CryoSat-2 SAR/SARin processing at ESA ESRIN

Feedback from the trainee proposed at ESA/ESRIN
by Salvatore Dinardo and Jérôme Benveniste,
on 6-9 November 2012.

Sara Fleury, Nicolas Bercher

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Context

- Increasing interest nadir-SAR technology in altimetry:
  - OSTST 2011 and 2012,
  - Sentinel-3, AirSwot, Jason-CS, ...
- But : Few information related to nadir SAR/SARin and CryoSat2 + difficulties to access data.
- Invitation by J. Benveniste for a technical presentation of SAMOSA chain product (Sentinel-3) by S. Dinardo
- Documents :
  - **FBR + L1b** : *CS-RS-ACS-GS-5106 v4.9*
  - **L2** : *CS-RS-ACS-GS-5123 v2.1*
  - Salvatore Dinardo, Coastalt 2011 and 2012
  - *Radar Altimetry Tutorial*, Rosmorduc et all. 2011

Plan

1. Cryosat2 mission (~5mn)
2. An introductive example (~10mn)
3. **SAR/SARin principles (~30mn)**
4. Synthesis and products (~10mn)
5. **Examples over various surfaces (~30mn)**
6. Conclusion (~10mn)

Plan

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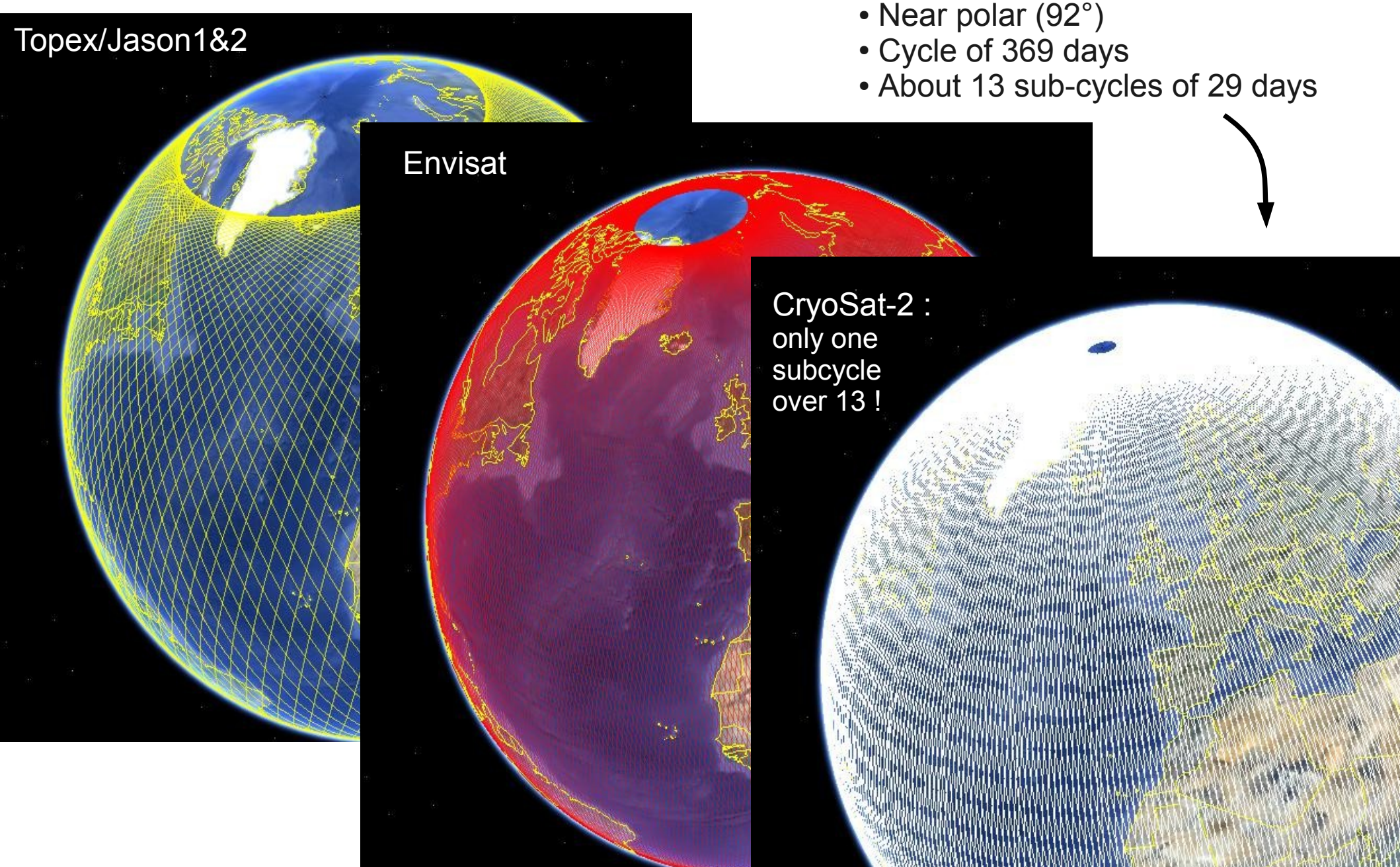
CryoSat-2 mission

- Objective: Measure ice mass variation
- Orbit type: near-circular, polar, low-earth orbit
- Mean altitude: **717 km**
- Inclination: **92.00°**
- Repeat period: **369 days** (5344 revolutions); 29 day sub-cycle (shift of 30km at equator every rev.)
- Inter-track spacing: 7.5 km at the equator
- Orbit control : +- 5km
- **3 radar modes : LRM, SAR, SARin**
- **SAR: Preparation for Sentinel3**, AirSWOT, Jason-CS

CryoSat-2 orbit

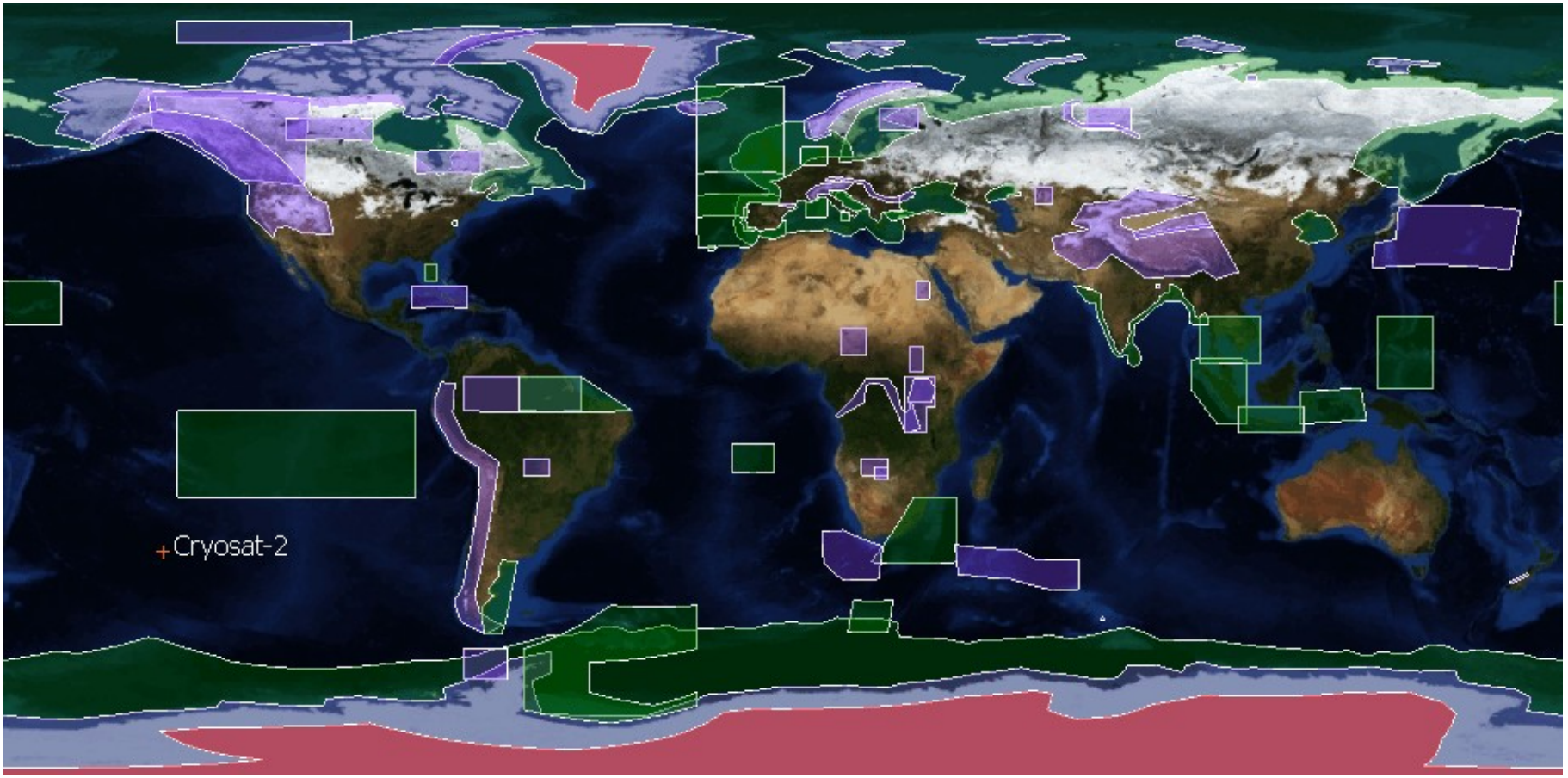
- Near polar (92°)
- Cycle of 369 days
- About 13 sub-cycles of 29 days



The 3 radar modes of CryoSat-2

(mask v3. 4, end 2012)

LRM every where, but: SAR (+ P-LRM), SARin, LRM



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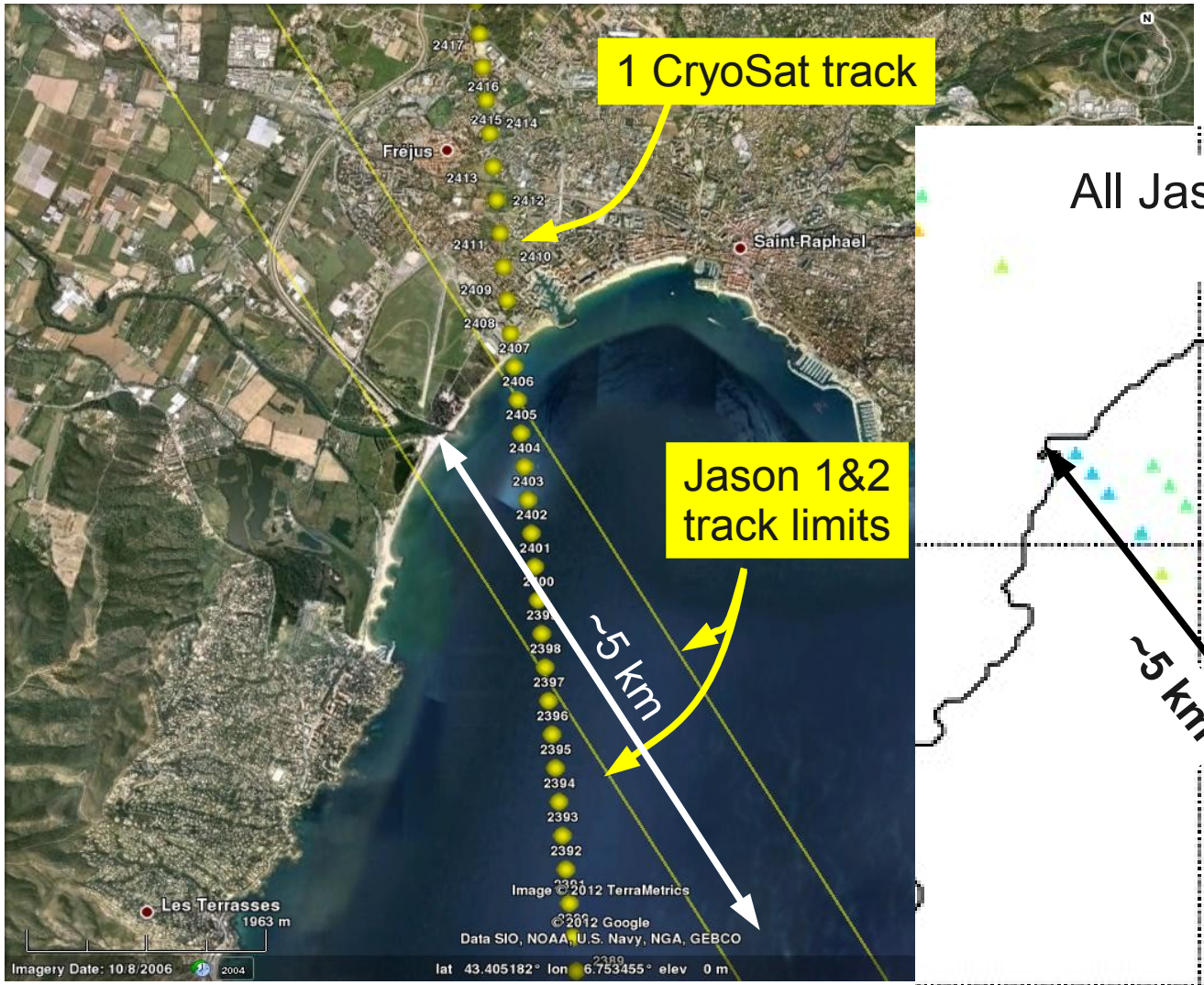
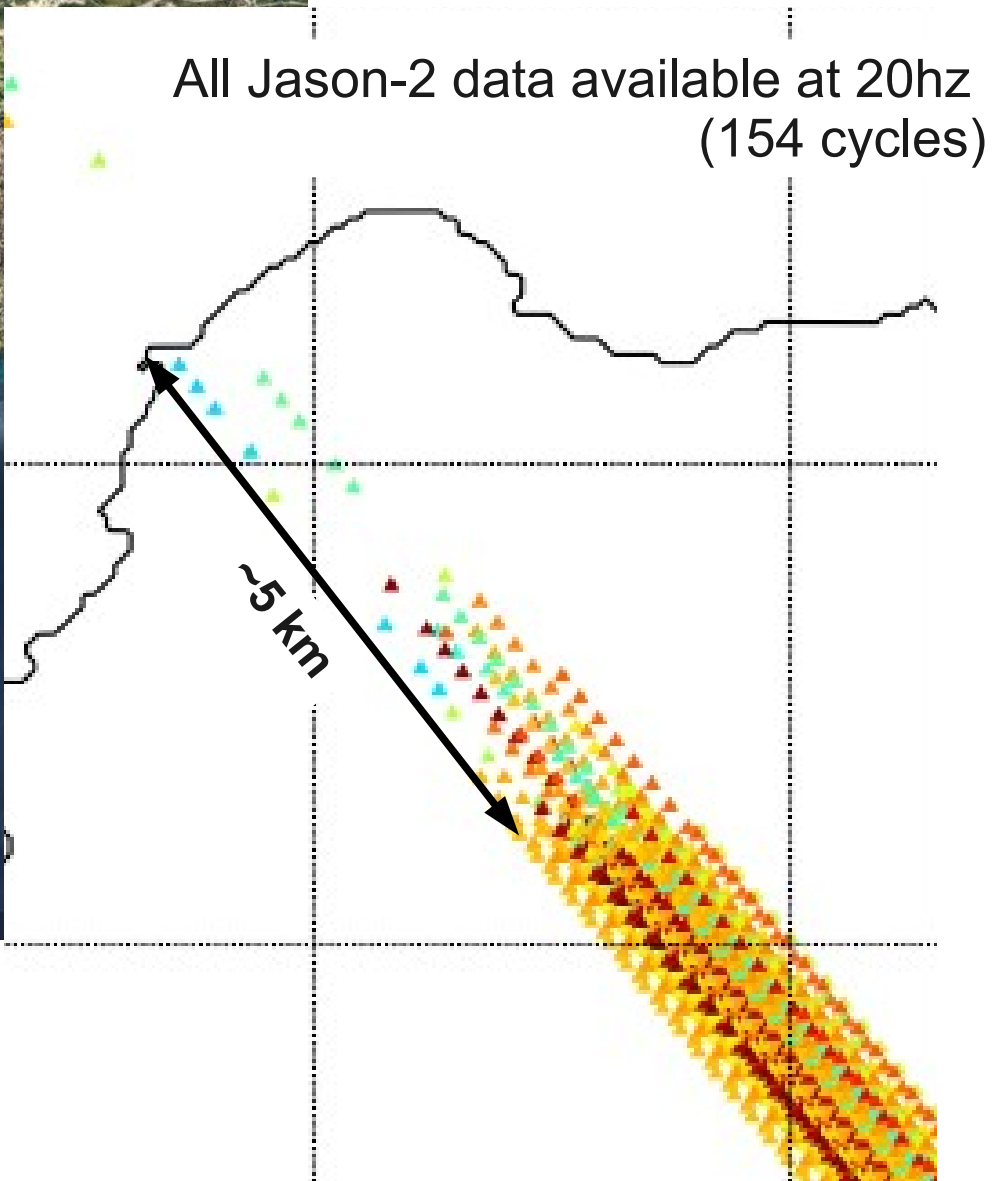
LRM vs SAR on coastal zone (Frejus)



All Jason-2 data available at 20hz
(154 cycles)



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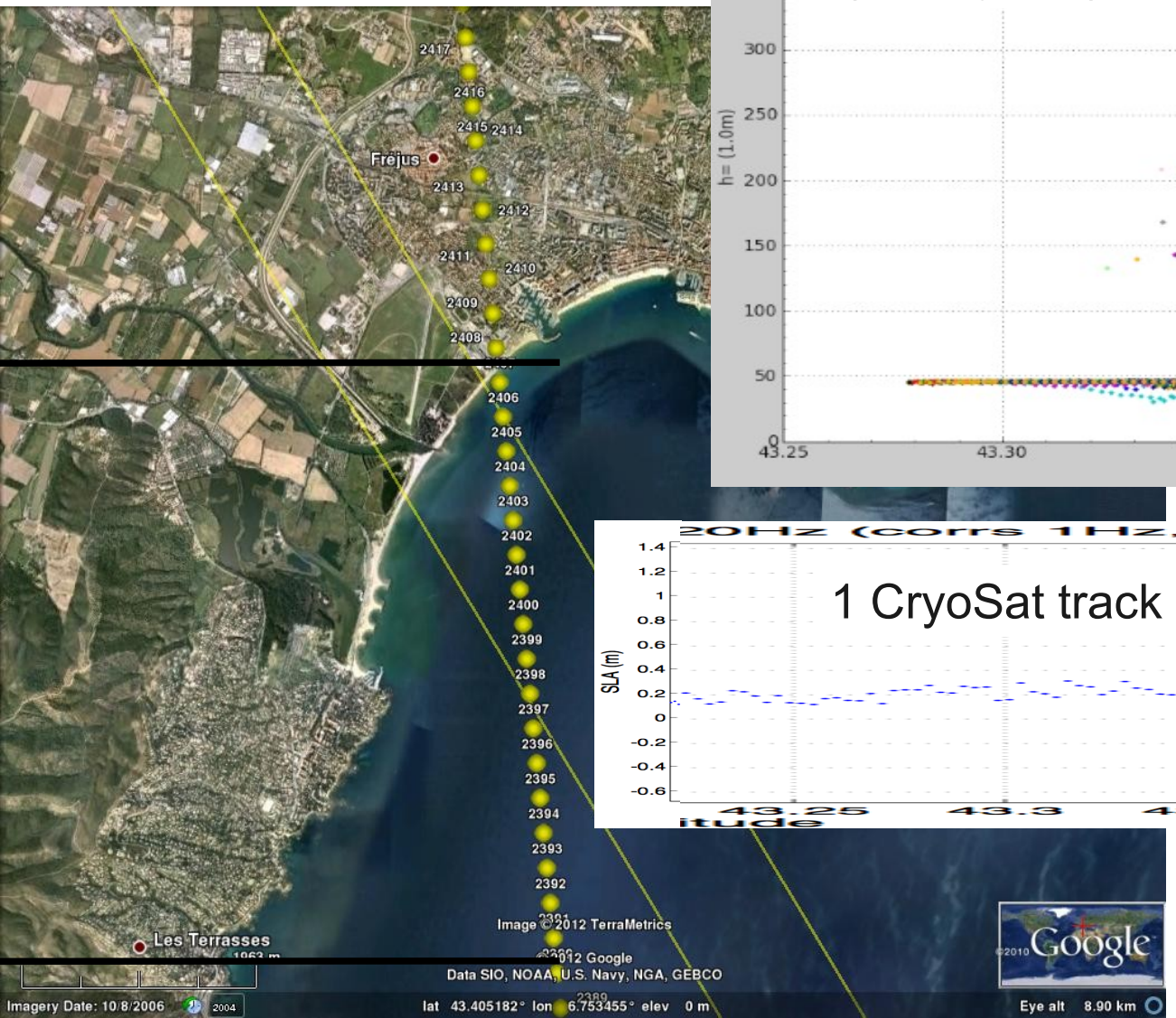
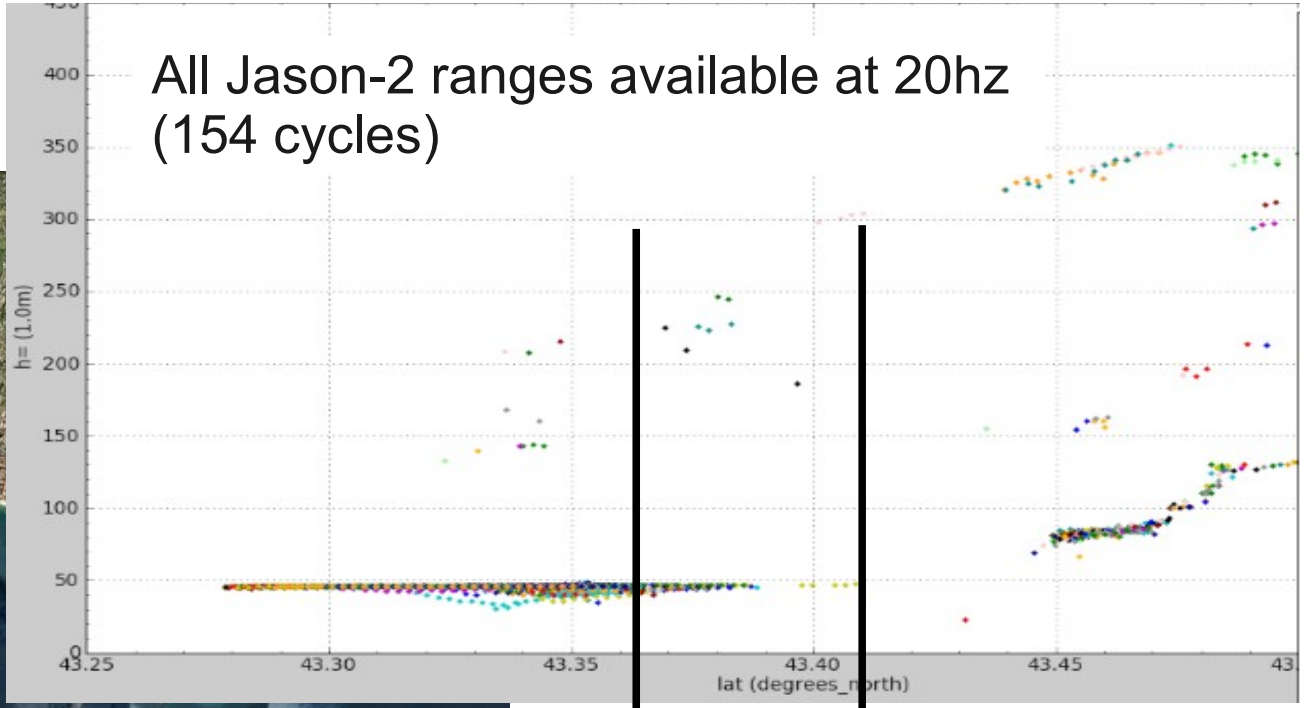
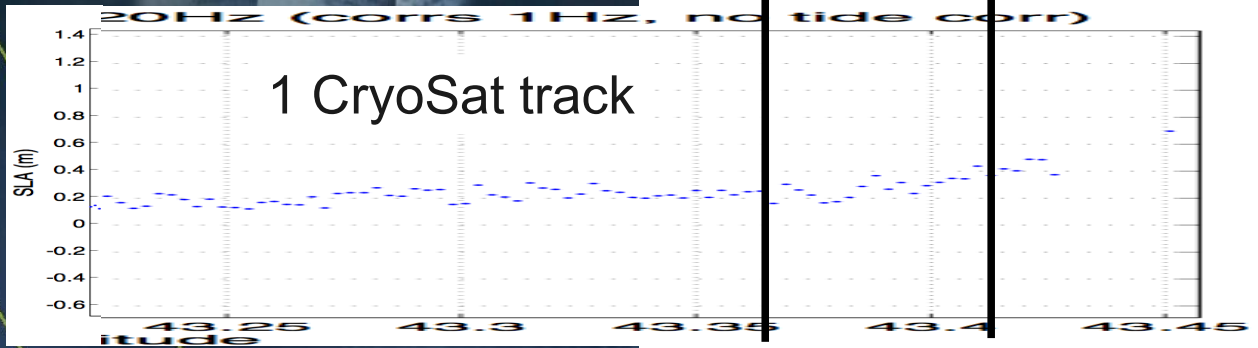
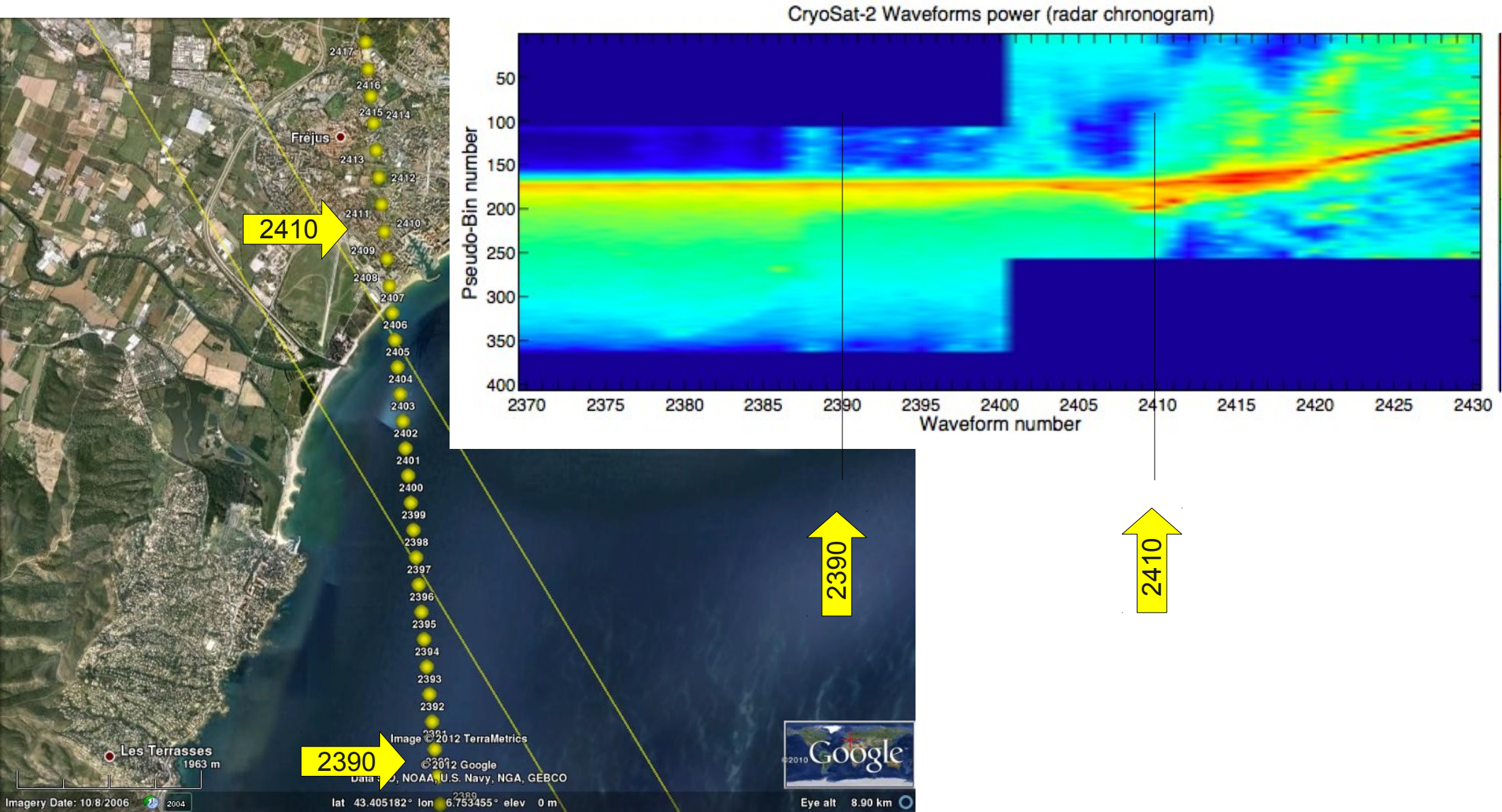






LRM vs SAR on coastal zone (Frejus)

