



SAR images statistics and preprocessing

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Lecture D3Pb4



SAR measurement

Statistical properties and data preprocessing



SAR images

The basic measurement made by a SAR is S (amplitude and phase). This is the **complex image**.

Main types of images:

A is the **amplitude image**.

$I = A^2$ is the **intensity image**.

(the phase of a single image is not exploitable)



Exploitation of multiple images

multi temporal, multi polarisation, multi incidence

◆ **polarimetric images** derived from S the complex image if the SAR system is polarimetric

◆ **interferometric images**
(coherence, phase) derived from S

➔ ASAR repeat pass

◆ **multi polarisation intensity images**

➔ ASAR APP

◆ **multitemporal intensity images**

➔ ASAR



The radar cross-section

The radar cross-section (RCS) is defined as

$$\sigma_{pq} = 4\pi \left| S_{pq} \right|^2 = 4\pi R^2 \frac{P_s}{P_i} \quad [\text{m}^2]$$

R is the radar-target distance

P_i is the incident power,

P_s is the power scattered by the target.



The backscattering coefficient

For **distributed targets** each resolution cell contains many scatterers and the phase varies rapidly with position.

The **differential backscattering coefficient**, σ^o , is

$$\sigma^o = \frac{4 \pi R^2}{\Delta A} \frac{P_s}{P_i} \quad [\text{m}^2/\text{m}^2]$$

where ΔA is the area of the illuminated surface over which the phase can be considered constant.



What is a SAR image?



The image is seen as a **picture**.

Pixels are **numbers**.

Image is affected by **speckle** noise

Most commonly used: Intensity image



Speckle effects



Same image, with speckle reduced



Estimating the backscattering coefficient

Given L independent measurements from a uniform distributed target, the MLE of σ^0 is given by

$$I = \frac{1}{L} \sum_{k=1}^L I^{(k)}$$

where the $I^{(k)}$ are individual intensity measurements.

N.B. This does not depend on the original form of the data (amplitude, intensity or complex).

L is called the **number of looks**.



The multi-look intensity distribution

The PDF of I is:

$$P_I(I) = \frac{1}{\Gamma(L)} \left(\frac{L}{\sigma} \right)^L I^{L-1} e^{-LI/\sigma} \quad (1)$$

Hence $\langle I \rangle = \sigma$ $\text{var}(I) = \frac{\sigma^2}{L}$

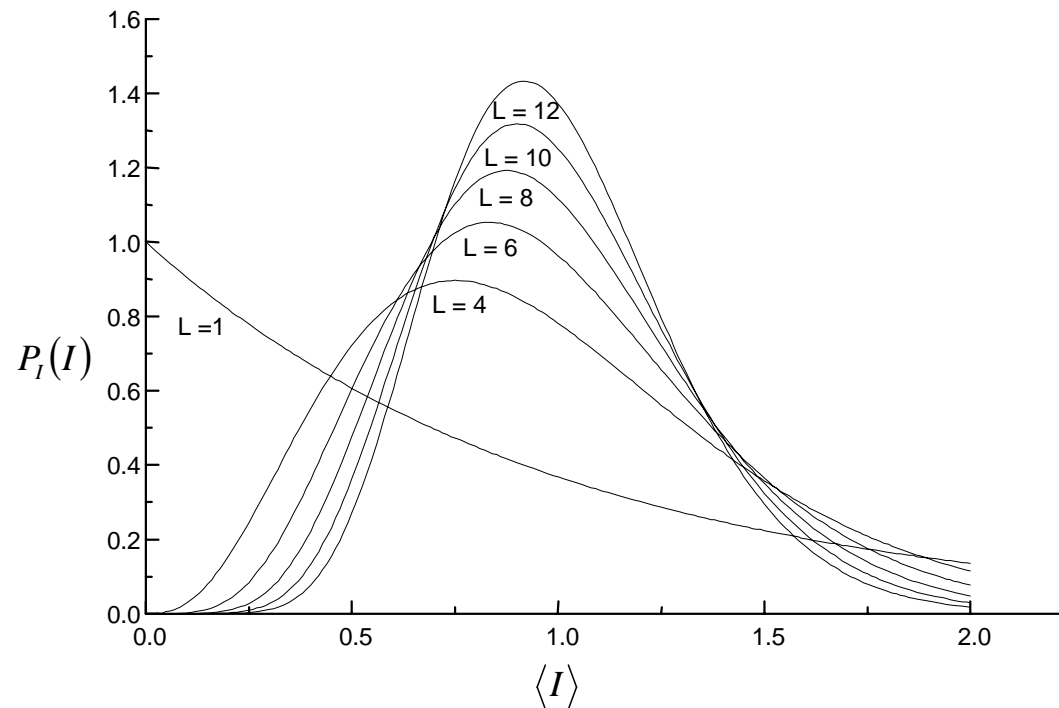
Coefficient of variation = CV = SD/ mean $\frac{1}{\sqrt{L}}$.

Putting $L = 1$ (single look) gives SD = mean, CV = 1.

For calibrated data, the symbol σ in (1) is equal to σ^0 .
More generally, it will be **proportional** to σ^0 .



