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# ONERA Airborne experiment over south Greenland for ice sheet multi-frequency SAR imagery

SCI-329 RSM on Capabilities for Sensing, Search and Surveillance in the Arctic

*19 June 2023, Nuuk, Greenland*

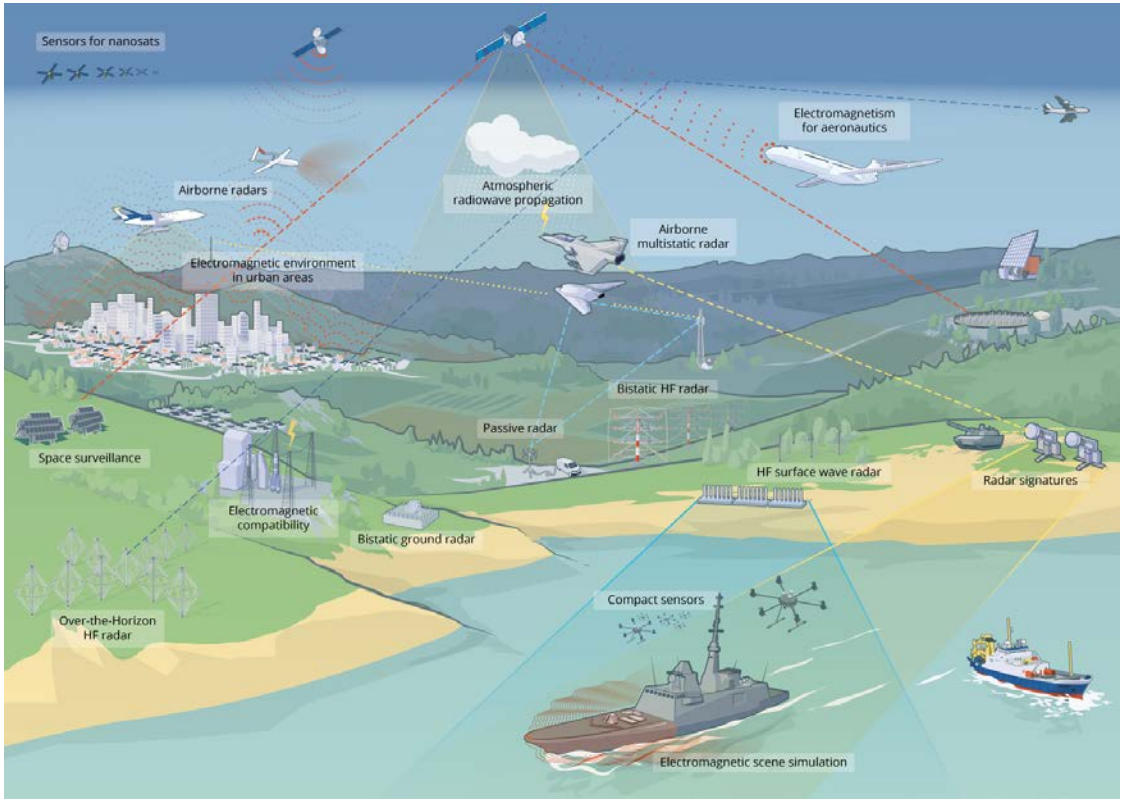
***Rémi Baqué***, *Pascale Dubois-Fernandez, Hubert Cantalloube*

# Let me tell you a story !

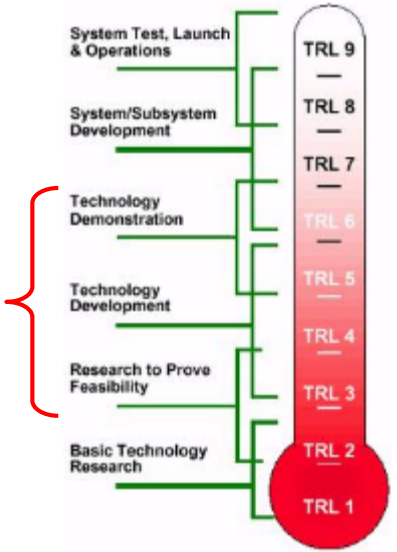
It all started as a quite trip to L.A. USA ...

FHRJE: "**Goose bay, we'va had a problem!**"
T.A.C: "**Okay, we copy that.**"

# ONERA Electromagnetic and Radar Department




**ONERA Technology Readiness Level**



# ONERA Airbone Radar Prototype Facilities (PoC)

## SETHI


- **Platform:** Falcon 20
- **Pods:** 2 x 190 kg Payload
- **Sensors:**
  - **Radars:** Ku, X, L and V-UHF
  - **Camera:** Hyperspectral, IR, visible
- **Autonomy:** 2h45
- **Altitude:** up to 30 000 ft
- **Speed:** 160 to 310 knts

## BUSARD

- **Platform:** Motoglider STEMME
- **Pods:** 2 x 60 kg Payload
- **Sensors:**
  - **Radars:** X, Ka
  - **Camera:** IR, visible
- **Autonomy:** 2h00
- **Altitude:** up to 10 000 ft
- **Speed:** 97 to 140 knts

## SAR-Light

- **Platform:** DGI M600
- **Payload:** 6 kg
- **Sensors:**
  - **Radars:** X, C, UHF+L
- **Autonomy:** 15’
- **Altitude:** up to 150 m