CryoSat-2 SAR radar chronogram



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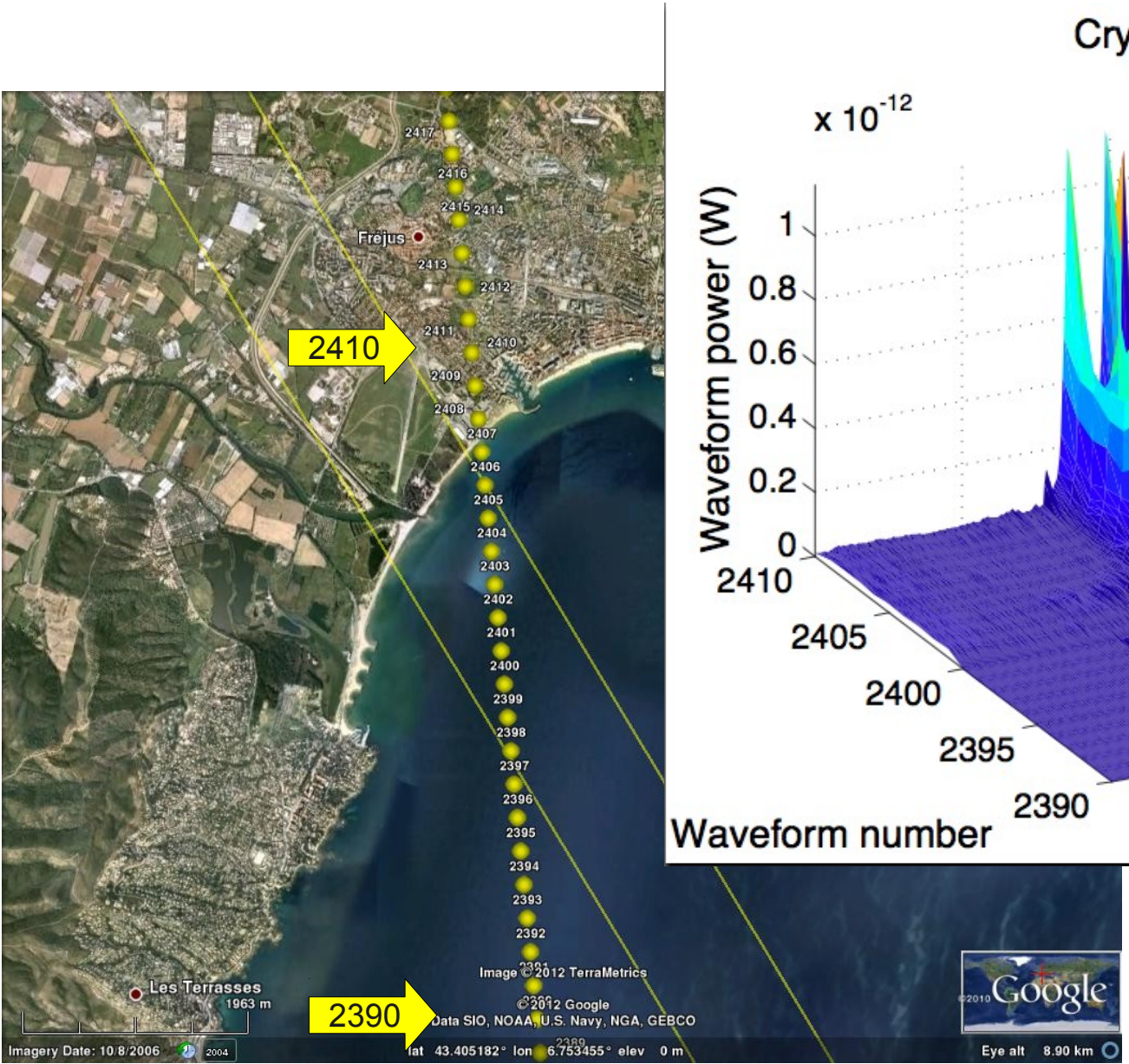
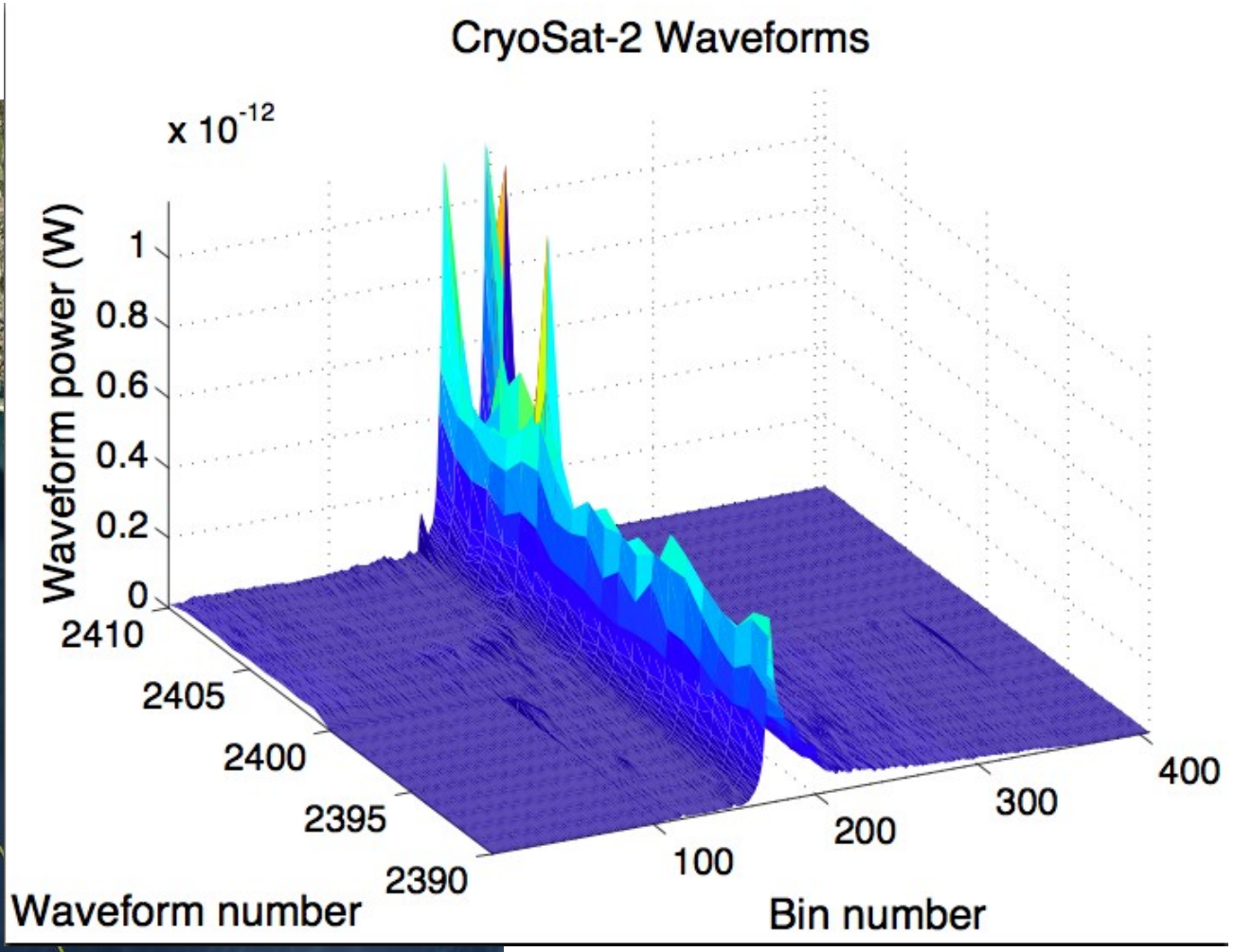
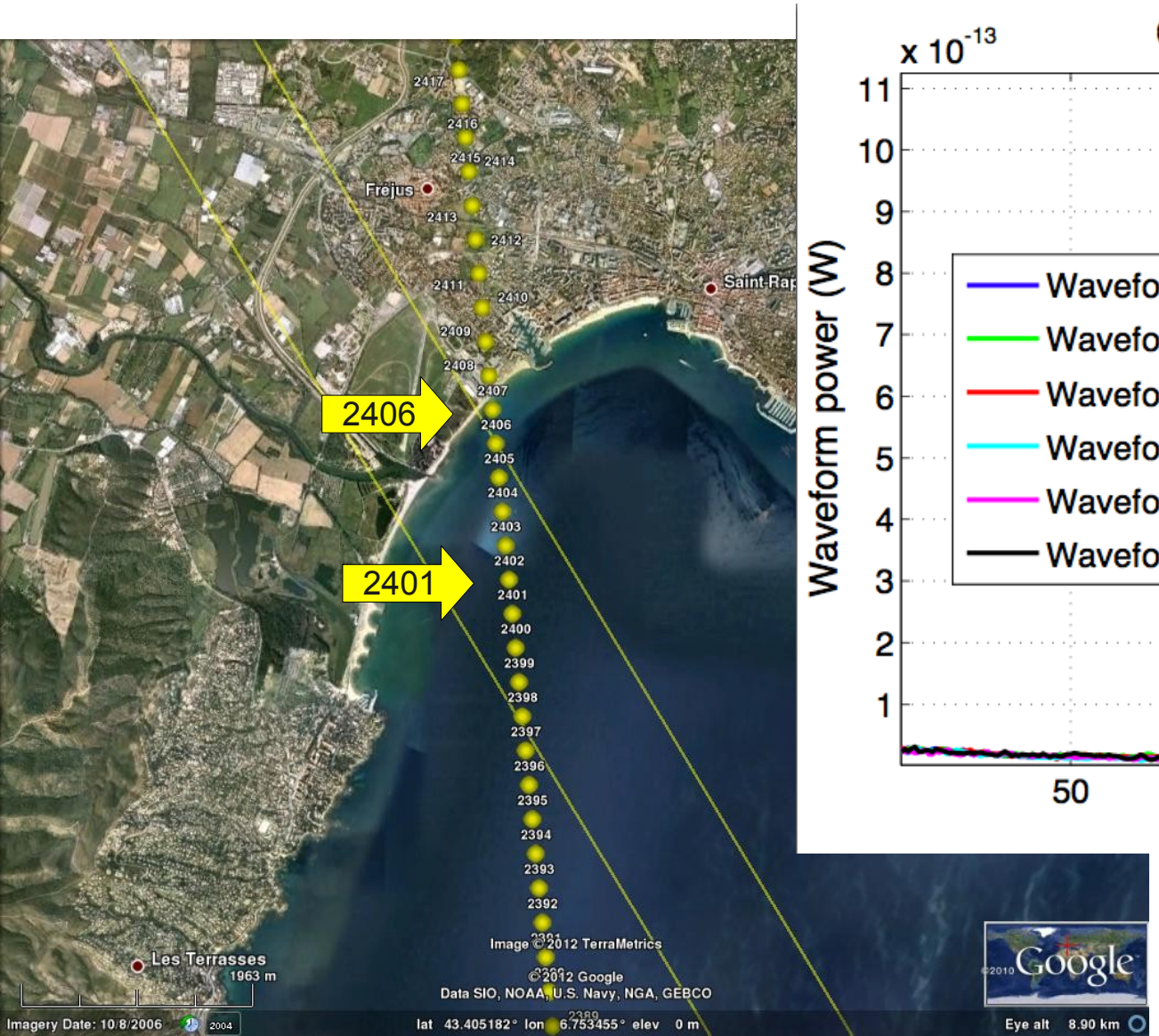
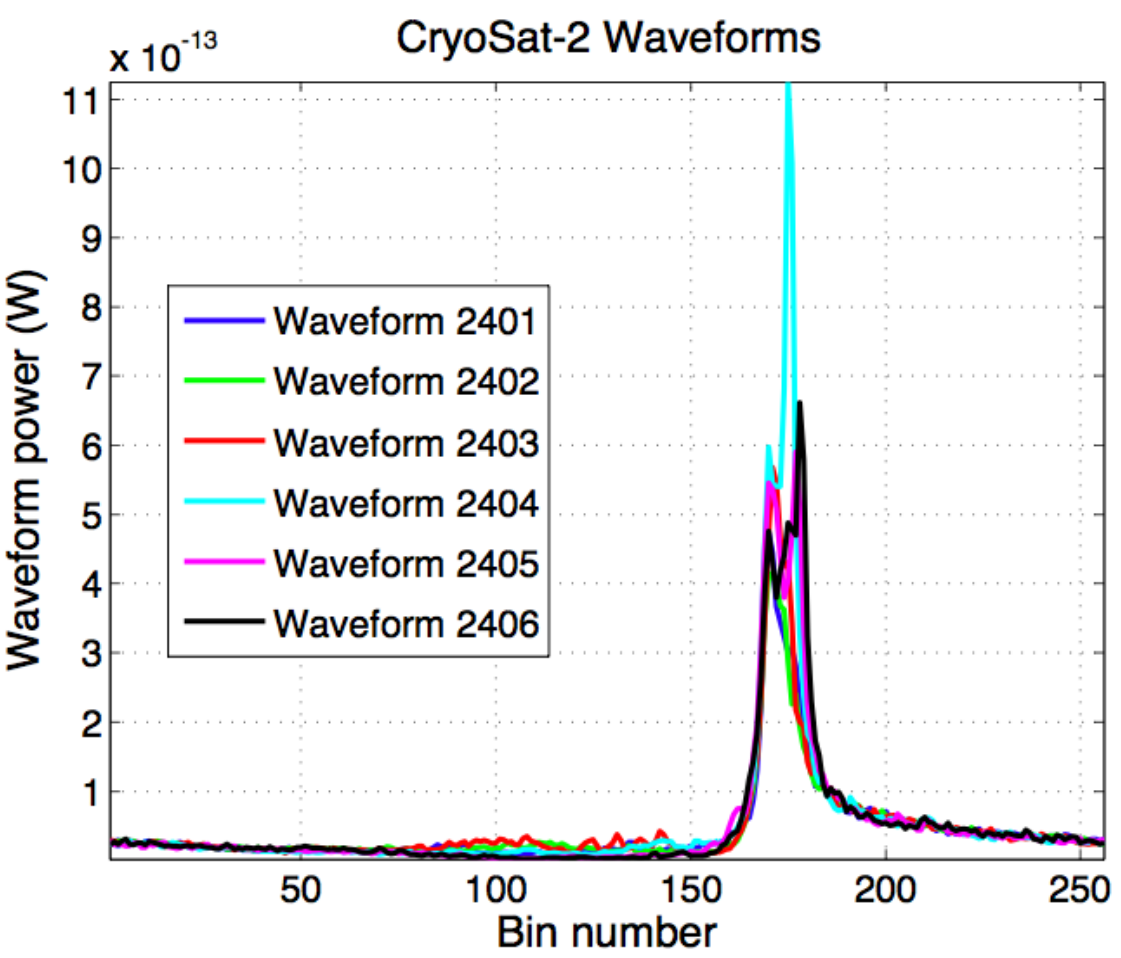




LRM vs SAR on coastal zone (Frejus)

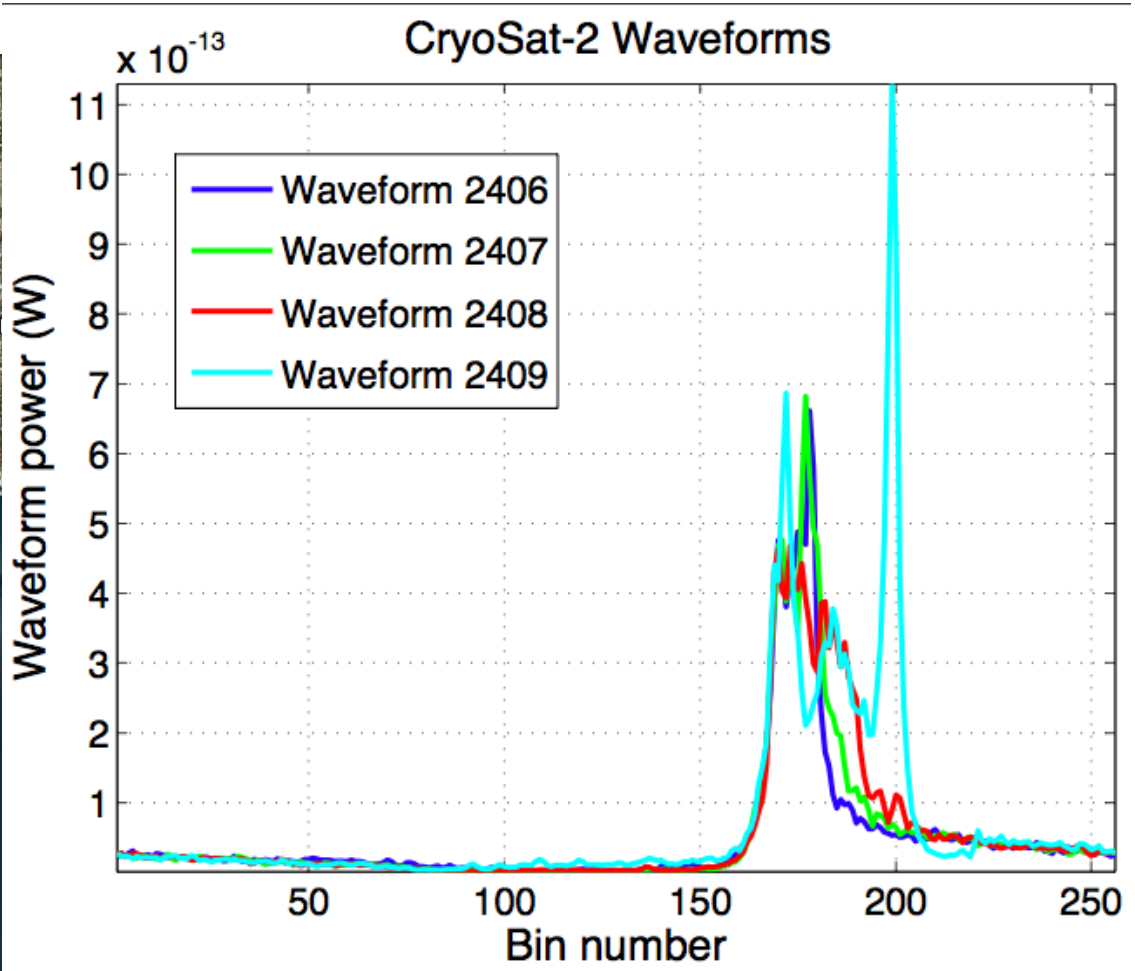
CryoSat-2 SAR can reach the beach ...





LRM vs SAR on coastal zone (Frejus)

… CryoSat-2 SAR can even go on the beach !



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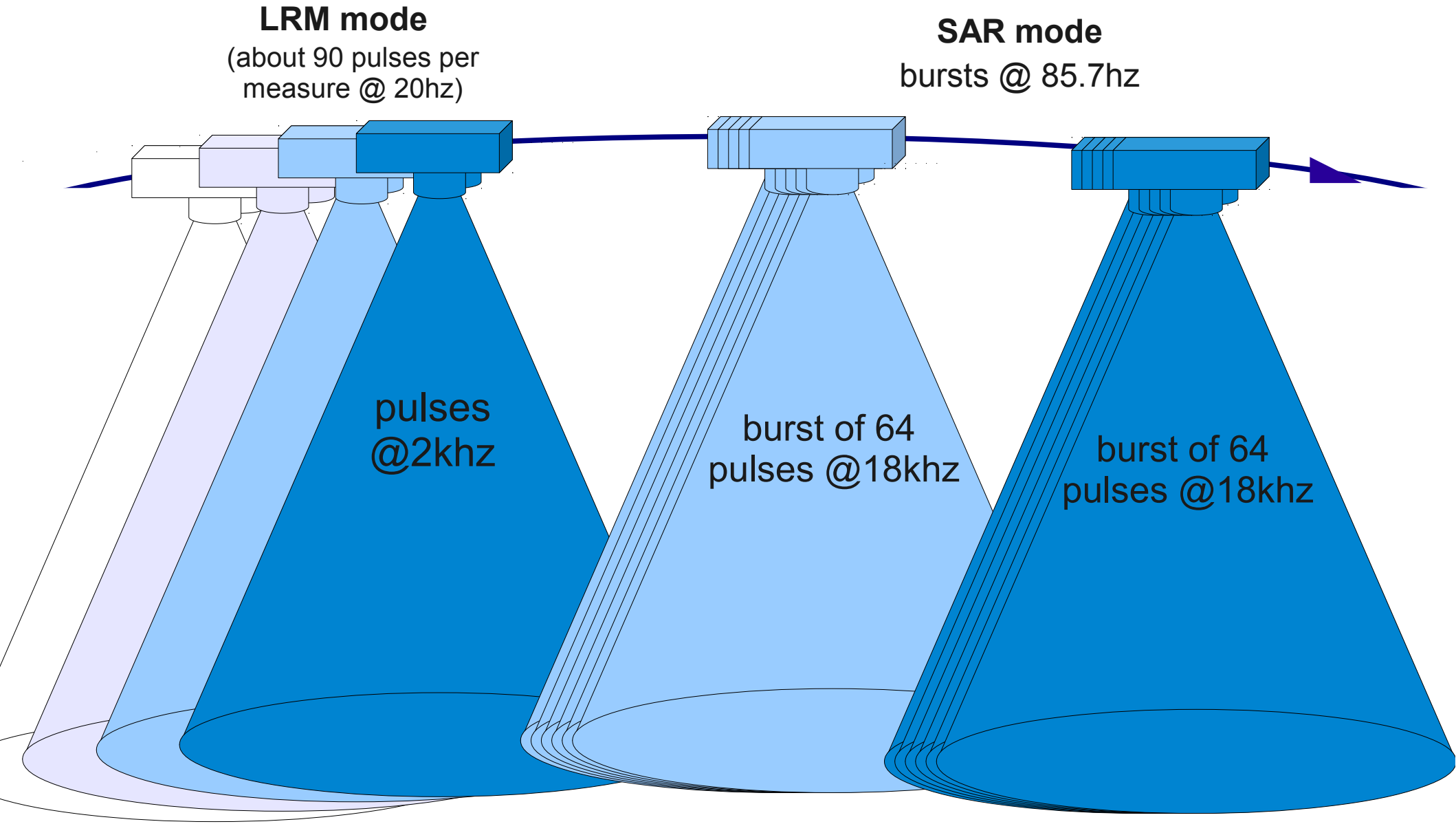
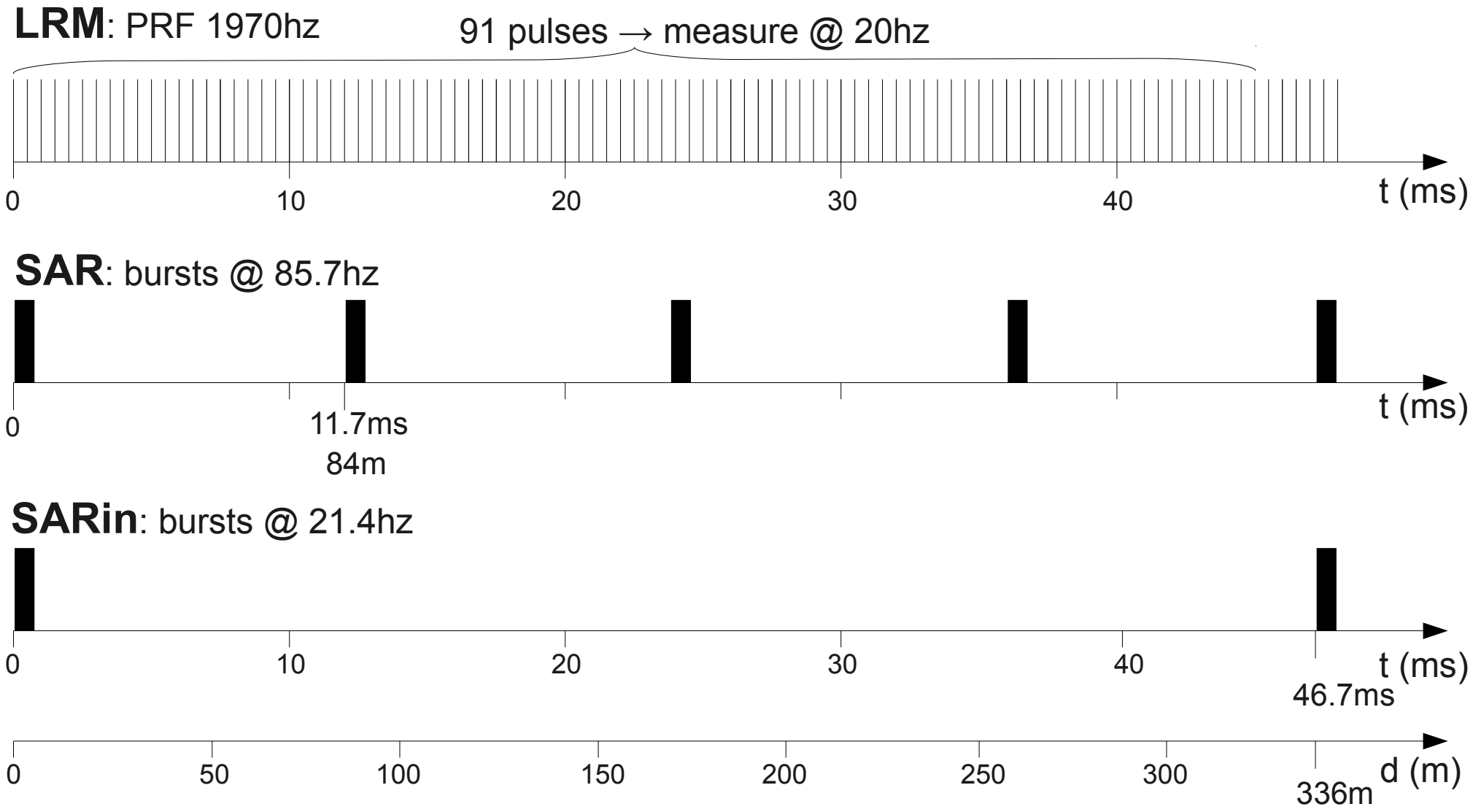
LRM vs SAR

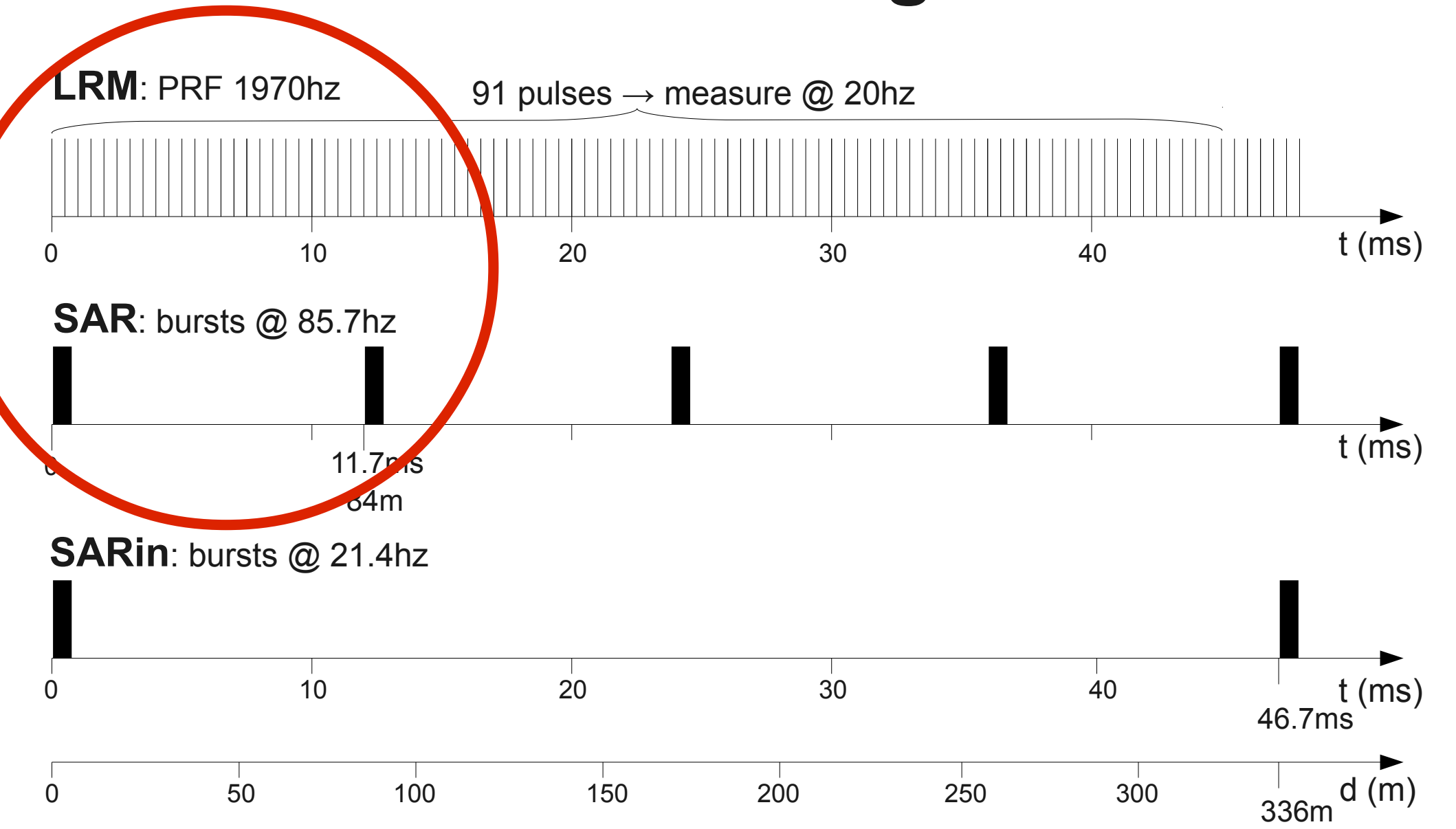

LRM mode
(about 90 pulses per measure @ 20hz)
SAR mode
bursts @ 85.7hz
pulses @2khz
burst of 64 pulses @18khz
burst of 64 pulses @18khz