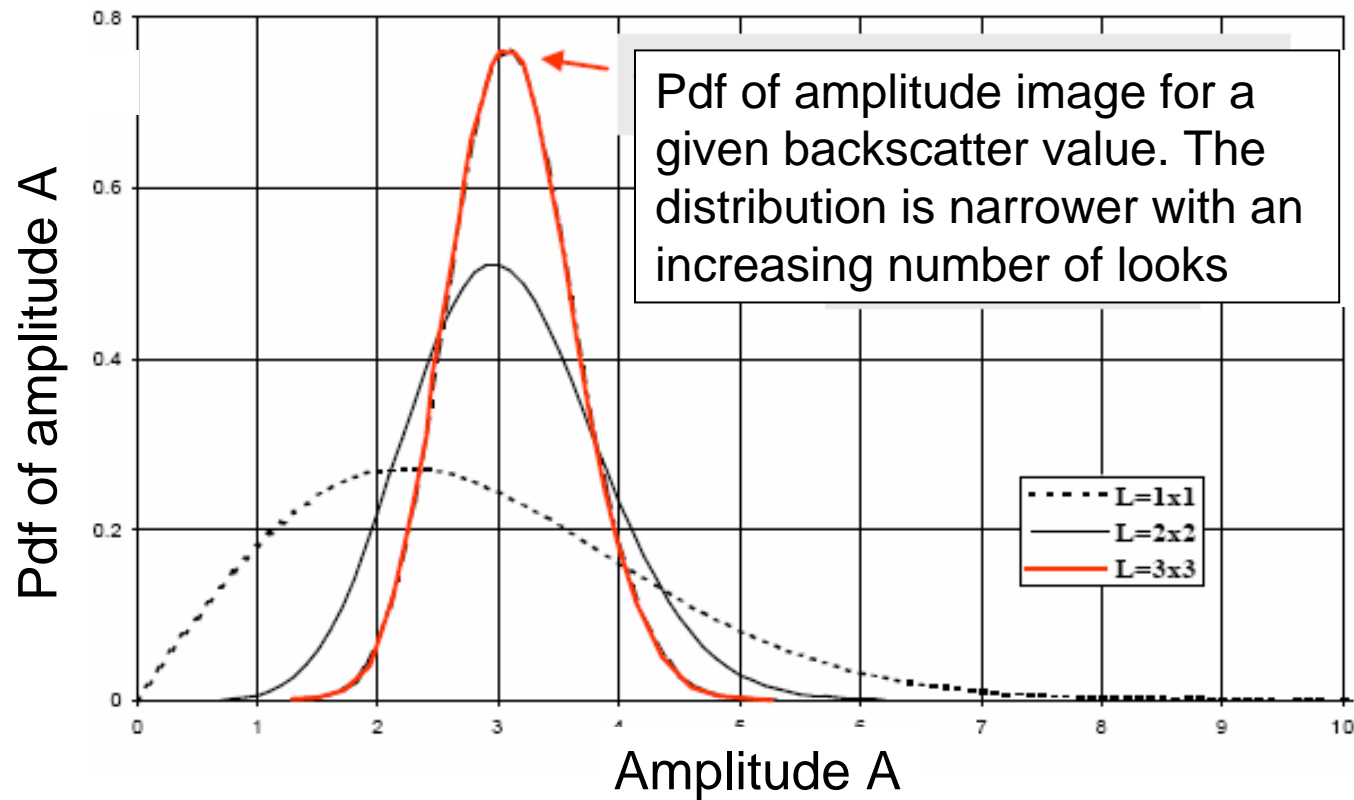
The gamma distribution



Unit mean Gamma distributions of orders of 1, 4, 6, 8, 10 and 12. The distribution tends to normality as L increases.



Speckle: Multilooking effect





Equivalent Number of Looks (ENL)

In SAR intensity data, the speckle variance is proportional to the mean intensity squared.

$$\text{ENL} = \frac{(\text{mean})^2}{\text{variance}}$$

If ENL is **large**, the spread of values due to speckle is **small**.



Speckle filtering

To reduce the speckle noise in order to retrieve the useful information content: structure in images, physical information..

1. Frequency filtering: spectral filtering during SAR processing
ASAR images provided to users: 3 Looks

2. Spatial filtering: local estimation on gliding windows
Filters of Lee, Kuan, Frost, MAP widely available

3. Multi channel filtering: applied on multiple images of the same scene multi polarisation, multi temporal, and multi frequency

ASAR dual polarisation and multitemporal images



Spatial filtering and adaptivity

Various methods are available

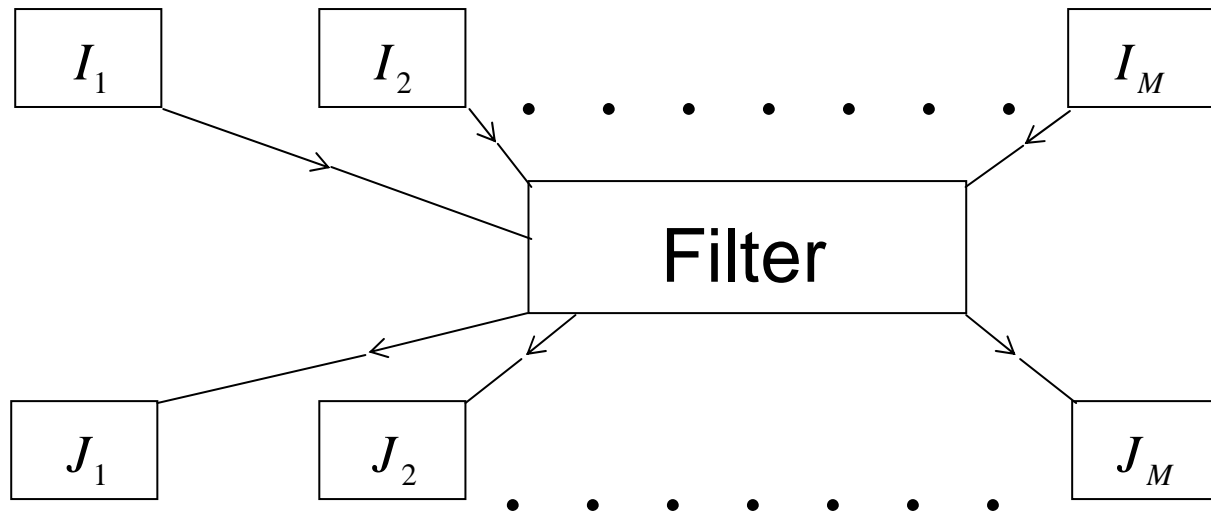
- ◆ Minimum mean square error (Kuan and Lee)
- ◆ Maximum a posteriori MAP (applicable to textured regions)

The filters tend to degrade resolution unless they use spatially adaptive windows to estimate local filter parameters (e.g. Frost).



