



Master d'Informatique *ITI* *Initiation au Traitement d'Images*

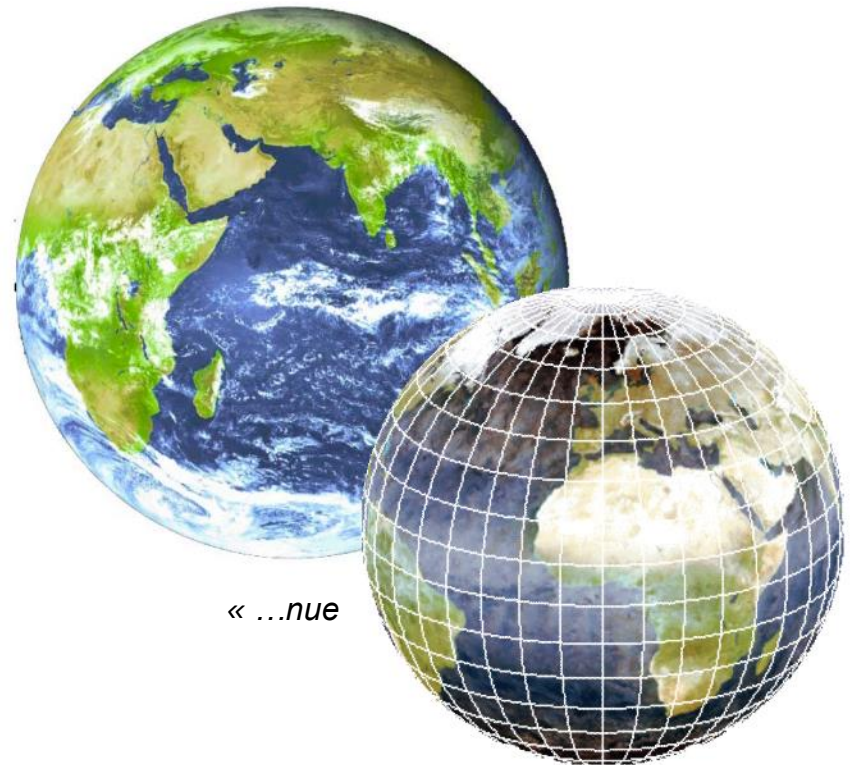
image Landsat - désert d'Australie

Une histoire d'amours

Léna



La Terre



« ...nue

ou habillée... »



Table des matières

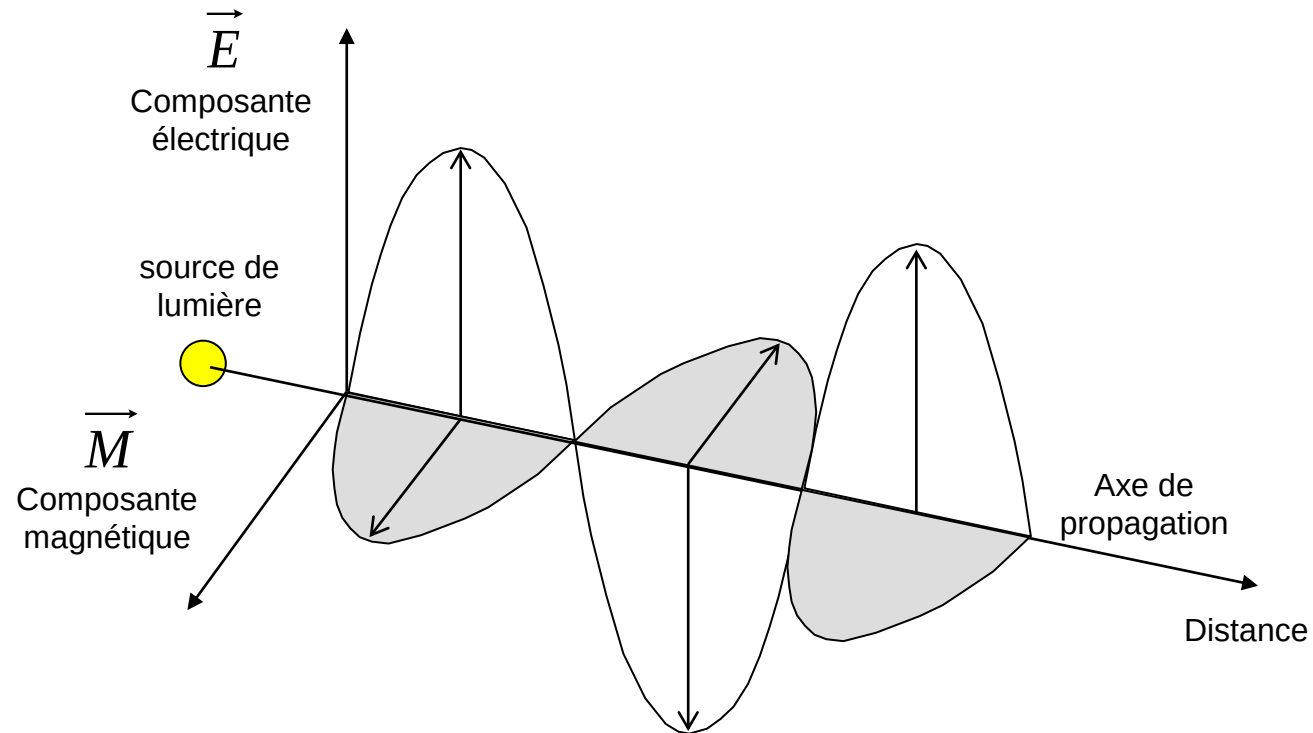
- ⊕ Physique de la lumière
- ⊕ Physique de l'acquisition
- ⊕ Représentation et format des données
- ⊕ Visualisation d'images sous X-Window
- ⊕ Pseudo-couleurs et compositions colorées
- ⊕ Ratios et indices normalisés
- ⊕ Distributions et statistiques
- ⊕ Traitement radiométrique global par transformation d'histogrammes
- ⊕ Traitement radiométrique par filtrage
- ⊕ Traitement géométrique
- ⊕ Bibliographie



⊕ Physique de la lumière

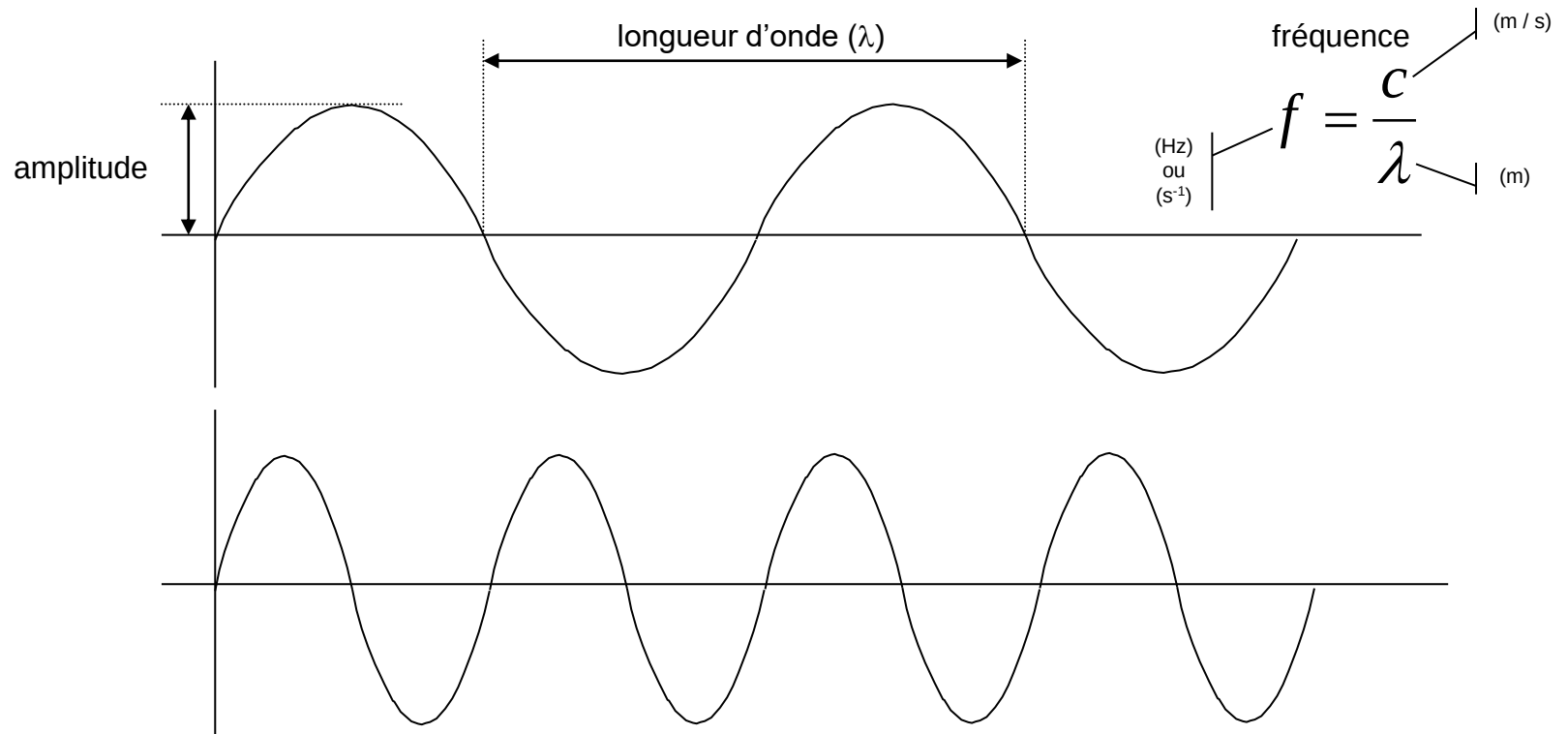
- ⊞ radiation / onde / spectre électromagnétiques
- ⊞ transmission à travers l'atmosphère
- ⊞ interaction lumière / matière
- ⊞ synthèse additive / soustractive

La radiation électromagnétique





✚ L'onde électromagnétique

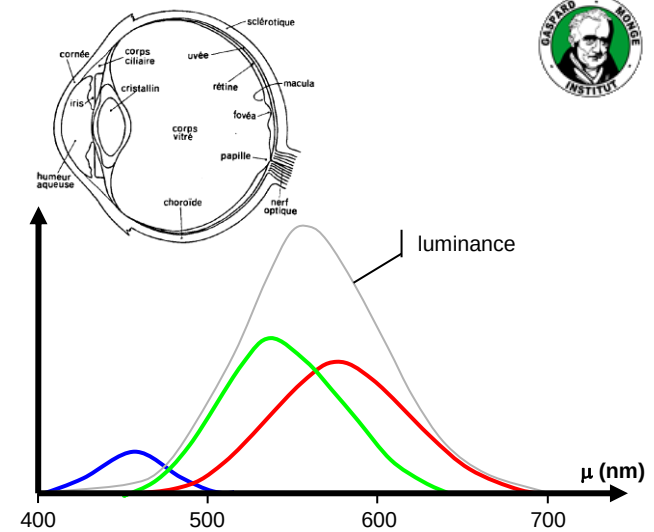
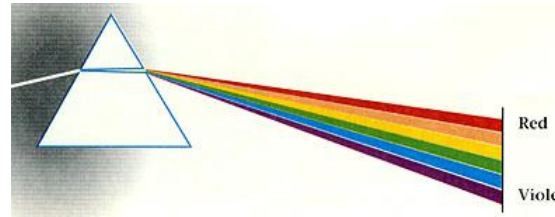




Le spectre électromagnétique

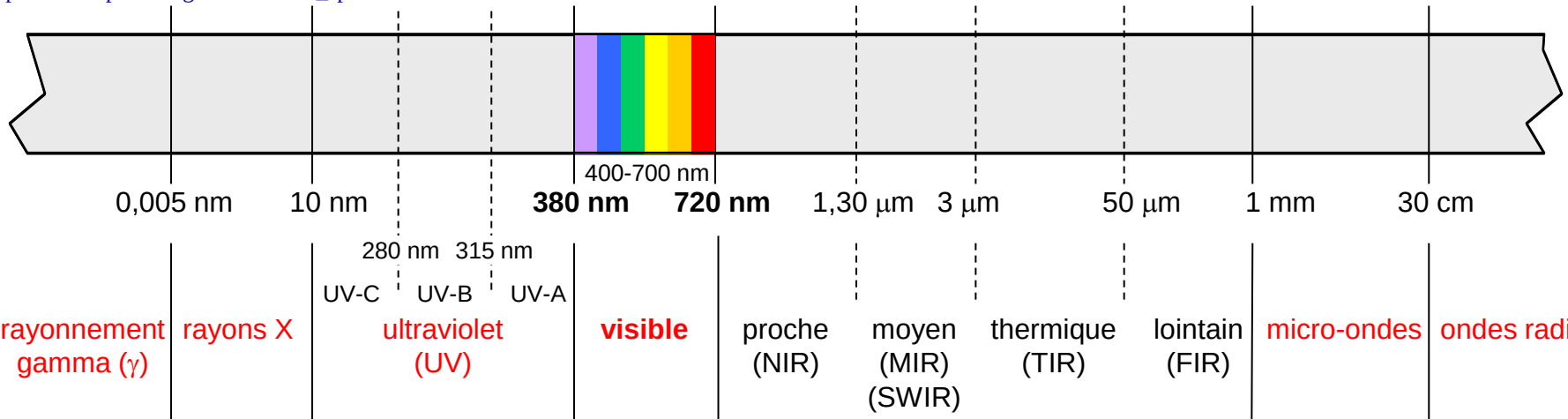
violet	380–450 nm
blue	450–495 nm
green	495–570 nm
yellow	570–590 nm
orange	590–620 nm
red	620–750 nm

http://en.wikipedia.org/wiki/Visible_spectrum



Sensibilité spectrale des cônes de l'œil

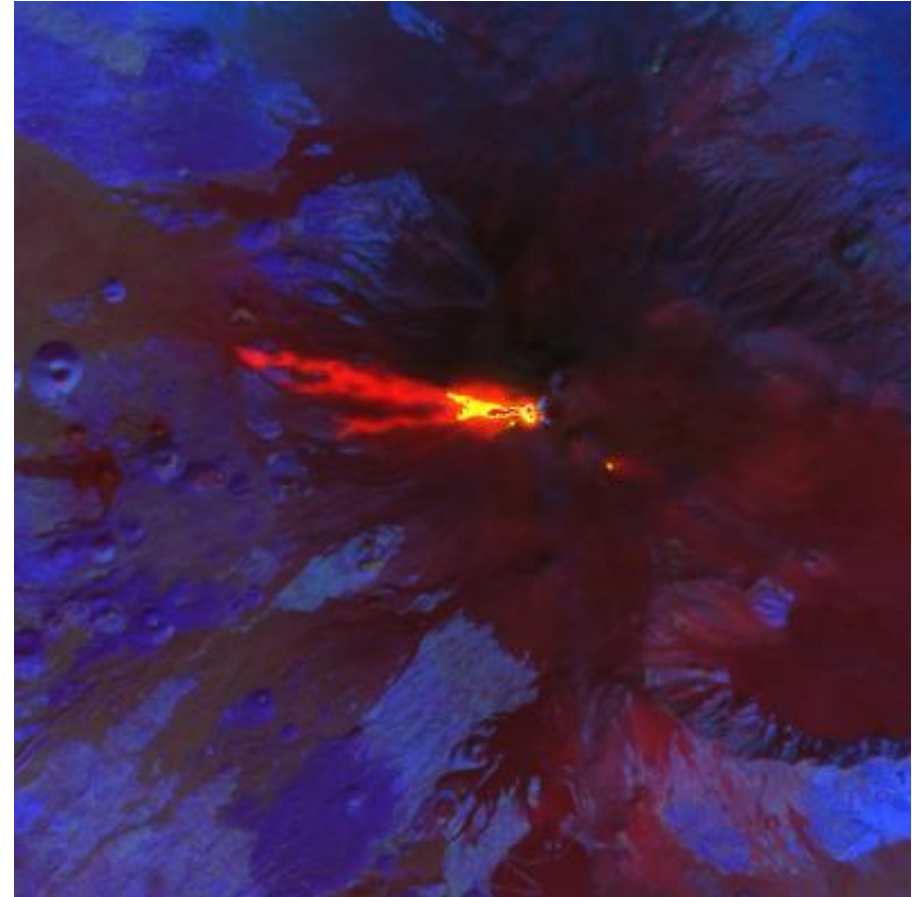
<http://www.rennes.supelec.fr/ren/perso/jweiss/tv/perception/percept4.html>



Energie du photon: $E = h \times \nu$

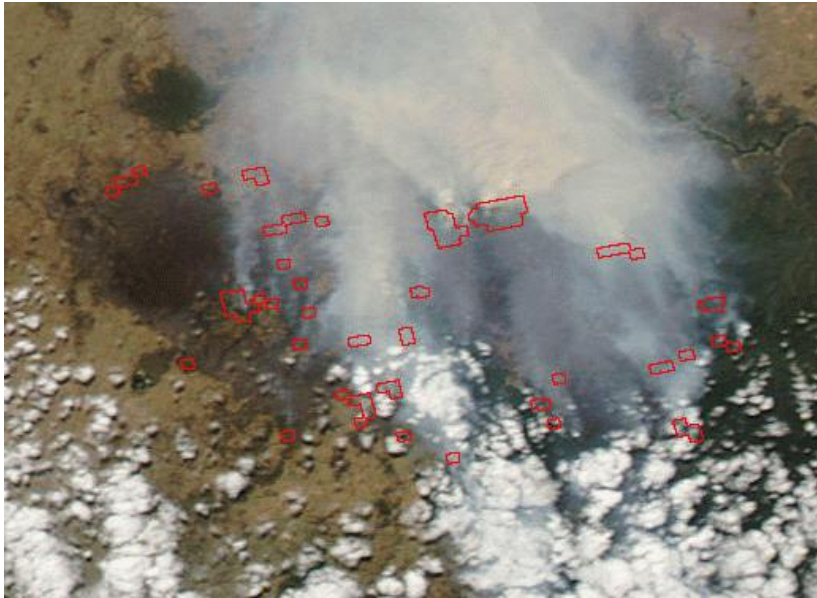
Constante de Planck: $h = 6,626\,068\,96 \times 10^{-34} \text{ J.s}$

🌀 Application en observation de la Terre



Vue de l'éruption d'un volcan.

http://igett.delmar.edu/08/Resources/NASA_Landsat_Intro/Geospatial+Landsat_Allen_2007.ppt

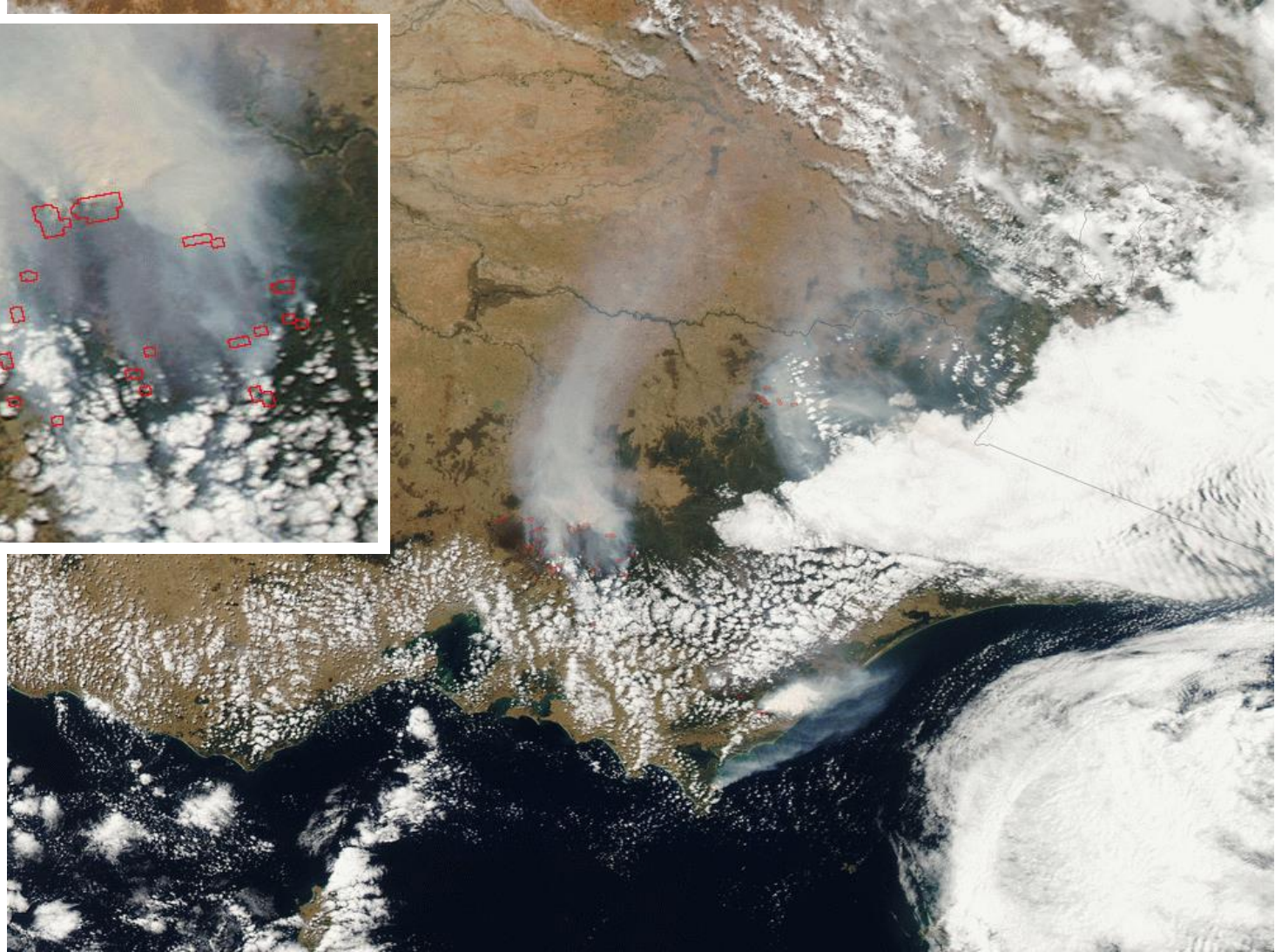


B-V-R



VIS-NIR-SWIR

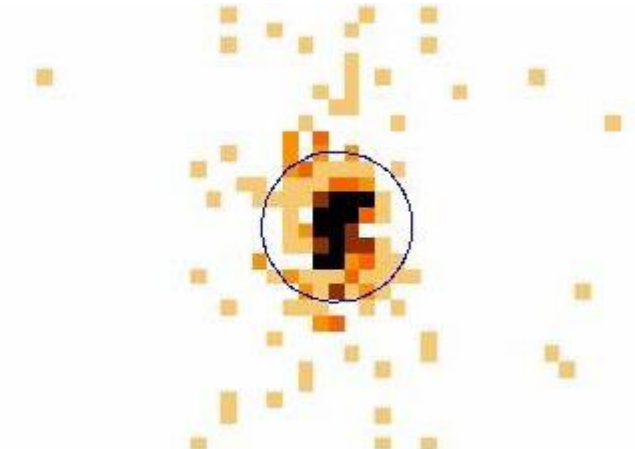
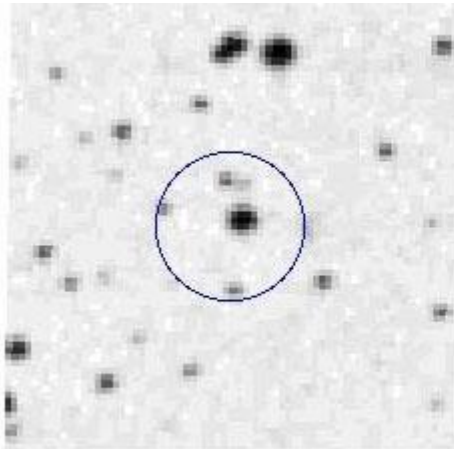
<http://www-igm.univ-mlv.fr/~riazano/>
version 2.09



Incendie en Australie (Barry Mountains of central Victoria) le 2 février 2009.

<http://earthobservatory.nasa.gov/IOTD/view.php?id=36979>

🌀 Application en astronomie



Images acquises par XMM-Newton dans le spectre visible (gauche) et Rayons-X (droit).

Vue de la supernova «V598 Puppis». Crédit ESA.

http://www.esa.int/esaSC/SEMH9HWIPIF_index_0.html

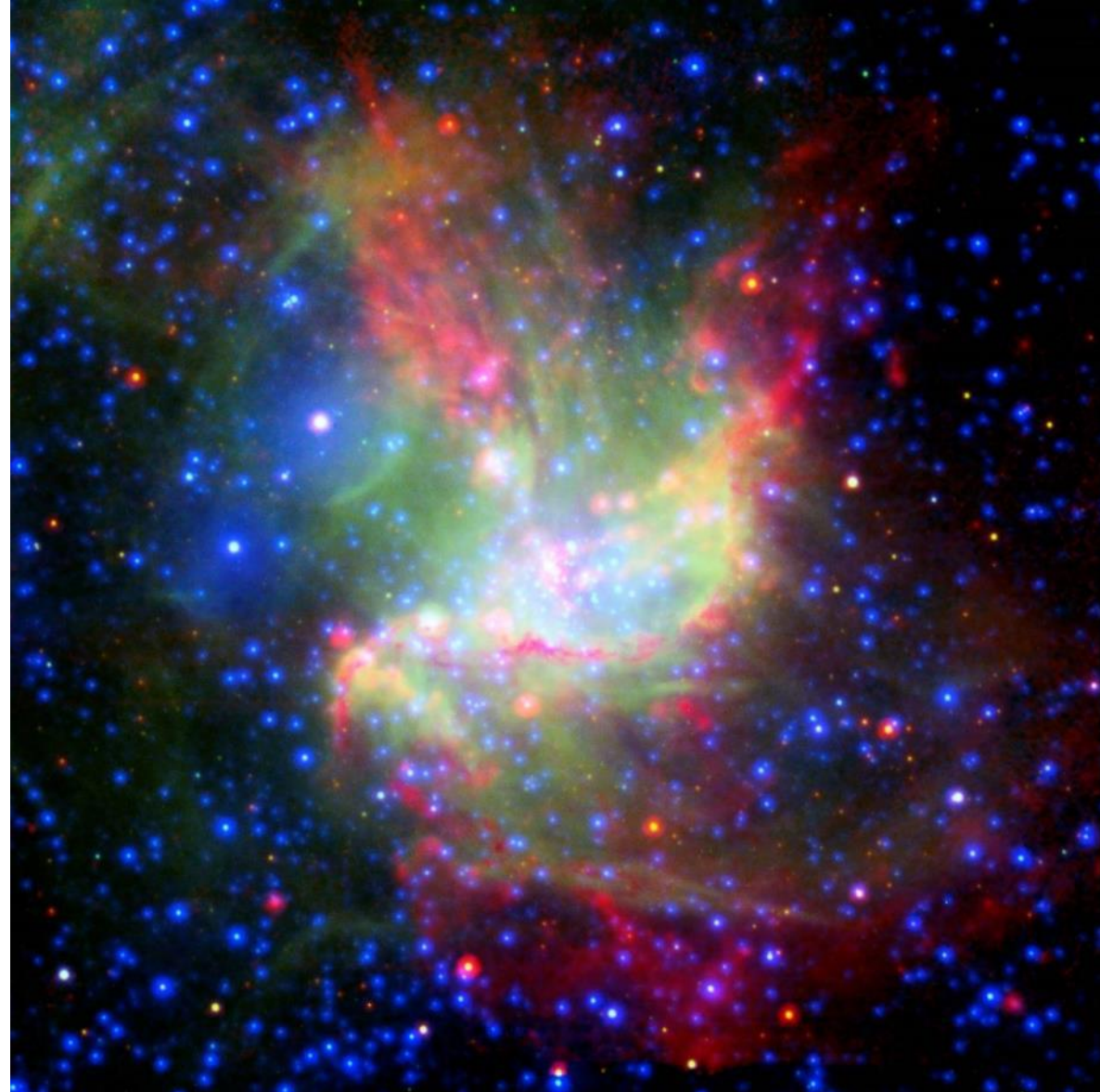


Images acquises par XMM-Newton de la
pépinière d'étoiles «NGC 346» dans la
Constellation de Magellan. Crédit ESA.

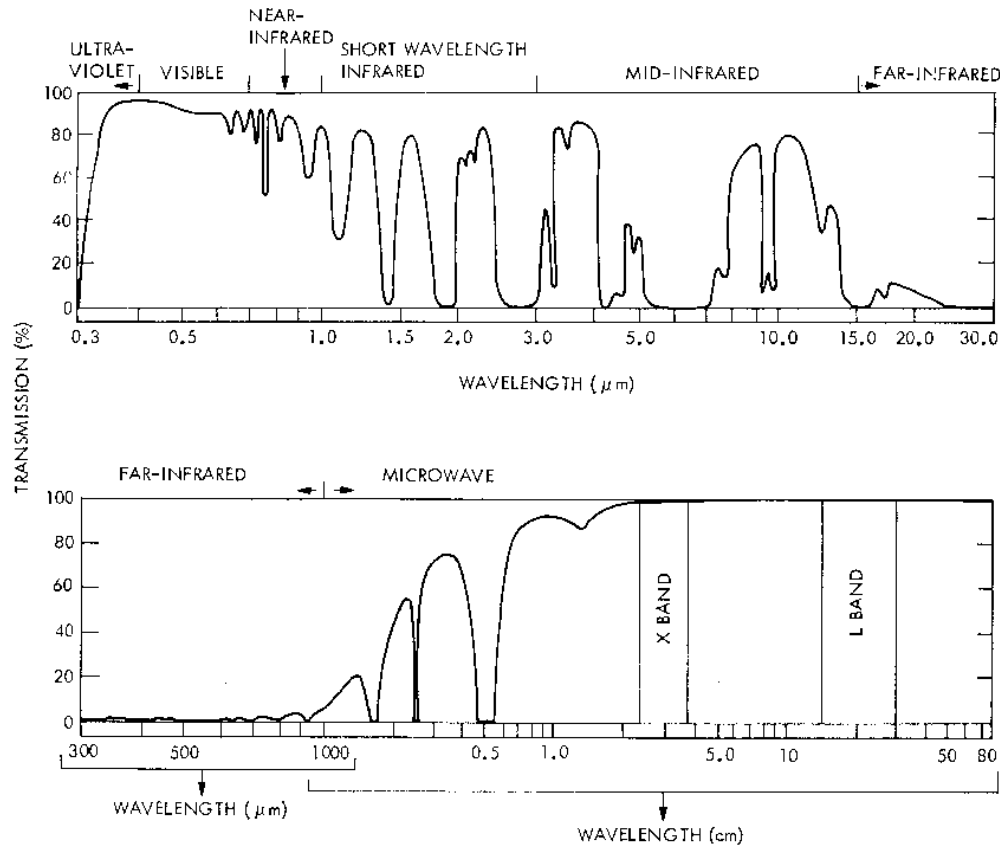
Composition colorée:

- Rouge: rayonnement infrarouge
- Vert: visible (gaz interstellaire)
- Bleu: rayons X (étoiles à hautes énergie)

http://www.esa.int/esaCP/SEMLKL4N0MF_index_0.html



Transmission à travers l'atmosphère au zénith



*Manual of Remote Sensing –
Second edition – American
Society of Photogrammetry –
1983, vol. I, fig. 13-1, page 572.*

☉ Rayonnement du « corps noir »

❏ Loi de Stefan-Boltzmann

Corps noir: Source d'énergie idéale absorbant toute radiation incidente (aucune réflexion) et émettant intégralement l'énergie résultant d'une élévation de sa température.

$$W = \sigma \times T^4$$

W radiation totale émise (W.m^{-2})

T température absolue (K)

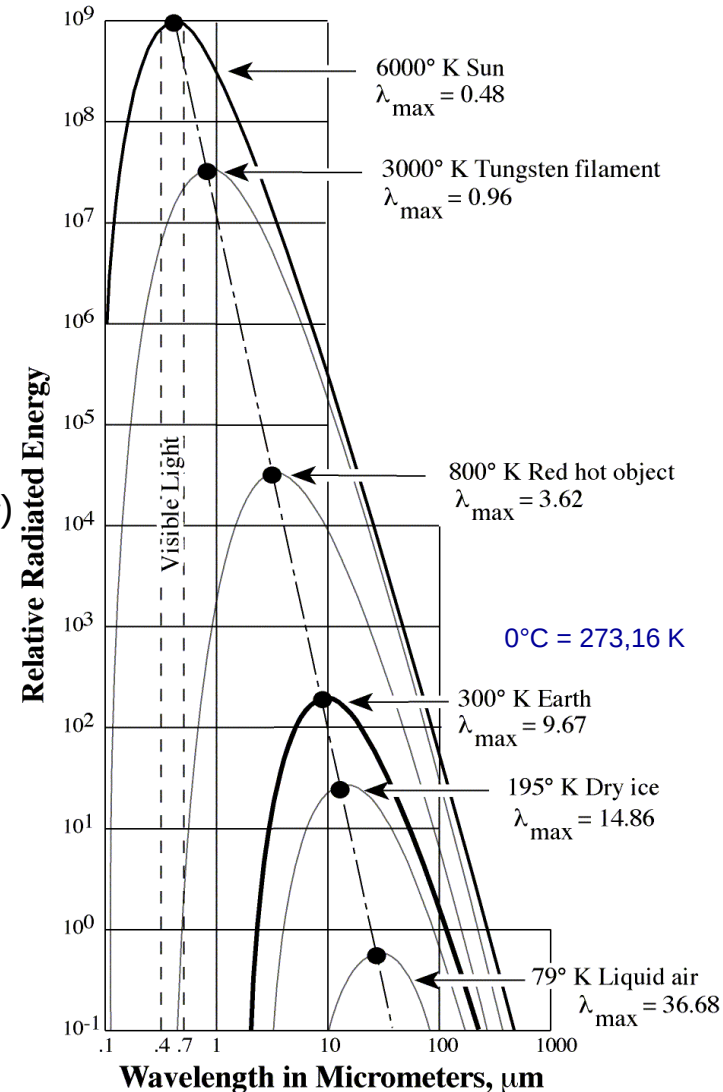
s constante de Boltzmann ($5.6697 \cdot 10^{-8} \text{ W.m}^{-2} \cdot \text{K}^{-4}$)

❏ Loi de Wien

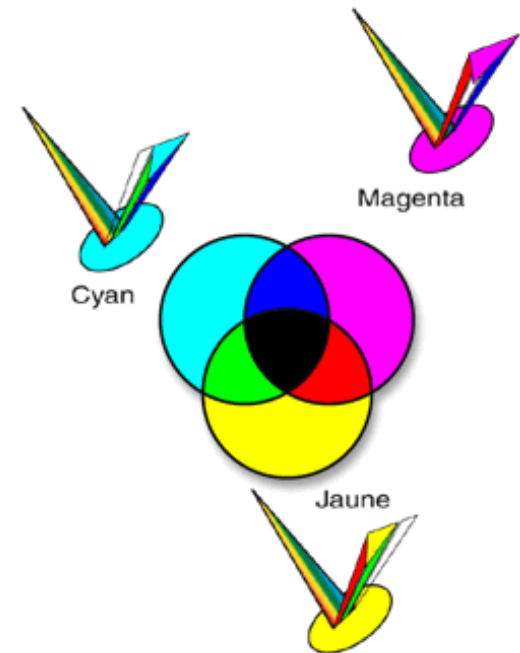
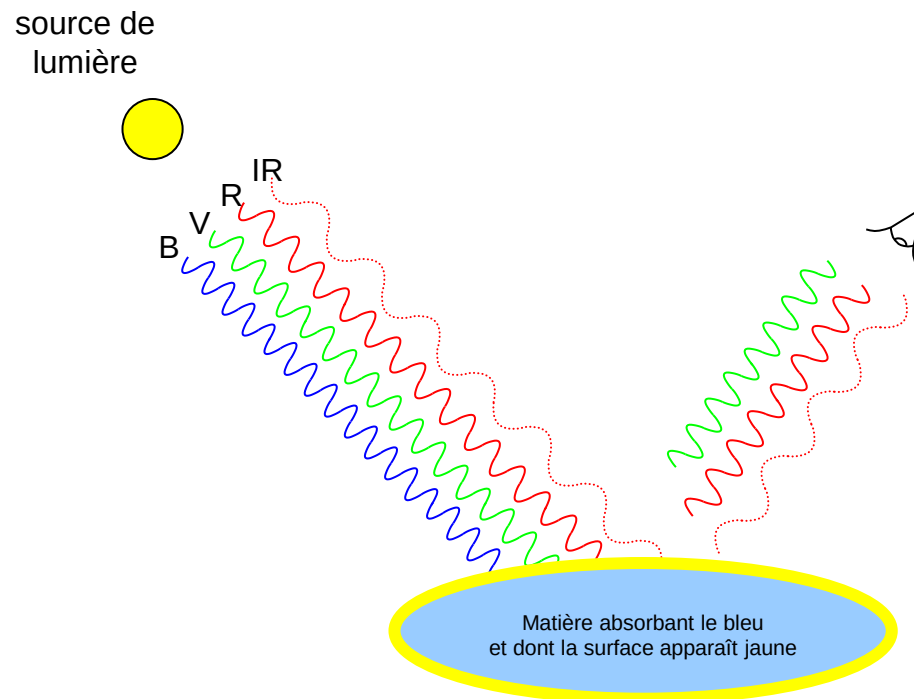
$$\lambda = 2897,8 / T$$

λ longueur d'onde pour laquelle la radiance est maximale (m)

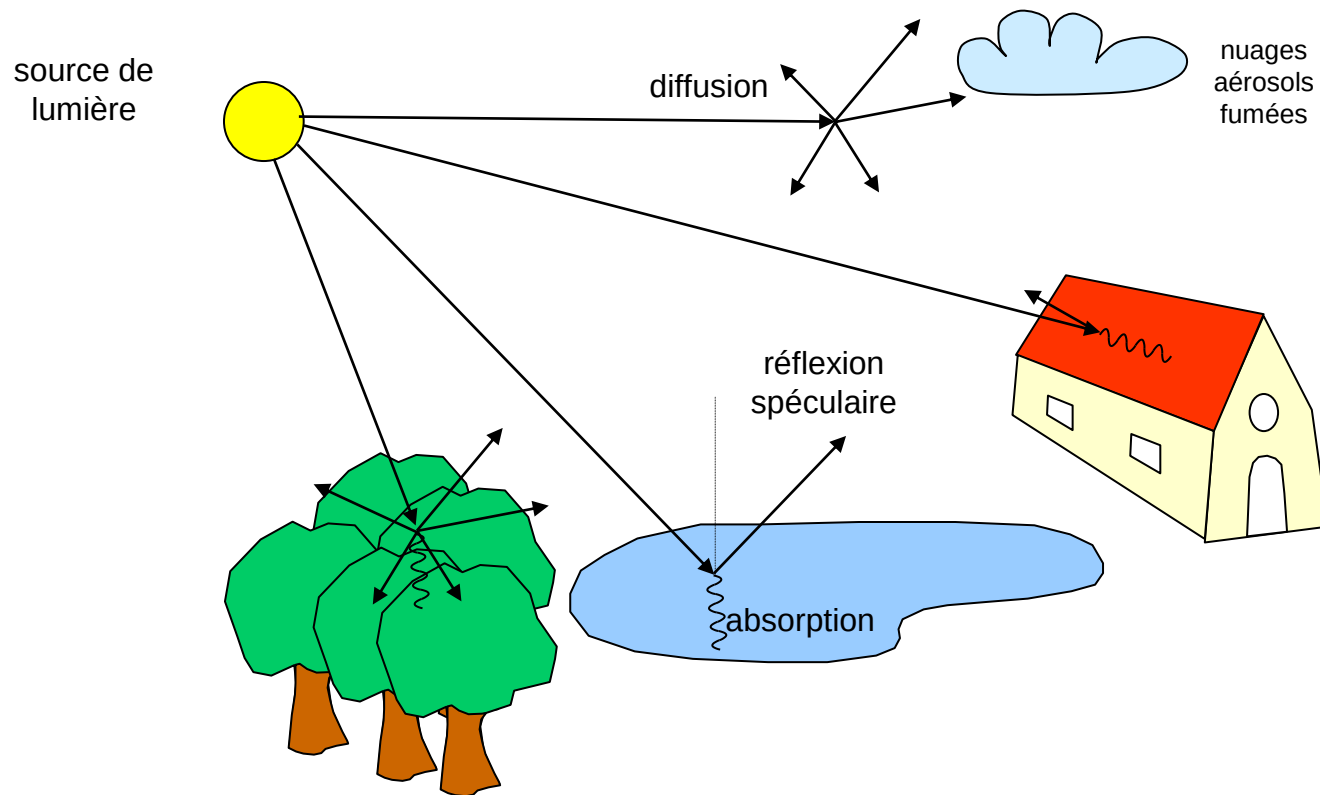
T température absolue (K)



Interaction de la lumière avec la matière

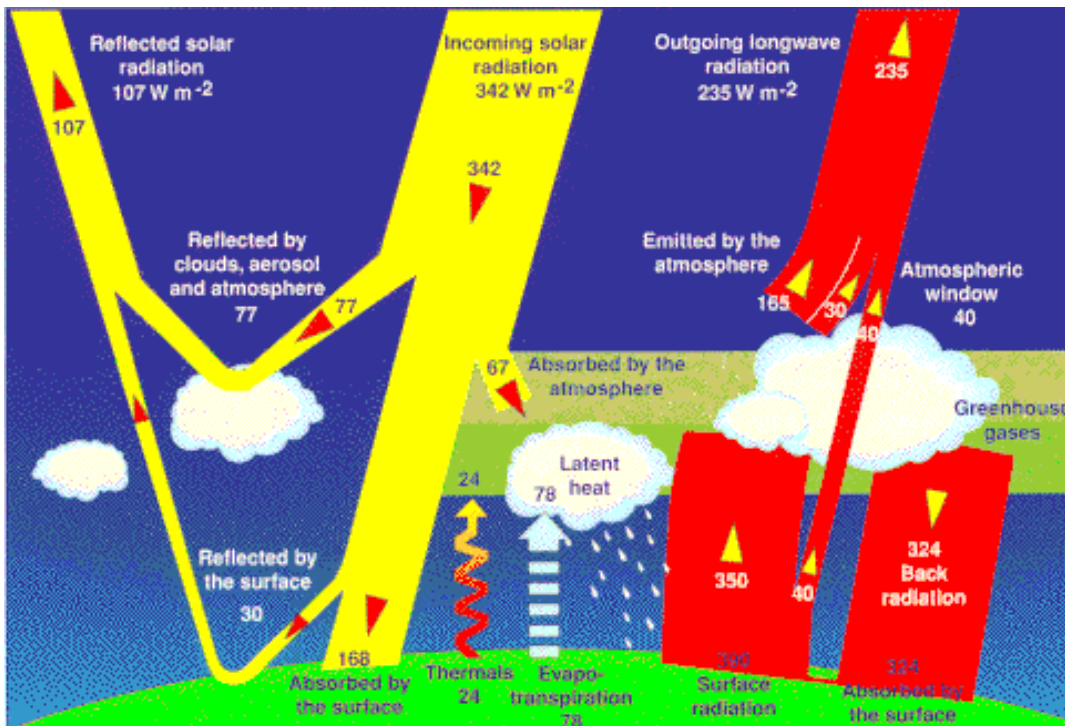


☉ Réflexion, absorption et diffusion de la lumière



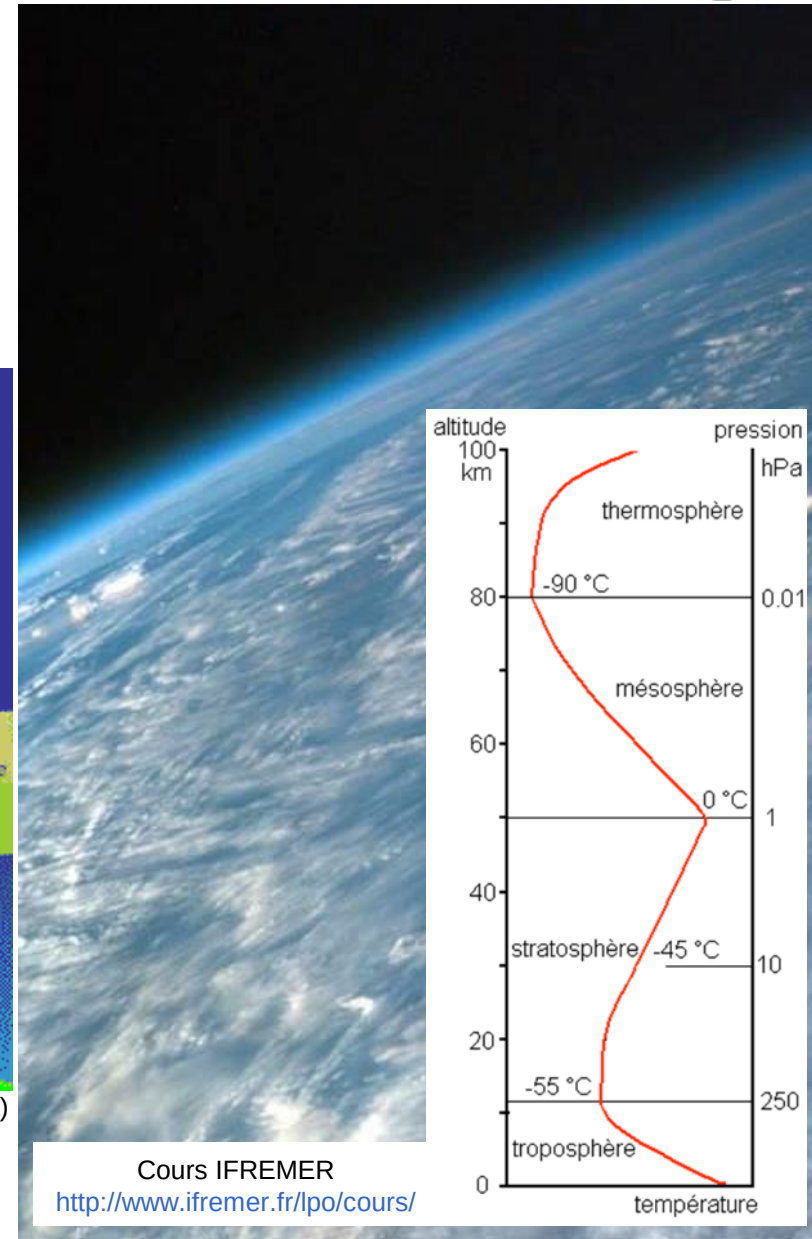
Bilan de radiation

$$\text{albedo} = \frac{\text{énergie réfléchie}}{\text{énergie incidente}}$$

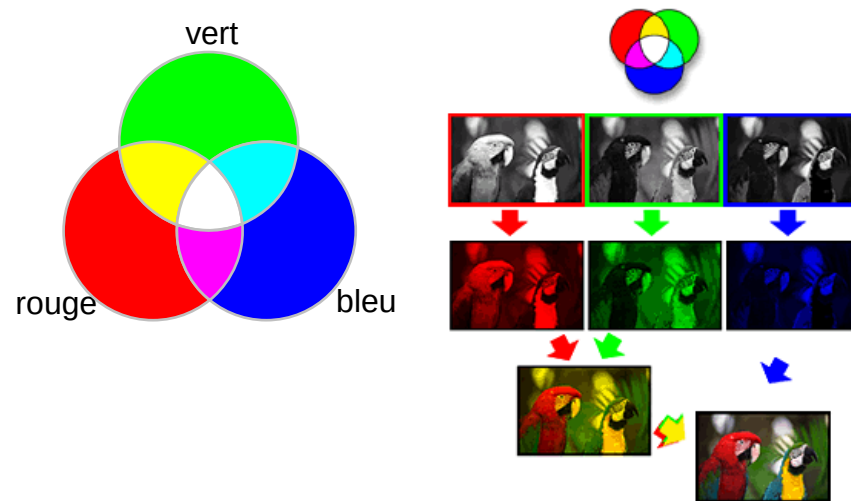


Exemple de mesure effectuée par l'instrument CERES (plate-forme TRMM et EOS Terra)

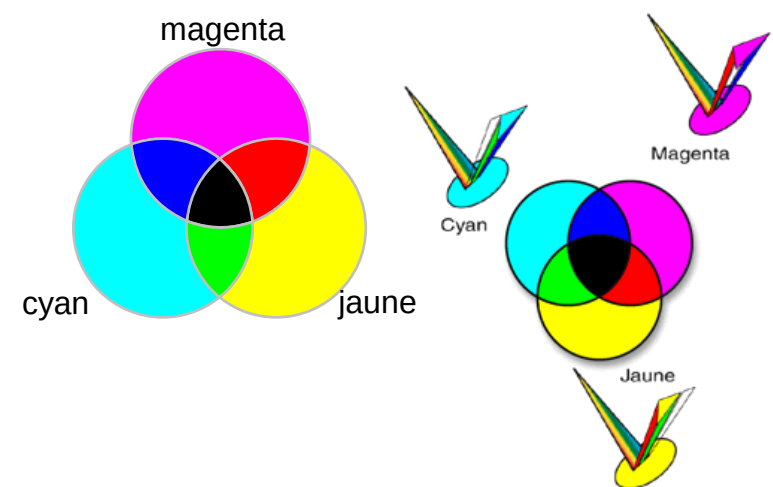
http://asd-www.larc.nasa.gov/ceres/brochure/clouds_and_energy.html



⊕ Synthèse par addition et par soustraction



Ajout des couleurs primaires
Mélange de lumières
(œil, CCD...)

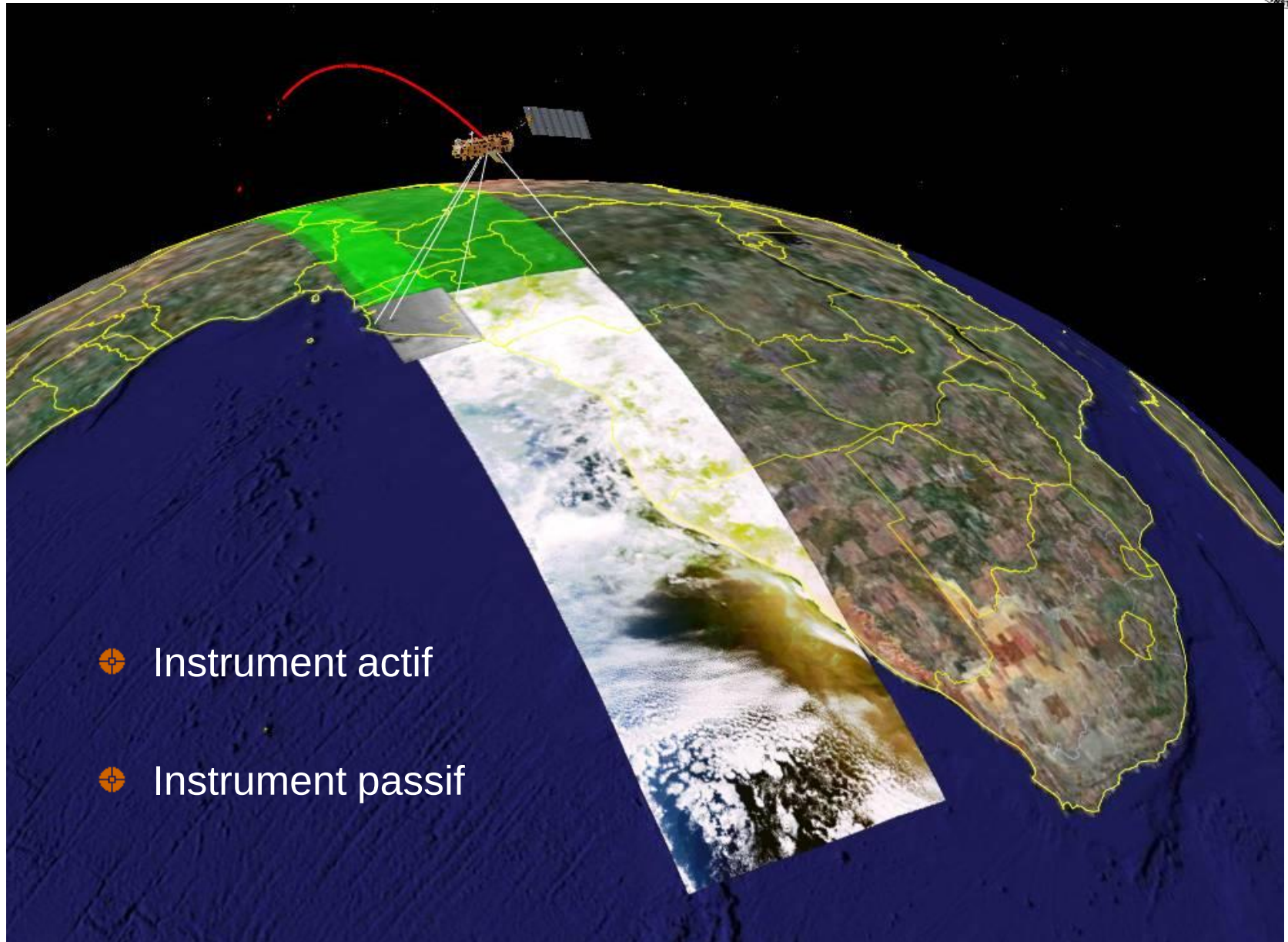


Soustraction des couleurs primaires
Mélange de pigments
(absorption, imprimantes jet d'encre...)



