CNES R&D

and available software

for Space Images based

risk and disaster management

Geo-Information for disaster management
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Use of satellite images for disaster management (1/2)

Advantages:

- **Spatial coverage** **$(10\text{-}20\ km)^2$ for very high resolution satellites,**
  $(60\text{-}100 km)^2$ for high resolution ones – *Spot5, Envisat* -
  $(500\text{-}1000 km)^2$ for global coverage ones -*Vegetation*-
- **Many operational satellite systems, at different resolution hence adapted to different kind of disasters**
- **Acquisition possible independently from local facilities (telecommunications, operators), processing possible in remote sites**
- **Archive images growing**
- **Optical and / or Radar images possible: complementarity**

BUT

Use of satellite images for disaster management (2/2)

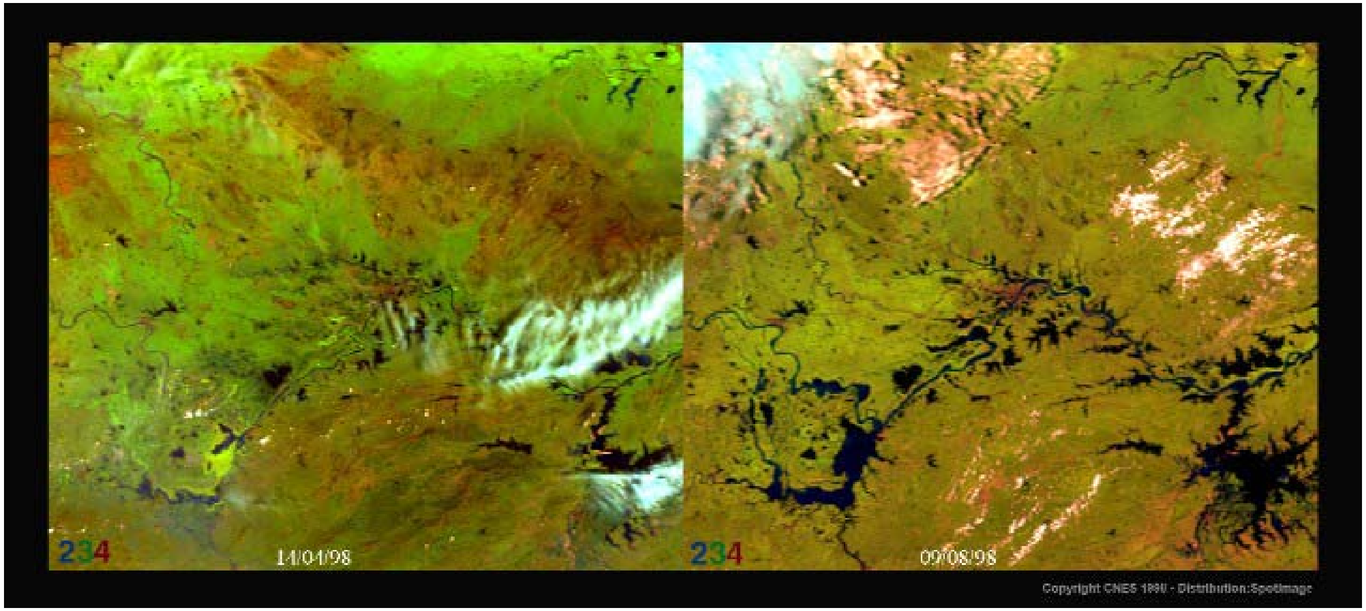
⇨ **Operational timing constraint: no real time acquisition yet**

⇨ **Images are not directly interpretable => much work required from raw data to usable information**

- Images co-registration / geo-referencing
- Change detection
- Damage assessment
- Product generation (adding map info, etc…)
- Transfer to the local authorities (fax, email, ftp…)

Almost real-time acquisition and operational systems dedicated to risk are a pre-requisite to provide really usable spatial products (on time, with the useful information).