Multi-image Intensity Filtering

Original Images



Filtered images

Purpose of filter:

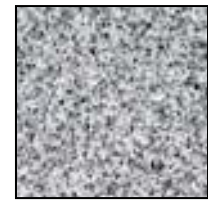
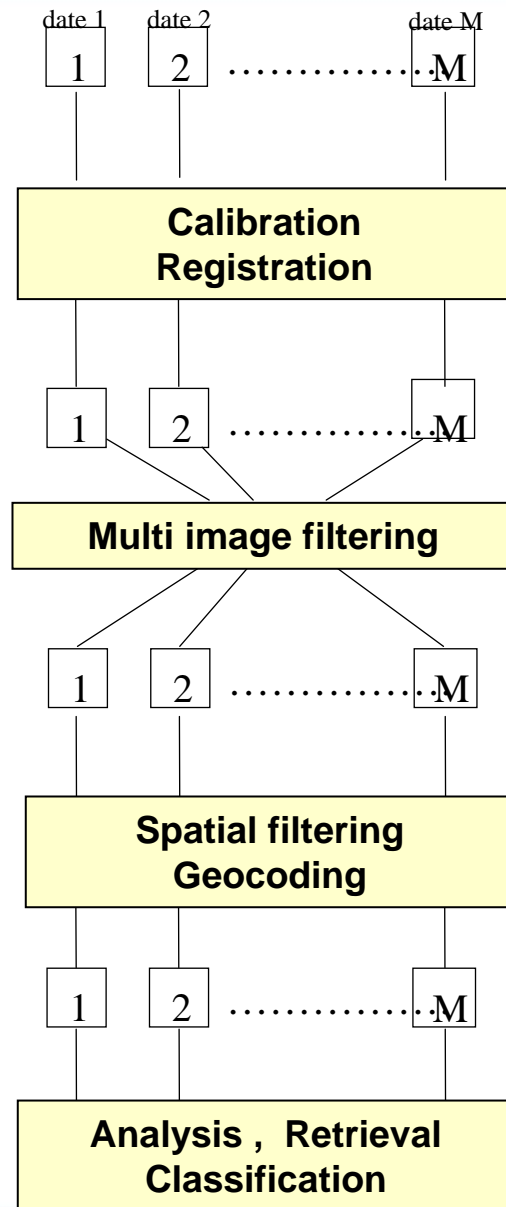
(1) Preserve radiometry \Rightarrow unbiased

$$\langle I_k(x, y) \rangle = \langle J_k(x, y) \rangle \quad 1 \leq k \leq M$$

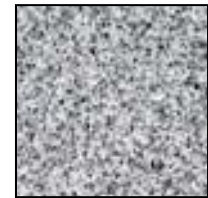
(2) Minimise the variance of J_k subject to the M constraints in (1)



Processing chain



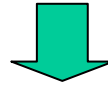
Initial images



Calibrated
coregistered



Filtered



Filtered
geocoded

- Example of Chain developed using:
- Gamma ASAR (Gamma RS)
 - Multi-image filtering (Quegan et al., 2000)
 - Temporal change (Le Toan et al., 1997)



Image preprocessing

1. Calibration, to convert the data to standard geophysical measurement units.
2. Geocoding, to allow the data to be referenced to a map and to allow geolocation.
3. Registration, to make sure multiple images can be matched point to point.

There are well-developed methods for each of these operations.



Calibration

Calibration is the process converting voltages measured at the sensor to geophysical units; (usually σ^0).

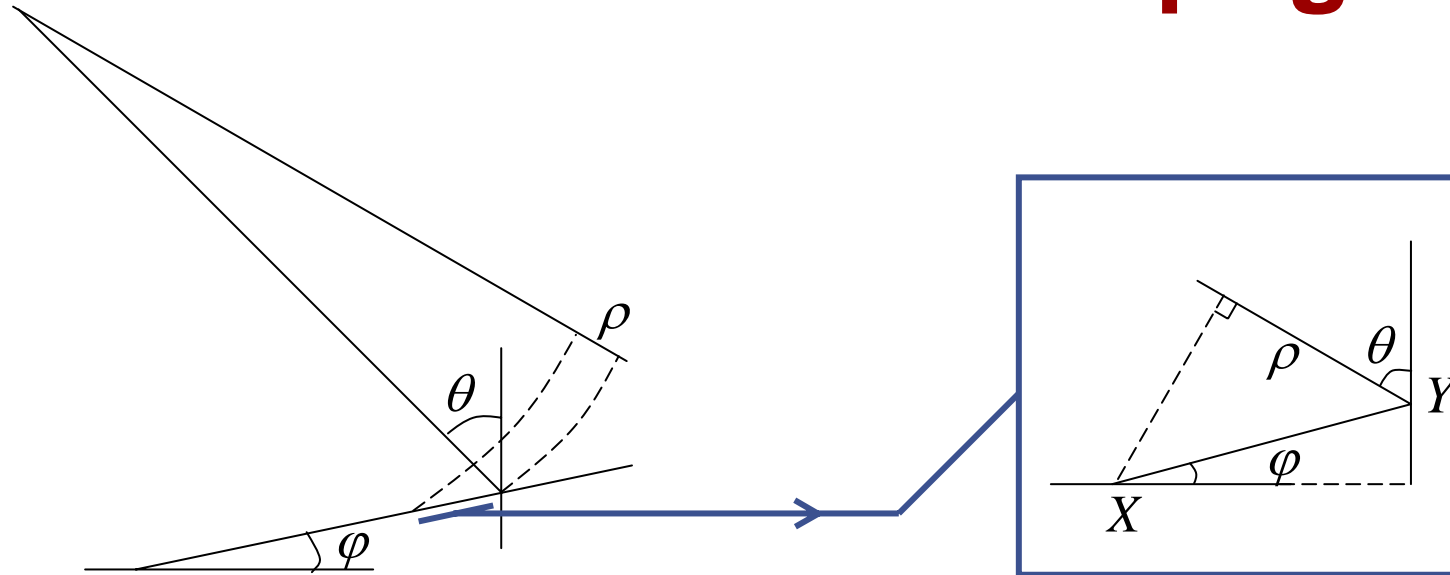
Relative calibration ensures that the values everywhere in a single image are **proportional** to σ^0 .