Pulses chronograms

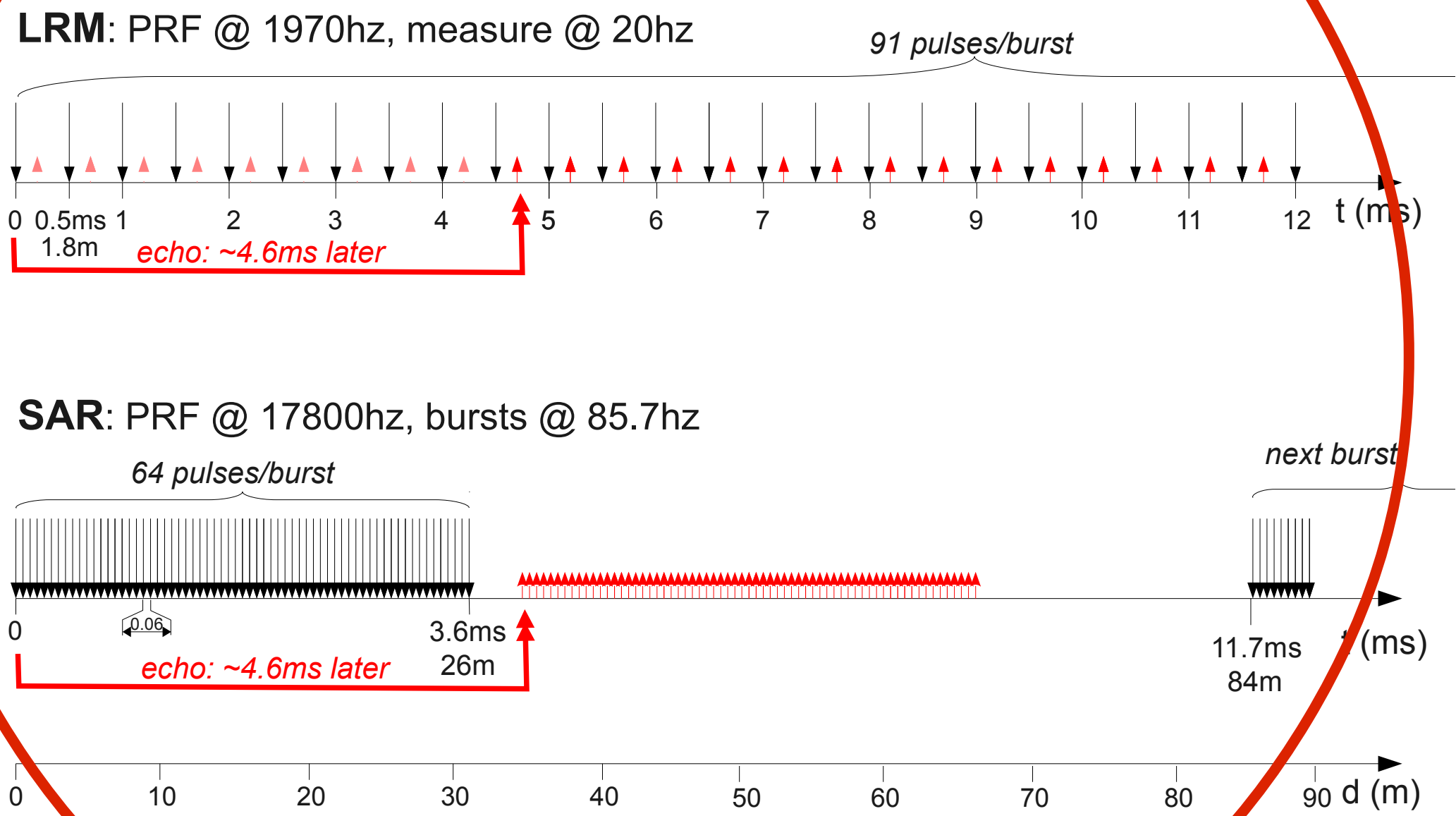


Pulses chronograms

ZOOM

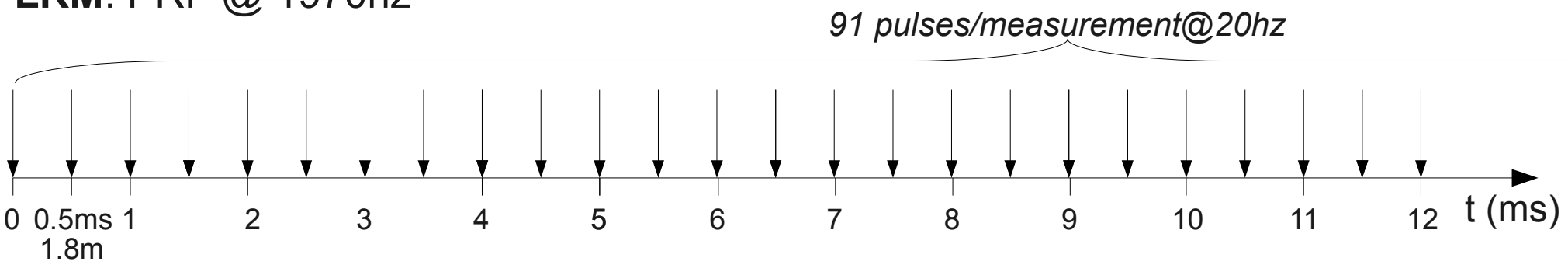


Pulses chronograms: zoom

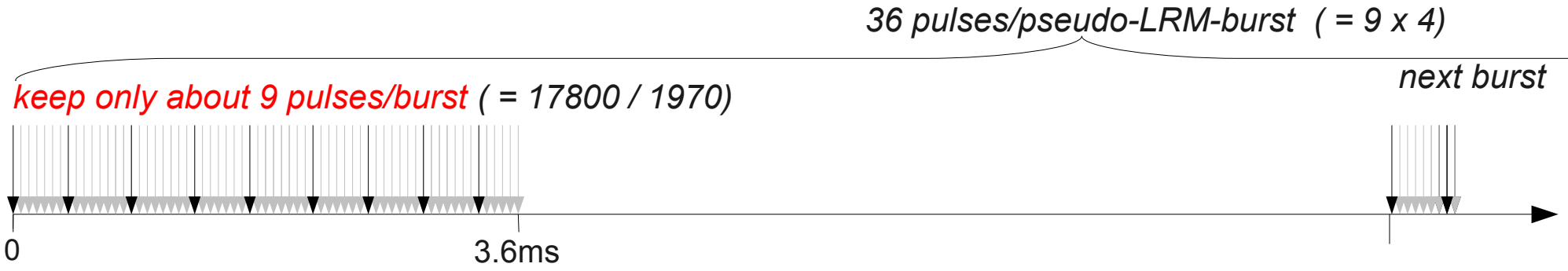


pseudo-LRM

LRM: PRF @ 1970hz

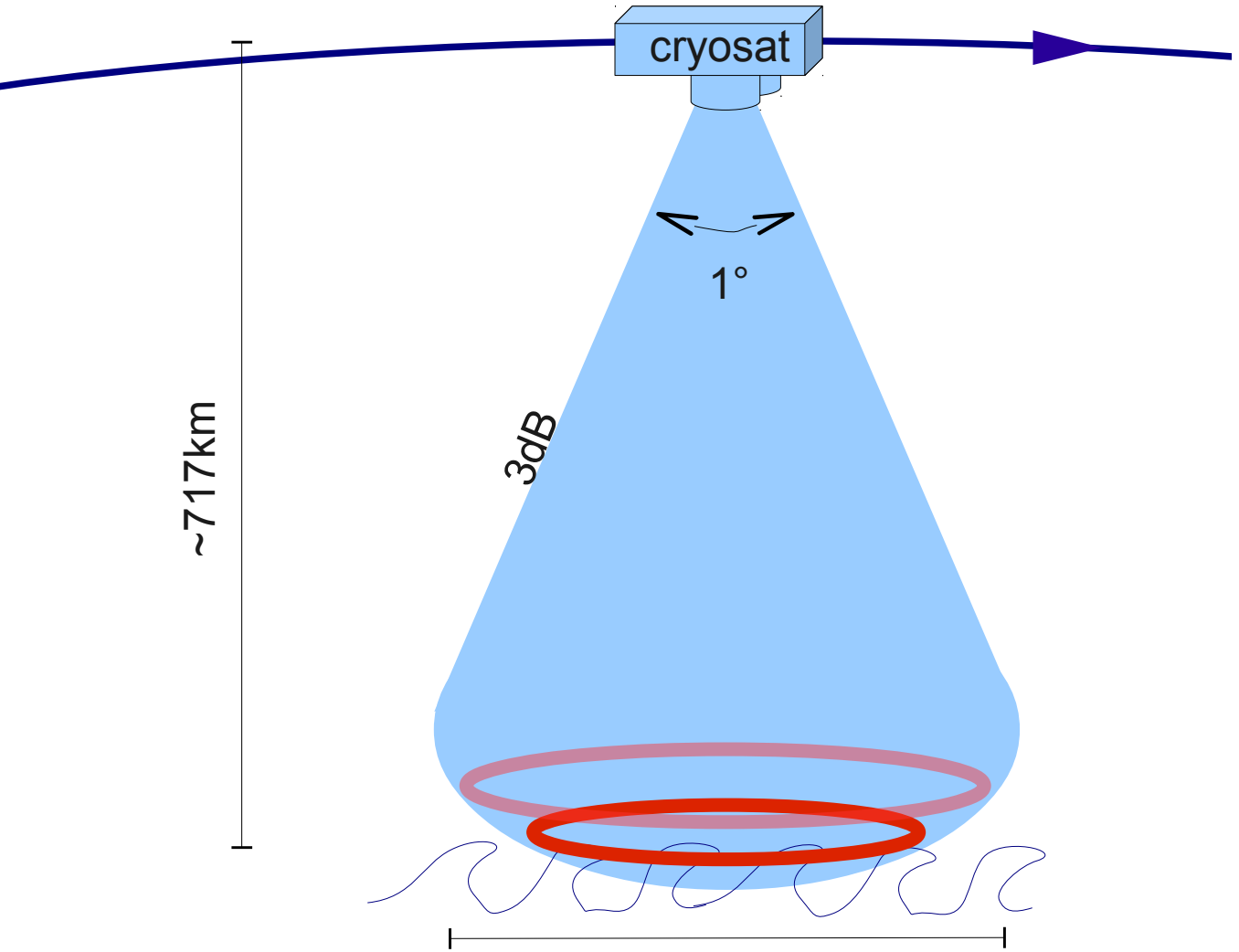


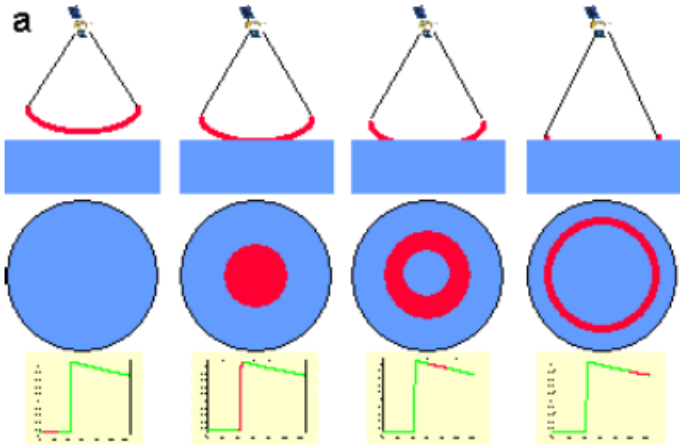
Pseudo-LRM: pseudo-PRF @ 774 hz (= 9 x 85.7hz)



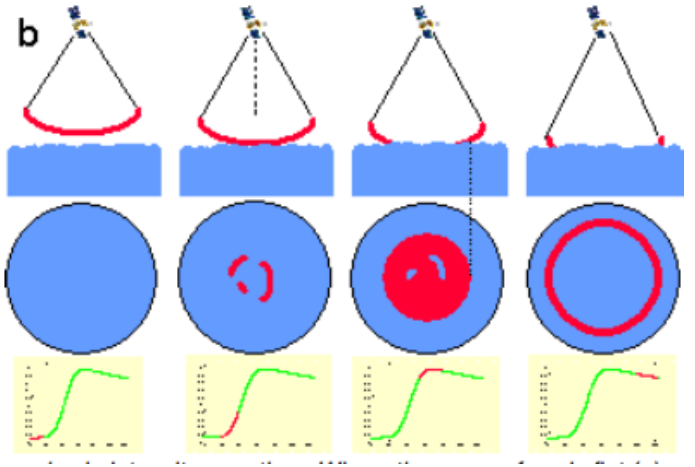
→ only about 1/3rd of data regarding LRM

Geometry of one Pulse



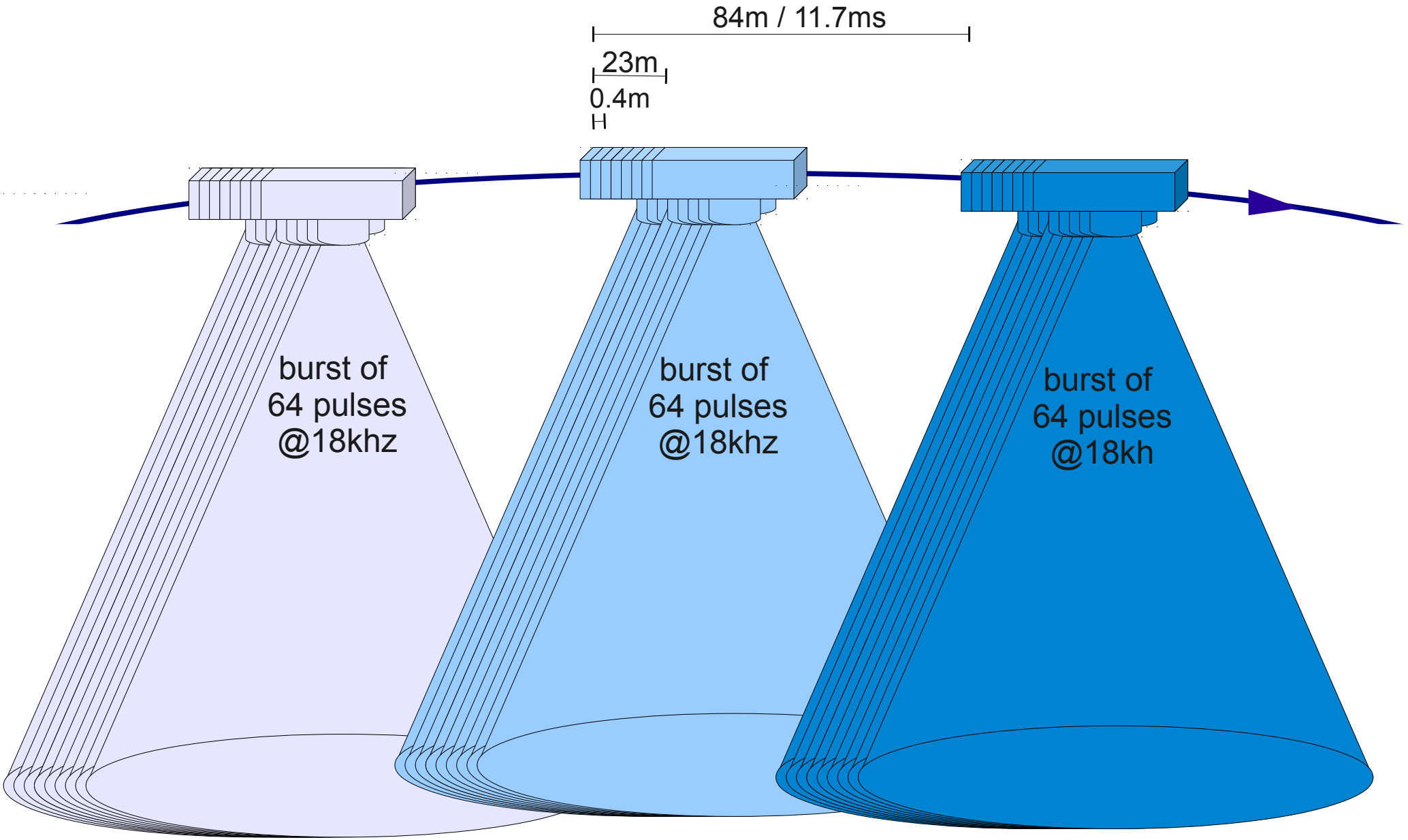


Wave-form over flat surface



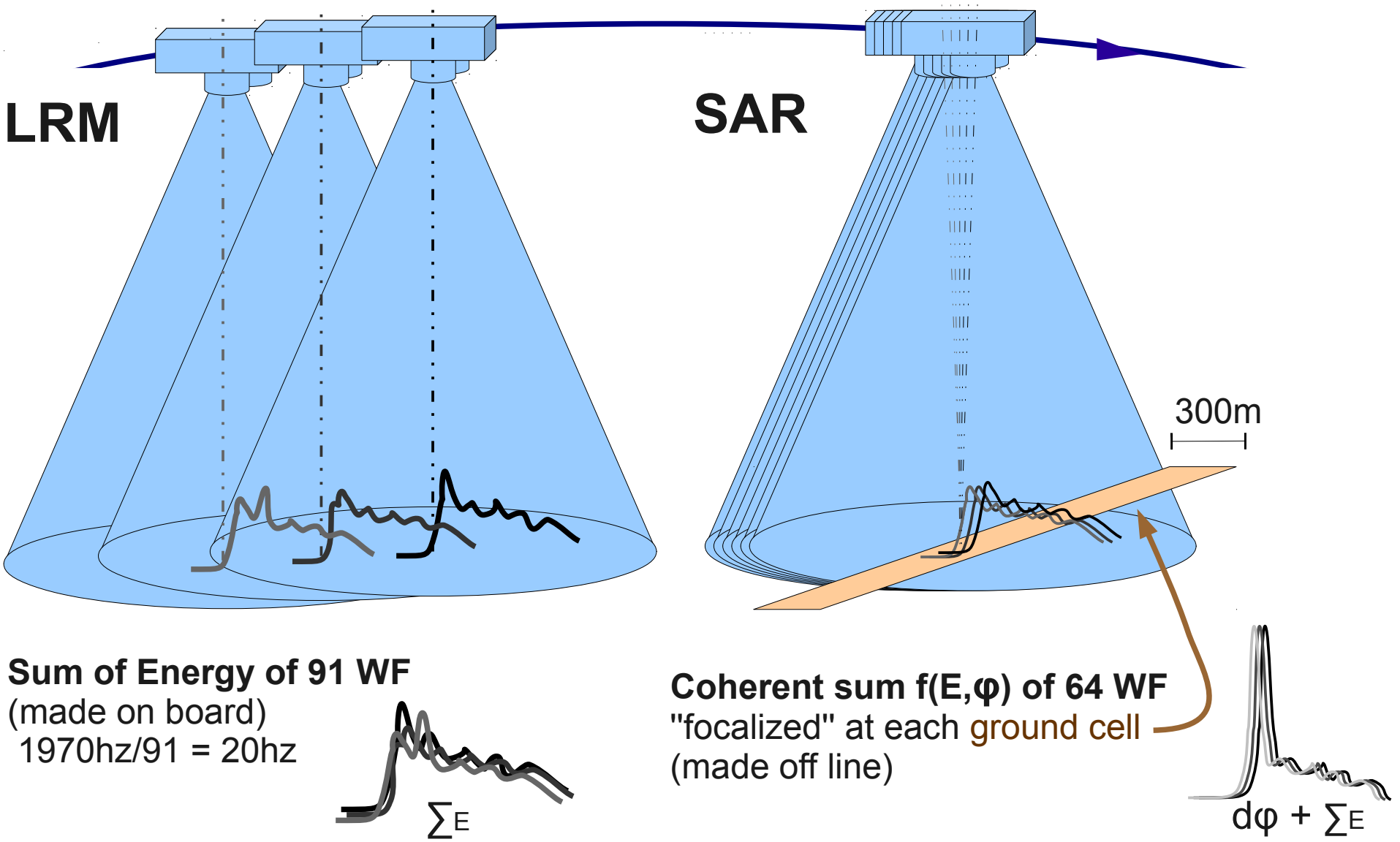
Wave-form over rough sea

SAR mode: bursts of 64 pulses

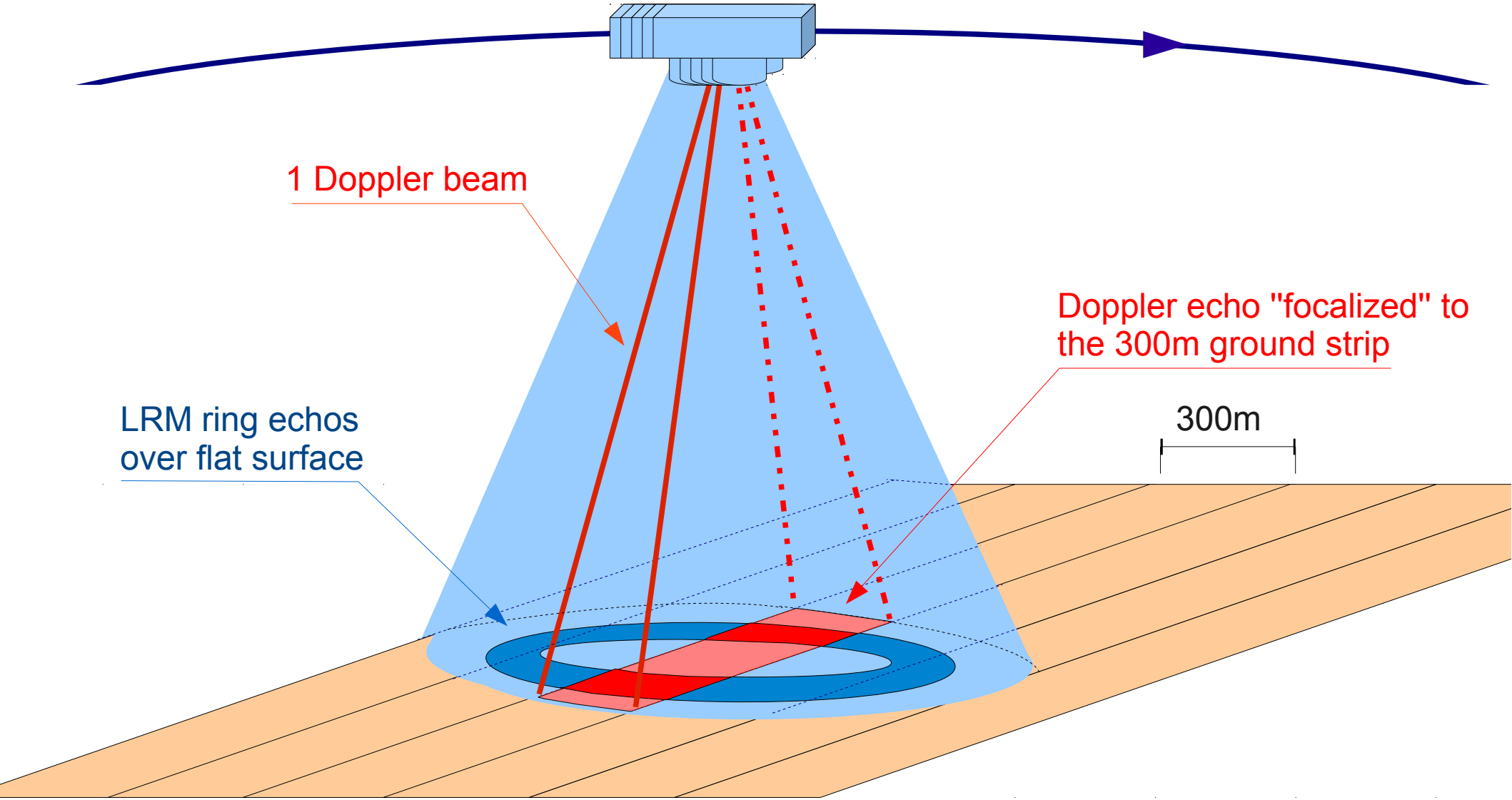


Doppler beam

1 doppler WF = a coherent sum of 64 Brown's WF

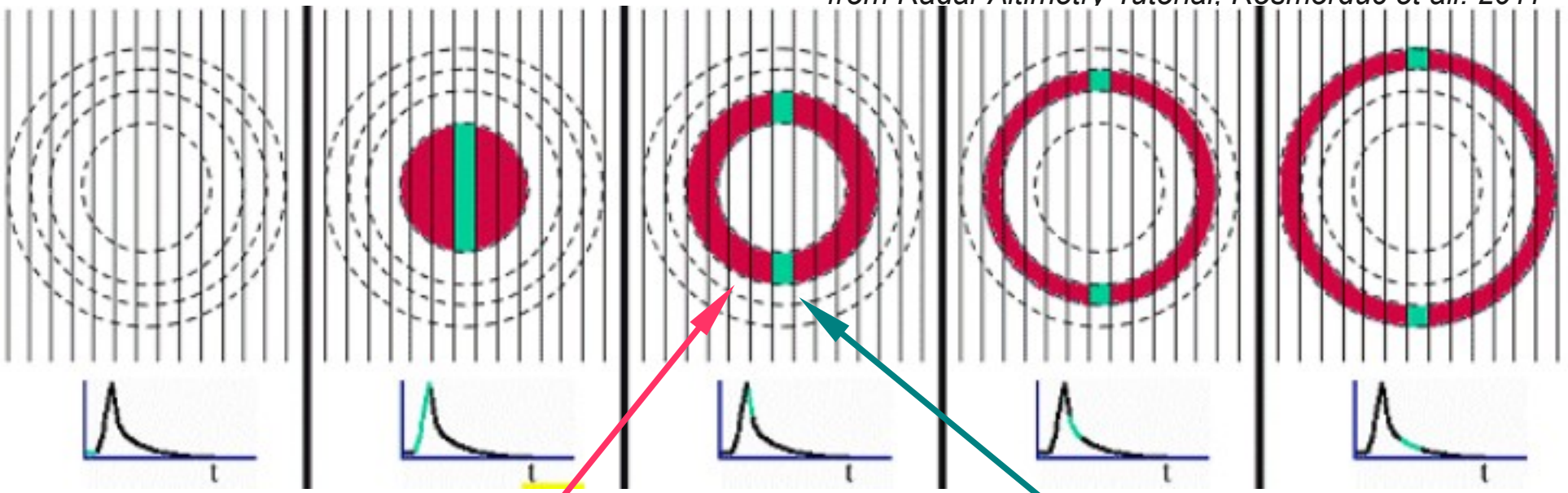


SAR: focalisation on one ground cell ≡ a Doppler beam

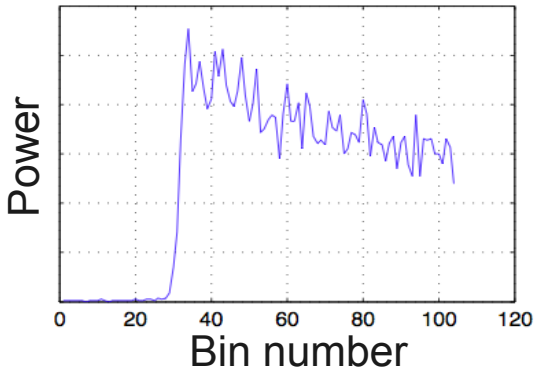


Doppler beam footprint

from Radar Altimetry Tutorial, Rosmorduc et all. 2011

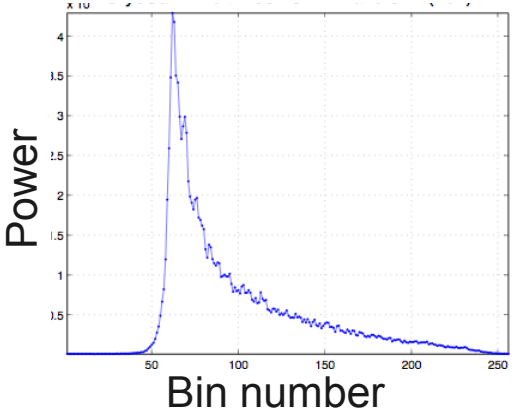


Brown wave-form

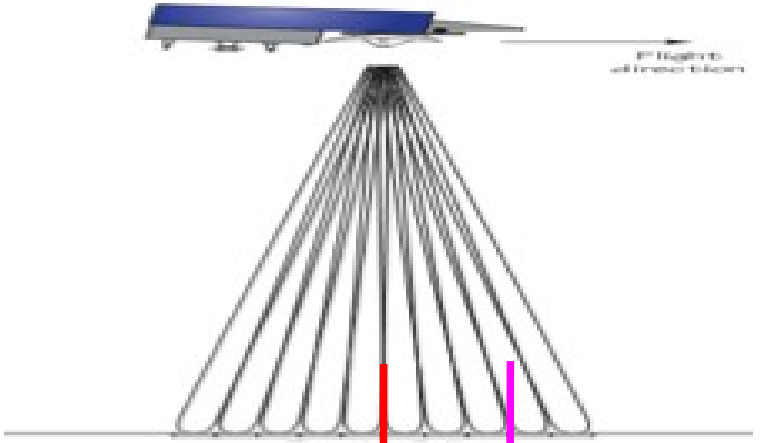


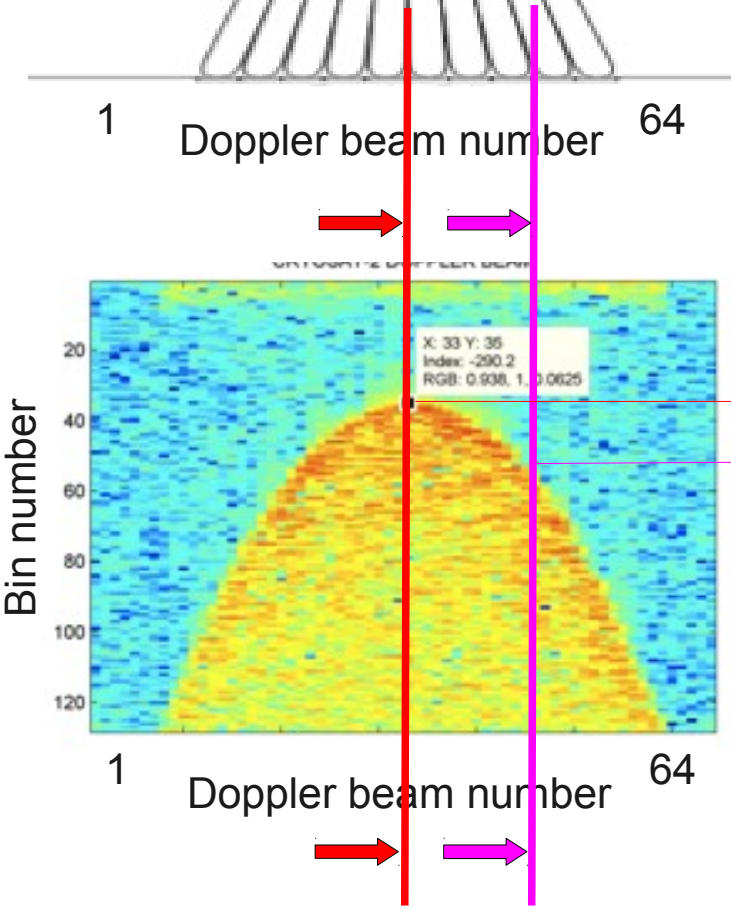
SAR wave-form much more « peaky » than Brown's wave-form (because of surface reduction from internal to external rings)