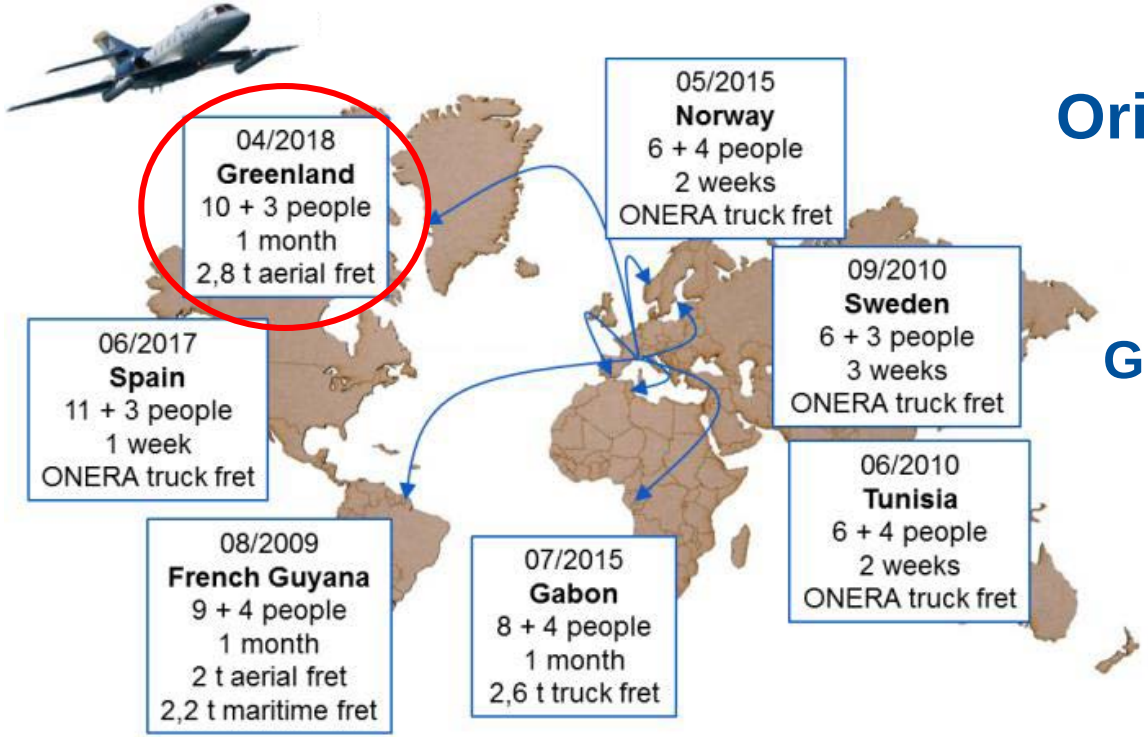
# ONERA SAR SETHI Payloads

| Radar | V/UHF | L | X | X-UHR | Ku |
|---|---|---|---|---|---|
| **Central Frequency (MHz)** | 340 | 1325 | 9500 | 9500 | 16500 |
| **Bandwidth (MHz)** | 240 | 150 | 1500 | 4000 | 2000 |
| **Resolution (cm)** | 70 | 100 | 10 | 4 | 8 |
| **Polarization** | Full | Full | Full | V-v/h ou H-h/v | Full |
| **Transmit peak power (W)** | 500 | 500 | 300 | 8000 | 300 |
| **Antenna** | dipoles | Patch array | Horn | Parabolic | Horn |
| **Elevation Beamwidth** | 100° | 30° | 16° | 7° | 16° |
| **Azimuth Beamwidth** | 50° | 10° | 16° | 5° | 16° |
| **Waveform generator** | 2 voies, 2.5 GS/s, 1 GHz, 16 bits | | | | |
| **Sampling system** | 4 voies, 2 GS/s, 800 MHz, 12 bits | | | | |
| **Recording / storage** | 3.4 GB/s, 7 TB | | | | |

# ONERA optical SETHI Payloads

| Sensor | LWIR | HYSPEX VNIR | HYSPEX SWIR | Optical |
|---|---|---|---|---|
| Number of pixels | 640x512 | 1600 | 320 | 7256x5462 |
| Swath | 385 x 308 m | 1600 m | 700 m | 1300 x 950 |
| Spectral domain | 7,7 – 9,3 µm | 0,4 - 1 µm | 1 - 2,5 µm | 0,4 - 0,8 µm |
| Number of bands | 1 | 160 | 256 | 1 |
| Pixel sampling @ 9000 ft [perp. x paral. flight] | 0,6 m | 0,51 m x 1,03 m | 2,06 m x 2,06 m | 0,17 m x 0,17 m |
| Looking | Nadir | Nadir | Nadir | Aligned with SAR |

# ONERA previous SAR campaign and studies




## Original and unique story

**GreenSAR**

**Greenland**

**Synthetic Aperture Radar**
**Search And Recovery**

# Context : 30 September 2017

It all started as a quite trip to L.A. USA ...

FHRJE: "**Goose bay, we'va had a problem!**"
T.A.C: "**Okay, we copy that.**"

# Engine parts localization and recovery missions

# SETHI detection capacity identified by BEA experts (10-11/2017)

**X-band (9.215 – 9.935 GHz)**
++ resolution 18 cm
−− strong extinction, shallow penetration
+ high target RCS

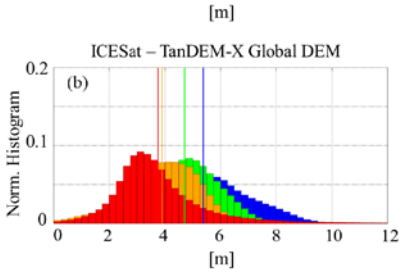
**L-band (1.25 – 1.40 GHz)**
−− resolution 100 cm
+ low extinction, good penetration
− low target RCS

**UHF-band (222 – 247 MHz)**
− resolution 63 cm
++ least extinction, best penetration
−− lower target RCS

Penetration versus target RCS tradeoff not clear prior to mission.