Calibration is **essential** to allow comparison of data from

- ◆ different sensors
- ◆ different times
- ◆ different positions



Radiometric Effects of Topography



$$XY = \frac{\rho}{\sin(\theta - \varphi)}$$

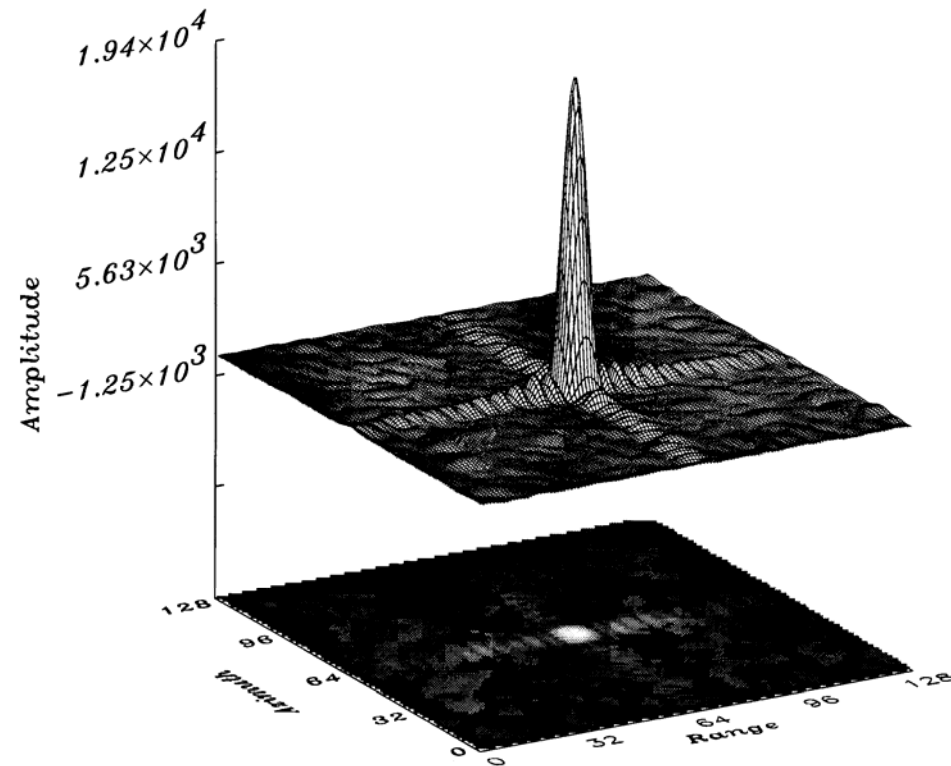
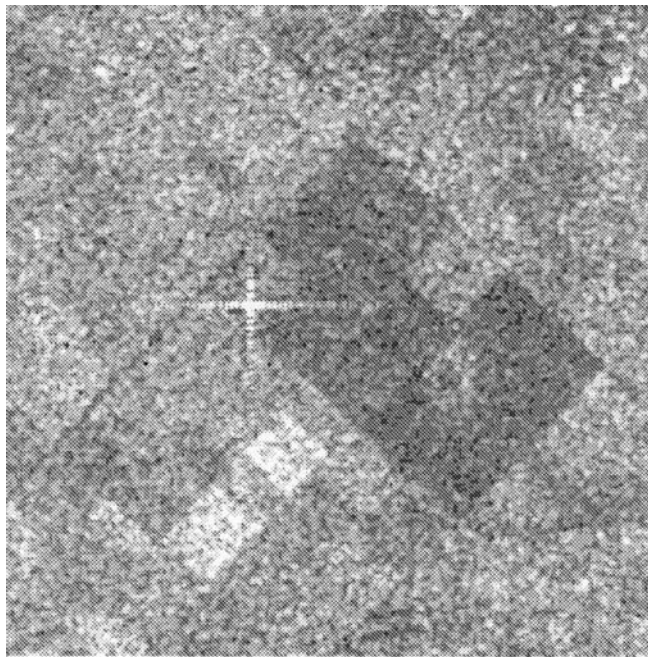
$$\text{Power / m}^2 \propto \cos(\theta - \varphi)$$

$$\text{Relative increase in returned power} = \frac{\sin \theta}{\sin(\theta - \varphi)}$$