⊕ Physique de l'acquisition

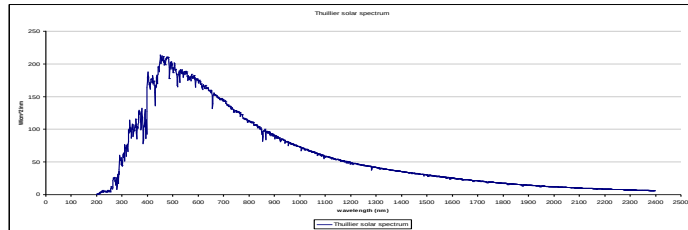
- ❑ instrument passif / actif
- ❑ résolution spatiale / fréquentielle
- ❑ rapport signal sur bruit – quelques bruits
- ❑ satellites et instruments – géométrie de prise de vues



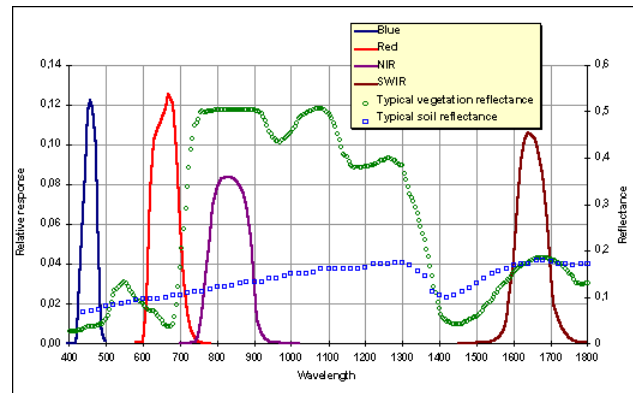
- ➊ Instrument actif
- ➋ Instrument passif



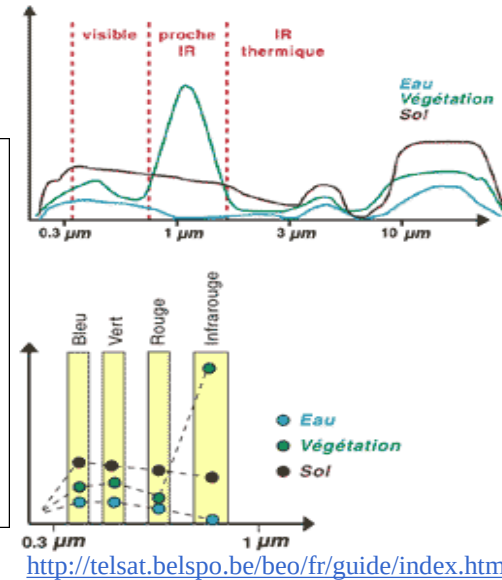
Instrument passif



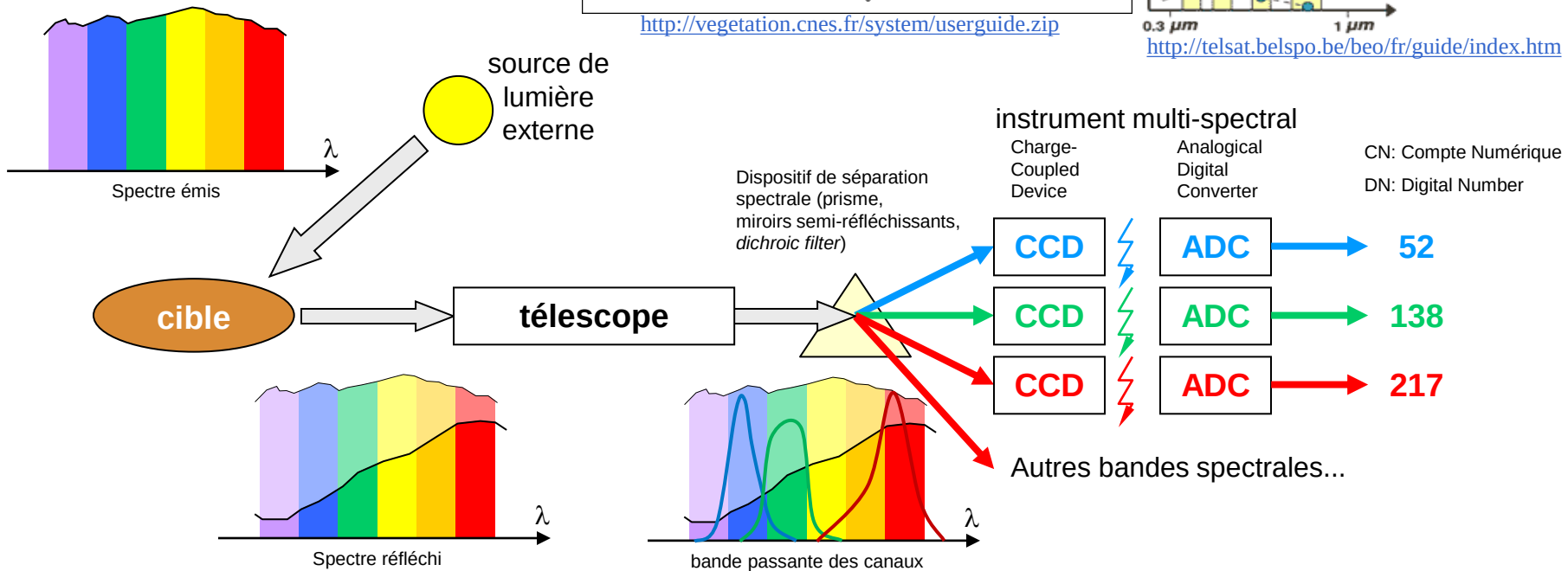
Thuillier (2003) solar spectrum - wavelength range 200 - 2397nm
Thuillier, G., M. Hersé, P. C. Simon, D. Labs, H. Mandel, D. Gillotay, and T. Foujols, 2003, "The solar spectral irradiance from 200 to 2400 nm as measured by the SOLSPEC spectrometer from the ATLAS 1-2-3 and EURECA missions, Solar Physics, 214(1): 1-22
http://oceancolor.gsfc.nasa.gov/DOCS/RSR_tables.html



<http://vegetation.cnes.fr/system/userguide.zip>



<http://telsat.belspo.be/beo/fr/guide/index.htm>





Absorption et transmission dans l'atmosphère

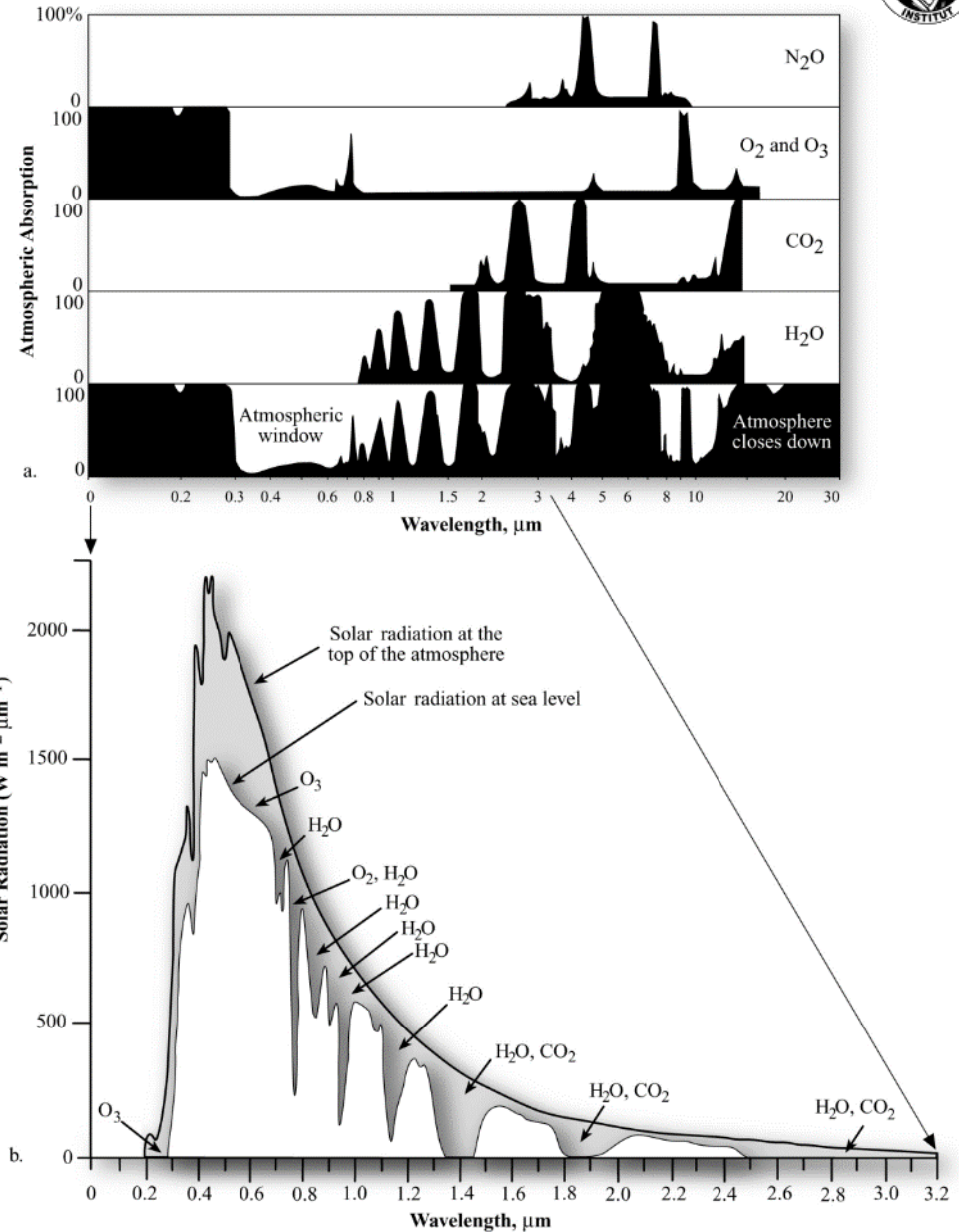
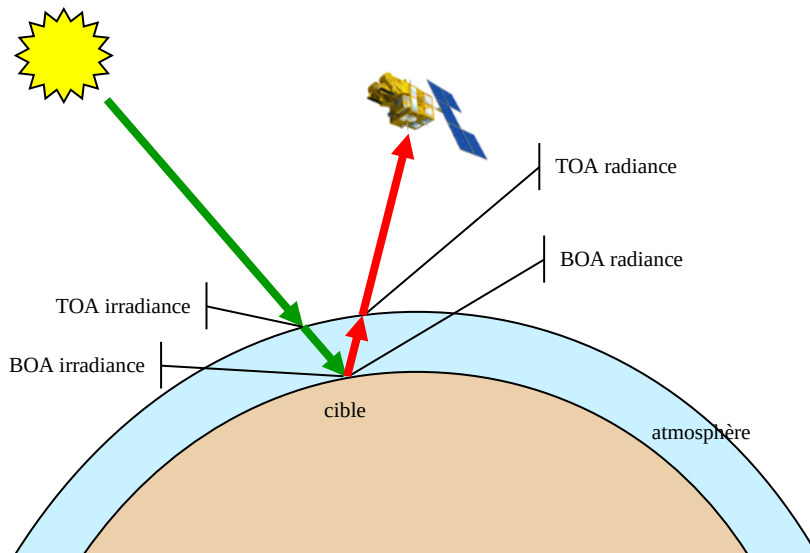
JENSEN-2007

"Principles of Remote Sensing" tutorial

University of South Carolina

Center for GIS and Remote Sensing

<http://www.cas.sc.edu/geog/rsrab/551/index.html>





Calibration

- avant vol
- à-bord (courant d'obscurité, étoiles)
- à partir de données de terrain

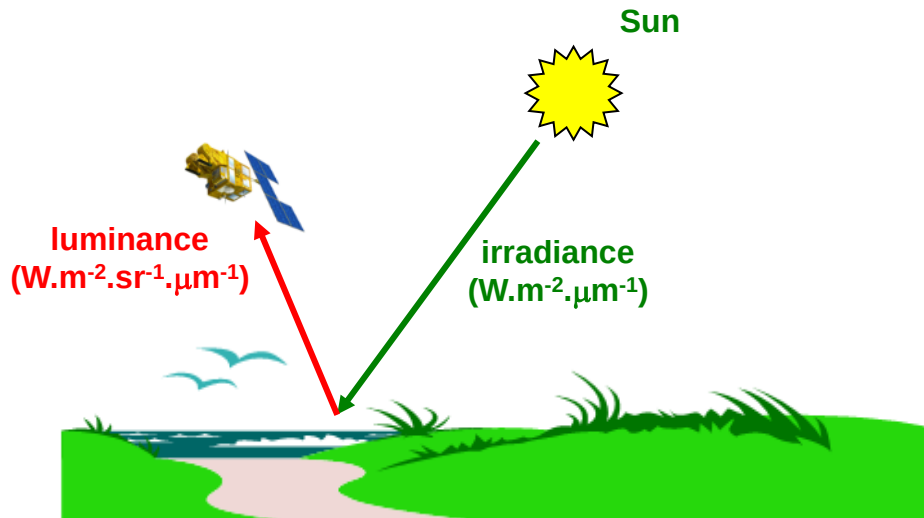
mesure_physique = F (CN,données_auxiliaires)

Exemples:

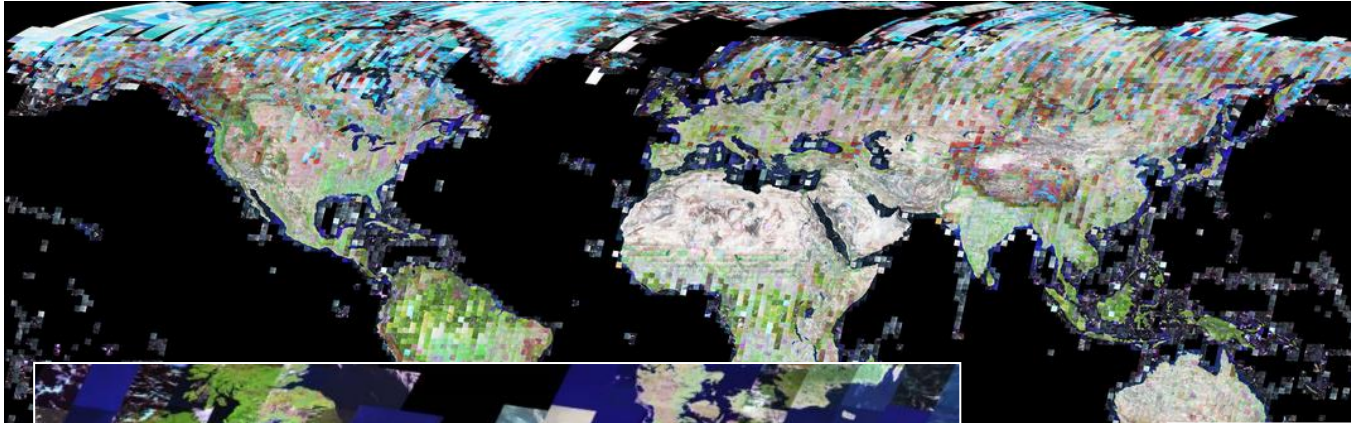
radiance = $A \times \text{CN} + B$

température = $A \times \log(C \times \text{CN}) + B$

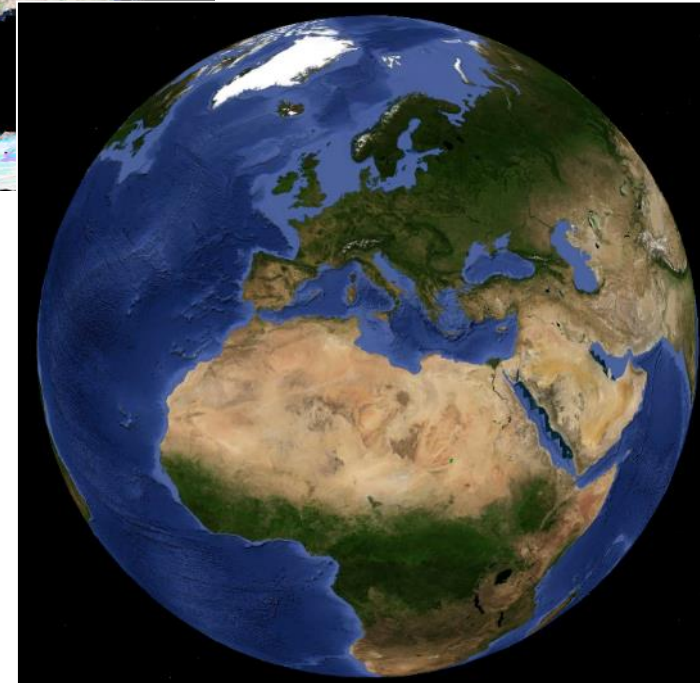
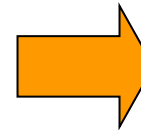
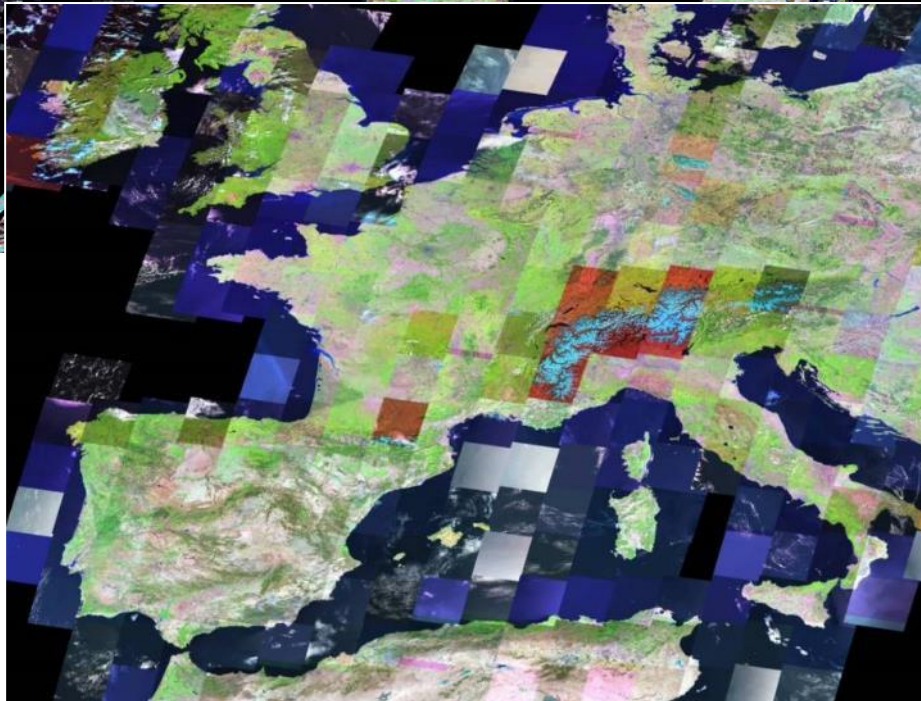
Irradiance solaire et luminance



✚ Egalisation des radiométries – Les mosaïques



Mosaïque Landsat-7 ETM+
produite le 31/12/2000
<http://landsat.usgs.gov/gallery/view.php?category=grayflag&thesort=mainTitle>
http://landsat.usgs.gov/images/gallery/89_L.jpg



Exemples



Iéna

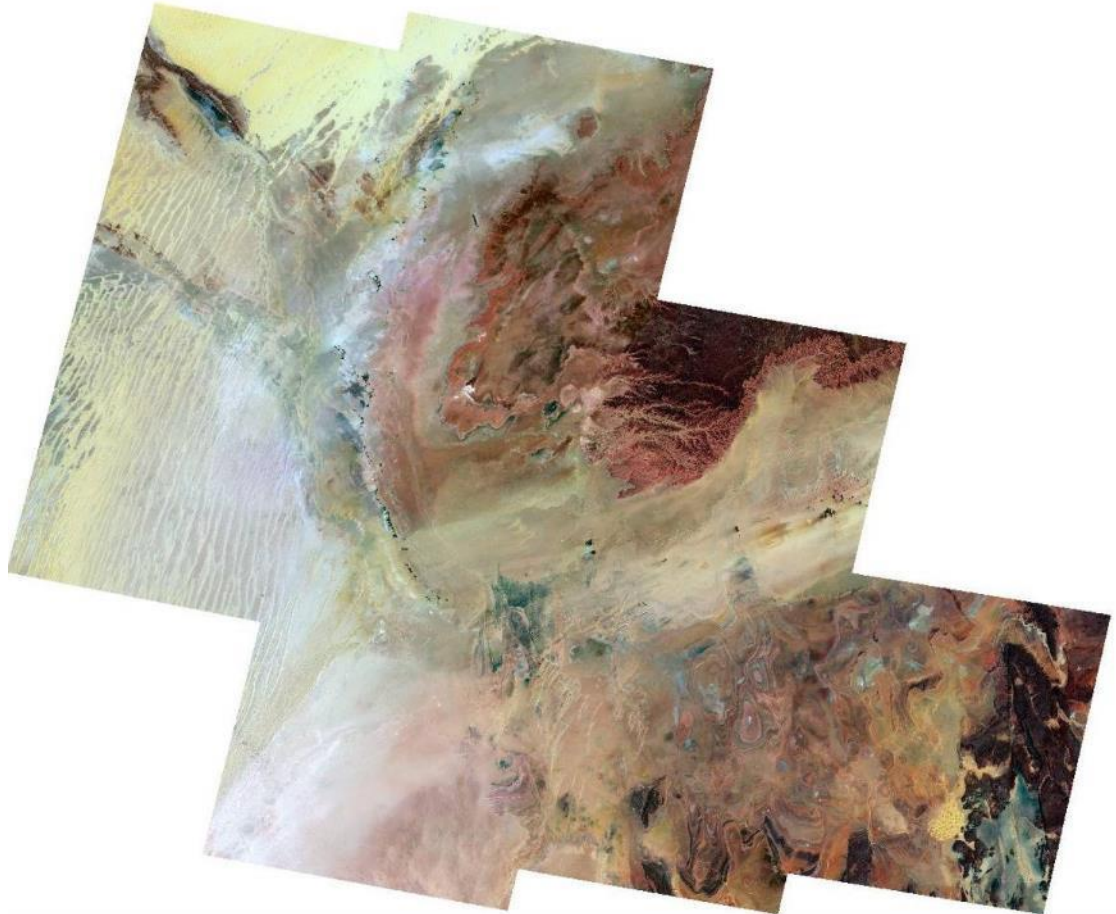
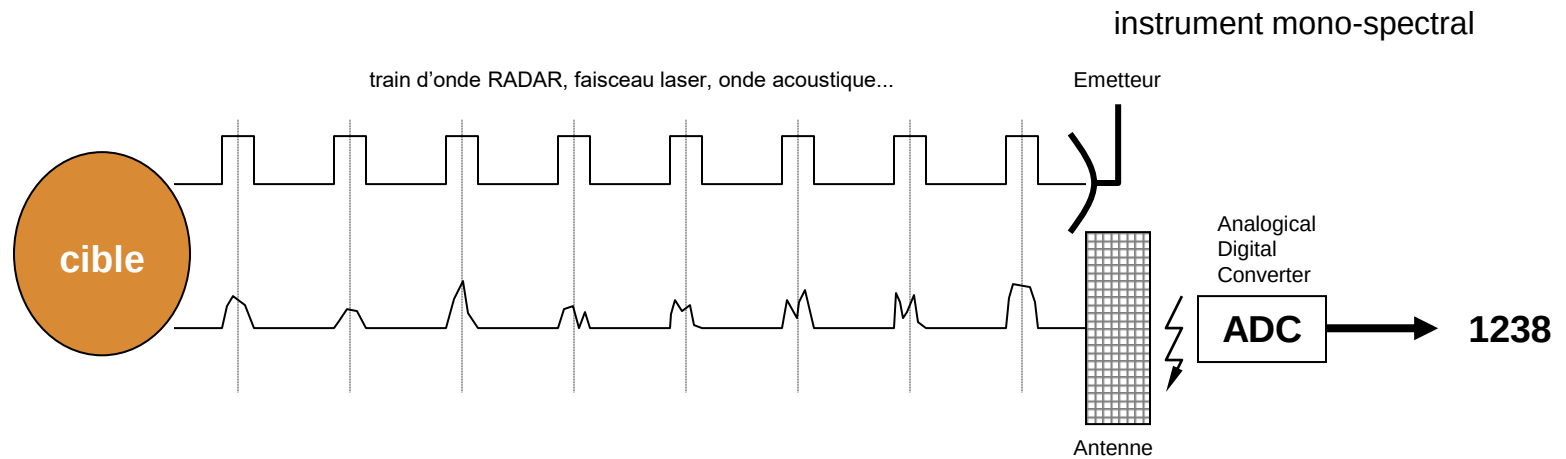


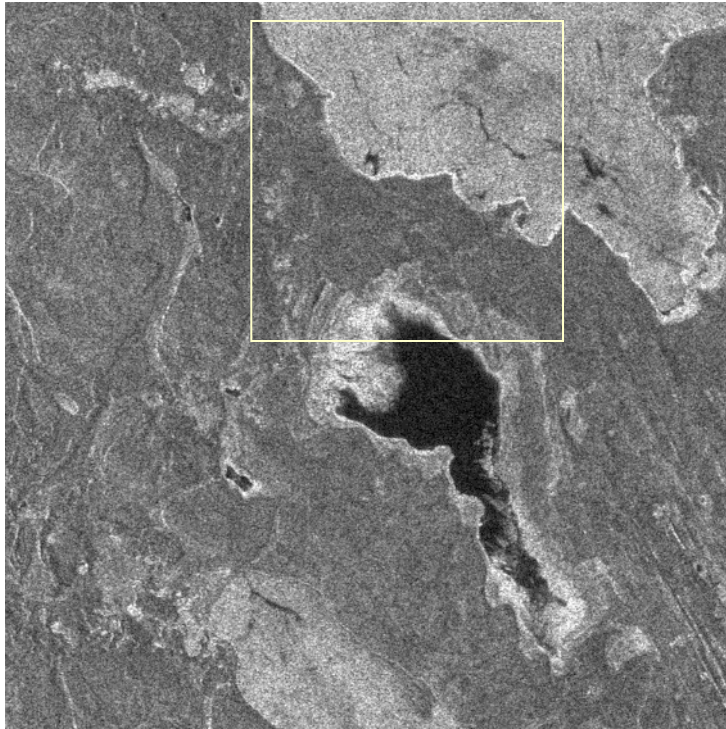
image Landsat ETM+ du sud de l'Algérie

Instrument actif

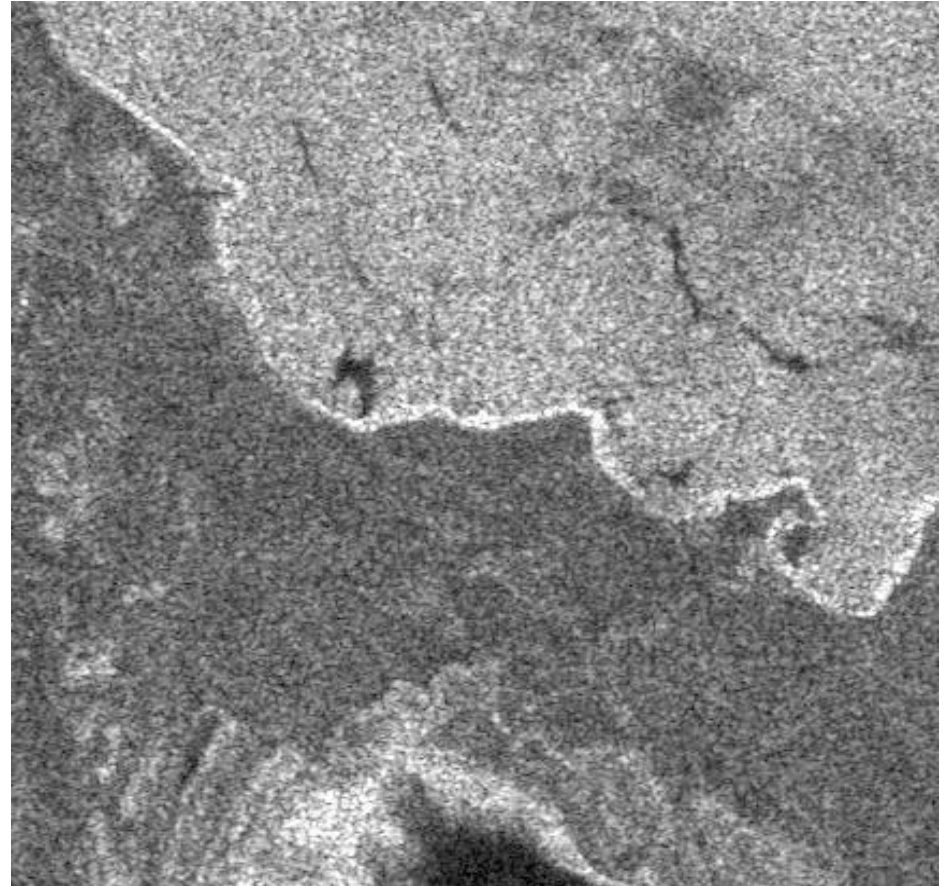


Cours détaillé en [SR-RADAR-COURS-01-01.ppt](http://www-igm.univ-mlv.fr/~riazano/SR-RADAR-COURS-01-01.ppt)

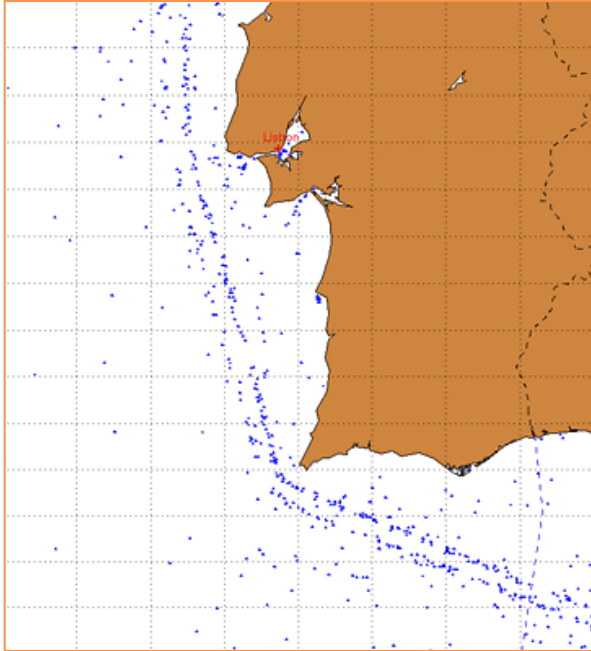
■ Exemple 1 – ERS Patagonie



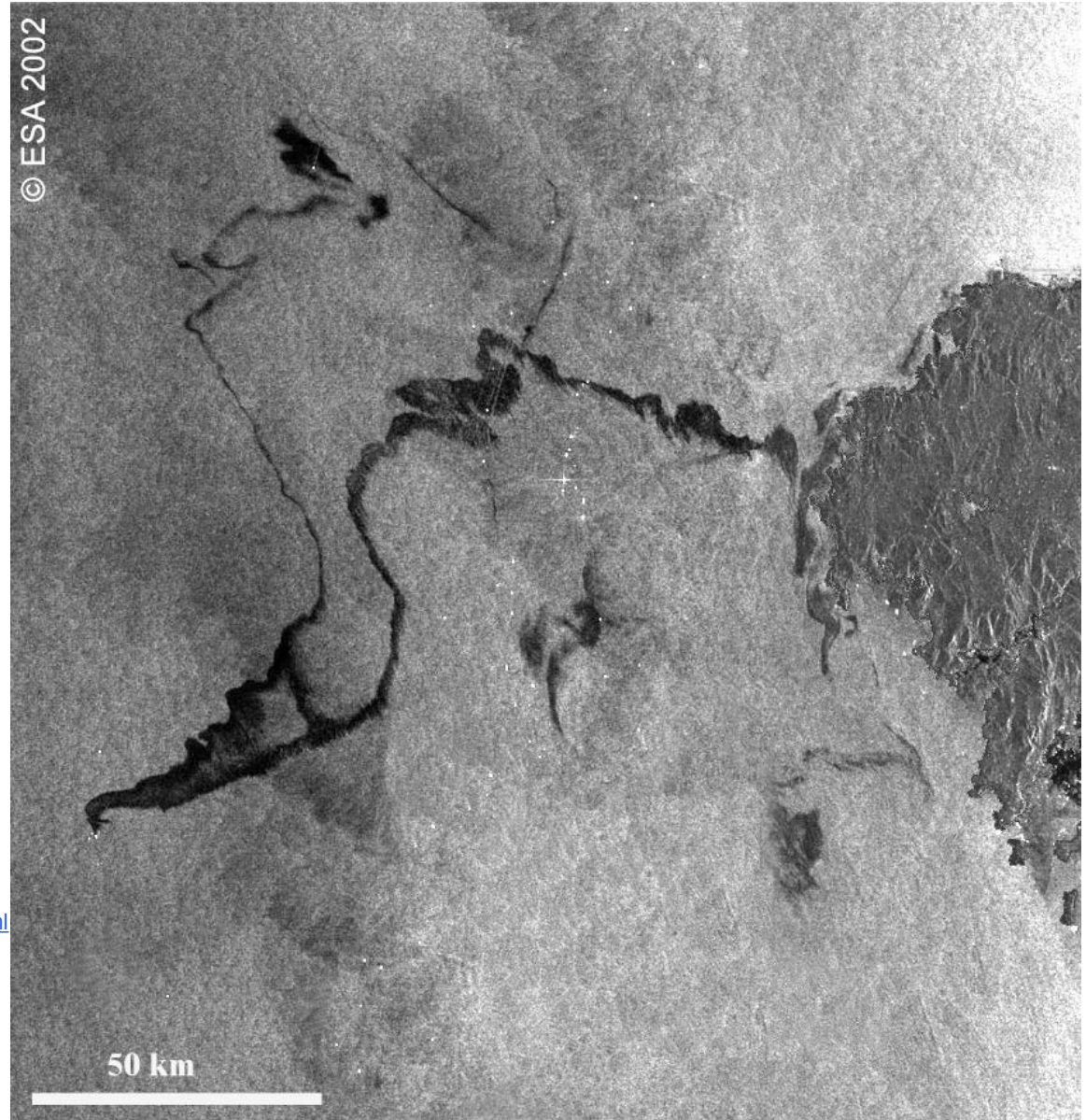
Radar ERS Patagonie



■ Exemple 2



© ESA 2002



50 km

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Initiation au Traitement d'Images

Repérage des navires par ASAR

Effet du changement de route maritime entre Cap Roca et Cap São Vincent au 1^{er} juillet 2005

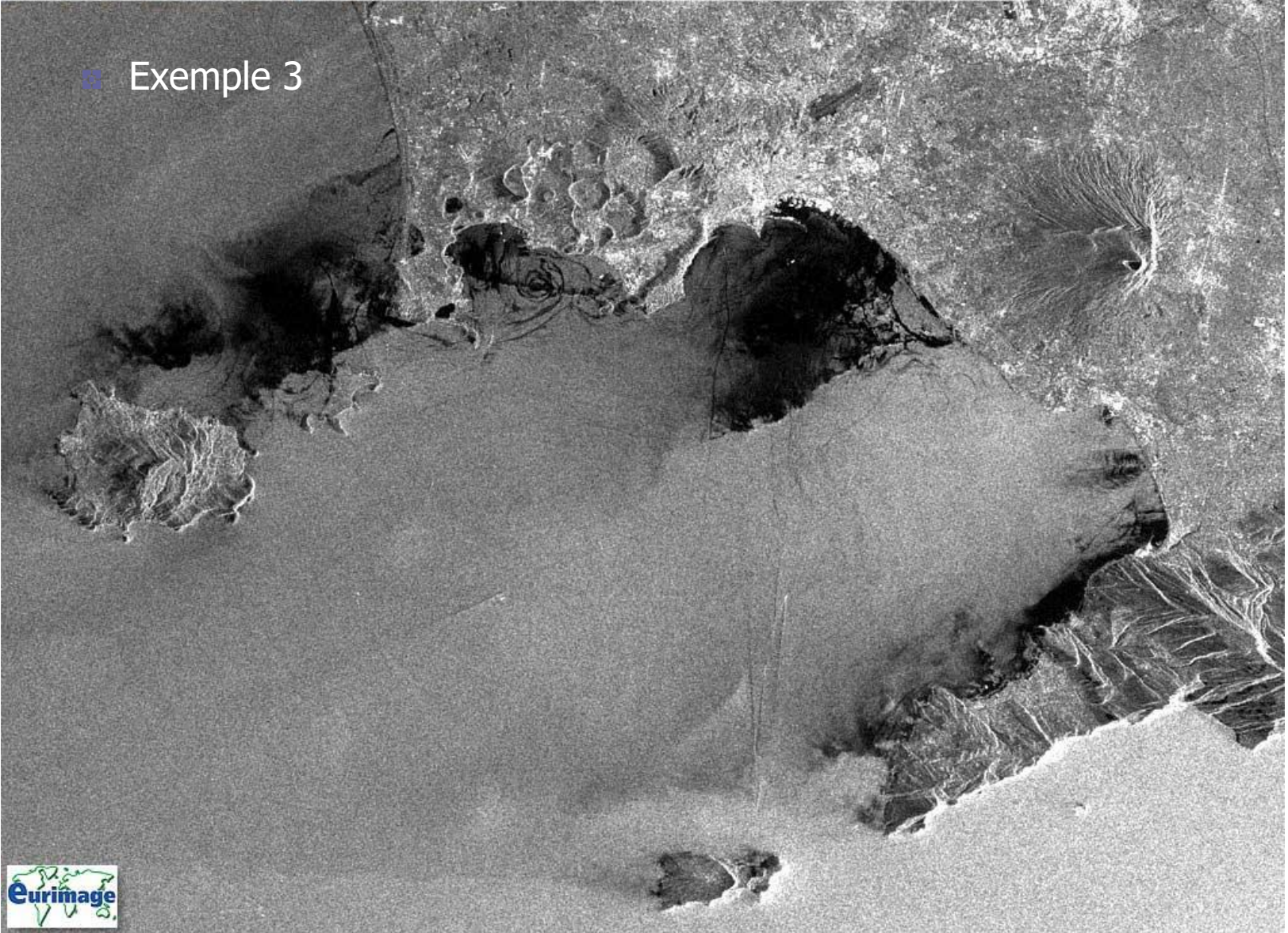
http://www.esa.int/esaEO/SEMBDI0OWUF_index_0.html

Naufrage du « Prestige ».
Image Envisat ASAR
acquise le 20 novembre 2002



ERS-2 SAR, Naples 1999

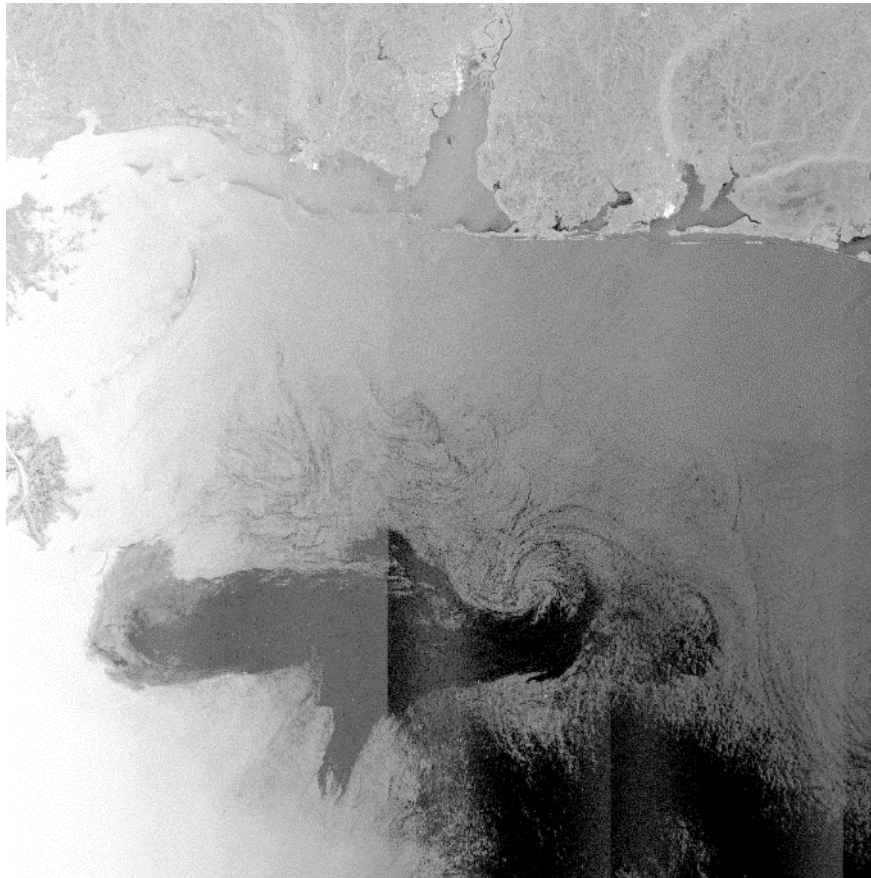
Exemple 3



⊕ Comparaison optique - Radar

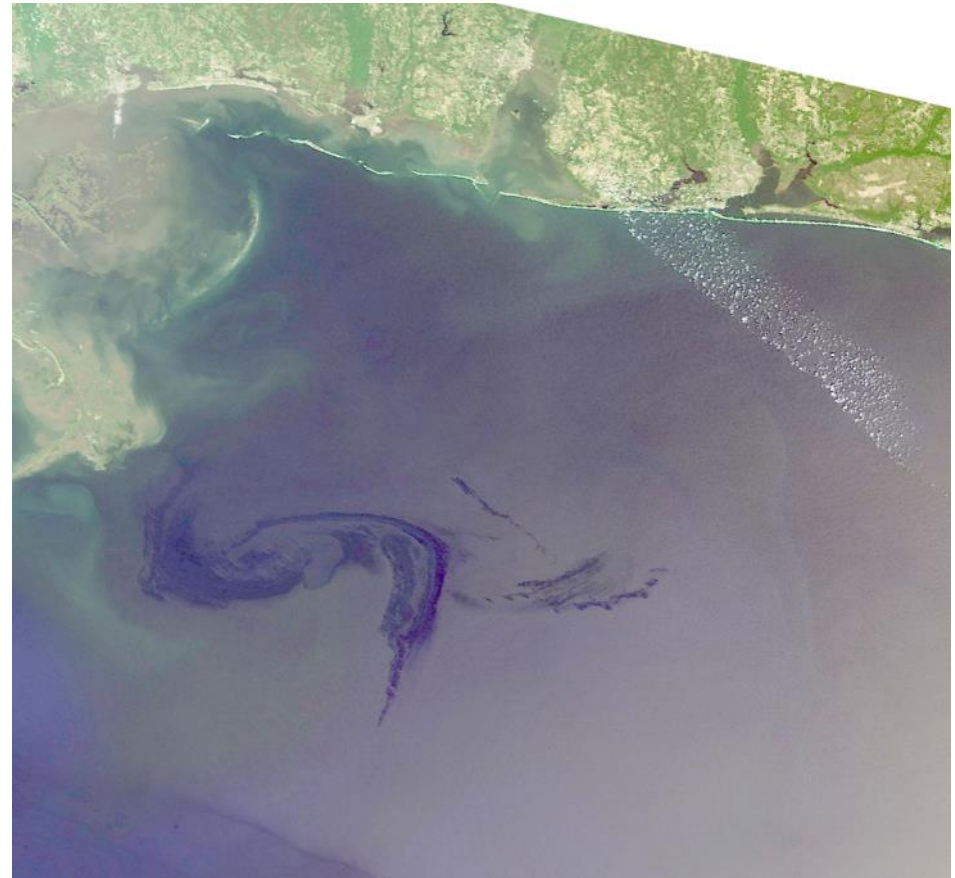
Pollution de la plateforme BP dans le Golfe du Mexique

http://www.esa.int/esaEO/SEMW1HHMI8G_index_0.html



Envisat / ASAR acquise le 28 avril 2010

<http://www-igm.univ-mlv.fr/~riazano/>
version 2.09



Envisat / MERIS acquise le 29 avril 2010

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✚ Comparaison optique - Radar

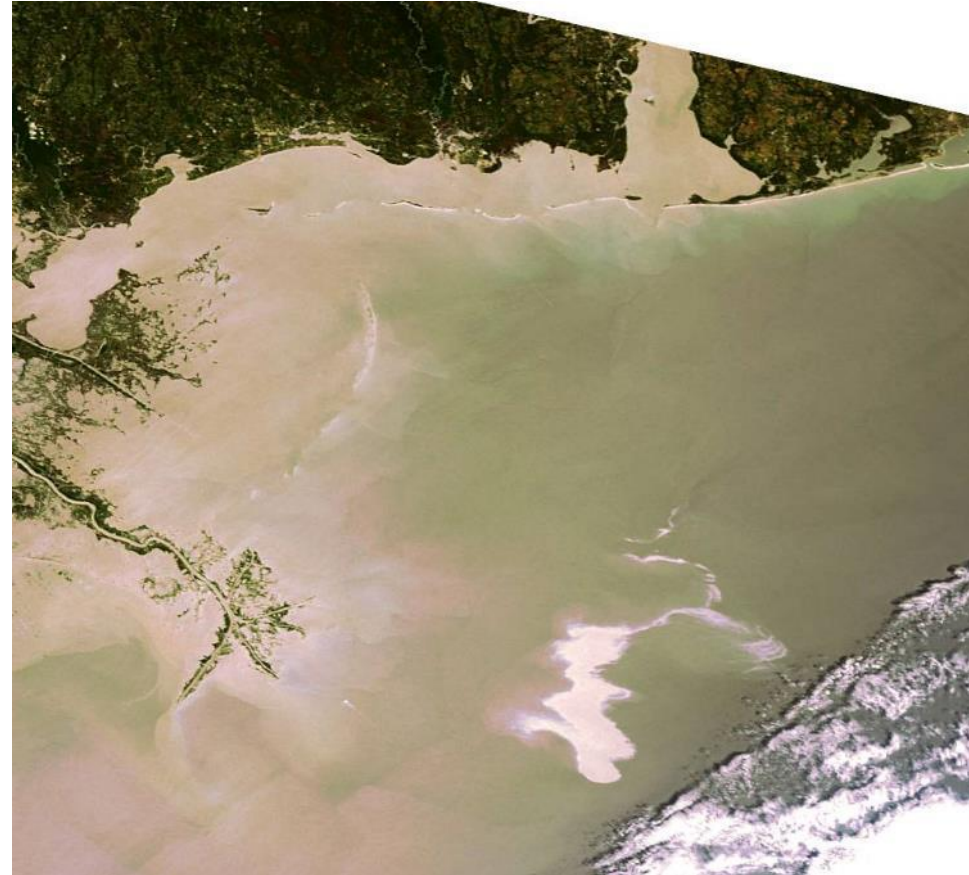
Pollution de la plateforme BP dans le Golfe du Mexique

http://www.esa.int/esaEO/SEM990HMI8G_index_0.html



Envisat / ASAR acquise le 22 avril 2010

<http://www-igm.univ-mlv.fr/~riazano/>
version 2.09

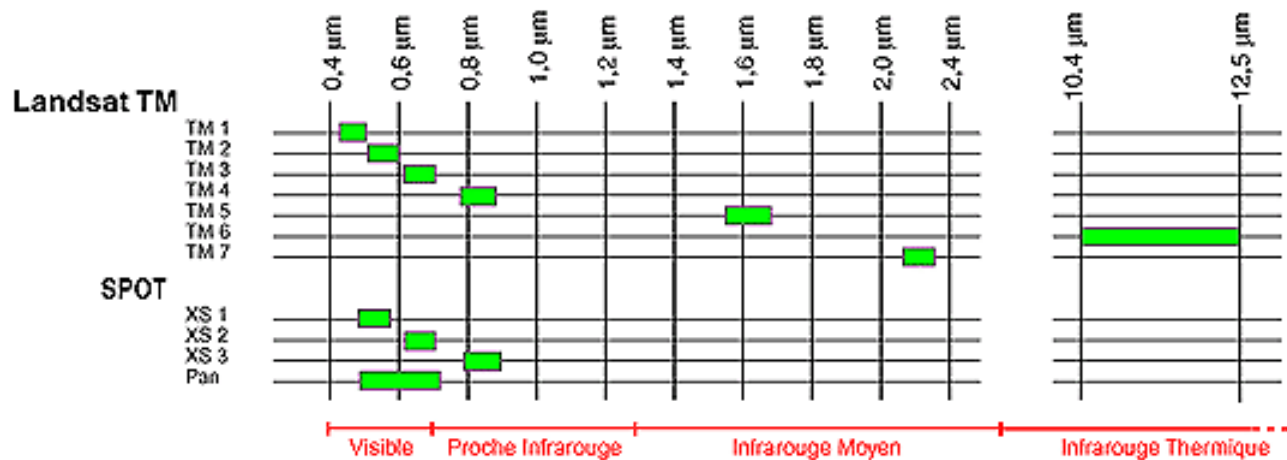
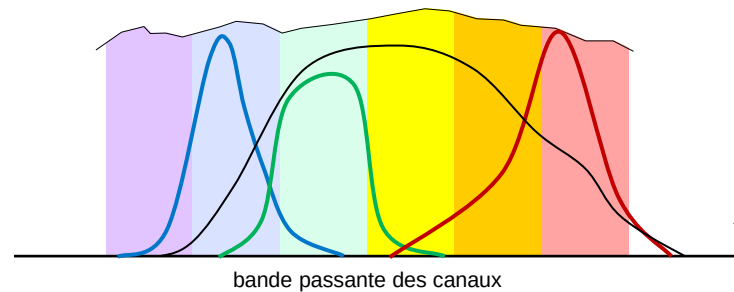


Envisat / MERIS acquise le 25 avril 2010

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Caractéristiques des instruments

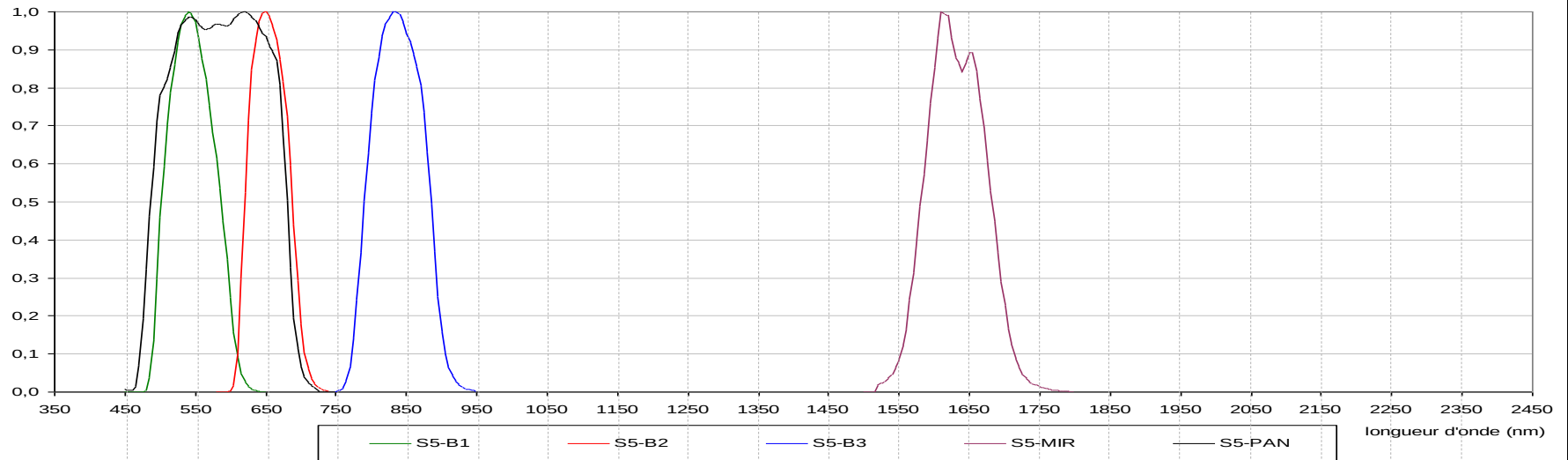
Réponse spectrale et résolution fréquentielle (ou spectrale)



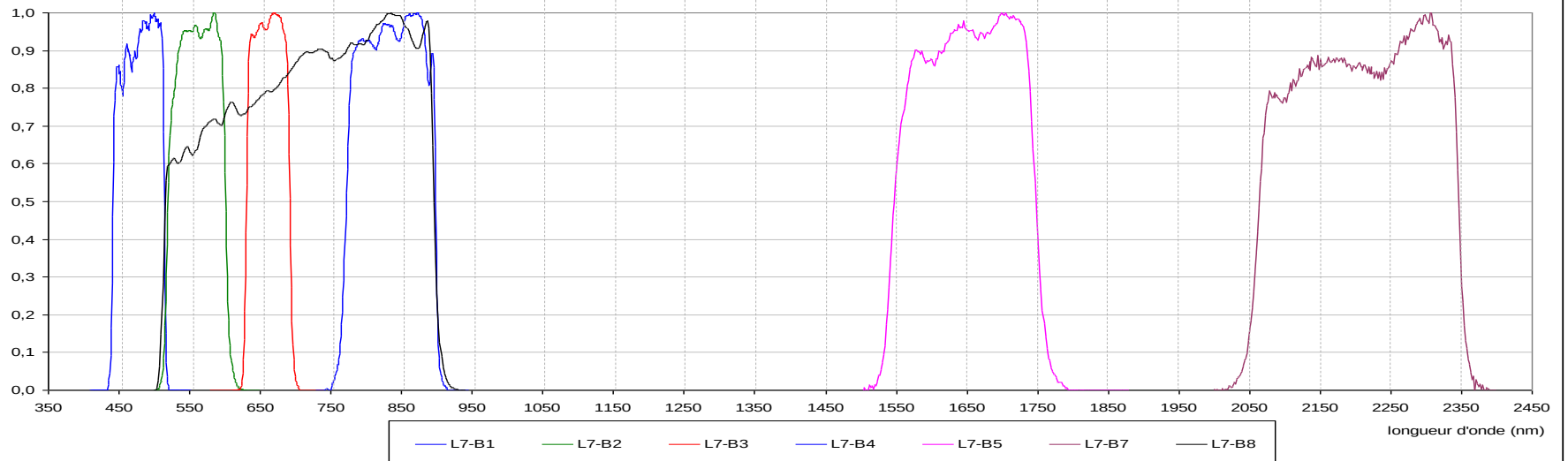
<http://telsat.belspo.be/beo/fr/guide/index.htm>



REPONSES SPECTRALES SPOT-5



REPONSES SPECTRALES LANDSAT-7



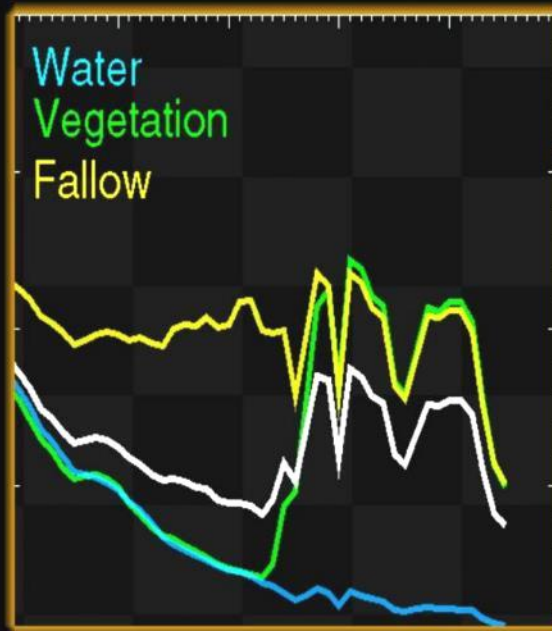


EO-1/Hyperion

Site de référence Hyperion:

<http://eo1.gsfc.nasa.gov/Technology/Hyperion.html>

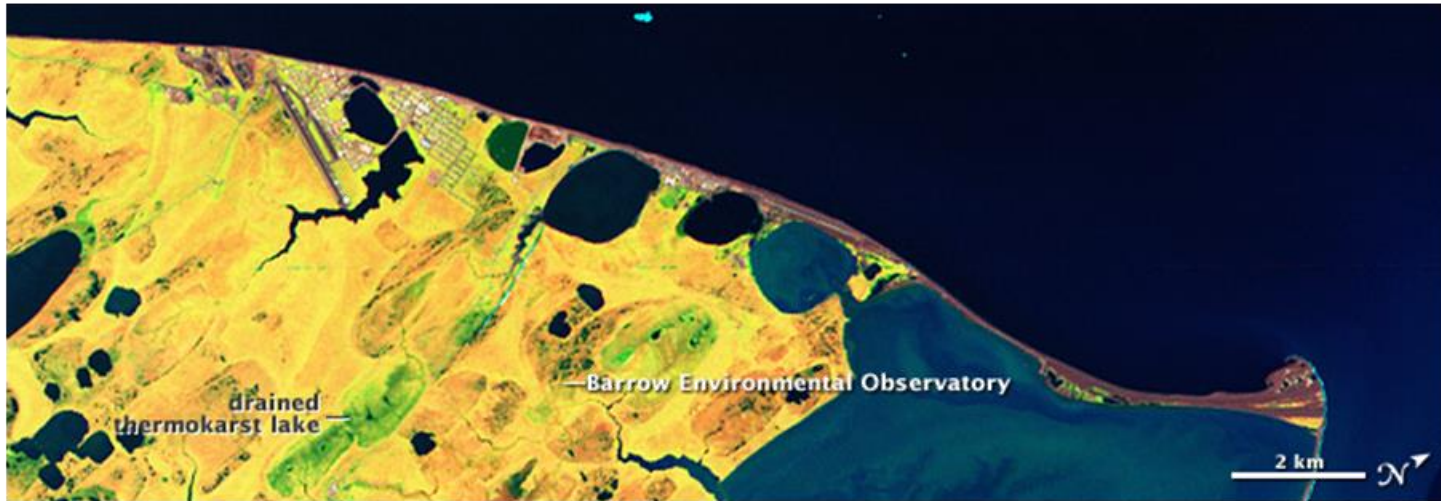
Analysis



Instrument Hyperion – 220 bandes dans l'intervalle 0,4 μm (bleu) à 2,5 μm (MIR) – 30 m résolution – 7.5 km x 100 km
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=4828



False Color



acquired July 20, 2009

Natural Color



Instrument Hyperion – 220 bandes dans l'intervalle $0,4 \mu\text{m}$ (bleu) à $2,5 \mu\text{m}$ (MIR)
<http://earthobservatory.nasa.gov/IOTD/view.php?id=40853>

acquired July 20, 2009



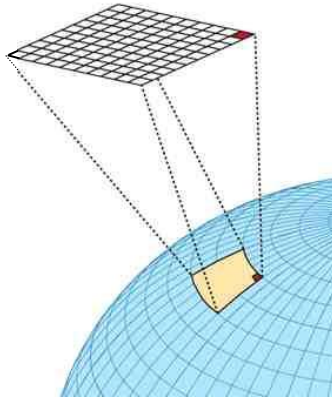
- Comparer la réponse spectrale de différents instruments

Table 4 Characteristics of SPOT-4 and IRS P6 imagery compared to Landsat-7

Satellite	Landsat-7	SPOT-4	IRS P6
Sensor	ETM	HRVIR	LISS III
Swath width (km)	180	60-80 (depending on looking angle)	141
Pixel size (m)	30 (multi-spectral) 15 (panchromatic)	20 (multi-spectral) 10 (panchromatic)	23
Image dynamics (bits)	8	8	7
Number of bands	7 + 1	4 + 1	4
Blue band	0.45 — 0.52 μm (TM1)	--	--
Green band	0.53 — 0.61 μm (TM2)	0.50 — 0.59 μm (XI1)	0.52 — 0.59 μm (MS1)
Red band	0.63 — 0.69 μm (TM3)	0.61 — 0.68 μm (XI2)	0.62 — 0.68 μm (MS2)
Near-infrared band	0.75 — 0.90 μm (TM4)	0.78 — 0.89 μm (XI3)	0.77 — 0.86 μm (MS3)
Middle-infrared band	1.55 — 1.75 μm (TM5)	1.58 — 1.75 μm (XI4)	1.55 — 1.70 μm (MS4)
Thermal infrared band	10.4 — 12.5 μm (TM6)	--	--
Middle-infrared band	2.09 — 2.35 μm (TM7)	--	--
Panchromatic band	0.52 — 0.90 μm (PAN)	0.61 — 0.68 μm (M)	--
Observation mode	Vertical only	Tiltable sensor (up to +- 31 degree)	Vertical only

