Compact Active Transponders for SAR Interferometry

Experimental validation

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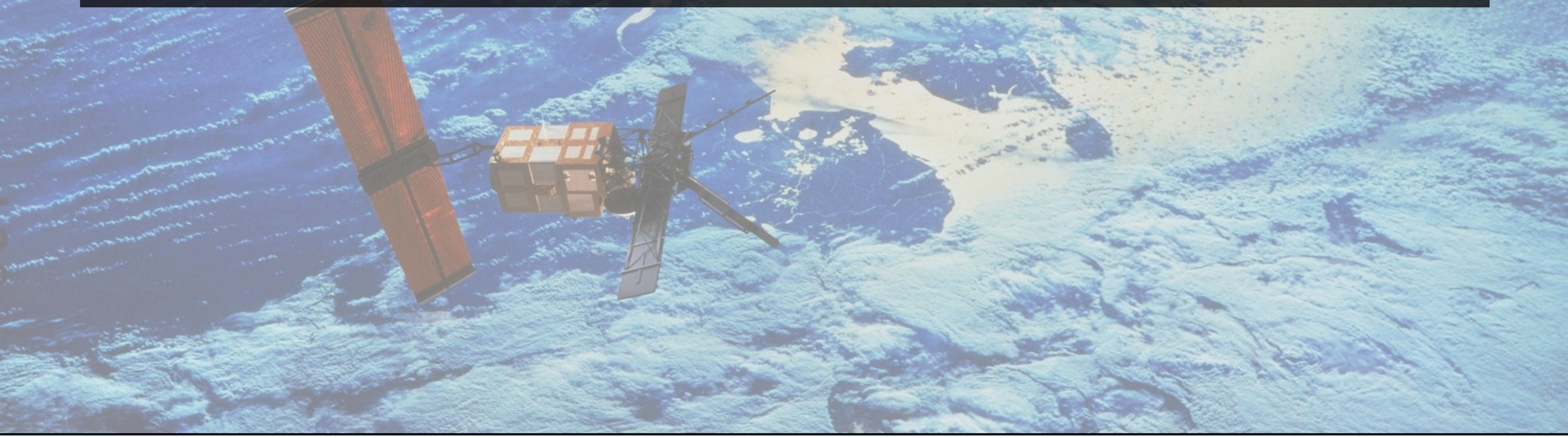

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Outline

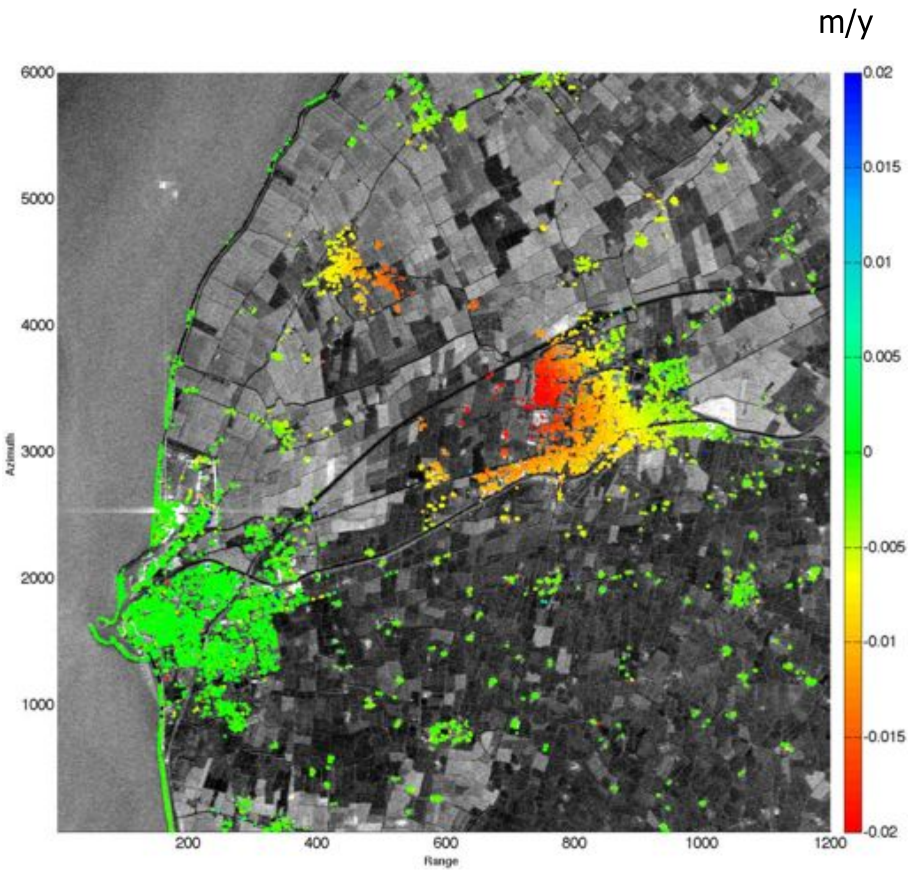
- Persistent Scatterer (PS) Interferometry
- Need for artificial PS
  - Compact active transponders (CATs) vs. corner reflectors (CRs)
- Validation experiment

Can a CAT replace a CR for deformation monitoring?
In other words, is a CAT phase-stable?

- Results and conclusions

PS density can be suboptimal

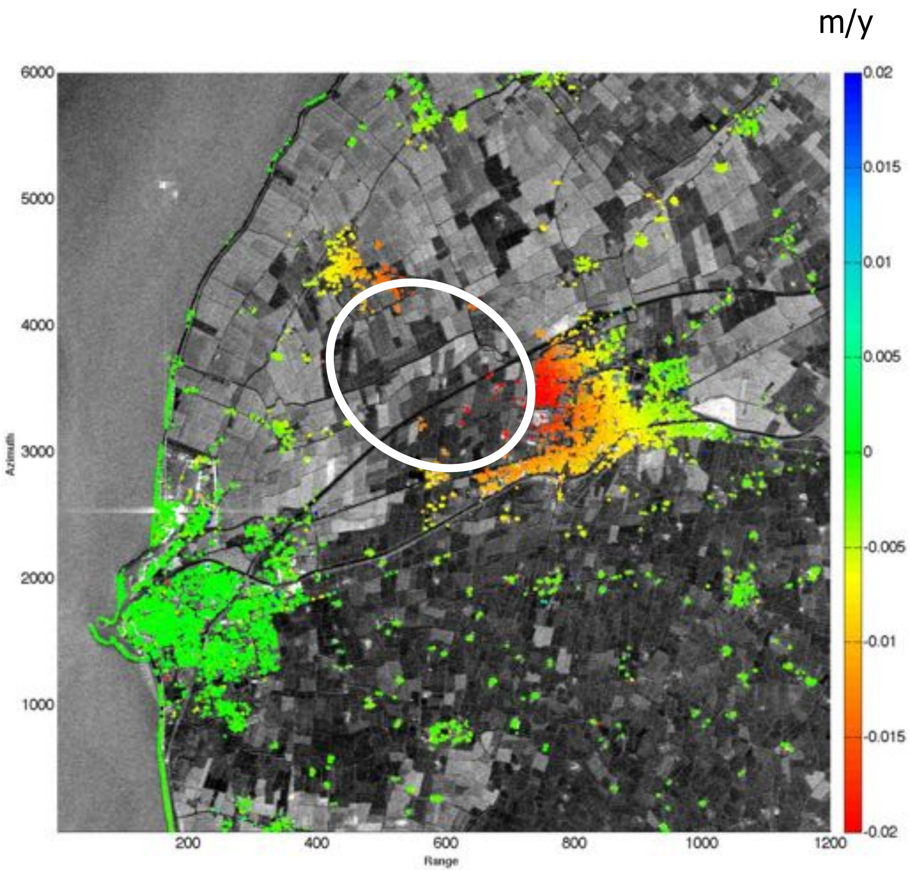
- Persistent Scatterer Interferometry (PSI):
  - Measurements of ground deformation at **radar scatterers** (PS) that are **phase coherent** over a period of time



Ground deformation per year (2003-2009) due to gas extraction and salt mining at Harlingen, The Netherlands, using PSI on Envisat ASAR data.