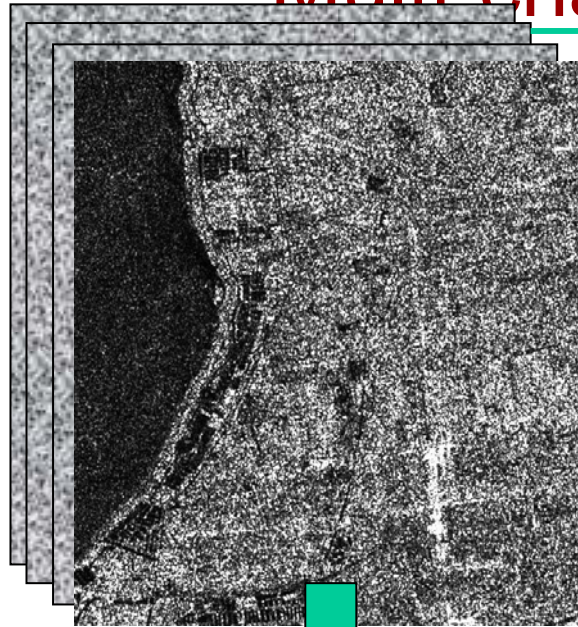
Coregistration

Example: Use of the point spread function in spatial correlation





Multi-channel speckle filtering



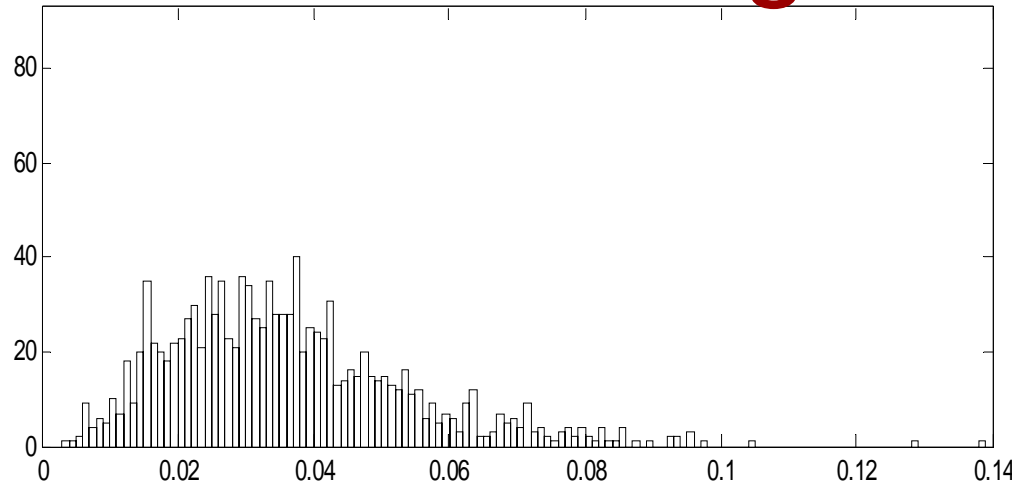
Intensity 3 Looks
images
Hongze (Jiangsu)
2004 09 06



Filtered images
using HH, VV
at multidates (10)