Extraite de « CLC2006 technical guidelines » édité par l'EEA en 2007
http://www.igeo.pt/gdr/pdf/CLC2006_technical_guidelines.pdf

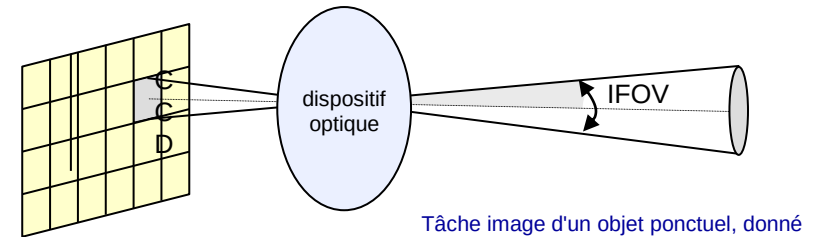
■ Résolution spatiale



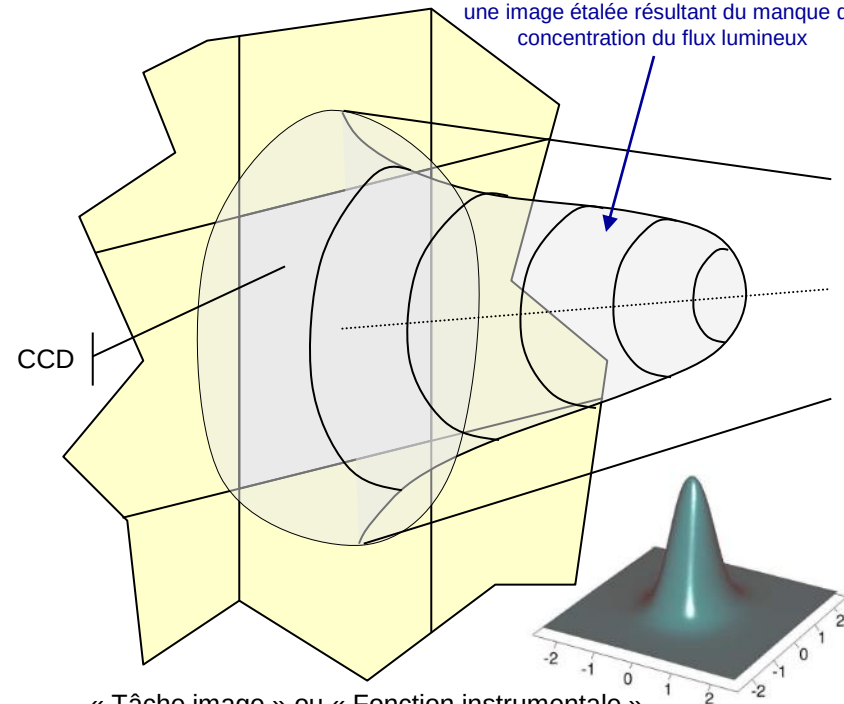
Landsat TM (30 mètres)

SPOT PAN (10 mètres)

<http://telsat.belspo.be/beo/fr/guide/index.htm>



Tâche image d'un objet ponctuel, donné par un instrument d'optique entaché d'aberration sphérique, caractérisée par une image étalée résultant du manque de concentration du flux lumineux



« Tâche image » ou « Fonction instrumentale »
ou « Bande passante spatiale »
(PSF: Point Spread Function)

(FTM: Fonction de Transfert de Modulation
dans le domaine fréquentiel)



❖ Résolution spatiale – Exemple de SPOT

XS 20 metres



XI 10 metres



XI+P 5 metres



XI+P 2.5 metres



Full resolution (x1)



Zoomed (x8 x4 x2 x1)

❏ résolution fréquentielle (ou spectrale) contre résolution spatiale

moins bonne résolution spectrale
(bande passante large ≈ 200 nm)

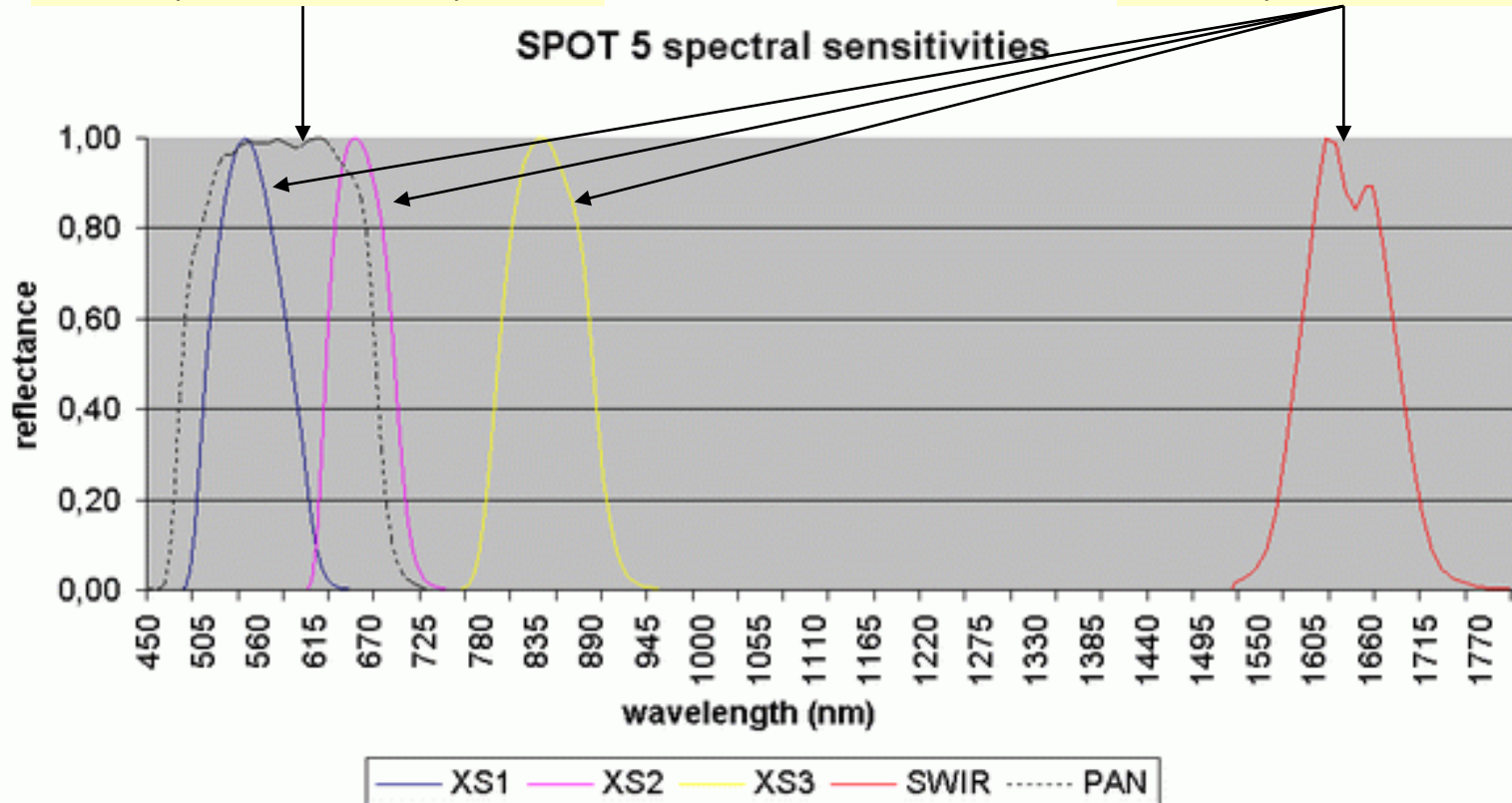


meilleure résolution spatiale
(SPOT-5 PAN à 5 m)

meilleure résolution spectrale
(bande passante étroite ≈ 100 nm)



moins bonne résolution spatiale
(SPOT-5 XS à 10 m)





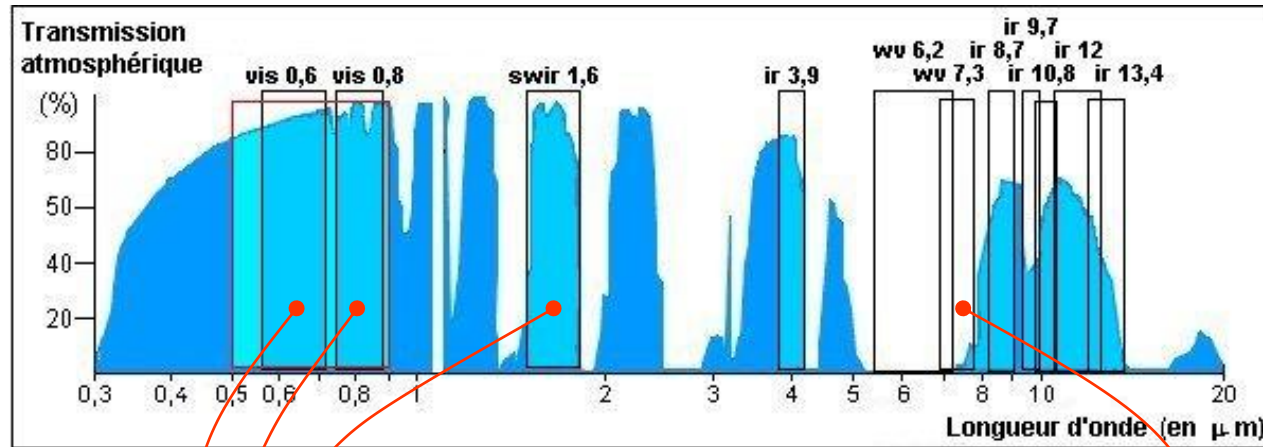
■ Satellites et instruments – Exemple de SPOT

<i>satellite</i>	<i>instrument</i>	<i>nom de la bande spectrale</i>	<i>longueur d'onde (μm)</i>	<i>résolution spatiale⁽¹⁾</i>	<i>nb. de CCD par ligne</i>
SPOT123	HRV1 ou HRV2	XS1	0.50-0.59	20 m	3000
		XS2	0.61-0.68	20 m	3000
		XS3	0.78-0.89	20 m	3000
		PAN	0.50-0.73	10 m	6000
SPOT4	HRVIR1 ou HRVIR2	XS1	0.50-0.59	20 m	3000
		XS2	0.61-0.68	20 m	3000
		XS3	0.78-0.89	20 m	3000
		SWIR	1.58-1.75	20 m	3000
		M	0.61-0.68	10 m	6000
SPOT5	HRG1 ou HRG2	XS1	0.495-0.605	10 m	6000
		XS2	0.617-0.687	10 m	6000
		XS3	0.780-0.893	10 m	6000
		SWIR	1.545-1.750	20 m	3000
		HMA	0.475-0.710	5 m	12000
		HMB	0.475-0.710	5 m	12000
	HRS	HRS1 (<i>visée avant</i>)	0.49-0.69	10 m x 5 m	12000
		HRS2 (<i>visée arrière</i>)	0.49-0.69	10 m x 5 m	12000

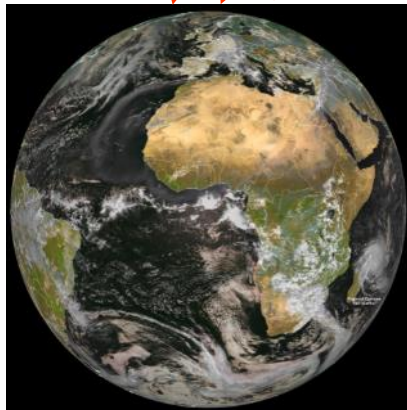
(1) Distance d'échantillonnage au sol en visée verticale.

• Satellites et instruments – Exemple de Meteosat-8 SEVIRI

	12	1	2	3	4	5	6	7	8	9	10	11
	HRV	VIS 0.6	VIS 0.8	SWIR	IR 3.9	WV 6.2	WV 7.3	IR 8.7	IR 9.7	IR 10.8	IR 12	IR 13.4
domaine spectral (μm)	0.5-0.9	0.6-0.7	0.7-0.9	1.5-1.8	3.5-4.4	5.3-7.1	6.8-7.9	8.3-9.1	9.4-9.9	9.8-11.8	11-13	12.4-14
résolution spatiale au NADIR	1 km	3 km	3 km	3 km	3 km	3 km	3 km	3 km	3 km	3 km	3 km	3 km



<http://www.educnet.education.fr/orbito/system/meteosat/met23.htm>

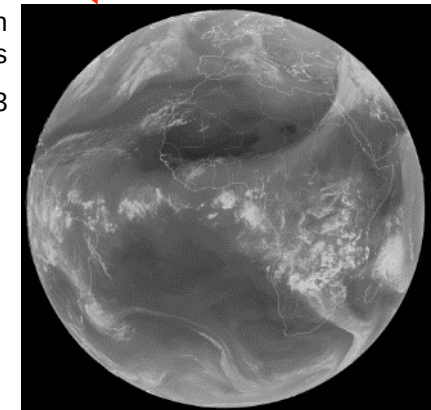


Composition
colorée

VIS 0.6 (B)
VIS 0.8 (V)
SWIR 1.6 (R)

Image en
niveaux de gris

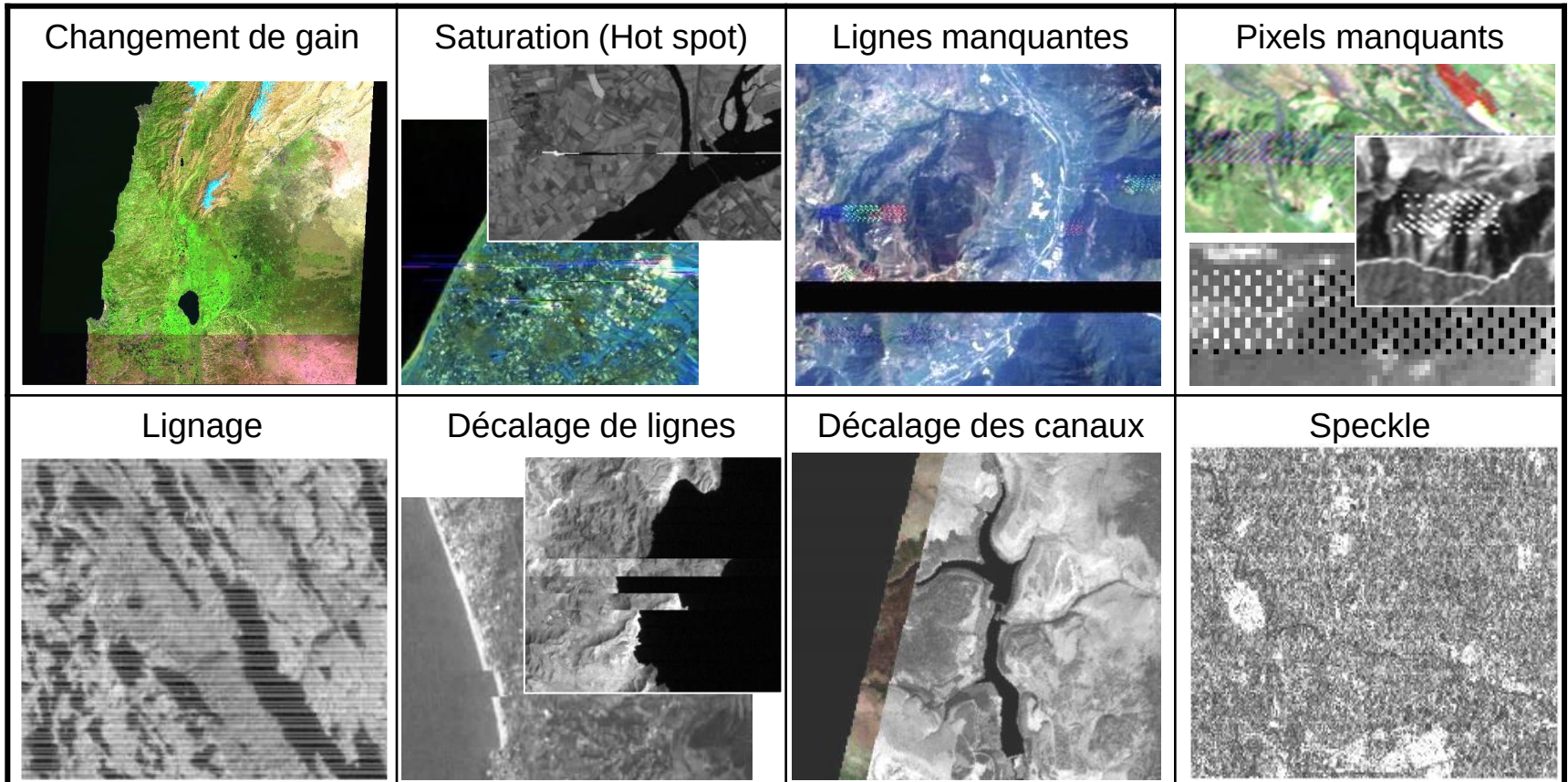
WV 7.3



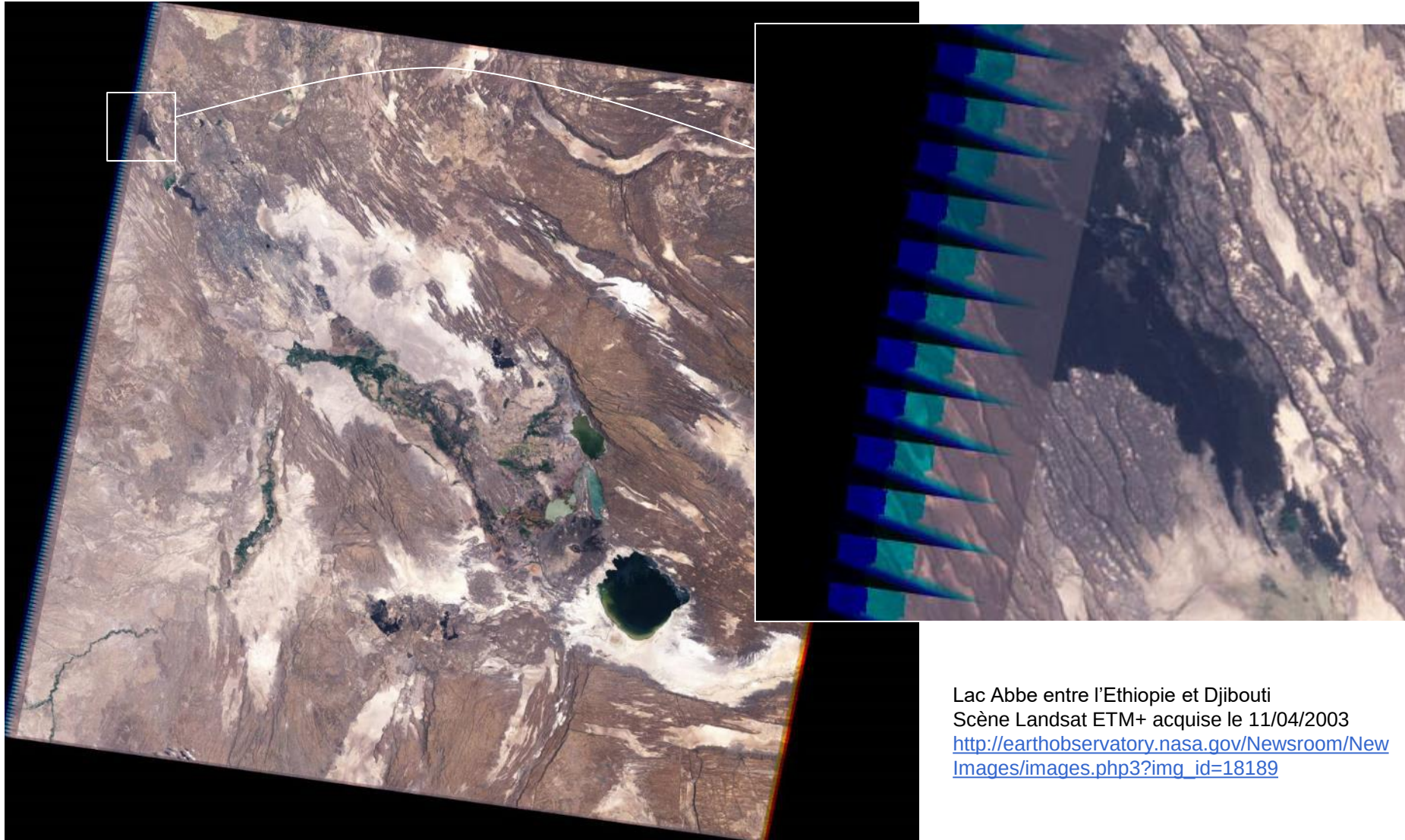
Meteosat-8 acquis le 06/03/2004 12:00 UTC

http://www.eumetsat.int/Home/Main/Image_Gallery/PR_Images/Fulldisk_Images/index.htm

■ Rapport signal / bruit (SNR) - Quelques exemples de bruit dans les images



■ Landsat / ETM+ – Emprise incomplète des bandes spectrales



Lac Abbe entre l'Ethiopie et Djibouti
Scène Landsat ETM+ acquise le 11/04/2003
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=18189

❏ AQUA / MODIS – Défaut de calibration des détecteurs



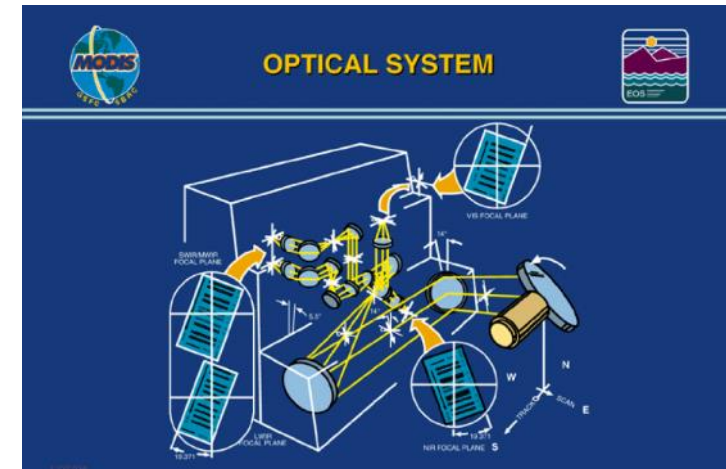
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=18054

<http://www-igm.univ-mlv.fr/~riazano/>

version 2.09

Serge RIAZANOFF

Initiation au Traitement d'Images

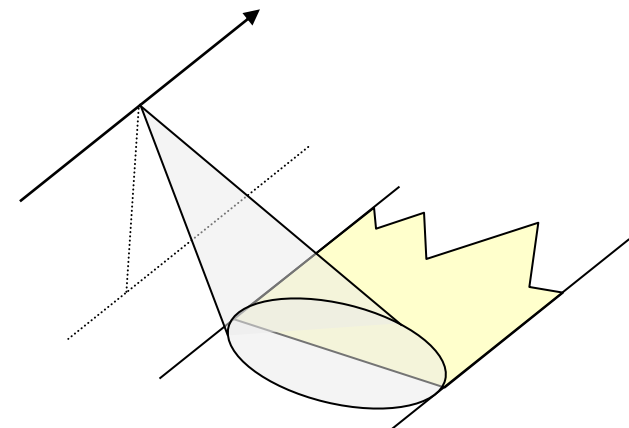
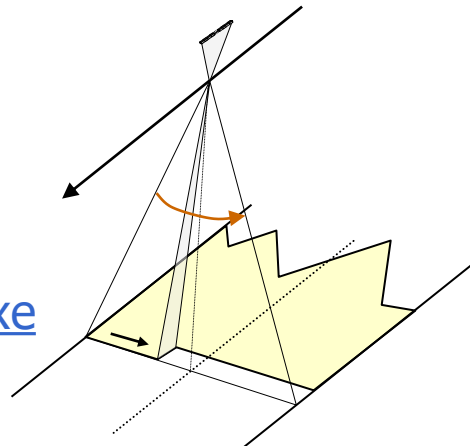
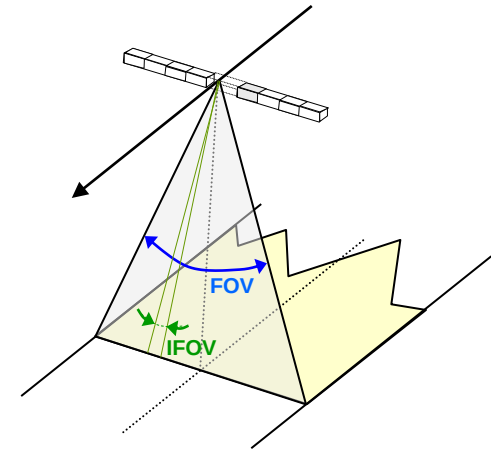
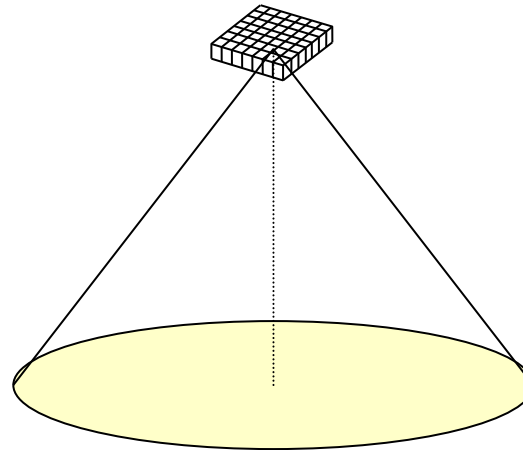


Wiskbroom 40 (B1-2) / 20 (B3-7) /10 (B8-36) CCDs

http://modis.gsfc.nasa.gov/MODIS/CAL/DOCS/L137_014.pdf

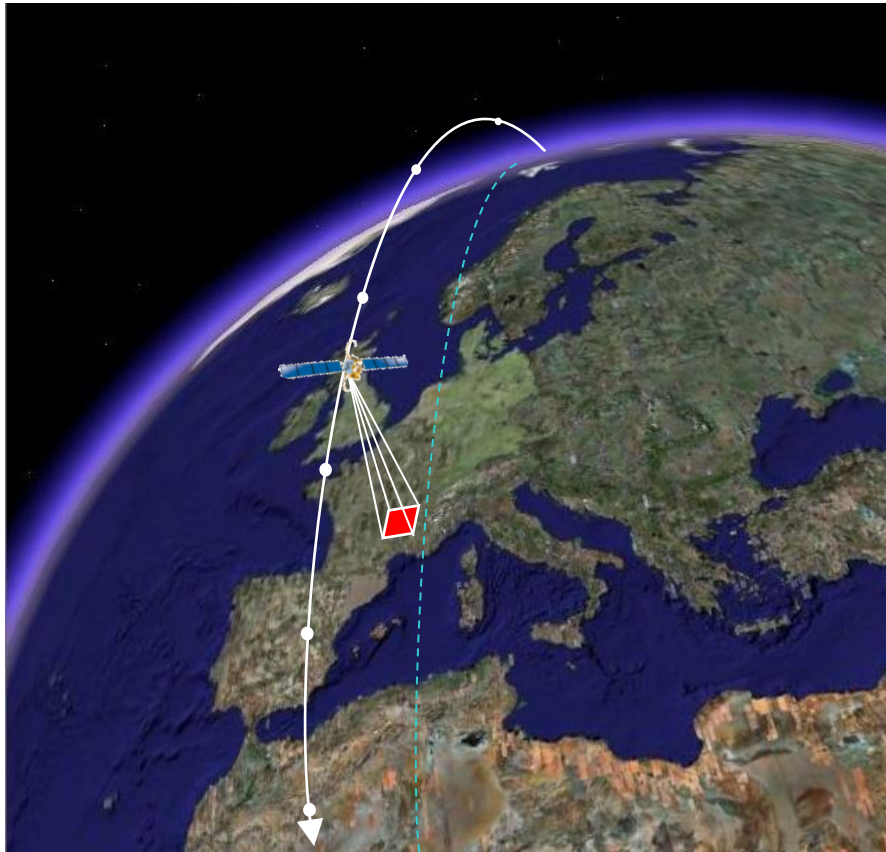
❁ Satellites et instruments – Géométrie de prise de vue

- ❁ Capteur matriciel
Géométrie conique
(*frame camera*)
- ❁ Capteur en peigne
(*pushbroom*)
- ❁ Fauchées latérales
(*whiskbroom*)
- ❁ Radar



Erreurs de parallaxe

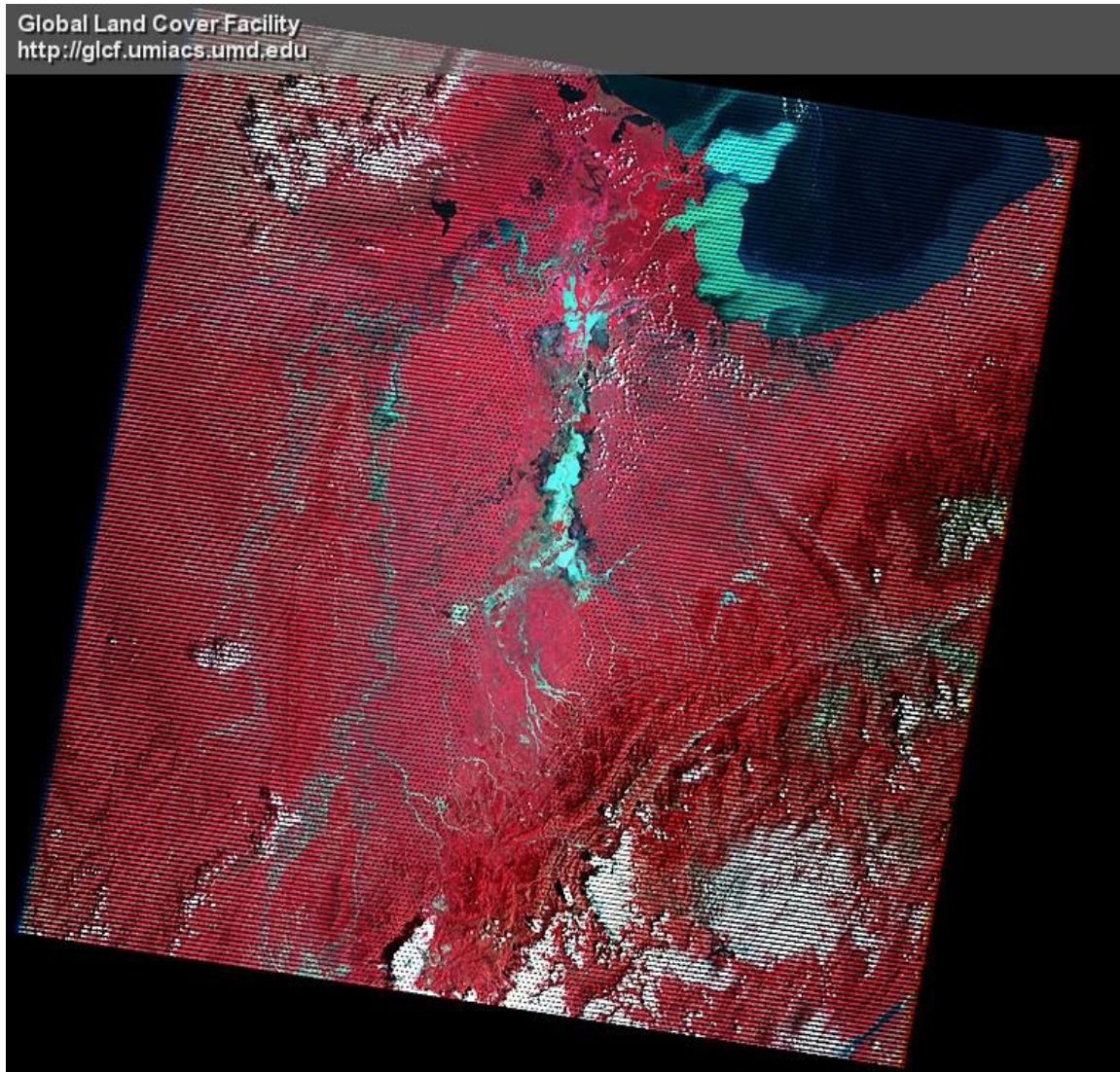
■ Prise de vue instantanée
Frame camera



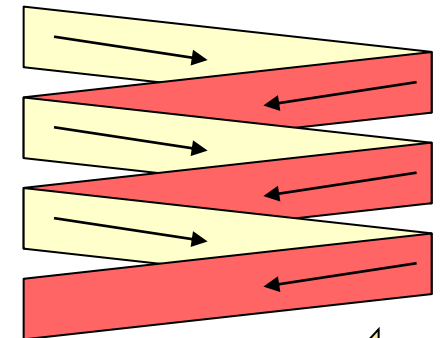
• Prise de vue en peigne
Pushbroom



❏ Landsat 7 – Défaut des miroirs correcteurs

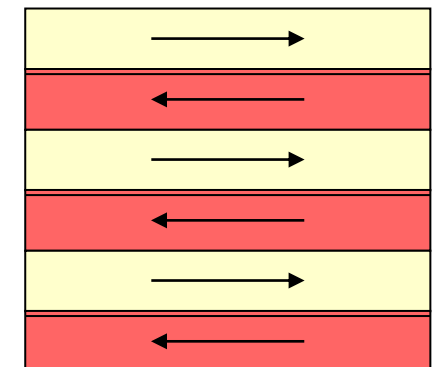


Landsat 7 ETM+
path 007 – row 054
Acquired on 26/02/2005
South of Maracaibo Lake
(Venezuela)



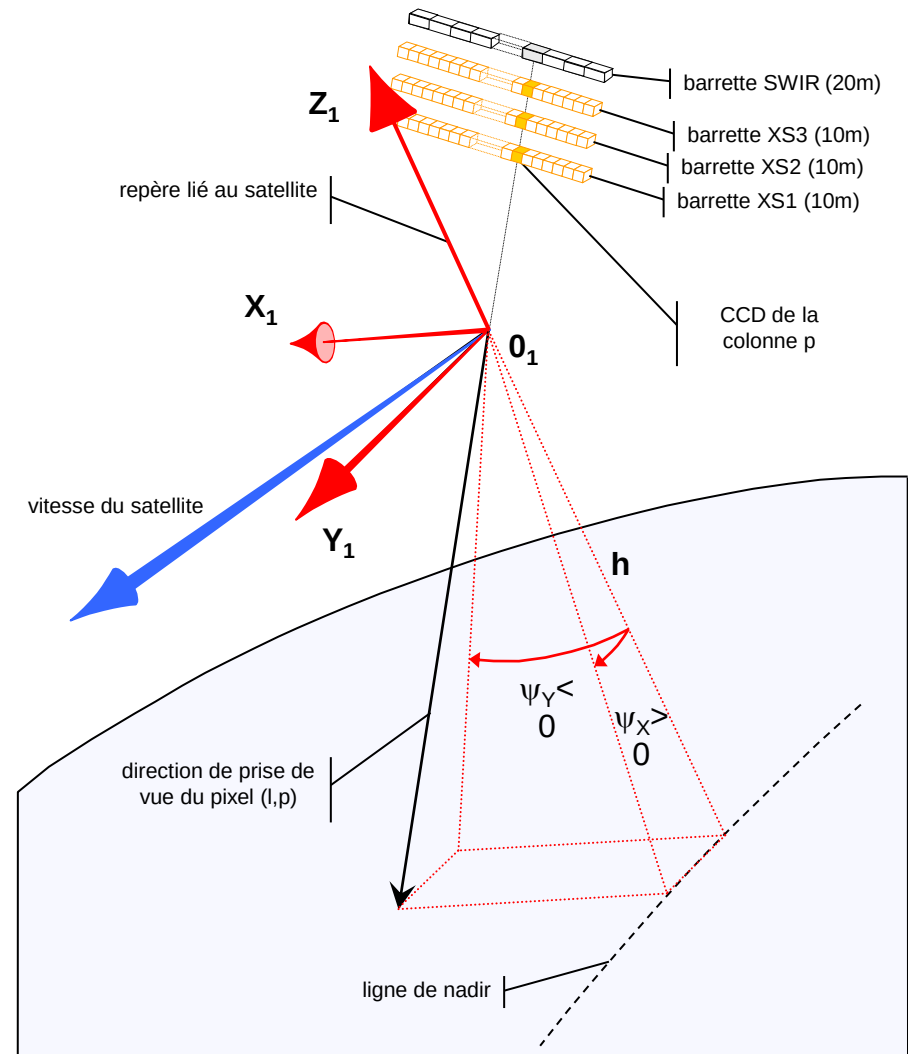
SLC-off

panne le 31 mai 2003



SLC-on

Exemple de SPOT 5





⊕ Représentation et format des données

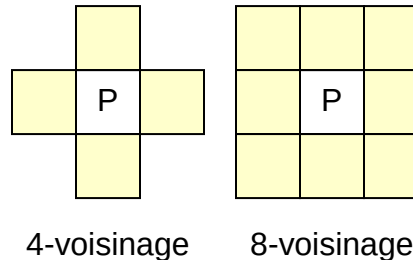
- ▣ trame et topologie
- ▣ repère image
- ▣ représentation des pixels
- ▣ formats BSQ, BIL, BIP
- ▣ supports - transport et compression des données



Images: trame et topologie

Trame carrée

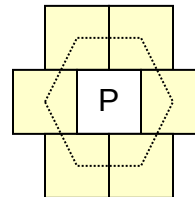
123	98	76	69	61
118	112	93	85	77
97	99	101	105	107
92	82	59	103	129



123	98	76	69	61
118	112	93	85	77
97	99	101	105	107
92	82	59	103	129

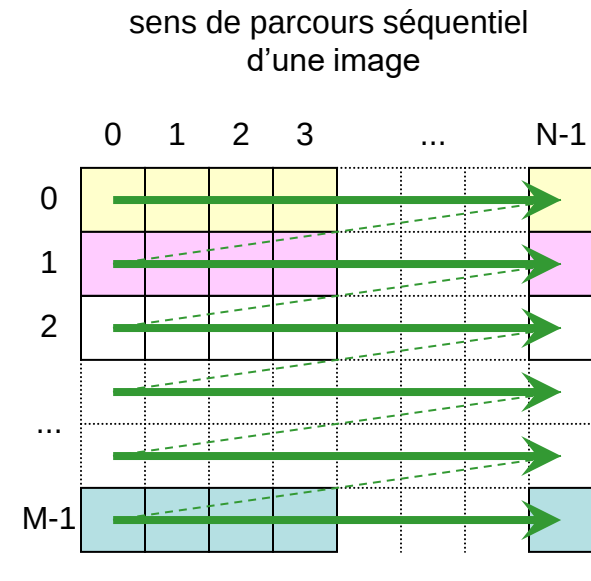
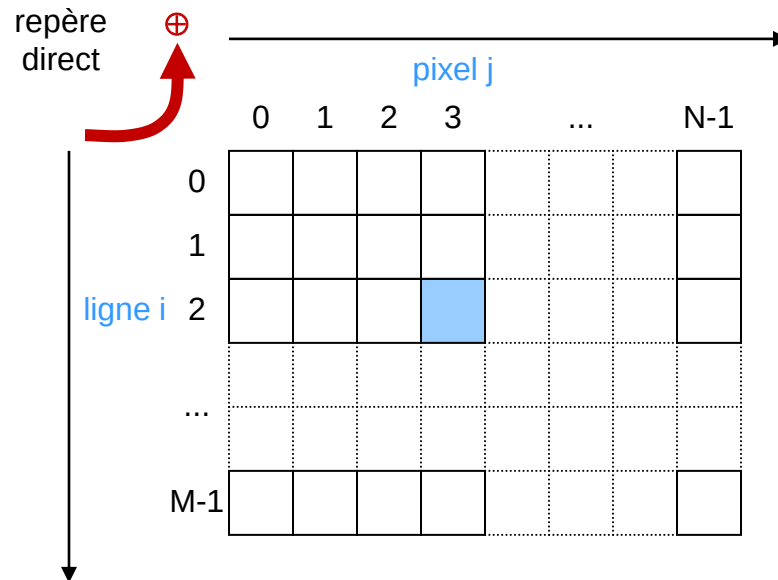
Trame hexagonale

123	98	76	69	61	
122	118	112	93	85	77
97	99	101	105	107	
89	92	82	59	103	129

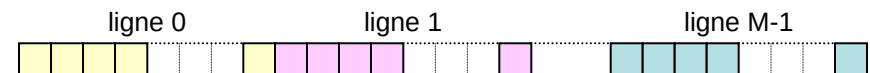


123	98	76	69	61	
122	118	112	93	85	77
97	99	101	105	107	
89	92	82	59	103	129

Représentation et repère image



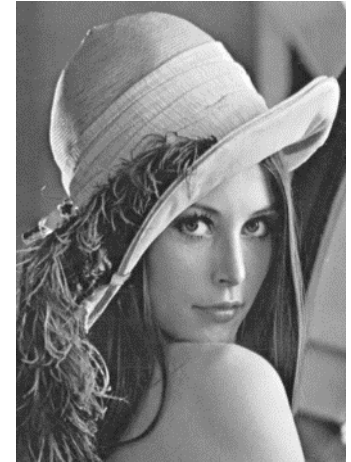
pour des raisons d'optimisation, c'est dans ce sens que seront rangés les pixels dans le tableau image



⊕ Représentation des pixels

unsigned integer – signed integer – float – double

- 1 bit par pixel → {0,1}
- 8 bits par pixel → [0,255]
- 16 bits par pixel → [0,65535]



original (8 bits/pixel)

1 bit
{0,1}



2 bits
[0,3]



3 bits
[0,7]



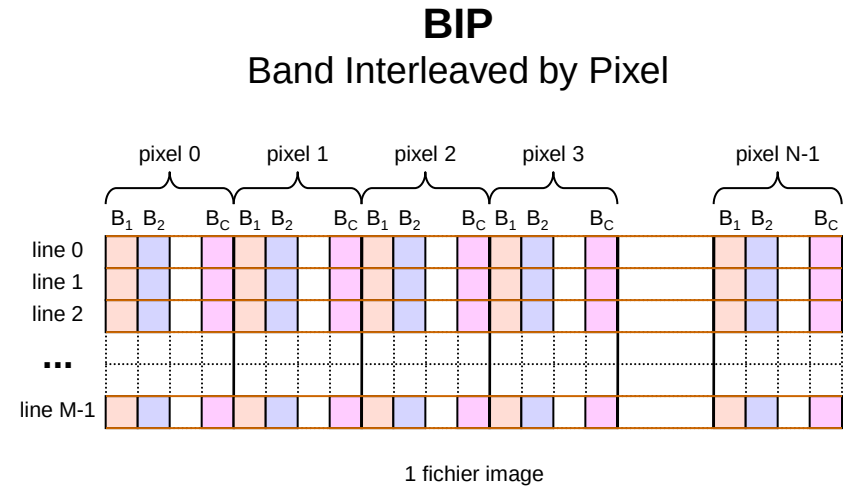
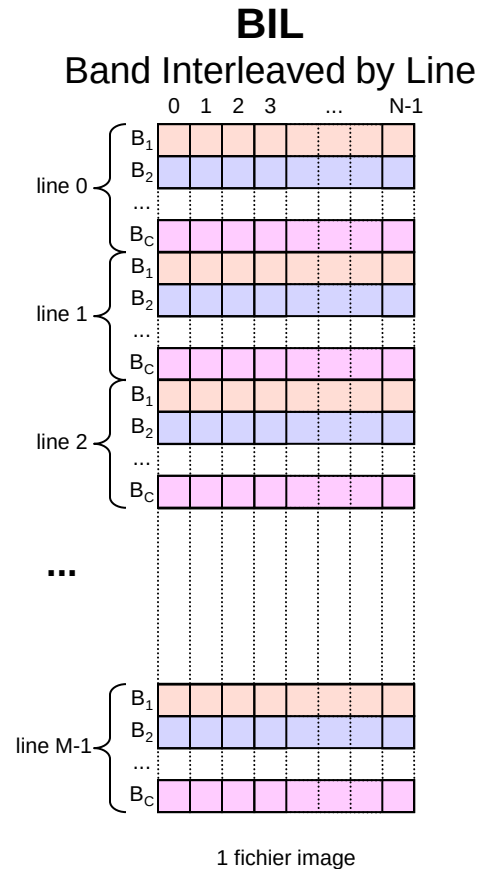
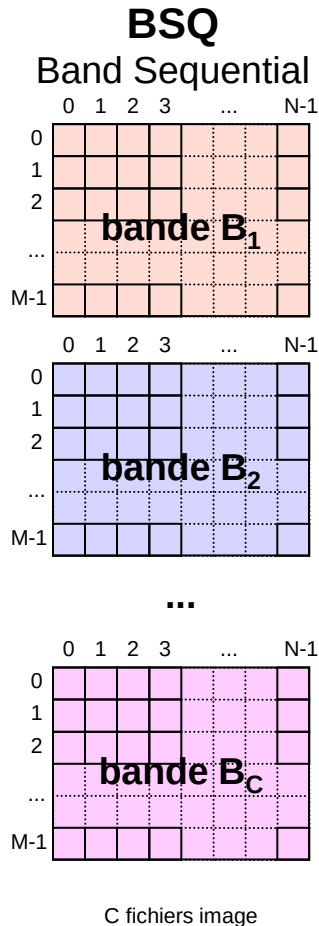
4 bits
[0,15]



5 bits
[0,31]



Formats BSQ, BIL et BIP

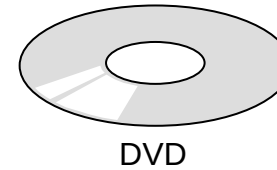
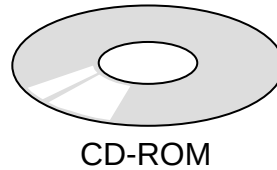
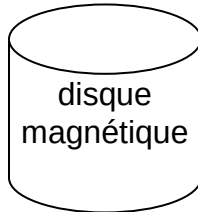


+ Données auxiliaires

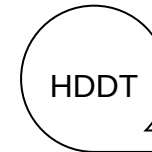
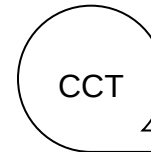
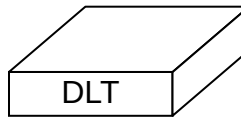
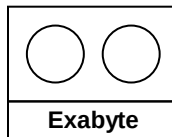
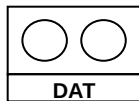
- En-tête ou fichier(s) associé(s)
- Structure: taille, nombre de canaux, nombre de lignes, nombre de colonnes, nombre de bits, type de valeurs (entier/flottant, signé/non signé...)
- Plate-forme / Instrument: nom du satellite, nom de l'instrument, date d'acquisition, path/row, niveau de traitement, mode spectrale, angles de visée, éphémérides...
- Physique: gain, offset, unité...
- Administration: date de création, historique de traitement...

Supports de données image

Supports à accès direct



Supports à accès séquentiel



name	print	value
yotta	Y	1×10^{24}
zetta	Z	1×10^{21}
exa	E	1×10^{18}
peta	P	1×10^{15}
tera	T	1×10^{12}
giga	G	1×10^9
mega	M	1×10^6
kilo	k	1×10^3
hecto	h	1×10^2
deka	da	1×10^1
deci	d	1×10^{-1}
centi	c	1×10^{-2}
milli	m	1×10^{-3}
micro	μ	1×10^{-6}
nano	n	1×10^{-9}
pico	p	1×10^{-12}
femto	f	1×10^{-15}
atto	a	1×10^{-18}
zepto	z	1×10^{-21}
yocto	y	1×10^{-24}

The prefix symbols – UCUM
(Unified Code for Units of Measure)

<http://aurora.regenstrief.org/UCUM/ucum.html>

✚ Transport et compression des données

- ✚ Bande passante des réseaux
- ✚ compression sans perte
- ✚ compression avec perte

TIFF sans perte	JPEG quality 100 perte minimale	JPEG quality 30	JPEG quality 20	JPEG quality 10
170760	11133	7633	6004	4120

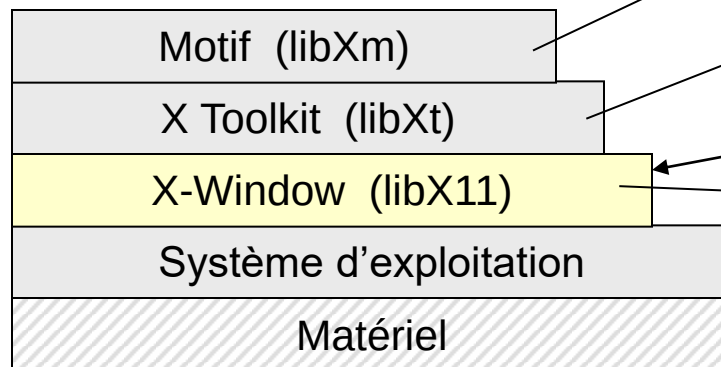
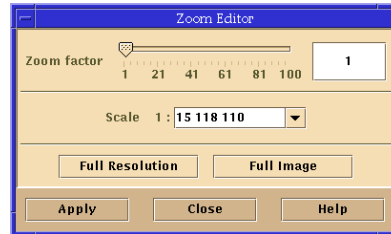




✧ Visualisation d'images sous X-Window

- ✧ introduction à X-Window – serveur X
- ✧ du disque à l'écran – visual et colormap – compositions colorées
- ✧ couleurs prédéfinies de X-Window
- ✧ l'application « xv »

✚ Présentation succincte de X-Window



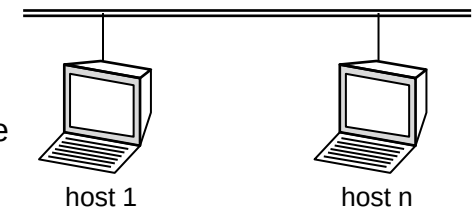
Widget classes
Window manager

Widget (design, actions)

visual_true_colo

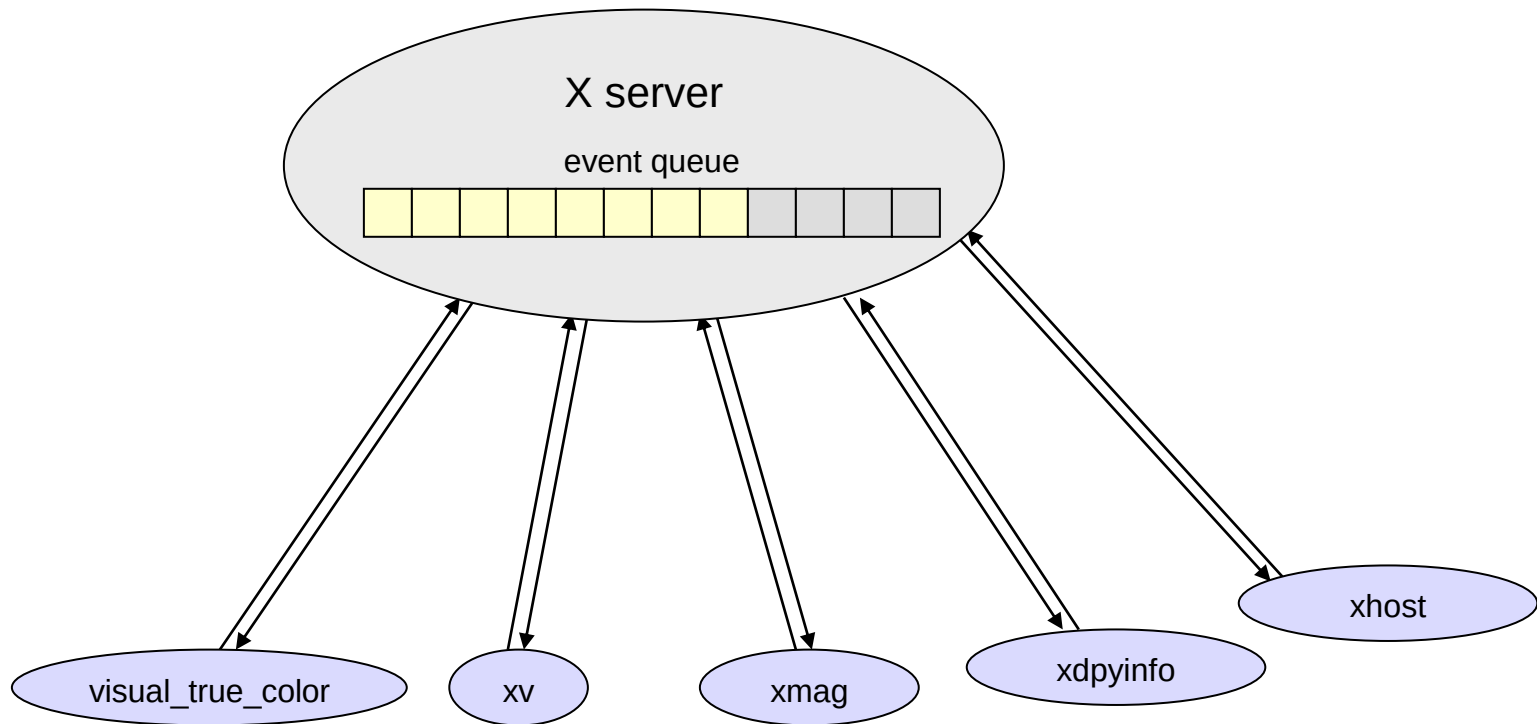
X Protocol

librairie graphique
(fenêtres, tracés,
événements...)