Case 1: Flood in China



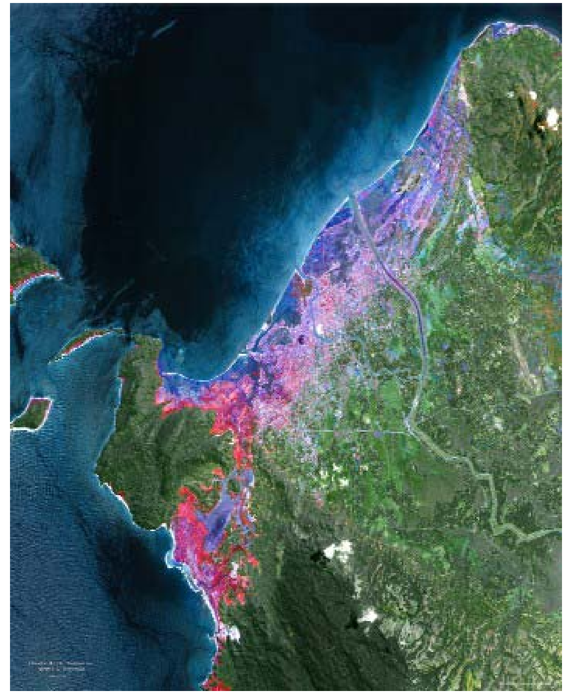
Before | **After**

- Extension has been assessed at a very large scale
- 1km resolution optical images used (Vegetation on Spot4)
- No damage assessment

Case 2: Tsunami

Before

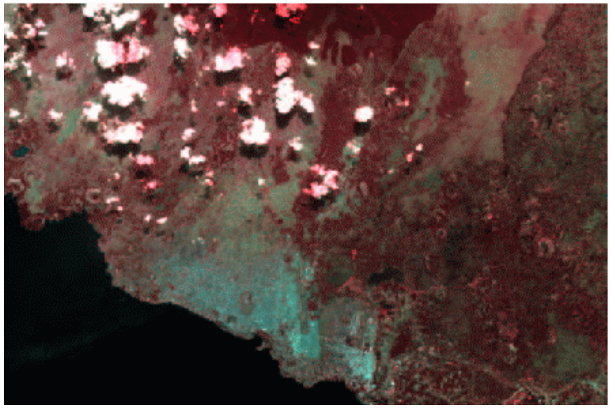
After



Change image (manual process)

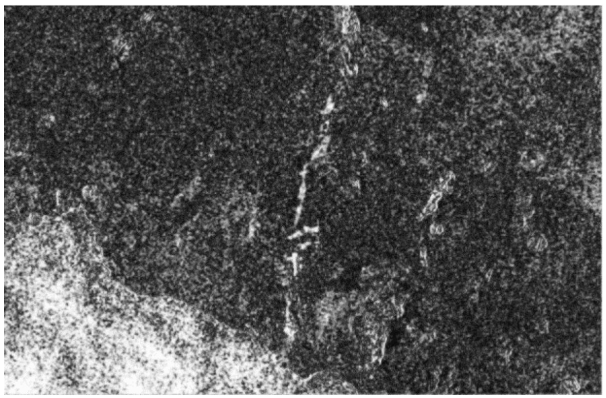
- ⇨ **Many images should be used because of the spatial extend**
- ⇨ **Locally, 2.5 resolution optical images used (Spot5)**

Case 3: Nyiragongo (Congo): Smaller extend. Clouds => Radar images used

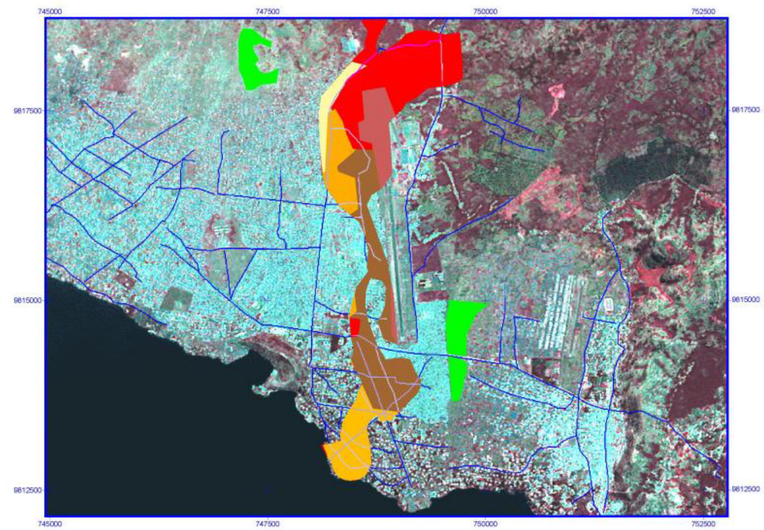


Spot P+XS image (before)

An optical image from the archived is used for <u>land cover</u> estimation.
A before/after radar images pair (all weather) allows for <u>damage assessment</u>.
Their joint use allows to recognize the type of damage.