# Risk mitigation in France in December 2017

## Tests and theoretical study



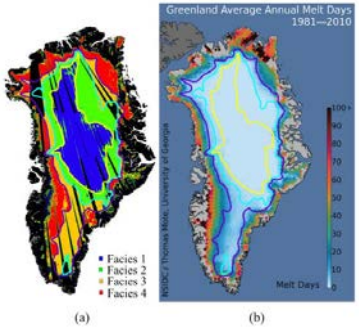
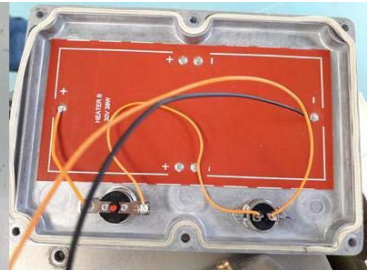




Table 1.1: *Studies on microwave penetration into snow and ice. * $z_p$ measured as transmission (one-way) opposed to reflection (two-ways). # Measured thickness of snow bridges over crevasses.*

| Location | z [m] | f [GHz] | Comment | Reference |
|---|---|---|---|---|
| Antarctic plateau | 8.1 | 10.3 | $z_p$* | Rott et al. (1993) |
| Antarctic plateau | 21.7 | 5.2 | $z_p$* | Rott et al. (1993) |
| Antarctic plateau | 35-45 | 1.75 | $z_s$ | Paper II |
| Lake Vostok, Antarctica | >4.7 | 10.0 | $z_p$# | Davis and Poznyak (1993) |
| Coastal DML, Antarctica | 17.5±2.9 | 1.75 | $z_s$ | Paper II |
| Fimbulisen, Antarctica | 9.6±0.8 | 1.75 | $z_s$ | Paper II |
| Amery ice shelf, Antarctica | 5.7±1.2 | 13.2 | $z_p$# | Lacroix et al. (2007) |
| Greenland, dry snow zone | 27 | 5.3 | $z_p$* | Horn and Zebker (2000) |
| Ryder glacier, Greenland | 20 | 5.3 | $z_p$* | Horn and Zebker (2000) |
| Geikie ice cap, Greenland | 13 | 5.2 | $z_s$ | Dall et al. (2001) |
| Greenland, cold marginal ice | 60-120 | 1.2 | $z_s$ | Rignot et al. (2001) |
| Brady glacier, Alaska | 12±6 | 1.2 | $z_s$ | Rignot et al. (2001) |
| Brady glacier, Alaska | 4±2 | 5.3 | $z_s$ | Rignot et al. (2001) |
| Kongvegen glacier, Svalbard | 12.0±4.3 | 1.2 | $z_s$ | Paper III |
| Kongvegen glacier, Svalbard | 3.7±2.1 | 2.5 | $z_s$ | Paper III |
| Kongvegen glacier, Svalbard | 3.5±2.1 | 5.3 | $z_s$ | Paper III |