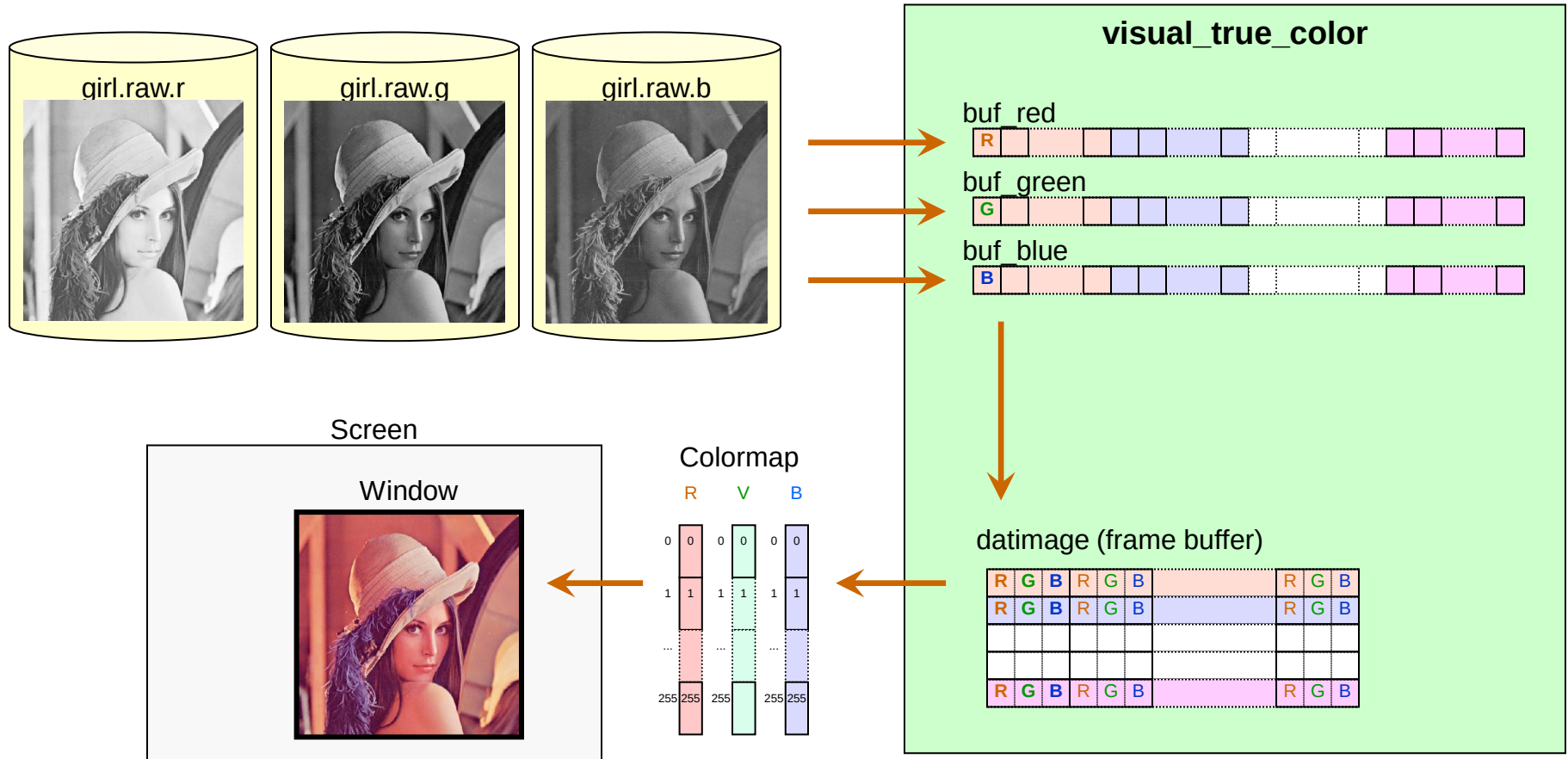




Le serveur X



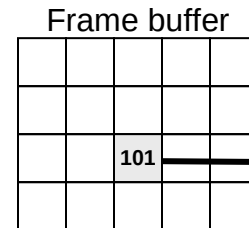
✚ Du disque à l'écran



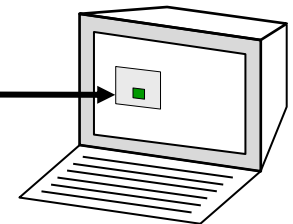
Visual et Colormap

	Visual	
	Colormap en read-only	Colormap en read-write
Monochrome / Gray	StaticGray	GrayScale
1 seule colormap RGB	StaticColor	PseudoColor
3 colormaps R, G et B	TrueColor	DirectColor

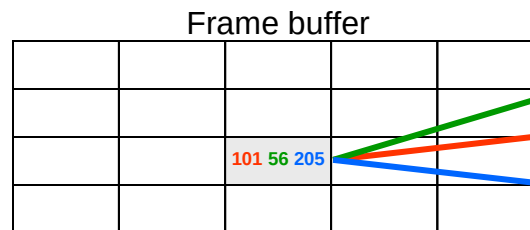
PseudoColor



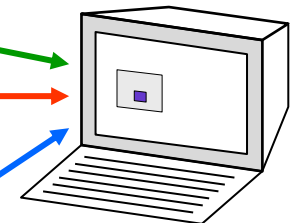
	R	V	B
0	255	255	255
1	0	0	0
...			
17	157	19	255
...			
100	0	0	0
101	0	255	17
102			
...			
255			



TrueColor



	R	V	B
0	0	0	0
1	1	...	1
...			
56		56	...
57		57	...
...			
101	101	...	...
102	102	...	...
...			
205	...	...	205
...			
255	255	255	255

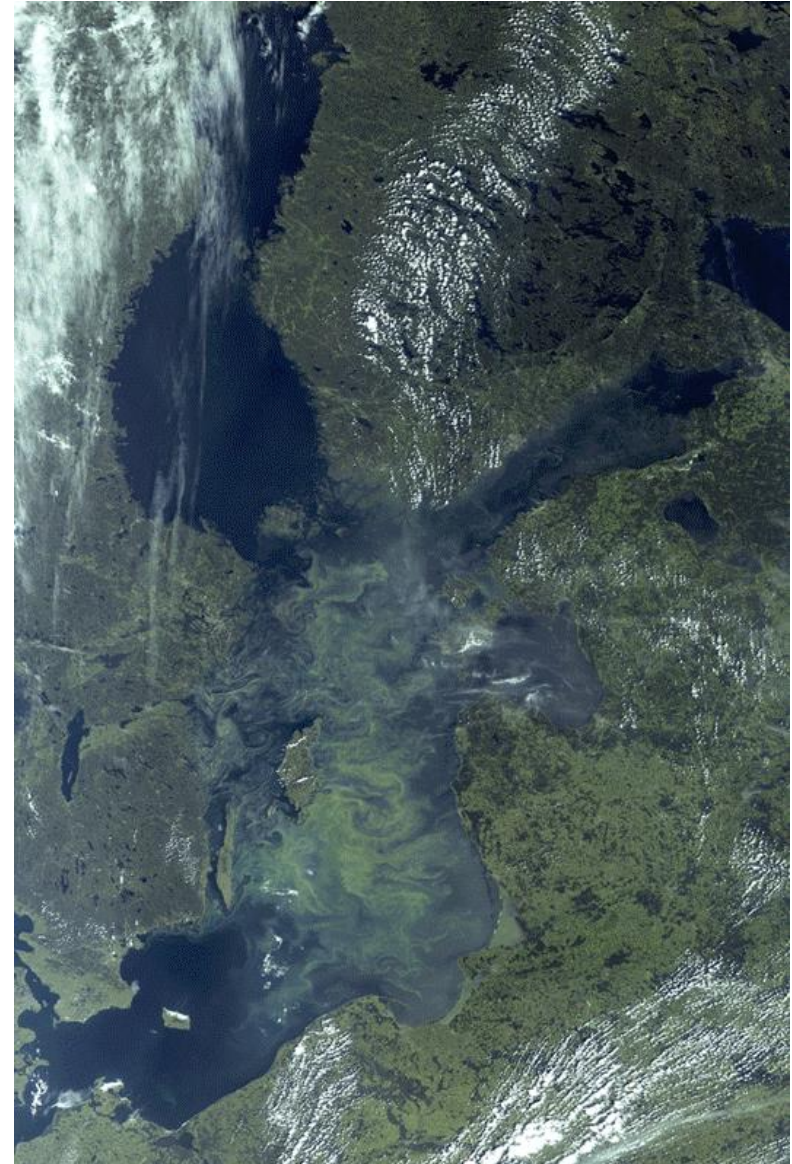




TrueColor et PseudoColor

Scène Envisat MERIS de la Mer Baltique
Sédiments en suspension dérivés de l'image multispectrale
au large de Talinn (Estonie)

http://www.esa.int/esaCP/SEMXTLLTRJG_index_0.html





Les couleurs prédéfinies de X-Window

Color name	RGB decimal	hexa																					
Snow	255 255 255	#FFFFFF	Light Cyan	224 255 255	#E0FFFF	Pale Violet Red	219 112 147	#B07093	Lavender Blush3	205 193 197	#CDC1C5	Light Cyan4	122 139 139	#7A8BB8	Khaki1	255 246 143	#FFF68F	Firebrick2	238 44 44	#EE2C2C	Pale Violet Red3	205 104 137	#CD6889
Ghost White	248 248 255	#F8BFF8	Cladde Blue	95 158 160	#5F9EAO	Maroon	174 68 99	#B03060	Lavender Blush4	139 131 134	#B883B6	Pale Turquoise1	187 255 255	#B0FFFF	Khaki2	238 230 213	#EEE68E	Firebrick3	205 38 38	#CD8B26	Pale Violet Red4	139 171 93	#8B475D
White Smoke	245 245 245	#F5F5F5	Medium Aquamarine	102 205 170	#66CDAA	Medium Violet Red	191 21 133	#C71585	Misty Rose1	255 228 225	#FFC0CB	Pale Turquoise2	174 238 238	#B0E0E6	Khaki3	205 198 115	#CDCC73	Firebrick4	139 26 26	#8B1A1A	Maroon1	255 19 19	#FF4500
Gainsboro	220 220 220	#DCDCDC	Aquamarine	127 255 212	#7FFFD4	Violet Red	208 32 144	#D02090	Misty Rose2	238 213 210	#E0D5D0	Pale Turquoise3	150 205 205	#90F0D0	Khaki4	139 134 178	#8B864E	Brown1	255 64 44	#FF4500	Maroon2	238 48 167	#EE3A00
Floral White	255 250 240	#FFDAB9	Dark Green	0 100 0	#006400	Magenta	255 0 255	#FF00FF	Misty Rose3	205 183 181	#C08B75	Pale Turquoise4	102 139 139	#90F0F0	Light Goldenrod1	256 236 139	#FFD700	Brown2	238 59 59	#8B4513	Maroon3	205 41 144	#CD2990
Old Lace	253 245 230	#F0F5E6	Dark Olive Green	85 107 47	#556B2F	Violet	238 130 238	#800080	Misty Rose4	139 125 123	#8B7D7D	Cadet Blue1	152 245 255	#90F0FF	Light Goldenrod2	238 230 130	#EEDC8E	Brown3	205 51 51	#CD3333	Maroon4	139 28 98	#8B1C1E
Linon	250 240 230	#FAF0E6	Dark Sea Green	143 188 143	#8FBC8F	Plum	218 160 221	#DDA0DD	Azure1	240 255 255	#00FFFF	Cadet Blue2	142 229 238	#87CEEB	Light Goldenrod3	205 190 112	#CDBE70	Brown4	139 35 35	#8B2323	Violet Red1	255 62 150	#FF3E3E
Antique White	250 235 215	#FAEBD3	SeaGreen	46 139 87	#2E8B57	Orchid	218 112 214	#DA70D6	Azure2	224 238 238	#60EEEE	Cadet Blue3	122 197 205	#7AC5CD	Light Yellow1	139 129 76	#FFD700	Salmon1	255 140 105	#FF8C00	Violet Red2	238 58 140	#EE3A7C
Papaya Whip	255 239 213	#FFDAB9	MediumSeaGreen	60 119 133	#3CB371	Medium Orchid	185 85 211	#BA55D3	Azure3	193 205 205	#1CCDCD	Cadet Blue4	83 134 139	#5CB8E6	Light Yellow2	255 255 224	#FFFFE0	Salmon2	238 130 98	#EE8262	Violet Red3	205 50 120	#CD3A78
Blanched Almond	255 235 205	#FFDAB9	Light Sea Green	32 178 170	#20B2AA	Dark Orchid	153 50 204	#9932CC	Azure4	131 139 139	#938BB8	Turquoise1	0 245 255	#00FFFF	Light Yellow3	238 238 209	#EEDD81	Salmon3	205 112 84	#CD7054	Violet Red4	139 34 82	#8B2255
Bisque	255 228 196	#FFDAB9	Light Green	152 251 152	#90EE90	Dark Violet	148 0 211	#9400D3	State Blue1	131 111 255	#836FFF	Turquoise2	0 292 238	#00EEEE	Light Yellow4	205 205 180	#C0C08A	Salmon4	139 76 57	#8B4C39	Magenta1	255 0 255	#FF00FF
Peach Puff	255 218 185	#FFDAB9	Spring Green	0 255 127	#00FF00	Blue Violet	134 83 226	#8A2BE2	State Blue2	122 103 238	#7BA7EE	Turquoise3	255 160 127	#00E0E0	Light Yellow5	139 139 122	#8BB87A	Light Salmon1	255 160 122	#FFA07A	Magenta2	238 0 238	#EE00EE
Navajo White	255 222 173	#FFDAB9	Lawn Green	124 250 2	#7CFC00	Purple	160 32 240	#A020F0	State Blue3	105 89 205	#6993CD	Turquoise4	0 134 139	#008080	Yellow1	255 255 0	#FFFF00	Light Salmon2	238 149 114	#EE9572	Magenta3	205 0 205	#CD00CD
Moccasin	255 228 181	#FFDAB9	Green	0 255 0	#00FF00	Medium Purple	147 112 219	#9370DB	State Blue4	71 60 139	#473C8B	Cyan1	0 255 255	#00FFFF	Yellow2	238 238 0	#EEEE00	Light Salmon3	205 129 98	#CD8162	Magenta4	139 0 139	#8B008B
Corn silk	255 248 220	#FFDAB9	Chartreuse	127 255 0	#7FFF00	Thistle	161 219 116	#D8BFD8	Royal Blue1	72 118 255	#4836F9	Cyan2	0 238 238	#00EEEE	Yellow3	205 205 0	#C0C000	Light Salmon4	139 87 66	#8B5742	Orchid1	255 131 250	#FF83FA
Ivory	255 255 240	#FFFF00	MediumSpringGreen	0 250 154	#00FA9A	Snow1	255 250 250	#FFFFFF	Royal Blue2	67 110 238	#436EEF	Cyan3	0 205 205	#00CCCC	Yellow4	139 139 0	#8B8B00	Orange1	255 165 0	#FFA500	Orchid2	238 122 233	#EE7AE9
Lemon Chiffon	255 250 205	#FFFACD	Green Yellow	173 255 47	#ADFF2F	Snow2	238 233 233	#EEEE99	Royal Blue3	58 95 205	#3A5FCD	Cyan4	0 139 139	#008080	Gold1	255 215 0	#FFD700	Orange2	238 154 0	#E98000	Orchid3	205 105 201	#CD69C9
Seashell	255 245 238	#FFDAB9	Light Green	50 205 32	#90EE90	Snow3	205 201 201	#C0C0C0	Royal Blue4	36 41 238	#247088	Dark Slate Gray1	151 255 255	#2F4F4F	Gold2	238 201 0	#EEC900	Orange3	205 133 0	#D2691E	Orchid4	139 171 137	#8B69A9
Honeydew	240 255 240	#90EE90	Yellow Green	154 205 50	#9ACD32	Snow4	139 137 137	#808080	Royal Blue5	101 0 255	#0000FF	Dark Slate Gray2	141 238 238	#2F4F4F	Gold3	205 173 0	#CDA000	Orange4	139 90 0	#8B5A00	Plum1	255 187 255	#FF8000
Mint Cream	245 255 250	#90EE90	Forest Green	34 139 34	#228B22	Seashell1	255 245 238	#FFDAB9	Plum2	0 238 205	#800080	Dark Slate Gray3	121 205 205	#7030A0	Gold4	139 107 0	#FFD700	Dark Orange1	255 127 0	#FF4500	Plum2	238 174 238	#EE6A00
Azure	240 255 255	#0080FF	Olive Drab	107 142 35	#6B8E23	Seashell2	238 229 222	#EEEEE0	Plum3	0 205 205	#0000CD	Dark Slate Gray4	82 139 139	#528B8B	Goldenrod1	255 193 37	#FFD700	Dark Orange2	238 118 0	#FF4500	Plum3	205 150 205	#CD69C9
Alice Blue	240 248 255	#F0F8FF	Dark Khaki	189 183 107	#8B672B	Seashell3	205 197 191	#C0C0C0	Blue4	0 139 205	#000080	Aquamarine1	127 255 212	#7FFFD4	Goldenrod2	238 180 34	#EEB422	Dark Orange3	205 102 0	#C06000	Plum4	139 102 139	#8B69A9
Lavender	230 230 250	#E6E6FA	Pale Goldenrod	238 232 170	#EEB88A	Seashell4	139 134 130	#808080	Dodger Blue1	30 144 255	#1E90FF	Aquamarine2	118 238 198	#76EEC6	Goldenrod3	205 155 29	#CD8B1D	Dark Orange4	139 69 0	#8B4500	Medium Orchid1	224 102 255	#C060FF
Lavender Blush	255 240 245	#FFF0F5	Light Goldenrod Yellow	250 250 210	#FFAF4D	Antique White1	255 239 219	#FFDAB9	Dodger Blue2	28 134 238	#1CB8E6	Aquamarine3	102 205 170	#66CDAA	Goldenrod4	139 105 20	#8B691A	Coral1	255 114 86	#FF7F50	Medium Orchid2	209 95 238	#D15FE8
Misty Rose	255 228 225	#FFC0CB	Yellow	255 255 224	#FFFFE0	Antique White2	238 223 204	#FFDAB9	Dodger Blue3	24 116 205	#1874AD	Aquamarine4	69 139 116	#4682B4	Dark Goldenrod1	255 185 15	#FF8C00	Coral2	238 106 80	#EE6A00	Medium Orchid3	180 82 205	#B45CD4
White	255 255 255	#FFFFFF	Gold	255 255 0	#FFD700	Antique White3	205 192 170	#C0C0C0	Dodger Blue4	16 78 139	#104E8B	Dark Sea Green1	193 255 193	#1CFFC1	Dark Goldenrod2	238 173 14	#9EAD00	Coral3	205 91 69	#C0504D	Medium Orchid4	122 59 139	#7A378B
Black	0 0 0	#000000	Light Goldenrod Yellow	238 221 130	#EEDD81	Antique White4	139 131 126	#808080	Steel Blue1	99 184 255	#638FFF	Dark Sea Green2	180 238 180	#14B8A8	Dark Goldenrod3	205 149 12	#005400	Coral4	139 62 47	#FF6347	Dark Orchid1	161 62 255	#8B0032
Dark Slate Gray	47 79 79	#2F4F4F	Gold	255 255 0	#FFD700	Bisque1	255 228 196	#FFDAB9	Steel Blue2	92 172 238	#5CAEC6	Dark Sea Green3	155 205 155	#90C090	Rosy Brown1	139 101 8	#8B688B	Tomato1	255 99 71	#FF6347	Dark Orchid2	178 58 238	#8B2A2E
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Slate Gray	112 128 144	#708090	Dark Goldenrod	184 134 11	#8B6914	Bisque3	205 183 158	#C08070	Steel Blue4	54 100 139	#366A88	Sea Green1	84 255 159	#4682B4	Rosy Brown3	238 180 180	#EE8A4B	Tomato3	205 79 57	#CD4F39	Dark Orchid4	104 34 139	#682B8F
Light Slate Gray	110 135 153	#778899	Rosy Brown	188 143 13	#C8A2C8	Bisque4	139 125 107	#80706B	Deep Sky Blue1	0 191 205	#00BFFF	Sea Green2	78 238 148	#4682B4	Rosy Brown4	205 155 155	#C09090	Tomato4	139 54 38	#8B3E3E	Purple1	158 45 255	#800080
Gray	190 190 190	#808080	Indian Red	205 92 9	#CD5C5C	Peach Puff1	255 218 185	#FFDAB9	Deep Sky Blue2	0 178 238	#00B0E0	Sea Green3	67 205 128	#43C8D0	Rosy Brown5	139 105 105	#8B6969	Orange Red1	255 69 0	#FF4500	Purple2	154 44 238	#912CE2
Light Gray	211 211 211	#D3D3D3	Saddle Brown	139 69 19	#8B4513	Peach Puff2	238 203 173	#FFDAB9	Deep Sky Blue3	0 154 205	#009ACD	Sea Green4	46 139 87	#2E8B57	Indian Red1	255 106 106	#FF6A6A	Orange Red2	238 64 0	#EE4000	Purple3	125 80 255	#912CE2
Midnight Blue	25 112 131	#191970	Sienna	160 82 45	#A0522D	Peach Puff3	205 179 149	#FFDAB9	Deep Sky Blue4	0 104 139	#0080FF	Pale Green1	154 255 154	#90EE90	Indian Red2	238 99 99	#EE3E3E	Orange Red3	205 50 0	#CD3700	Purple4	85 26 139	#551A8B
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Cornflower Blue	100 149 237	#6495ED	Burlywood	222 184 135	#DEB887	Navajo White1	255 222 173	#FFDAB9	Blue3	126 192 238	#70C0EE	Pale Green3	124 205 124	#70C0C0	Indian Red4	139 58 58	#8B3A3A	Black1	0 0 0	#000000	Medium Purple2	159 121 238	#9F77EE
Dark Slate Blue	72 61 139	#483D8B	Beige	245 245 220	#F5F5DC	Navajo White2	238 207 161	#EEC0E1	Blue4	108 166 205	#6A5ACD	Pale Green4	84 139 84	#90EE90	Sienna1	255 130 71	#FF8C00	Black2	0 0 0	#000000	Medium Purple3	137 104 205	#8B69CD
State Blue	106 90 205	#6A5ACD	Wheat	245 222 179	#F5DEB3	Navajo White3	250 179 139	#C0D838	Blue5	74 112 139	#4A7088	Spring Green1	0 255 127	#00FF00	Sienna2	238 121 66	#EE7A92	Black3	0 0 0	#000000	Medium Purple4	93 71 139	#54278B
Medium Slate Blue	123 104 238	#7B68EE	Sandy Brown	244 164 96	#F4A460	Navajo White4	139 121 94	#80795F	Light Sky Blue1	176 226 255	#80E2FF	Spring Green2	0 238 118	#00EE76	Sienna3	205 104 57	#8B473E	Red4	139 0 139	#8B0000	Thistle1	255 225 255	#DDA0DD
Light Slate Blue	132 112 255	#8A70FF	Tan	210 180 140	#D2B48C	Light Chiffon1	255 250 205	#FFDAB9	Light Sky Blue2	164 211 238	#ADD8E6	Spring Green3	0 205 102	#00C076	Sennat	139 71 38	#8A672B	Deep Pink1	255 20 147	#FF1493	Thistle2	238 210 238	#EEDE2E
Medium Blue	0 205 205	#0000CD	Chocolate	210 105 30	#D2691E	Light Chiffon2	238 233 191	#EEC99F	Light Sky Blue3	141 182 205	#80BDCD	Spring Green4	0 139 69	#008080	Burlywood1	255 211 155	#FFD39B	Deep Pink2	238 137 38	#EE1289	Thistle3	205 181 205	#C060CD
Royal Blue	65 105 225	#4169E1	Firebrick	178 34 4	#B22222	Light Chiffon3	205 201 165	#C0C9A5	Light Sky Blue4	96 123 205	#60788B	Green1	0 255 0	#008000	Burlywood2	238 197 145	#EEC951	Deep Pink3	205 16 118	#C0D107	Thistle4	139 123 139	#8B788B
Blue	0 0 255	#0000FF	Brown	165 42 42	#A52A2A	Light Chiffon4	139 137 112	#808070	Slate Gray1	198 226 255	#808080	Green2	0 238 0	#008000	Burlywood3	205 170 125	#CDA07D	Deep Pink4	139 10 80	#8B0A0A	gray11	28 28 28	#808080
Cornflower Blue	30 144 255	#1E90FF	Dark Salmon	233 152 12	#996633	Light Chiffon5	255 248 220	#FF8000	Slate Gray2	185 211 238	#603E3E	Green3	0 205 0	#008000	Burlywood4	139 115 85	#8B7355	Hot Pink1	255 100 180	#FF69B4	gray21	54 54 54	#303030
Deep Sky Blue	0 191 255	#00BFFF	Salmon	250 128 114	#FA8072	Corn silk1	238 232 205	#EE8000	Slate Gray3	159 182 205	#9F8080	Green4	0 139 0	#008000	Wheat1	255 231 189	#FFD7BA	Hot Pink2	238 106 167	#EE6A00	gray31	79 79 79	#4F4F4F
Sky Blue	135 206 235	#87CEEB	Light Salmon	255 160 122	#FFA07A	Corn silk2	205 200 177	#C0C8B1	Slate Gray4	108 123 139	#6C7B8B	Chartruese1	127 255 0	#77FF00	Wheat2	238 216 174	#EEDB8A	Hot Pink3	205 96 144	#C06090	gray41	105 105 105	#696969
Light Sky																							

SR-ITI-COURS\rgb.txt – X Window Color Database - /usr/include/X11/rgb.txt ou /usr/share/X11/rgb.txt

<http://www-igm.univ-mlv.fr/~riazano/>

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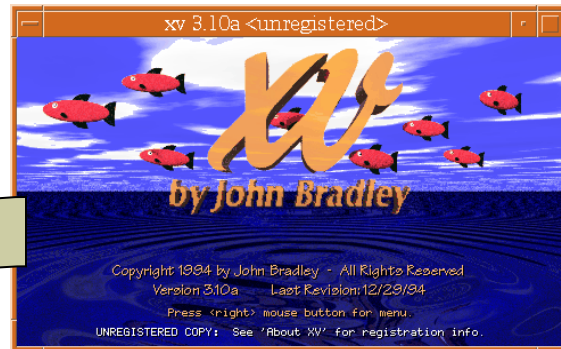
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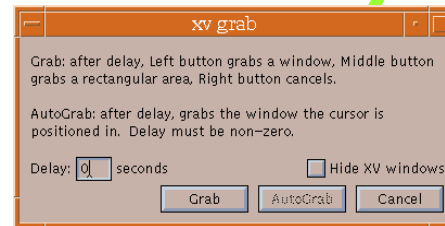
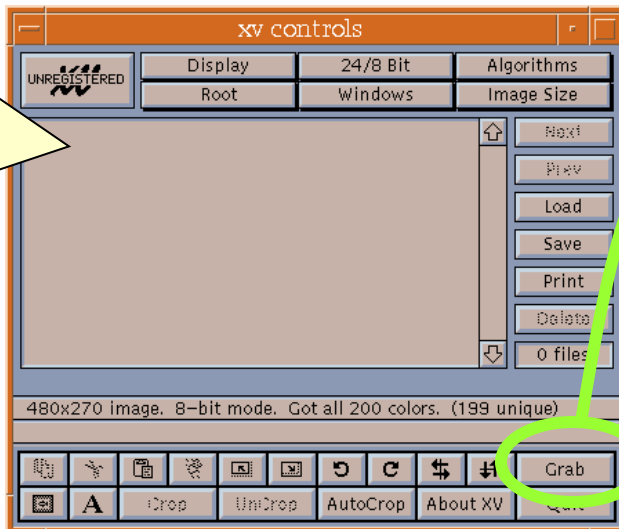


L'application « xv »

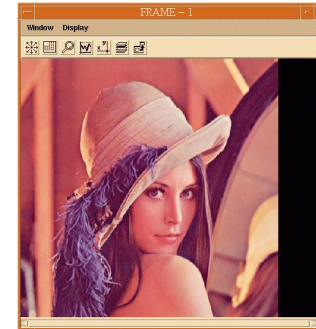
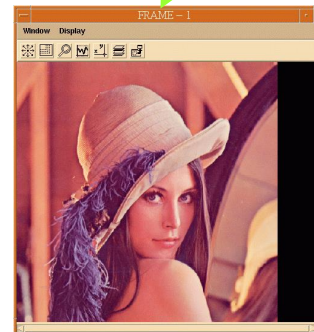
✚ Capture d'une image



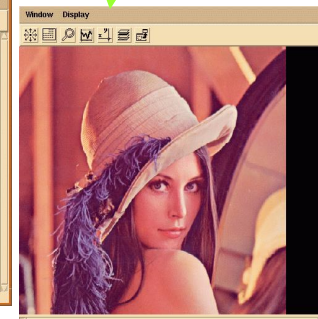
Bouton droit



bouton gauche dans
barre fenêtre



bouton gauche dans
intérieur fenêtre

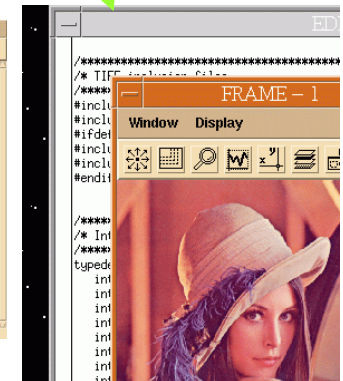


Affichage d'une
application à
capturer

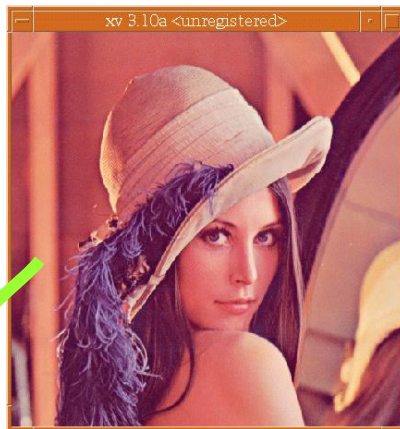
Delay > 0 – AutoGrab
intérieur fenêtre

Open new frame	F7
Background color	
Close	Shift+F6
Quit	Shift+F4

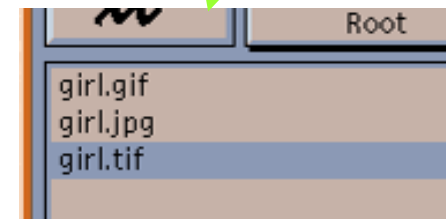
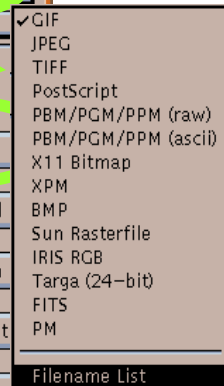
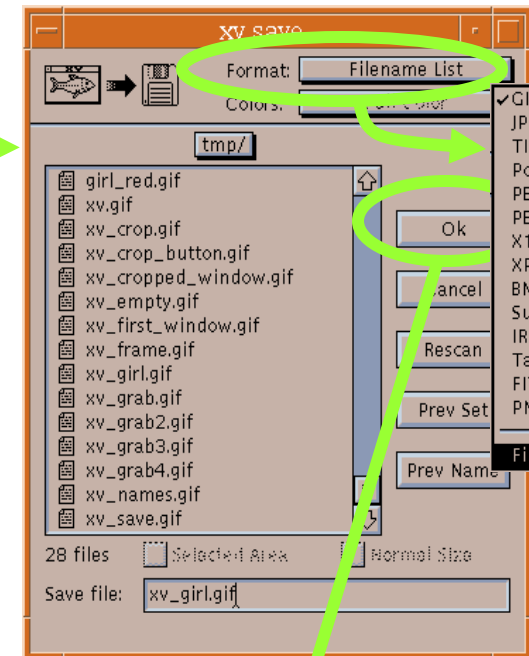
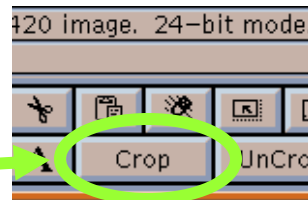
bouton droit à partir
intérieur fenêtre



✱ Cadrage et sauvegarde d'une image



Bouton droit
rubber
banding

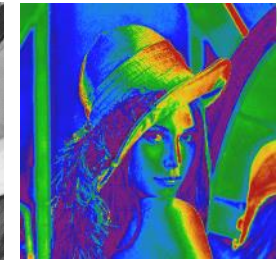




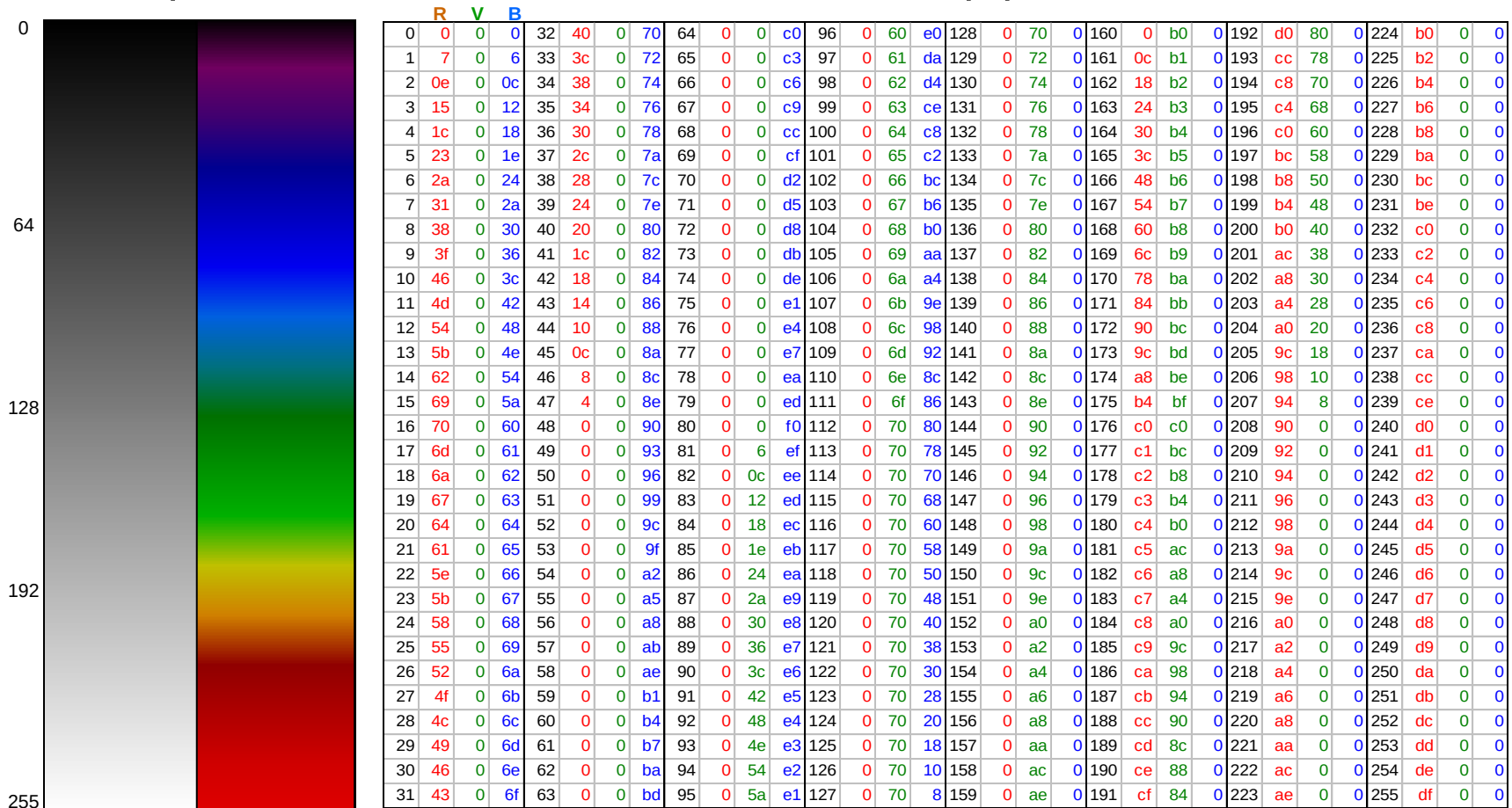
❖ Pseudo-couleurs et compositions colorées

- ❖ Images monochromatiques
Tables de pseudo-couleurs (LUT)
- ❖ Images multispectrales et visualisation Rouge/Vert/Bleu
Compositions colorées

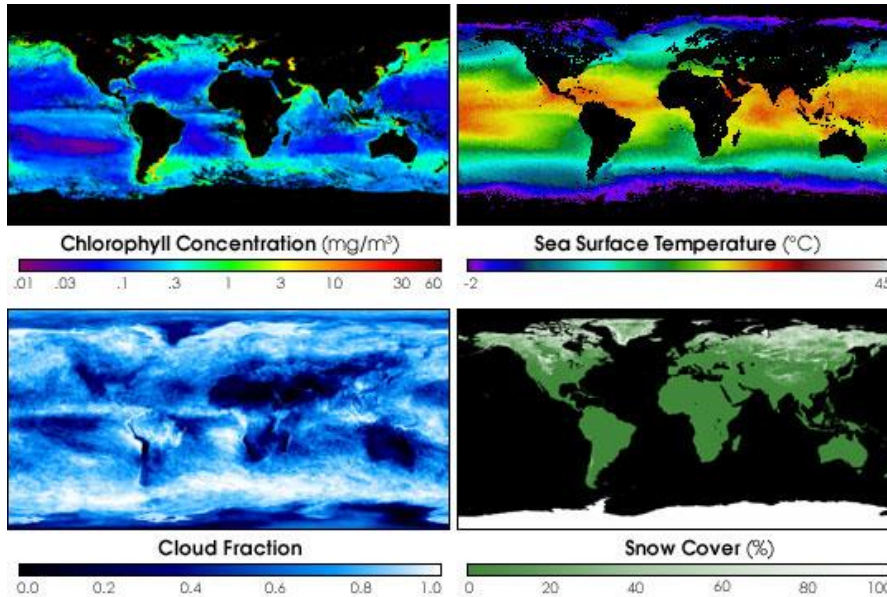
- Images monochromatiques
- Tables de pseudo-couleurs (LUT)



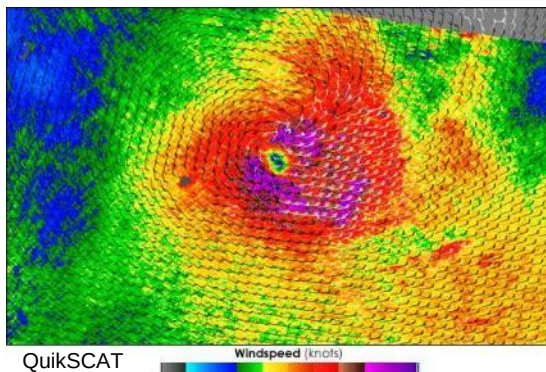
Exemple de Visual PseudoColor: la colormap pseudo-couleur



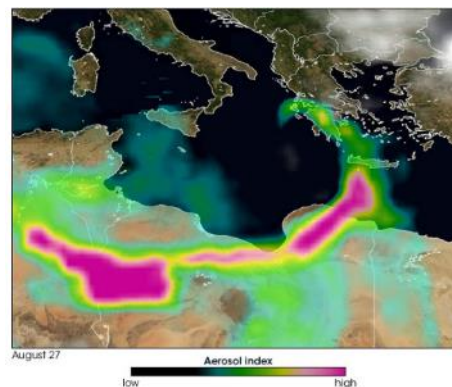
D'autres exemples de tables pseudo-couleur



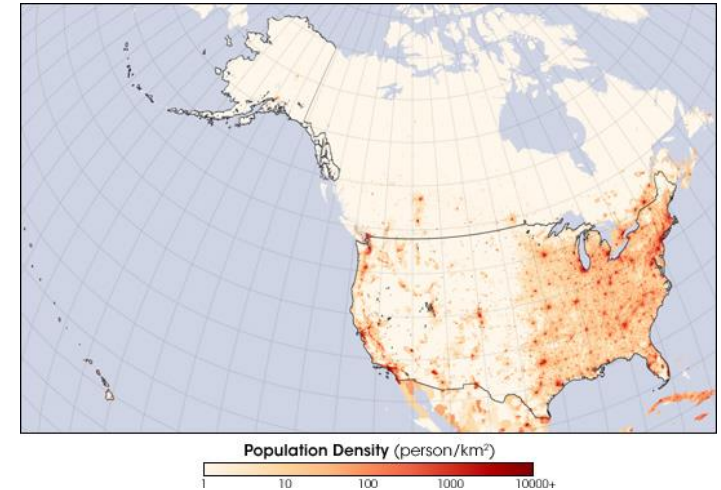
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17559



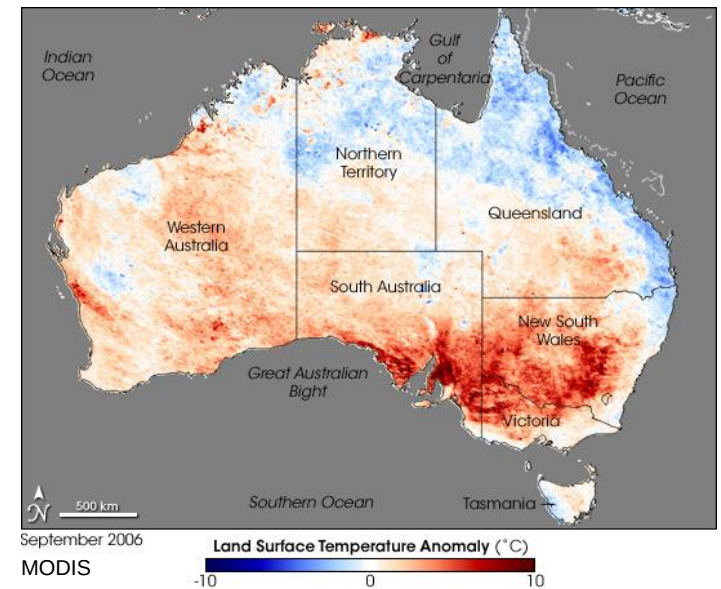
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17546



http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17755



http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17439

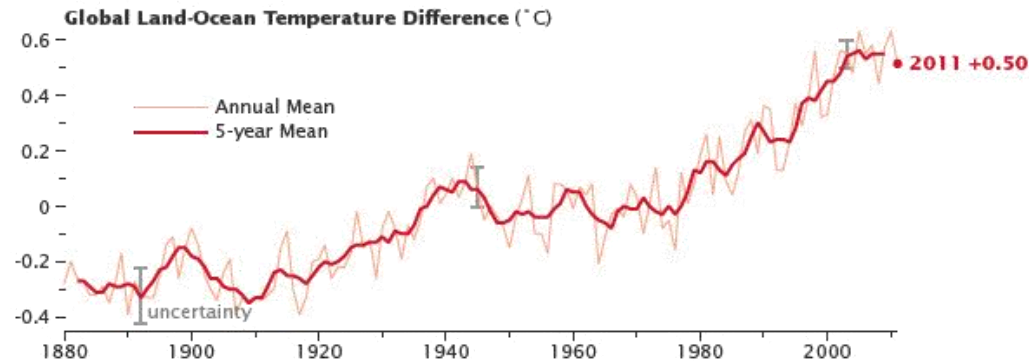
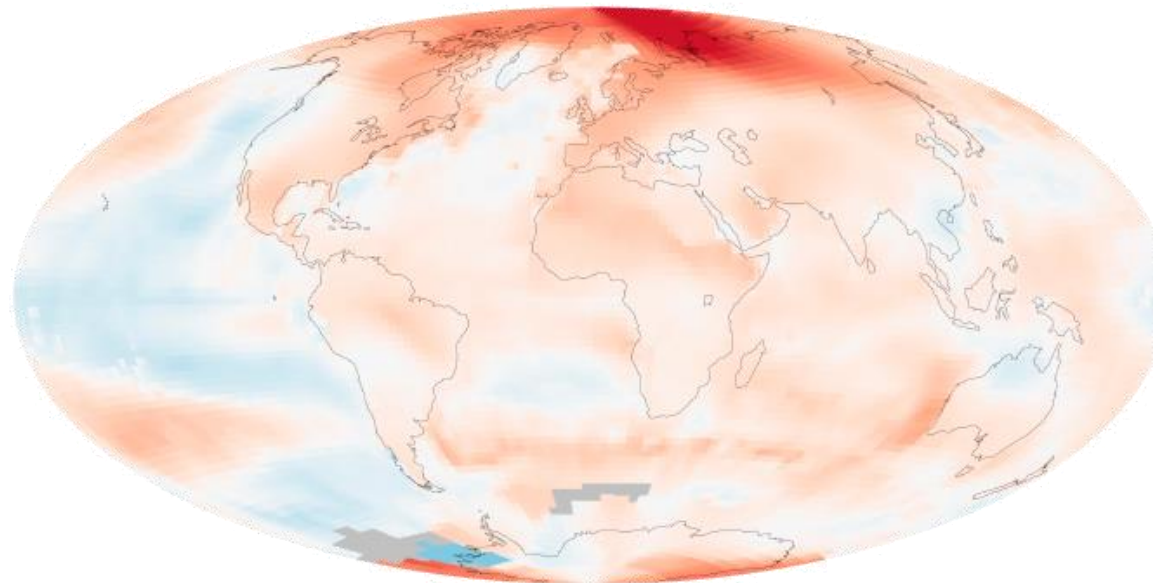


September 2006

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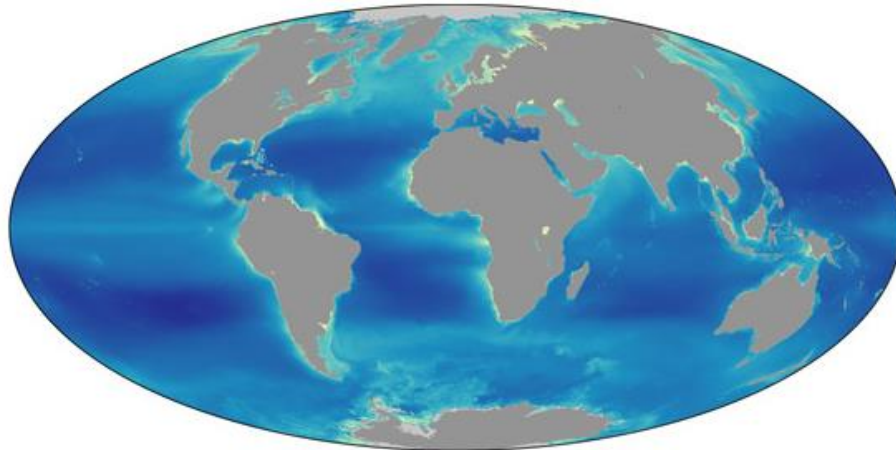
http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17440

Une table de pseudo-couleur pour illustrer une mesure biophysique



<http://earthobservatory.nasa.gov/IOTD/view.php?id=76975>

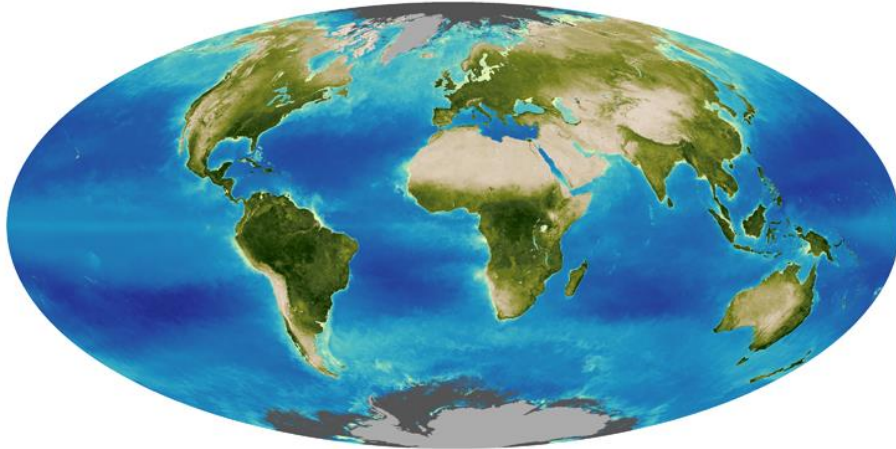
✪ D'autres exemples de tables pseudo-couleur (suite)



Chlorophyll Concentration (mg/m³)

0.01 0.03 0.1 0.3 1 3 10 30 60

http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17801



Chlorophyll Concentration (mg/m³)

0.01 0.1 1 10 50

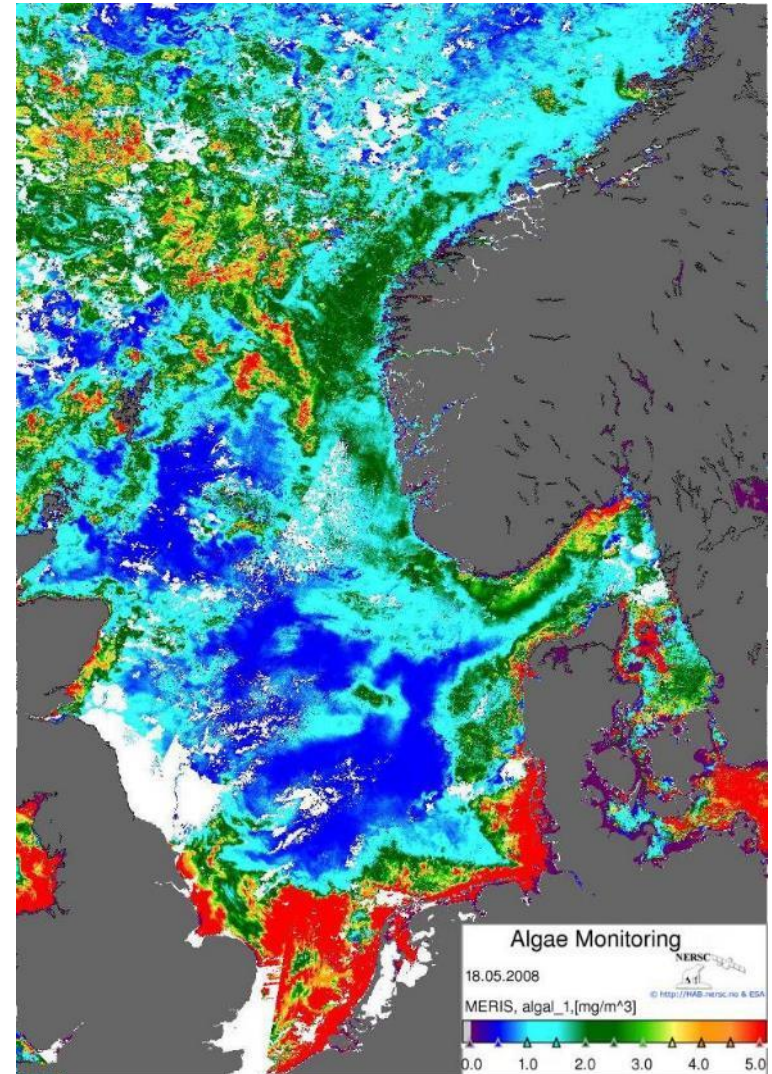
Vegetation Index

0 0.2 0.4 0.6 0.8

<http://earthobservatory.nasa.gov/IOTD/view.php?id=38889>

<http://www-igm.univ-mlv.fr/~riazano/>

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http://esamultimedia.esa.int/images/EarthObservation/sst_20080509_H1.jpg

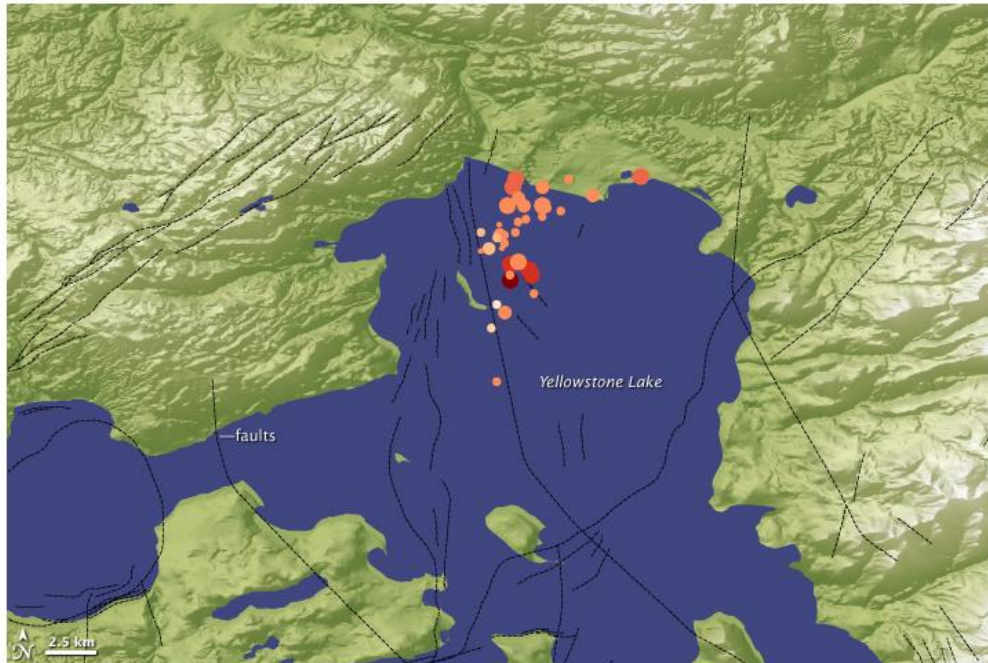
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✪ D'autres exemples de tables pseudo-couleur (suite)

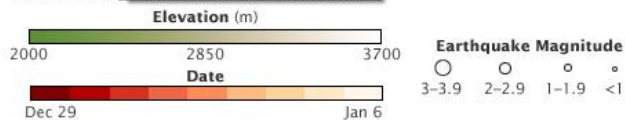
Earthquake Swarm in Yellowstone Park

Posted January 8, 2009

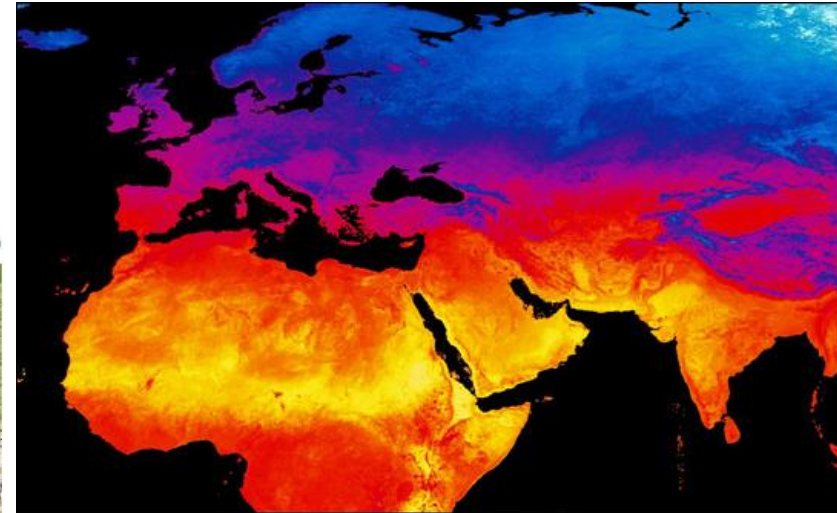


download large [Earthquake Swarm in Yellowstone Park](#)

acquired December 29, 2008 - January 6, 2009

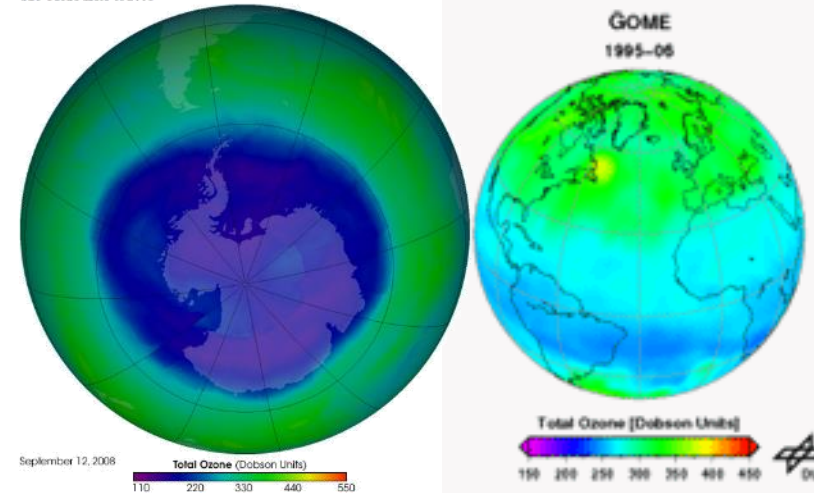


<http://earthobservatory.nasa.gov/IOTD/view.php?id=36494>



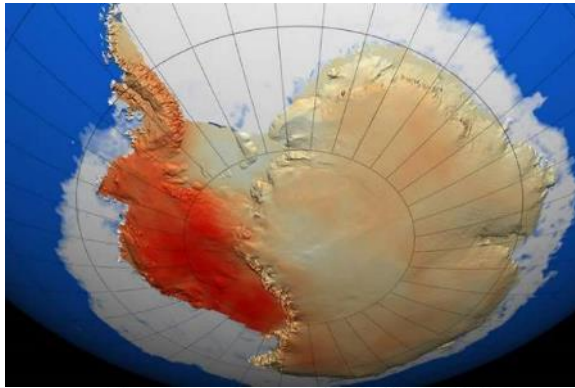
Land Surface Temperature (°C)
-25 10 45
<http://neo.sci.gsfc.nasa.gov/Search.html>

The Ozone Hole of 2008

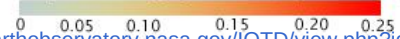


http://www.esa.int/esaEO/SEMHSZJVUF_index_0.html

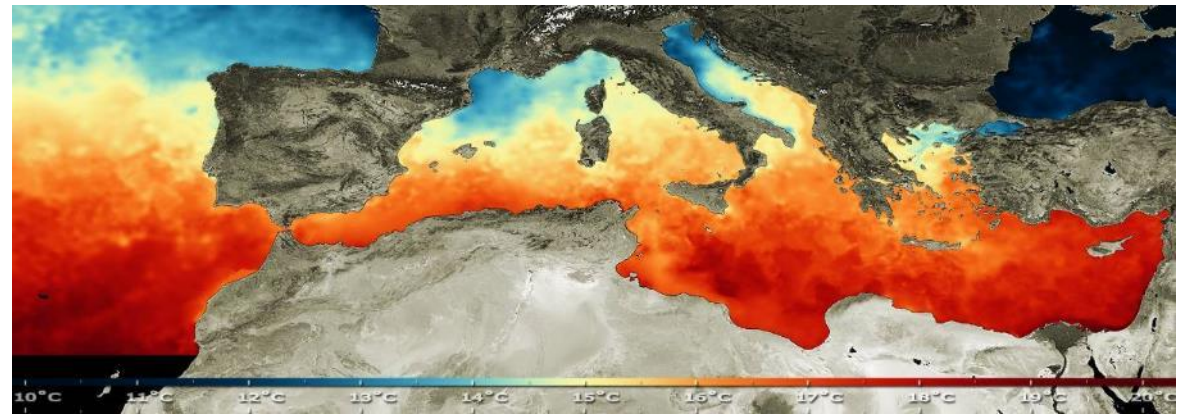
D'autres exemples de tables pseudo-couleur (suite)



Temperature change per decade (degrees Celsius)



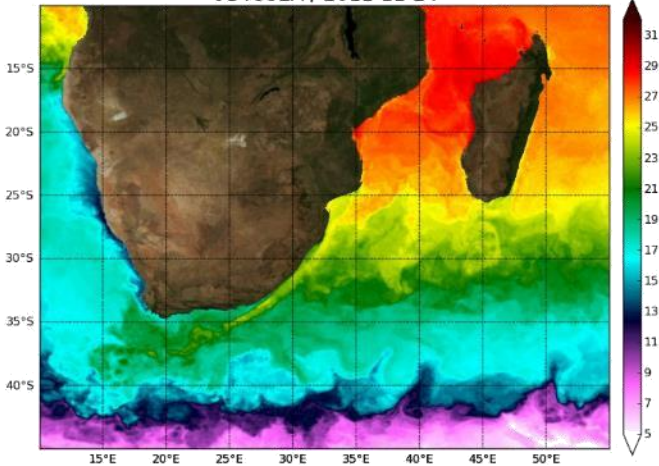
<http://earthobservatory.nasa.gov/IOTD/view.php?id=36736>