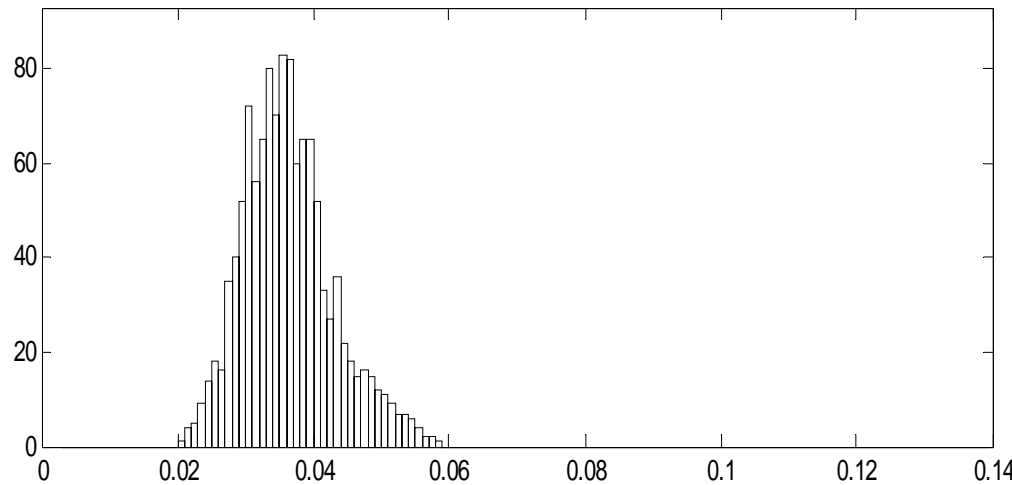


Multi image filtering



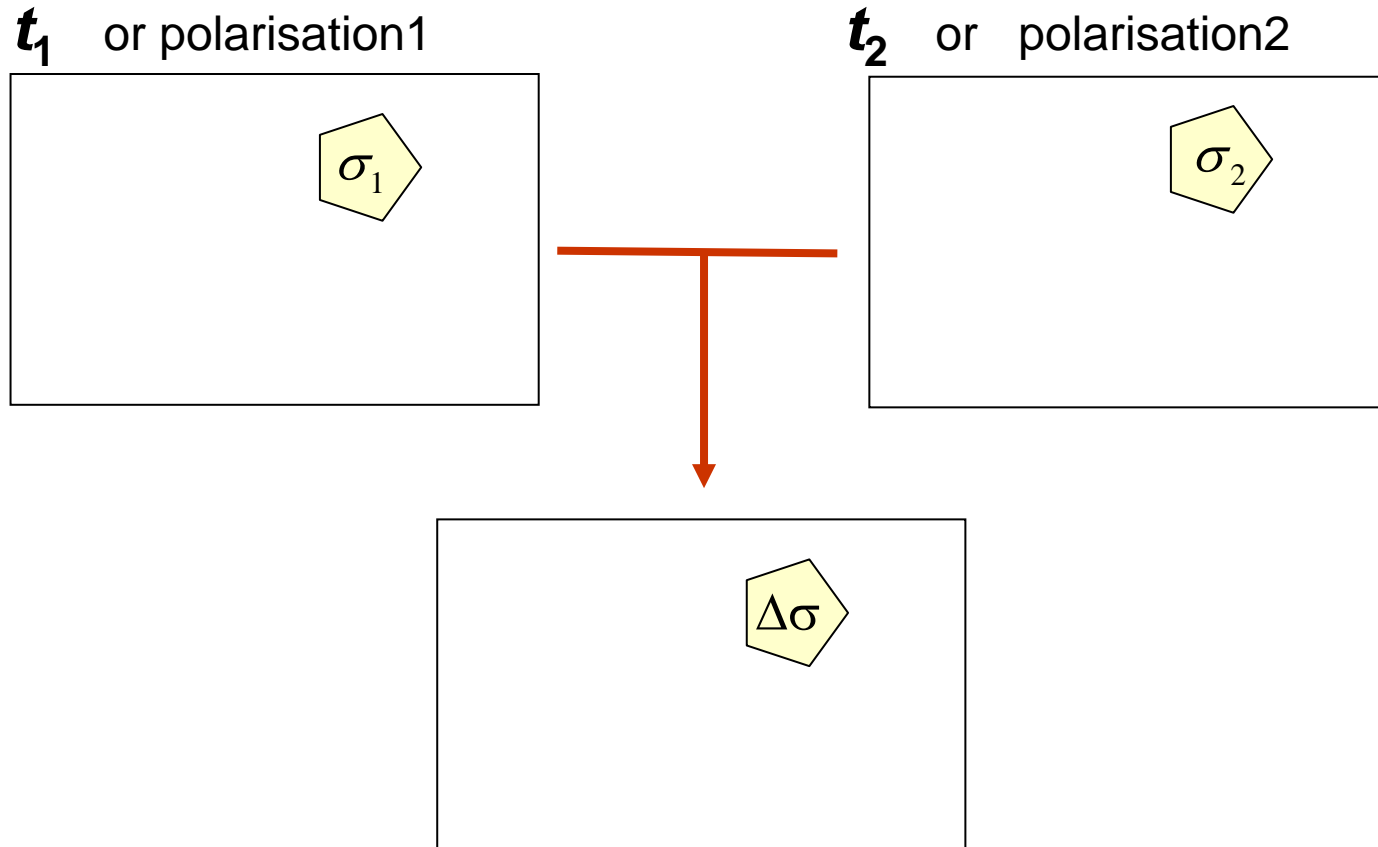
Histogram of a homogeneous area before and after filtering using 6 dates HH and VV (12 images)