Doppler wave-form

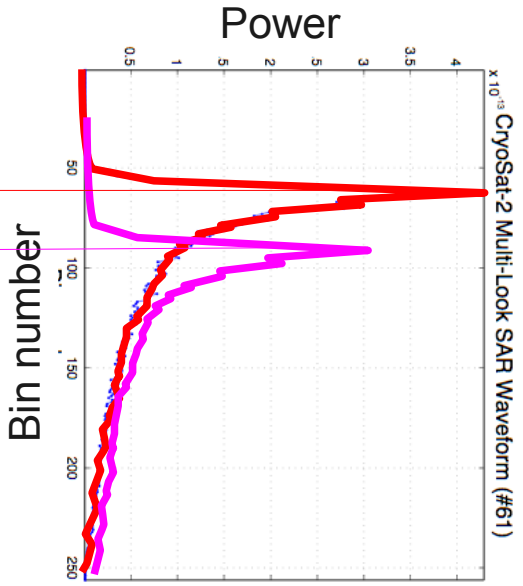


The 64 Doppler beams



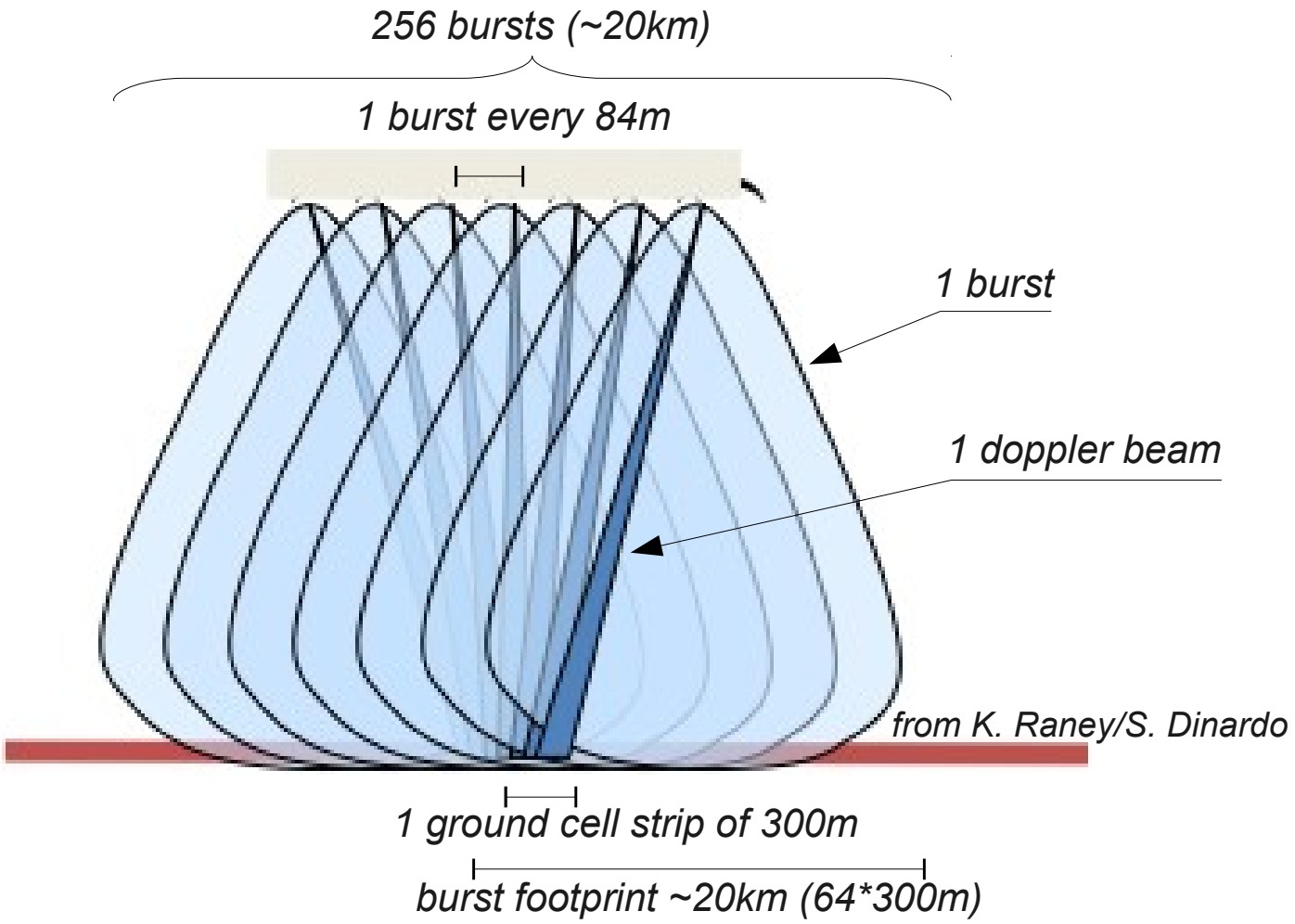


2 Doppler waveforms over 2 ground cells



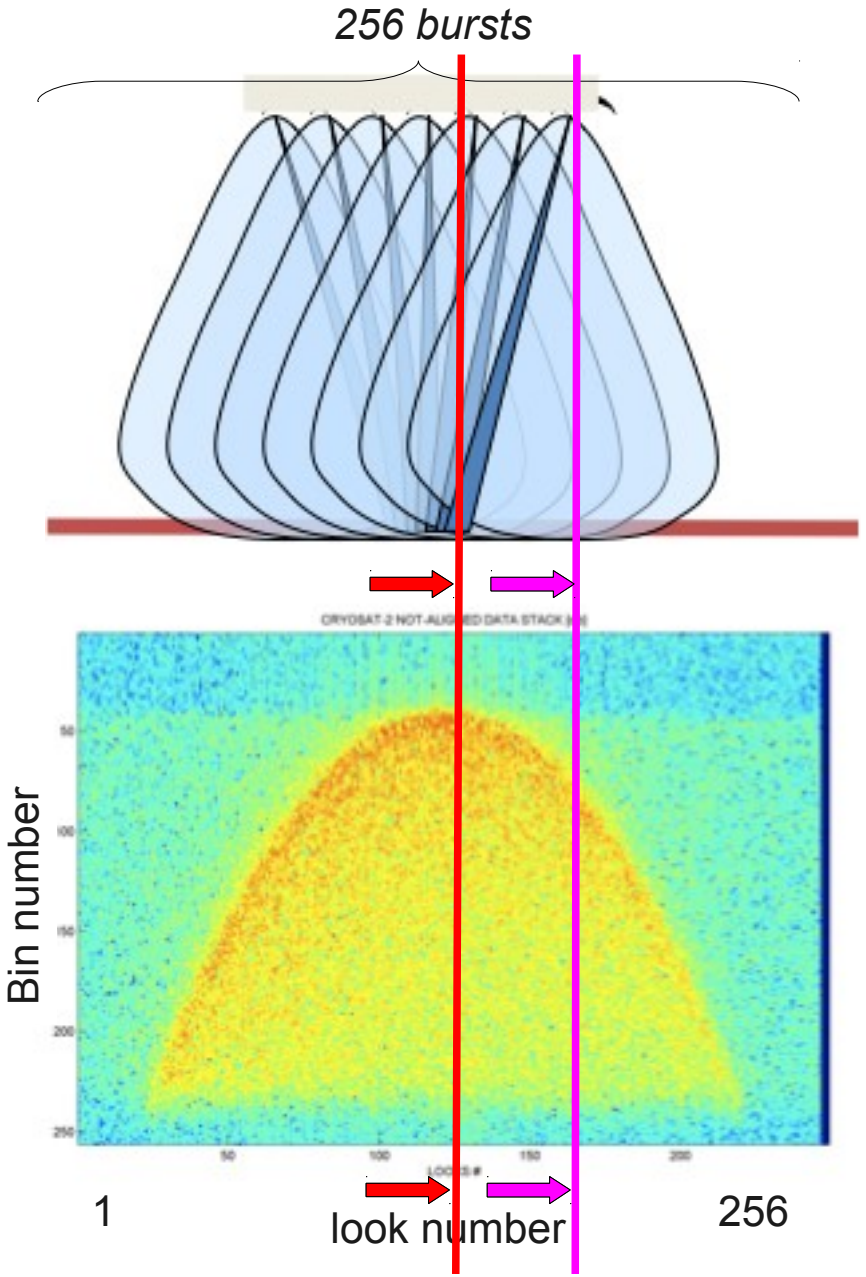
from S. Dinardo, 6th Costalt Altimetry Workshop, 2012

The multi-look over one ground cell

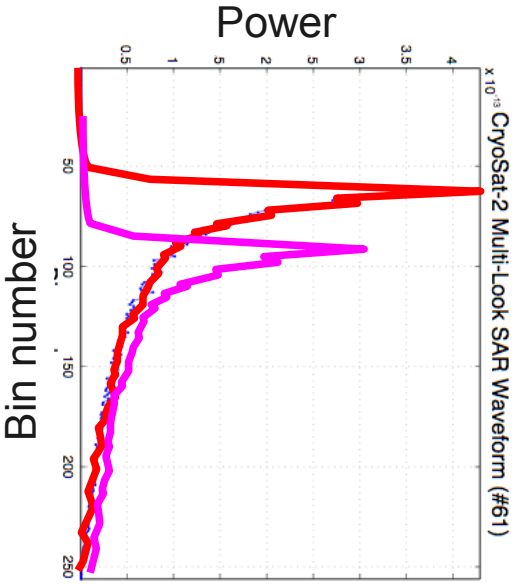


Each ground cell can be seen per theoriticaly 256 bursts
(~223 in practice over ocean)

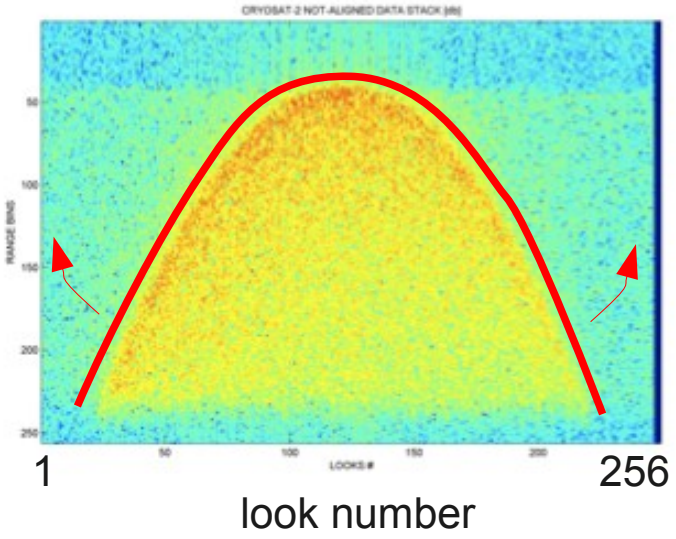
The multi-look : the stack



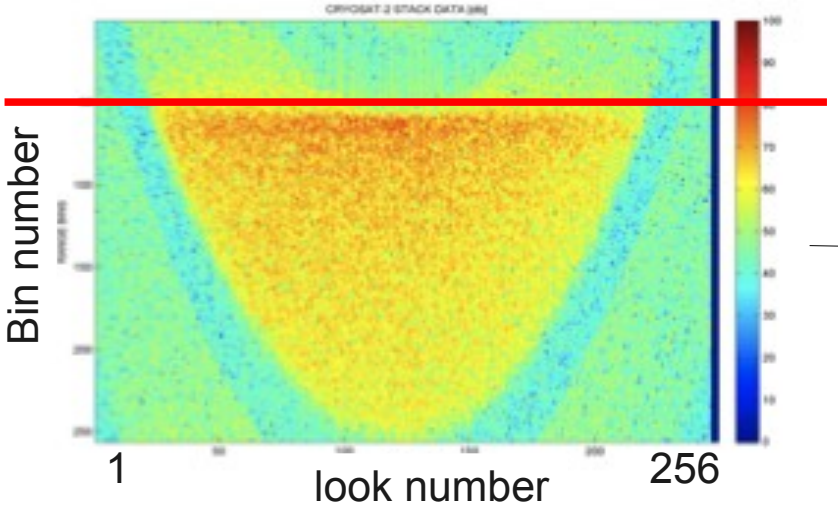
2 Doppler waveforms « looking » the same ground cell



The multi-look: range migration

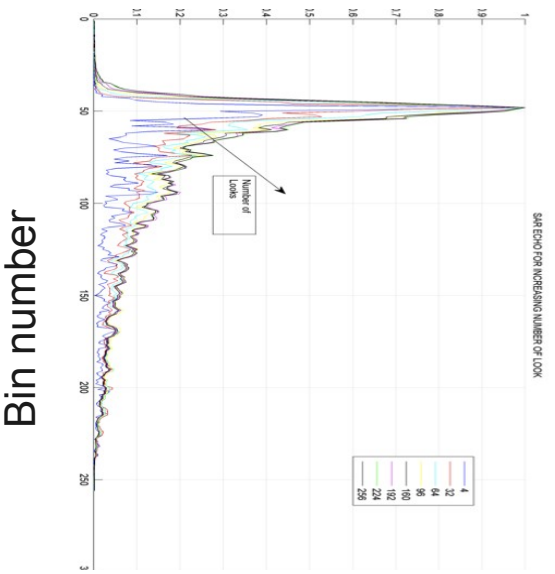


Range migration

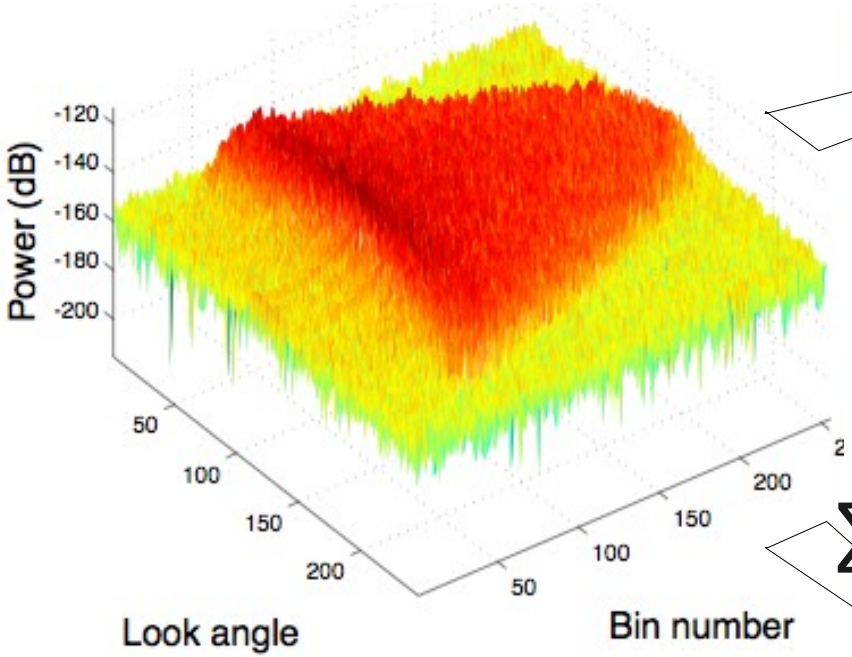


Σ

Power



The multi-look: stack



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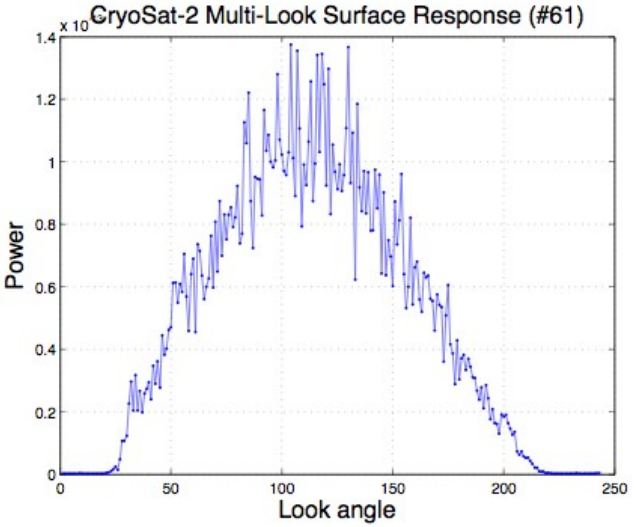
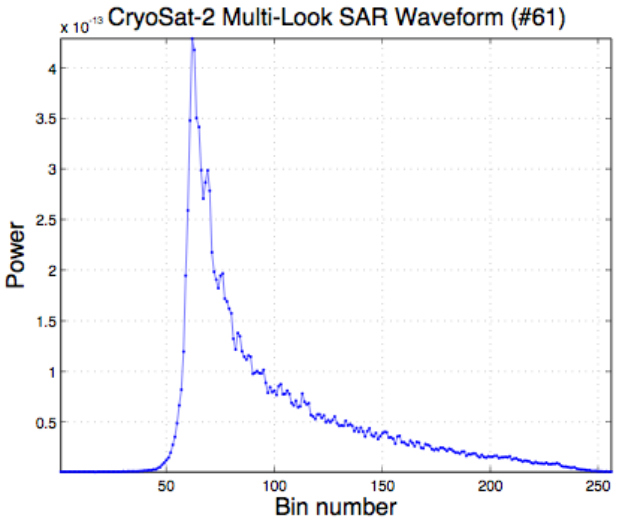
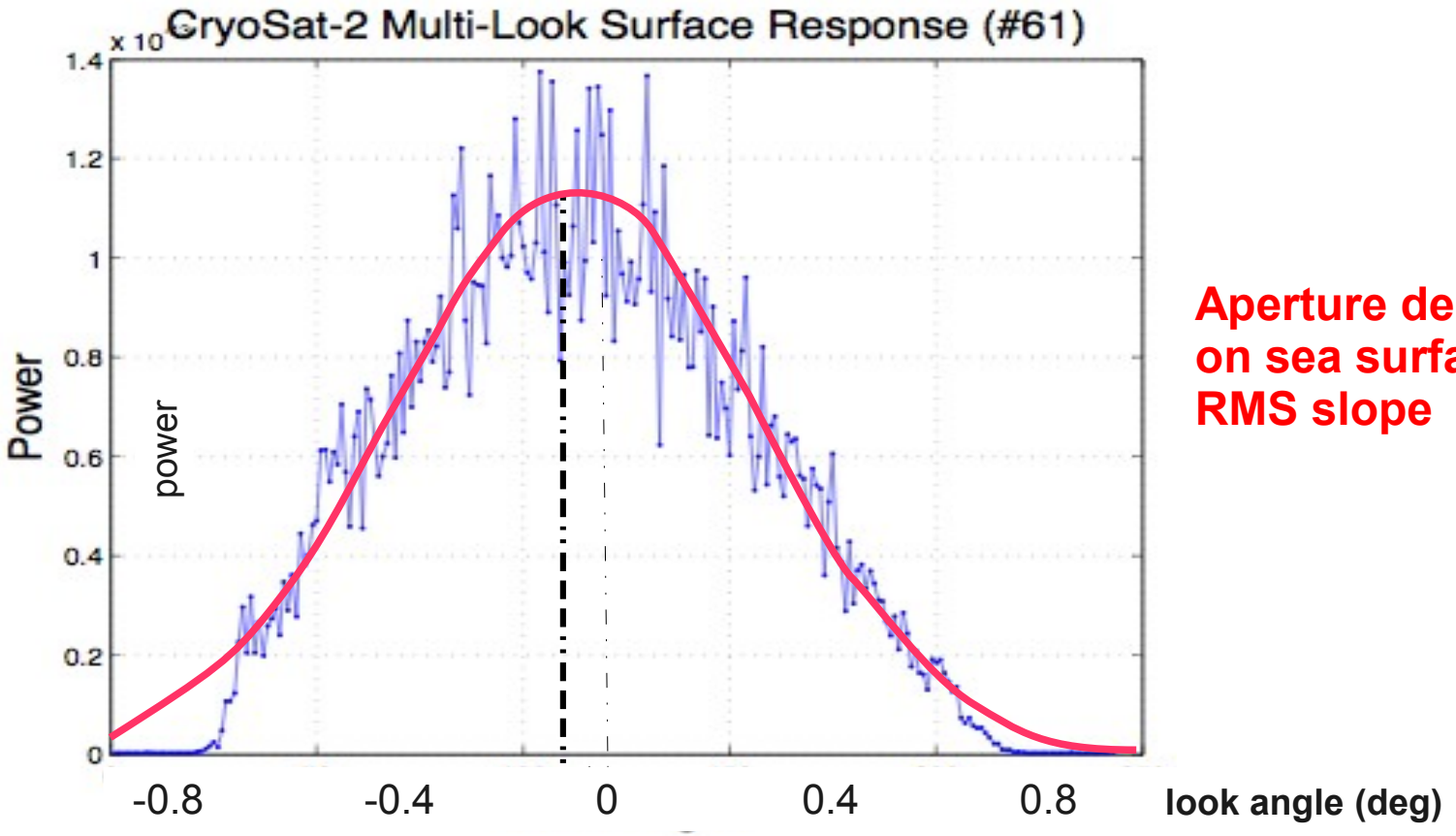


Σ



L1b product

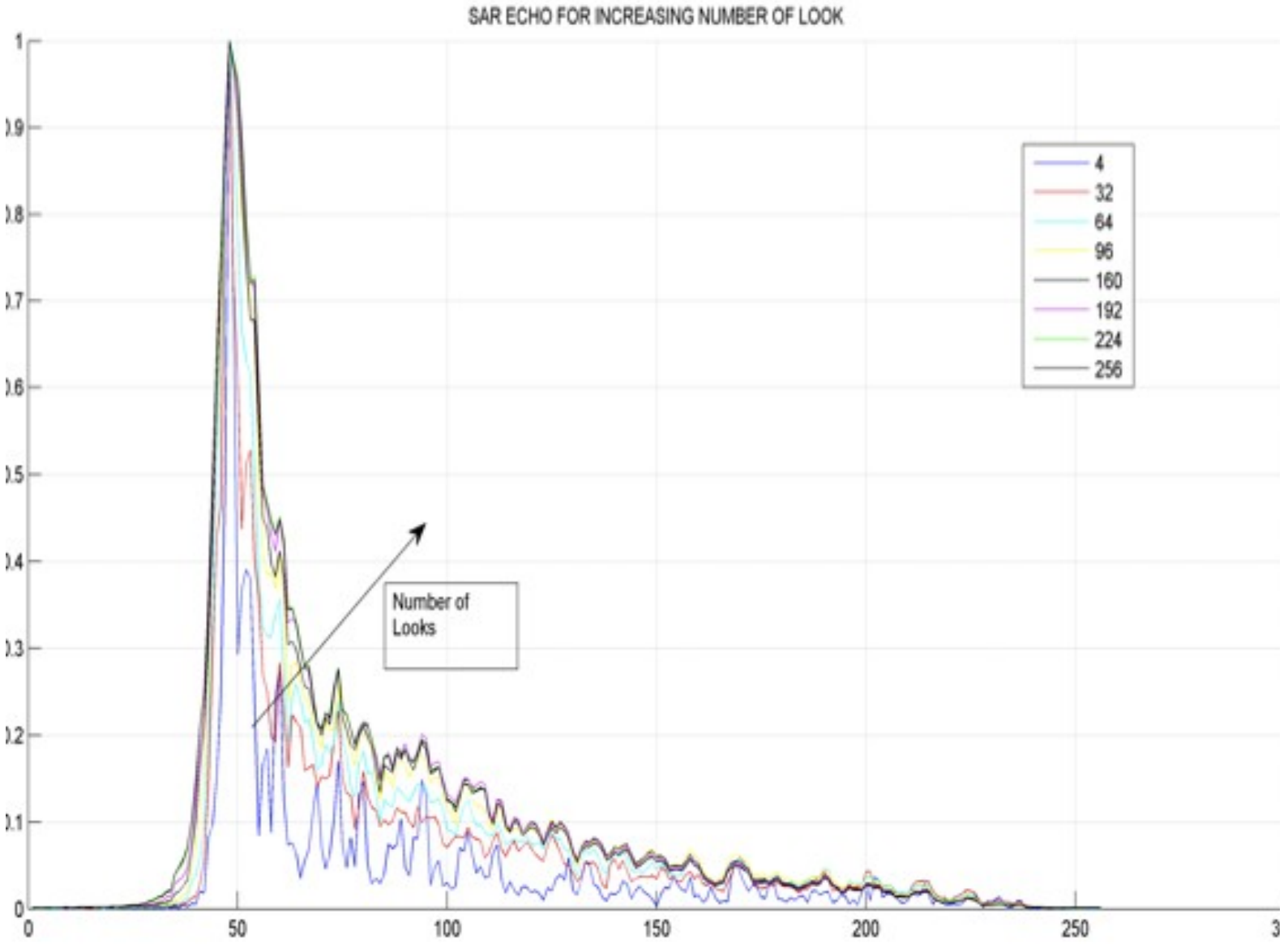
The multi-look: stack look-angles



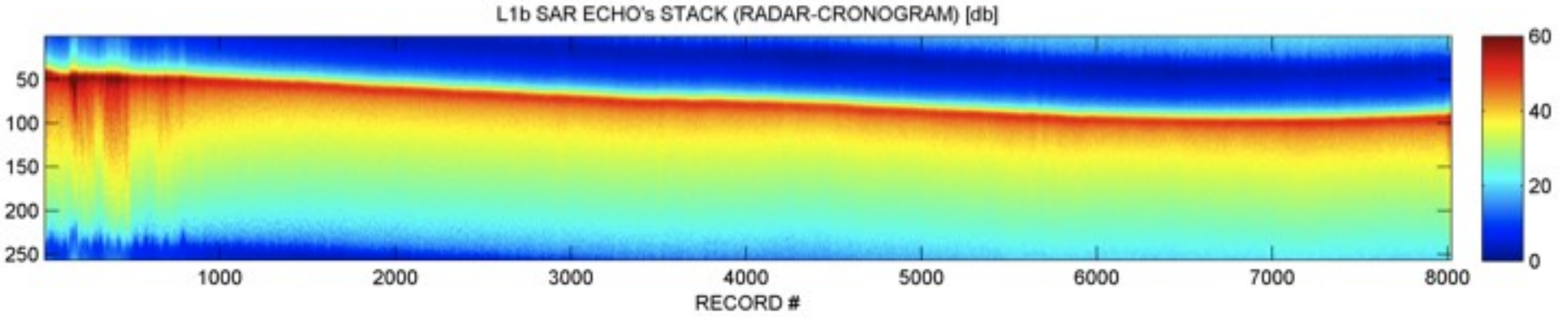
Aperture depending on sea surface RMS slope

Offset depending on pitch mispointing

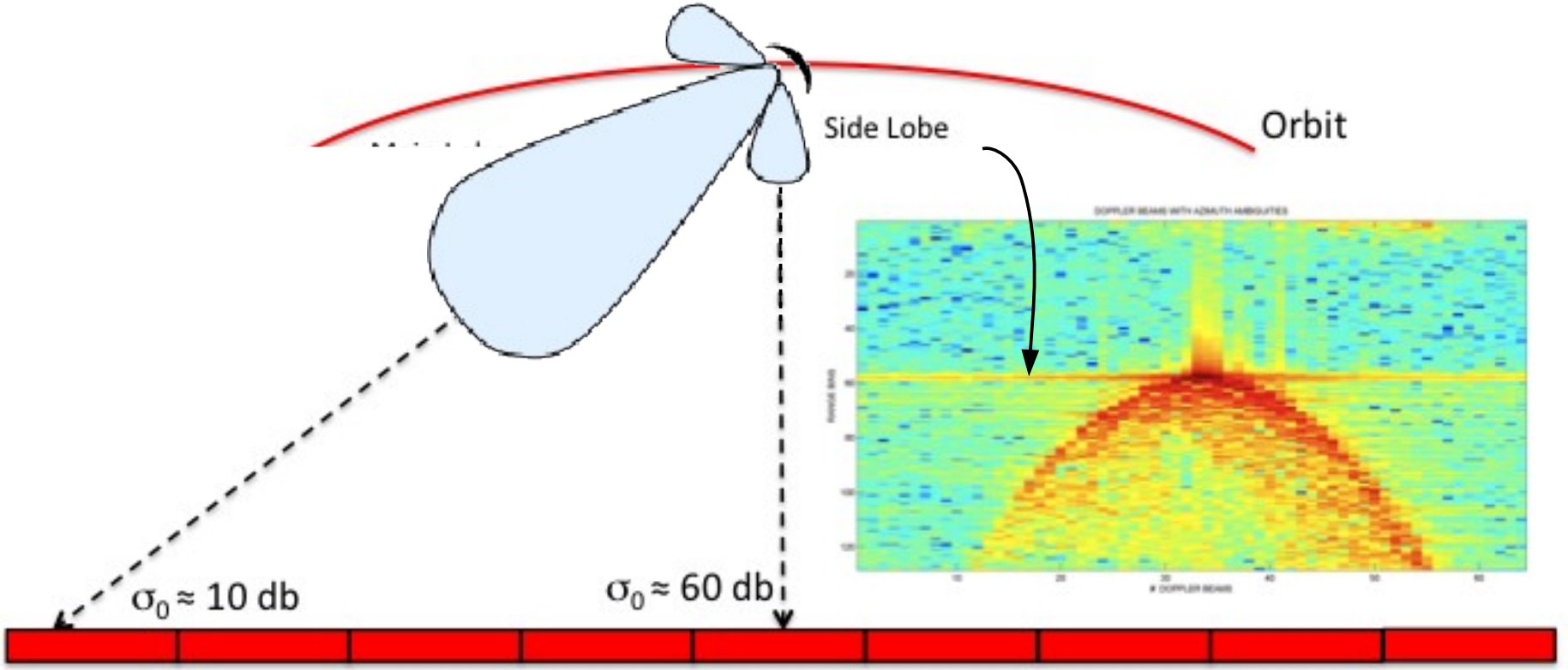
The multi-look: mean WF



Radar chronogram

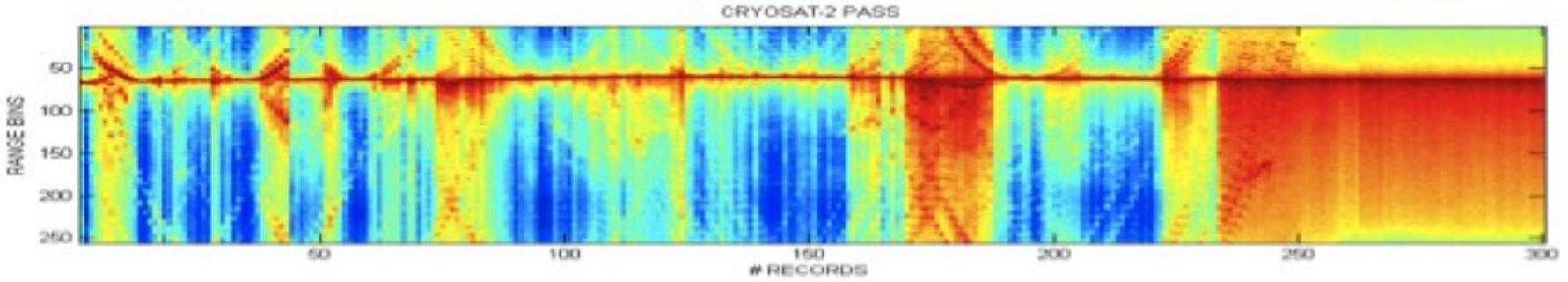


Specular echos

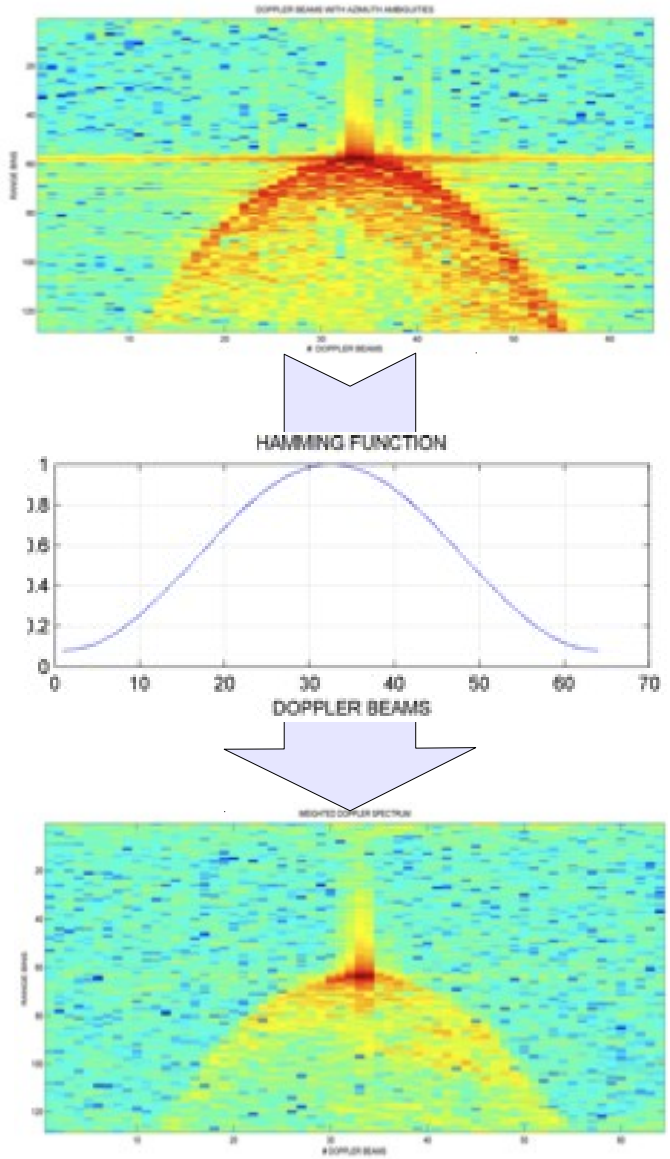


Specular surface (rivers, lakes, coastal still waters)