Envisat AATSR - Sea surface temperature

http://esamultimedia.esa.int/images/EarthObservation/sst_20080509_H1.jpg

ODYSSEA / 2011-11-24



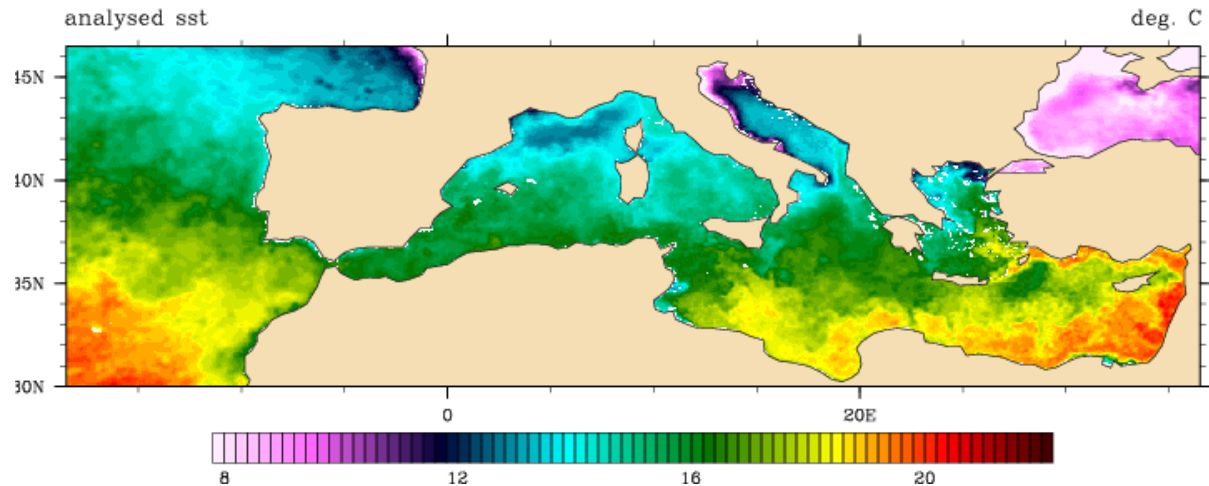




http://www.esa.int/esaEO/SEM8OVJXB4H_index_0.html

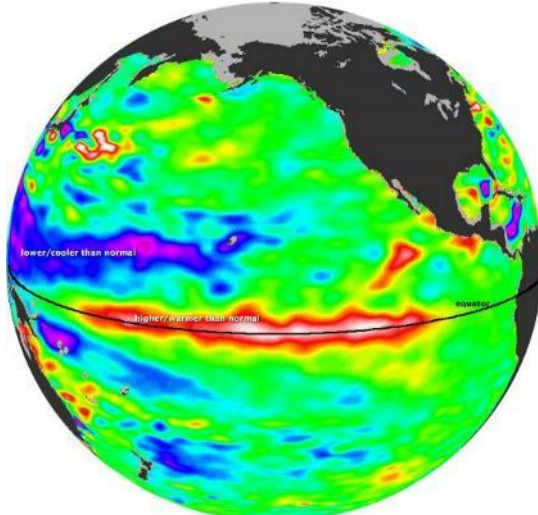
ODYSSEA L4 , 03 Jan 2008

analysed sst



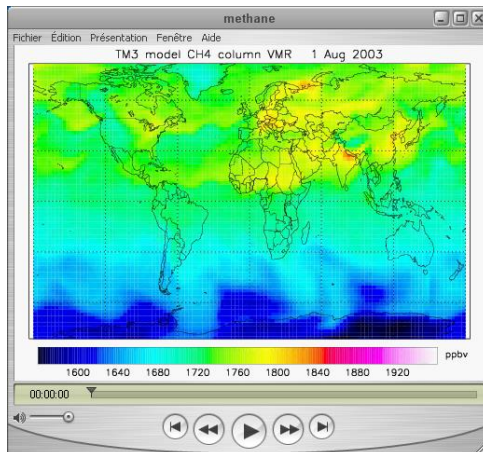
<http://www.medspiration.org/>

✪ D'autres exemples de tables pseudo-couleur (suite)



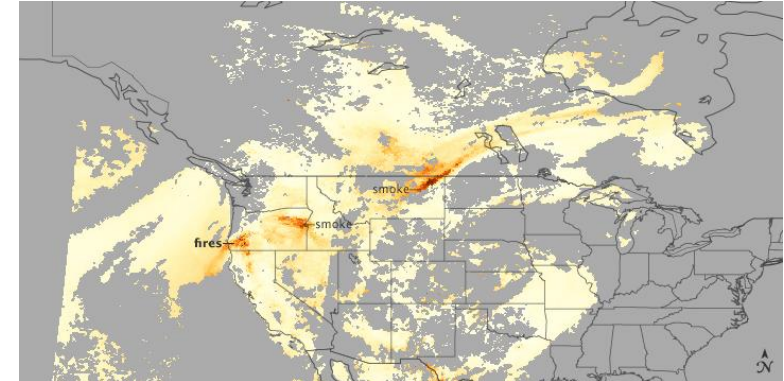
Sea Level Anomaly (mm)
-180 -140 -100 -60 -20 20 60 100 140 180

<http://earthobservatory.nasa.gov/IOTD/view.php?id=41302>



http://www.esa.int/SPECIALS/Space_for_our_climate/SEM7OASS2G_1.html

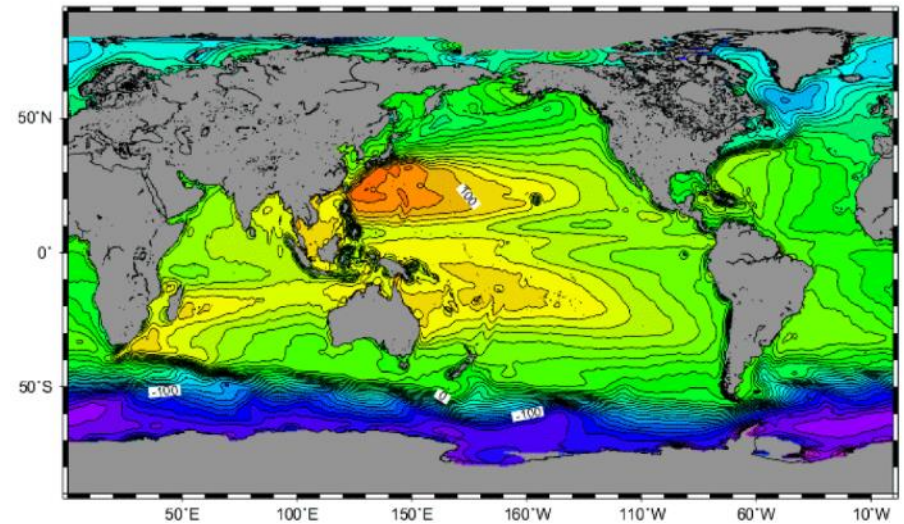
<http://www-igm.univ-mlv.fr/~riazano/>
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Aerosol Optical Thickness (index)

0.0 0.5 1.0
<http://earthobservatory.nasa.gov/IOTD/view.php?id=40845>

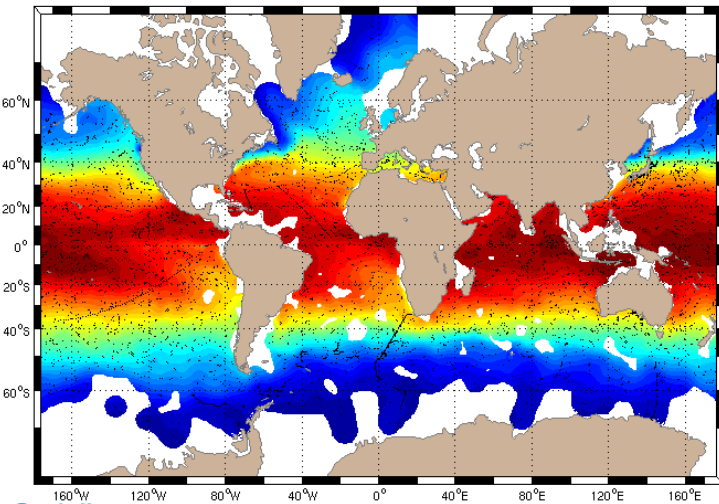


-200 -180 -160 -140 -120 -100 -80 -60 -40 -20 0 20 40 60 80 100 120 140 cm
Topographie Dynamique Moyenne (TDM)

http://ganymede.ipgp.jussieu.fr/frog/journees/20juin2007/Rio_20juin2007.pdf

D'autres exemples de tables pseudo-couleur (suite)

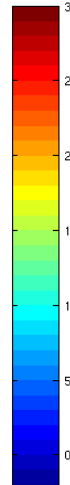
TEMP - 28 December 2009 - 10 m



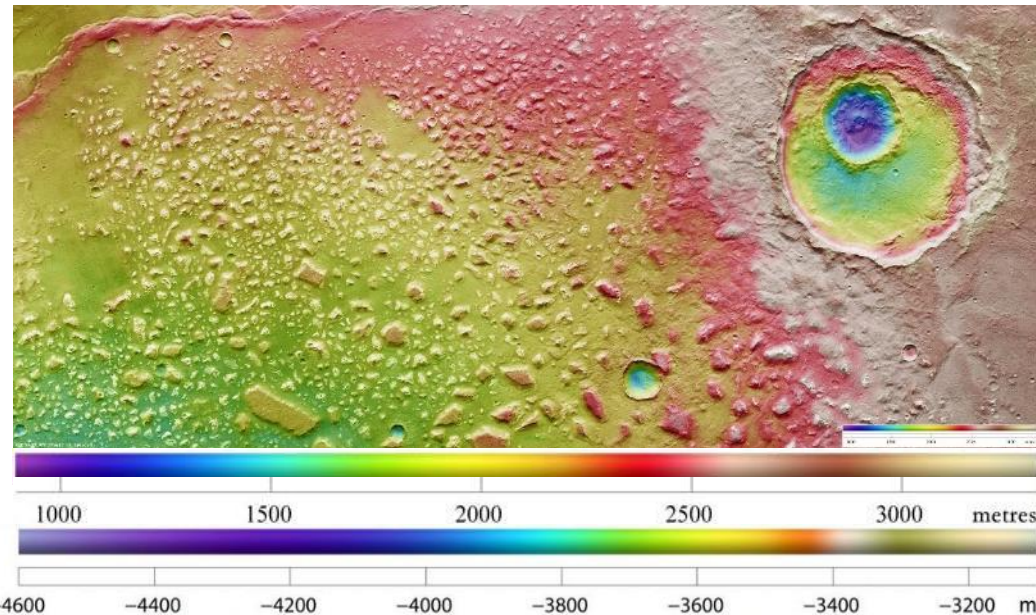
Coriolis

min = -2.13 max = 30.73 count = 6037 last update : 28/12/2009

<http://www.coriolis.eu.org/>



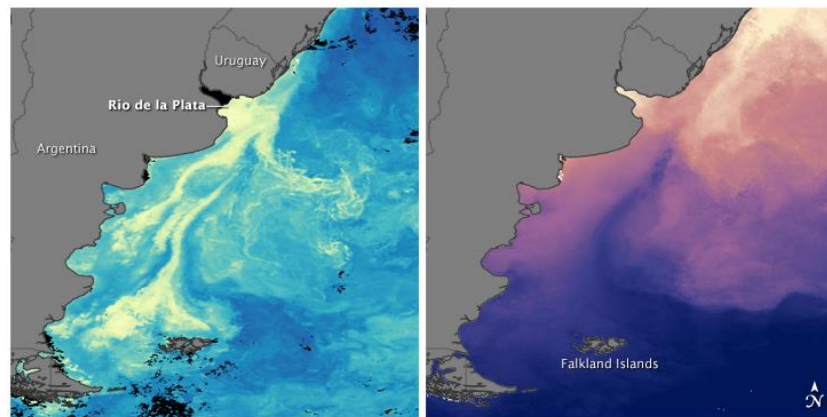
http://www.esa.int/SPECIALS/Mars_Express/SEM8JKANJTF_0.html



-4600 -4400 -4200 -4000 -3800 -3600 -3400 -3200 m



http://www.esa.int/spaceinimages/Images/2009/06/The_flood_after_the_impact



Chlorophyll Concentration (mg/m³)

≥0.01 0.1 1.0 10 60

Sea Surface Temperature (°C)

5 15 25

<http://earthobservatory.nasa.gov/IOTD/view.php?id=42270>

<http://www.igm.univ-mlv.fr/~riazano/>

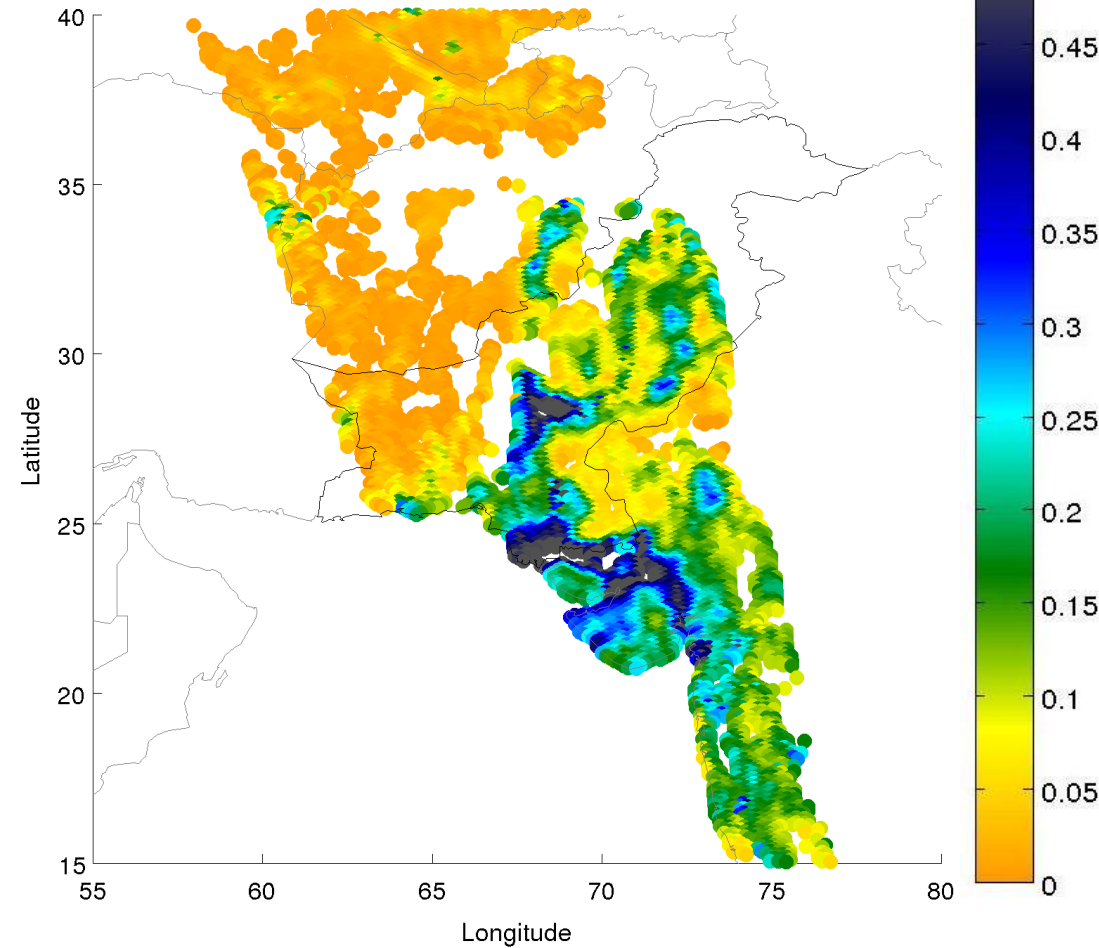
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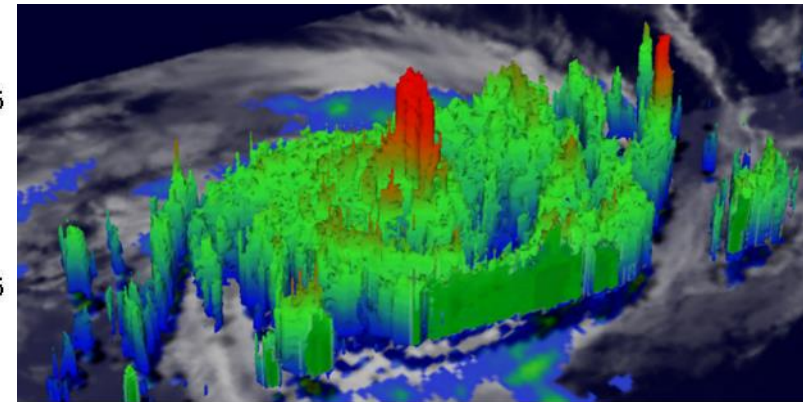
⊙ D'autres exemples de tables pseudo-couleur (suite)

28-07-2010

00:32:12 - 01:26:11

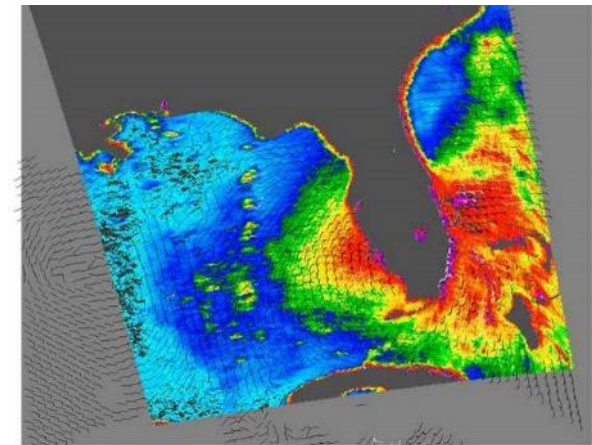


http://www.cesbio.ups-tlse.fr/SMOS_blog/?p=861



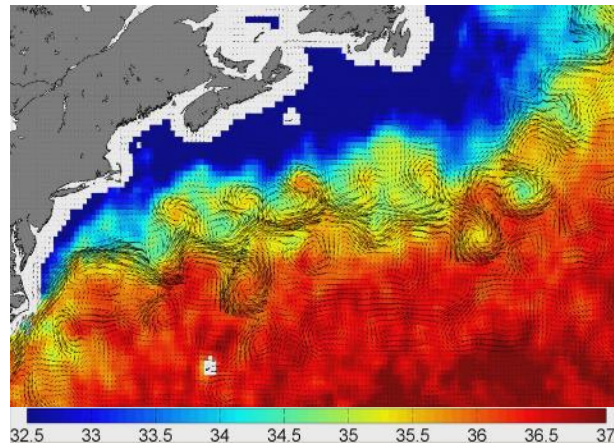
Ouragan Danielle (large de la Floride) observé le 27.08.2010 par l'instrument «Tropical Rainfall Measuring Mission (TRMM) »

<http://earthobservatory.nasa.gov/IOTD/view.php?id=45517>



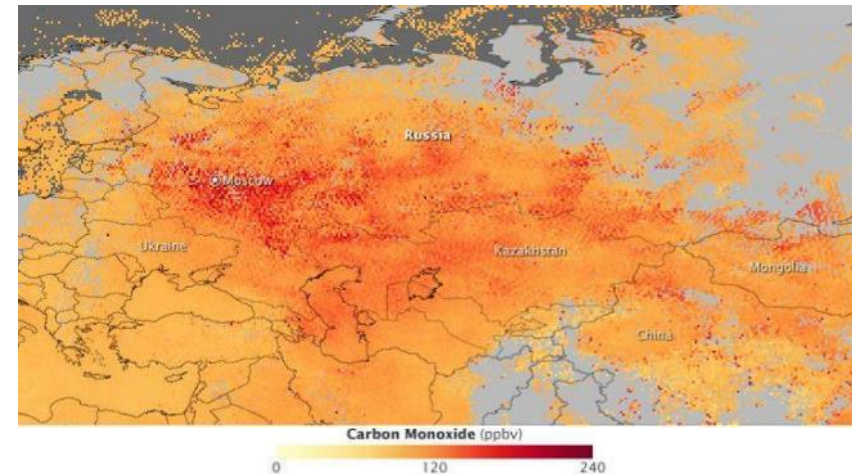
http://www.nasa.gov/images/content/353948main_267765main_fay_20080820_q_lg.jpg

D'autres exemples de tables pseudo-couleur (suite)

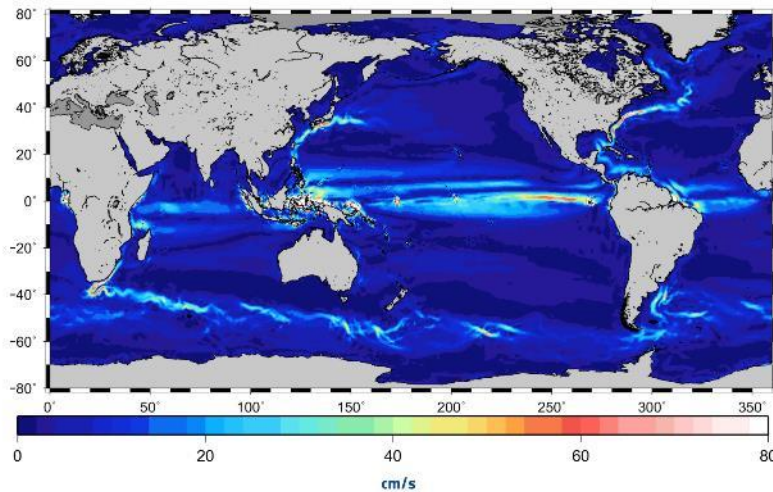


SMOS - Salinité de surface et courants marins

http://www.esa.int/Our_Activities/Observing_the_Earth/SMOS/SMOS_the_global_success_story_continues

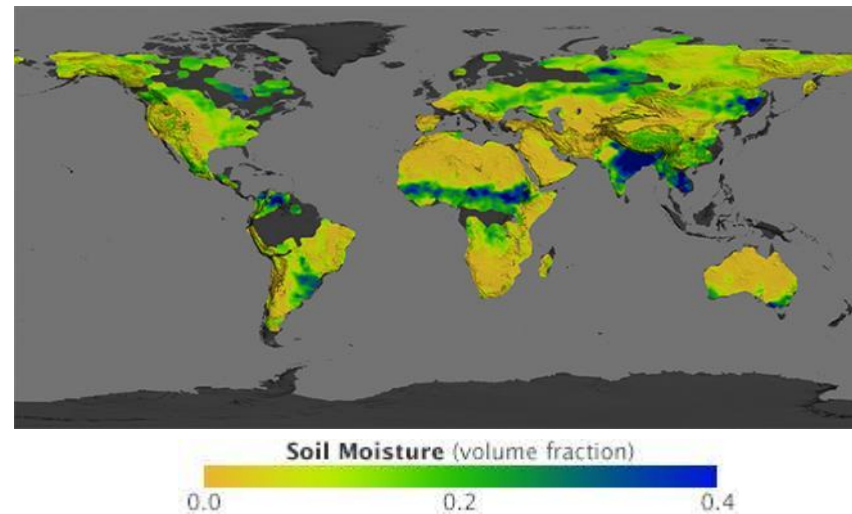


<http://earthobservatory.nasa.gov/IOTD/view.php?id=45150>



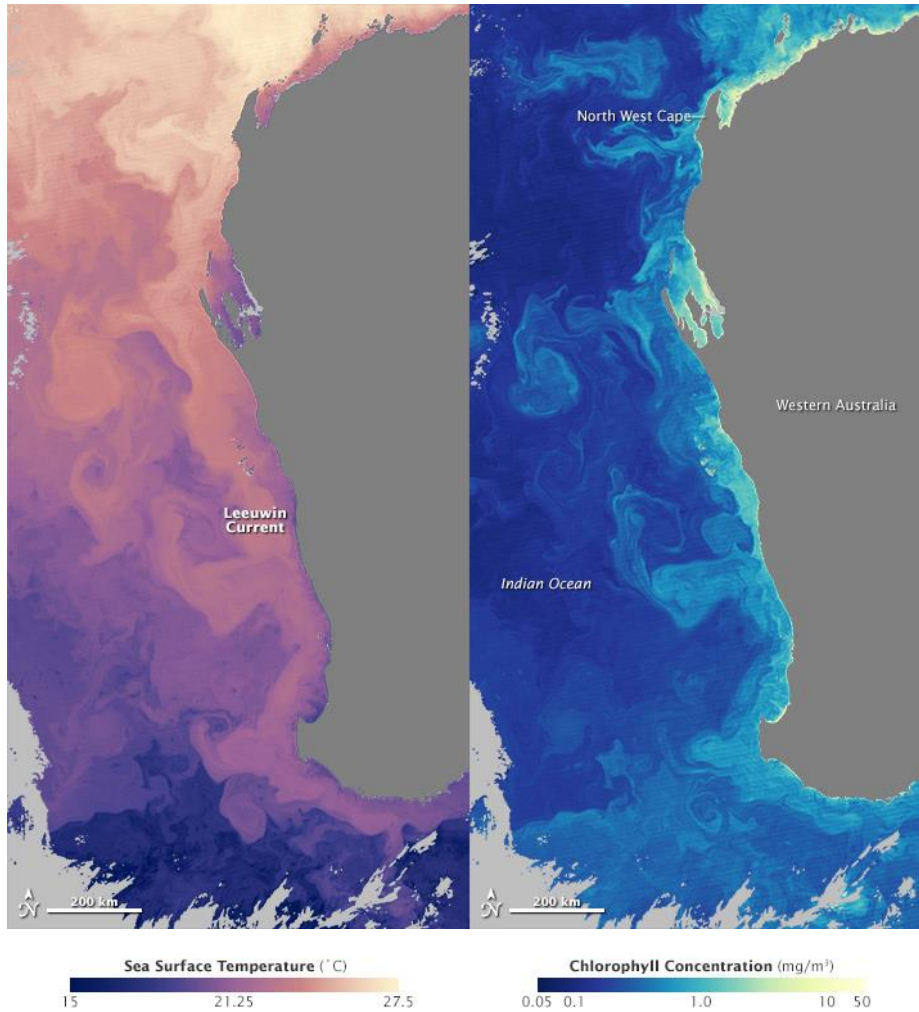
GOCE – Courants océaniques

http://www.esa.int/spaceinimages/Images/2014/11/Ocean_currents_from_GOCE



<http://earthobservatory.nasa.gov/IOTD/view.php?id=84017&eocon=image&eocon=moreiotd>

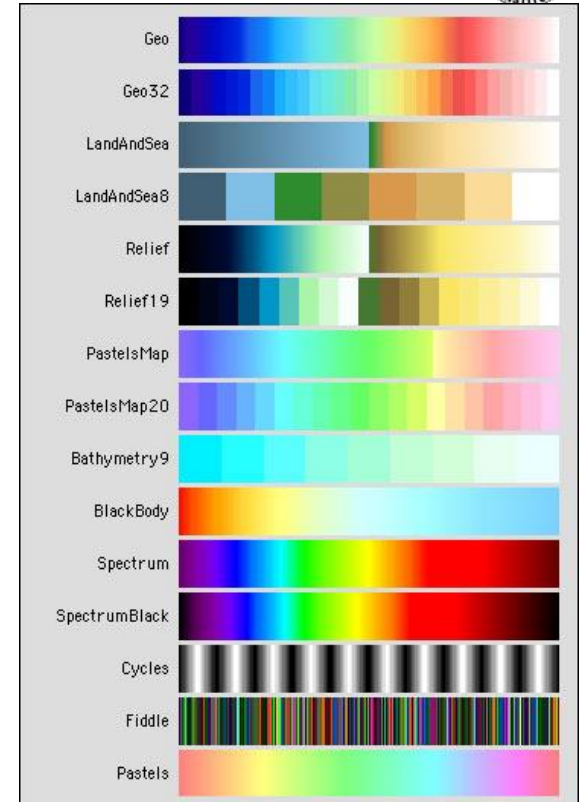
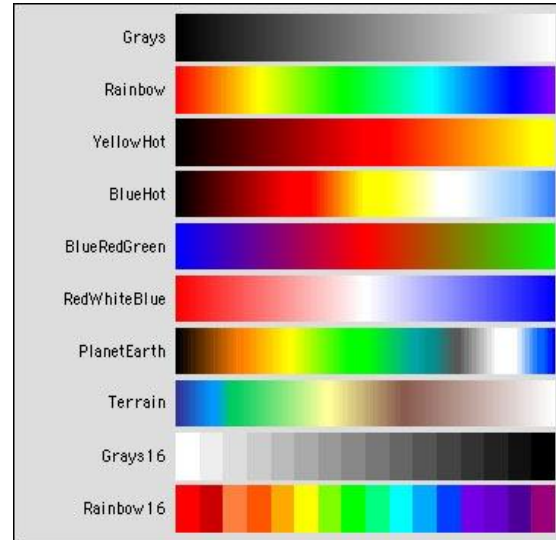
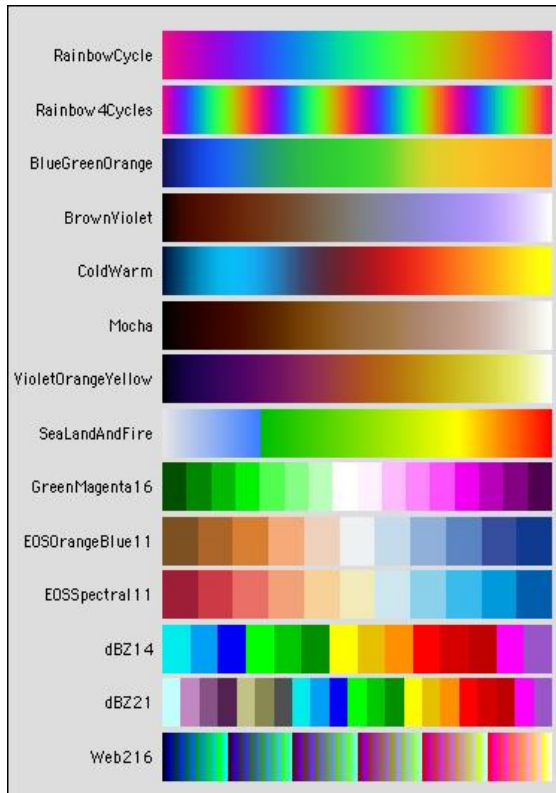
D'autres exemples de tables pseudo-couleur (suite)



<http://earthobservatory.nasa.gov/IOTD/view.php?id=83944&eocn=image&eoci=moreiotd>



Choix de tables de pseudo-couleur dans un logiciel (WaveMetrics™)



<http://www.wavemetrics.com/products/igorpro/creatinggraphs/colortab.htm>

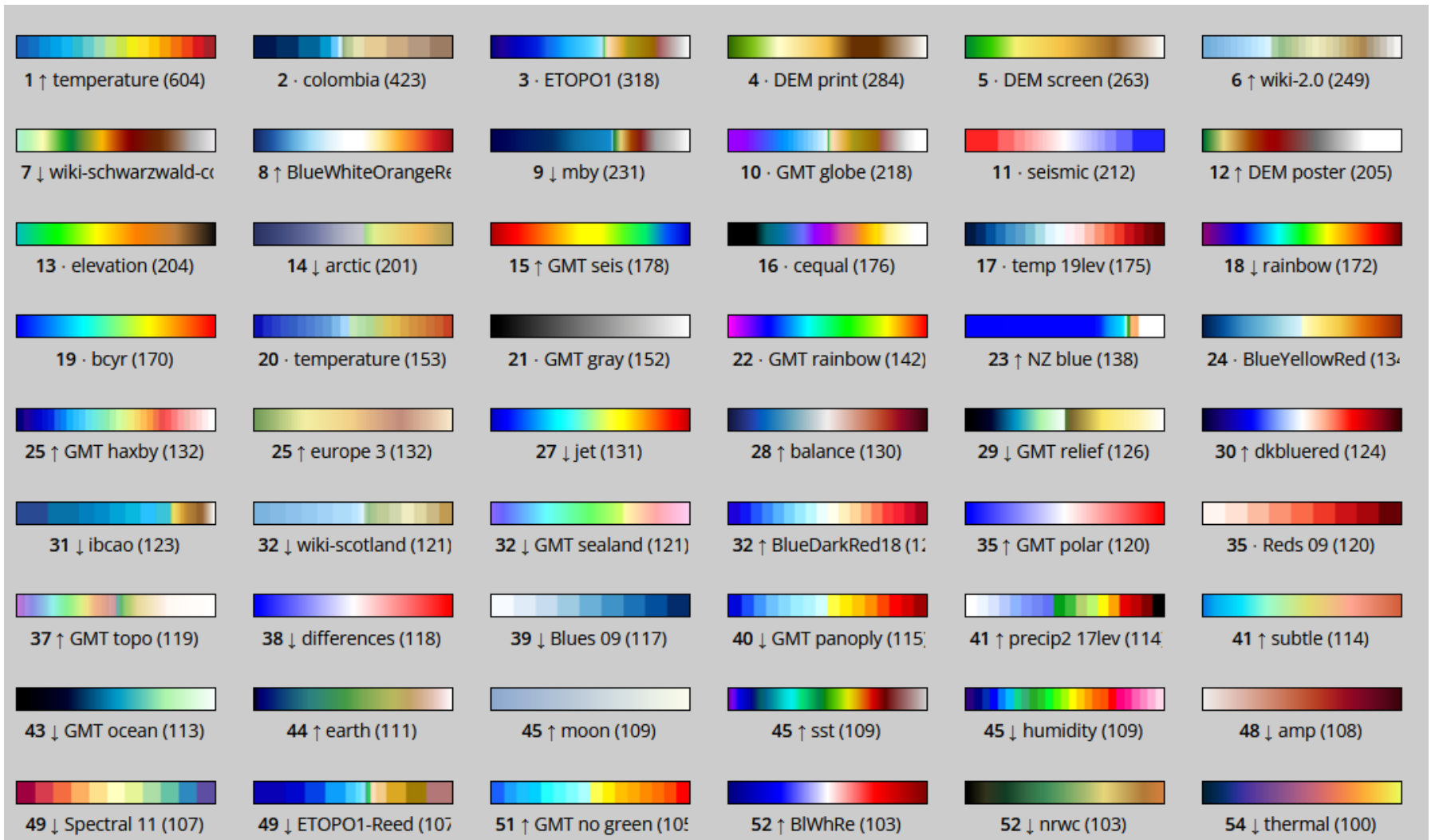
<http://www-igm.univ-mlv.fr/~riazano/>
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 cpt-city

<http://soliton.vm.bytemark.co.uk/pub/cpt-city/index.html>





⊕ Niveaux de gris – Niveaux d'une couleur

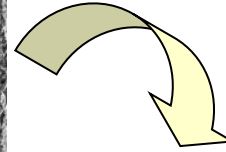
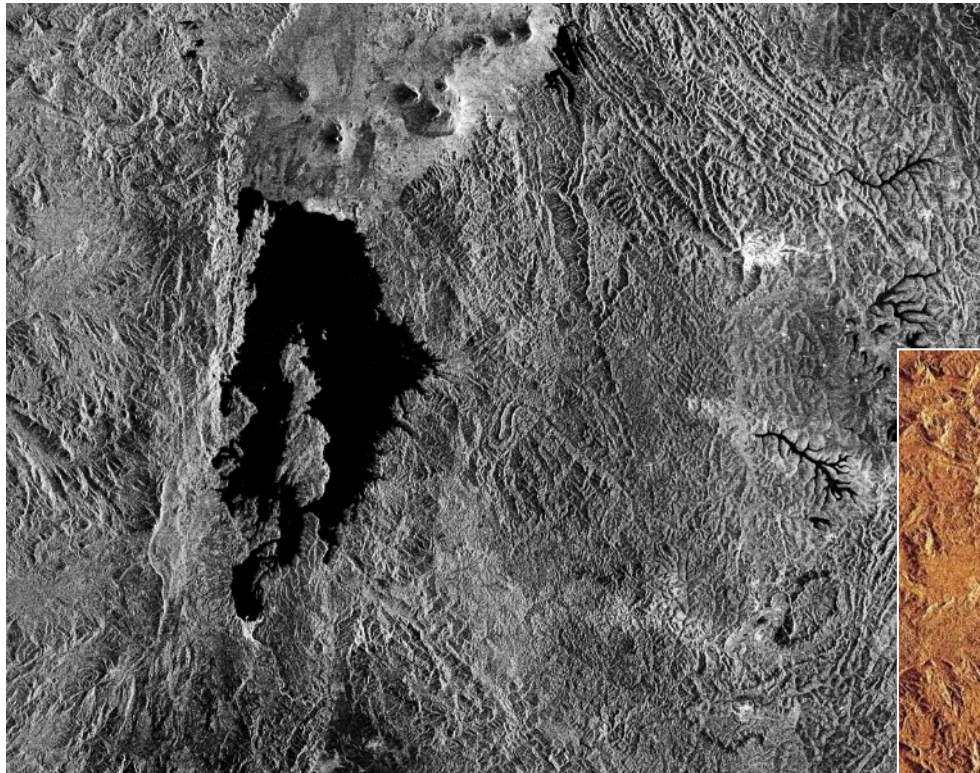


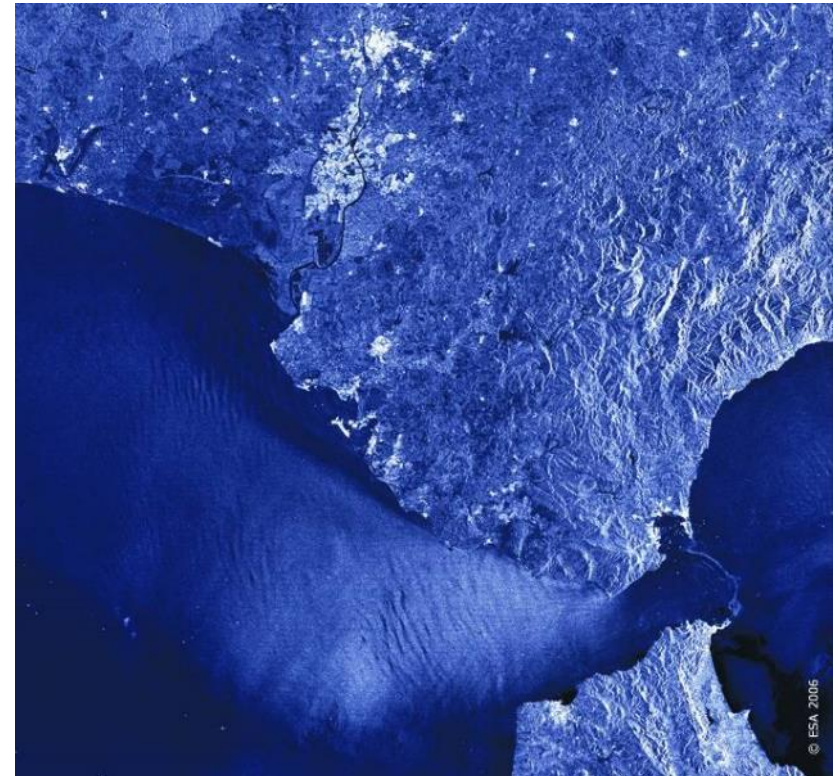
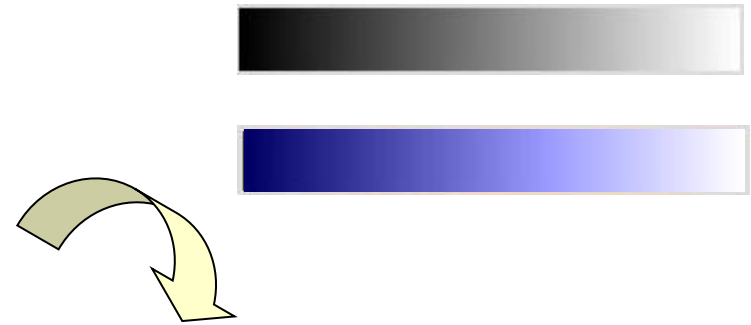
Image Envisat/ASAR Wide Swath Mode
Rift Africain – 24/09/2007

http://www.esa.int/esaEO/SEM3I7VHJCF_index_0.html

➊ Niveaux de gris – Niveaux d'une couleur



Image Envisat/ASAR Wide Swath Mode
Détroit de Gibraltar – 20/10/2002

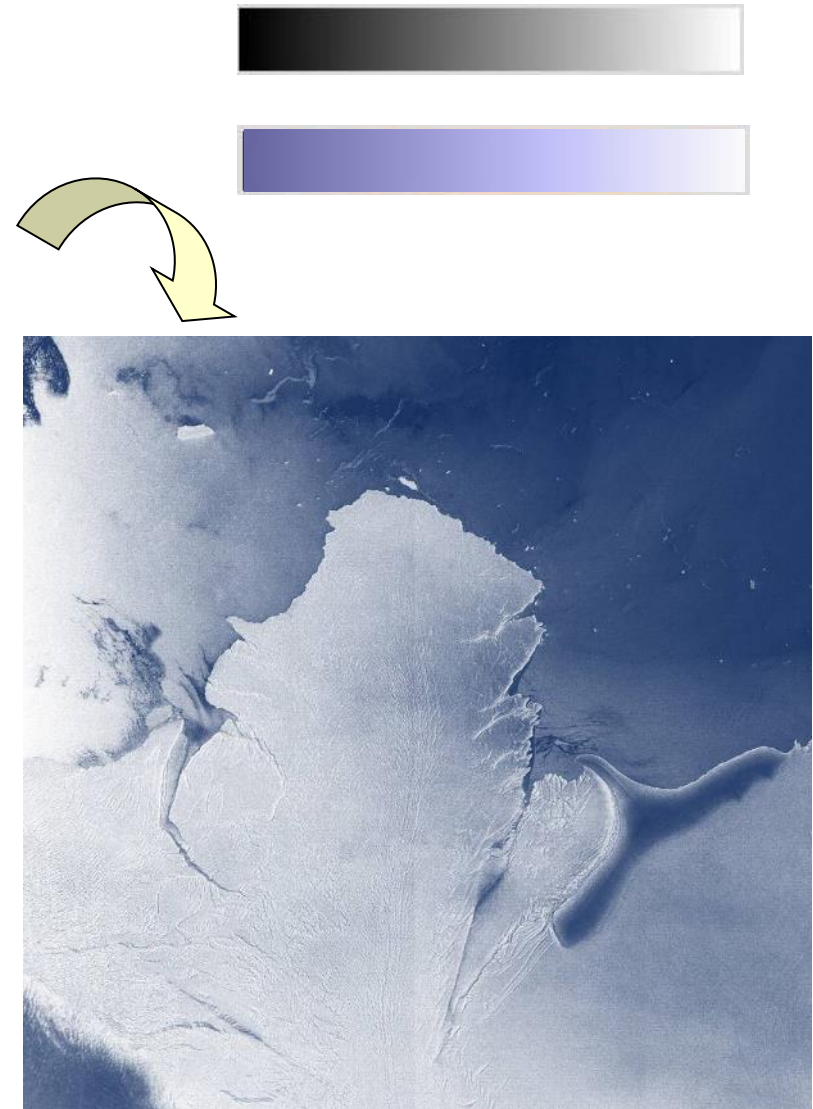




🌀 Niveaux de gris – Niveaux d'une couleur



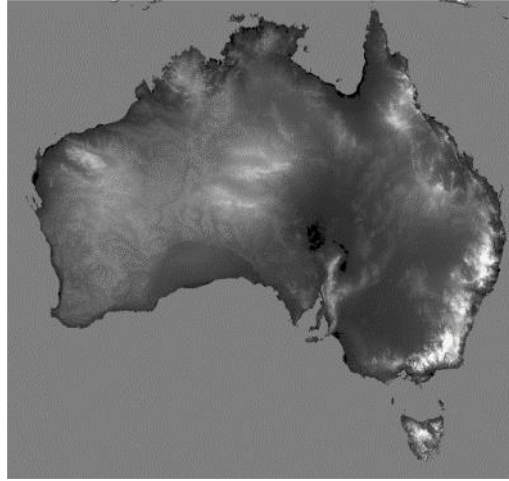
Image Envisat/ASAR
Plateau de Brunt / Mer de Weddell (Antarctique) – 05/03/2011



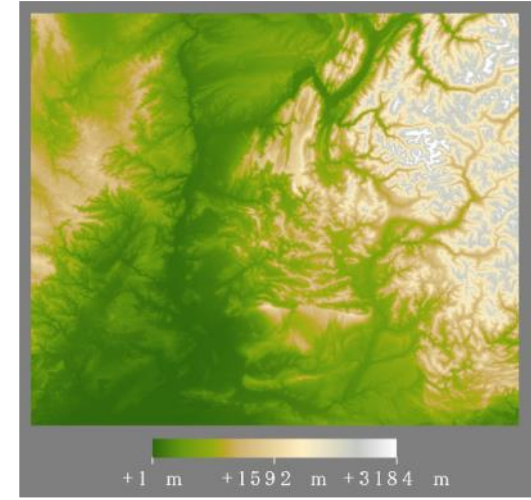
Retrouver une table de pseudo-couleur



Modèle de LUT



MNT SRTM reprojeté



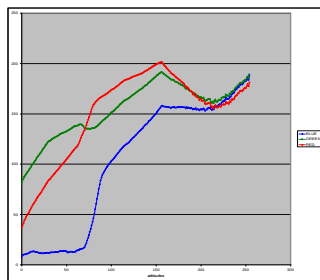
LUT et ombrage appliqué à un autre MNT

<http://photojournal.jpl.nasa.gov/catalog/pia06665>

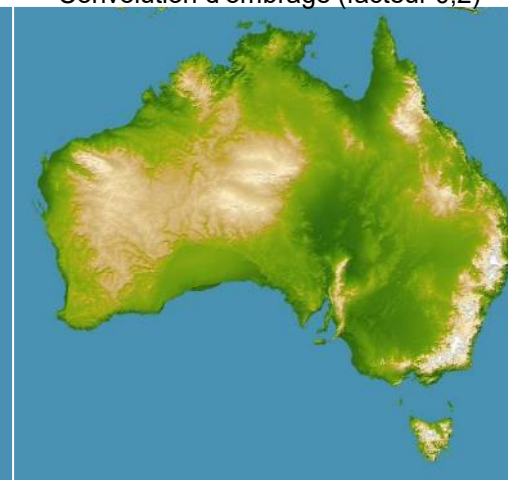
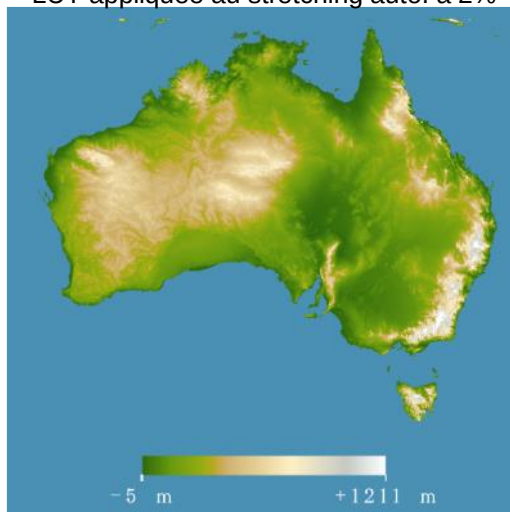
LUT appliquée au stretching auto. à 2%

Convolution d'ombrage (facteur 0,2)

Convolution d'ombrage (facteur 0,4)



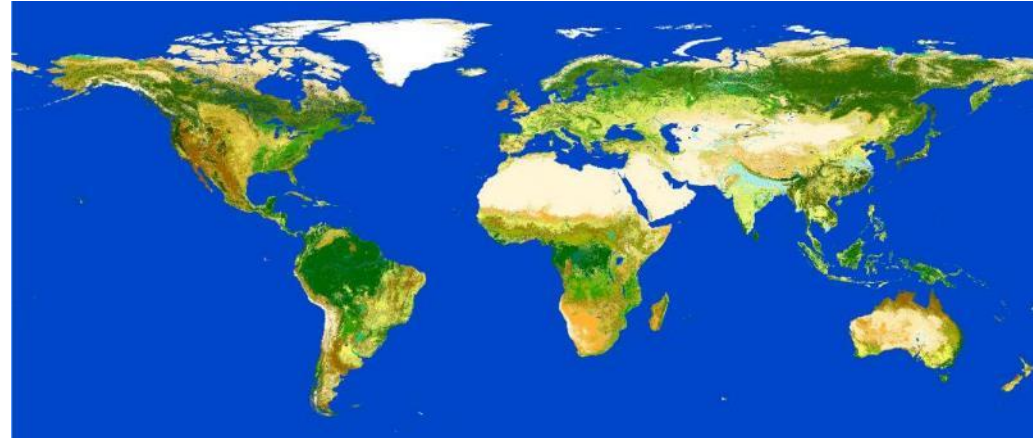
Résultat de l'analyse de régression





Les images thématiques

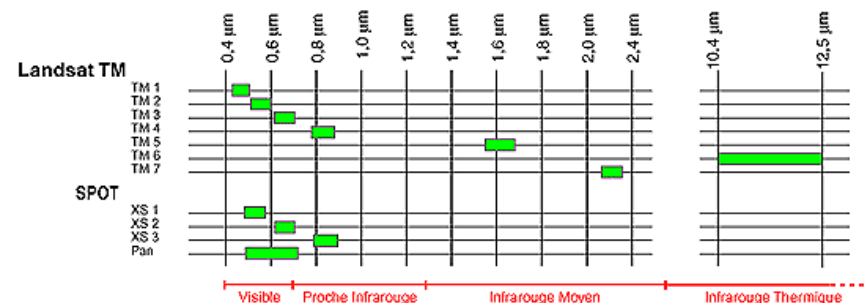
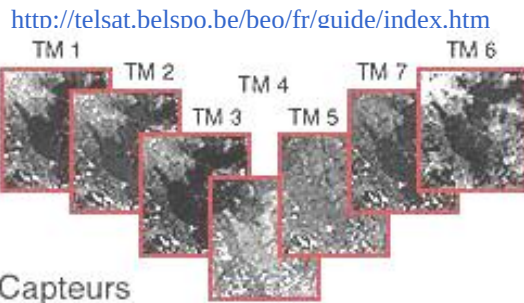
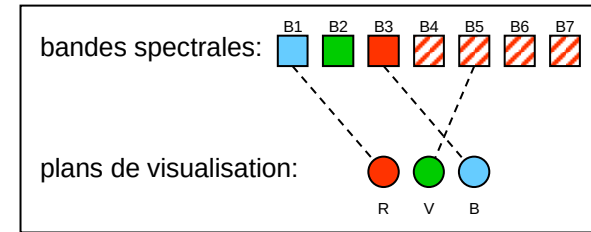
Value	R	G	B	Global Globcover legend (level 1)
11	170	240	240	Post-flooding or irrigated croplands (or aquatic)
14	255	255	100	Rainfed croplands
20	220	240	100	Mosaic cropland (50-70%) / vegetation (20-50%)
30	205	205	102	Mosaic vegetation (50-70%) / cropland (20-50%)
40	0	100	0	Closed to open (>15%) broadleaved evergreen or semi-deciduous forest (>5m)
50	0	160	0	Closed (>40%) broadleaved deciduous forest (>5m)
60	170	200	0	Open (15-40%) broadleaved deciduous forest/woodland (>5m)
70	0	60	0	Closed (>40%) needleleaved evergreen forest (>5m)
90	40	100	0	Open (15-40%) needleleaved deciduous or evergreen forest (>5m)
100	120	130	0	Closed to open (>15%) mixed broadleaved and needleleaved forest (>5m)
110	140	160	0	Mosaic forest or shrubland (50-70%) / grassland (20-50%)
120	190	150	0	Mosaic grassland (50-70%) / forest or shrubland (20-50%)
130	150	100	0	Closed to open (>15%) (broadleaved or needleleaved, evergreen or deciduous) shrubland (<5m)
140	255	180	50	Closed to open (>15%) herbaceous vegetation (grassland, savannas or lichens/mosses)
150	255	235	175	Sparse (<15%) vegetation
160	0	120	90	Closed to open (>15%) broadleaved forest regularly flooded (semi-permanently or temporarily) - Fresh or brackish water
170	0	150	120	Closed (>40%) broadleaved forest or shrubland permanently flooded - Saline or brackish water
180	0	220	130	Closed to open (>15%) grassland or woody vegetation on regularly flooded or waterlogged soil - Fresh, brackish or saline water
190	195	20	0	Artificial surfaces and associated areas (Urban areas >50%)
200	255	245	215	Bare areas
210	0	70	200	Water bodies
220	255	255	255	Permanent snow and ice
230	0	0	0	No data (burnt areas, clouds,...)