PS density can be suboptimal

- Persistent Scatterer Interferometry (PSI):
  - Measurements of ground deformation at **radar scatterers** (PS) that are **phase coherent** over a period of time
  - **Urban areas:** spatial density of PS usually high (**100- 300 PS/km²** with ERS/Envisat)
  - Ground deformation phenomena may occur in **uninhabited or rural areas** with few man-made structures



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PSI is opportunistic

- For reliable and effective monitoring in such areas, PS density may be insufficient
- PS form a **geodetic network of opportunity**, but the exact location of PS ‘benchmarks’ is not under our control

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Artificial PS: corner reflectors (CRs)

✔ Conceptually **simple**

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✖ **Big** and **heavy**

✖ Should be strongly **anchored** to the ground; **autonomous motion**

✖ **Difficult** to deploy and maintain, especially in remote areas

✖ Can be **disturbed** by weather conditions, fauna, vandalism or theft during long-term measurements

✖ Snow, rain and debris can accumulate; periodic **maintenance**

✖ **Oriented** according to the satellite pass and imaging modes; only **ascending or descending** passes can be utilised

Compact active transponders (CATs)

- **Passive** devices need to be **large,** to be able to return sufficient power to the satellite
- **Active** devices can be more **compact**
- CATs are designed to be used **in place of CRs**

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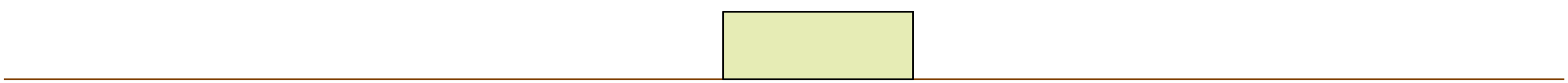

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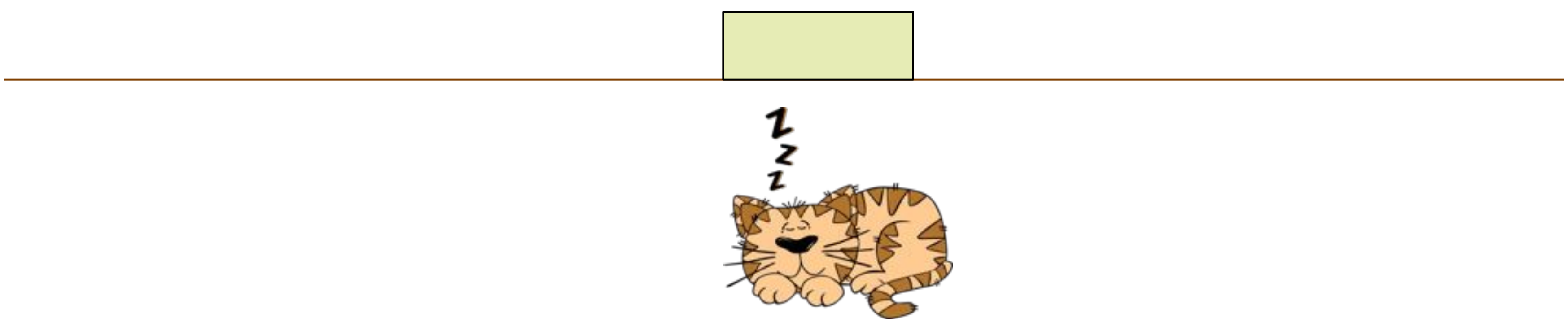

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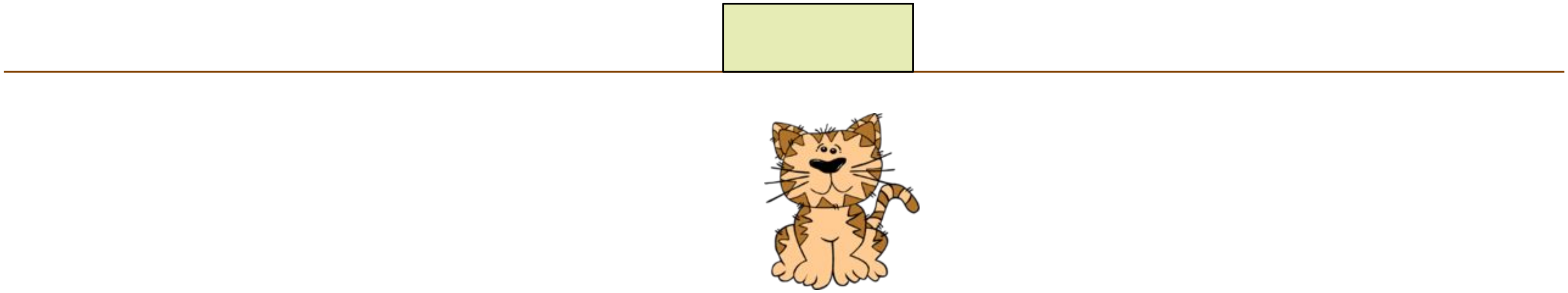

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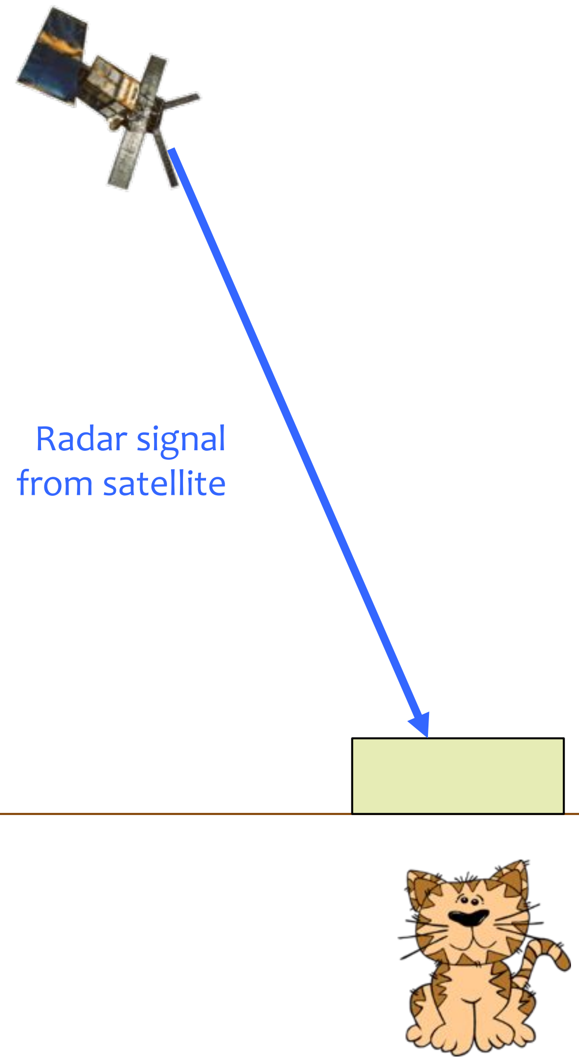