Initial: APP 3 Looks





Changes in backscatter



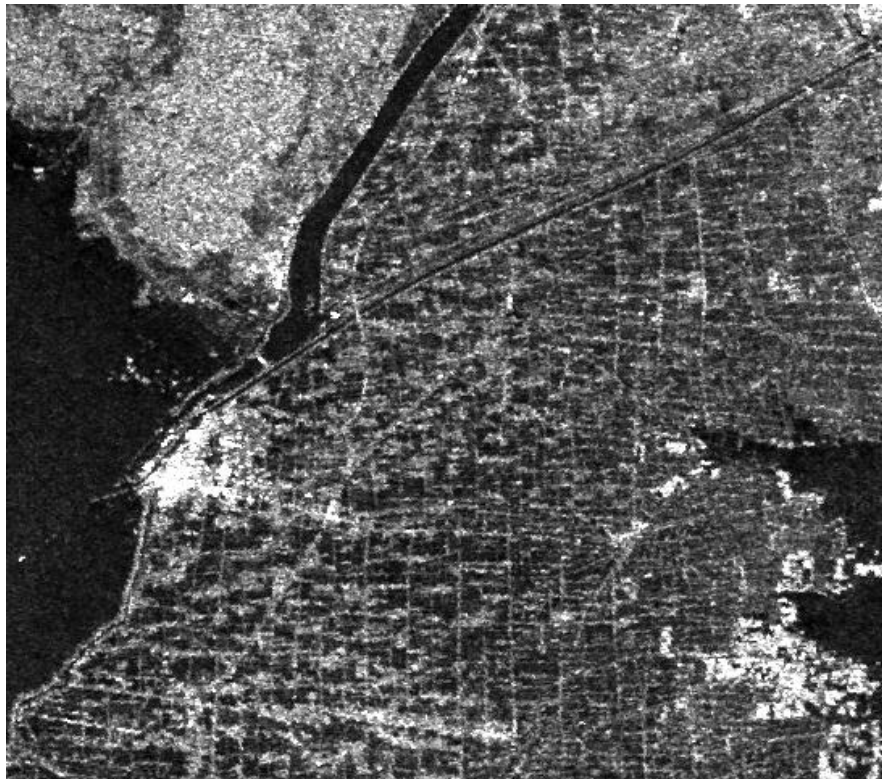
Temporal or polarisation changes



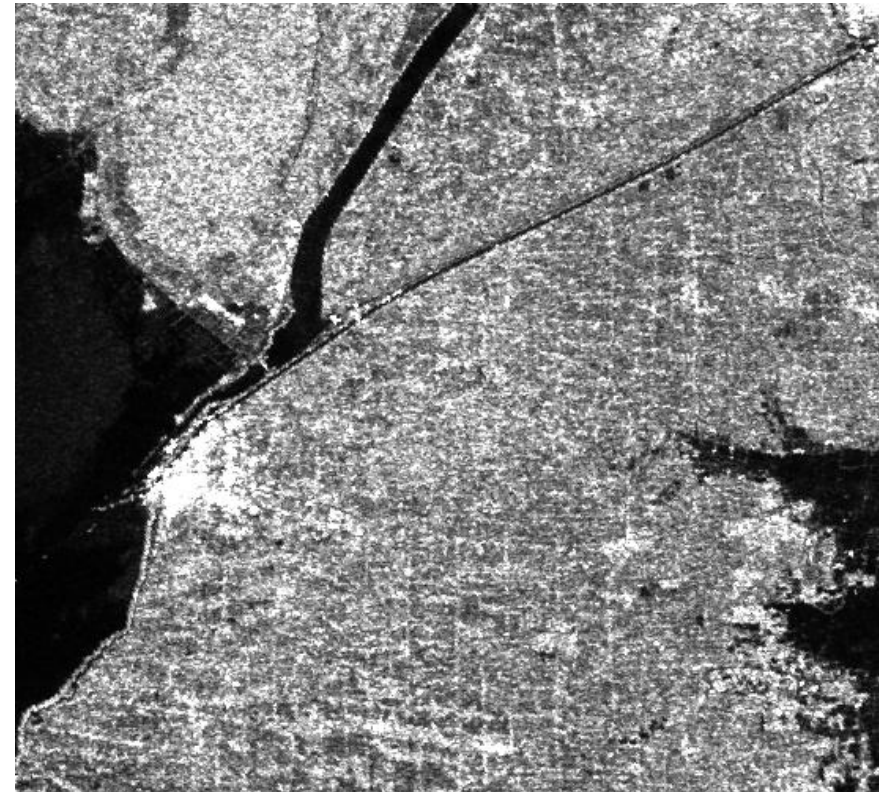
Changes in backscatter

Temporal change

2004 08 18



2004 10 08

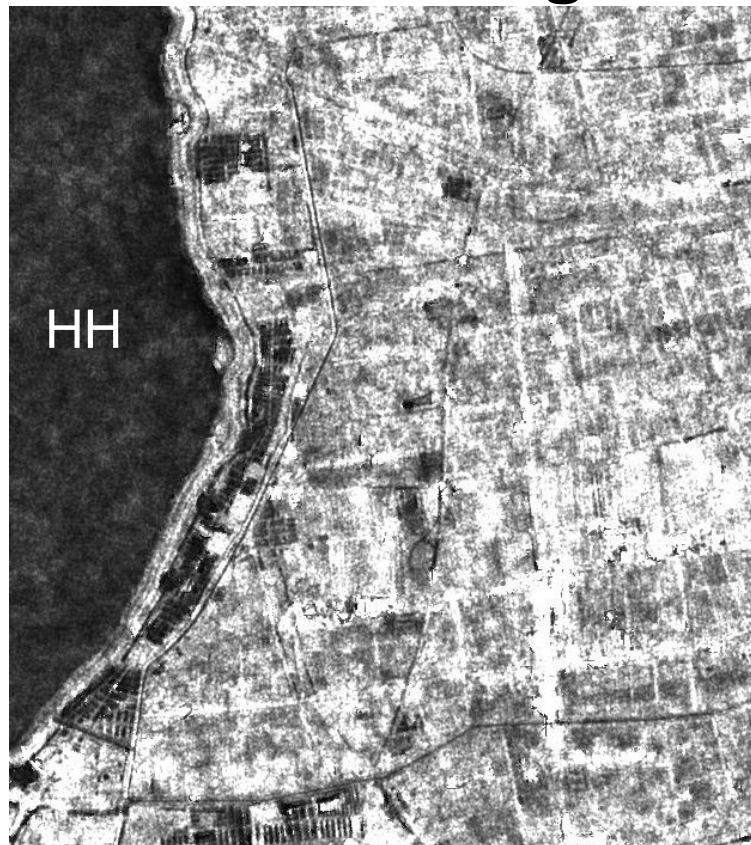


Hongze Lake WideSwath VV



Changes in backscatter

Changes in Polarisation



Hongze (Jiangsu) 2004 09 06



Change based on ratios

The distribution of the ratio $Z = I_1 / I_2$ is given by

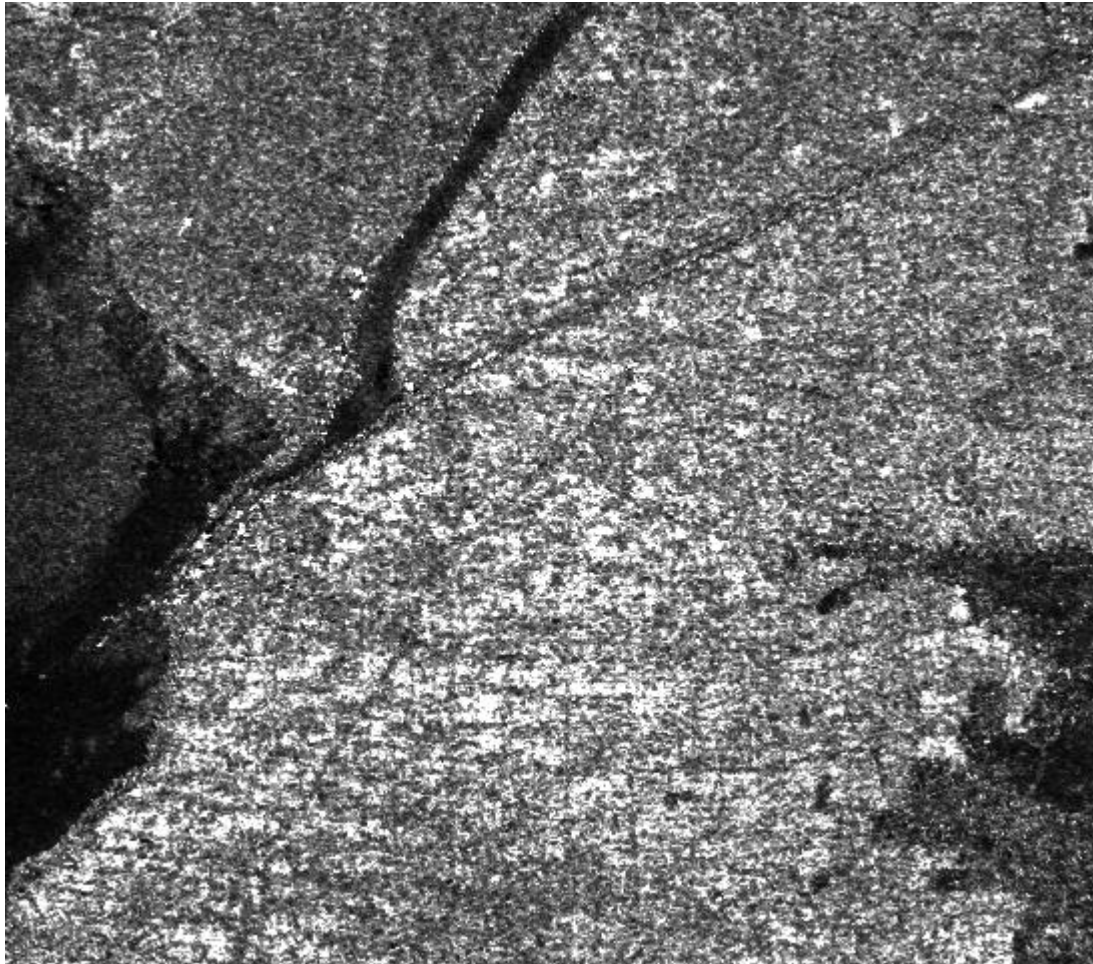
$$p(Z) = \frac{\Gamma(2L)\gamma^L Z^{L-1}}{\Gamma^2(L)(\gamma + Z)^{2L}}$$

