sheets exploration - The fractal dimension," 2017 IEEE AP-S Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, San Diego, California, USA, July 9–14, 2017 (submitted).

National Conference Papers

[NC.1] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., "Electromagnetic Model for SAR Shape from Shading," RiNEm, pp. 277-280, Padova, September 15-18, 2014.

[NC.2] Di Martino, G.; **Di Simone, A**.; Iodice, A.; Riccio, D.; and Ruello, G., "Electromagnetic Scattering and a New Perspective in SAR Despeckling," RiNEm, Parma, September 12 – 14, 2016.

[NC.3] Di Martino, G.; **Di Simone, A.**; Iodice, A.; Riccio, D.; and Ruello, G., "Modelli di scattering: una nuova prospettiva nell'ambito del filtraggio di immagini SAR," VIII Convegno Nazionale AIT, Palermo, June 15-17, 2016.

List of publications

Journal Papers

[J.1] Di Martino, G.; **Di Simone, A**.; Iodice, A.; Riccio, D. “Scattering-Based Non-Local Means SAR Despeckling,” *IEEE Transactions on Geoscience and Remote Sensing*, vol. 54, no. 6, pp. 3574-3588, Jun. 2016. doi: 10.1109/TGRS.2016.2520309

[J.2] Di Martino, G.; **Di Simone, A**.; Iodice, A.; Poggi, G.; Riccio, D.; Verdoliva, L. “Scattering-Based SARBM3D,” *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*, vol. 9, no. 6, pp. 2131-2144, Jun. 2016. doi: 10.1109/JSTARS.2016.2543303

[J.3] **Di Simone, A.** “Sensitivity Analysis of the Scattering-Based SARBM3D Despeckling Algorithm,” *Sensors,* vol. 16, no. 7, Jun. 2016. doi: 10.3390/s16070971

[J.4] Di Martino, G.; **Di Simone, A**.; Iodice, A.; Riccio, D. “Sensitivity Analysis of a Scattering-Based Nonlocal Means Despeckling Algorithm,” *European Journal of Remote Sensing*, vol. 50, no. 1, pp. 87-97, 2017. doi: 10.1080/22797254.2017.1274153

[J.5] **Di Simone, A.**; Park, H.; Riccio, D.; Camps, A. “Sea Target Detection using Spaceborne GNSS-R Delay-Doppler Maps: Theory and Experimental Validation using TDS-1 Data,” *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing (under review).*