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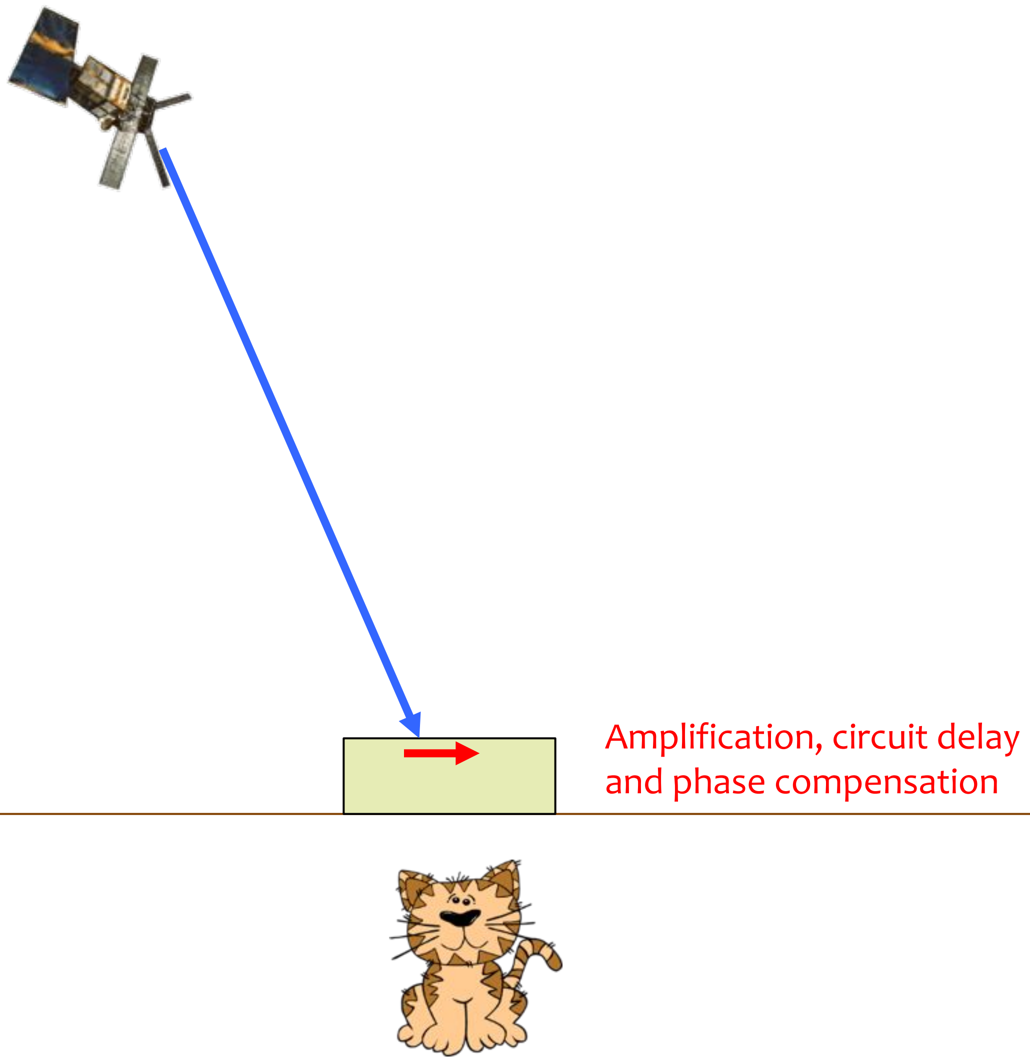

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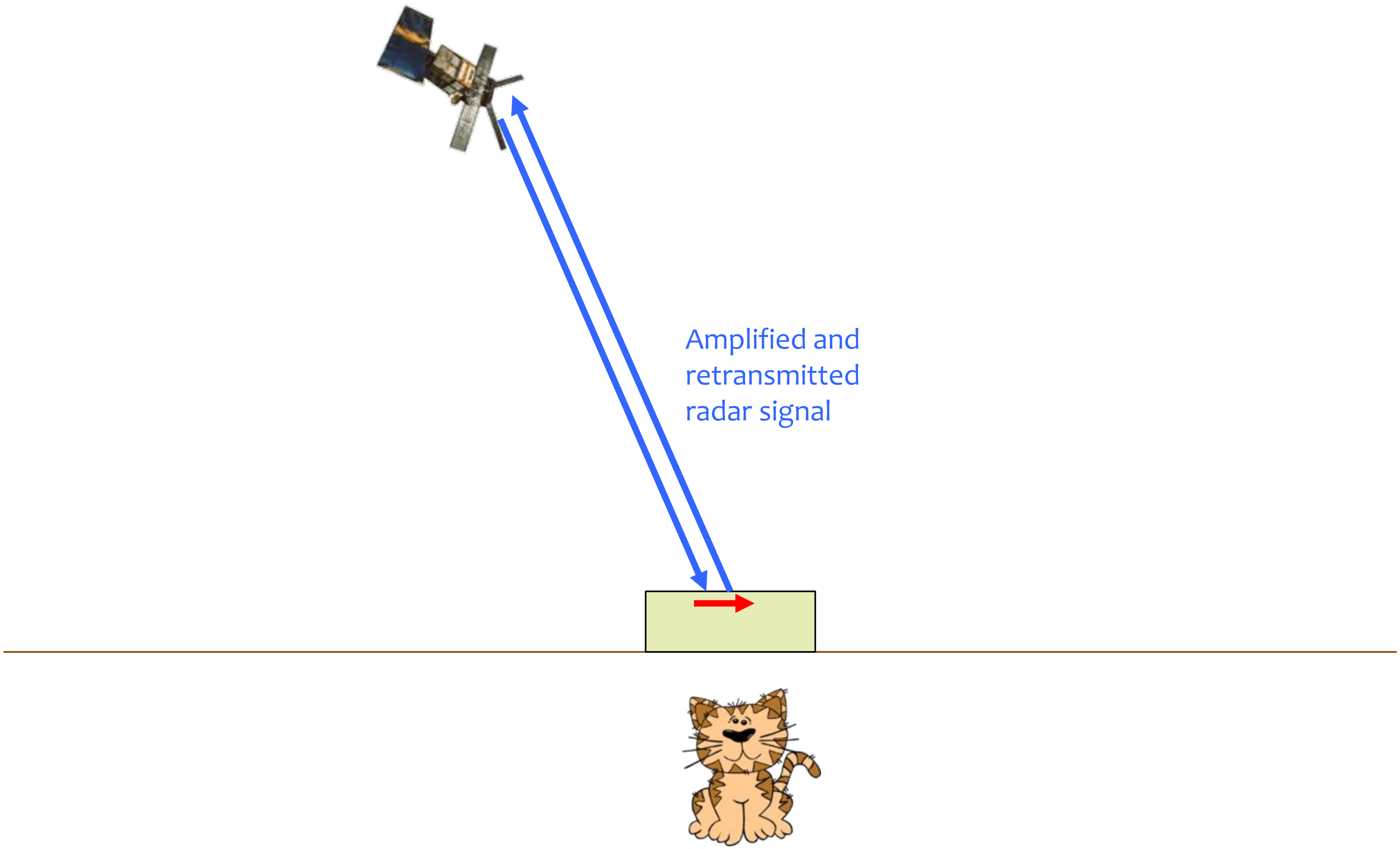

