KaRIn/SWOT hydrology phenomenology

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What will things look like in SWOT HR images?

Radar and backscattering basics

SWOT phenomenology with direct impact on performance
- RCS, $\sigma_0$, water/land contrast
- SNR, thermal noise
- Layover
- Water movement /decorrelation
- Accuracy of water surface detection and delineation
- Accuracy of water surface height and slope, discharge...

Results from:
- Publications
- Simulated KaRIn/SWOT data (L0, L1, “L1.5”)
- Airborne data: DRIVE/BUSARD, AirSWOT
- Near-field / ground radar measurements
- Spaceborne data: TanDEM-X, AltiKa, …
- Representative?
- Realistic?
KARIN/SWOT IMAGES

From raw data to geophysical products...

- For each half swath:  (image extracts for illustration)

  - L0
    - Raw data (complex)
  - L1
    - Master
      - Single Look Complex (SLC)
    - Slave
      - SAR processing
  - "L1.5"
    - Interferometric product (here multilooked)
  - L2
    - Water mask, height, slope, discharge
Example of interferometric product computed from simulated L1 data

Amplitude

Interferometric phase

Coherence
Radar backscattering depends on many physical parameters

Radar system:
- Wavelength
- Incidence (view angle)
- ...  

SWOT
- Wavelength: 8.6 mm
- Incidence: 0.6°-4°
- Local incidence

Observed area:
- Topography (slope)
- Surface roughness at the scale of the wavelength
- Composition, dielectric properties
- Vegetation: species, density...
- ...

Sensitivity to surface roughness at the scale of the wavelength

- For conventional side-looking SAR geometry (~30°)

Low backscattering radar response for smooth surfaces
  ➔ low average intensity

Increased radar response due to stronger surface roughness
  ➔ high average intensity

Except for smooth surfaces facing radar and double-bounce
  ➔ high average intensity
Influence of the meteorological conditions on the Vaccarès lagoon and Rhône
higher wind $\rightarrow$ + water roughness $\rightarrow$ + backscattering $\rightarrow$ + coherence?

From: D. Desroches et al. (CNES / Altamira), "Height map generation for hydrology from low incidence TanDEM-X data", 4th TanDEM-X Science Team Meeting
Sensitivity to surface roughness at the scale of the wavelength

- For KaRIn/SWOT near-nadir geometry (1-4°)

  Low backscattering radar response for smooth surfaces
  - low average intensity

  Increased radar response due to stronger surface roughness
  - higher average intensity

  Except for smooth surfaces facing radar
  - high average intensity

"acts like a mirror"

cf. nadir altimetry
Example: Impact of soil moisture
(for conventional side-looking SAR)

Humid soil: high backscattering

Dry soil: low backscattering
Penetration depth increases with wavelength

- Weak penetration expected at Ka-band ($\lambda = 8.6$ mm)
  - Into ground, ice, snow, vegetation…

  - **L-band**
    $\lambda = 23$ cm

  - **C-band**
    $\lambda = 6$ cm

  - **X-band**
    $\lambda = 3$ cm

- Volume scattering in vegetation
  - Integration of contributions within the volume corresponding to a range (and azimuth) gate
  - KaRIn/SWOT: near-nadir incidence
BACKSCATTERING MECHANISMS

Speckle “noise”

- Seemingly random, but actually a deterministic phenomena (reproducible)
- Can be modeled as a very strong multiplicative noise
- Makes pixelwise analysis of amplitude (intensity) images at full resolution inefficient (estimation, detection, segmentation, classification, …)

\[ R = \sigma_0 \times \text{surface of resolution cell} \]

The transition between the two regions is difficult to recognize in the speckled image

\[ \frac{R_1}{R_2} = 3 \text{ dB} \]
\[ \frac{R_1}{R_3} = 6 \text{ dB} \]

Radar cross section (RCS)
Relatively few reports on near-nadir Ka-band $\sigma_0$ – until recently

- Ulaby and Dobson (1989) [0°-5°(and above)]
  - land/vegetation $\sim$ -5 to -10 dB, roads $\sim$17 to 0 dB, snow $\sim$5 to -5 dB
- Vandermark et al. (2004) [nadir only]
  - Ocean $\sim$16 dB at 2 m/s to $\sim$8 dB at 18 m/s wind speeds (U10)
- Tanelli and Durden (2006) [down to 4° only]
  - Similar to Vandermark et al. (2004) when extrapolated towards nadir

Water/land contrast typically in the order of 10 dB (but not always)

- Short-pulse radar measurements of water from bridges
- Near-field measurements of water in LASIF wind/water tank
- GLISTIN (rolled)
- DRIVE/BUSARD
- AirSWOT
- AltiKa (nadir)
Acquisition sites in the Camargue area

Simultaneous ground truth:
- Wind speed
- Water surface roughness
- Water surface height and slope
- Wave height (buoys)
- Soil humidity