where $\gamma = \frac{\sigma_1}{\sigma_2}$ is the true intensity ratio.

Ratio of intensities is equivalent to the difference of the logs.

Advantages:

- ◆ Depends only on the **relative change** in intensity between the images.
- ◆ Unaffected by topography and other multiplicative effects, e.g., calibration.



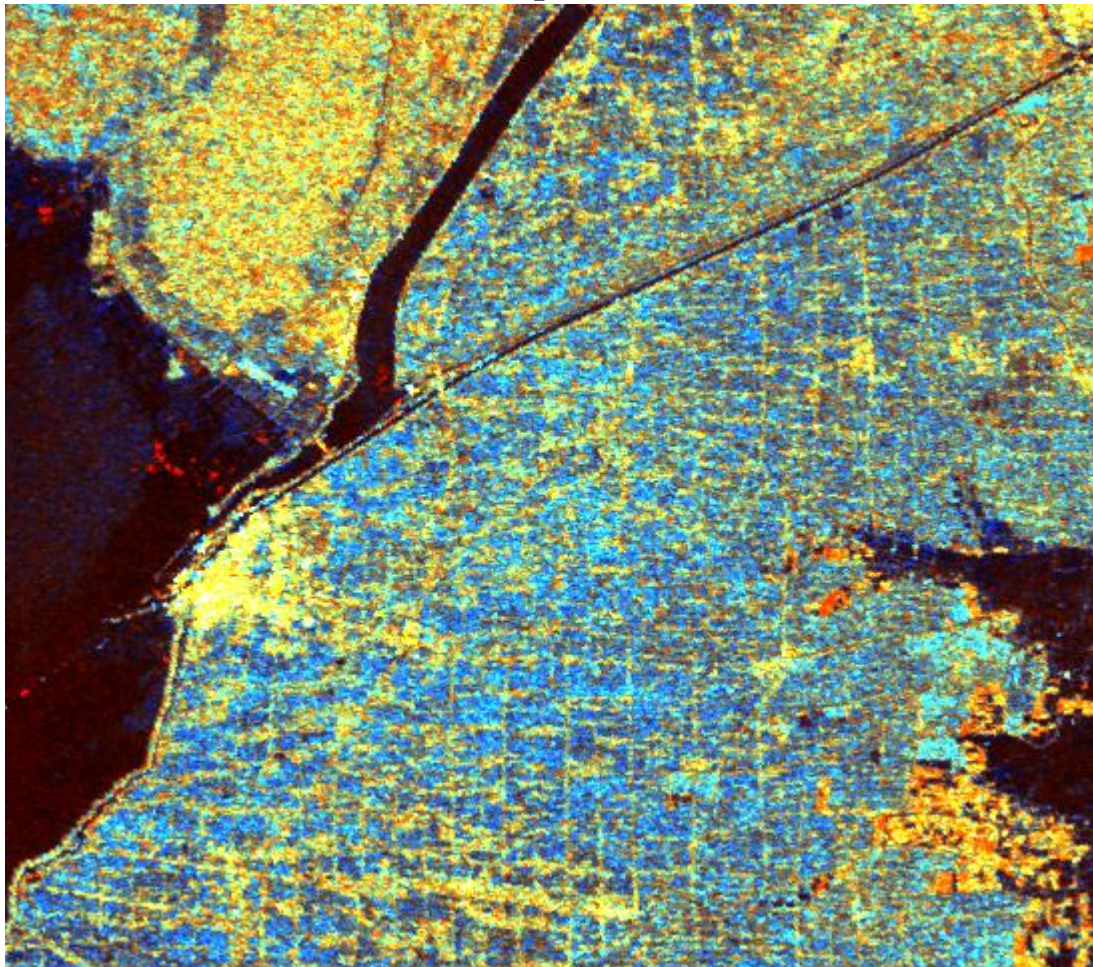
Hongze Lake

The ratio image

20040818 /
20041008



Temporal change image



Hongze Lake WS

R : VV_20040818

G : VV_20041008

B : VV_2 / VV_1



Remarks

- ◆ An important topic is the effect of speckle noise which need to be reduced before to use the SAR image as physical measurements
- ◆ Preprocessing steps are important
- ◆ Knowledge of the scattering physics and the SAR statistical properties is essential in applications