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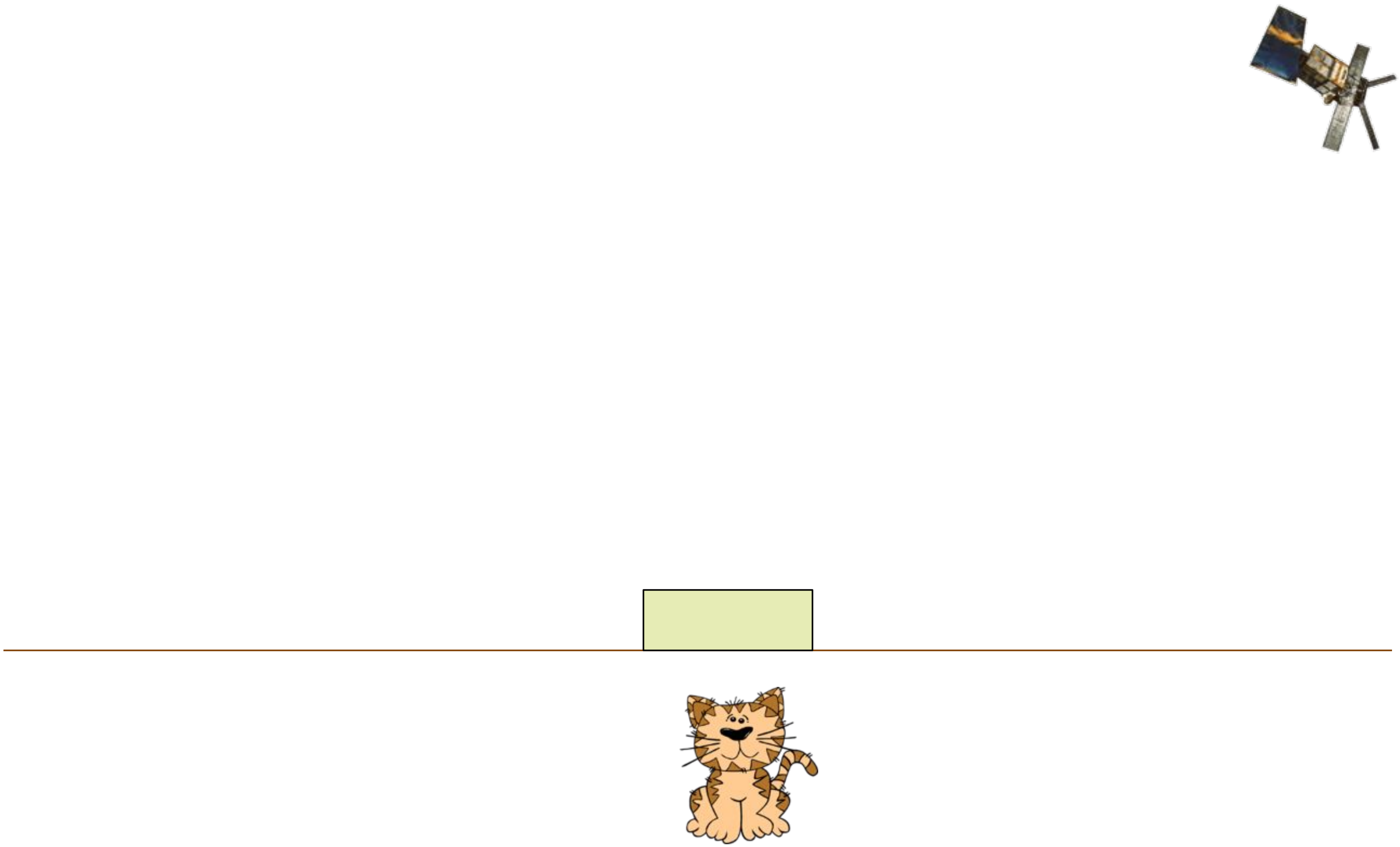

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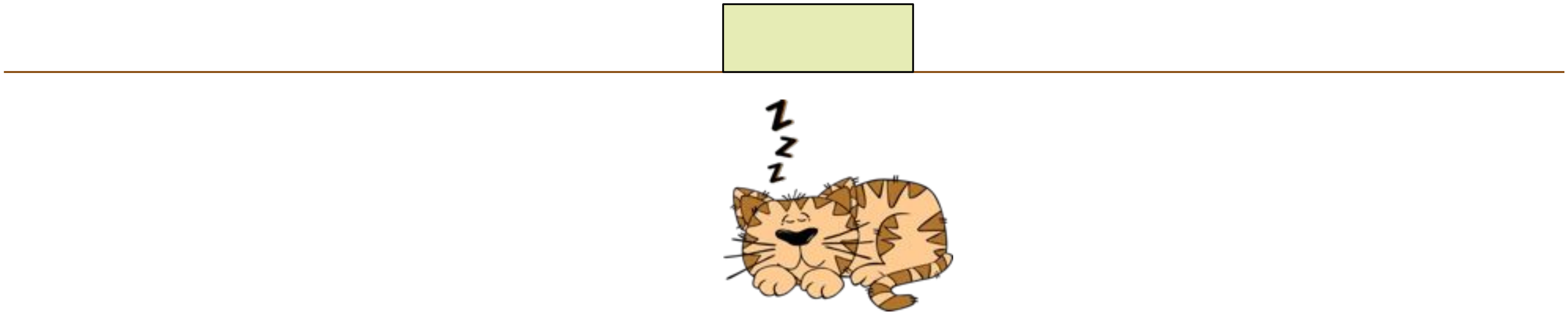

CATs as artificial PS

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✔ **Small** (a few tens of cm), **lightweight** (less than 4 kg) and **inconspicuous**

✔ **Sealed**, function autonomously and over a wide temperature range with **internal power** for **more than a year**

✔ **Not affected** by strong winds, precipitation and debris accumulation

✔ **Low maintenance:** only to change/charge battery, check for clock drift, or upload new SAR acquisition schedule if needed

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CATs as artificial PS

✔ Frequency-specific, only turned on during overpass: offers **little interference** to other radar or radio targets

✔ Can be used **for both ascending and descending** satellite modes in a single setup

✔ Wide beamwidth: can be used over **a range of incidence angles**

✔ Signal polarisation can be preprogrammed: can be used with **any existing C-band satellite** without highly accurate orientation and adjustment

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In other words, is a CAT phase-stable?