Same day/week/month:
- Soil roughness
- Vegetation characteristics
- Landcover

Available static data:
- Digital maps
- DEM
DRIVE/BUSARD AIRBORNE CAMPAIGN 2011

DRIVE/BUSARD acquisition 25/05/2011 (Rhône)
DRIVE/BUSARD AIRBORNE CAMPAIGN 2011

DRIVE/BUSARD acquisition 25/05/2011 (Rhône)

Folding artifact, specific to BUSARD

Amplitude

Coherence

Phase

Instrument artifacts

0°

14°

~0.95
DRIVE/BUSARD EXTRACTS SHOWN AS $\Sigma_0$ IMAGES

Excerpts of DRIVE/BUSARD acquisitions shown as $\Sigma_0$ images: (a) the Vaccarès lagoon and nearby fields (14 April 2011), (b) the Mediterranean near the Espiguette buoy (14 April 2011), (c) the Rhône river and surrounding rice fields (25 May 2011), (d) forest and vineyards near the Rhône river (25 May 2011), (e) the Piemanson beach (25 May 2011), and (f) the Mediterranean off the Piemanson beach (25 May 2011).

DRIVE/BUSARD $\Sigma_0$ PROFILES: WATER SURFACES

Wind speed $\sim 4$ m/s

NEAR-FIELD MEASUREMENTS IN KA-BAND

- Using a network analyzer and an automatically steerable (0-10°) parabolic antenna (ONERA)
- Only the incoherent part of the backscattering is measured
- Acquisitions in the Large Air-Sea Interaction Facility (LASIF) at MIO (Luminy): 40 m wind tunnel + 40 m water tank
- Possibility to study wind-generated water roughness (waves) in stable conditions (as well as to add waves mechanically)
- Equipment for optical roughness characterization (MIO)
- Comparison of $\sigma_0$ profiles with radiometric models
NEAR-FIELD MEASUREMENTS IN KA-BAND (LASIF)

Ka-band $\sigma_0$ of water vs. incidence and wind (incoherent part only)

Wind perpendicular to incidence direction ("along-track" wind direction)

NEAR-FIELD MEASUREMENTS IN KA-BAND (LASIF)

Ka-band $\sigma_0$ of water vs. incidence and wind (incoherent part only)

Wind parallel to incidence direction (“across-track” wind direction)

LOW WIND (1.7 m/s)

STRONG WIND (10 m/s)

Bragg scattering phenomenon (monochromatic waves)

Limited transmit power leads to relatively weak SNR for KaRIn/SWOT

- Continuous acquisition, non-sun-synchronous orbit, off-nadir, $\sigma_0$…
- Strong thermal noise (power amplifiers) relative to received signal
- Current SNR margin: 5 dB

- Noise-equivalent $\sigma_0$: the value the $\sigma_0$ of a surface must have in order that the return signal equals the thermal noise floor.

Noise-equivalent $\sigma_0$ (for the SWOT orbit reviewed at the SWOT MCR). E. Rodriguez, SDT meeting, Paris, June 2013

- Amplitude of surfaces with lower $\sigma_0$ will be “drowned” in noise
- Thermal noise is also the dominating phase noise
SIMULATION WITH/WITHOUT THERMAL NOISE

Amplitude without... and with thermal noise
SIMULATION WITH/WITHOUT THERMAL NOISE

Phase without… and with thermal noise
SIMULATION WITH/WITHOUT THERMAL NOISE

Coherence without... and with thermal noise
GEOMETRICAL DISTORTIONS
(Illustrated for conventional side-looking SAR)
The extent of layover increases as the incidence decreases

Can be predicted based on a DEM (of sufficient precision/resolution)

KaRIn: Impact of land/water layover on water surface detection and height estimation is limited by the high water/land contrast (~10dB)
Example: DRIVE/BUSARD near-nadir Ka-band airborne InSAR images

24/02/2011 Southbound

25/05/2011 Northbound

Trihedrals observed “as if they were in the river” due to layover and strong water/land contrast
**LAYOVER**

\(\sigma_0\)-weighted sum of contributions within the same range cell

- **Land/water layover** (and vegetation/water)
  - Higher amplitude -> not a major problem for water surface detection
  - Introduces a phase bias (affecting height & geolocation) -> flagged
  - Lower coherence (geometric decorrelation)

- **Land/land layover** (and vegetation/land)
  - No \(\sigma_0\) contrast to help us…
SAR: high azimuth resolution by simulating a very long antenna

- Implicit hypothesis that nothing changes during the integration time (~250 ms for KaRIn/SWOT).
IMPACT OF MOVEMENT

Movement without deformation

TerraSAR-X stripmap, Gibraltar, © DLR

→ Minor impact on KaRIn/SWOT
Movement with deformation (down to cm/mm scale) - water decorrelation

Integration of responses will not be efficient over the entire integration time, only by piece:
- Degraded azimuth resolution $\rightarrow$ Degraded water delineation accuracy
- Height precision can to a large extent be preserved (multilooking)