# System preparation and adaptation

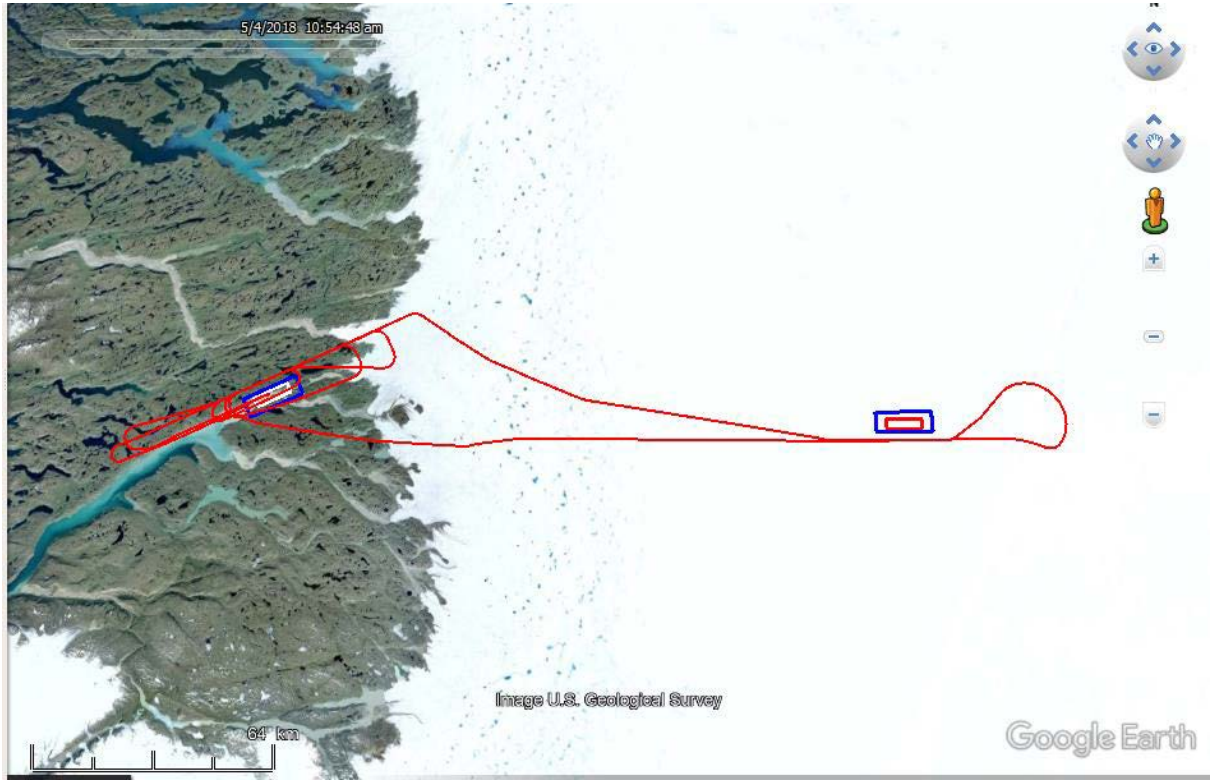







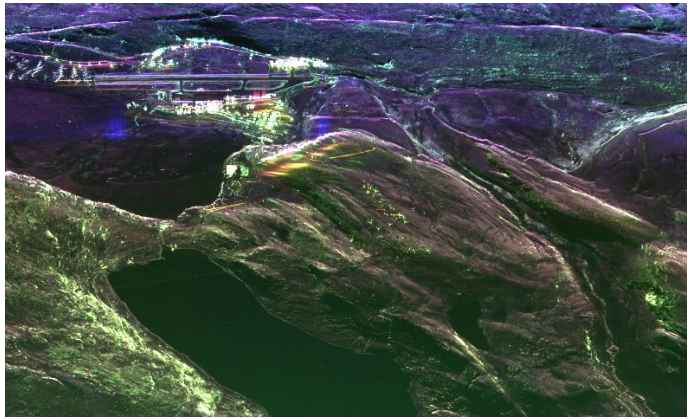


# Risk mitigation over Kangerlussuaq and Ice-sheet

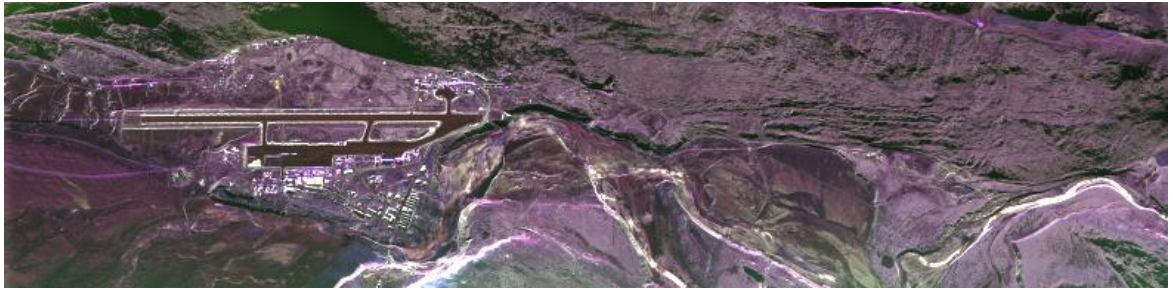


# Risk mitigation over Kangerlussuaq and Ice-sheet

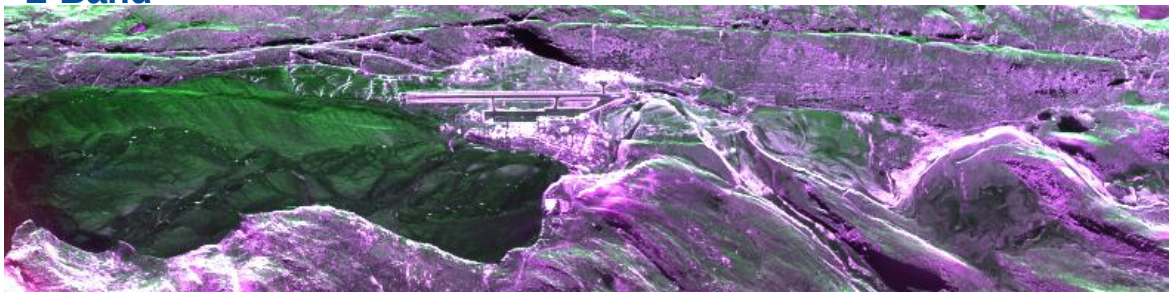
P-Band



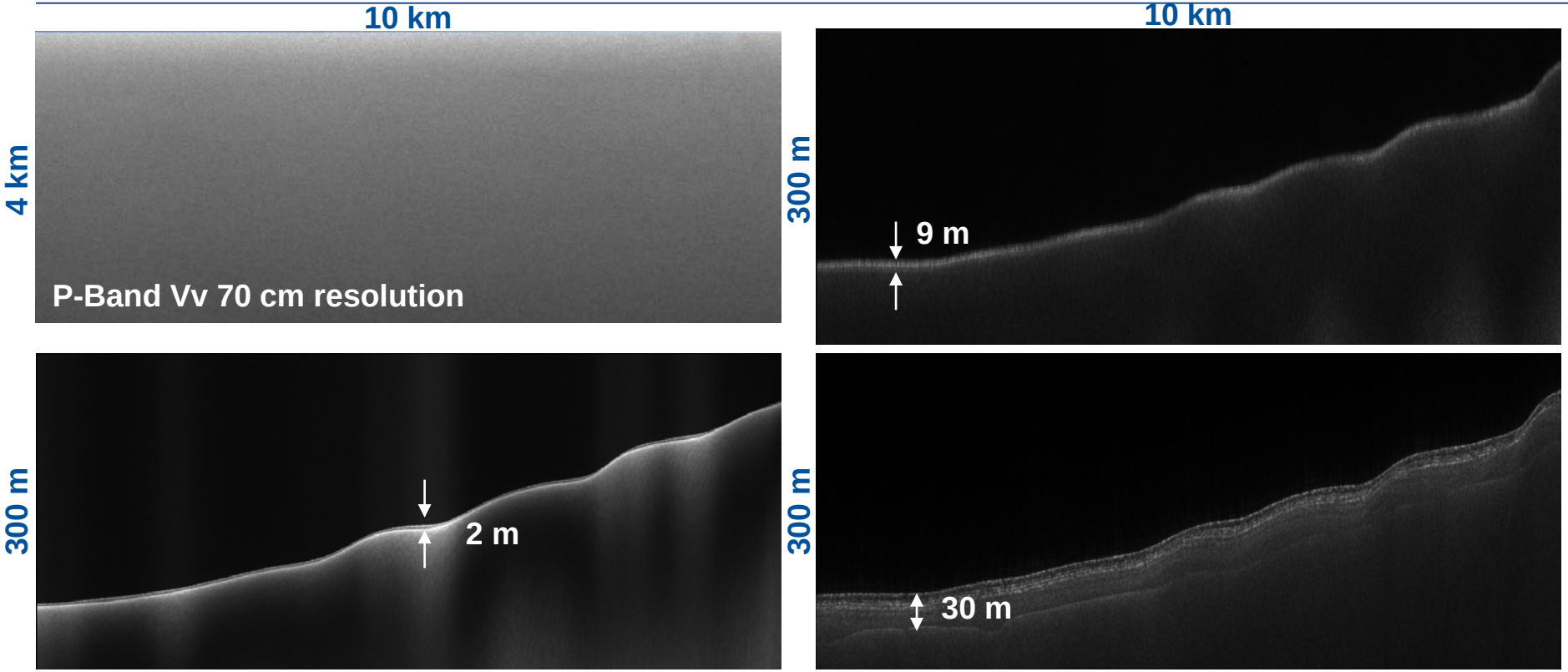
X-Band



L-Band