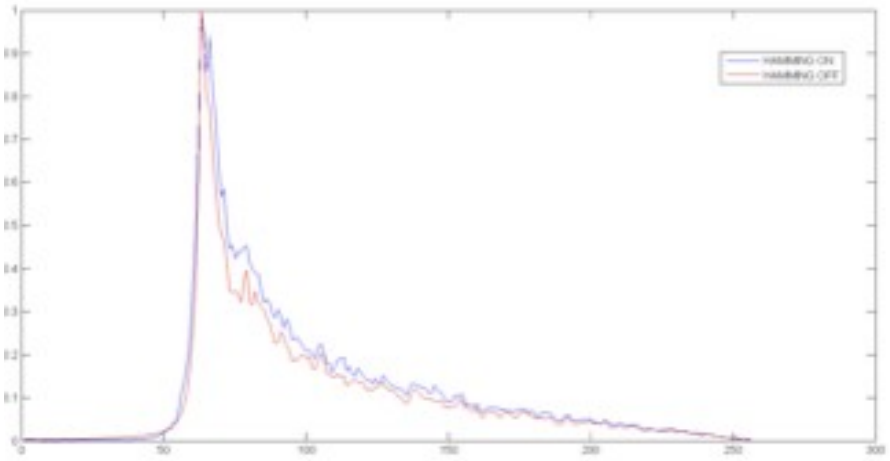
Over the Caspian sea :



Specular echos : Hamming filter



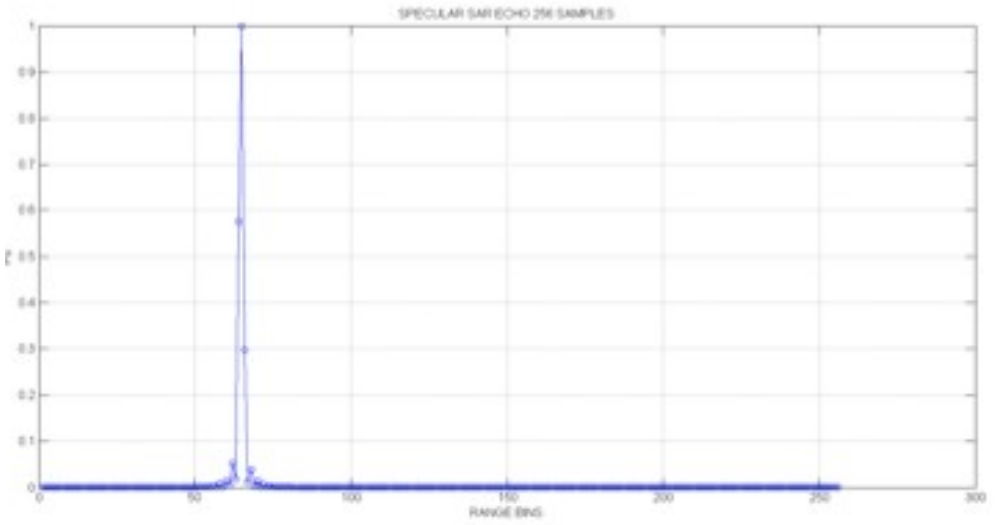
- Systematically applied in ESA products.
- Efficient on cryosphere and hydrosphere (*i.e.*, specular = low RMSS)
- But side effects over open ocean:
  - Degradation of ground cell resolution (450m instead of 300m)
  - Possible bias on SWH
  - Distortion of leading edge
  - Noise and bias in range ?



Retracking

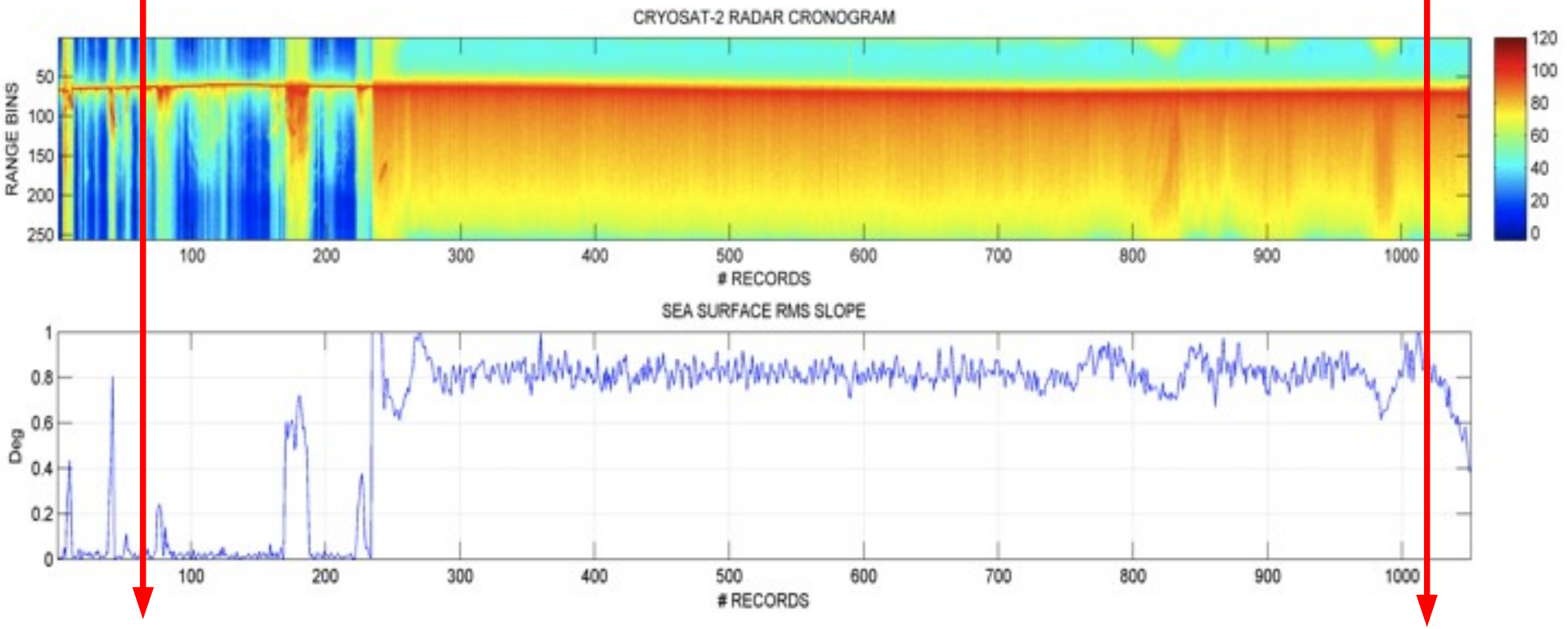
Samosa retracker:

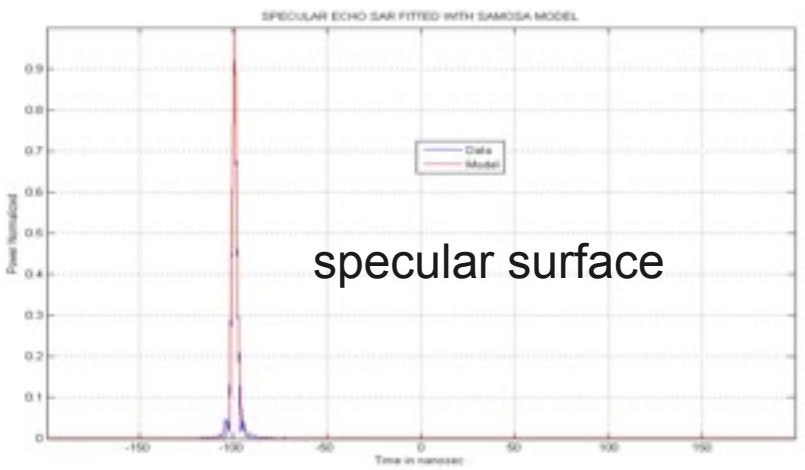
- Double sampling (for specular surface)
- Levenberg Marquardt least square
- f(Sea surface RMS slope)

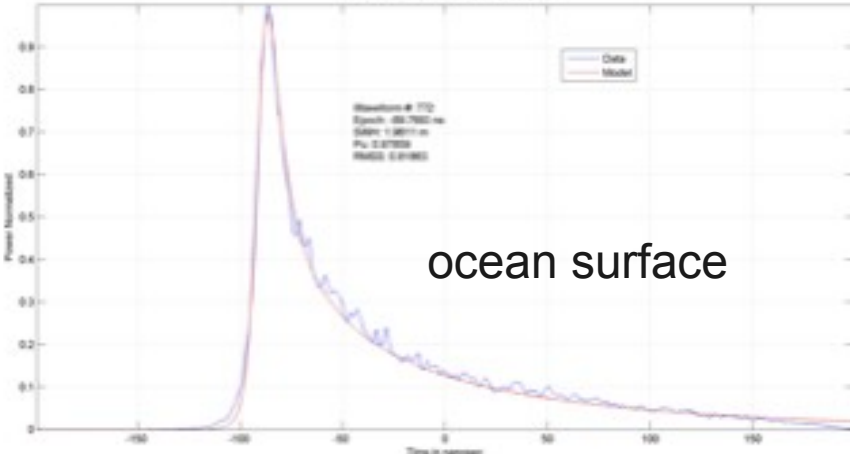


$$P_r^{SAR} = f_{SAMOSA}(t_0, SWH, P_u, RMSS)$$

Retracking

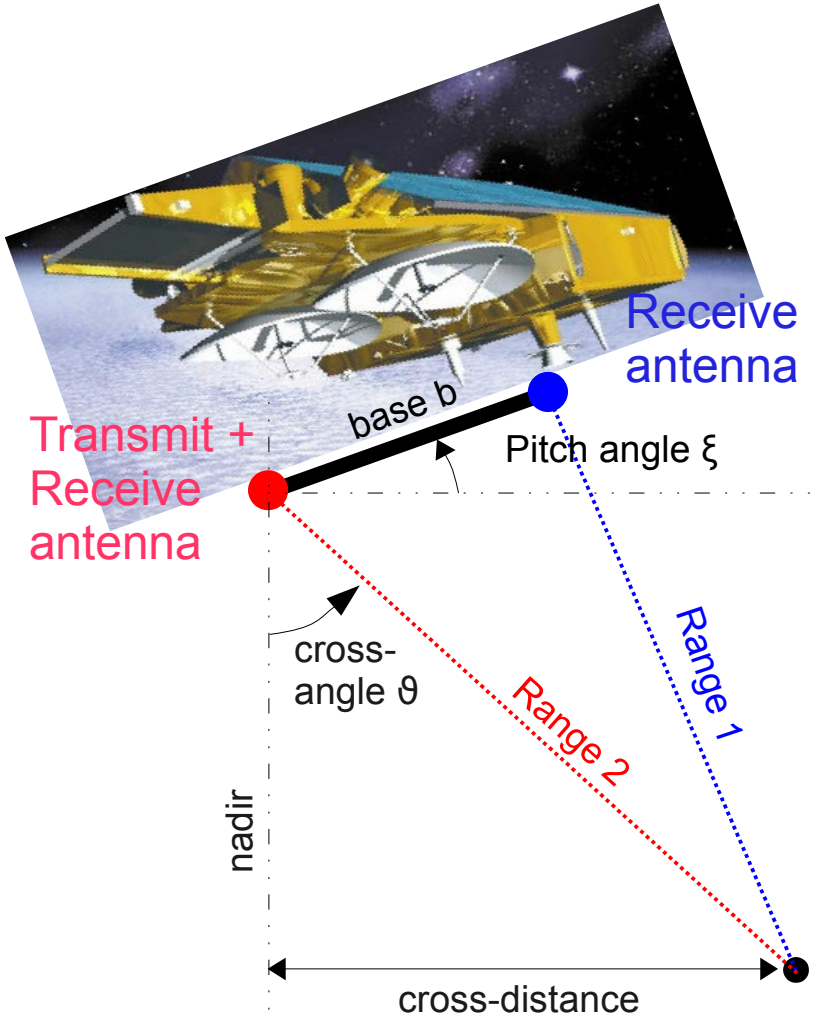

CRYOSAT-2 RADAR CRONOGRAM
RANGE BINS
RECORDS
SEA SURFACE RMS SLOPE
Deg
RECORDS


specular surface


ocean surface

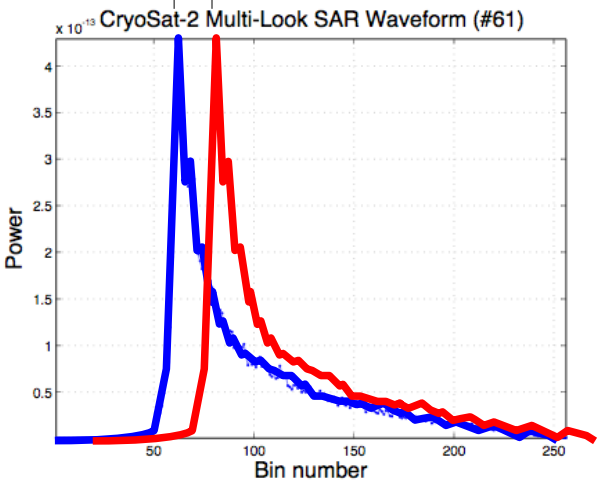
SAR interferometer

Solve right/left ambiguity



Phase shift between the 2 antennas

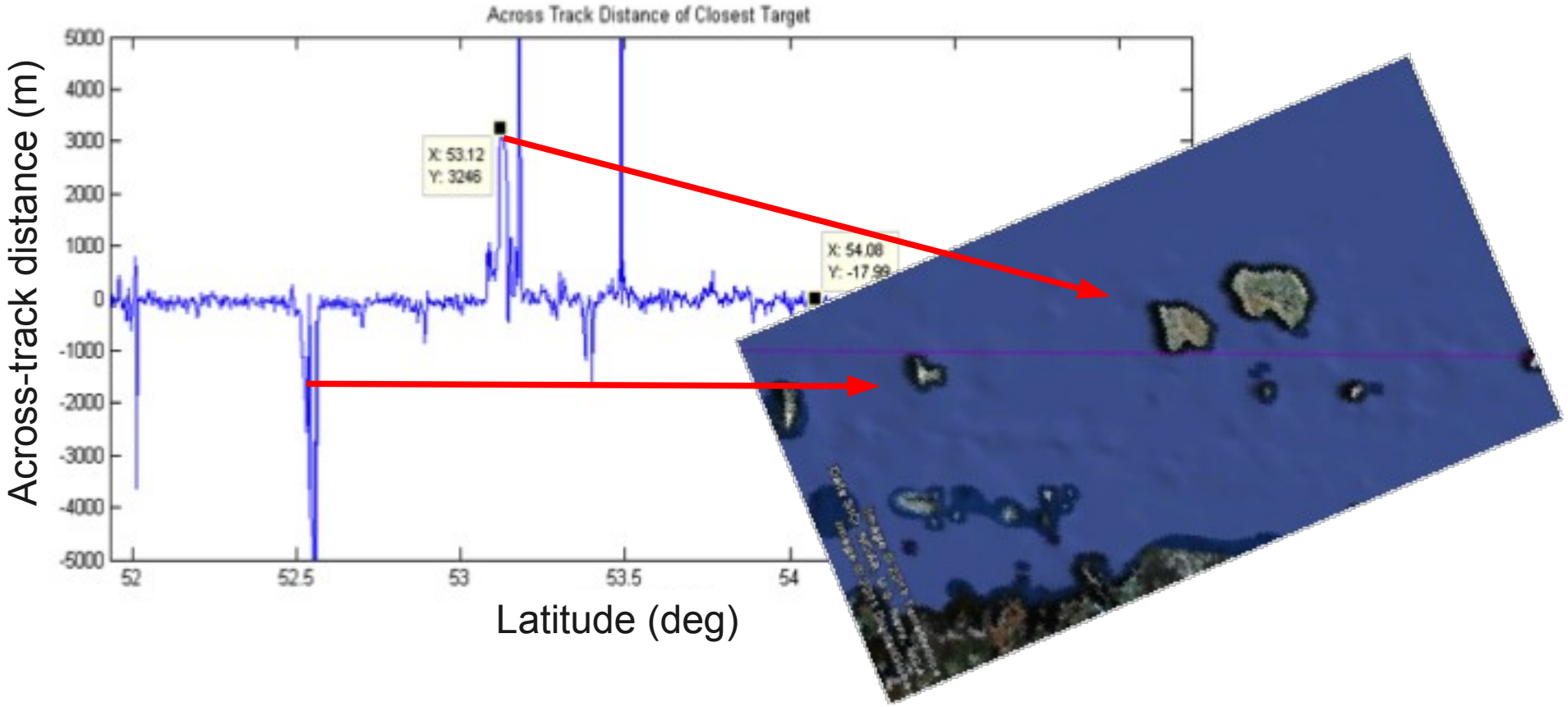
$\Delta\varphi$



$$\vartheta = \xi + \sin^{-1}\left(\frac{\lambda_0 \Delta\Phi(r_{closest})}{2\pi b}\right)$$

SARin

One across-track distance for every retracked range (in L2-intermediate products)



Remark: in L1b product, phase difference available for every waveform bin

Some numerical results (Samosa)

- **SAR range noise** (similar to CPP)
  - over ocean : 1.0 cm (0.8 theoretically)
  - over lakes ~ LRM over ocean
- **SARin range noise** over ocean : 1.8 cm
- **SAR SLA trend** : 1.0 cm over 8,000 km
- **ESA/SAMOSA vs. CNES/CPP :**
  - Retracker: analytic vs. numeric
  - Still some discrepancies to be solved (e.g., delta SSH slopes of 4 cm over 8,000 km)

Plan

1. Cryosat2 mission
2. An introductive example
3. SAR/SARin principles
4. **Synthesis and products**
5. Examples over various surfaces
6. Conclusion

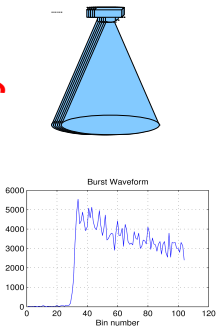
Product Levels

1Hz-20hz products

L0 / FBR | **L1b** | **L2 / L2I**

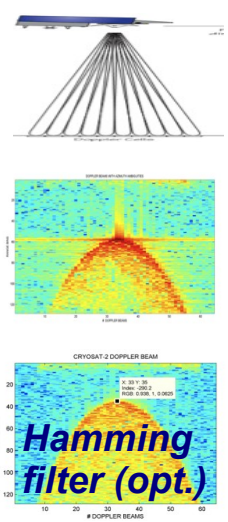
SAR mode

Telemetry



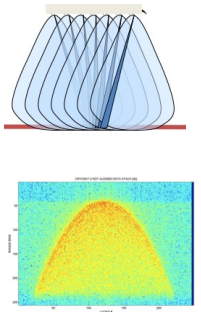
Bursts
64 echoes
Brown WF(I,φ)

SAR coherent sum



Doppler Beams
SAR WF(I)

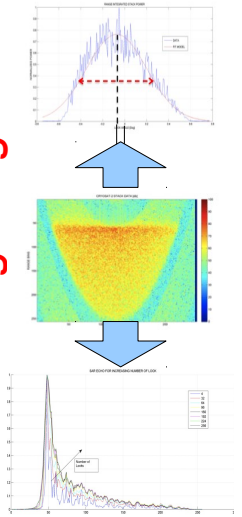
Merge SAR echoes



Multi-look

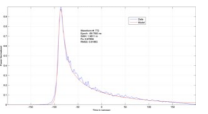
Stack (1/2)
256 ground cell views

Range migration



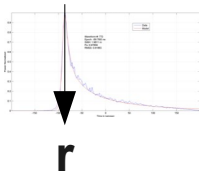
Stack (2/2)
256 ground cell views

Mean waveform



Waveforms
128 samples

SAR Retracking



Range

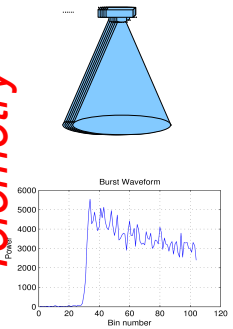
Product Levels

1Hz-20hz products

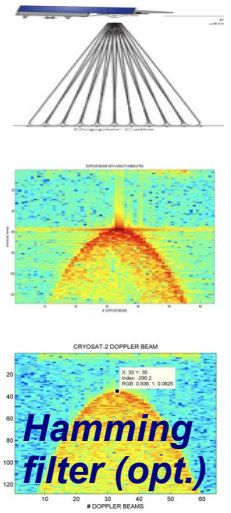
L0 / FBR | **L1b** | **L2 / L2I**

SAR mode

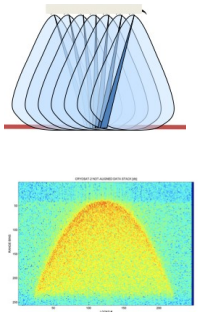
Telemetry



SAR coherent sum

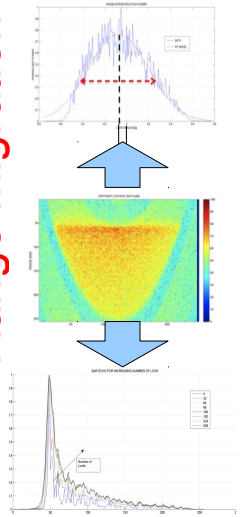


Merge SAR echoes

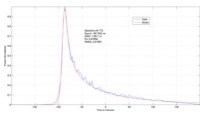


Multi-look

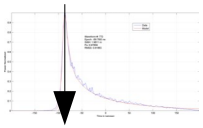
Range migration



Mean waveform



SAR Retracking



r

Bursts
64 echoes
Brown WF(I,φ)

Doppler Beams
SAR WF(I)

Stack (1/2)
256 ground cell views

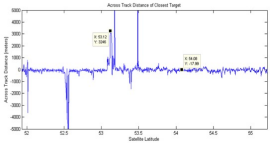
Stack (2/2)
256 ground cell views

Waveforms
128 samples

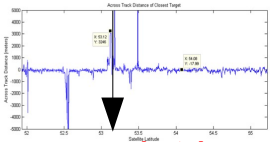
Range

SARin mode

...the "same" for 2 channels...
two reception antennas,
64 look angles instead of 256



Waveforms & Phase diff.
2×512 samples each



α,lat,lon

Cross-track Angle / Coords
(retracked bin, L2I only)

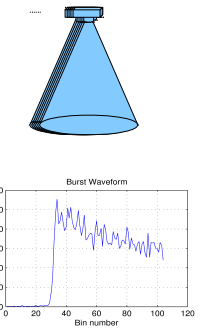
Product Levels

SAR mode

SARin mode

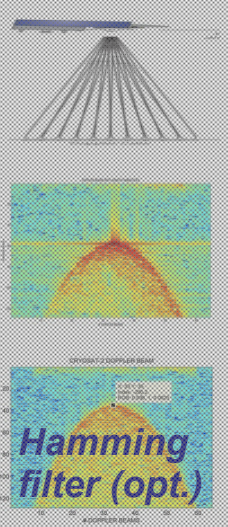
L0 / FBR

Telemetry



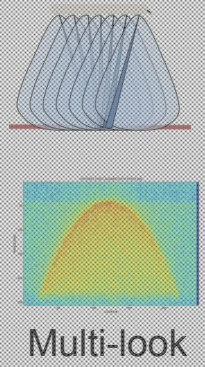
Bursts
64 echoes
Brown WF(I,φ)

SAR coherent sum



Doppler Beams
SAR WF(I)

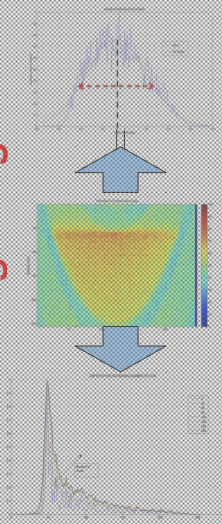
Merge SAR echoes



Multi-look

Stack (1/2)
256 ground cell views

Range migration

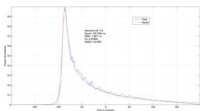


Stack (2/2)
256 ground cell views

1Hz-20hz products

L1b

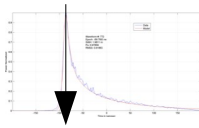
Mean waveform



Waveforms
128 samples

L2 / L2I

SAR Retracking



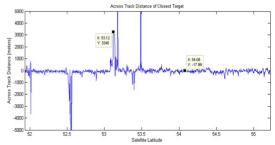
r

Range

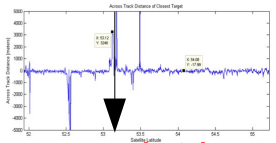
...the same for 2 channels...
(two reception antennas)

Intermediate stack
2×64 ground cell views

Stacks of
2×64 ground cell views



Waveforms & Phase diff.
2×512 samples each



α,lat,lon

Cross-track Angle / Coords
(retracked bin, L2I only)

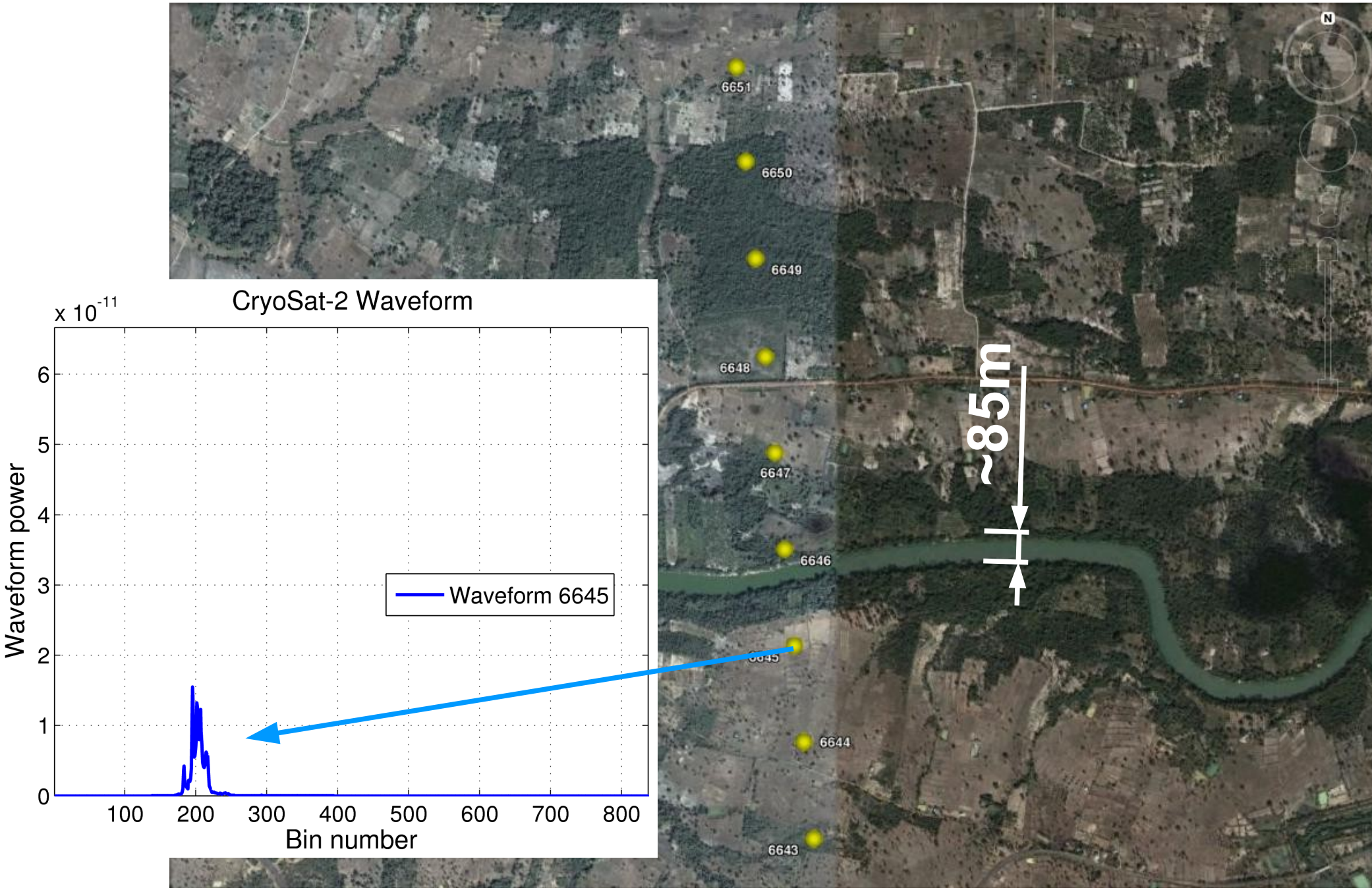
Distribution / Availability

		Input	Modes				20Hz	Dedicated Surface	Coverage	Output	Access	Remark
			LRM	P-LRM	SAR	SARin						
ESA/Kiruna		L0	✓	✓	✓	✓	✓	ice (Hamming)	global	FBR, L1b L2, L2I	Registration	Baseline A Too buggy !
	2013	L0	✓	✓			✓	ocean	global	IOP GPO	Registration	data from 07/2013 only
NOAA/RADS		L1b	✓	✓				ocean	~global	L2	Public	No data Over land ?
CNES/CPP		L0	✓	✓	✓		✓	ocean	global	range	No	
	2013	FBR			✓		✓	ocean	global	L2	TBD	
AVISO/DUACS		CPP	✓	✓			?	ocean	ocean	SLA	Public	
ESRIN/Samosa (proto Sentinel3)		FBR	✓		✓	✓	✓	~all	on demand	L1b/L2, Stacks	✈ Go to Frascati!	samples only

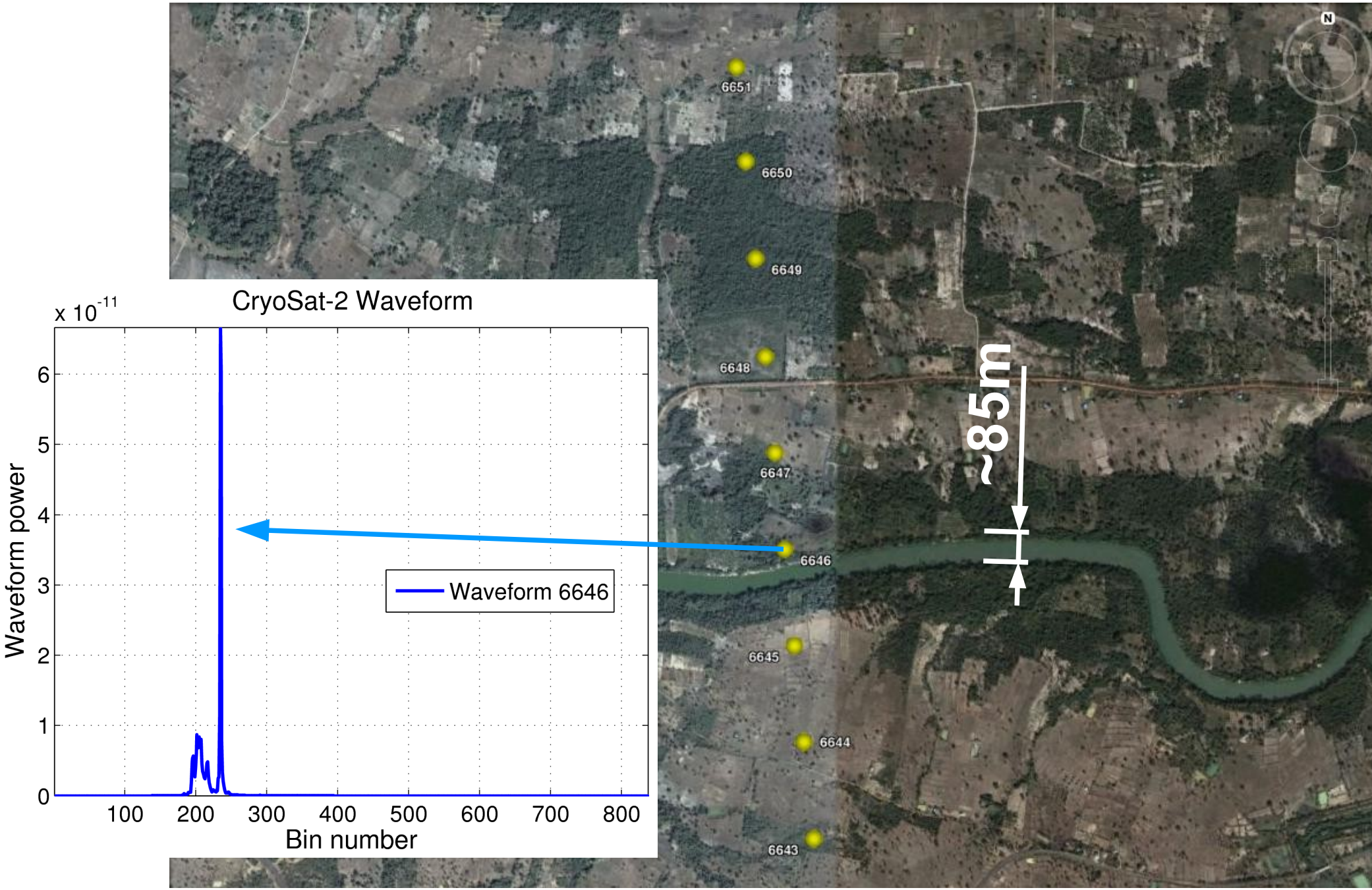
The use of the stacks...