The Delft field experiment

Location and setup

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InSAR and levelling

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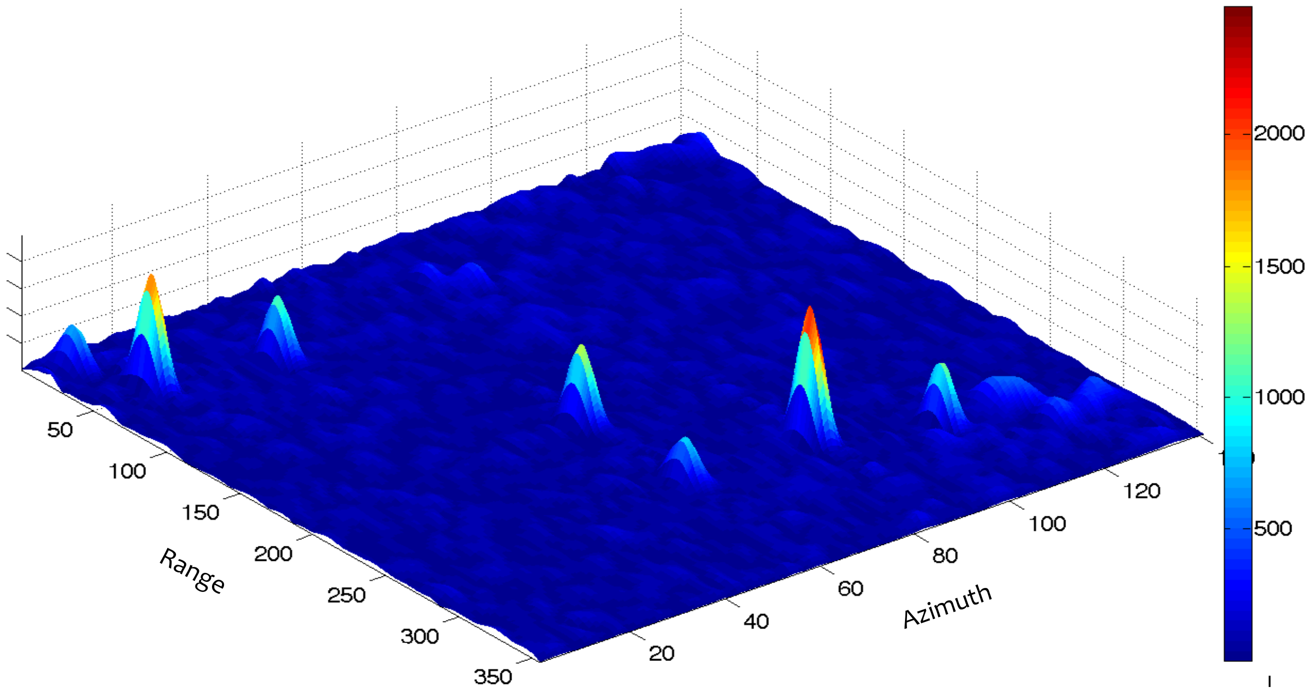
- SAR data acquired **every 3 days** (ERS-2 Ice-Phase Mission)
- **26 SAR images** after device installation (19 April to 3 July 2011)
- Levelling performed **within 24 hours** of most overpasses (19 out of 26)
- Levelling between **CAT-CR pairs**
- Redundancy introduced in levelling measurements, making **outlier detection** possible