# Risk mitigation over Kangerlussuaq and Ice-sheet



# Research Area : Calibration and Test Targets

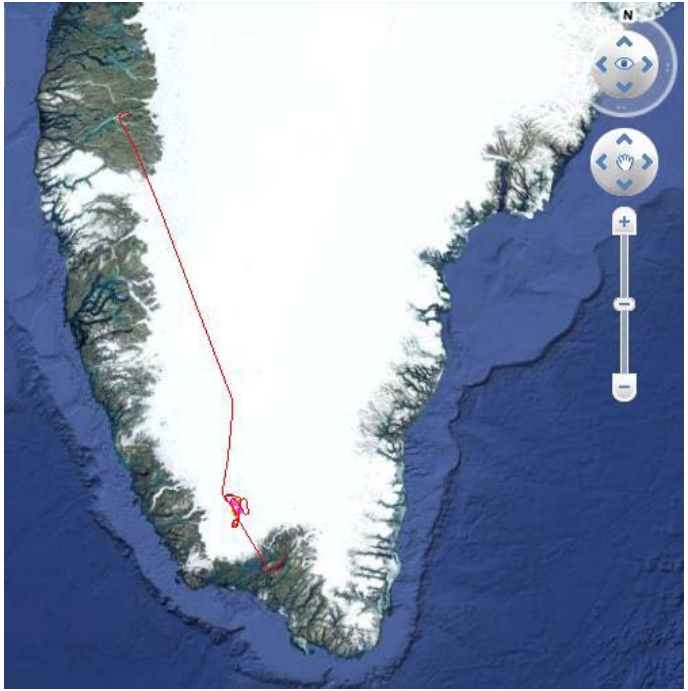
Corner reflector (CR)
Calibration of RCS attenuation by snow/ice cover

Luneburg sphere (LSp)
Reference position for registration

Fan hub fragment mockup (FHFM)
expected target fragment size

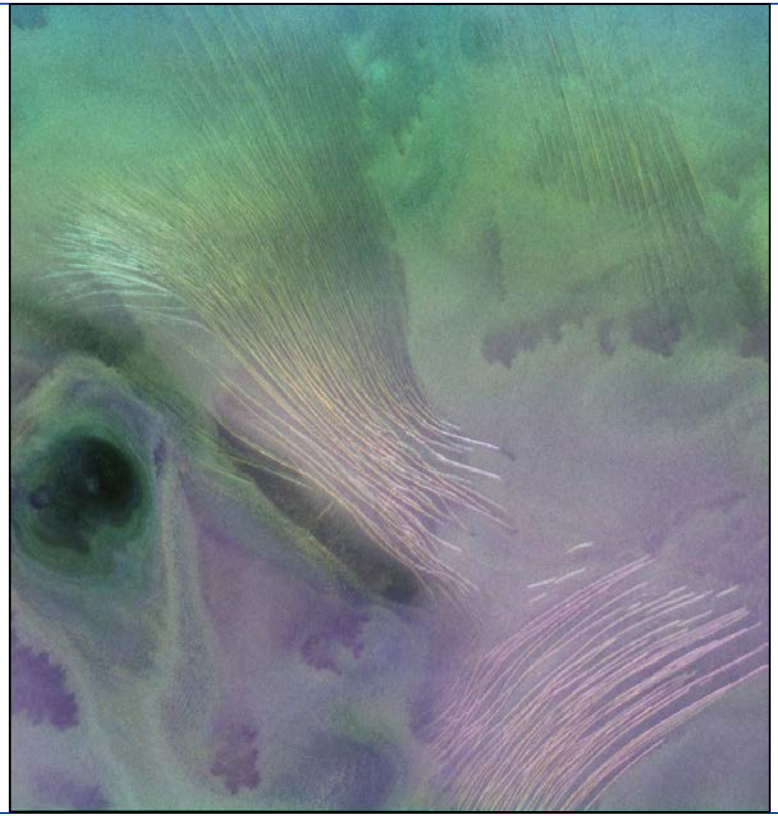
Intentional ice lens (I2L)
aka "false alarm" mockup