Classification **GlobCover** à partir de données Envisat / MERIS acquises de décembre 2004 à juin 2006
<http://ionia1.esrin.esa.int/index.asp>



Images multispectrales et visualisation Rouge/Vert/Bleu Compositions colorées



Nombre de composition
colorées

N bandes



Sans respecter l'ordre
des fréquences (arrangements):

$$CC(N) = A_N^3 = N \times (N-1) \times (N-2)$$

En respectant l'ordre
des fréquences (combinaisons):

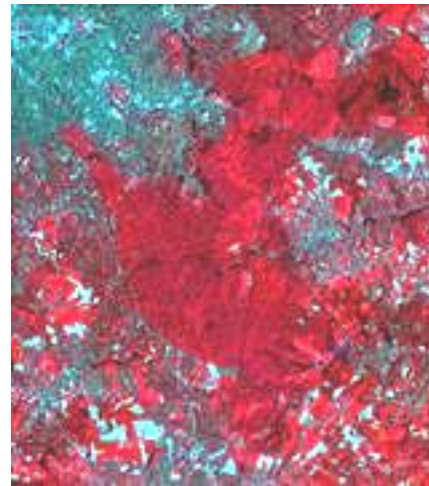
$$CC(N) = N \times (N-1) \times (N-2) / 6$$

	sans ordre	avec ordre
CC(3) →	6	1
CC(4) →	24	4
CC(5) →	60	10
CC(6) →	120	20
...		
CC(15) →	2730	455

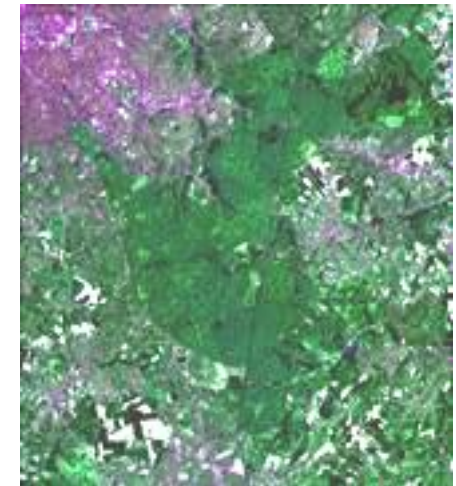
TM 321 (« Vraies couleurs »)



TM 432 (« Proche Infrarouge »)



TM 354





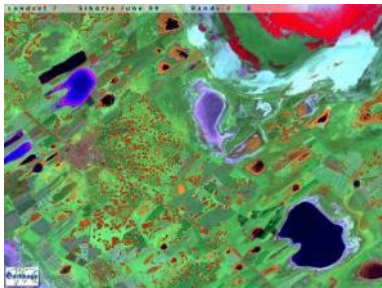
Visible et infrarouge (Landsat)

Sibérie

**Landsat-7 ETM+
acquis en juin 1999**



Composition
« couleurs naturelles »
TM3 (R) TM2 (V) TM1 (B)



Composition
rouge + infrarouge
TM4 (R) TM5 (V) TM3 (B)





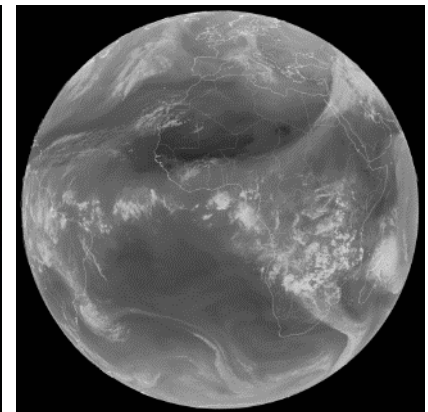
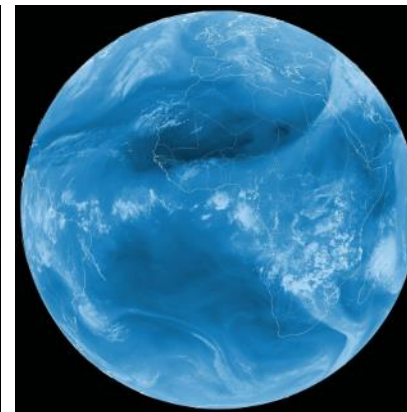
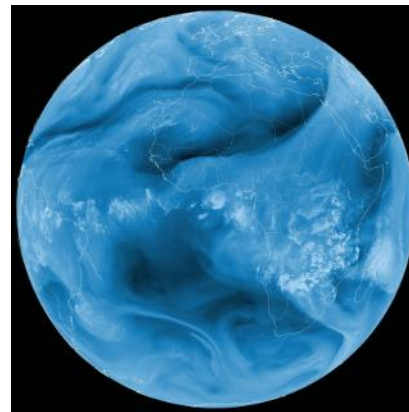
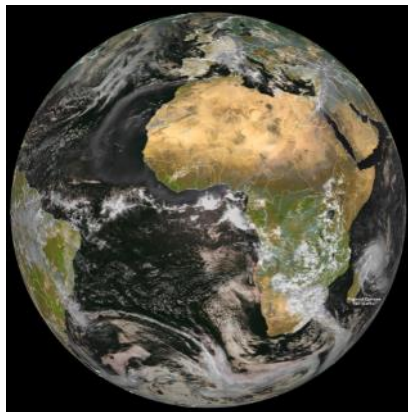
Visible et infrarouge (Meteosat)



Couleurs naturelles – rouge (R) vert (V) bleu (B)

Composition infrarouge – rouge (R) NIR (V) MIR (B)

http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17591



VIS0.6 (B) VIS0.8 (V) NIR1.6 (R) bande 5 WV6.2 (niveaux de bleus) bande 6 WV7.3 (niveaux de bleus) bande 6 WV7.3 (niveaux de gris)

Meteosat-8 acquis le 06/03/2004 12:00 UTC

http://www.eumetsat.int/Home/Main/Image_Gallery/PR_Images/Fulldisk_Images/index.htm

<http://www-igm.univ-mlv.fr/~riazano/>

version 2.09

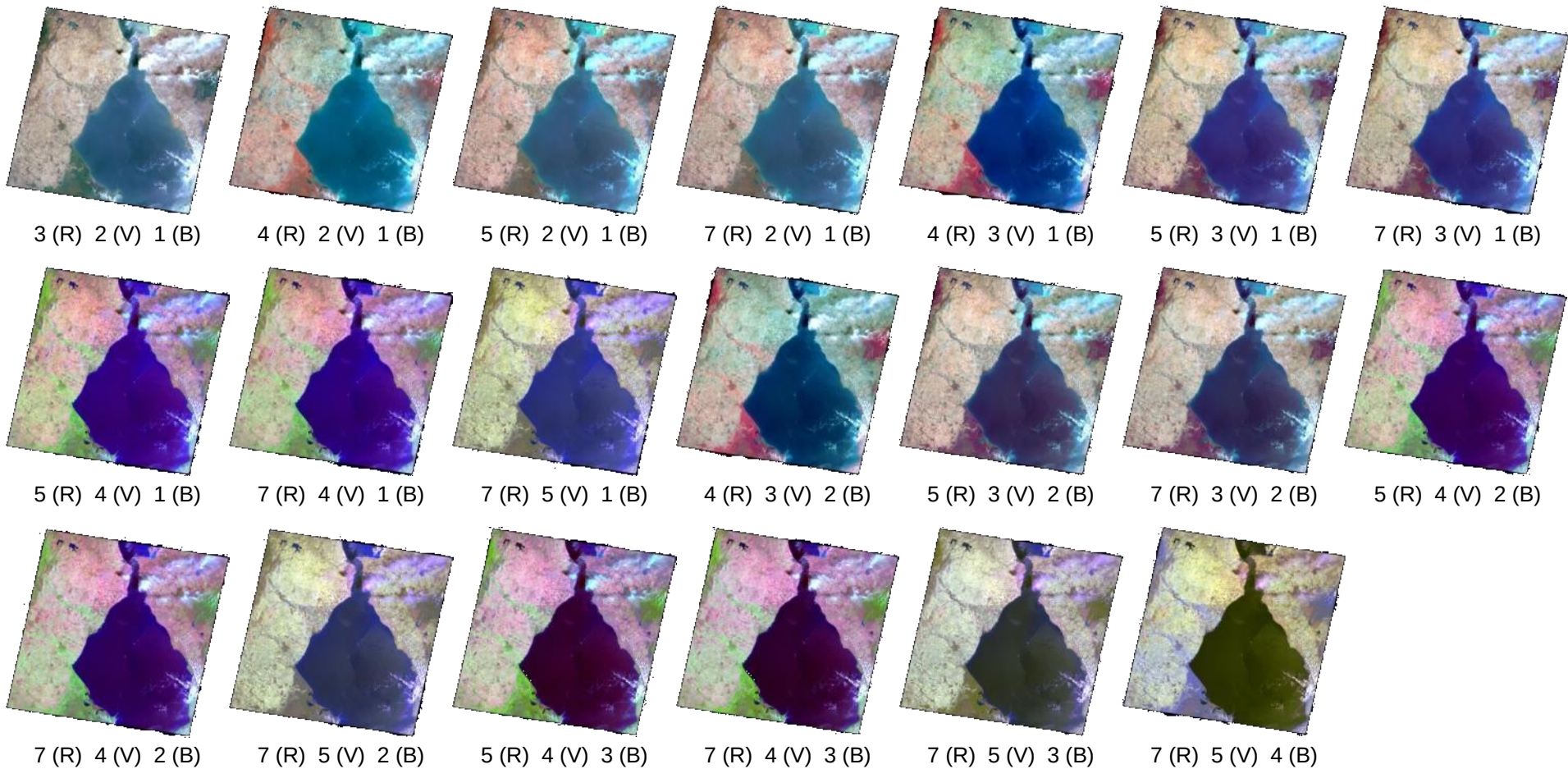
Serge RIAZANOFF
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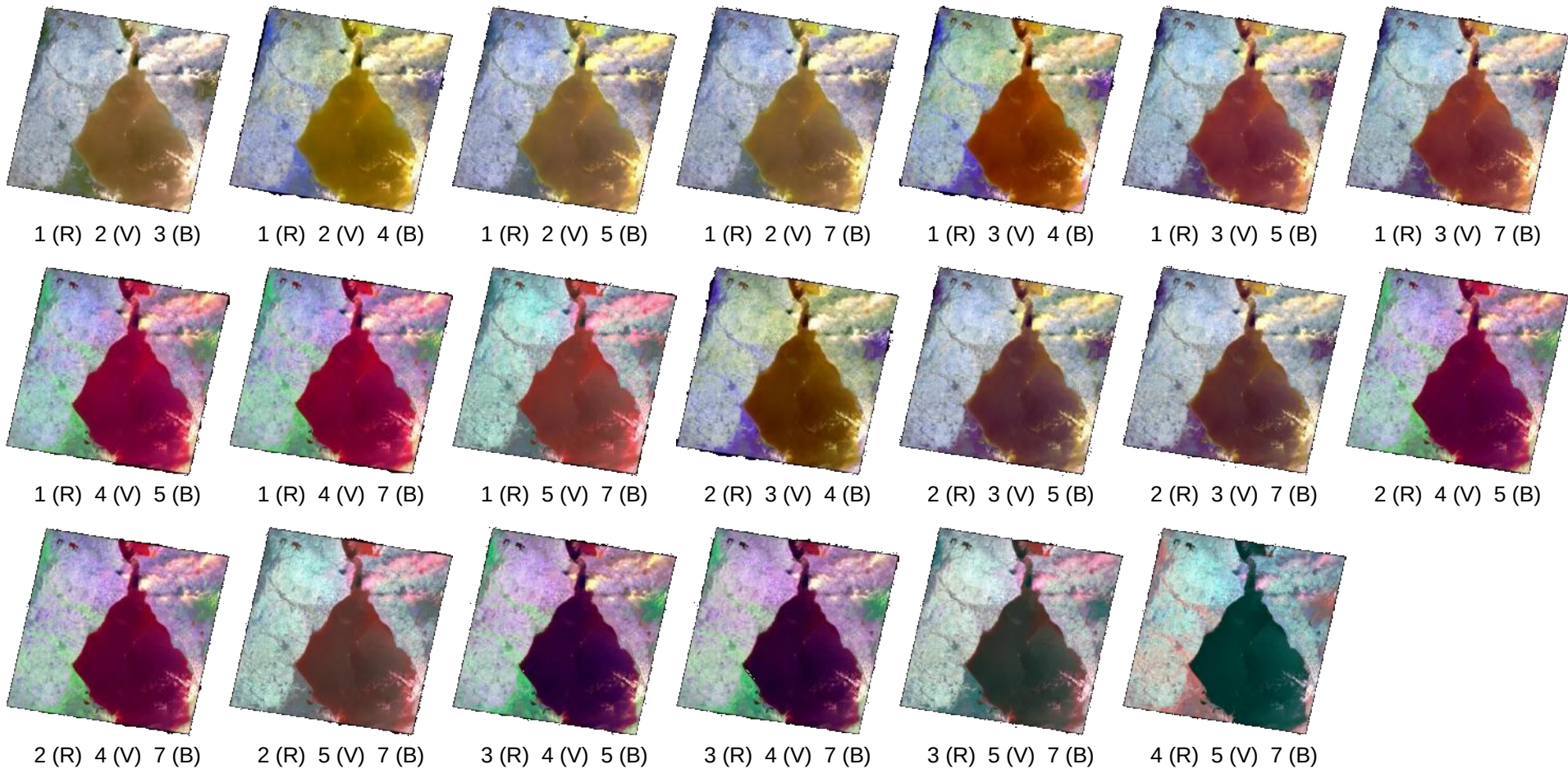
Compositions colorées

(exemples Landsat ETM+ Maracaibo – canaux VNIR/SWIR path/row 007-053 acquis le 03/03/2001)

Affectation RVB en respectant l'ordre des fréquences

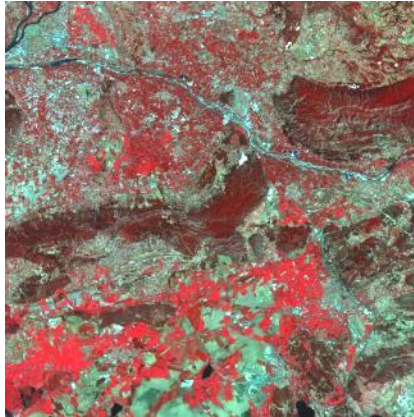
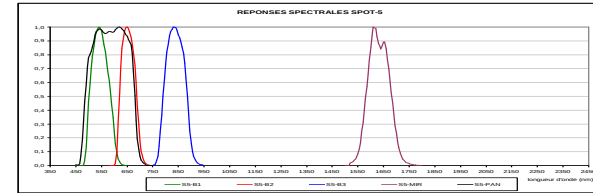


Affectation RVB dans l'ordre inverse des fréquences

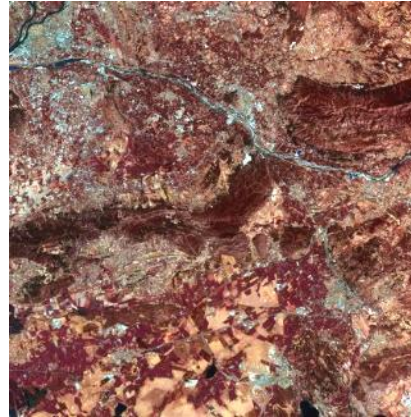




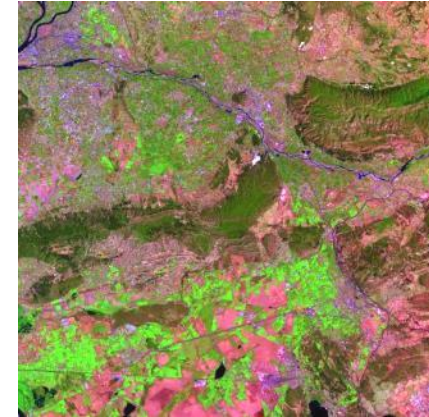
Compositions colorées (exemples SPOT5 HRVIR Avignon)



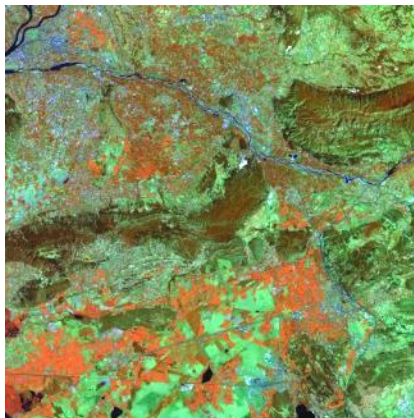
3 (R) 2 (V) 1 (B)



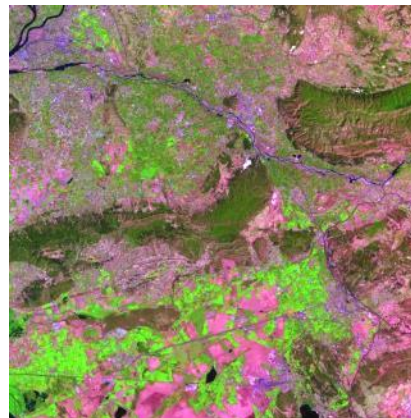
4 (R) 2 (V) 1 (B)



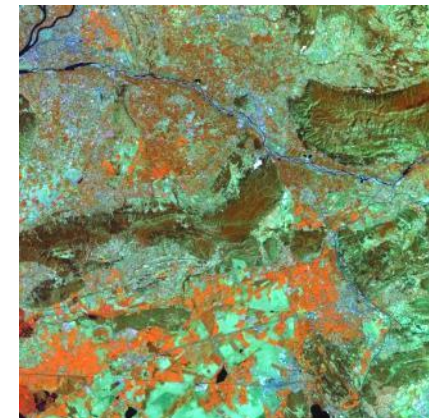
4 (R) 3 (V) 1 (B)



3 (R) 4 (V) 1 (B)



4 (R) 3 (V) 2 (B)



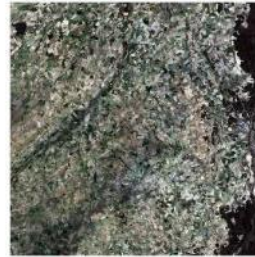
3 (R) 4 (V) 2 (B)



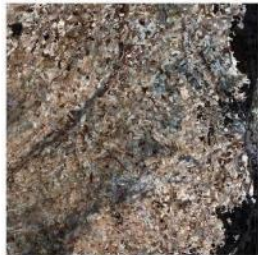
RapidEye

<http://www.rapideye.de/>

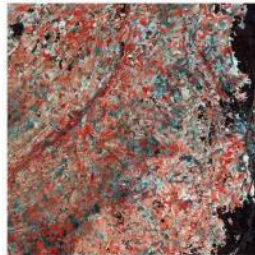
Zone agricole – Nord-ouest de la Pologne
22 avril 2009, RapidEye-2 (démonstration. 2)



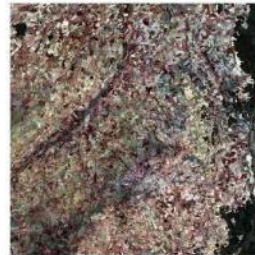
1-2-3



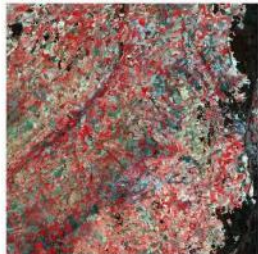
1-2-4



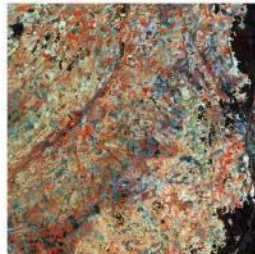
1-2-5



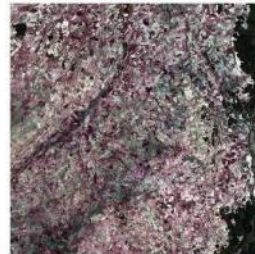
1-3-4



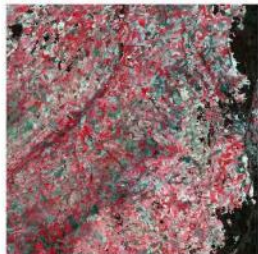
1-3-5



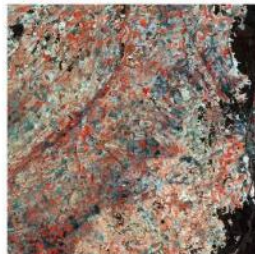
1-4-5



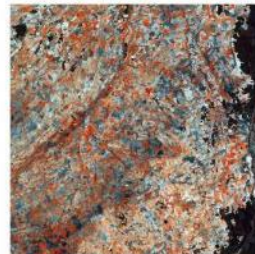
2-3-4



2-3-5



2-4-5



3-4-5

Bandes spectrales:

Blue	440-510 nm
Green	520-590 nm
Red	630-695 nm
Red edge	690-730 nm
NIR	760-850 nm

Zone côtière – Mer morte, Israël Palestine
17 mars 2009, RapidEye-3 (démonstration. 7)



1-2-3



1-2-4



1-2-5



1-3-4



1-3-5



1-4-5



2-3-4



2-3-5



2-4-5

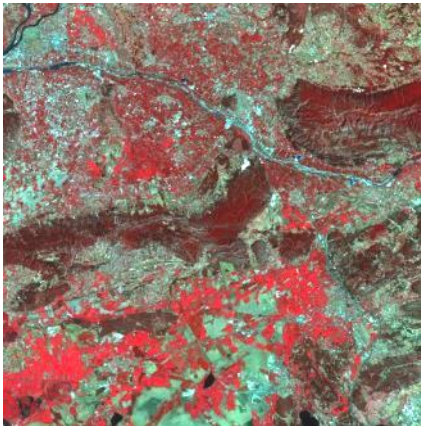


3-4-5

Compositions colorées et combinaisons de canaux

Préférences des photo-interprètes

Landsat TM	R	V	B	
	3	2	1	Couleurs naturelles
	4	5	3	Agriculture (AGRIT après 1997)
	4	3	2	Agriculture (AGRIT jusqu'en 1997)
	7	4	2	Géologie (ou 4-2-1 ou 4-5-2)
	(5+7)/2	(3+4)/2	(1+2)/2	Information « maximale »
SPOT	2	1	C(1,2,3)	Couleurs « naturelles »
	avec $C(1,2,3) = 1.4 \times XS1 + 0.6 \times XS2 - 0.7 \times XS3$			



3 (R) 2 (V) 1 (B)



2 (R) 1 (V) C(1,2,3) (B)

Landsat-7 ETM+ / Landsat-8 OLI/TIRS

<http://blogs.esri.com/esri/arcgis/2013/07/24/band-combinations-for-landsat-8/>

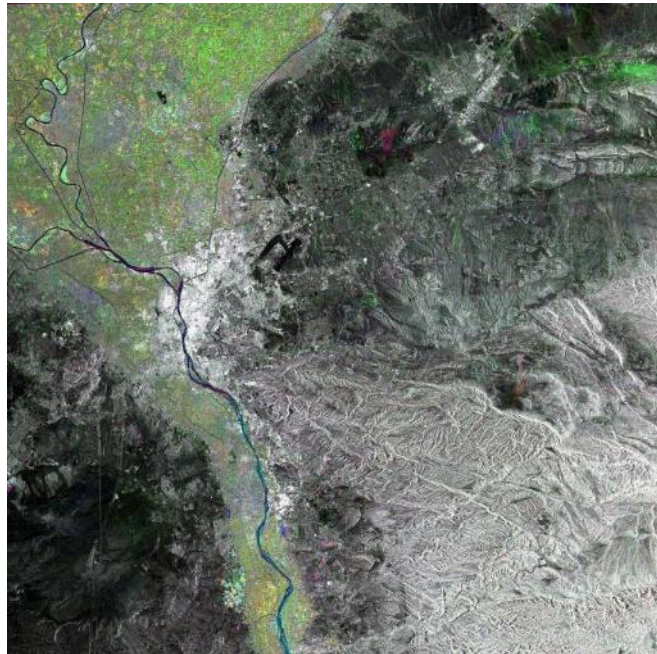
L7	L8	Use
321	432	Natural colour
753	764	False colour (urban)
432	543	Colour infrared (vegetation)
541	652	Agriculture
754	765	Atmospheric penetration
451	562	Healthy vegetation
453	564	Land / water
742	753	"Natural" with atmospheric removal
743	754	Shortwave infrared
543	654	Vegetation analysis

Compositions colorées de données monospectrales à 3 dates

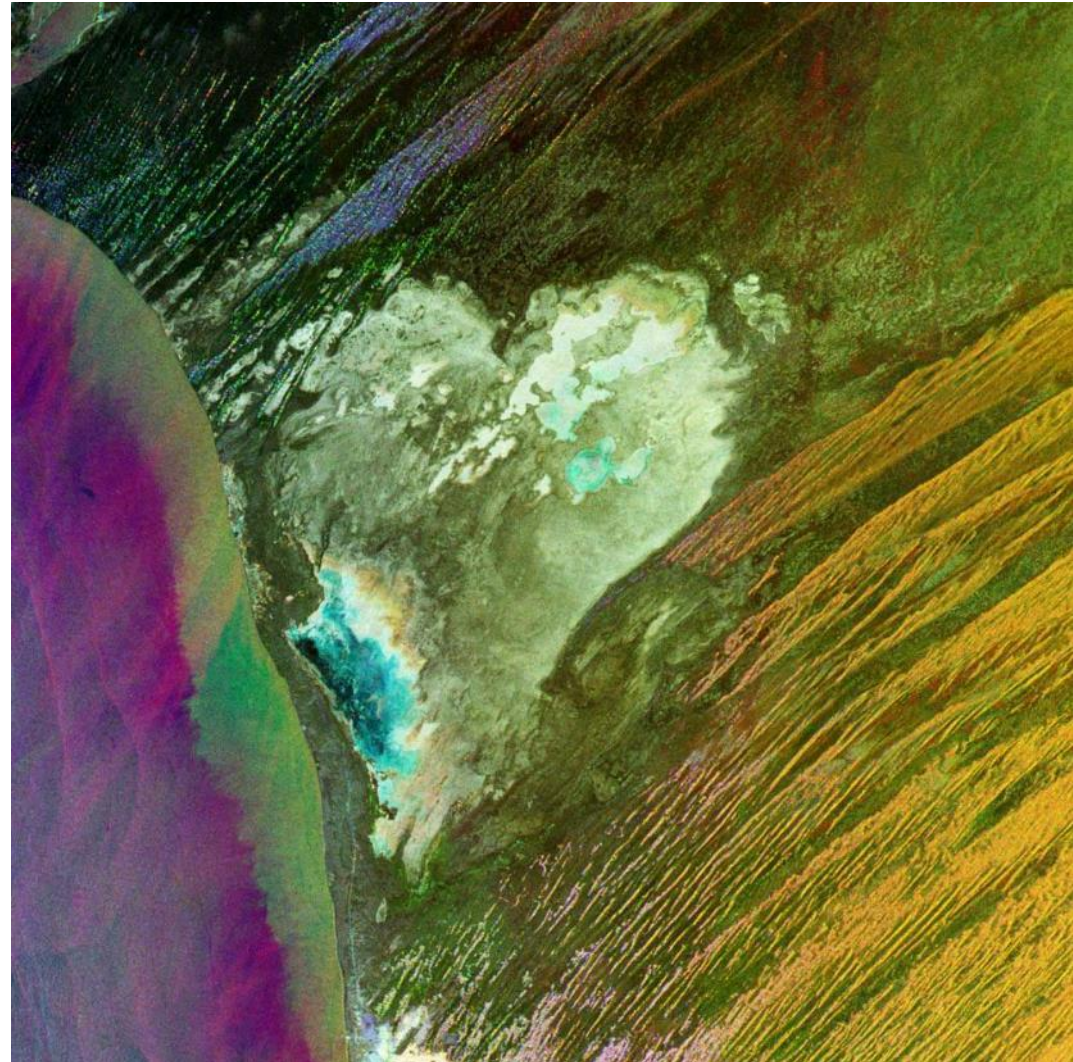
**Image Envisat / ASAR de
Mauritanie au nord de Nouakchott**

Rouge	23/11/2002
Vert	23/03/2003
Bleu	24/05/2003

http://www.esa.int/esaEO/SEMST_F1PGQD_index_0.html



asar_B20040408+G20031120+R20040607_Le_Caire_12.5m.jpg
http://www.esa.int/esaEO/SEMST_F1PGQD_index_0.html



<http://www.igm.univ-mlv.fr/~riazano/>
version 2.09

Serge RIAZANOFF
Initiation au Traitement d'Images

Compositions colorées d'images de polarisation Quad-Pol

RADARSAT-2

Rouge	polarisation HH
Vert	polarisation VV
Bleu	polarisation HV

Côte est du Groenland acquise le 18 décembre 2007 (4 jours après le lancement) en Quad-Pol.

<http://www.radarsat2.info/about/gallery/> !

Greenland

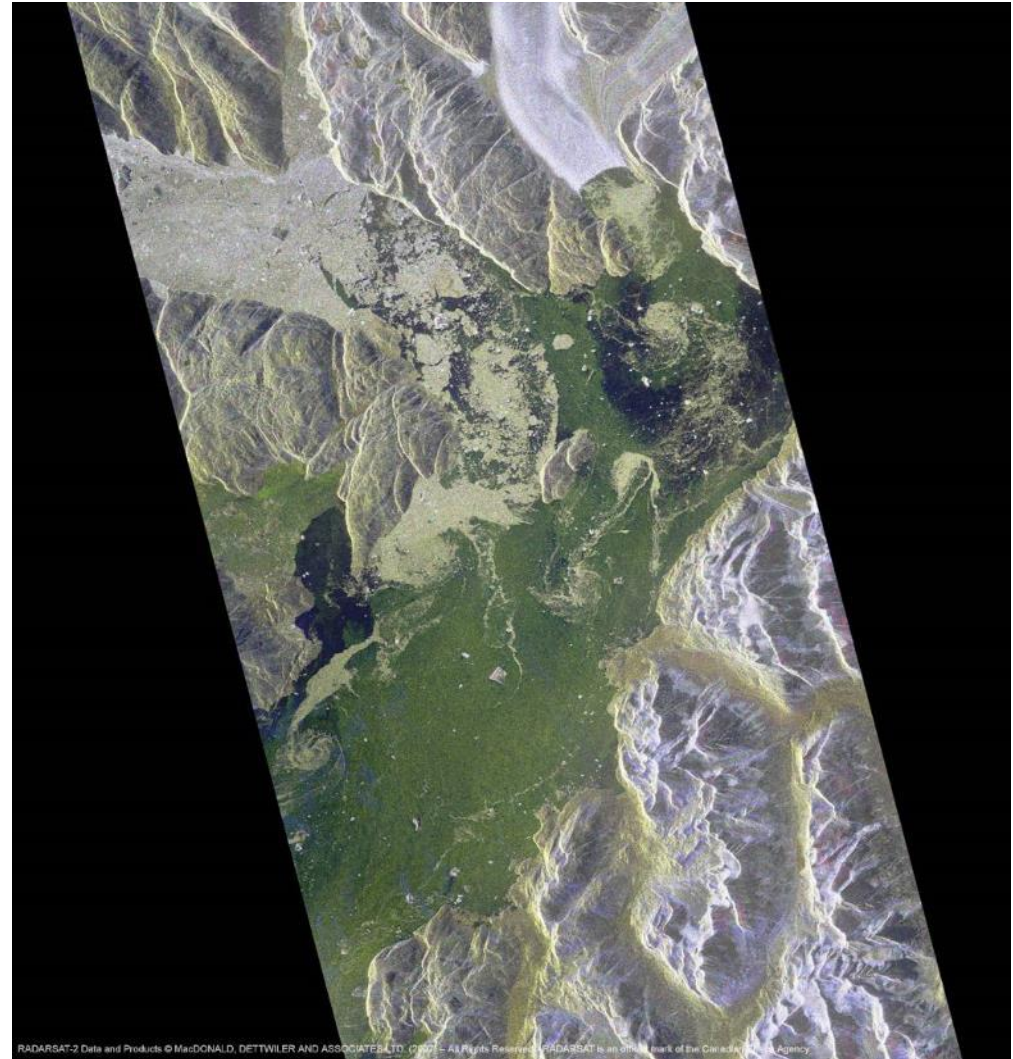
This RADARSAT-2 Standard Quad-Pol image shows the northern end of the Sermilik fjord on the east coast of Greenland. The image was acquired December 18, 2007 – four days after launch and is a composite of the three radar data channels (HH, VV, HV) displayed in a red-green-blue colour scheme. The scene is ~ 25km x 50km, with 25m nominal resolution.

The Fenrisgletscher glacier – a large, slow moving valley glacier that feeds into the Sermilik fjord - is visible in the upper right corner of the image. Glaciers in this area produce large volumes of icebergs that flow out to sea.

In the fjord, variations in colour represent different types of sea ice and leads (open water). The use of polarimetric data greatly improves ice edge detection and the identification of ice types as well as increasing ice topography and structural information. The information provided can be used for ship navigation, and land / sea ice studies (such as the position of glacier termini to support environmental monitoring).

This image was acquired early in the RADARSAT-2 commissioning phase.

RADARSAT-2 Data and Products © MacDonald, Dettwiler and Associates Ltd. (2007) - All Rights Reserved.



Compositions colorées d'images de polarisation Dual-Pol

RADARSAT-2

Rouge -
Vert polarisation VH
Bleu polarisation VV

Côte est du Groenland acquise le 18 décembre 2007 (4 jours après le lancement) en Quad-Pol.

<http://www.radarsat2.info/about/gallery/> !

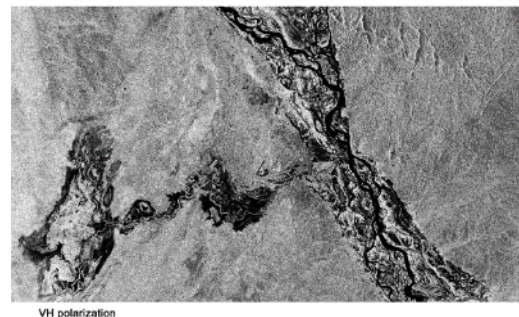
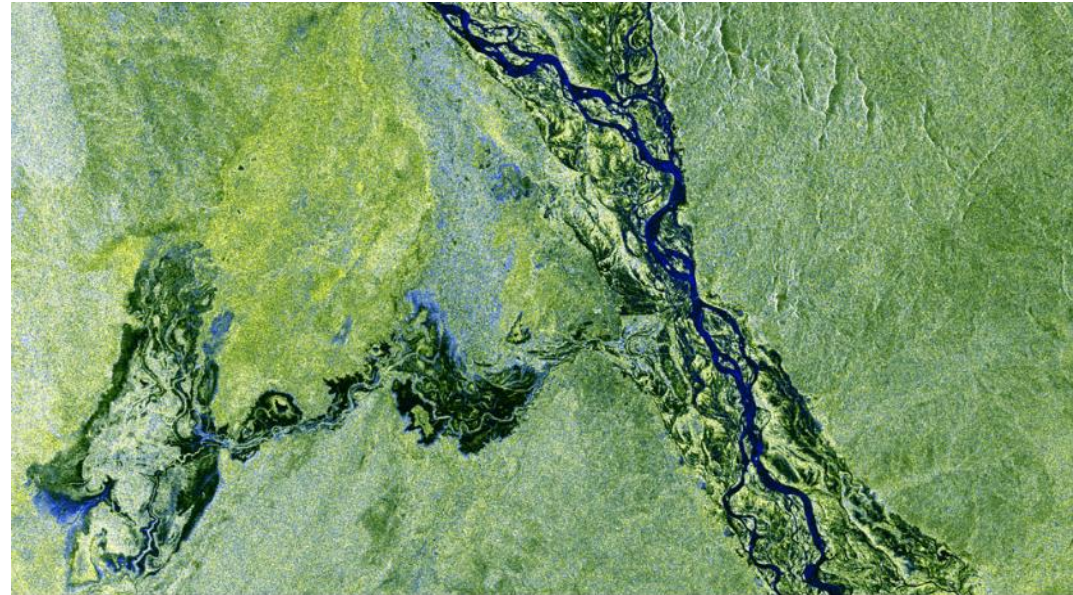
Zambezi River, Mozambique

This 76 x 42km subscene, of a RADARSAT-2 Wide dual polarized (VV and VH) image was acquired February 9, 2008. The image shows flooding along the Zambezi River and catchment area due to higher-than-normal rainfall. The main river channel, as well as flood extents, are evident. Colour variation along the river(s) and flooded areas illustrate the different scattering mechanisms associated with various surface features such as: stagnant vs. flowing water, flooded vs. non-flooded vegetation, vegetation density and type etc...

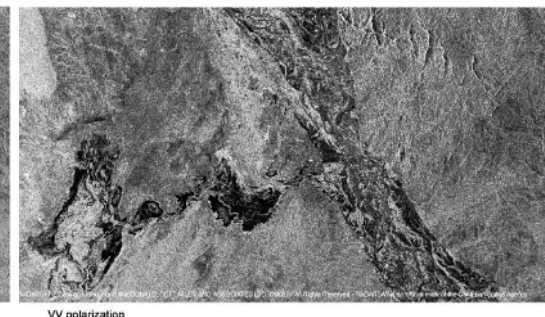
For example, the normal river course of the Zambezi River runs in the north-south direction. Due to the type of surface scattering, the normal river channel gives a stronger VV response and appears as blue in the colour composite image. In contrast, the open water and open flooded areas produce a weak response in both polarizations, and therefore appear black. To the west of the Zambezi River, a smaller river channel is flooded. Just north of this are areas of blue and green - which is likely low biomass, flooded vegetation. The blue-green colour is characteristic of radar scattering from the water (VV polarization) and vegetation (VH polarization).

The cross pol channel (VH) proves especially useful for detecting open water in a beam mode and position (Wide 1) that traditionally, due to its steep incidence angle, was often a poor choice for flood detection. With the advanced multi-polarizations available on RADARSAT-2, the range of incidence angles that can be readily used for flood detection has expanded.

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VH polarization



VV polarization



Compositions colorées avec 2 bandes

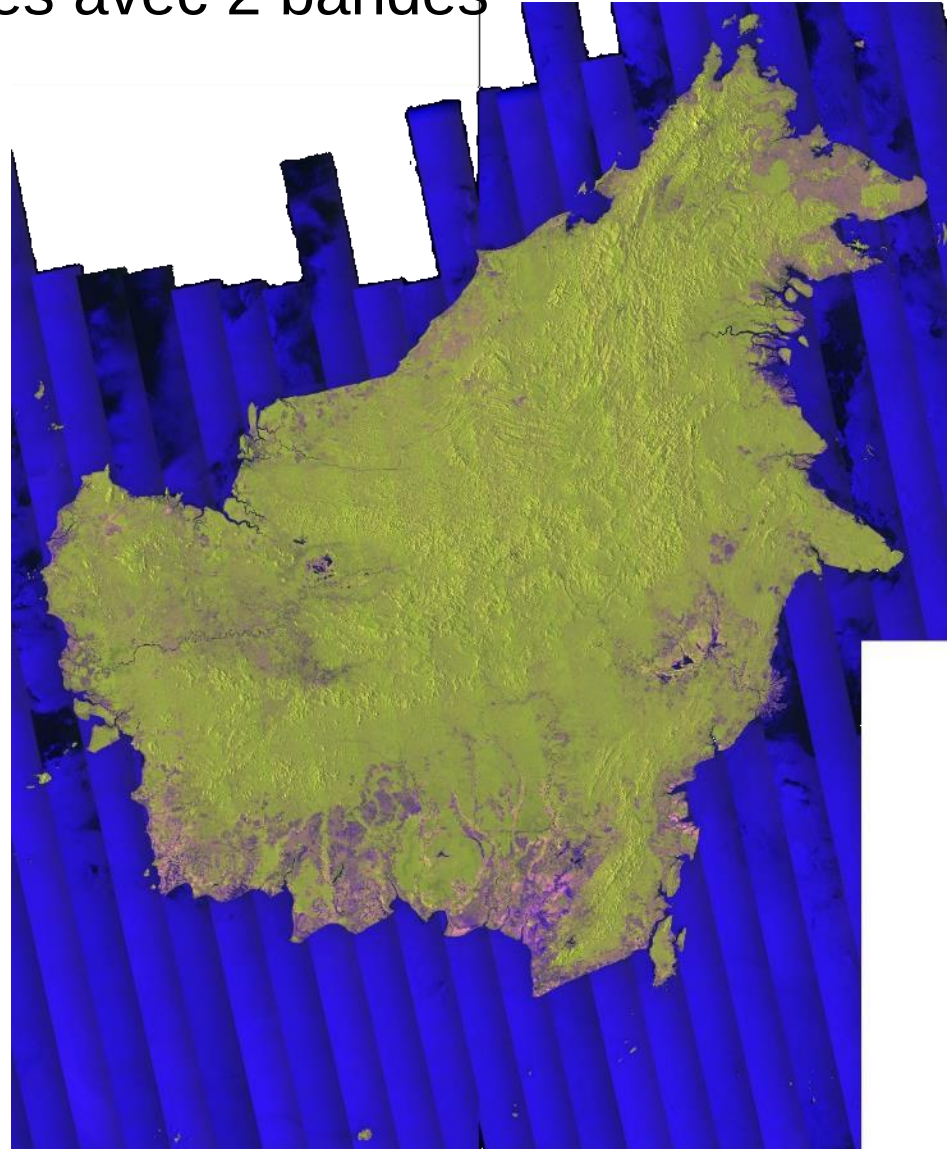
ALOS PALSAR

Rouge	polarisation HH
Vert	polarisation HV
Bleu	HH – HV

*Projet « K & C Mosaic », mosaïque 50m
Ile de Bornéo vue en 2007*

http://www.eorc.jaxa.jp/ALOS/en/kc_mosaic/kc_mosaic.htm

<ftp://ftp.eorc.jaxa.jp/pub/ALOS/ftp/KC50/>



Compositions colorées de statistiques locales

terraSAR-X

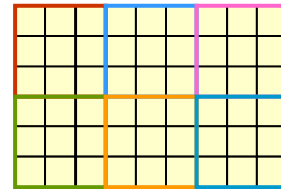
Red variance locale
Green luminosité locale
Blue variance – luminosité

*Vallée de Inn et Lac Chiemsee (Bavière)
observés le 24.12.2008 à la résolution
StripMap de 3 m et sous échantillonnée
à 10 m.*

[http://www.dlr.de/en/desktopdefault.aspx
/tabid-1/86_read-21543/ /](http://www.dlr.de/en/desktopdefault.aspx/tabid-1/86_read-21543/)



<http://www.igm.univ-mlv.fr/~riazano/>
version 2.09



$$\bar{m} = \frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} R(i, j)$$

$$\sigma = \sqrt{V} = \sqrt{\frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (R(i, j))^2 - (\bar{m})^2}$$



Serge RIAZANOFF
Initiation au Traitement d'Images



Compositions colorées avec 2 bandes et des statistiques



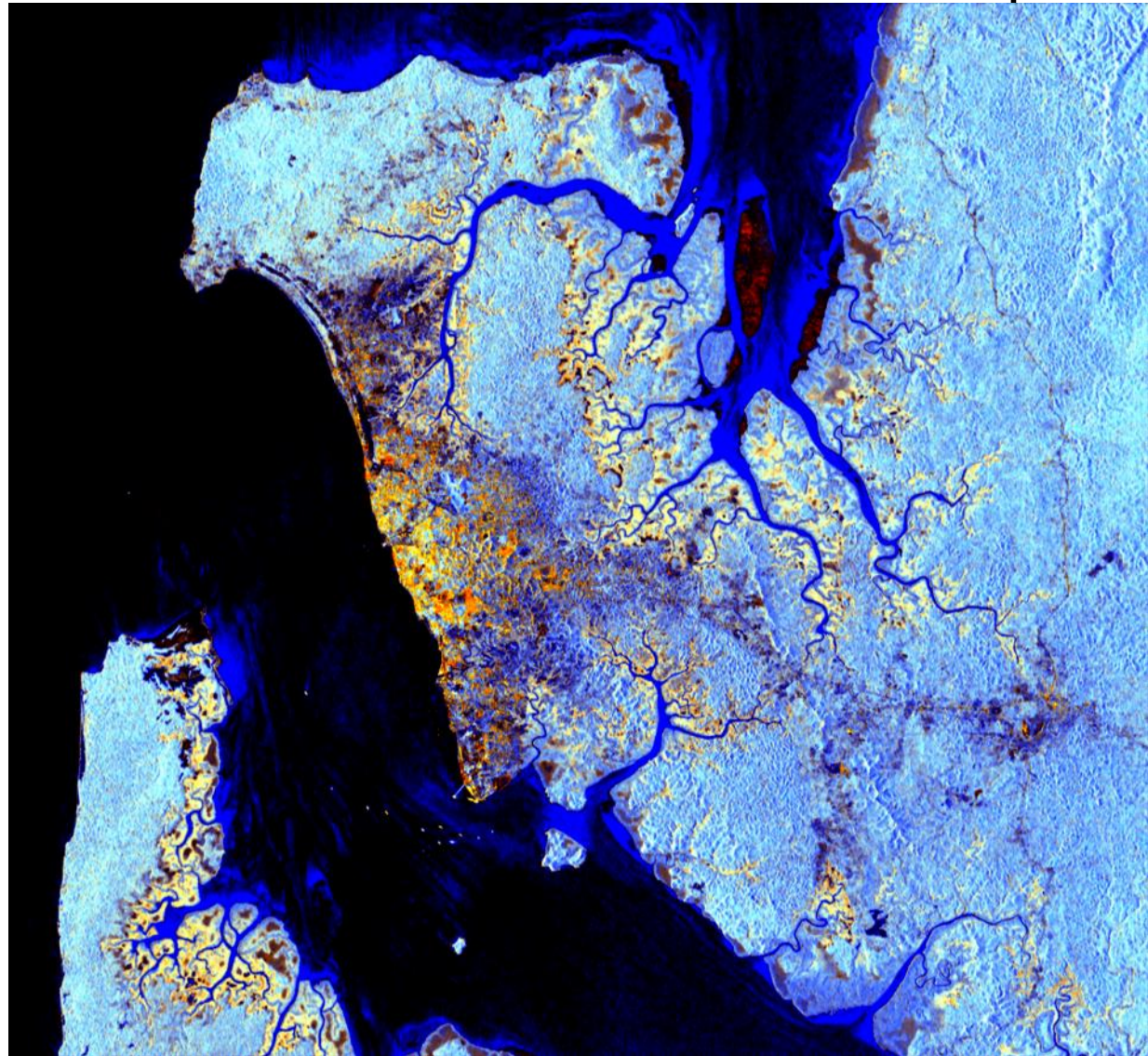
ALOS PALSAR

Red	polarisation HH
Green	polarisation HV
Blue	Entropie

Région de Libreville (Gabon)

acquise le 10 août 2007

Courtoisie Jean-Paul RUDANT (UMLV)





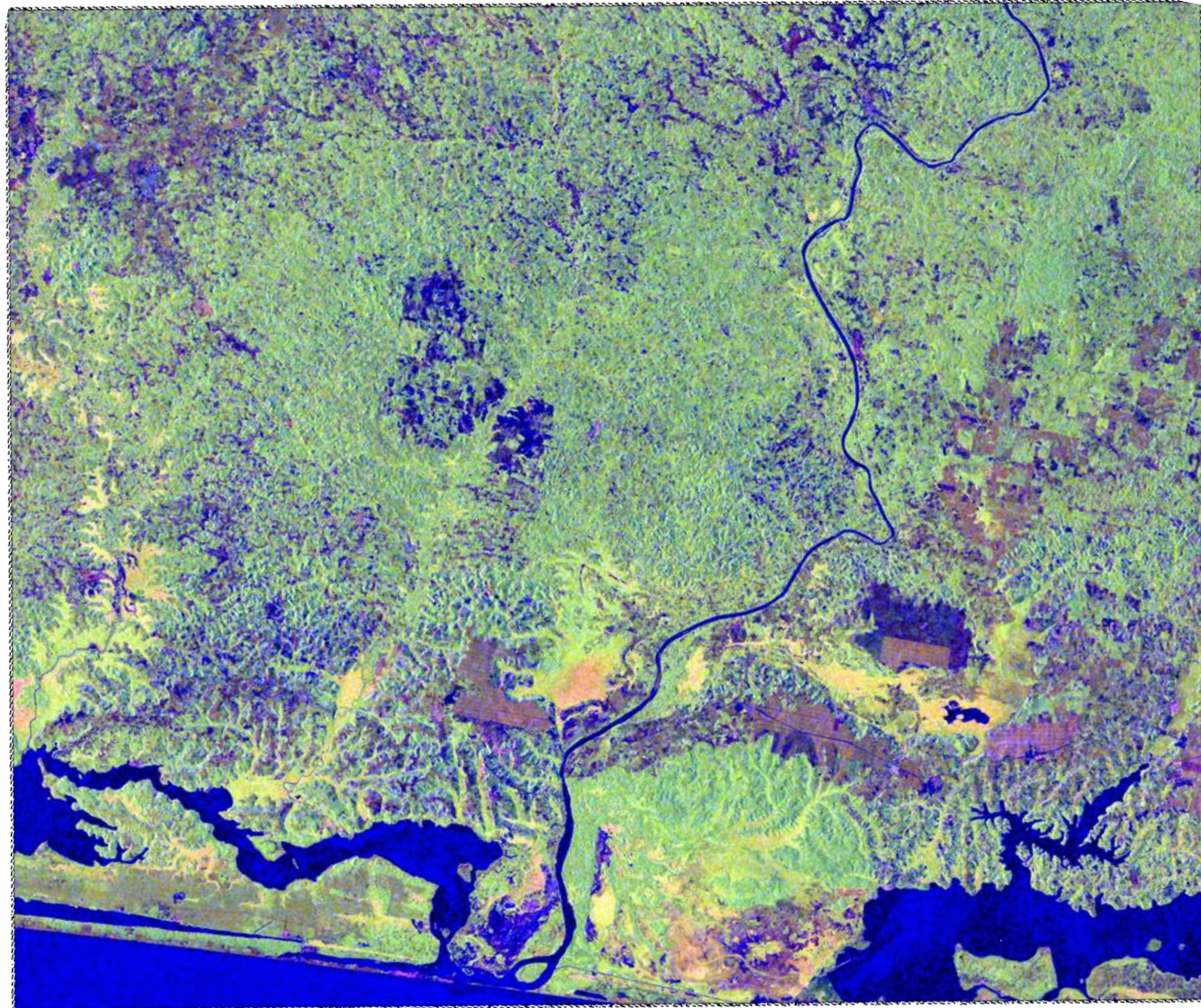
Compositions colorées avec 2 bandes et des statistiques



ALOS PALSAR

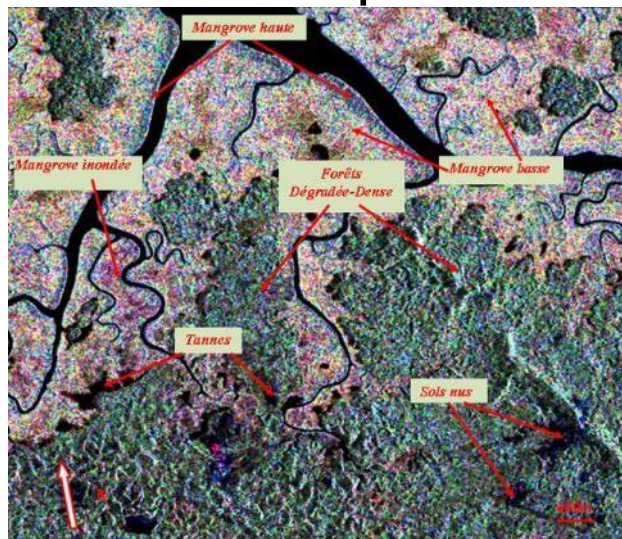
Red	polarisation HH
Green	polarisation HV
Blue	ρ (HH / HV)

*Grand Lahou (Côte d'Ivoire)
acquise le 6 juillet 2007
Courtoisie David NIAMIEN (UMLV)*





Compositions colorées avec 3 bandes HH, VV, HV



Radarsat-2 Quad Pol (HH,HV,VH,VV)

Red	$ HH - VV ^2$
Green	$4 \times HV^2$
Blue	$ HH + VV ^2$

Région nord de Libreville (Gabon)
acquise le 10 février 2009
Courtoisie Claude Sévérin MAÏLAT
MOUTSINGA (UMLV)



Compositions colorées et composantes principales

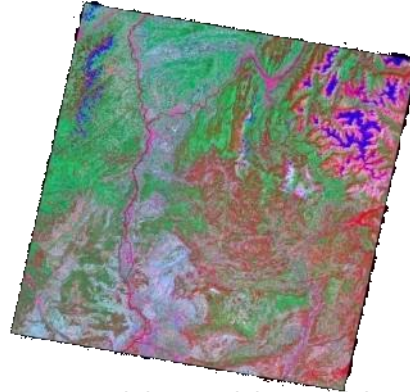
Landsat 7 ETM+ 169-029
acquise le 22/06/2002

bandes originales stretchées



3 (R) 2 (V) 1 (B)

composantes principales



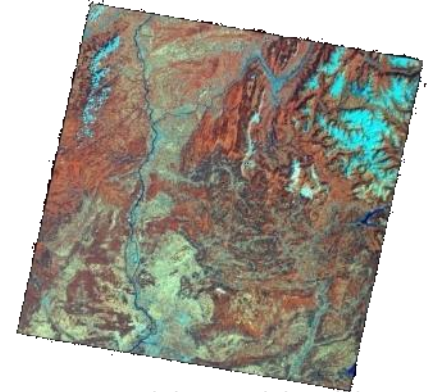
CP3 (R) CP2 (V) CP1 (B)

originale + 1^{ère} comp. principale

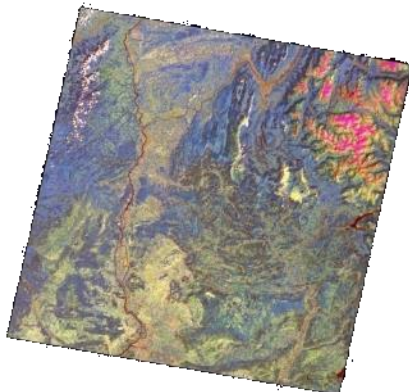


3 (R) CP1 (V) 1 (B)

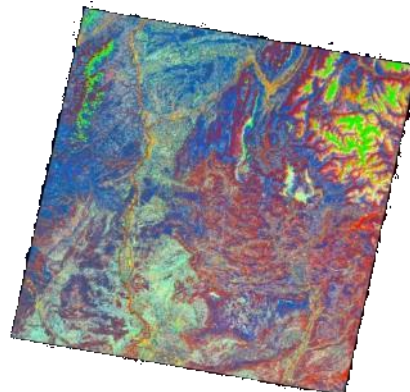
originale + 2 comp. principales



CP1 (R) CP2 (V) 1 (B)



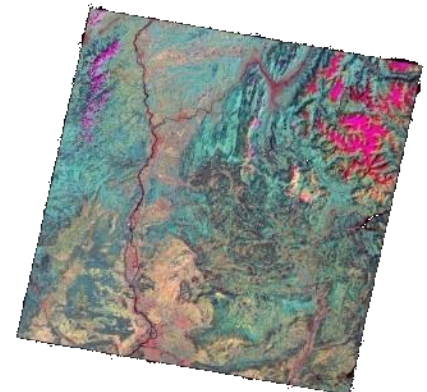
4 (R) 5 (V) 7 (B)



CP3 (R) CP1 (V) CP2 (B)



CP1 (R) 4 (V) 1 (B)



CP1 (R) CP2 (V) 4 (B)

$CP1 = 0.450 \times B1 + 0.469 \times B2 + 0.478 \times B3 + 0.188 \times B4 + 0.375 \times B5 + 0.416 \times B7$
 $CP2 = -0.392 \times B1 - 0.324 \times B2 - 0.269 \times B3 + 0.416 \times B4 + 0.601 \times B5 + 0.368 \times B7$
 $CP3 = -0.135 \times B1 - 0.102 \times B2 + 0.035 \times B3 - 0.865 \times B4 + 0.215 \times B5 + 0.419 \times B7$
 $CP4 = -0.694 \times B1 + 0.074 \times B2 + 0.652 \times B3 + 0.110 \times B4 - 0.256 \times B5 + 0.098 \times B7$
 $CP5 = 0.121 \times B1 - 0.071 \times B2 - 0.243 \times B3 + 0.170 \times B4 - 0.622 \times B5 + 0.711 \times B7$
 $CP6 = 0.360 \times B1 - 0.809 \times B2 + 0.462 \times B3 + 0.047 \times B4 - 0.019 \times B5 - 0.013 \times B7$

puis stretching imposé par les statistiques de
sortie $m_0=128$ $\sigma_0=60$

Compositions colorées et composantes ICS (*IHS*)

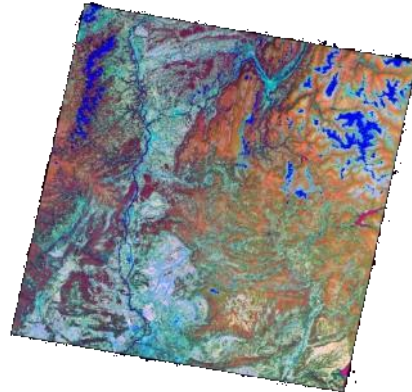
Landsat 7 ETM+ 169-029
acquise le 22/06/2002

bandes originales stretchées



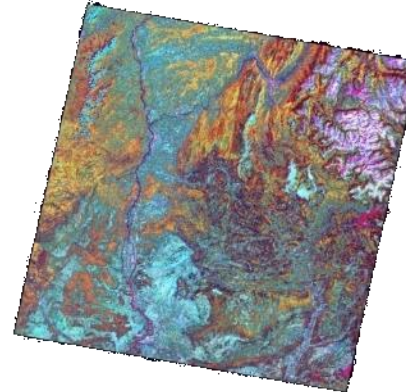
3 (R) 2 (V) 1 (B)

composantes ICS + stretch $\sigma_0=50$



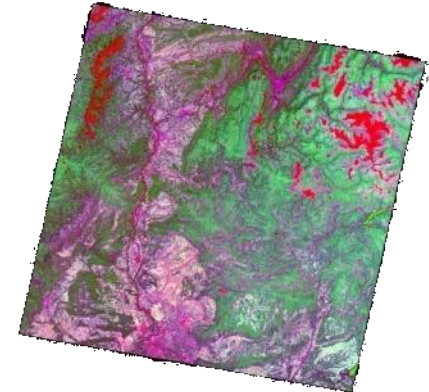
S_{123} (R) C_{123} (V) I_{123} (B)

mélange ICS₁₂₃ et ICS₄₅₇

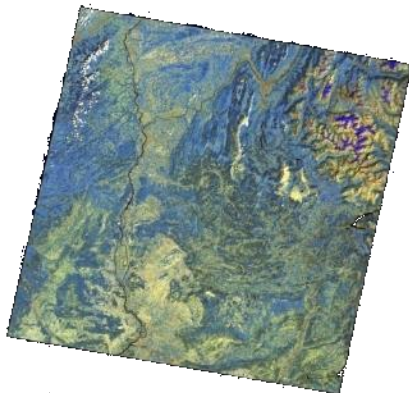


S_{457} (R) I_{457} (V) I_{123} (B)

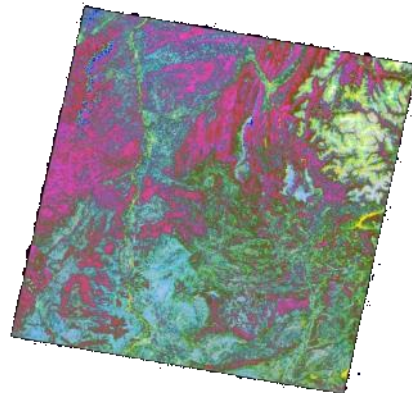
originale + composantes ICS



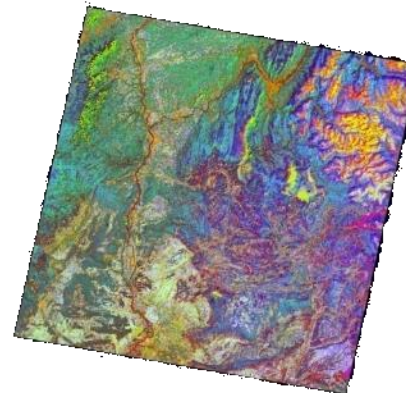
3 (R) C_{123} (V) S_{123} (B)



7 (R) 5 (V) 4 (B)



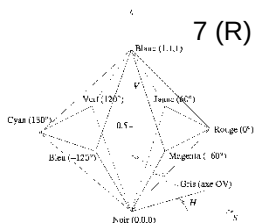
S_{457} (R) C_{457} (V) I_{457} (B)