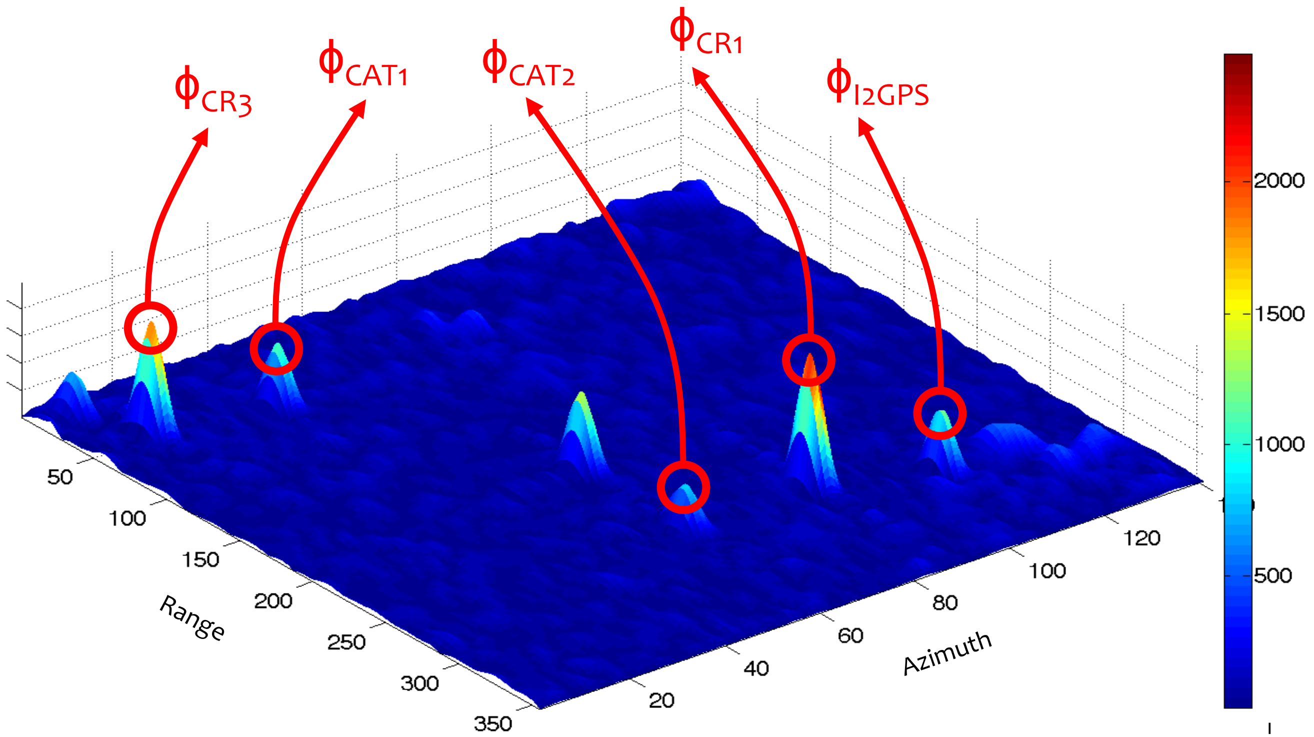
CAT and CR phase extraction

- Single master **interferograms** generated



CAT and CR phase extraction

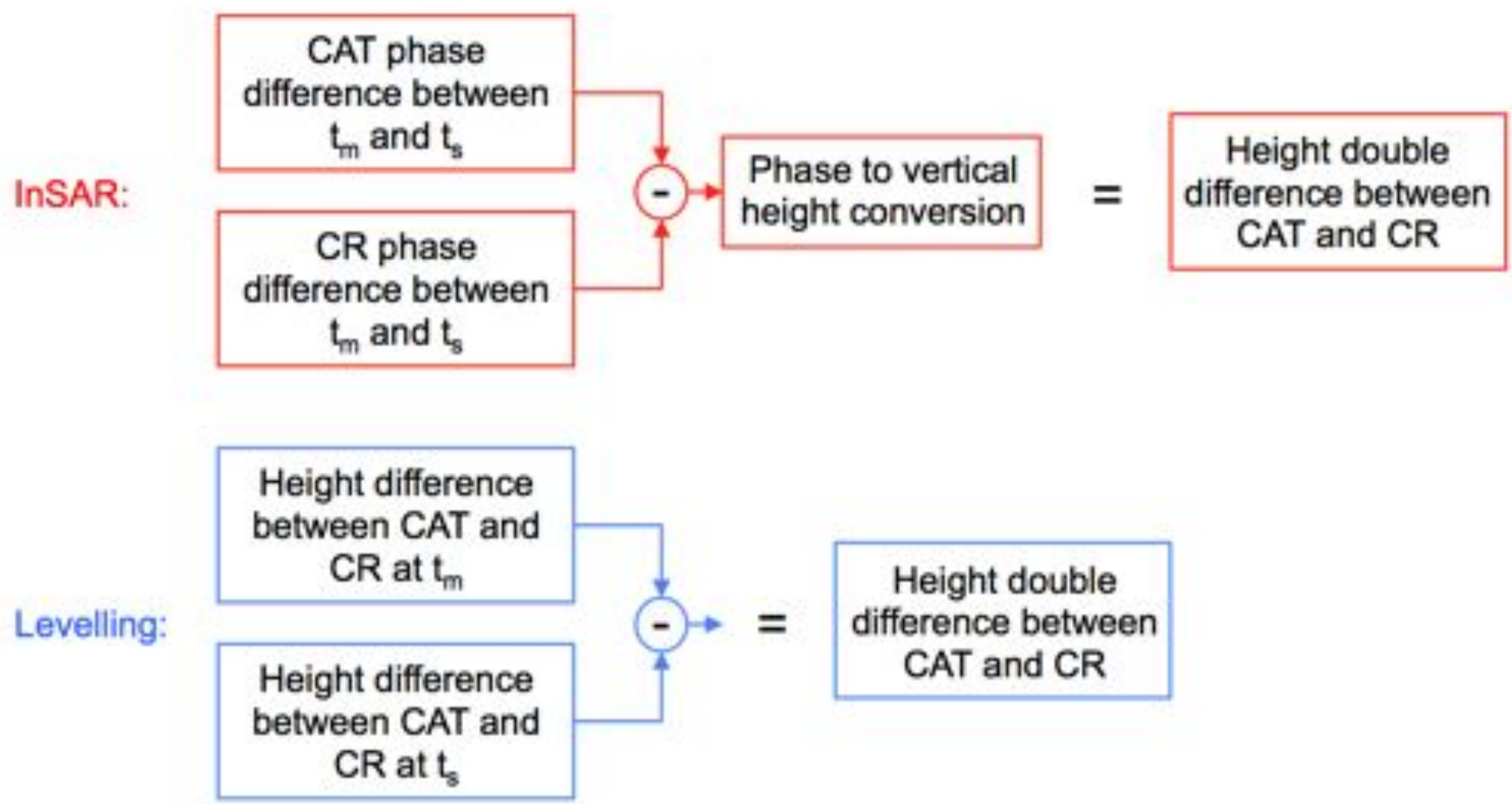
- Single master **interferograms** generated
- For each CR and CAT, the **phase of the pixel with maximum amplitude** extracted



InSAR processing

- ERS-2 was operating in Zero-Gyro Mode since 2001; continuous **variations of Doppler centroid**, not optimal
- **Subpixel phase correction** in azimuth and range
  - to correct for **systematic phase offsets** that depend on object position within a resolution cell
  - subpixel position determined by **oversampling with a factor of 32** with respect to SLC image
- InSAR and levelling vertical height double differences calculated using the **same reference time** (13 May)
- InSAR double differences **unwrapped** to the nearest levelling double differences

Double differences: basis of comparison



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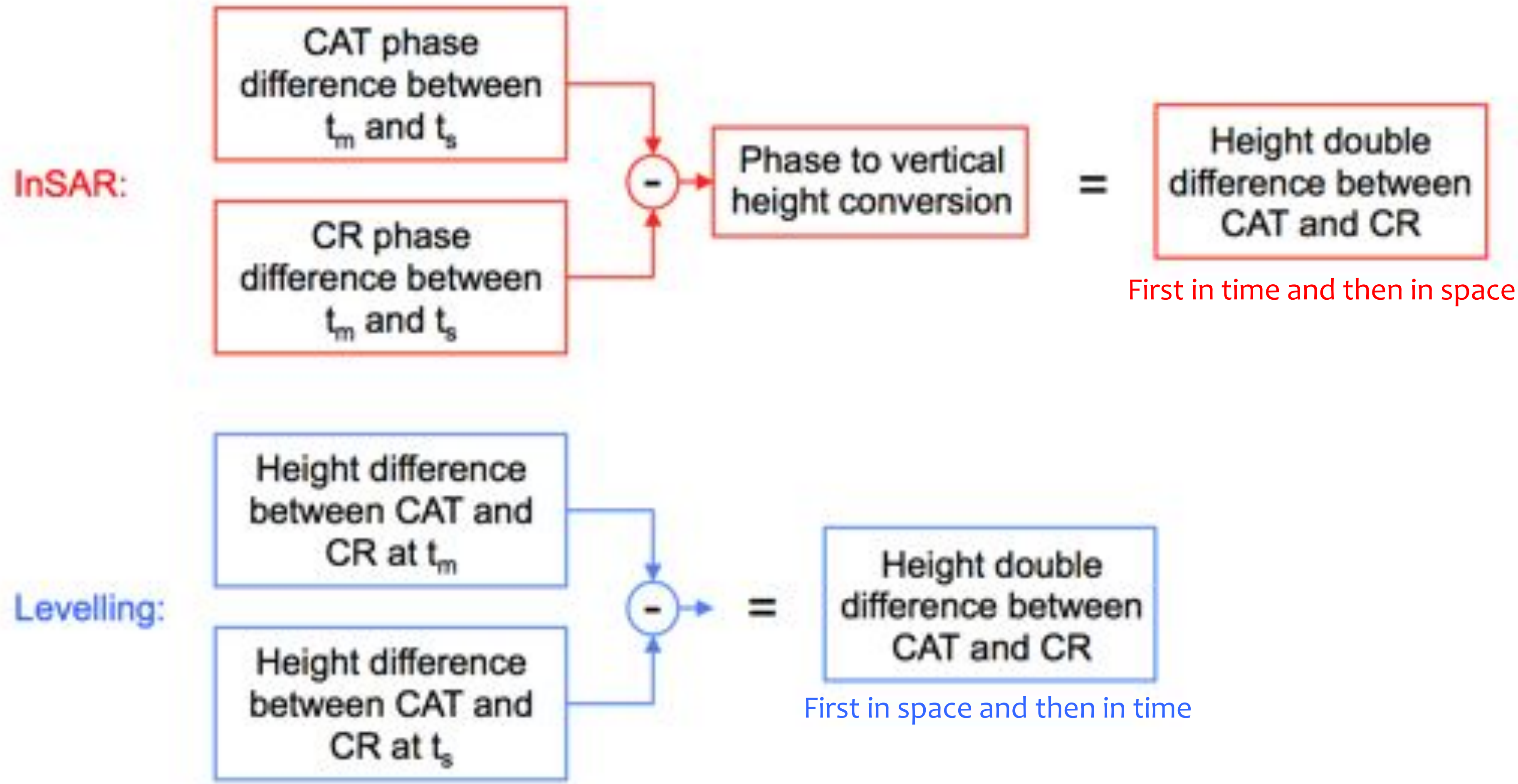

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Previous Delft CR experiment