# Research area : Trajectory examples




# Research area : Data Processing and analysis


# Target search method tried in Greenland (before return to France)



**Very beautifull ...**

but …

**How to find a (broken) needle in (frozen) a haystack ?**

# Target search method tried in Greenland (before return to France)

- Concentrate effort on lower (L & V/UHF) bands:
  - Try polarimetric analysis => not conclusive
  - Try interferometry to select echoes at the expected target depth => not conclusive

- Try X-Band at more deep angle to decrease path length in snow/ice => not conclusive

At the end of the mission in Greenland, no convincing target detections were found (and FHFM eluded detection) …
… perhaps SAR was not the apropriate tool.

# Target search method tried in Greenland (before return to France)

GPR exhaustive scanning by the Danish GEUS team
(photo: Stephan Otin, BEA)

# Airborne SAR signal reprocessing …

- Investigating why the corner reflector RCS was so much attenuated while buried at shallow depht under snow, we reprocess the X-Band acquisition signal with maximum azimuth resolution (~3 cm).

  ➢ Unexpected result : The FHFM buried at ~1,5m depth appeared on the images !

Further investigation showed that the ~30 dB RCS loss of corner reflector/Luneburg sphere in **mostly due to intrinsic target RCS decrease and not propagation losses** during snow/ice penetration.
– Ice/snow heterogeneities inside the corner make the vacuum equivalent corner surfaces neither flat nor orthogonal ⇒ drastic RCS loss.
– Cover refraction index (~1.3) around the sphere makes it "far sighted" ⇒ drastic RCS loss. Index discontinuity 1.3/1 at the sphere surface also produces an extra echo ⇒ duplication of the sphere echo observed on later X-band images.

# Airborne SAR signal reprocessing …

- Hower the FHFM was 10 dB below clutter level. Automatic detection with Speckle images would require hundreds of looks for incoherent summation.

  - We have hundreds of looks :
    - Imaging up to 6 dB down the antenna pattern => 6 looks per channel
    - 3 parallel tracks per direction
    - 4 directions
    - 4 polarizations
    - …

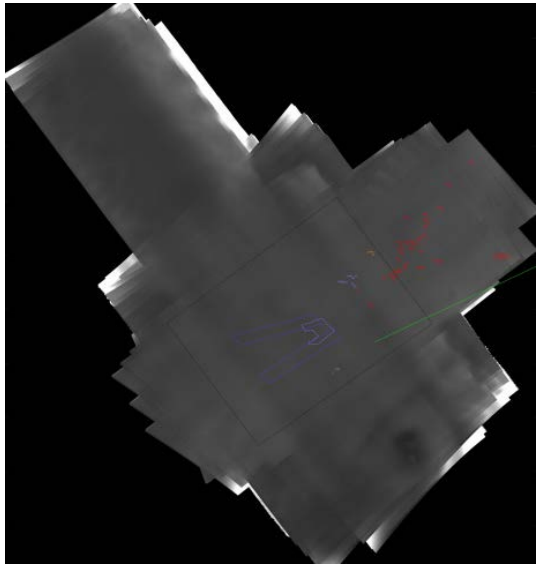
**A total of 432 X-Band looks !**

# Airborne SAR signal reprocessing …

- But this requires
  - High registration accuracy obtained by hybrid differential GPS trajectory and internal calibration signal record
  - Ice drift during time separation between acquisition compensation (1,9 m in the 13 days of measurement)
  - Position aberration correction due to refraction error in different direction of measurement

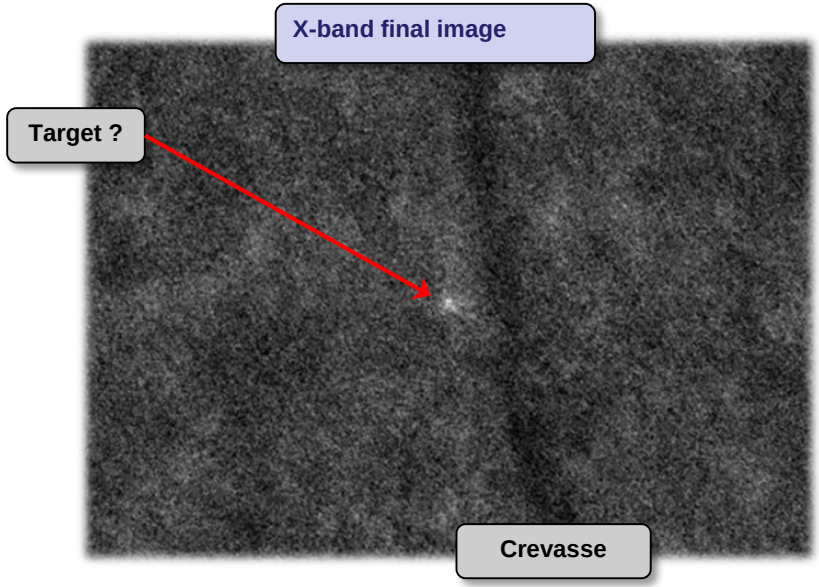
**We know the optimal combination law, we have the computing power for, hence we did it !**