Spotlight : focusing the SAR beams

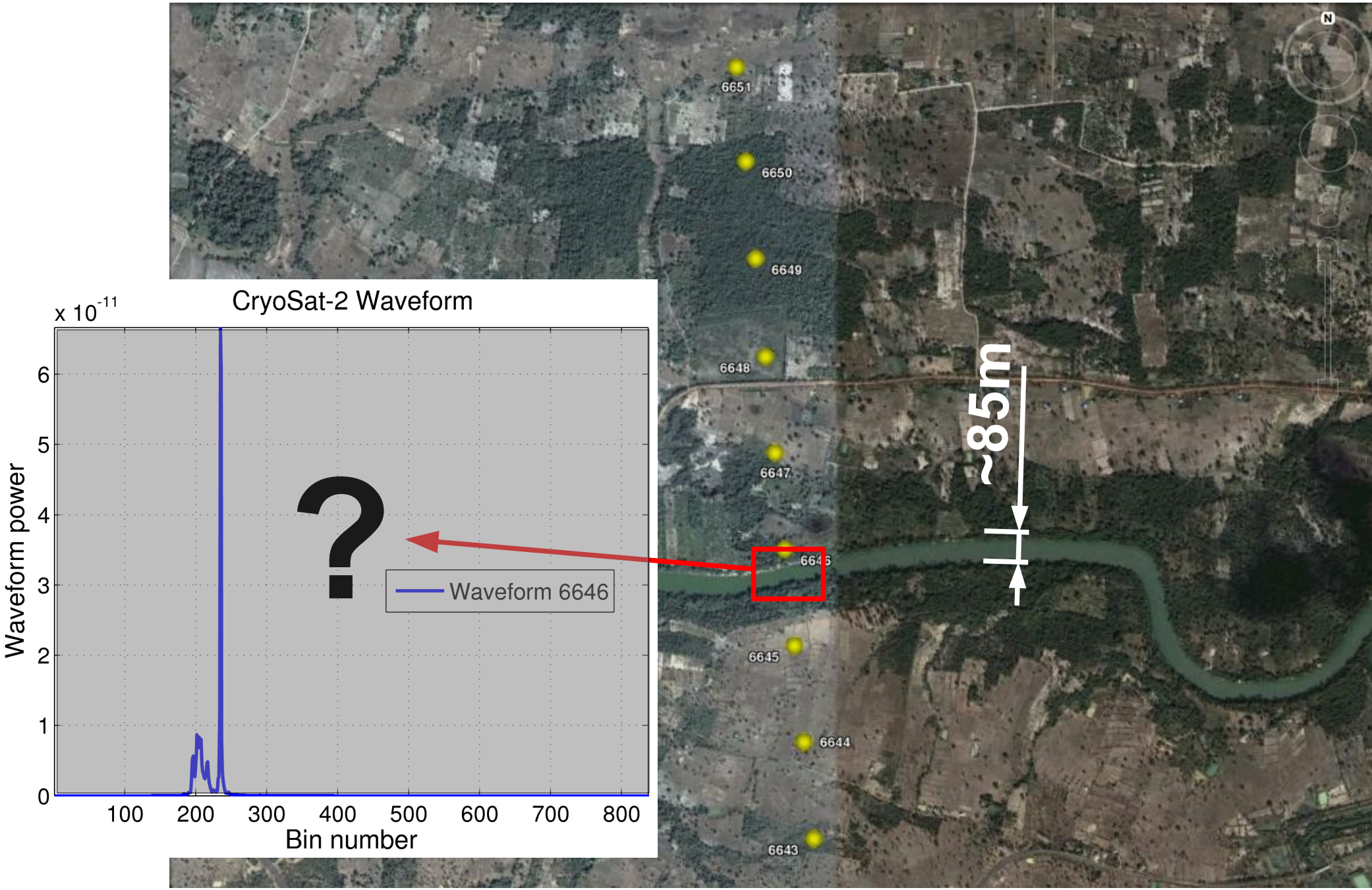
Spotlight : focusing the SAR beams



Spotlight : focusing the SAR beams

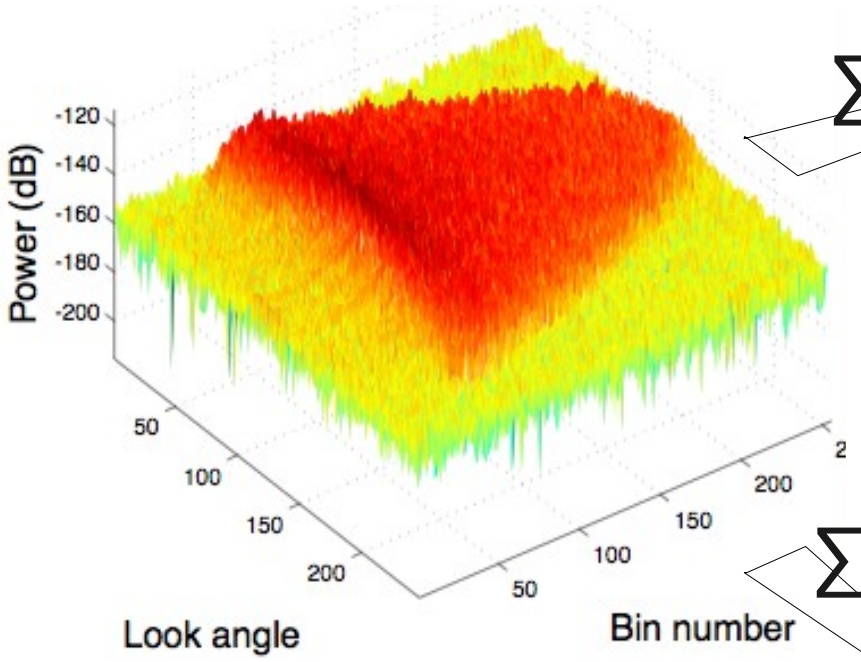


Spotlight : focusing the SAR beams

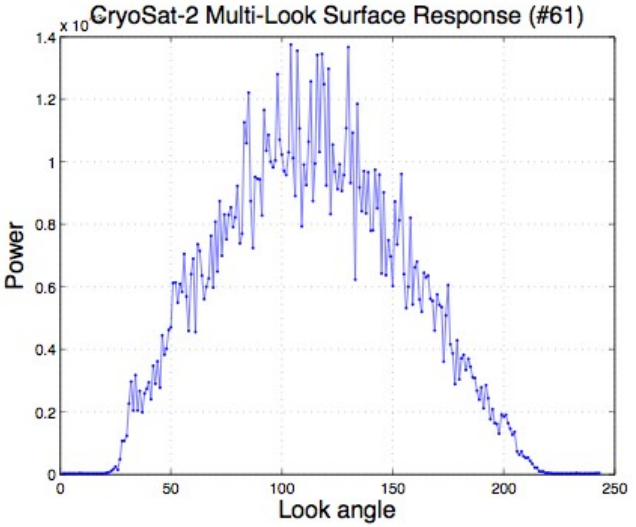


Spotlight : focusing the SAR beams

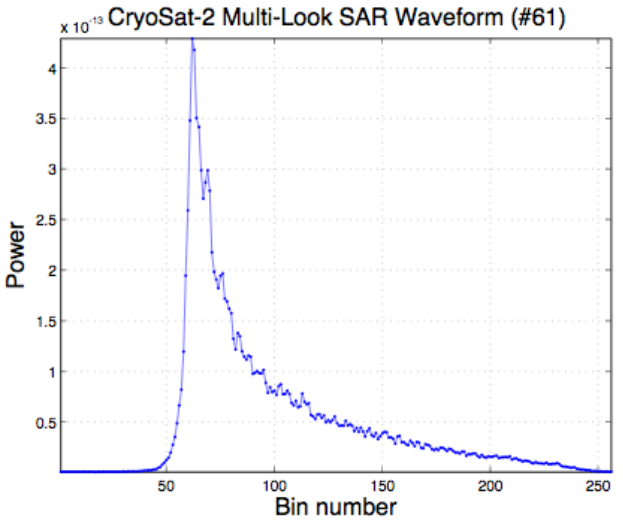
Applications of the stacks...



Σ

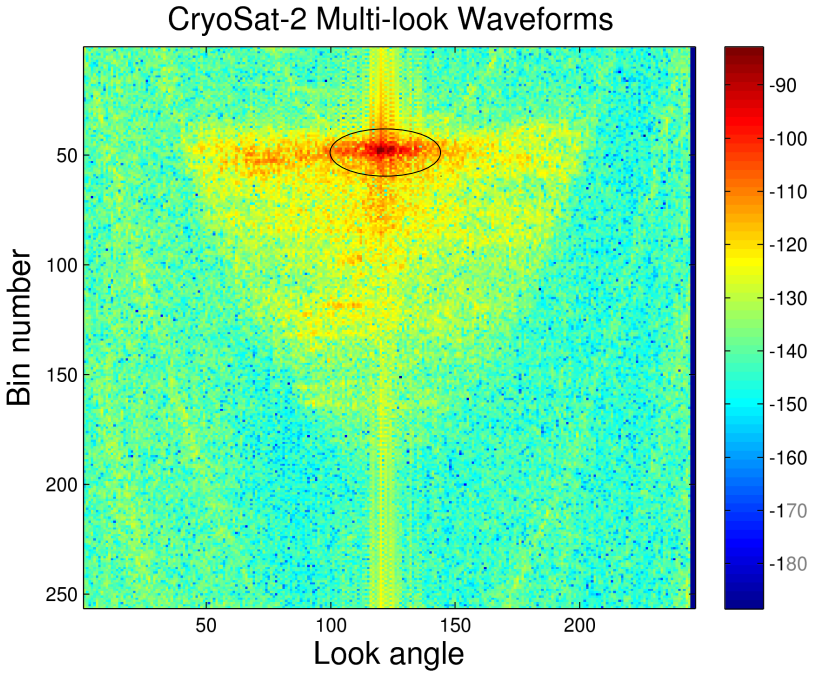


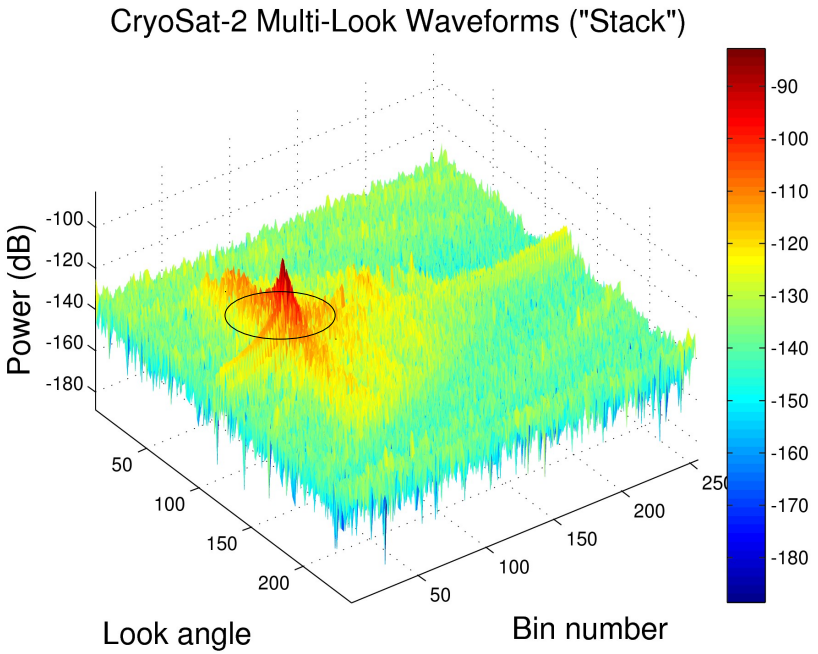
Σ



L1b product

Stack: mean waveform

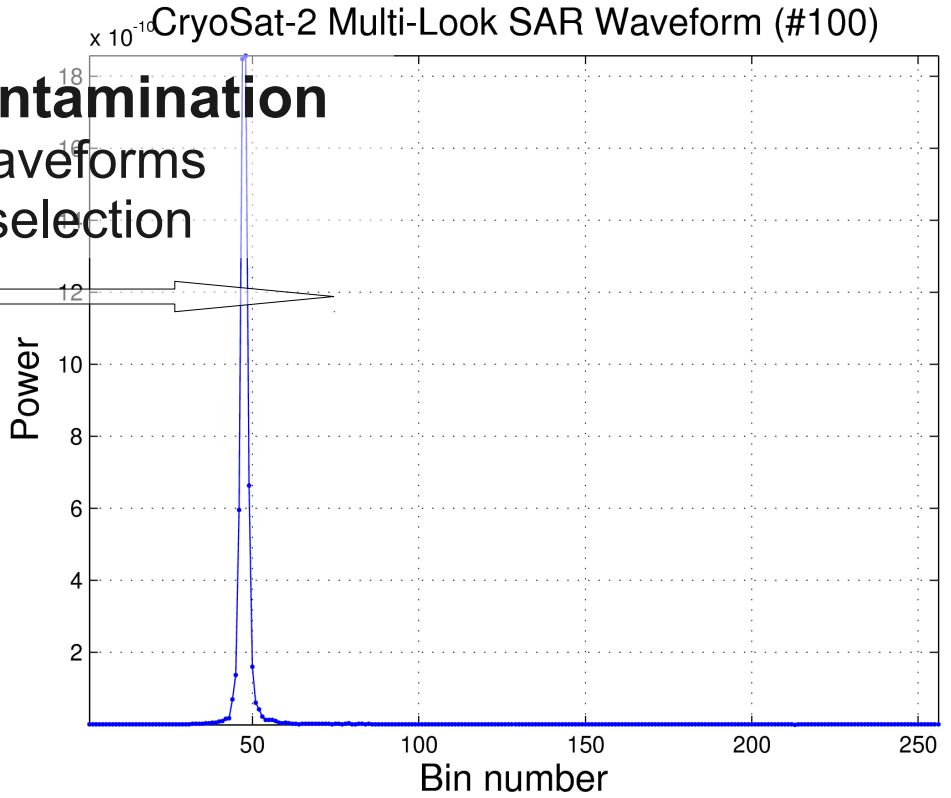




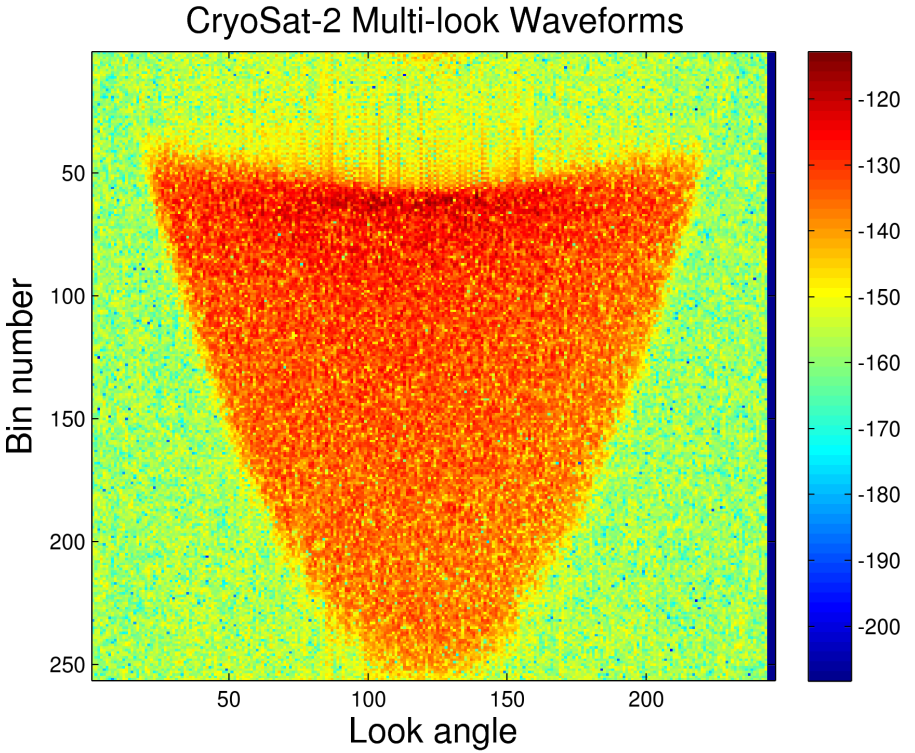
Land decontamination

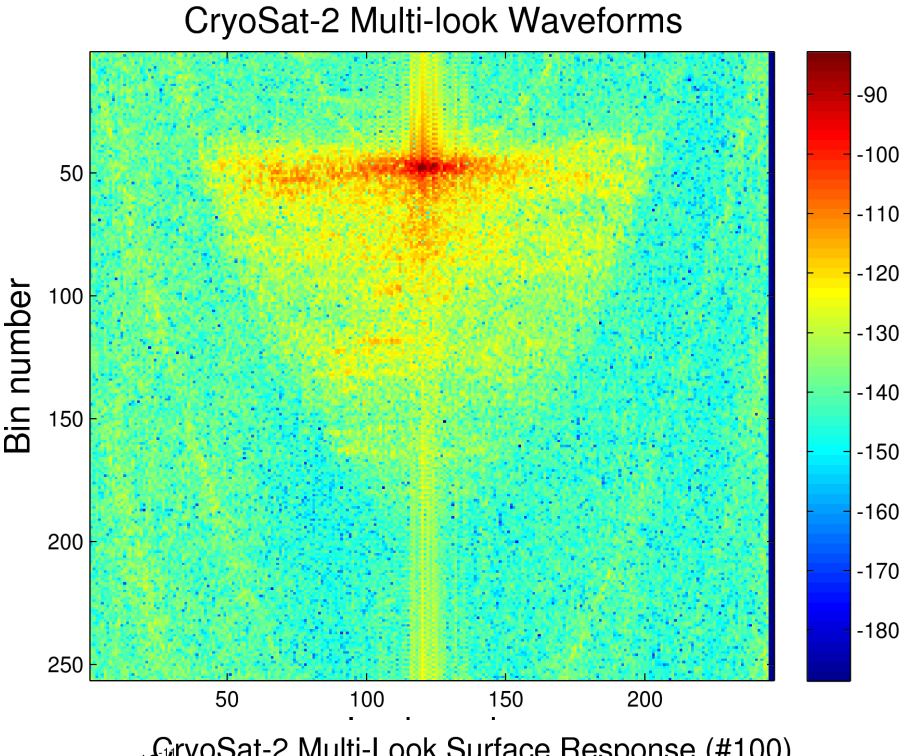
SAR waveforms

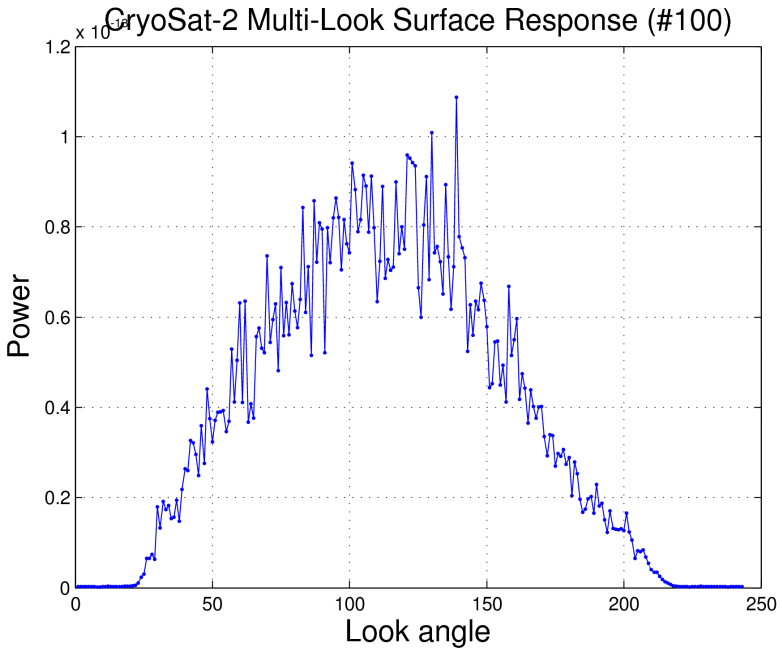
Index selection

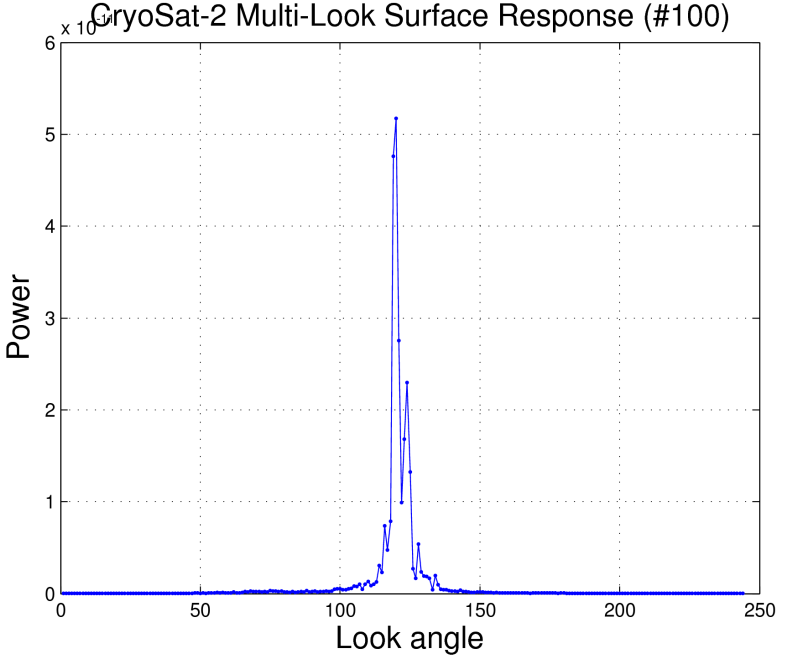


Stack: surface roughness









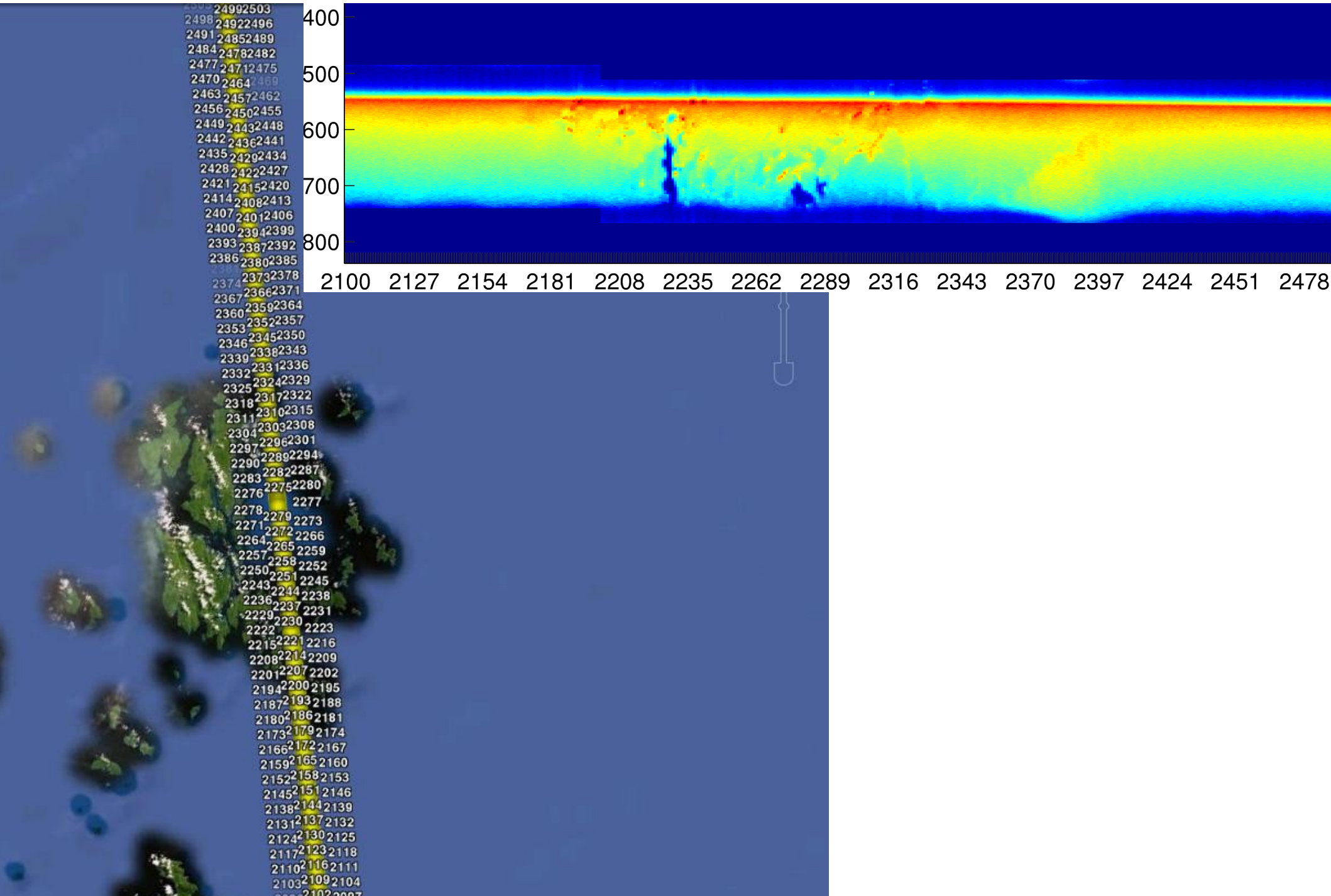
VIDEO...