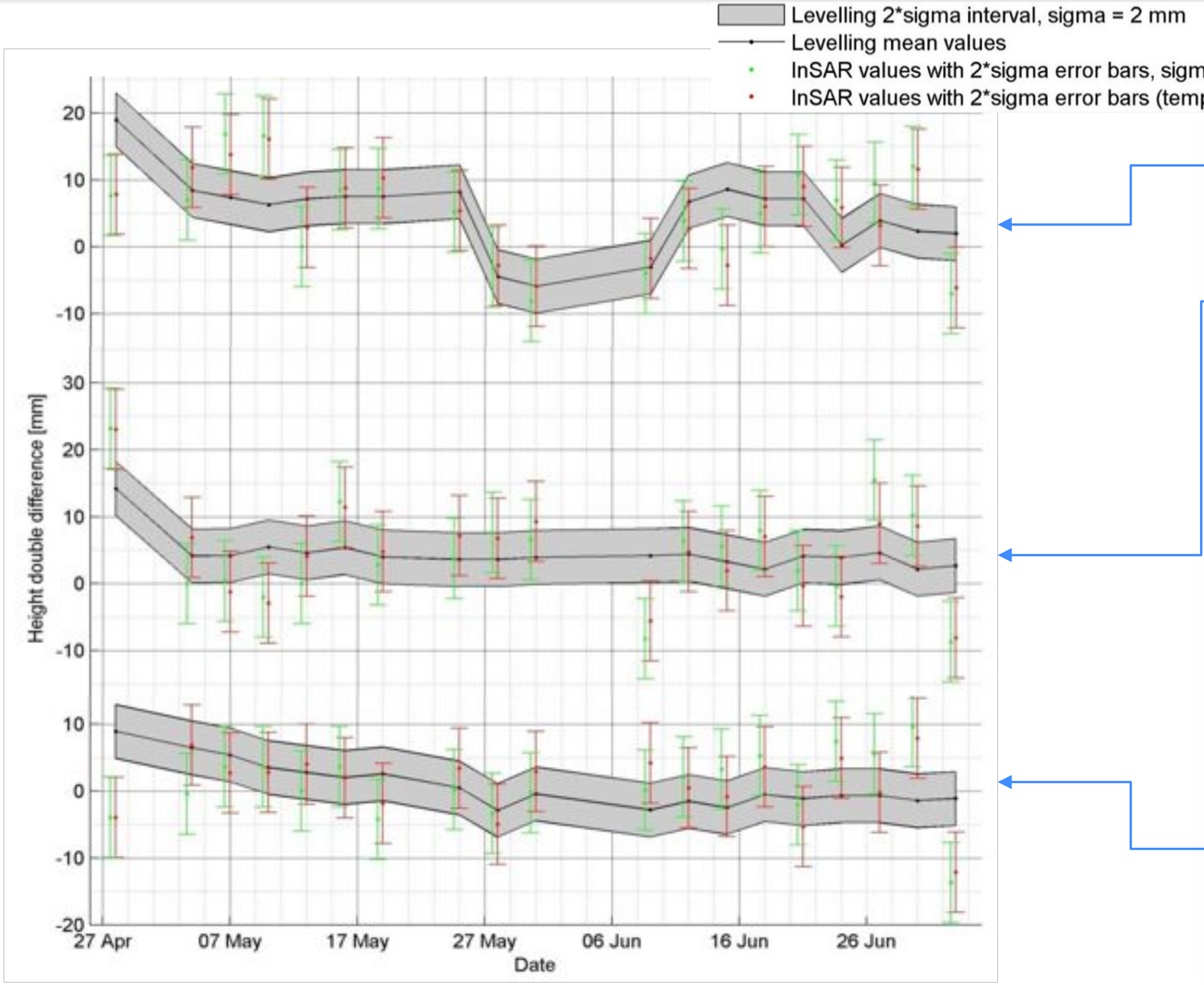
- **Controlled CR experiment** in Delft
- Five CRs deployed (2003 - 2007)
- InSAR ***a posteriori* precision** for **CR-CR double differences** with ERS-2 data after subpixel correction = **2.9 mm**

  (1σ standard deviation in the vertical direction)

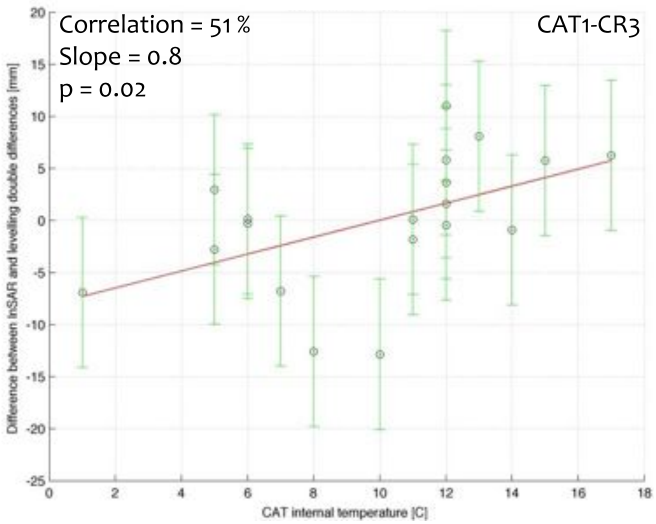
Reference

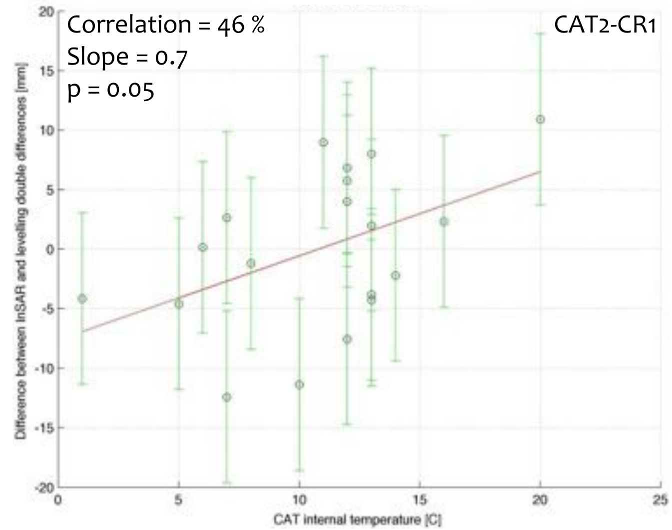
P. Marinkovic, G. Ketelaar, F. van Leijen, and R. Hanssen.
'InSAR quality control: Analysis of five years of corner reflector time series.'
In Fifth International Workshop on ERS/Envisat SAR Interferometry, 'FRINGE07', ESA-SP 649, 2008.

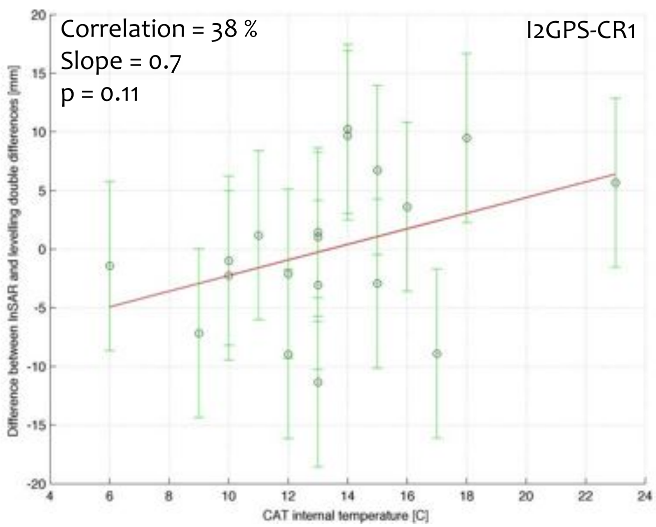
Comparison results



Basis of temperature correction







p is the **probability of getting a correlation as large as the observed value by random chance**, when the true correlation is zero.