# Airborne SAR signal reprocessing …



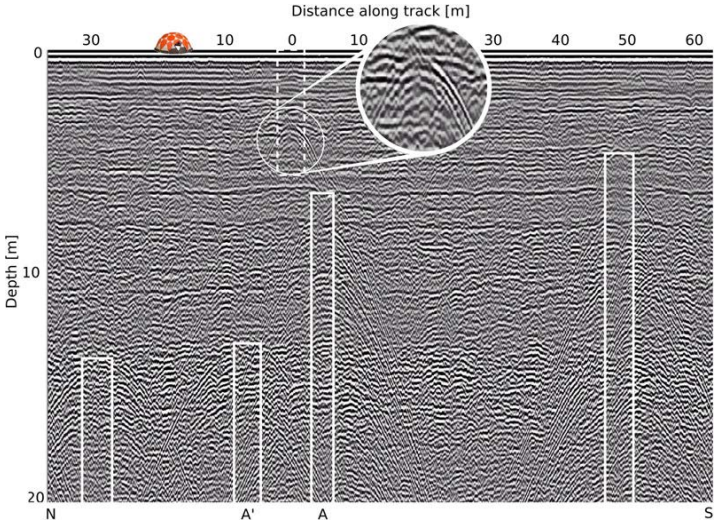
First X-band reprocessed image from 432 look X-band images (obtained on December 17th) 102000 x 110 000 pixels of 18 x 18 cm² (363 km²) that required 38.7 TB temporary storage and 750 computer hours (running on 120 cores in parallel)

# Target Localization



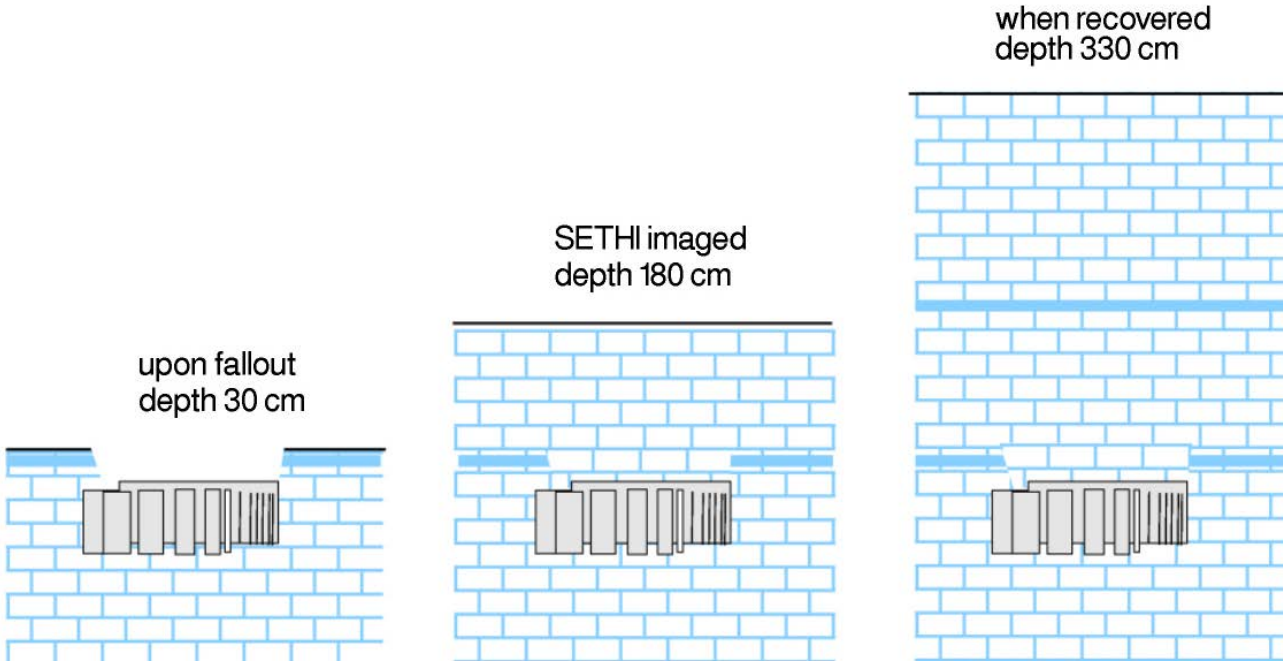

**Three candidates target locations and depth transmitted to the Investigation board in February 2019 with 1 best chance**

# Target Confirmation by GEUS GPR



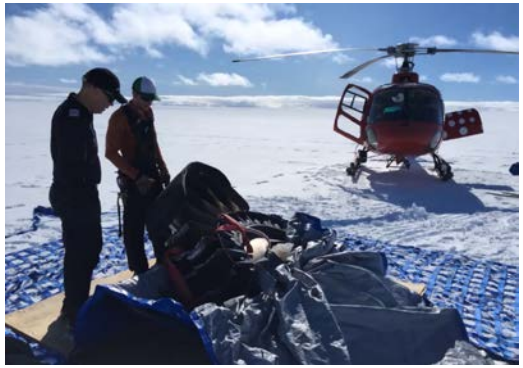

# Target Recovery : 19th June 2019

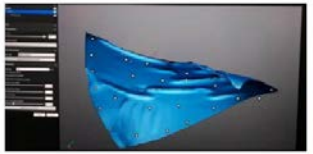
# Target Depth

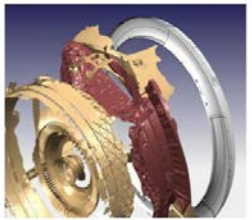



09/2017 04/2018 06/2019

# Target Recovery and Analysis







# Summary

- Incident : 09/2017
- Test campaign in France : 12/2017
- Preparation mission in Greenland : 02/2018
- Airborne campaign : 04/2018
- Fan Hub Localisation : 02/2019
- Fan Hub Recovery : 06/2019