Radar images based change detection
Before / After (automatic)



Damages assessment

Discussion

- ⇨ **Every case is different (in terms of disaster)**
- ⇨ **One uses the first available image after the disaster, and has to build the more adequate processing sequence, depending on**
  - Available archive images (instrument, spectral bands…)
  - Knowledge / availability of local DEMs
  - Availability of local maps
- ⇨ **To be reactive, one should tend to <u>automated processing</u>**

BUT what is common to all cases is

- ⇨ **The need for image co-registration (=> superimposable image)**
- ⇨ **The need for geo-referencing (if data used is not already geo-referenced)**

Images co-registration (1/4)

- **Superimposability must be accurate (typically better than ~0.5 pixels)**
- **Pre-requisite for change detection algorithms**
- **Ideally, should be achieved (but not easy)**
  - Without any knowledge about local DEM
  - Without any knowledge about acquisition geometry
  - Even after disaster, when landscape has changed locally
- **In practice, when images are geo-referenced independently, they do not have, on the whole image, such a co-registration accuracy => even in this case, need for fine co-registration before change detection.**

Images co-registration (2/4)

<u>SIMILAR IMAGES</u>

⇨ **Optical to Optical images**

- **General principle: shifts computation based on maximisation of local correlation, then one image is re-sampled to the geometry of the other**
  - 0.02 accuracy achievable (case of similar images, good quality interpolation filters, well sampled images), but poor accuracy may be experienced in particular with non similar images
  - In case of <u>disaster</u>, images <u>locally non similar</u>, because
    - elapsed time between acquisitions
    - surface changes due to damage
  - Damage assessment itself based on radiometry changes !!
- **Hence co-registration must be performed using homologous points on non-damaged areas, and interpolating / extrapolating on damaged areas**

Images co-registration (3/4)

SIMILAR IMAGES

⇨ **Radar to Radar images**

- **On same incidence images**
  - Good results using SLC because same speckle (interferometric conditions)
  - But no real add-on value for co-registration. Better use multi-look images correlation
- **On images with different incidences**
  - When acquisition angles become slightly different, speckle noise changes => accuracy decreases.
  - When acquisition angles are very different, ML images become very different =>
    - ➢ Refinement of NR and acquisition start time of both images by image simulation (using DEM)
    - ➢ Projection of both images on the terrain
    - ➢ Local co-registration like for optical images.

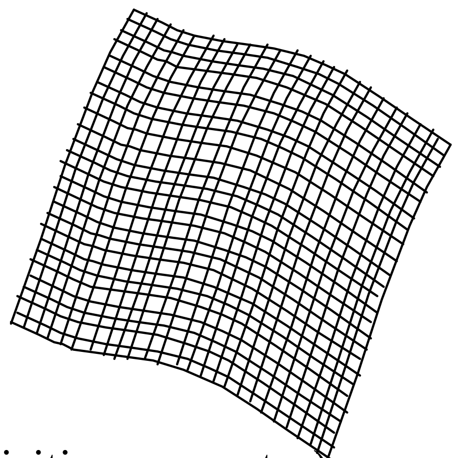
Images co-registration (4/4)

MULTI-SENSOR IMAGES

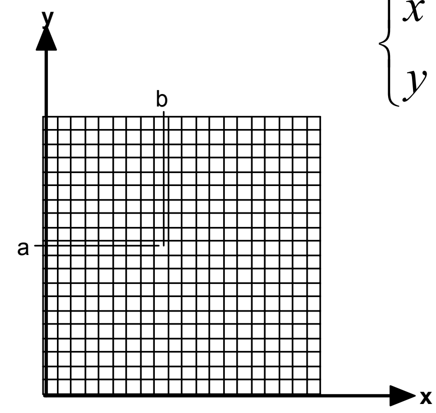
- **Correlation technique no more applicable**
- **Recent R & D work performed in the field of space images, based on algorithms already used in the medical imaging community**
  - Locally, radiometry is considered as a random variable (area must be large enough, larger than for correlation)
  - Measurement of the statistical dependence between the two distributions
  - Search for the position of the maximum similarity value => homologous points
- **Applicable to Radar / Optic but also Optic / Optic pairs, in different spectral bands**

Images geo-referencing (1/4)