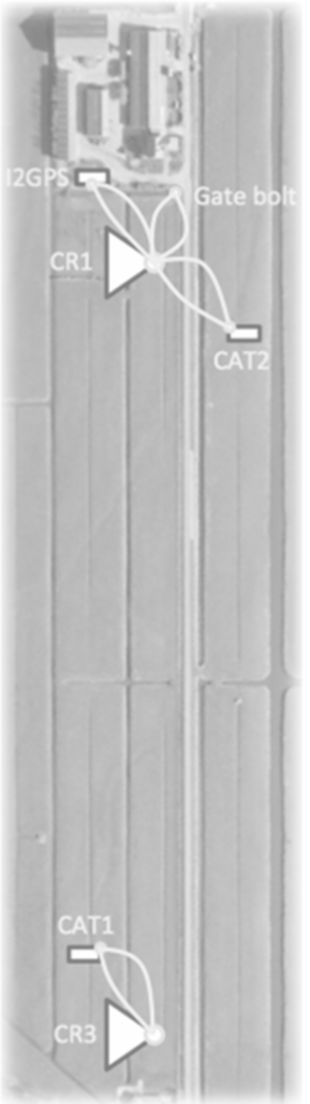
If p is small, say <0.05, then the **correlation is significant**.

A posteriori precision

Variance component estimation:

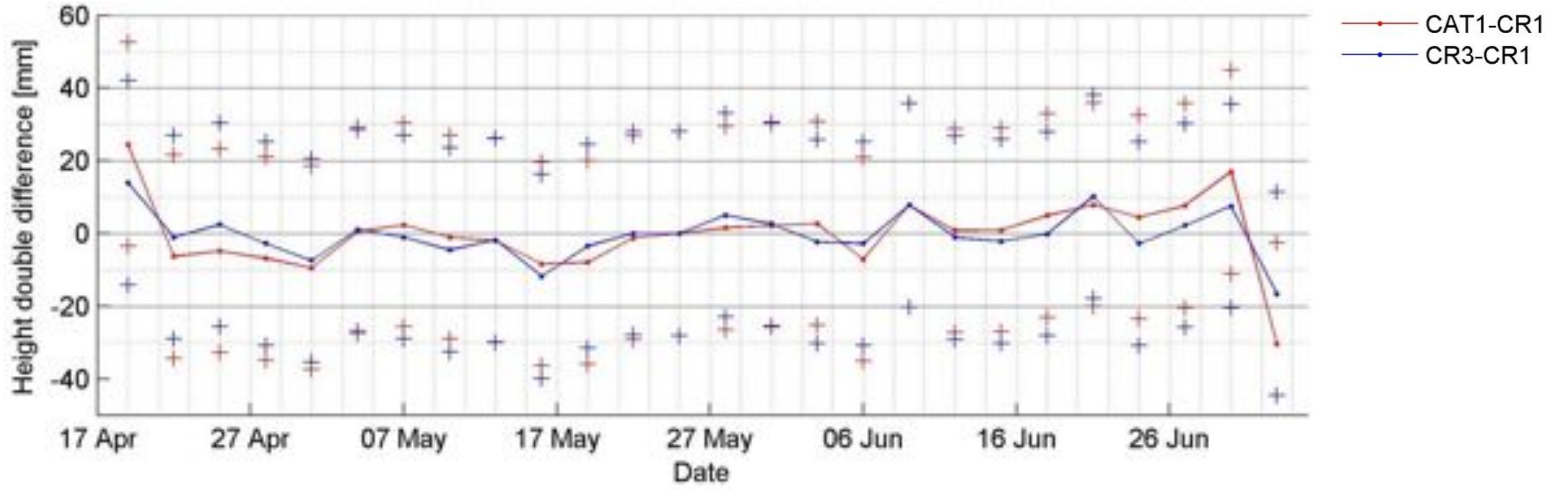
Pair	Without temperature correction	With temperature correction
CAT1 – CR3	3.6 mm	3.4 mm
CAT2 – CR1	5.3 mm	4.9 mm
I2GPS – CR1	5.0 mm	4.6 mm

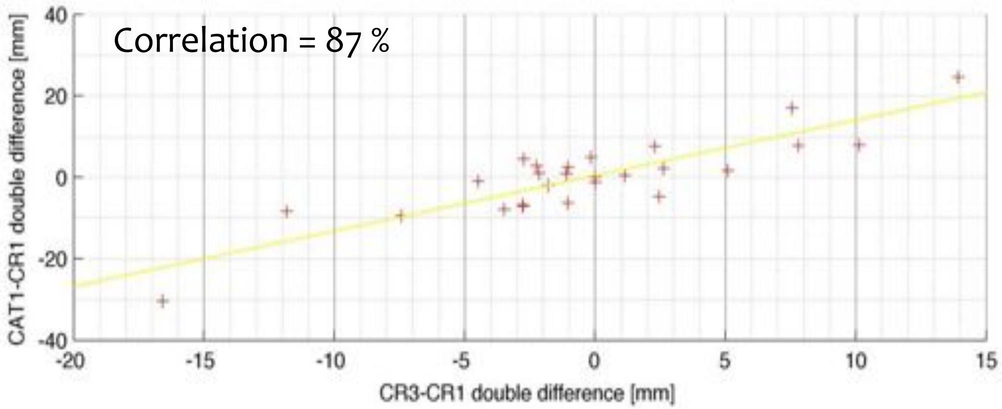
- For InSAR **CAT-CR double differences** with ERS-2 data, the average ***a posteriori* precision**
  - Without temperature correction = **4.6 mm**
  - With temperature correction = **4.3 mm**
- Values are 1σ standard deviations in the vertical direction

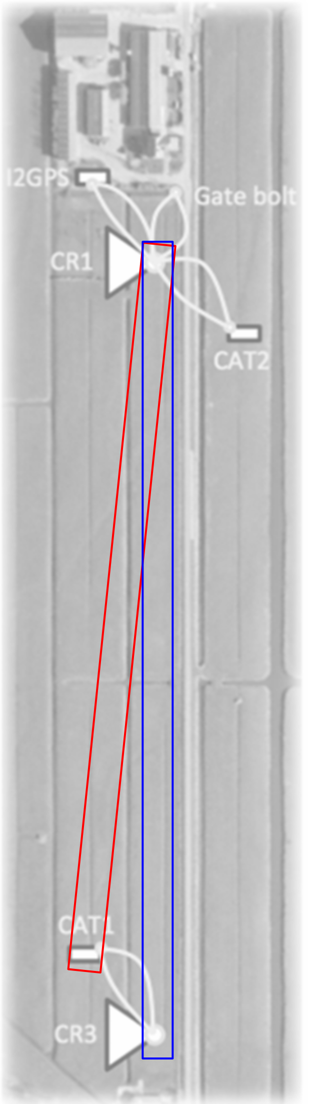


Can a CAT replace a CR?

Comparison of CAT-CR and CR-CR double differences over ~450 m:







Summary and conclusions

- The average ***a posteriori* precision** of **CAT-CR double differences** with ERS-2 data
  - Before temperature correction = **4.6 mm**
  - After temperature correction = **4.3 mm**

} Without outlier removal

Summary and conclusions

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- This can be compared with the **CR-CR double differences** from the **previous CR experiment** in Delft. The *InSAR* ***a posteriori* precision** after subpixel correction for ERS-2 data was
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  - With outlier removal = **2.9 mm**
- **Within a 95% confidence interval, the CAT-CR measurements (2011) are as precise as the CR-CR measurements (2007)**
- Further work: rigorous outlier removal, validation in a landslide-risk area in Slovenia with GPS

Thank you!