Plan

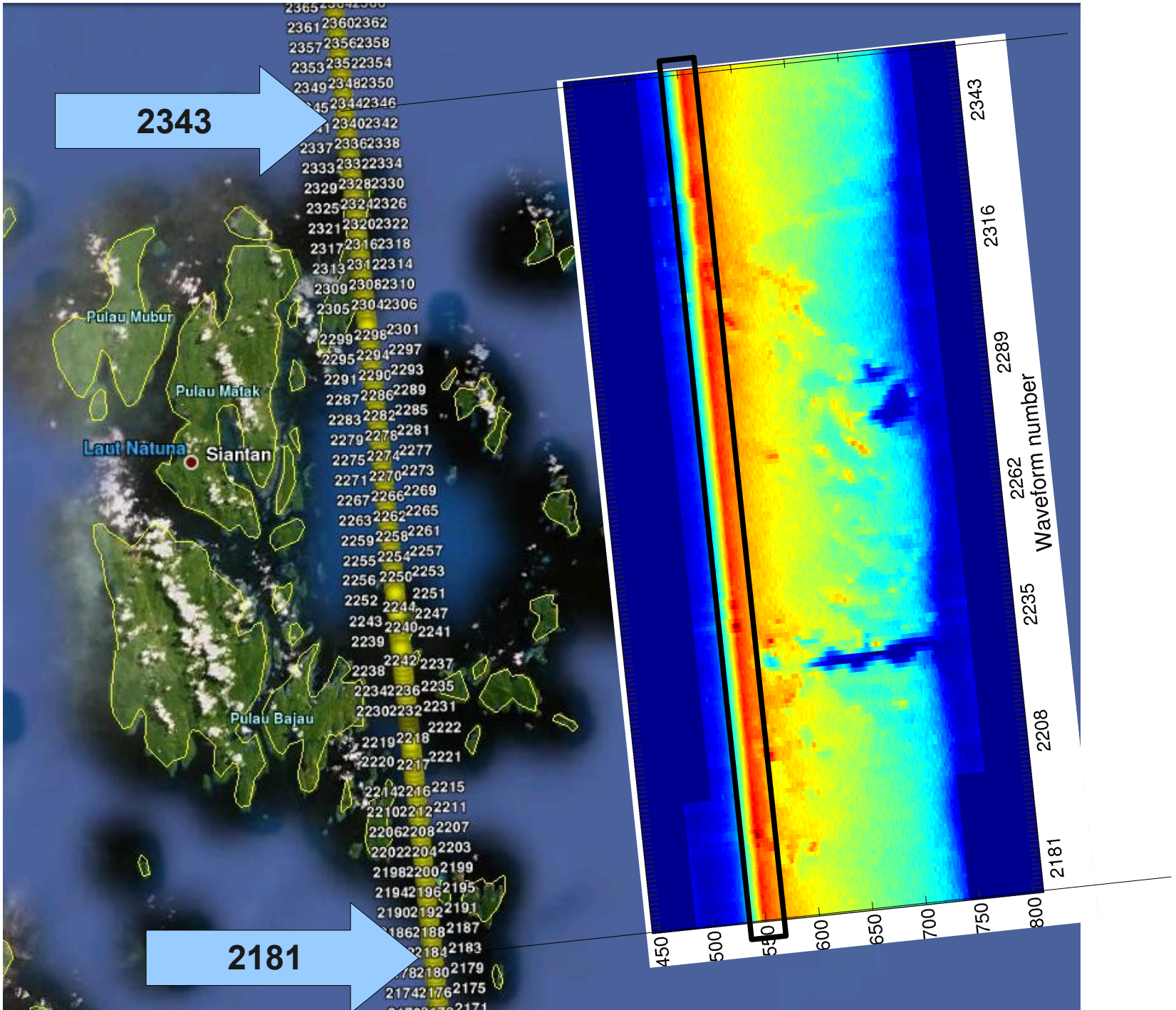
1. Cryosat2 mission
2. An introductive example
3. SAR/SARin principles
4. Synthesis and products
5. **Examples over various surfaces**
6. Conclusion