Geo-referencing is THE condition for being able to use map information



Raw image (acquisition geometry)



$$\begin{cases} x = x0 + r * b \\ y = y0 - r * a \end{cases}$$

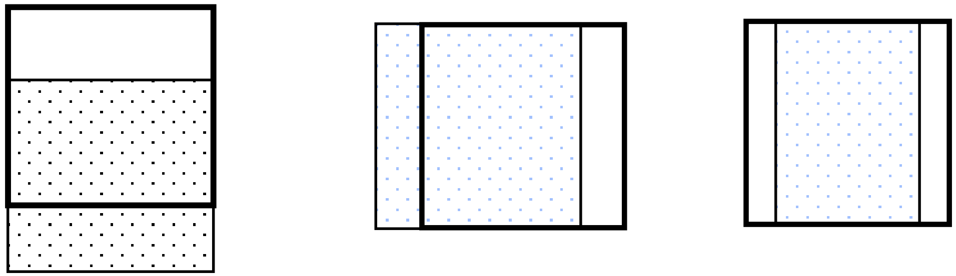
Geo-referenced image geometry: superimposable to a map

⇨ **Satellite position and attitude errors impact the geo-referencing, both globally and locally**

Images geo-referencing (2/4)

GLOBALLY

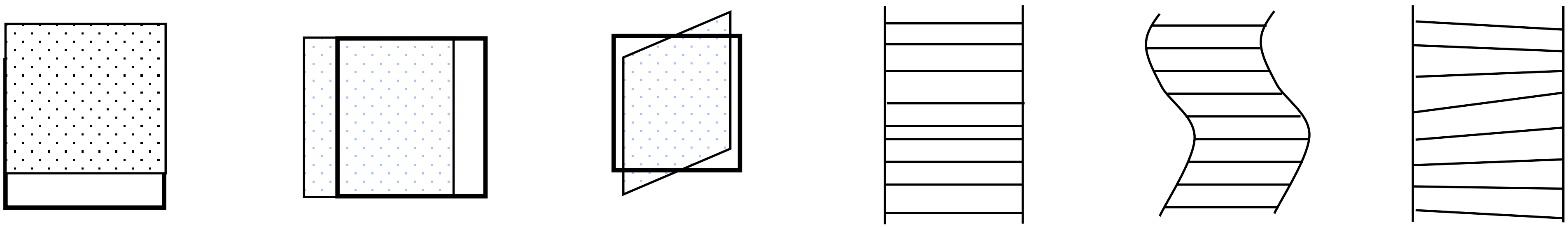
Impact of satellite <u>position</u> restitution errors



Along-track Across-track Altitude

Impact of satellite <u>attitude</u> restitution errors

<u>Biases</u> <u>Variations in time</u>

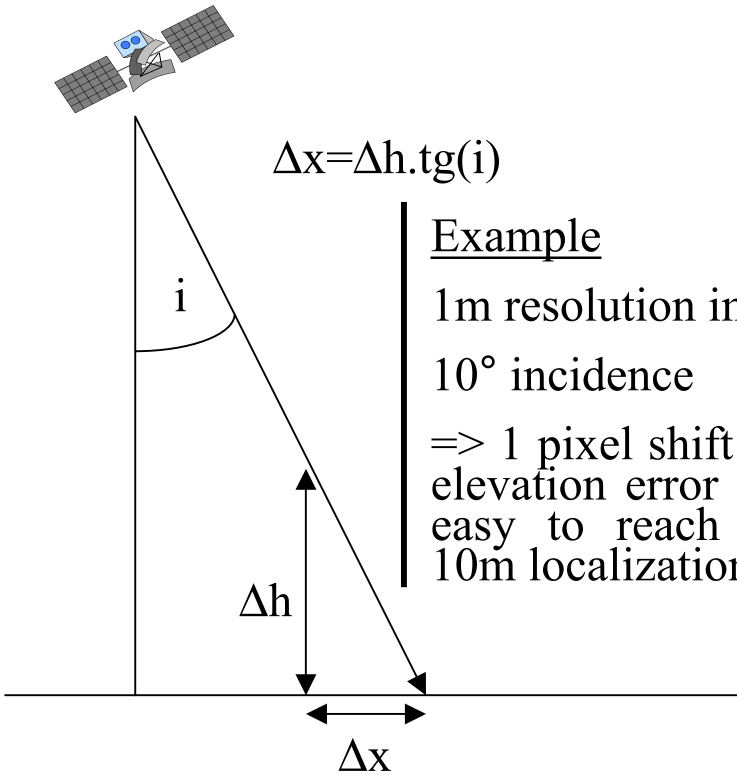


Pitch Roll Yaw Pitch Roll Yaw

Images geo-referencing (3/4)

LOCALLY

Satellite position / attitude restitution errors
=> errors on local elevation estimate