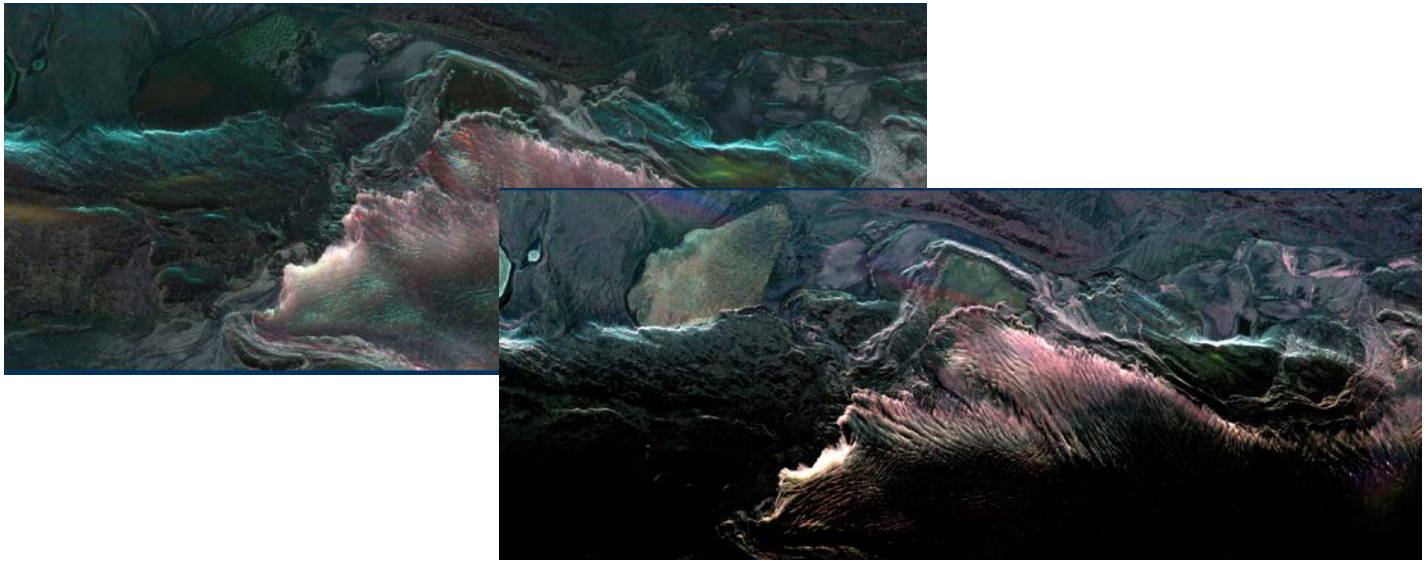
4 short months to prepare and send 3 tones of material, aircraft and 13 people

10 long months of re-processing

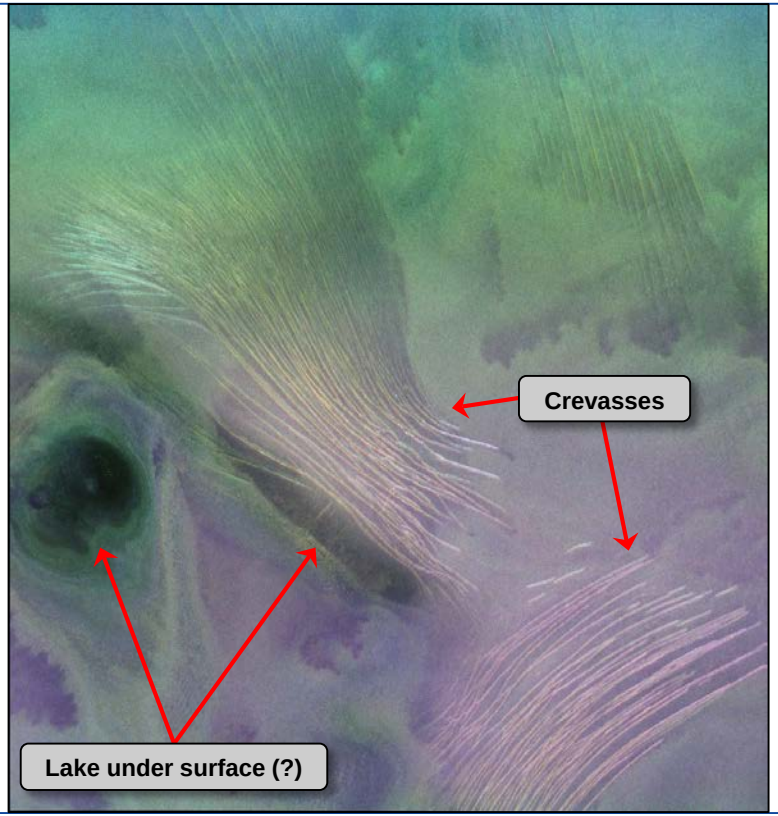
4 long months of waiting

➢ **Reactivity, Flexibility and Never give up**

# High Quality Radar Dataset



# High Quality Radar Dataset




V/UHF 260-450 MHz

Full polarimetric image
Image size: 8 x 8 km
Resolution :80 x 80 cm

# Perspectives and Motivations


- ONERA Self founded Research Project on existing data, based on GEUS cooperation
- Future scientific airborne campaign over Greenland with GEUS, DALO and eventually NATO-SPS ?

*Crevasse maping, See ice thickness measurement, people and objects detection, traficability, Iceberg/boat discrimination, …*

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# Thank you !

# Tak !

# Qujan !

# Merci !