SAR mode over Ocean / Islands

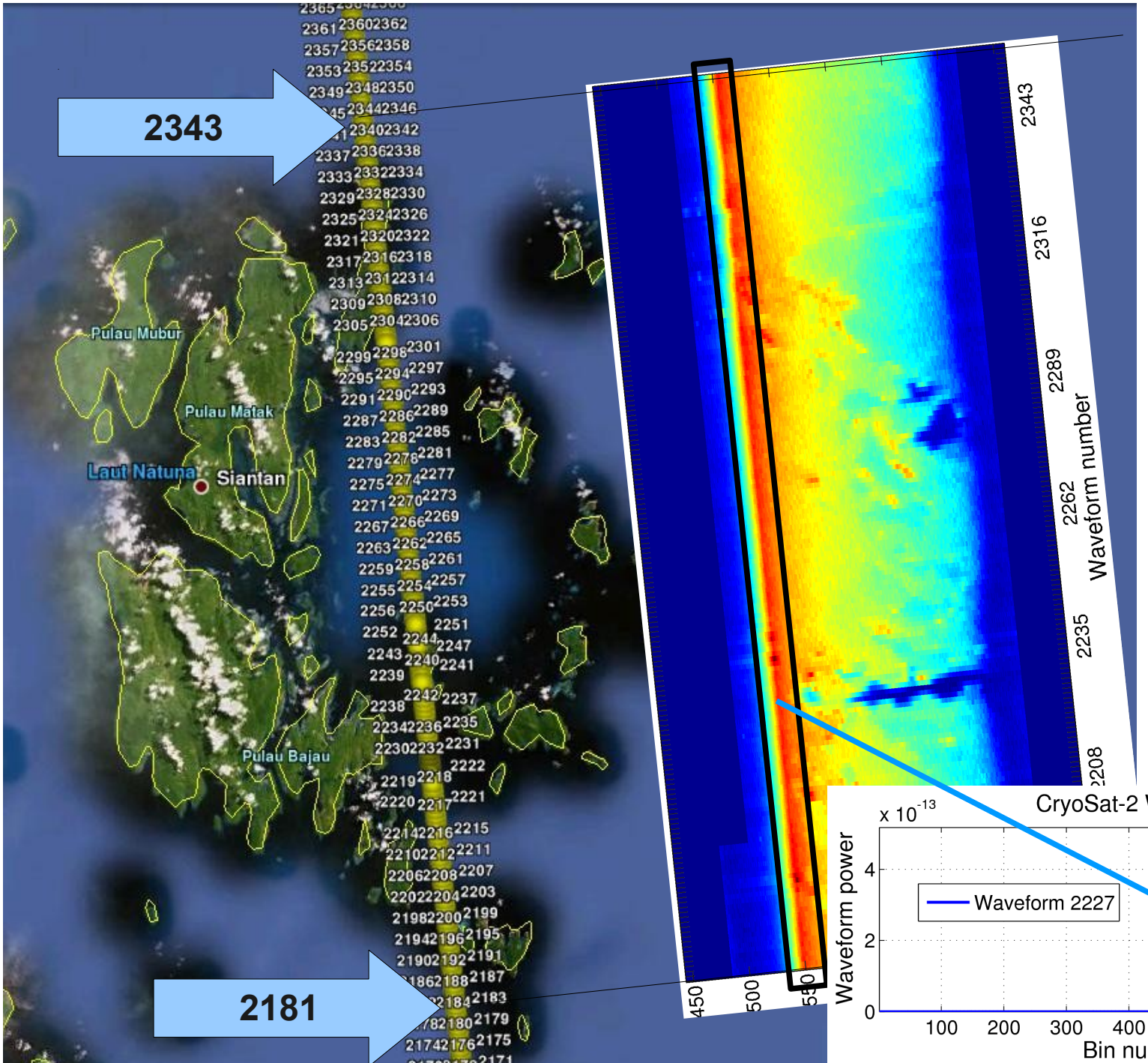
SAR mode over Ocean / Islands



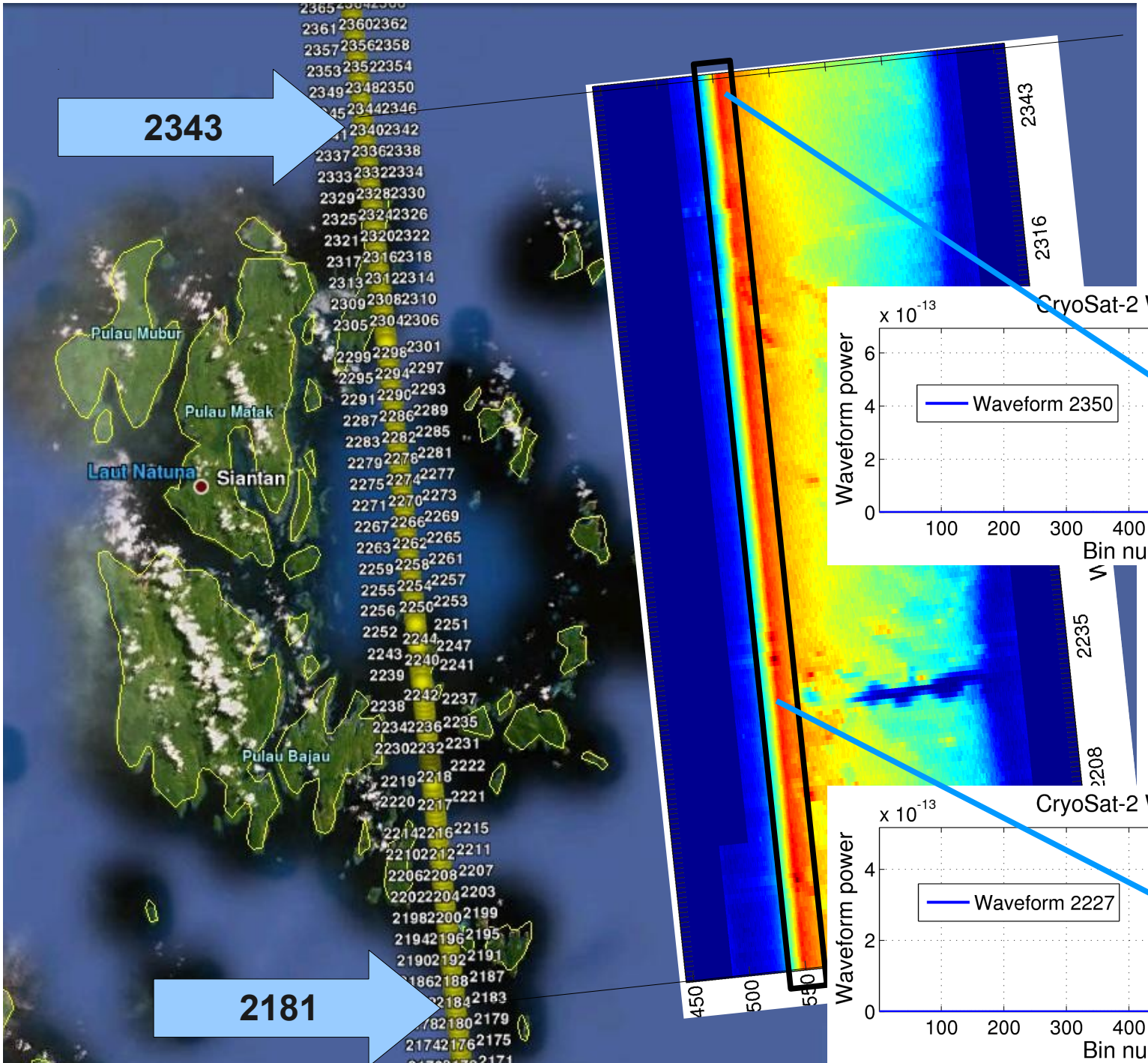
SAR mode over Ocean / Islands



SAR mode over Ocean / Islands

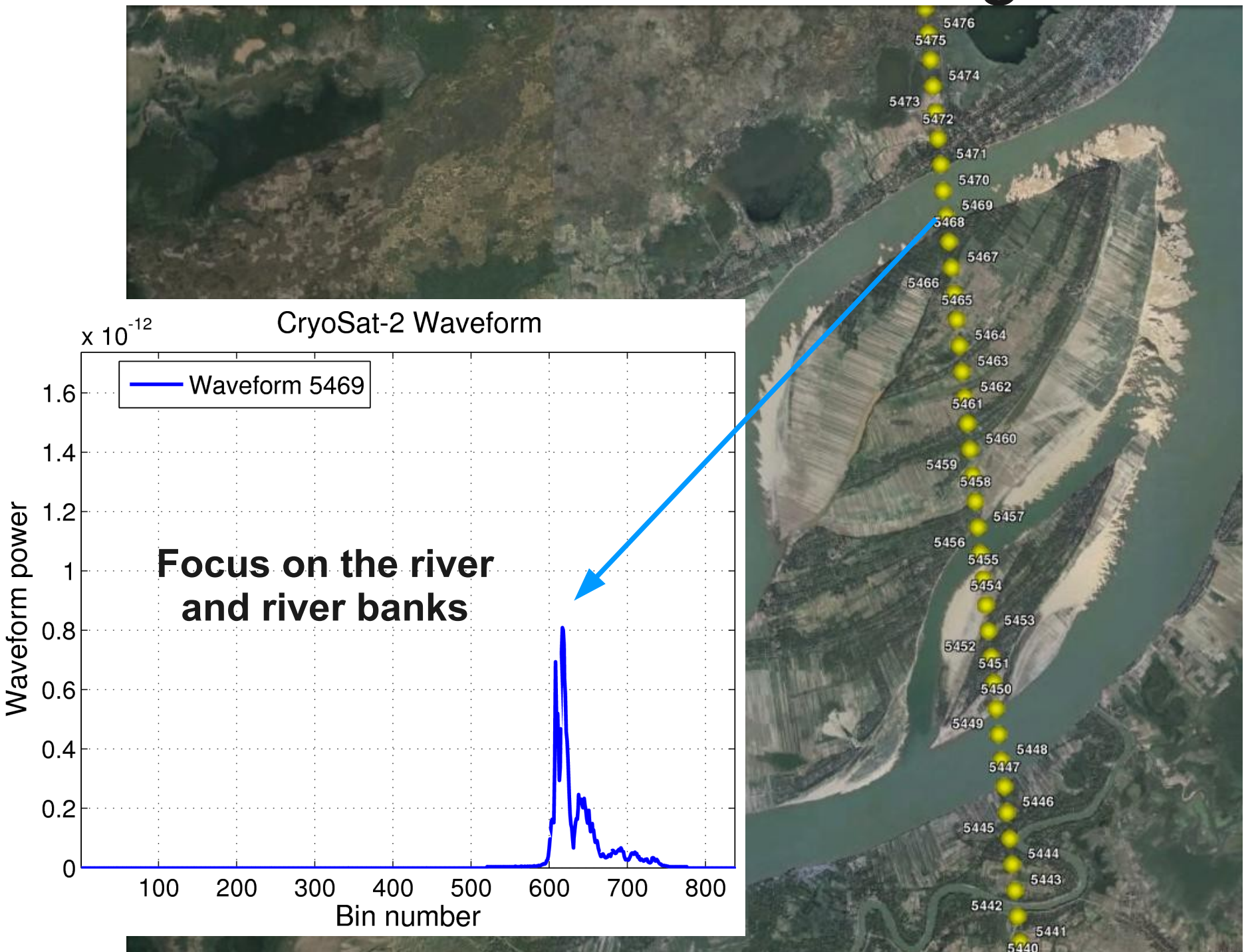


SAR mode over Ocean / Islands

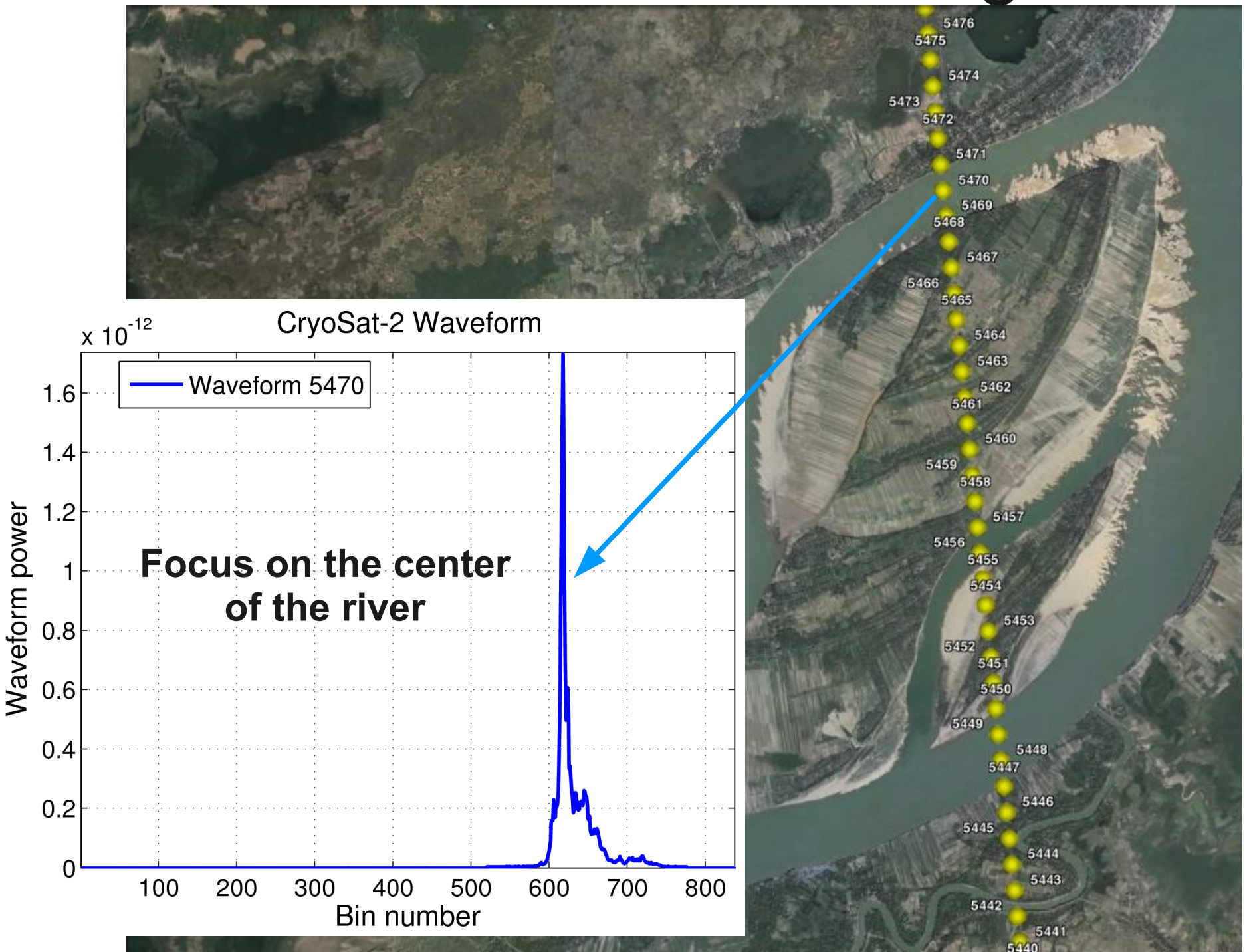


SAR mode over Mekong river

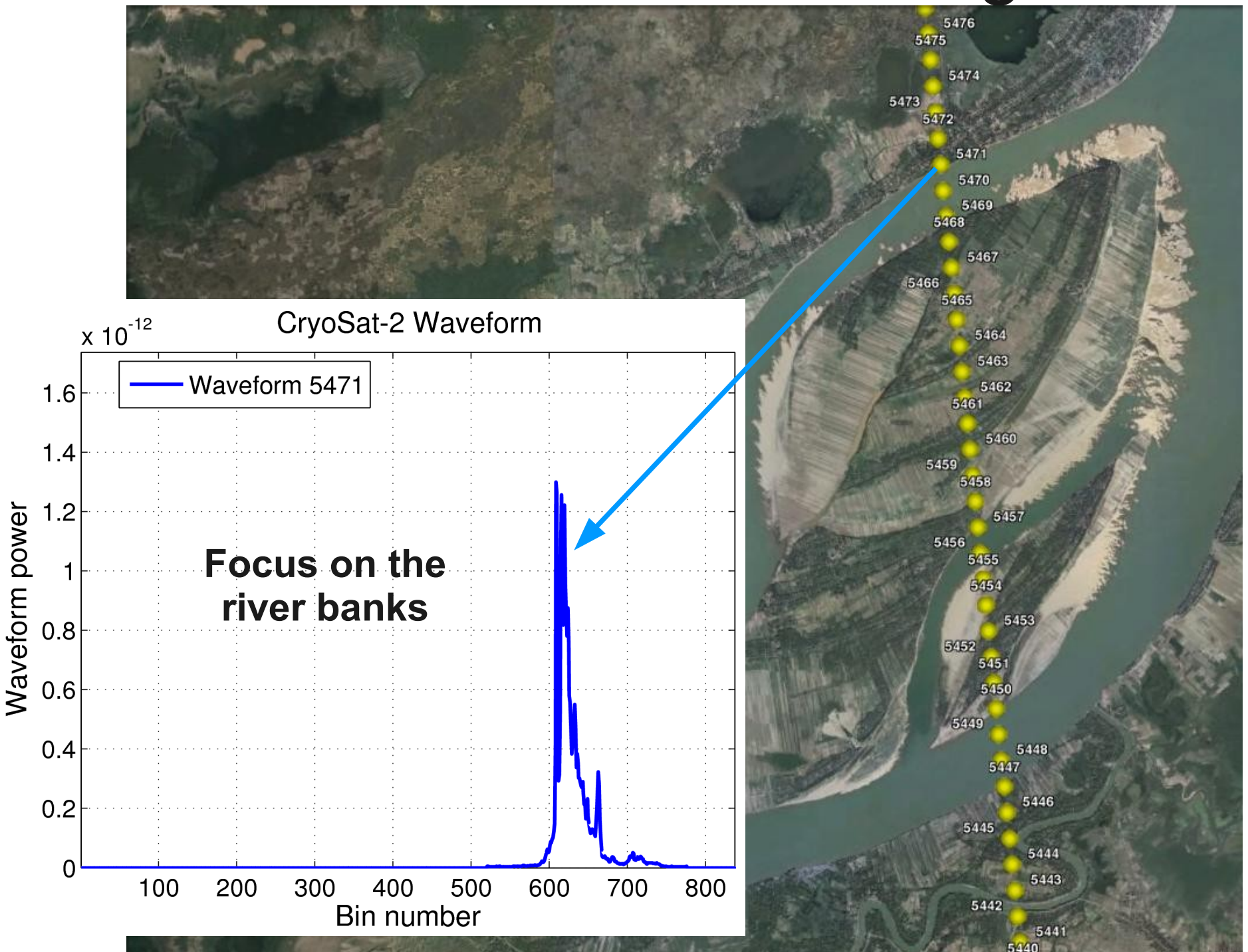
SAR mode over Mekong river



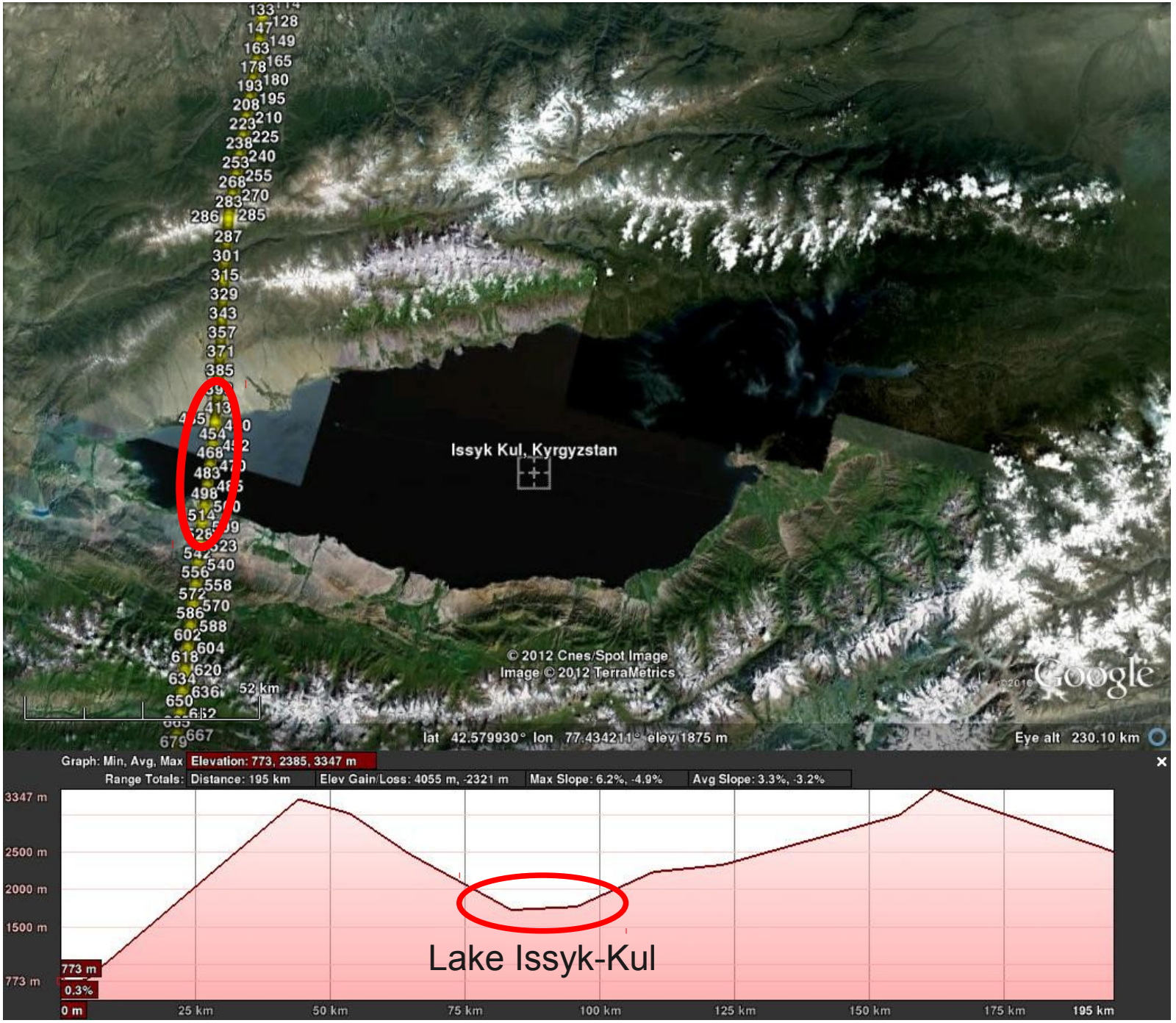
SAR mode over Mekong river



SAR mode over Mekong river

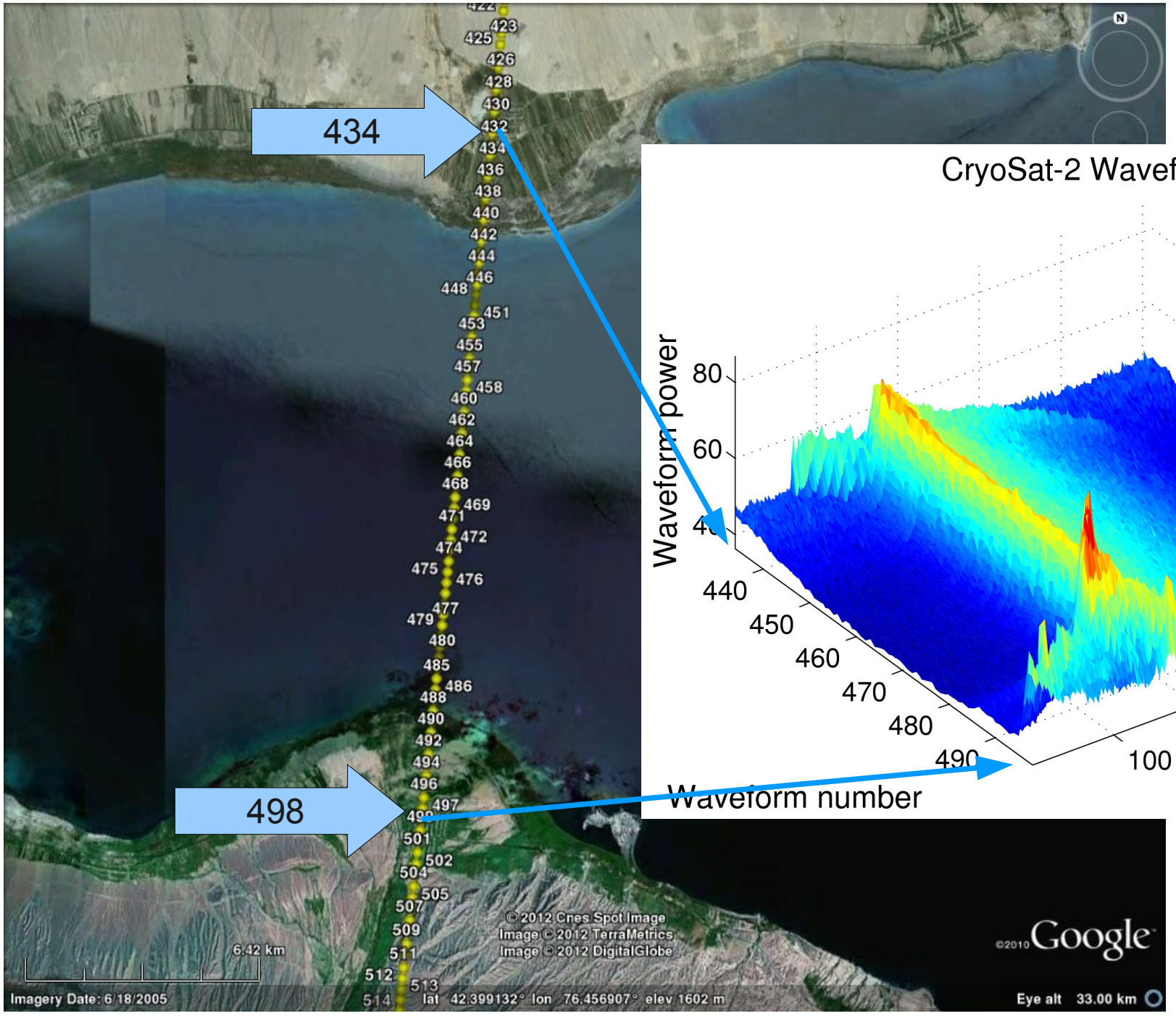


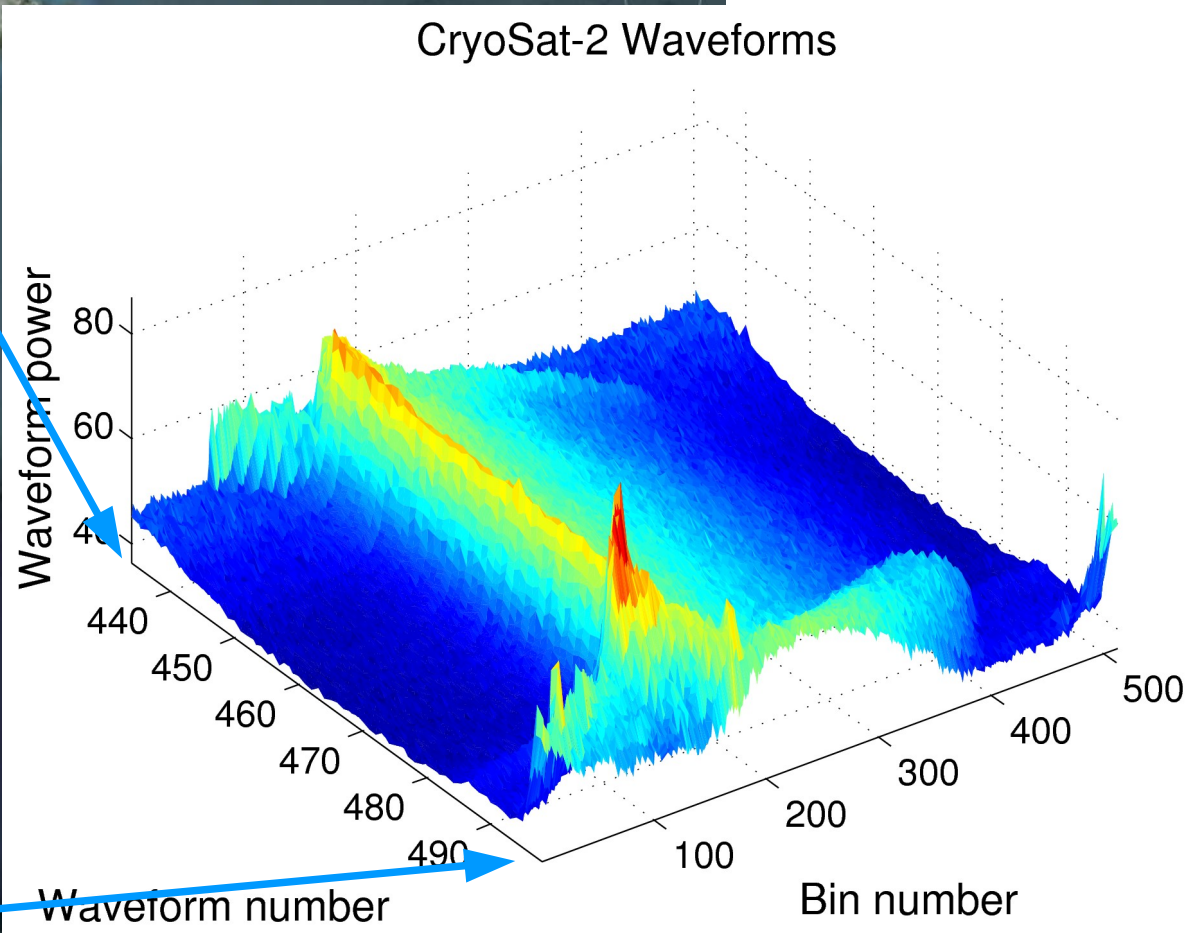
SARin mode over Lake Issyk-Kul



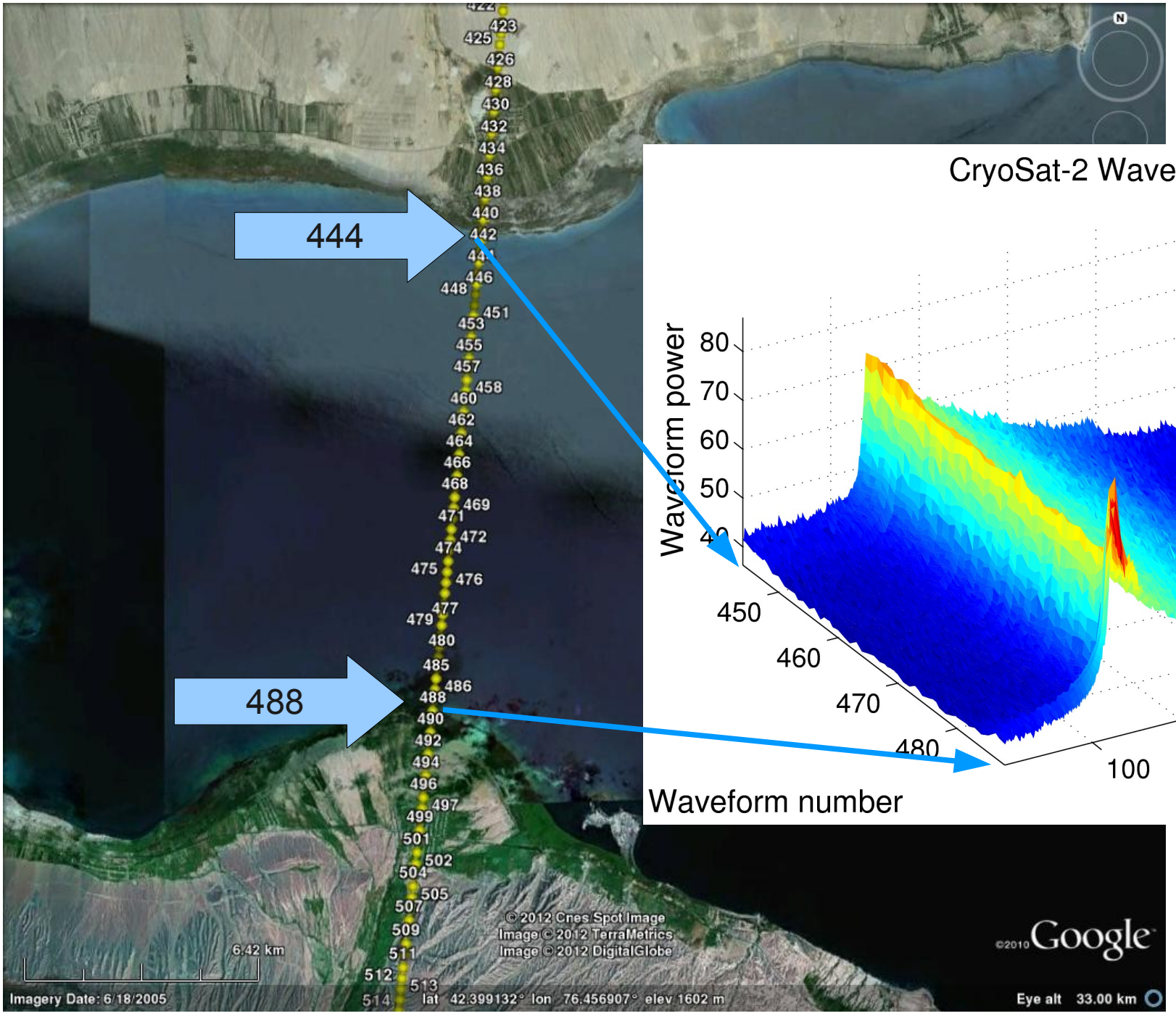
SARin mode over Lake Issyk-Kul

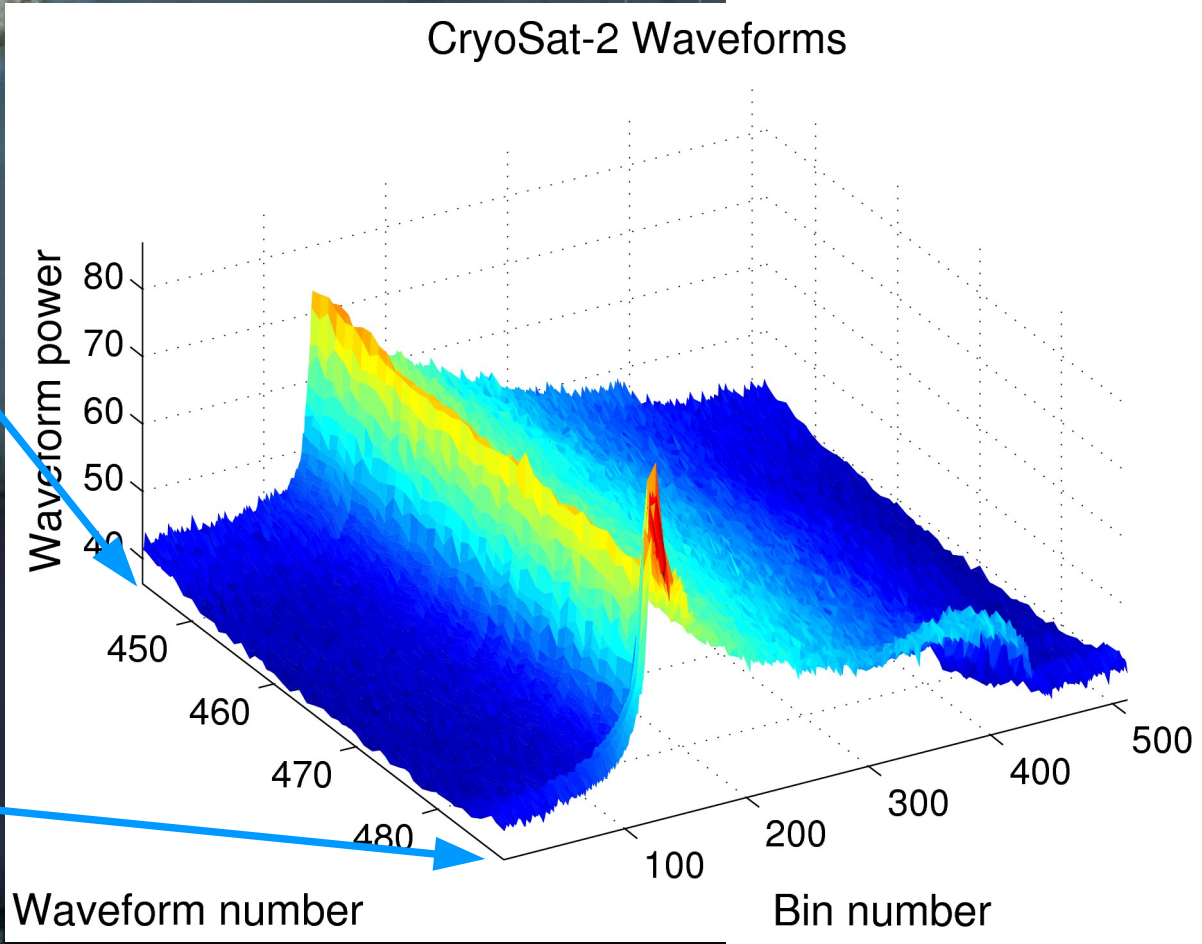
SARin mode over Lake Issyk-Kul



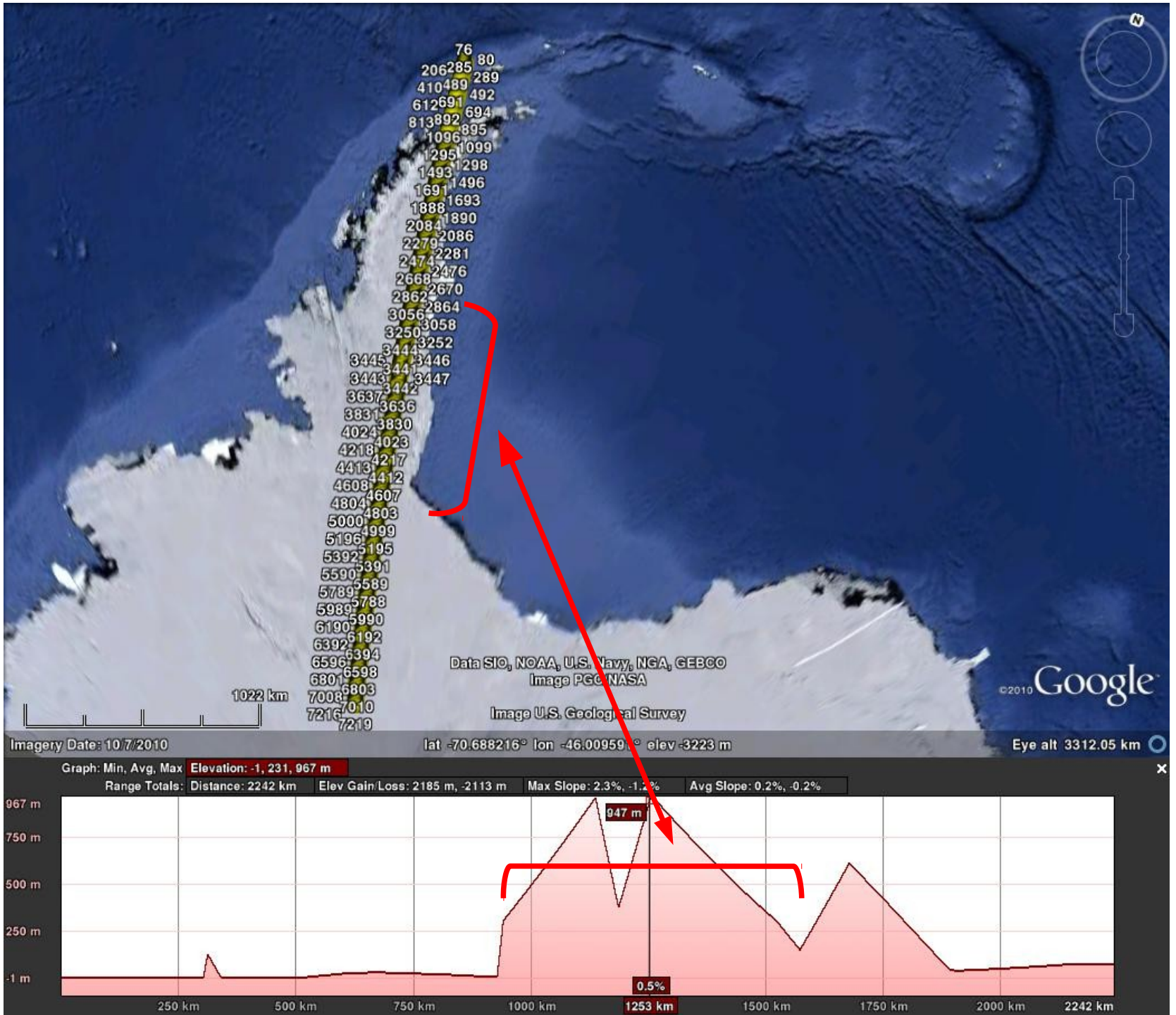


SARin mode over Lake Issyk-Kul

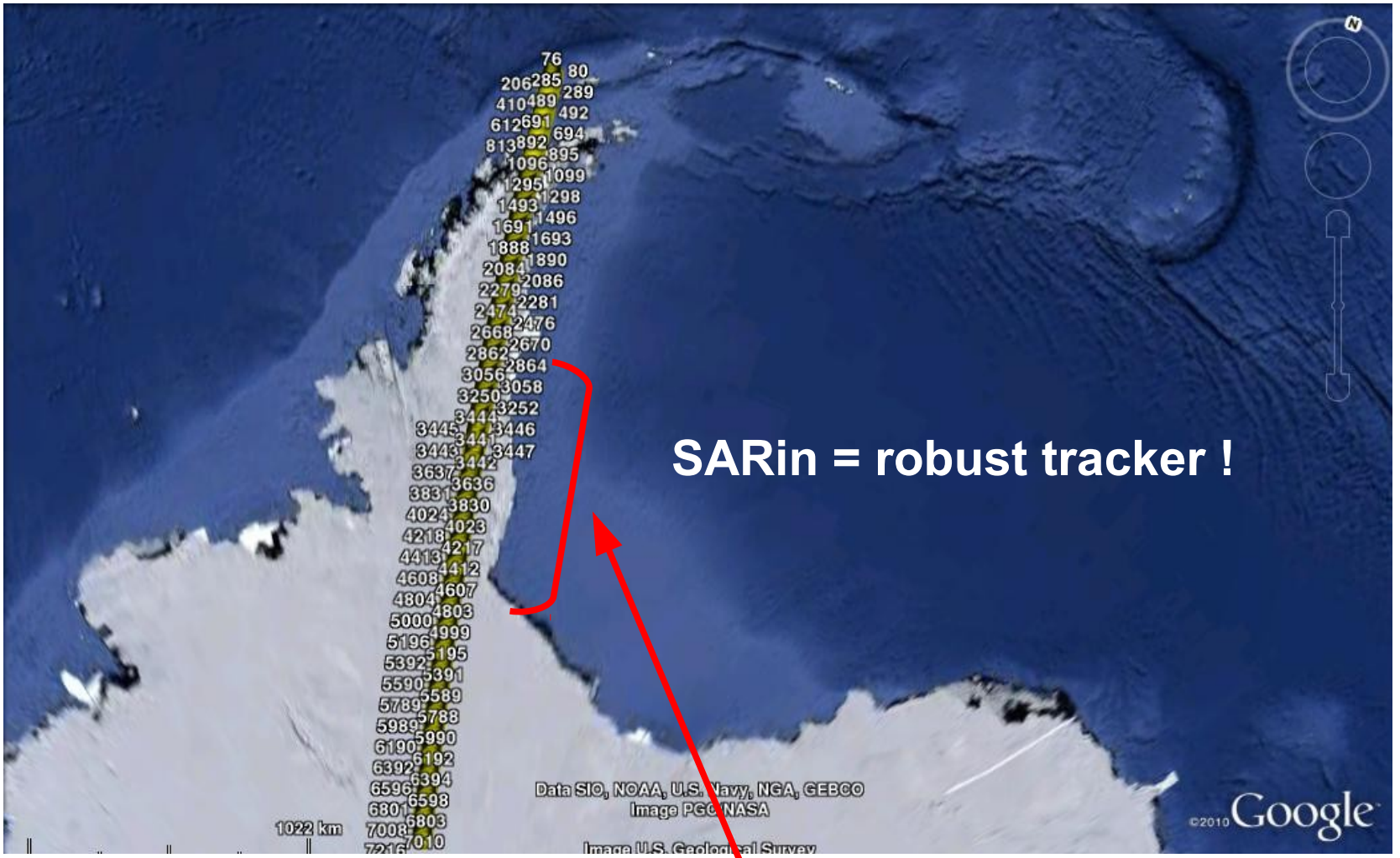


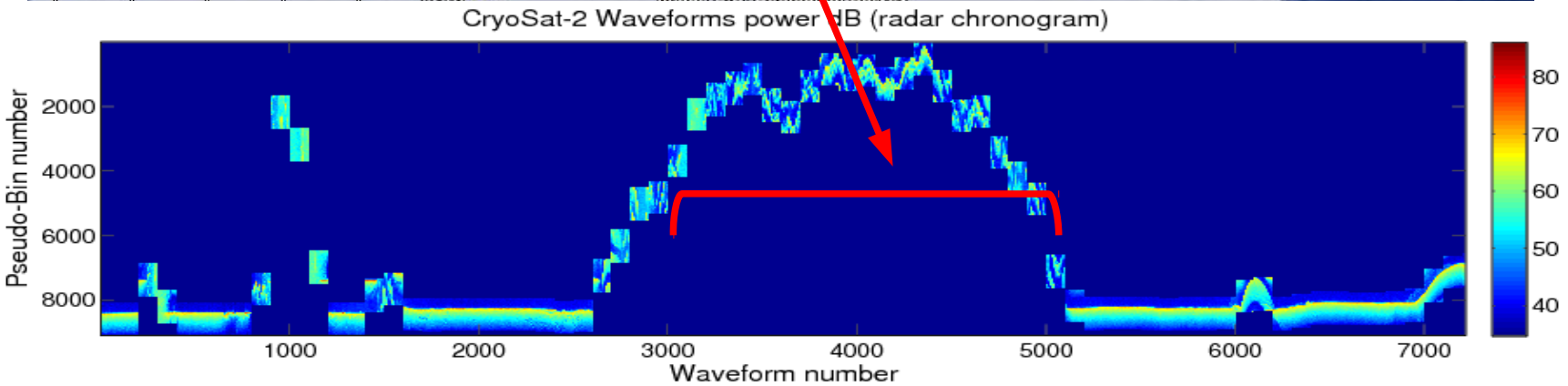


SARin mode : Antarctic Peninsula

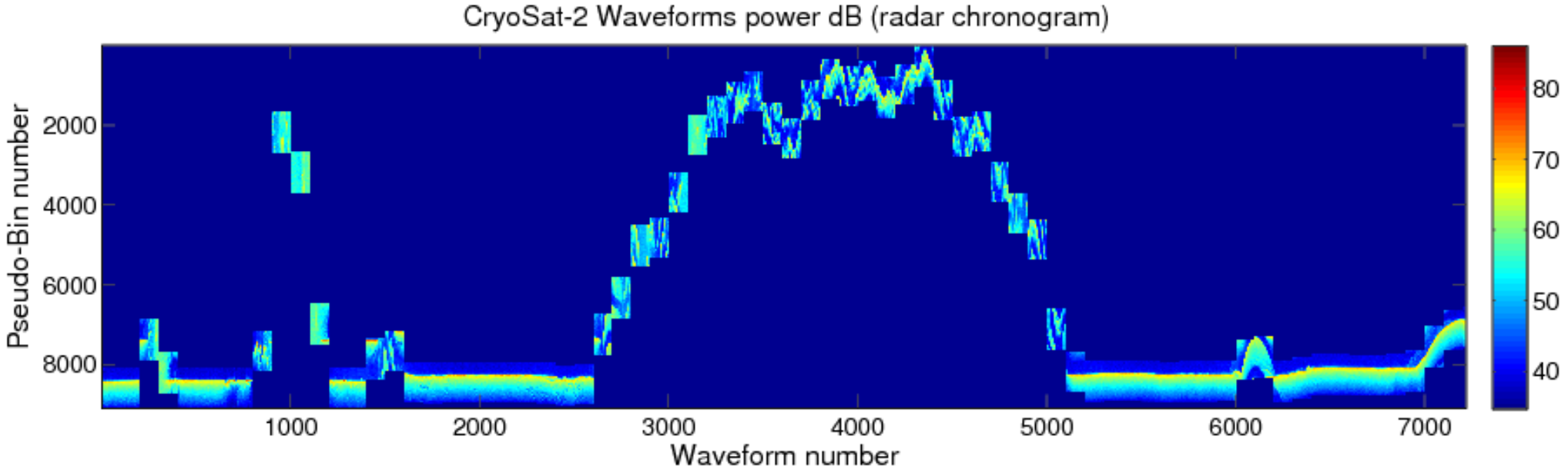


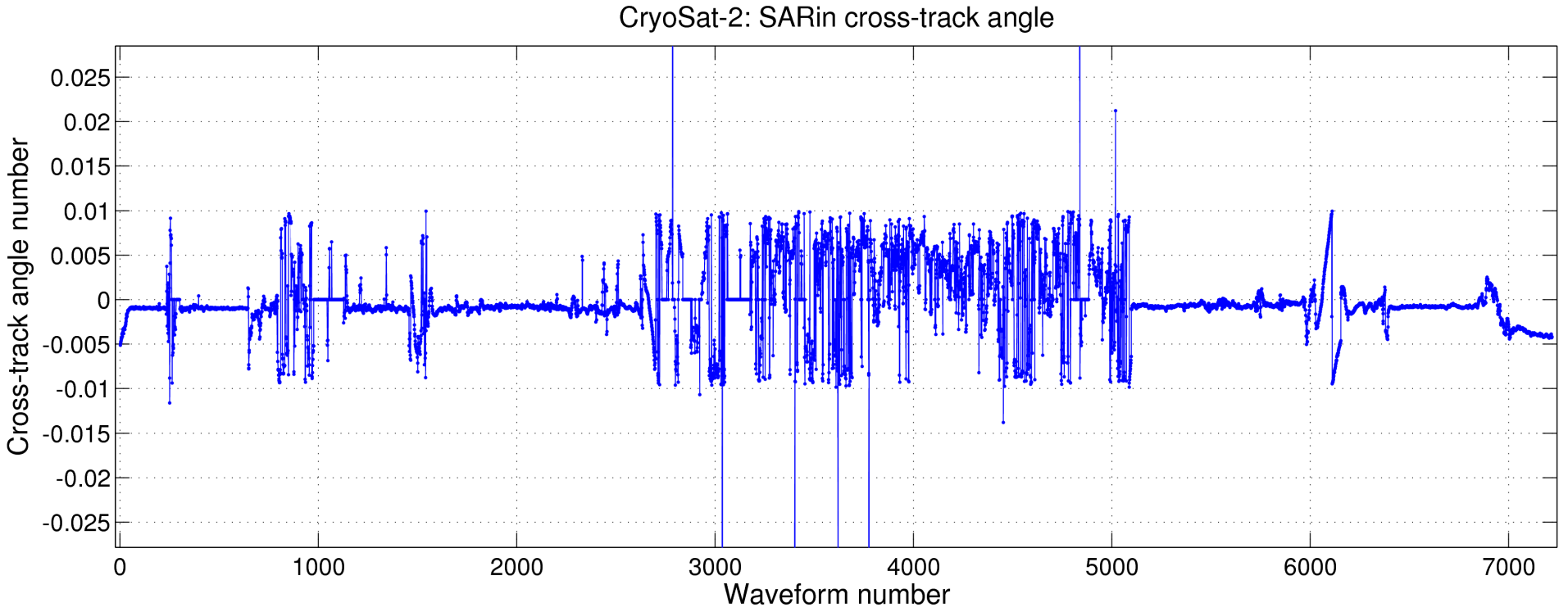
SARin mode : Antarctic Peninsula



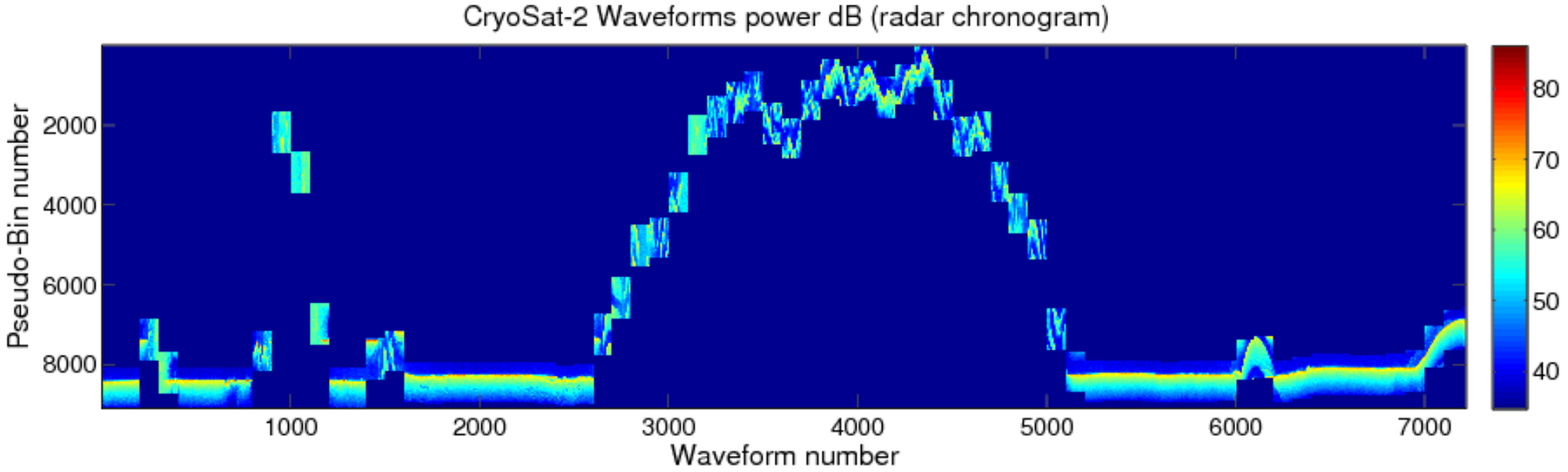


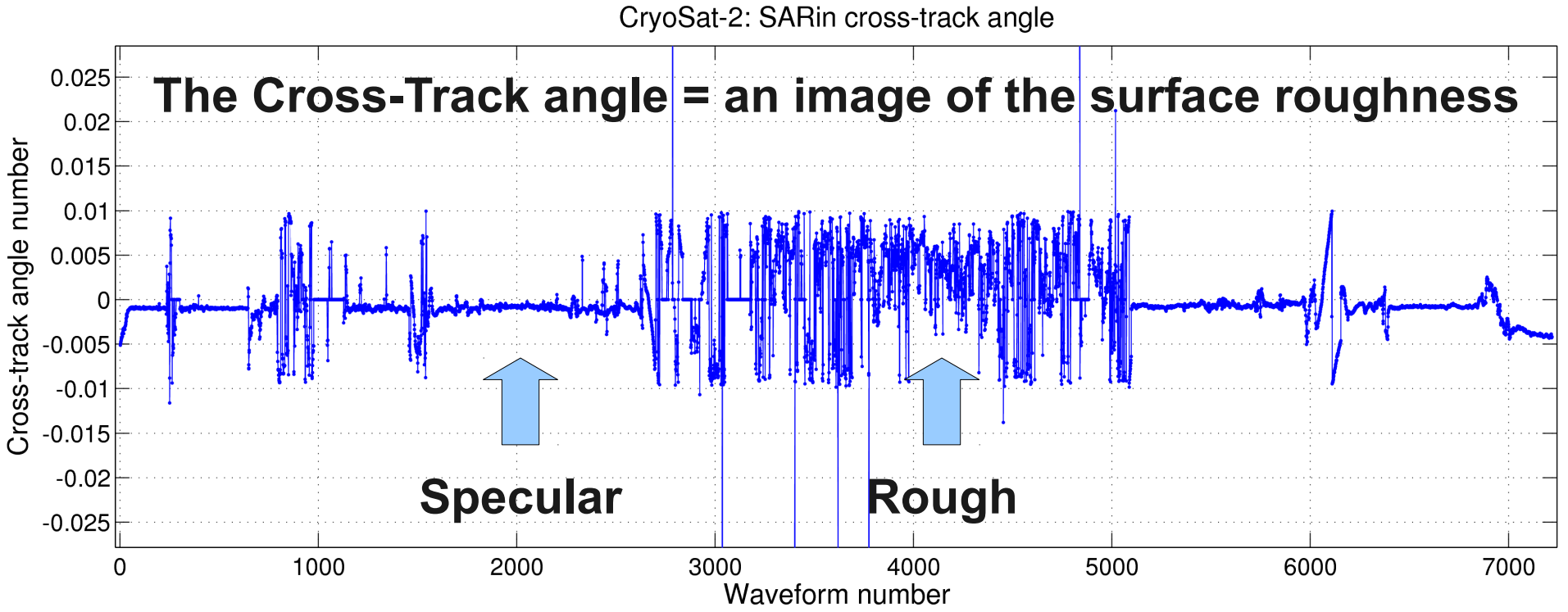
SARin mode : Antarctic Peninsula





SARin mode : Antarctic Peninsula





Plan

1. Cryosat2 mission
2. An introductive example
3. SAR/SARin principles
4. Synthesis and products
5. Examples over various surfaces
6. **Conclusion**

Conclusion

- CryoSat-2:
- unusual orbit (369 days, « drifting »)
- SARin mode « 4×4 » + SAR & LRM

- really interesting potential
- spotlight : along-track « over-sampling »
- stacks : surfaces response, slicing (useful for specular surfaces), etc.

- SAR & SARin :
- specific & heavy processing
- FBR : big dataset (30GB/day)

- SAR on Sentinel-3 :
- 70% SAR coverage... land vs. Ocean ?
- SAR/LRM : continuity issues ?

Conclusion

Product access issues

- Official products : Baseline A too buggy, Baseline B seems OK
  - temporal coverage:
    - 2011 Baseline A
    - since feb. 2012 Baseline B
    - planned for 2013 : 2011 reprocessing with Baseline B
  - Hamming applied on every surfaces → not suited for ocean !

- Data policy ESA too limiting:
  - L0 not distributed → CNES/CPP LRM not distributable!

- RADS/NOAA only 1Hz (no data over land?)

- 2013: Ocean products : IOP, GOP