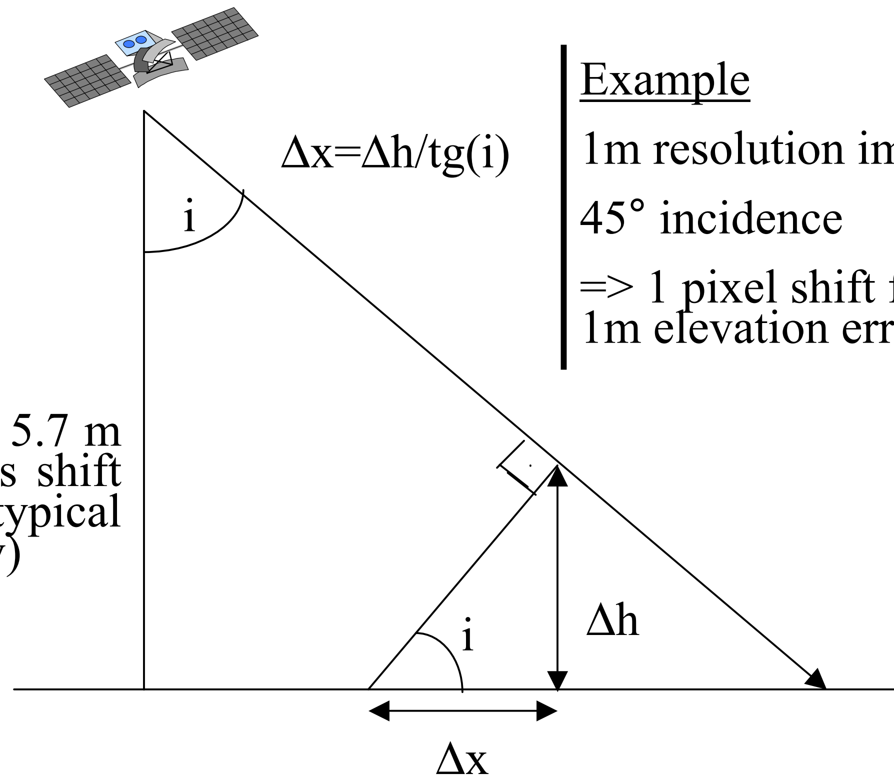


Example

1m resolution image

10° incidence

=> 1 pixel shift for every 5.7 m elevation error (0.5 pixels shift easy to reach with a typical 10m localization accuracy)



Example

1m resolution image

45° incidence

=> 1 pixel shift for every 1m elevation error

Images geo-referencing (4/4)

Conclusion on geo-referencing:

⇨ Even with already geo-referenced images, superposition is likely to be not precise enough for accurate change detection.

(experience with optical images times series, and optical to radar superposition)

=> There is always a need for automatic co-registration

⇨ The impact of non accurate geo-referencing is more sensitive with high resolution, proportionally to the resolution

⇨ With high resolution images, we are close (or already beyond) the accuracy of the map themselves (when available)… Therefore, for a fully automatic process, one should think about automatic **map to image co-registration**.

Change detection and information extraction (1/2)

- **Geometrical changes (e.g. Surface movement measurement)**
  - Shifts measured by optical correlation or radar interferometry
- **Radiometrical changes: CNES has implemented the following algorithms**
  - Intensity ratio, at pixel level
  - Mutual information, on a local area
  - Local morphological gradient average direction
  - Comparison of probability density distance (before / after disaster): has proven to be well suited for radar images acquired at different incidences
  - Loss of coherence (radar/radar but also optic/optic)

But a promising direction is the comparison of image objects

Change detection and information extraction (2/2)

⇨ Objects extraction

- CNES has been working on automated man-made object recognition (road, roundabouts, suburbs, bridges, isolated buildings…)
- Supervised learning approach based on Support Vector Machines
- Evaluation with the confusion matrix (good detection, non detection, false alarm)
- **Results**: with 10 object classes, 150 learning examples / class

  => 80% of good detection achieved
- Drawback: slow process => extensive tests difficult, in particular on large images like Spot5 ones (24000*24000 pixels)

  => Need for pre-selection using a different technique (pre-conscious user models used)

CNES software for risk management

Aim: Automatic production of damage maps

- Superpose images acquired at different dates, from any satellite instrument, radar or optical
- Detect changes
- Produce damage maps

Development environment: Python (portable, automatic MMI building)

- Not fully available yet, but expected soon. Underlying software used:
  - Geometrical modelling
  - Re-sampling
  - DEM generation (when not already available)
  - Object recognition
  - Change detection

CNES research program related to risks

⇨ **R&D on-going work**

- Continuation on object extraction (improvement of computer time by a two-pass method)
- Implementation of optical to radar image geometrical models
- Continuation of work on radar stable detectors
- Development of algorithms for optic / radar change detection