C_{457} (R) I_{457} (V) S_{123} (B)



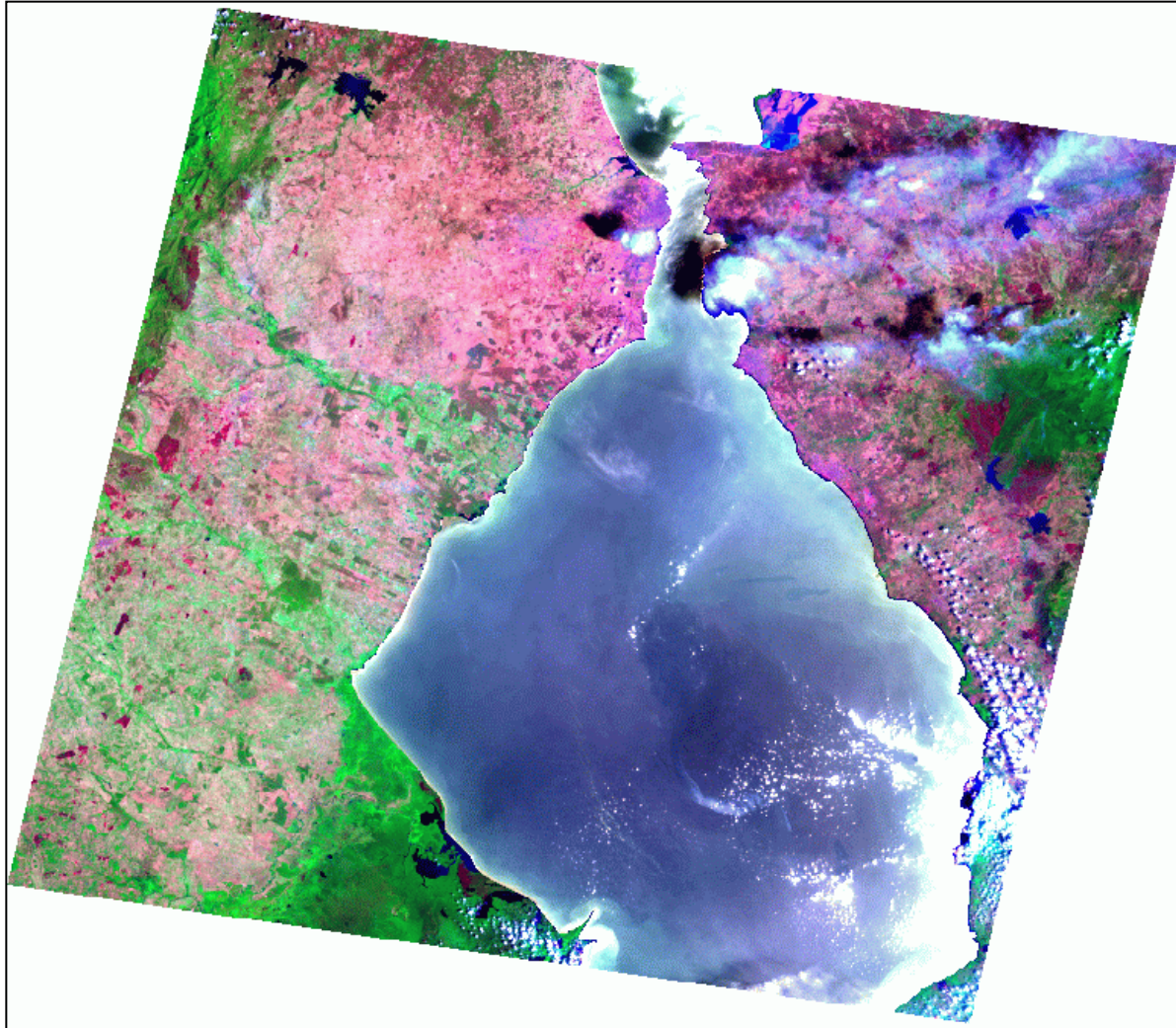
7 (R) I_{457} (V) 5 (B)





Compositions colorées par zone

terre: 7 4 2
mer : 3 2 1



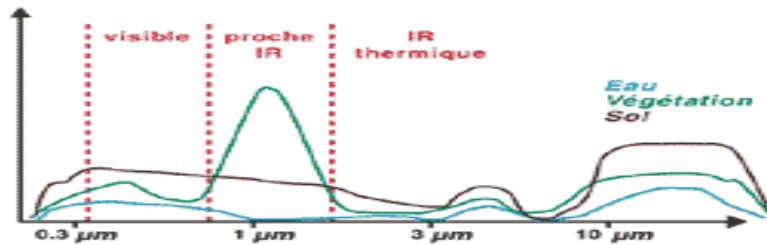


- ✱ Ratios et indices normalisés
 - ▣ Principe – Exploiter la diversité des signatures spectrales





✪ Principe – Exploiter la diversité des signatures spectrales



Exemple: Landsat TM

$$NDVI_{TM} = \frac{TM4 - TM3}{TM4 + TM3}$$

$$NDVI = \frac{IR - R}{IR + R}$$

<http://telsat.belspo.be/beo/fr/guide/index.htm>



A FAIRE

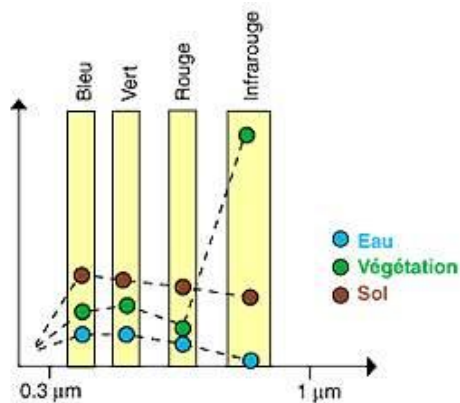
Indice de végétation

NDVI : Normalised Difference Vegetation Index

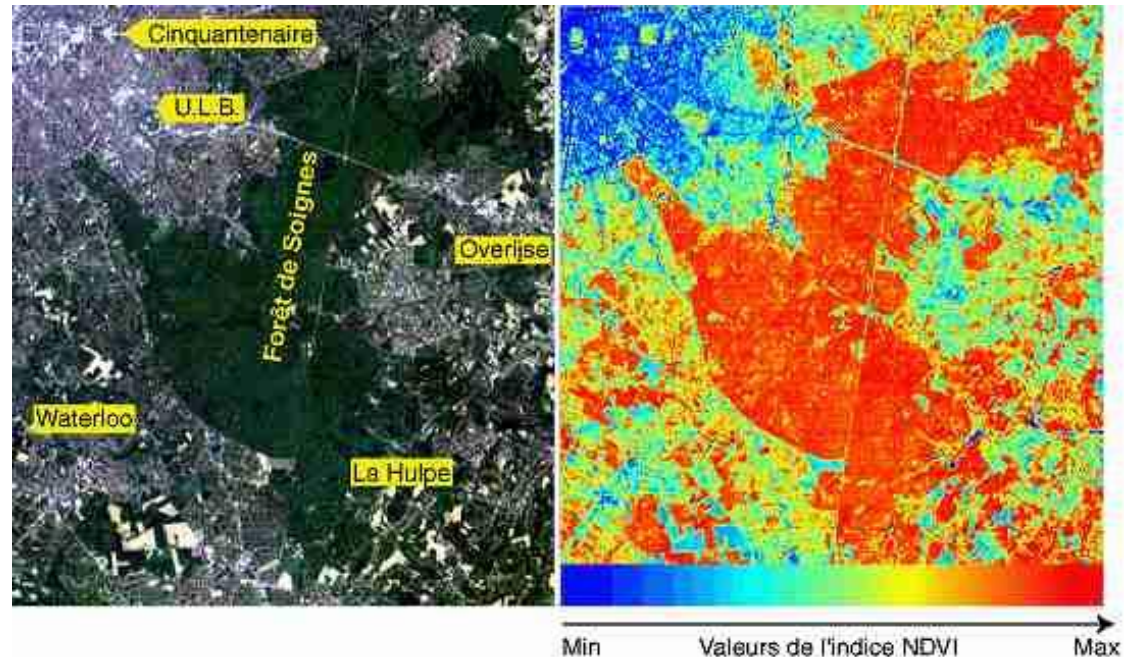
$$NDVI = \frac{IR - R}{IR + R}$$

Exemple: Landsat TM

$$NDVI_{TM} = \frac{TM4 - TM3}{TM4 + TM3}$$



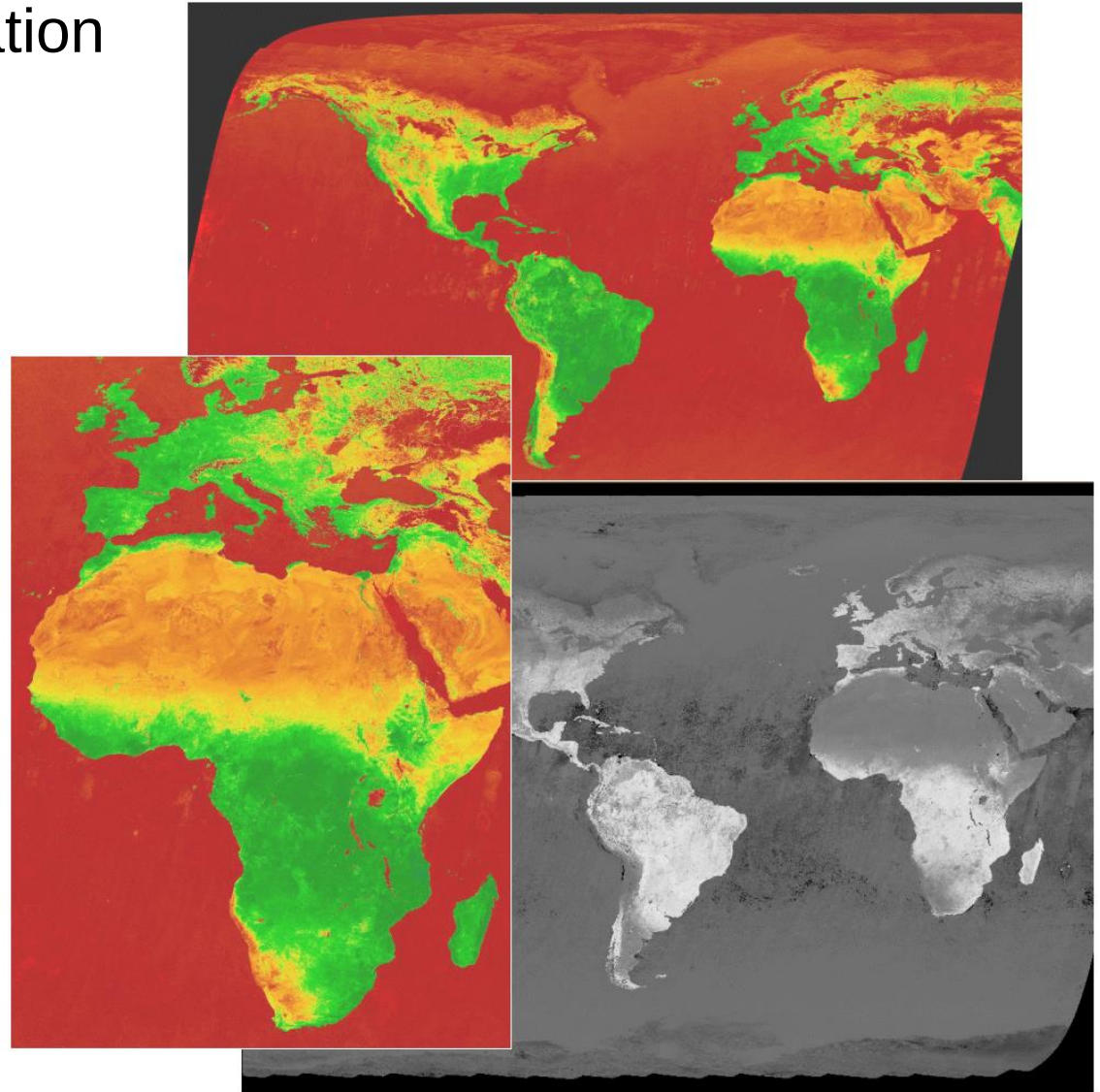
<http://telsat.belspo.be/beo/fr/guide/index.htm>



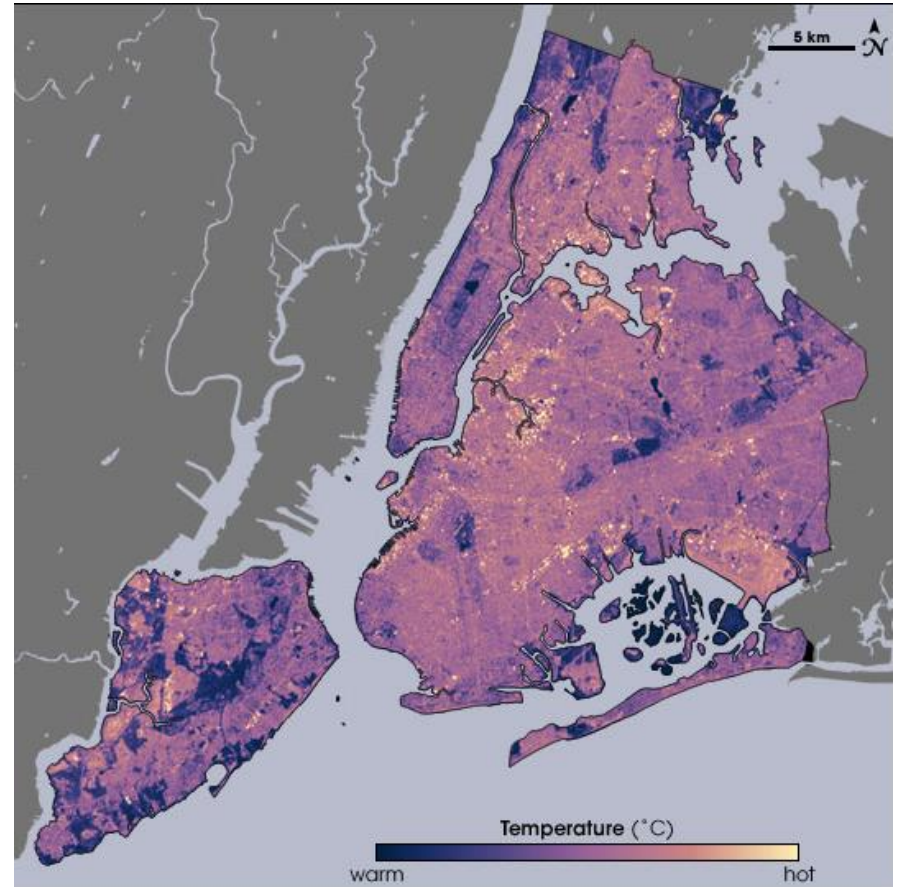
Voir aussi http://en.wikipedia.org/wiki/Normalized_Difference_Vegetation_Index

✚ Indice de végétation Envisat / MERIS

$$NDVI_{MERIS} = \frac{B13 - B7}{B13 + B7}$$



⊕ Indice de végétation et température - Landsat ETM+



New-York – Été 2002

http://earthobservatory.nasa.gov/Newsroom/NewImages/images.php3?img_id=17354



⊕ Indice d'humidité

NDMI : Normalised Difference Moisture Index

$$NDMI = \frac{NIR - MIR}{NIR + MIR}$$

Exemple: Landsat TM

$$NDMI_{TM} = \frac{TM4 - TM5}{TM4 + TM5}$$



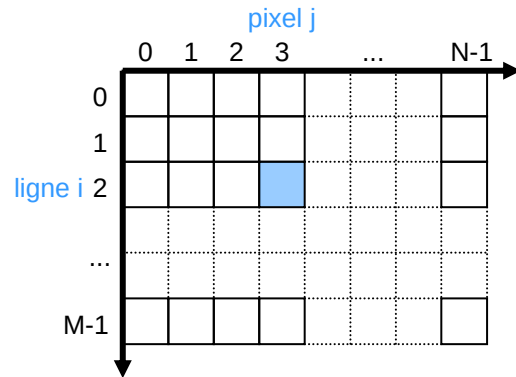
✚ Distributions et statistiques

- ✚ notion de distribution radiométrique
- ✚ background et image
- ✚ moyenne / variance / écart-type
- ✚ histogrammes / skewness / kurtosis
- ✚ distributions et populations - classification
- ✚ indice de végétation – indice d'humidité
- ✚ histogramme cumulé

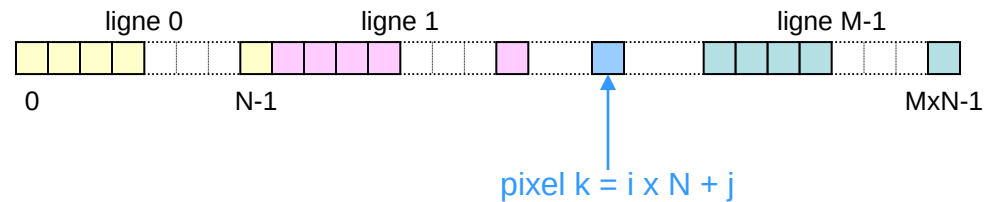


Notion de « distribution radiométrique »

Représentation à 2 dimensions



Représentation à 1 dimension



« Fonction image » ou « distribution radiométrique »

$R(i,j)$, $i=0..(M-1)$, $j=0..(N-1)$

$\forall i=0..(M-1)$, $\forall j=0..(N-1)$,

$R(i,j) \in [0, 2^d - 1]$

avec d: nombre de bits par pixels

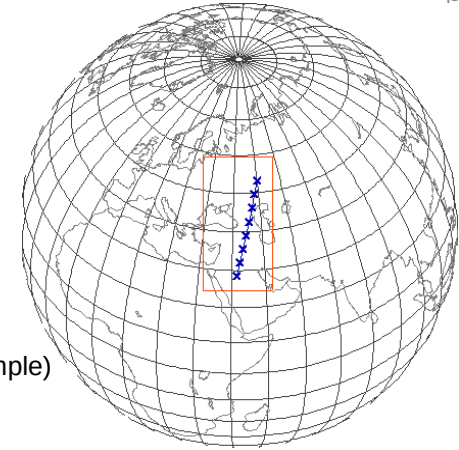
d = 8 bits
dans le cours
 $\Rightarrow [0, 255]$

représentation adoptée
dans le cours

$R(k)$, $k=0..(M \times N - 1)$

D'un point de vue statistique, $R(i,j)$ est un échantillon d'une variable aléatoire réalisée sur l'intervalle $[0, 2^d - 1]$

✚ Background et image



- pas de background
- pixel image $R(i,j) \in [0,255]$
- background de valeur 0 (par exemple)
- pixel image $R(i,j) \in [1,255]$

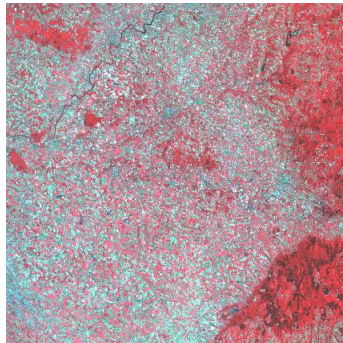
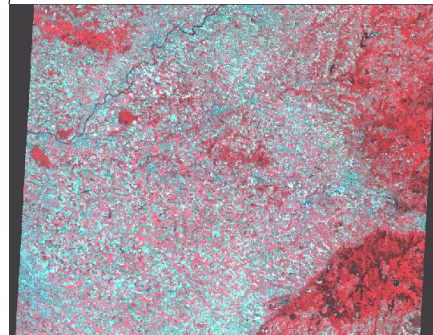
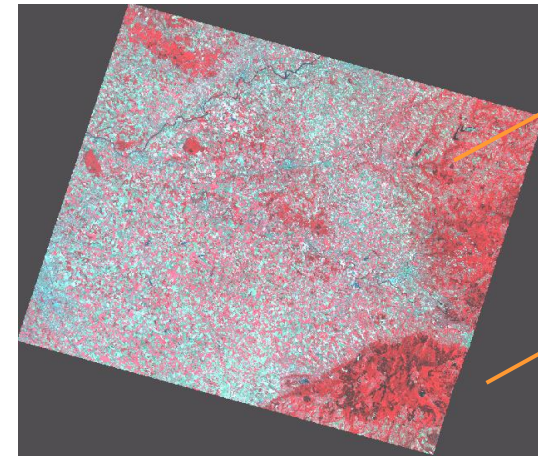


image acquise par le
satellite SPOT



correction des effets :
- panoramique,
- de sphéricité et
- de rotation de la Terre



mise en projection cartographique

pixels
image

pixels de
background
(ou padding)

Ne pas comptabiliser les pixels de background dans les statistiques !!!

Information relative à une image:

-format, -taille, -nombre bits par pixel, **-présence background, -valeur background**

⊕ Moyenne

$$\bar{m} = \frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} R(i, j)$$

mesure la luminosité



girl.r

girl.g

girl.b



m = 180,22

σ = 49,05

m = 99,05

σ = 52,88

m = 105,41

σ = 34,06

⊕ Variance

$$V = \frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} [R(i, j) - \bar{m}]^2$$

$$V = \frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (R(i, j))^2 - (\bar{m})^2$$

mesure la dispersion des
valeurs (contraste)

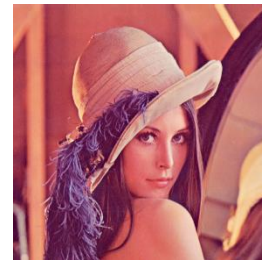
⊕ Écart-type

$$\sigma = \sqrt{V} = \sqrt{\frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (R(i, j))^2 - (\bar{m})^2}$$

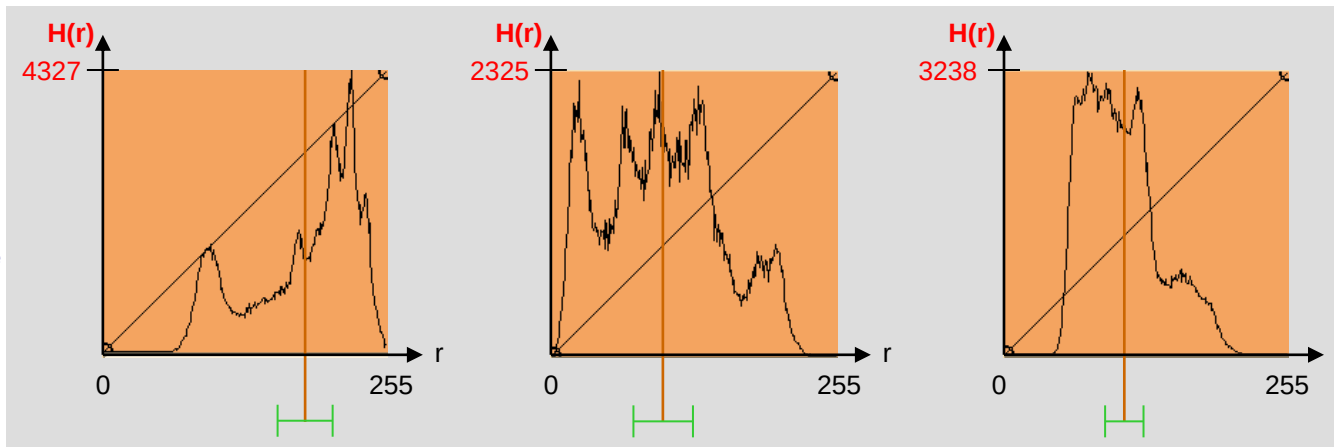
Histogramme

$$\forall r = 0 \dots 2^d - 1, H(r) = \text{Card} \left(\{ R(i,j)=r, i=0..(M-1), j=0..(N-1) \} \right) \quad \text{avec } d: \text{ nombre de bits par pixels}$$

$H(r)$
Occurrences de la
radiométrie r dans
l'image entière



affichage calibré
sur le maximum
de l'histogramme
($\max(H(k))$)



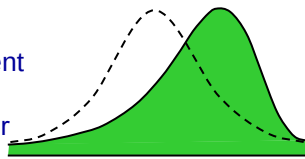


• Skewness et Kurtosis

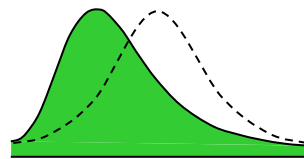
$$skewness = \frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left[\frac{R(i, j) - \bar{m}}{\sigma} \right]^3$$

$$kurtosis = \frac{1}{M \times N} \times \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left[\frac{R(i, j) - \bar{m}}{\sigma} \right]^4 - 3$$

Mesure le balancement
(la symétrie) de
l'histogramme autour
de sa moyenne



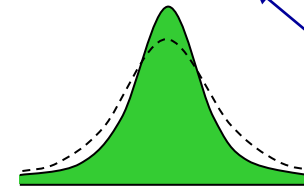
skewness < 0



skewness > 0



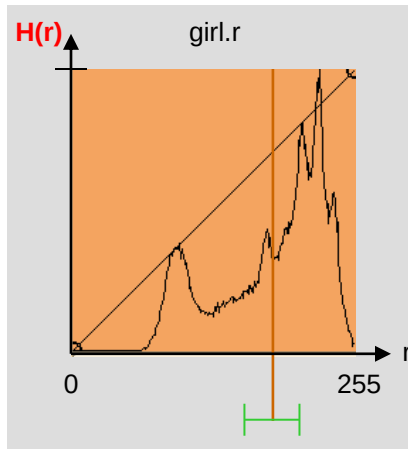
kurtosis < 0



kurtosis > 0

Mesure l'aplatissement
de l'histogramme par
rapport à la
«distribution normale»
de même moyenne et
écart-type

$$\frac{1}{\sigma \times \sqrt{2\pi}} \times e^{-\frac{(R(i, j) - \bar{m})^2}{2\sigma^2}}$$

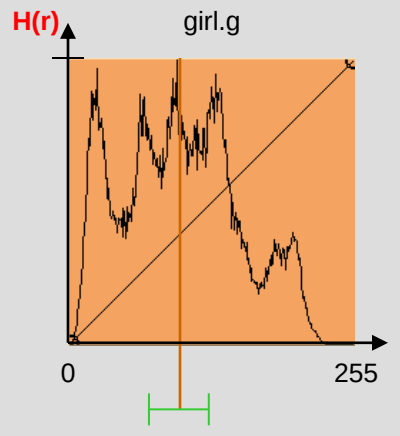


$m = 180,22$

$\sigma = 49,05$

skewness = -0.701

kurtosis = -0.783



$m = 99,05$

$\sigma = 52,88$

skewness = +0.223

kurtosis = -0.755



$m = 105,41$

$\sigma = 34,06$

skewness = +0.680

kurtosis = -0.169



Exemple 2 – Roissy (SPOT XS)

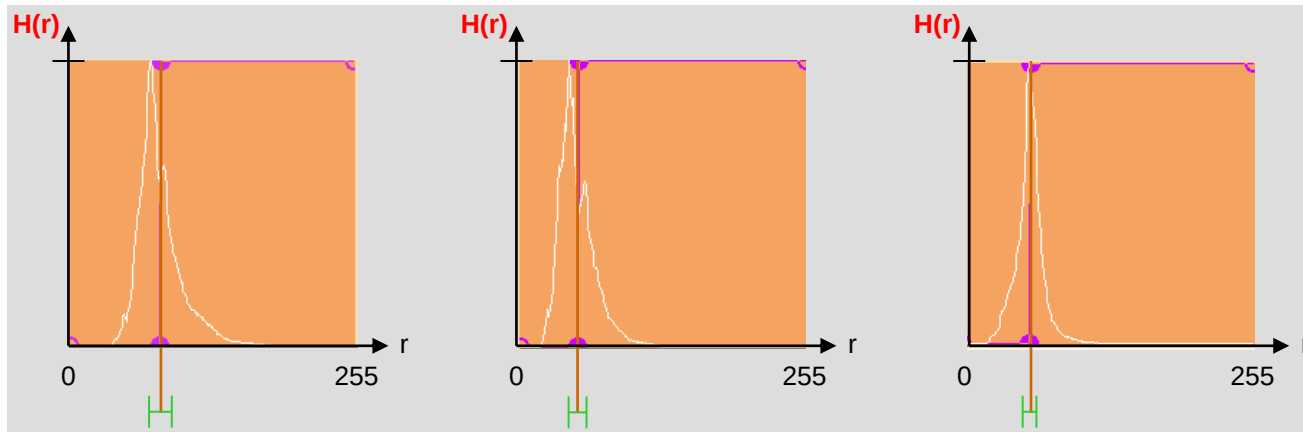
roissy.1



roissy.2



roissy.3



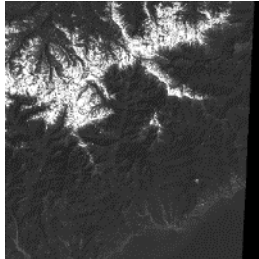
$m = 81.243$
 $\sigma = 19.546$
skewness = +1.255
kurtosis = +2.423

$m = 50.899$
 $\sigma = 15.791$
skewness = +1.077
kurtosis = +1.755

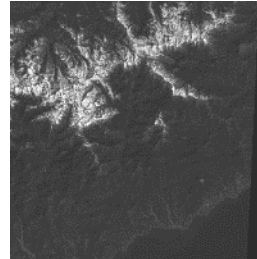
$m = 59.202$
 $\sigma = 11.888$
skewness = +0.413
kurtosis = +2.249

Exemple 3 – San-Remo (Landsat TM)

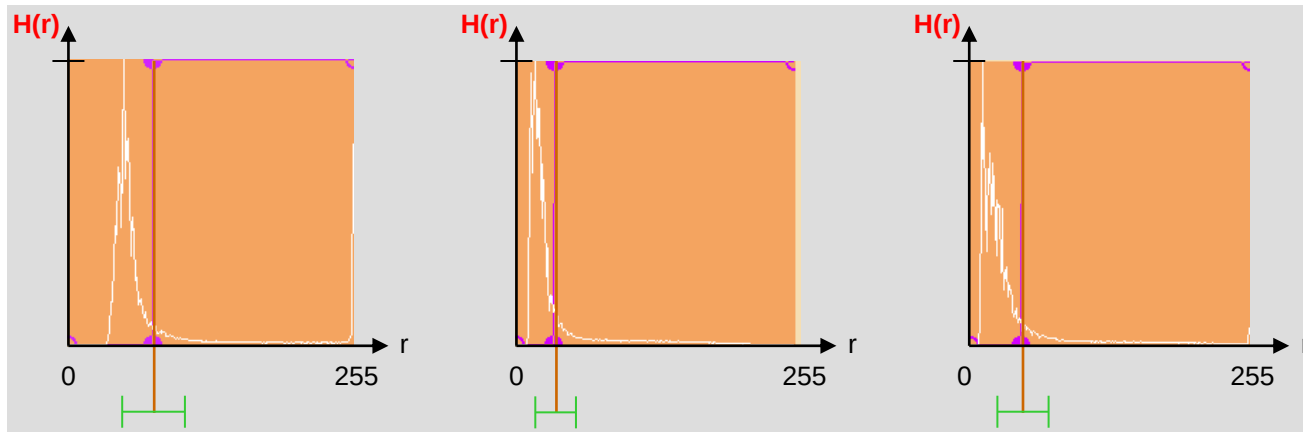
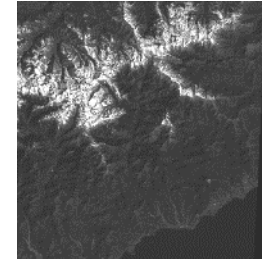
san-remo.1



san-remo.2



san-remo.3

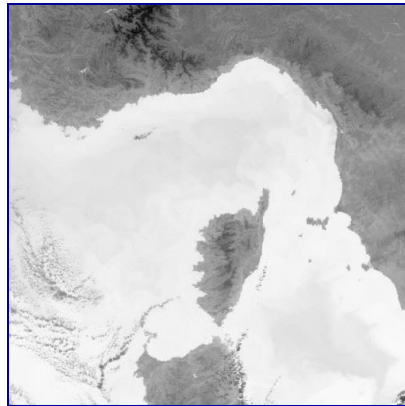


$m = 75.445$
 $\sigma = 55.984$
skewness = +2.359
kurtosis = +4.339

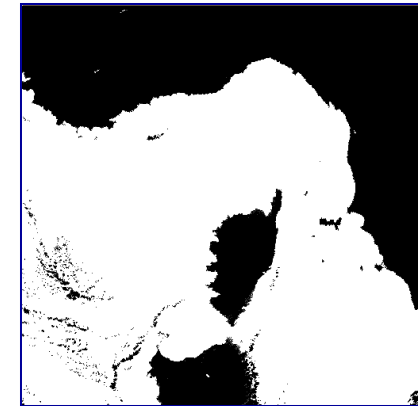
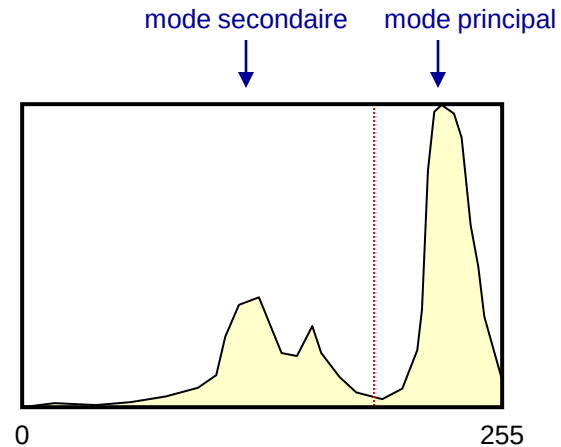
$m = 34.901$
 $\sigma = 36.624$
skewness = +2.891
kurtosis = +8.276

$m = 39.810$
 $\sigma = 45.782$
skewness = +2.735
kurtosis = +7.344

⊕ Distributions et populations



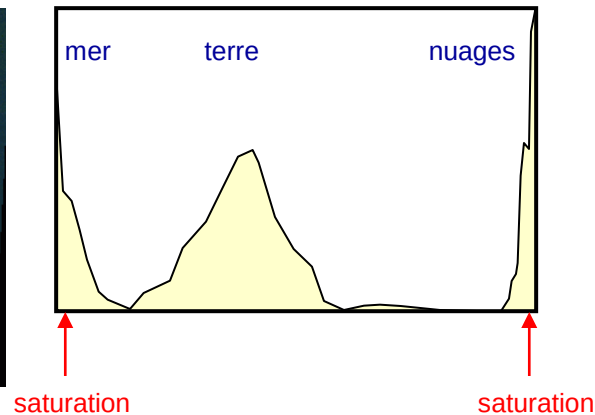
ERS - ATSR



séparation en 2 classes à partir
d'un canal

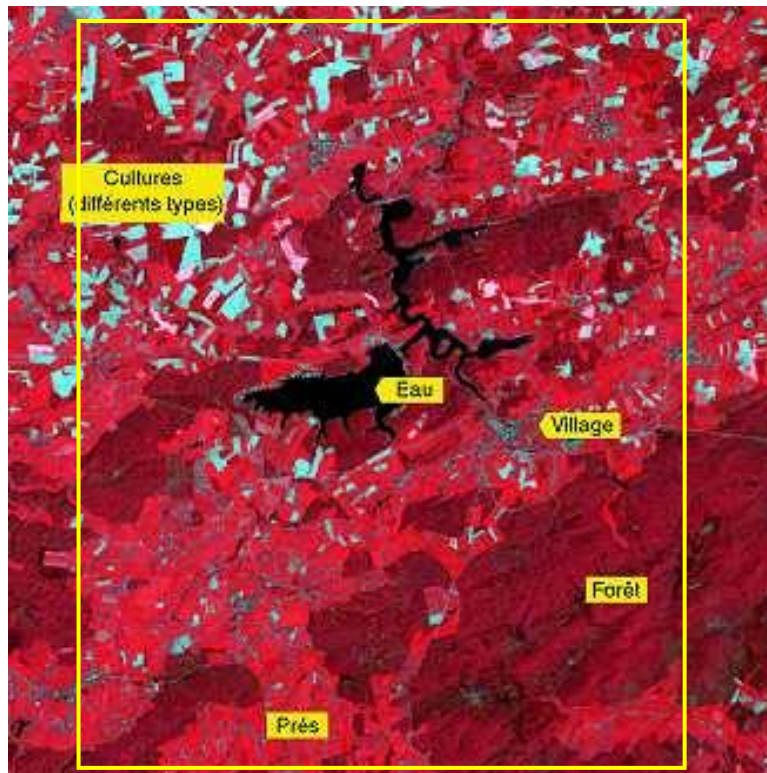


Landsat TM



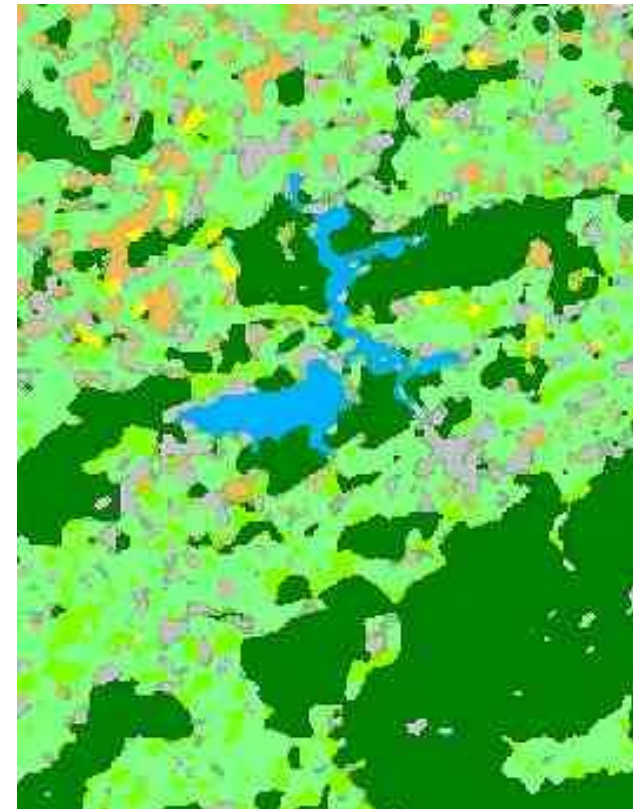
Classification

	Eau
	Voirie, urbain, sols nus
	Forêt
	Herbages 1
	Herbages 2
	Cultures 1
	Cultures 2



Landsat TM (sud de Bruxelles)

<http://telsat.belspo.be/beo/fr/guide/index.htm>



résultat d'une classification à partir de plusieurs canaux

Histogramme cumulé

$\forall r = 0 \dots 2^d - 1, H_C(r) = \text{Card} \left(\{R(i,j) \leq r, i=0..(M-1), j=0..(N-1)\} \right)$ avec d : nombre de bits par pixels

Définition

$$H_C(r) = \sum_{i=0}^r H(i)$$

$$H_C(r) = H_C(r-1) + H(r)$$

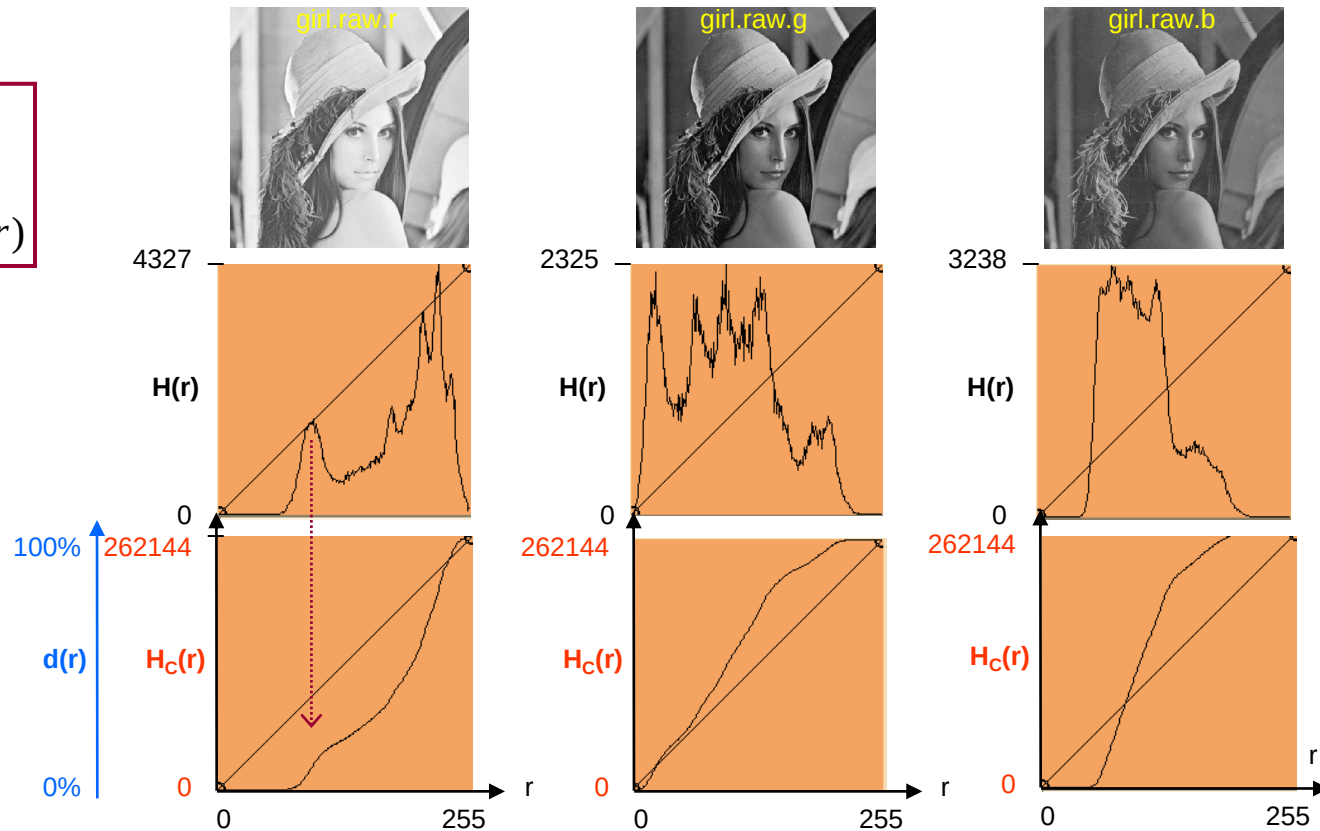
Propriété

$$H_C(255) = NP$$

Fonction de
distribution image

$$d(r) = \frac{H_C(r)}{NP}$$

$$d(r) \in [0,1]$$





✪ Traitement radiométrique global par transformation d'histogramme

- ✦ seuillage
- ✦ stretching linéaire
- ✦ contrôler la luminosité / le contraste
- ✦ stretching automatique
- ✦ fonction identique
- ✦ fonction inverse
- ✦ fonction passe-bande
- ✦ stretching linéaire défini par morceaux
- ✦ fonction gamma
- ✦ adaptation à un modèle analytique
- ✦ adaptation à une image
- ✦ fonctions différentes selon les canaux

Seuillage



Représentation mathématique

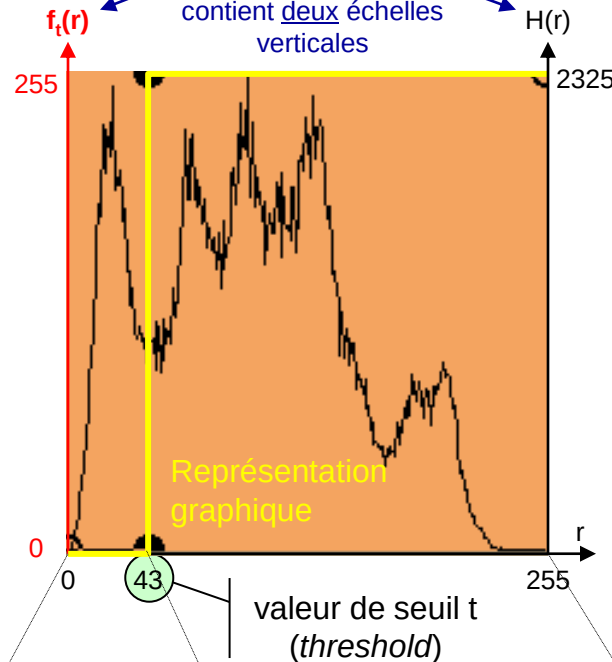
$$f_t(r) = \begin{cases} 0 & \text{si } r \leq t \\ 255 & \text{si } r > t \end{cases}$$

LUT de la
fonction f_t

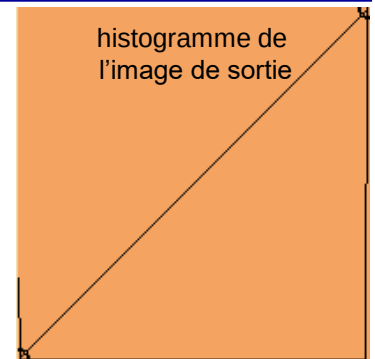
Représentation informatique

0	0	...	0	0	255	...	255	...	255	255
0	1		42	43	44		r		254	255

Attention: le graphique
contient deux échelles
verticales



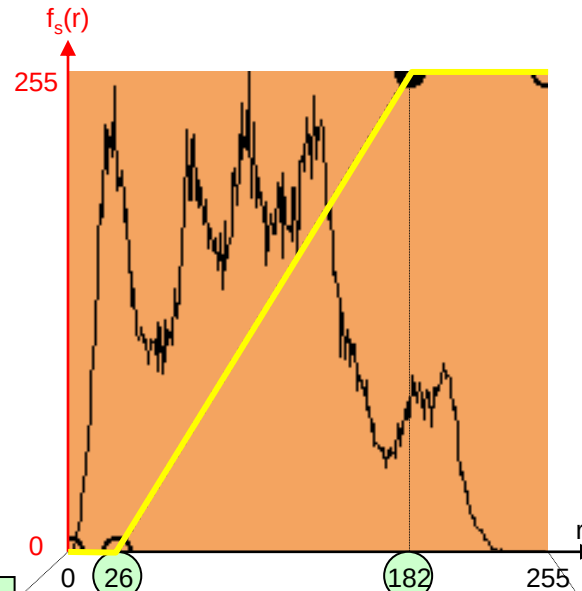
histogramme de
l'image de sortie



Représentation discrète (points par points) :

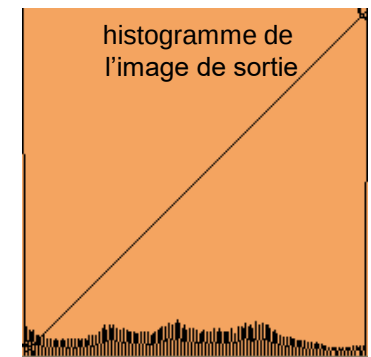
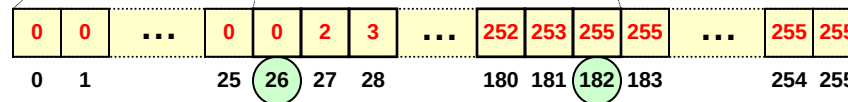
$$\{ (r_i, f_t(r_i)), i=1..4 \} = \{ (0,0) ; (43,0) ; (44,255) ; (255,255) \}$$

✱ Stretching linéaire (étirement linéaire de la dynamique)



$$f_s(r) = \begin{cases} 0 & \text{si } r < a \\ \text{Arrondi}\left(\frac{255 \times (r - a)}{(b - a)}\right) & \text{si } a \leq r \leq b \\ 255 & \text{si } r > b \end{cases}$$

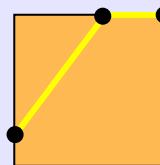
LUT de la
fonction f_s



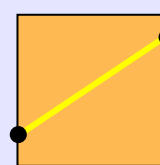
4 points

{ (0,0) ; (a,0) ; (b,255) ; (255,255) }

ou 3 points



ou 2 points





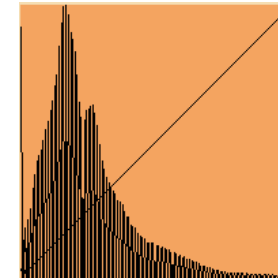
Contrôler la luminosité

image originale

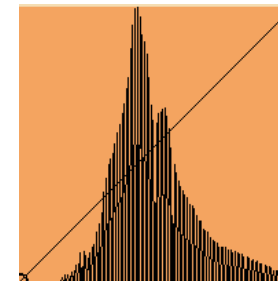


(roissy.1)

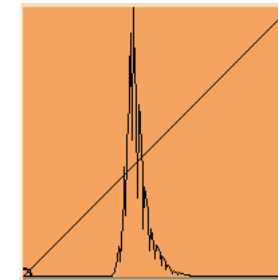
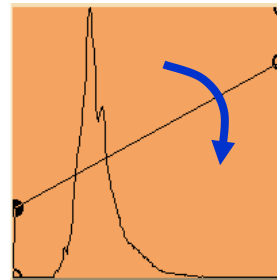
Contrôler le contraste



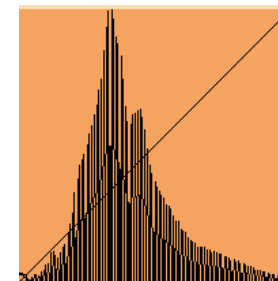
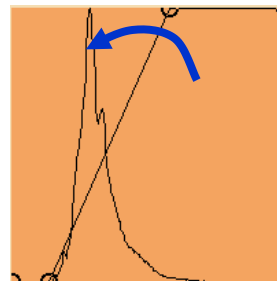
diminuer la
luminosité



augmenter la
luminosité



diminuer le
contraste

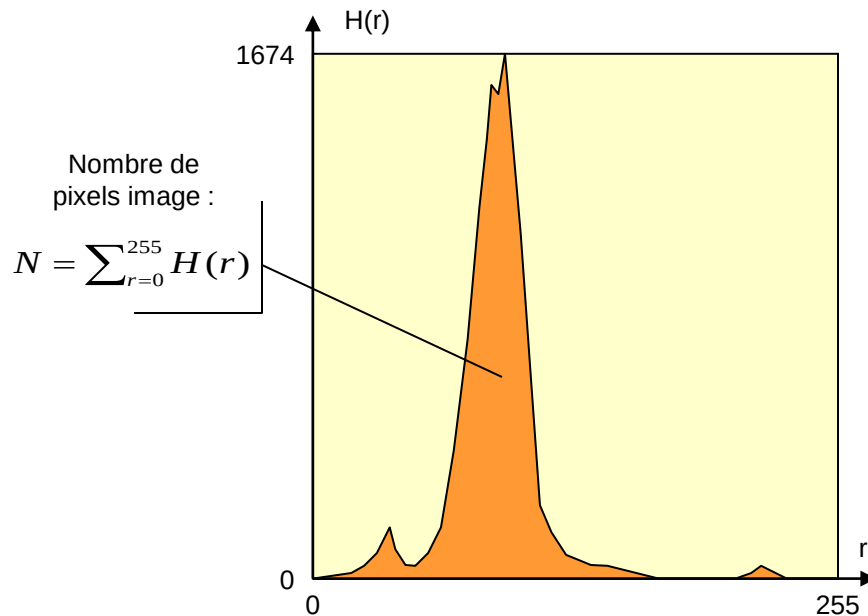


augmenter le
contraste

✪ Stretching linéaire automatique

Déterminer automatiquement les bornes a et b du stretching linéaire

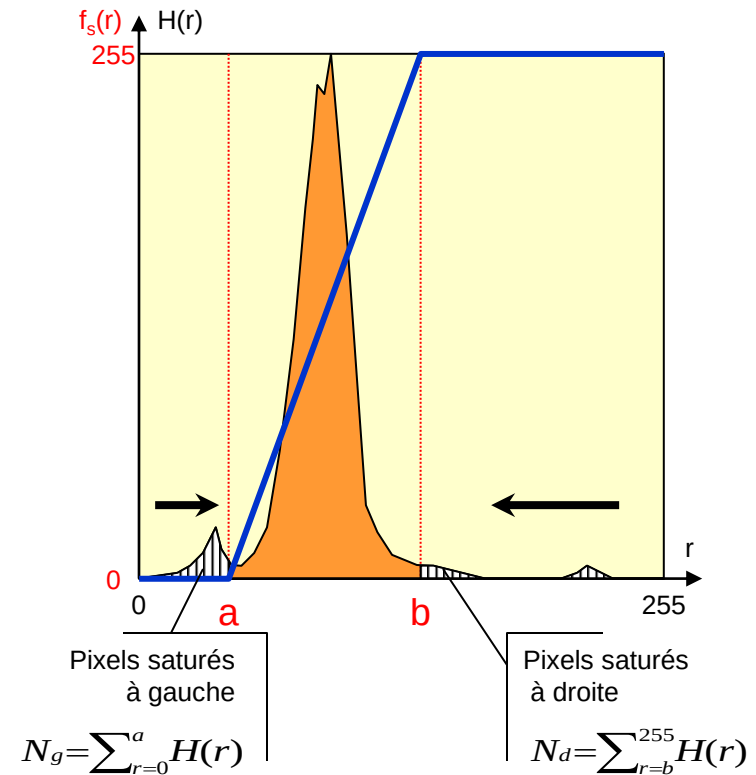
▣ Principe



α_s : Pourcentage de saturation

$N_s = N \times \alpha_s$: Nombre de pixels image saturés

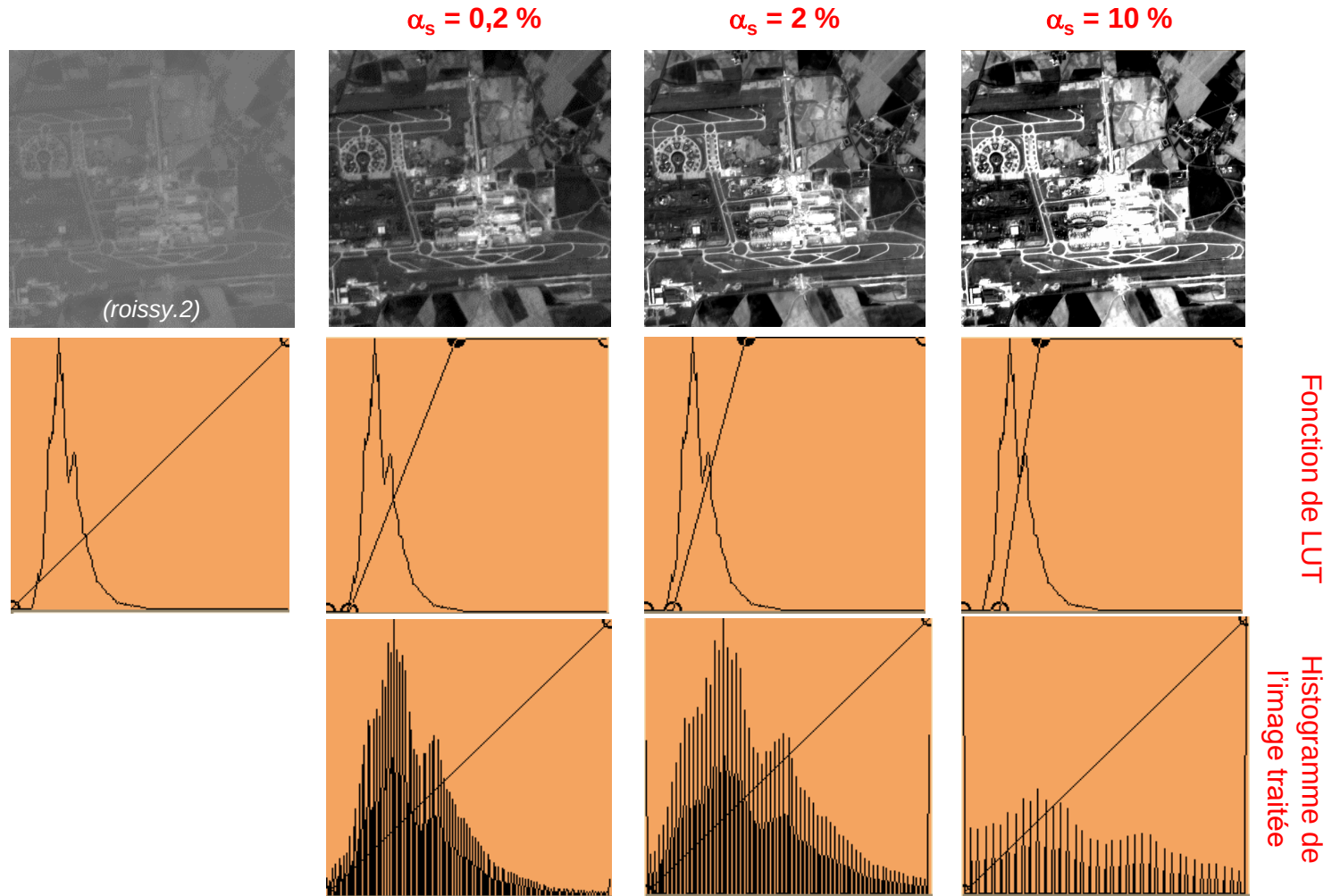
$N_s = N_g + N_d$



2 méthodes:

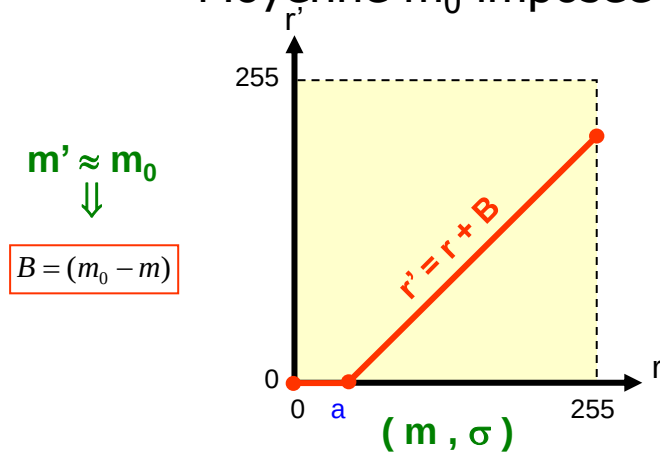
- saturer $N_s/2$ pixels à gauche puis $N_s/2$ pixels à droite
- saturer du côté où l'histogramme est minimal

■ Stretching linéaire automatique - Résultats



✿ Stretching imposé par des statistiques de sortie

▣ Moyenne m_0 imposée



roissy.2 (original)



$m = 50.9$
 $\sigma = 15.8$

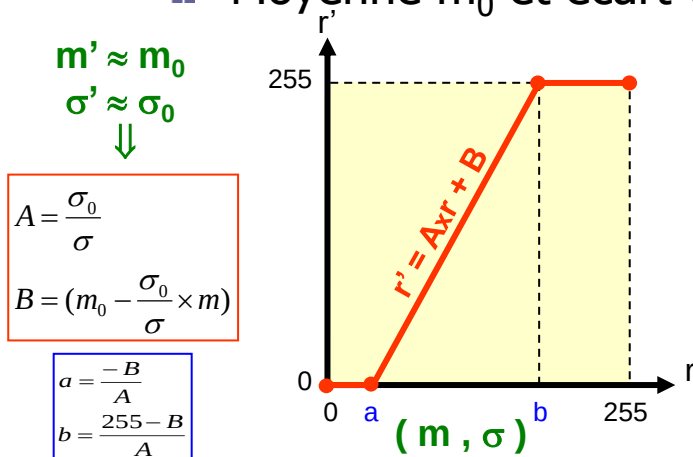


$m_0 = 128$
 σ inchangé



$m_0 = 200$
 σ inchangé

▣ Moyenne m_0 et écart-type σ_0 imposés



⇒ Lien « [Stretching local imposé par des statistiques de sortie](http://www-igm.univ-mlv.fr/~riazano/) »



$m_0 = 128$
 $\sigma_0 = 40$



$m_0 = 128$
 $\sigma_0 = 60$



■ Moyenne m_0 et écart-type σ_0 imposés – Exemples de compositions colorées (1)

roissy.{1,2,3} – image brute



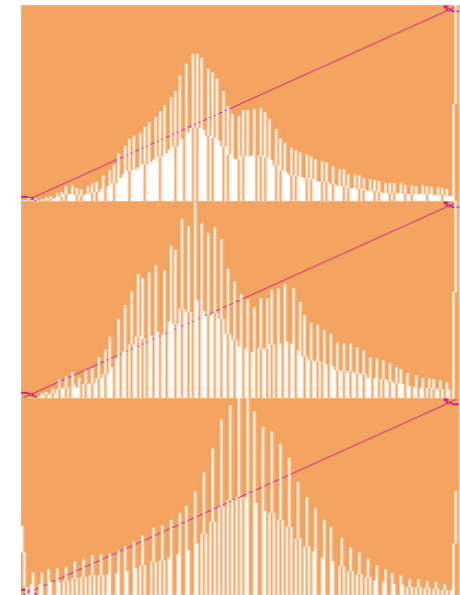
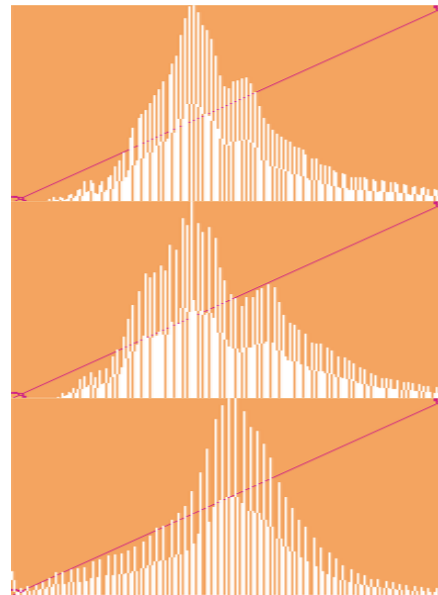
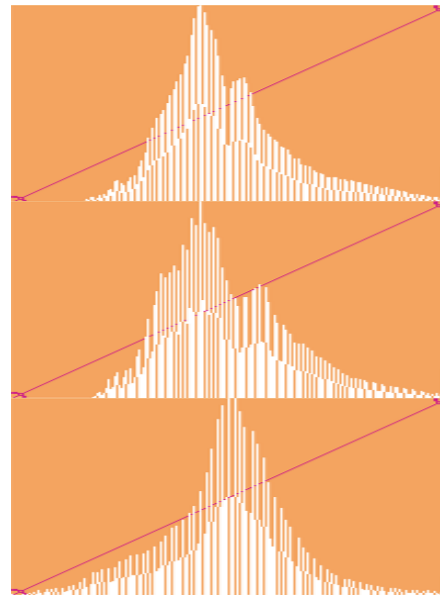
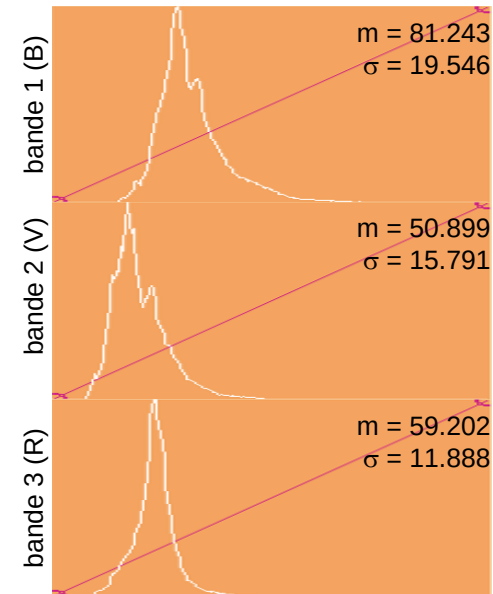
$m_0 = 128 - \sigma_0 = 40$



$m_0 = 128 - \sigma_0 = 50$



$m_0 = 128 - \sigma_0 = 60$

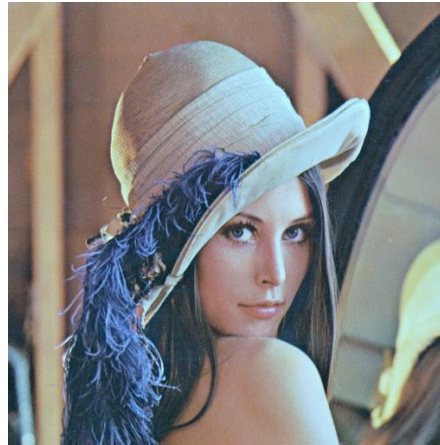


■ Moyenne m_0 et écart-type σ_0 imposés – Exemples de compositions colorées (2)

girl.{1,2,3} – image brute



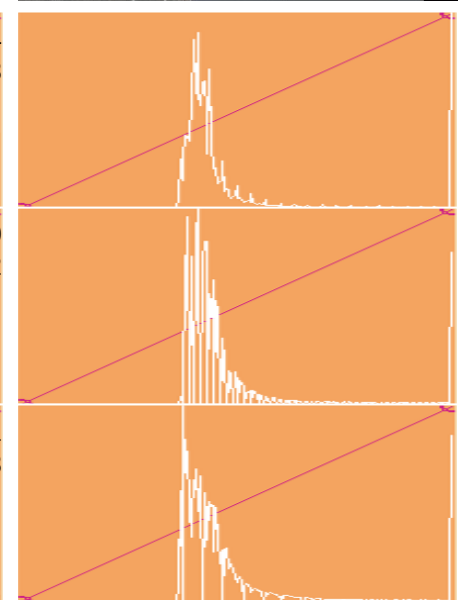
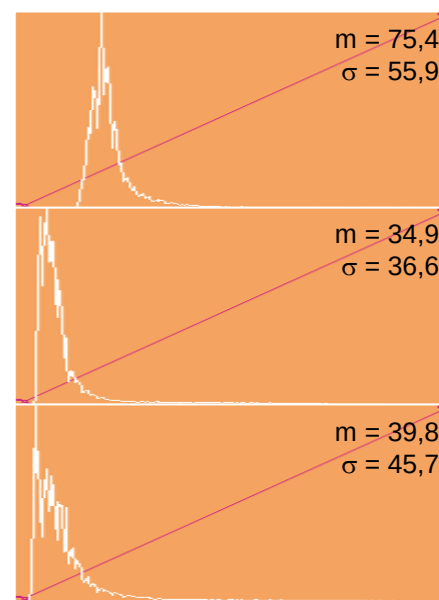
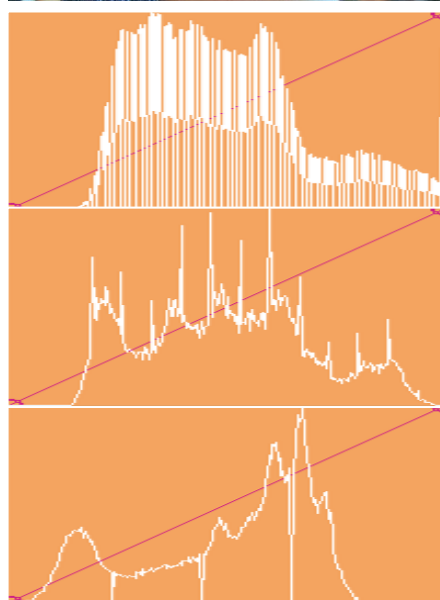
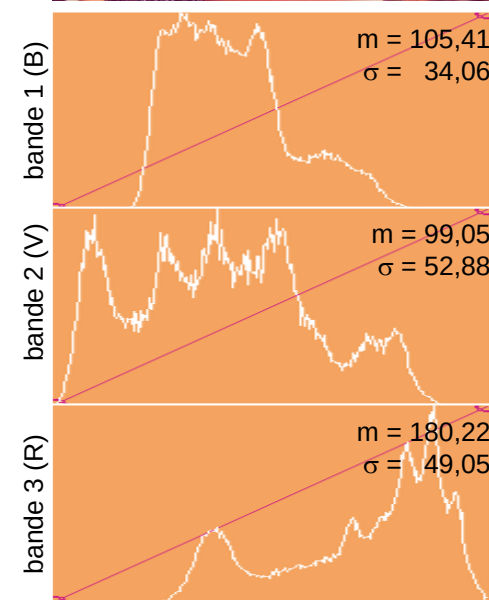
$m_0 = 128$ - $\sigma_0 = 50$



san-remo.{1,2,3} – image brute



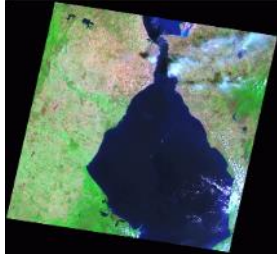
$m_0 = 128$ - $\sigma_0 = 50$





Stretching linéaire par zones

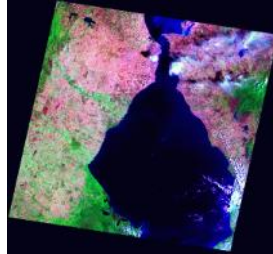
stretching terre + mer



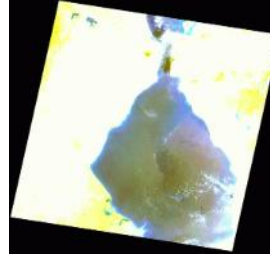
limite terre / mer



stretching terre



stretching mer



bande 2 (B)

a = 51
b = 126

t = 81

a = 60
b = 114

a = 56
b = 78

bande 4 (V)

a = 6
b = 111

t = 32

a = 46
b = 107

a = 8
b = 26

bande 7 (R)

a = 1
b = 144

t = 22

a = 32
b = 115

a = 1
b = 25

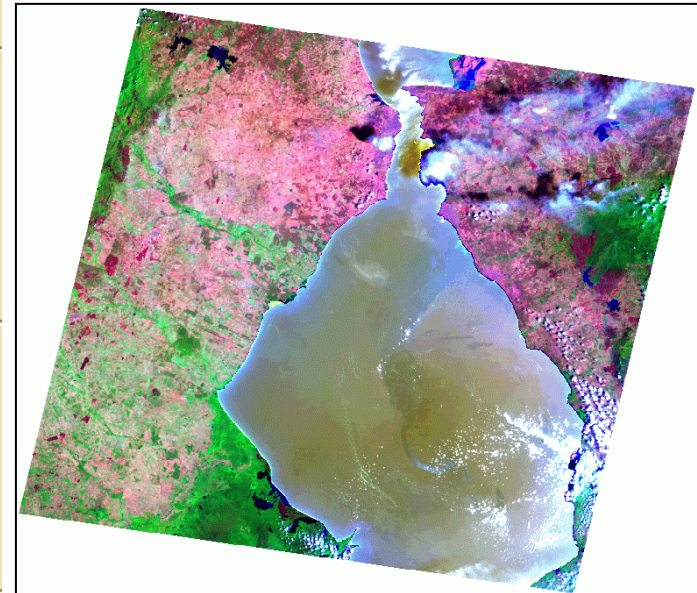
masque terre / mer



masque de terre

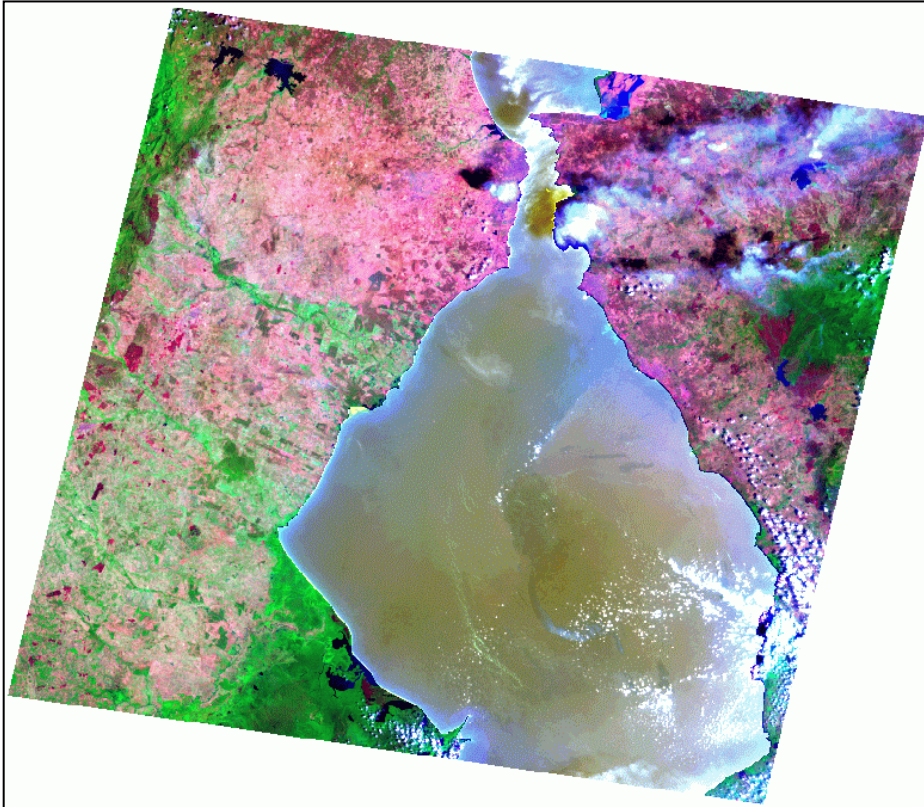


masque de mer



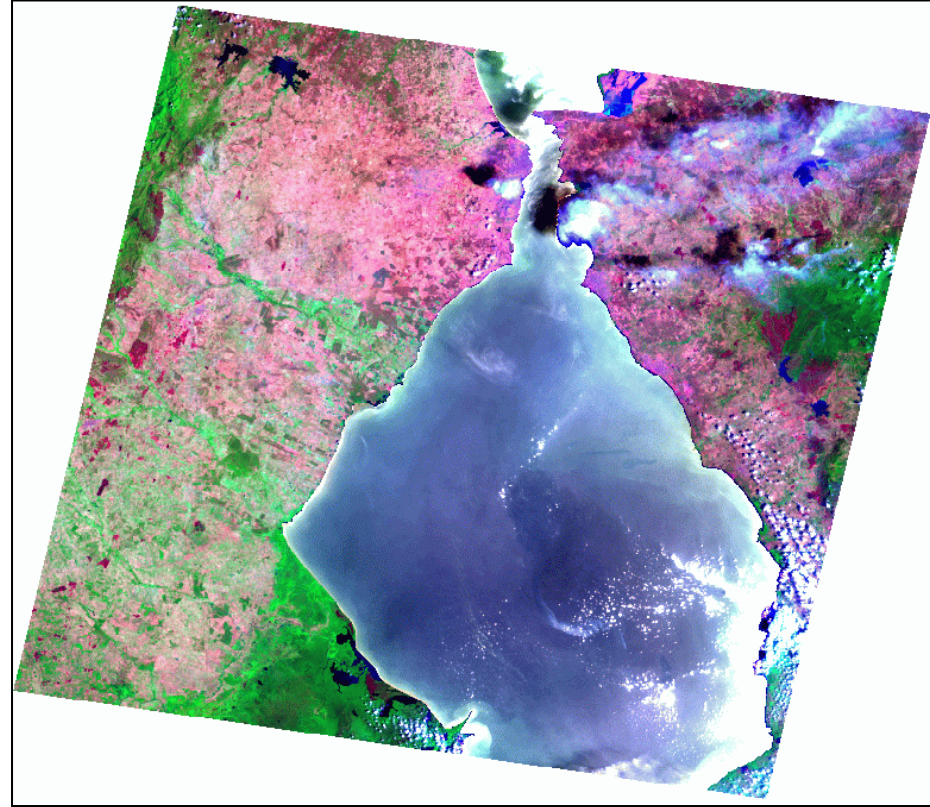
composition de stretchings de terre et de mer

❖ Composition de zones utilisant différentes bandes spectrales Landsat ETM+ - Maracaibo



Même bandes spectrales:

terre: 7 4 2
mer : 7 4 2



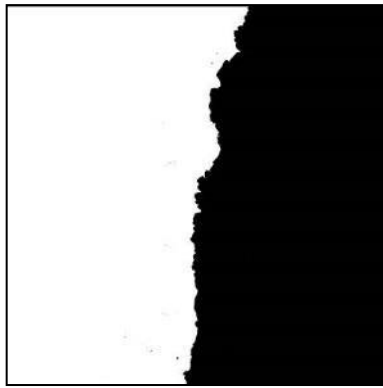
Bandes spectrales différentes:

terre: 7 4 2
mer : 3 2 1

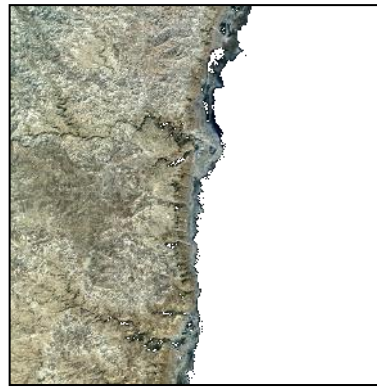
❖ Composition de zones utilisant avec les mêmes bandes spectrales RapidEye – Mer morte



A. stretching de la terre (321)



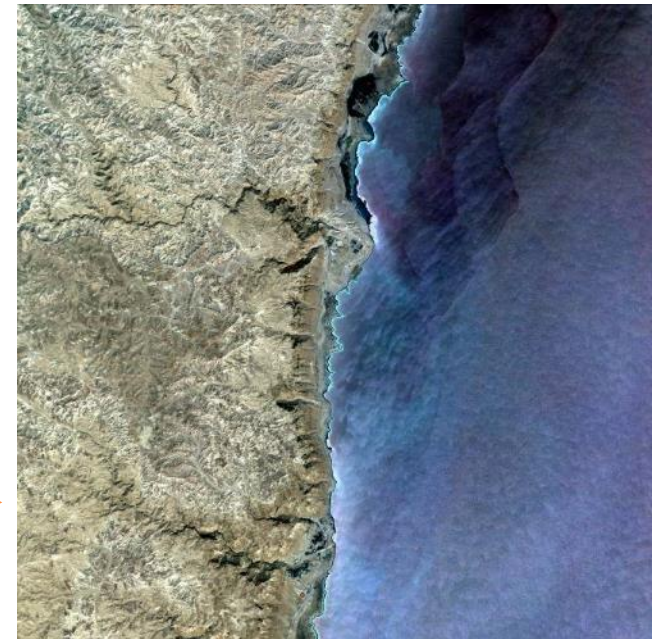
B. seuillage de la bande 3



C. image A masquée par B



D. stretching de la mer (321)



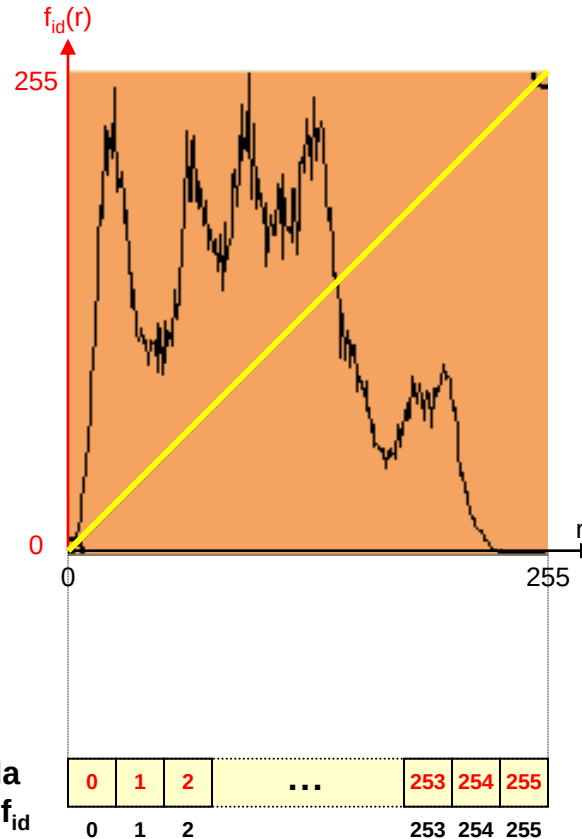
E. composition des images C et D

⊕ Fonction identique



$$f_{id}(r) = r$$

LUT de la
fonction f_{id}



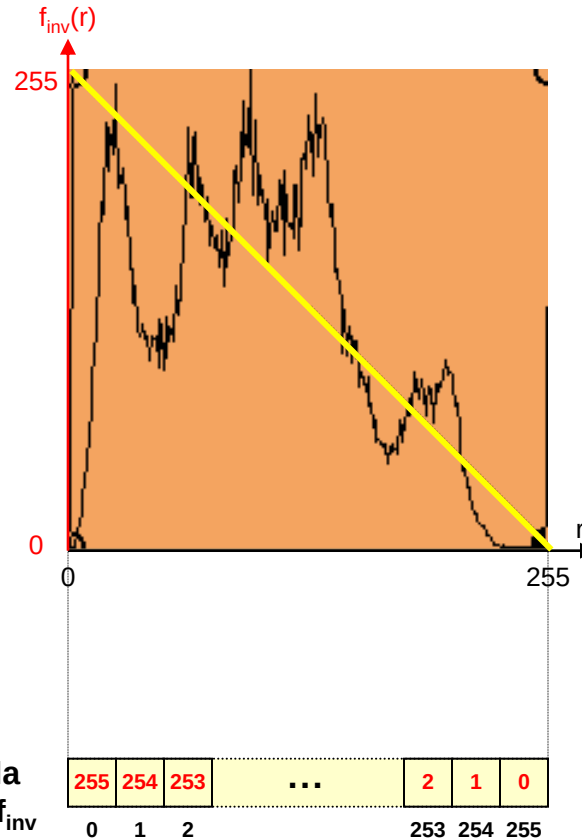
Représentation discrète (points par points) :
 $\{ (r_i, f_i(r_i)), i=1..2 \} = \{ (0,0) ; (255,255) \}$

⊕ Fonction inverse



$$f_{inv}(r) = 255 - r$$

LUT de la
fonction f_{inv}



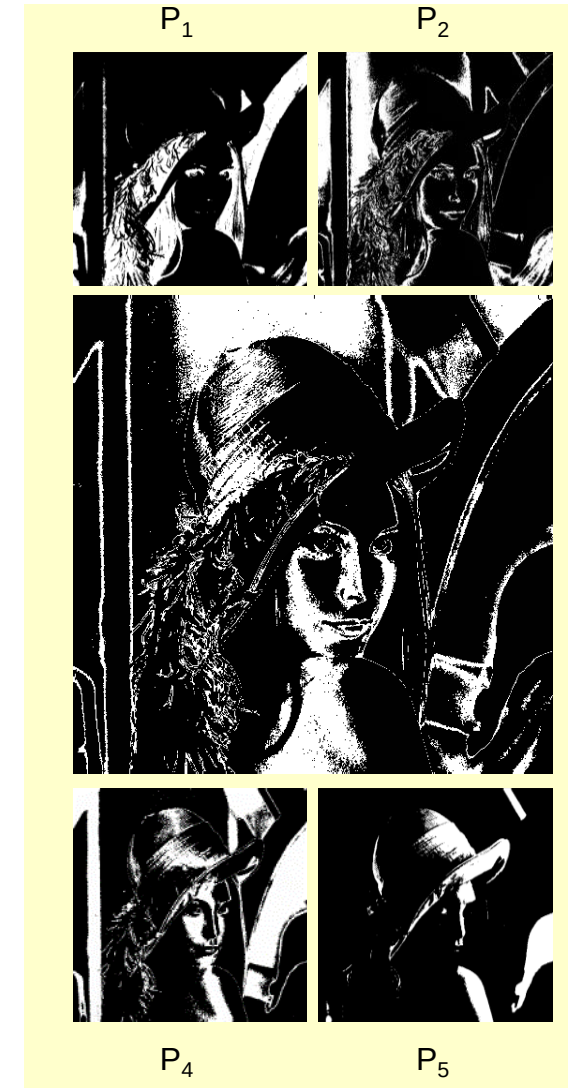
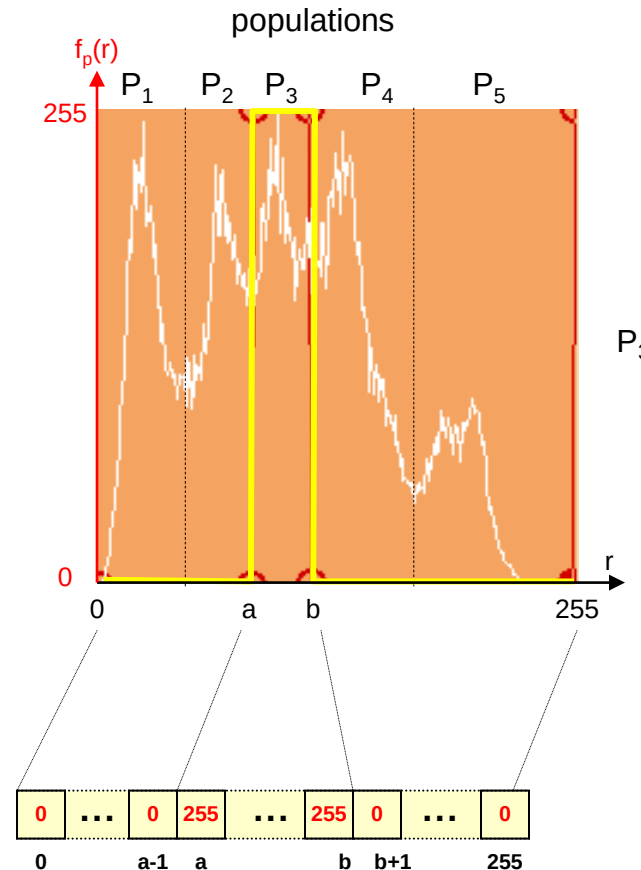
Représentation discrète (points par points) :
 $\{ (r_i, f_i(r_i), i=1..2) \} = \{ (0, 255) ; (255, 0) \}$

Seuillage passe-bande



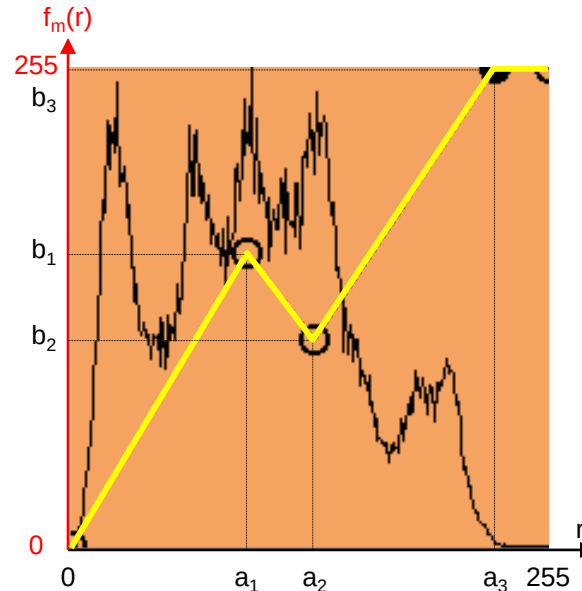
$$f_p(r) = \begin{cases} 0 & \text{si } r < a \\ 255 & \text{si } a \leq r \leq b \\ 0 & \text{si } r > b \end{cases}$$

LUT de la
fonction f_p



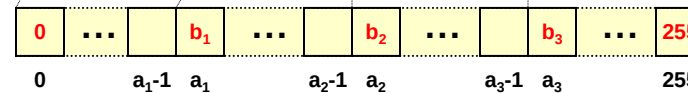
Représentation discrète (points par points) :
 $\{(r_i, f_i(r_i), i=1..6)\} = \{(0,0) ; (a-1,0) ; (a,255) ; (b,255) ; (b+1,0) ; (255,0)\}$

❖ Fonction définie par morceaux



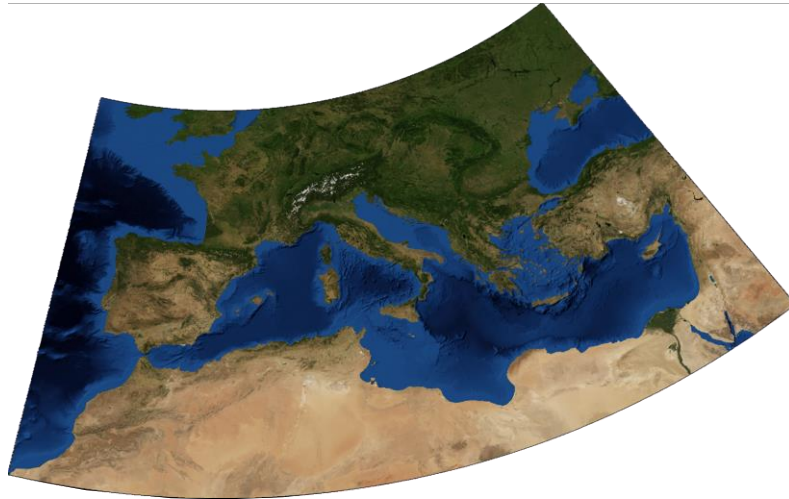
$$f_m(r) = \begin{cases} A \left((b_1 - 0) \times \frac{(r - 0)}{(a_1 - 0)} \right) & \text{si } 0 \leq r < a_1 \\ A \left((b_2 - b_1) \times \frac{(r - a_1)}{(a_2 - a_1)} \right) & \text{si } a_1 \leq r < a_2 \\ A \left((b_3 - b_2) \times \frac{(r - a_2)}{(a_3 - a_2)} \right) & \text{si } a_2 \leq r < a_3 \\ 255 & \text{si } a_3 \leq r < 255 \end{cases}$$

LUT de la
fonction f_m

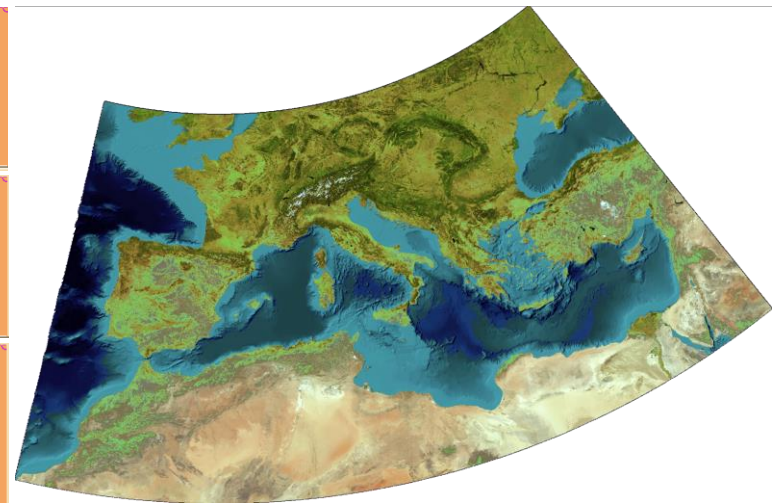
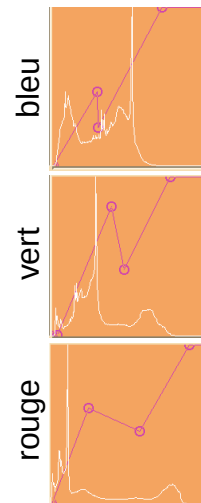
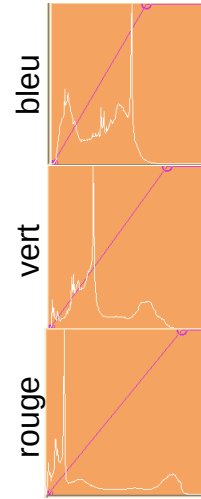


Représentation discrète (points par points) :
n segments $\Rightarrow$ (n+1) points:
 $\{ (a_1, b_1) ; (a_2, b_2) ; (a_{n+1}, b_{n+1}) \}$

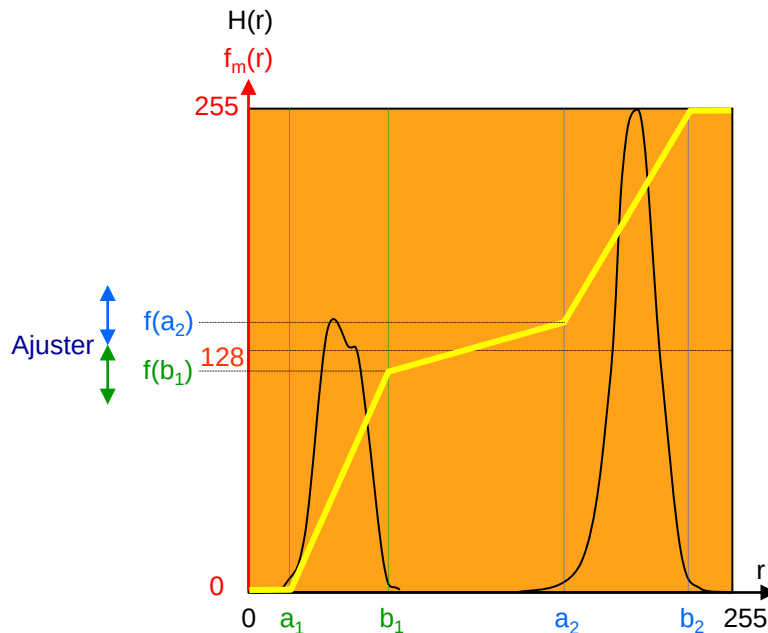
⊕ Fonction définie par morceaux – Exemple MODIS



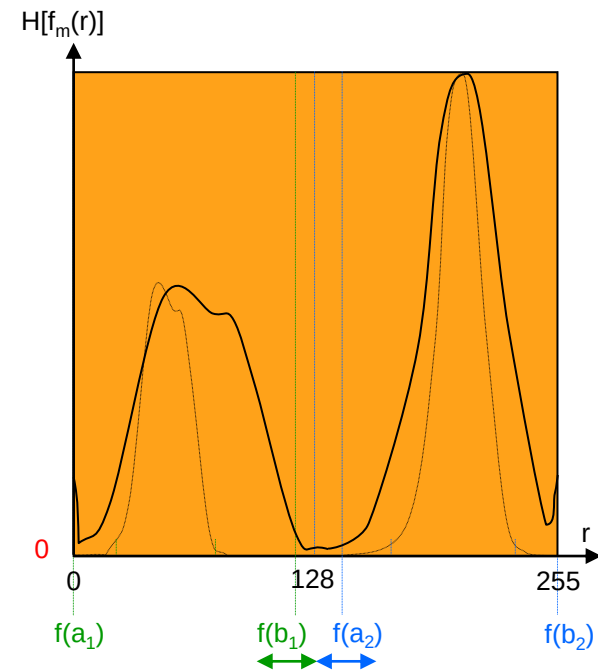
Synthèse MODIS + topo + bathy – Juillet 2004
projection stéréographique



Stretching linéaire par morceaux Cas des histogrammes bi-modaux

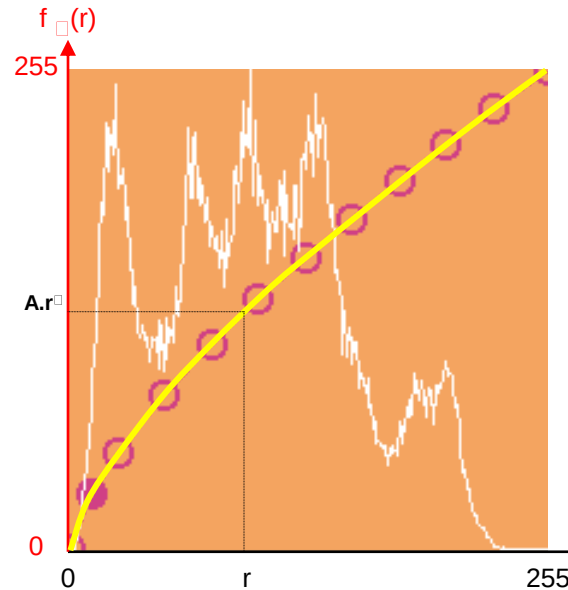


Histogramme de l'image source

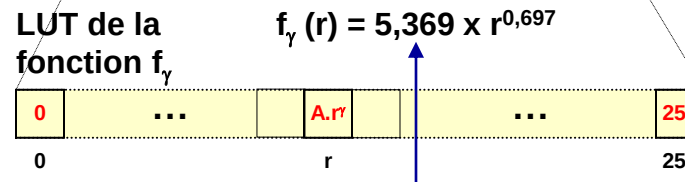


Histogramme de l'image destination

⊕ Fonction gamma

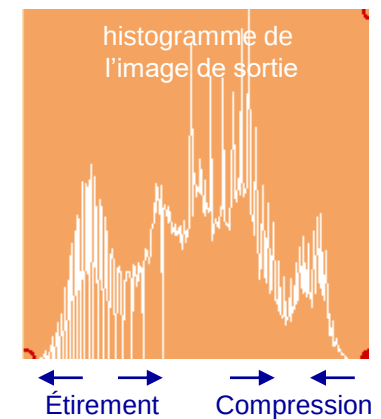


$$f_{\gamma}(r) = A \times r^{\gamma}$$



Représentation discrète (points par points)
≠ fonction continue

Déterminé automatiquement
pour que la moyenne de
l'image de sortie soit à 127,5



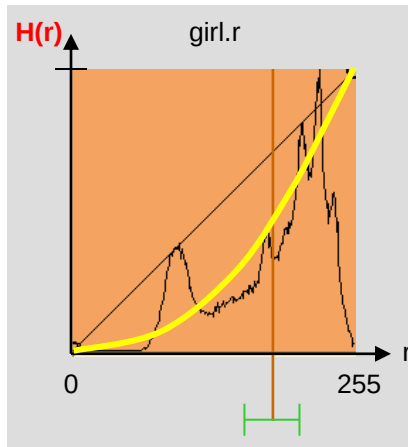


⊕ Fonction gamma Exemple 1 (Léna)



Skewness < 0 $\Rightarrow \gamma > 1$

$$f_\gamma(r) = 0,00081 \times r^{2,891}$$



$m = 180,22$

$\sigma = 49,05$

skewness = -0.701

kurtosis = -0.783

Skewness > 0 $\Rightarrow \gamma < 1$

$$f_\gamma(r) = 5,369 \times r^{0,697}$$



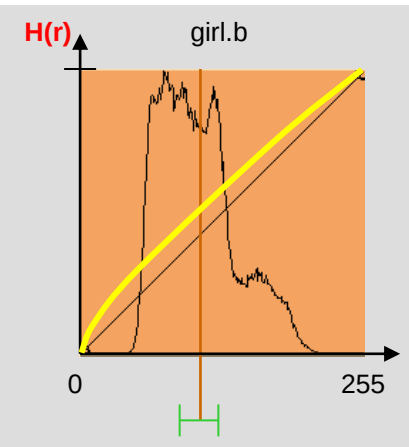
$m = 99,05$

$\sigma = 52,88$

skewness = +0.223

kurtosis = -0.755

$$f_\gamma(r) = 3,484 \times r^{0,775}$$



$m = 105,41$

$\sigma = 34,06$

skewness = +0.680

kurtosis = -0.169

Algorithme de
recherche
automatique.

$$f(r) = A \times r^\gamma$$

Trouver A et γ , tel que:

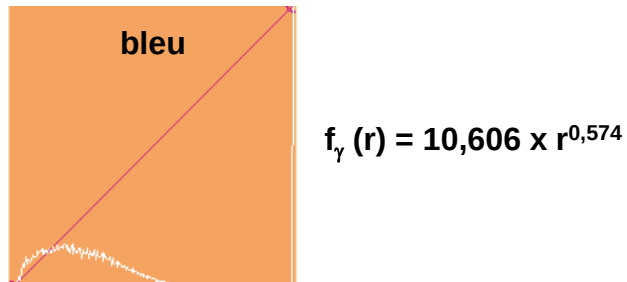
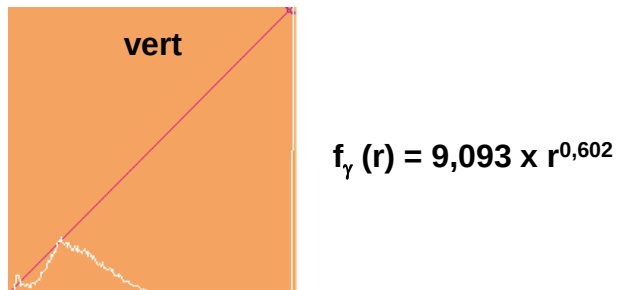
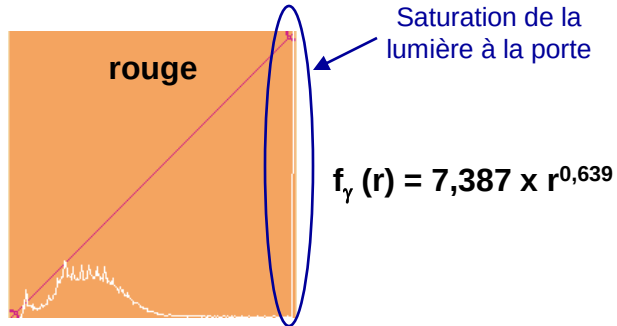
$$f(255) = 255$$

et

$$\text{moyenne}[f(r)] = 128$$



⊕ Fonction gamma Exemple 2 (cat)



⊕ Fonction gamma Exemple 3 (Aqua MODIS du 18/02/2010)



$\gamma = 0,3$



$\gamma = 0,5$



$\gamma = 0,7$



$\gamma = 0,9$



$\gamma = 1,1$



$\gamma = 1,3$



$\gamma = 1,5$



$\gamma = 1,7$



$\gamma = 1,9$



$\gamma = 2,1$



Image source

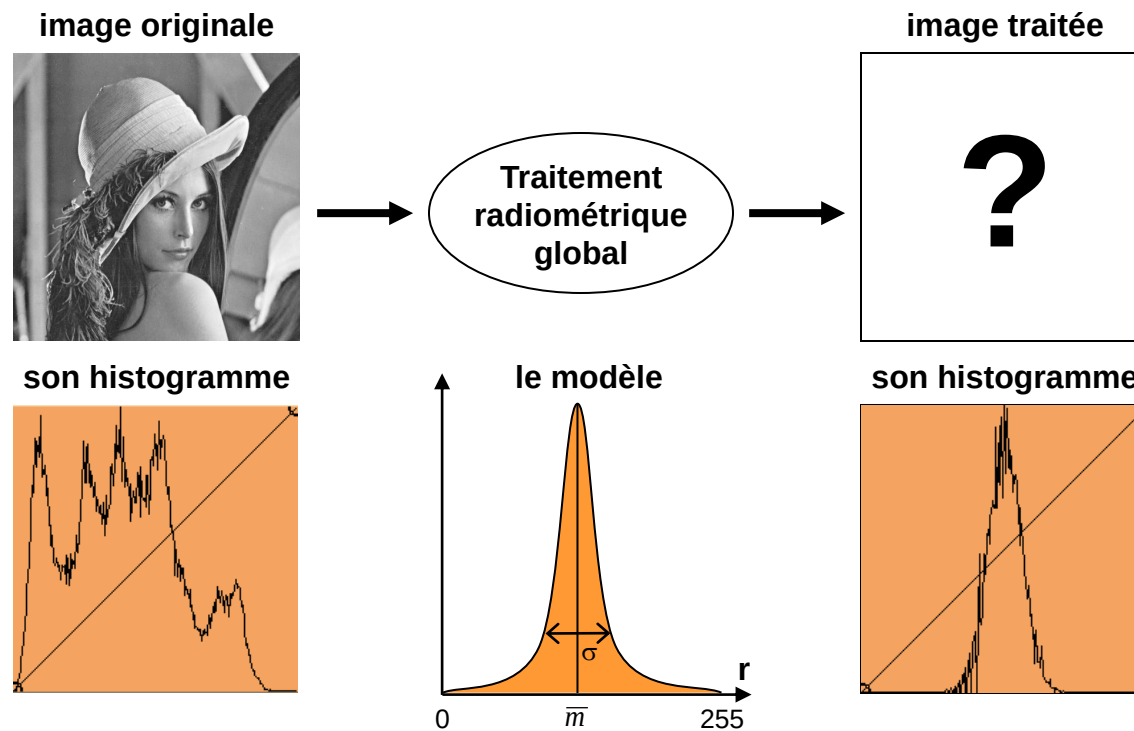


Stretching gamma automatique

$$\gamma_R = 1,16 \quad \gamma_V = 1,14 \quad \gamma_B = 0,96$$

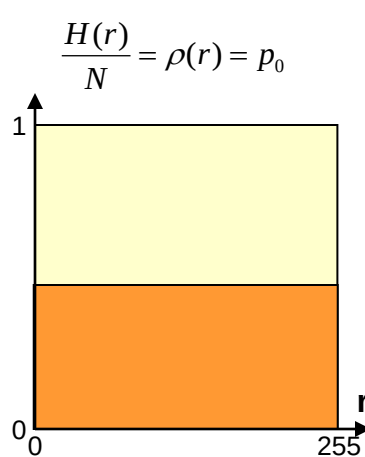
❖ Traitement radiométrique global par adaptation de l'histogramme à un modèle

❖ Principe

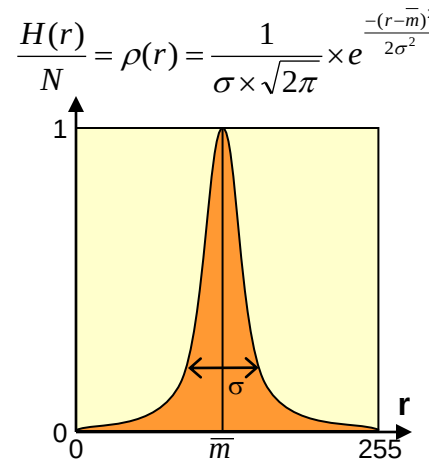




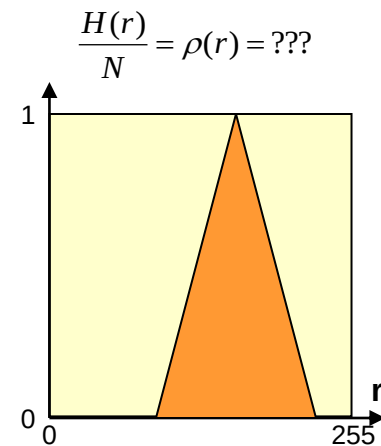
■ Modèles analytiques



**Modèle de
distribution
Uniforme**



**Modèle de
distribution
Gaussienne**

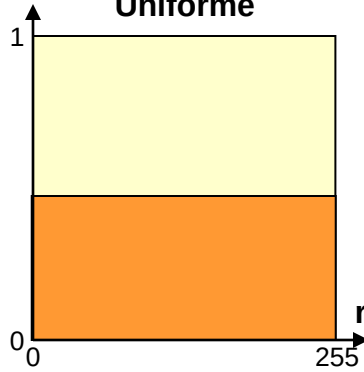


Votre modèle

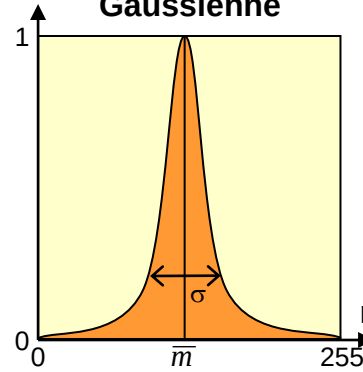
- pour décrire le monde
- pour améliorer le rendu



Modèle de
distribution
Uniforme



Modèle de
distribution
Gaussienne



Modèle de
distribution
en Triangle

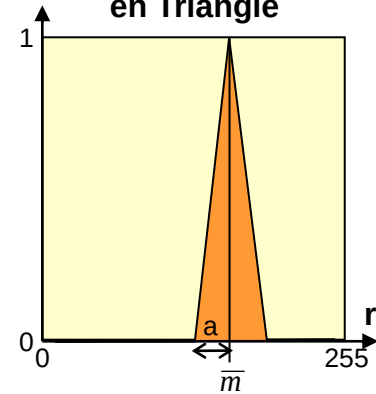
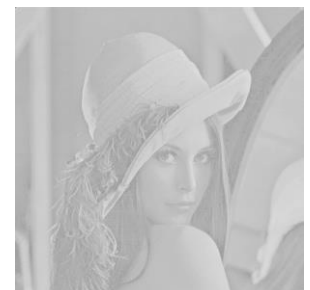
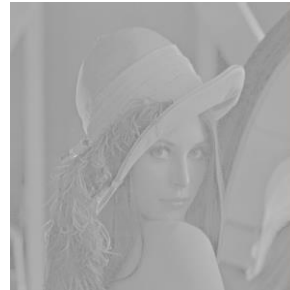
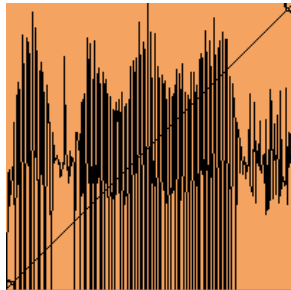
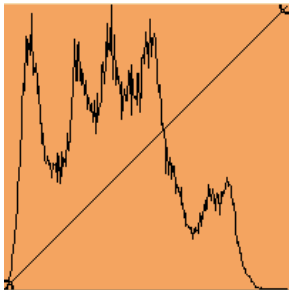


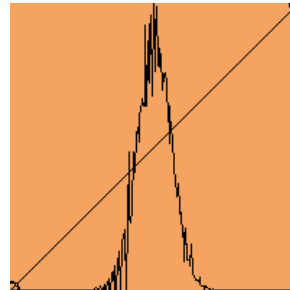
image originale



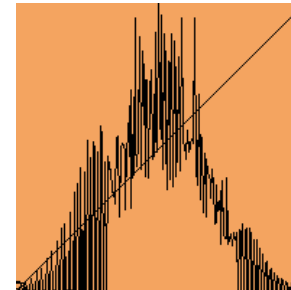
son histogramme



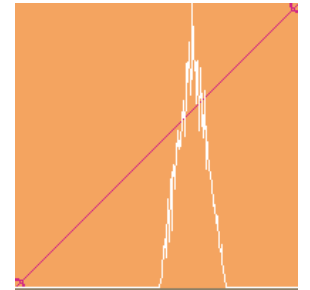
$m=128$ $\sigma=15$



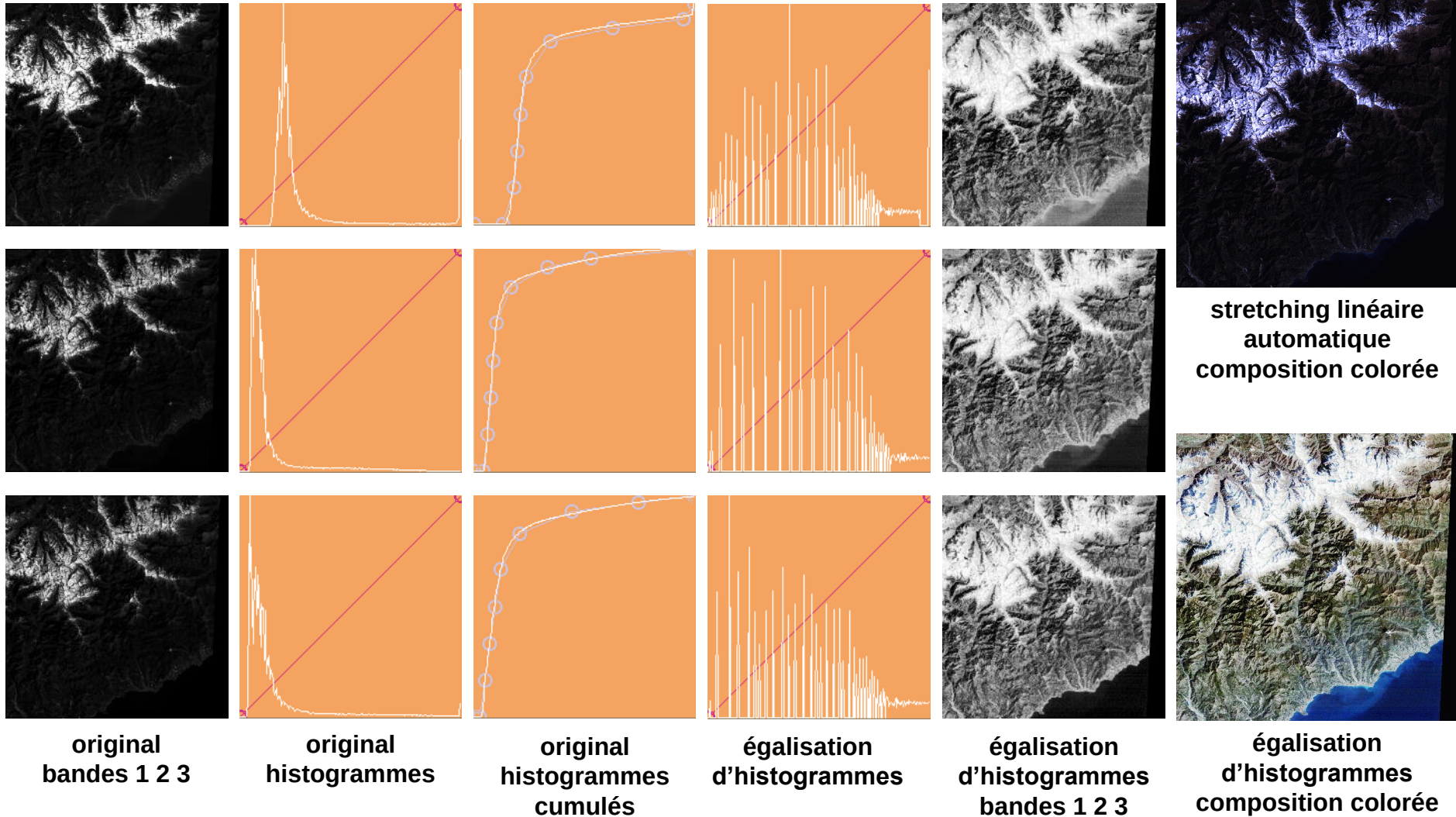
$m=128$ $\sigma=40$



$m=160$ $a=30$



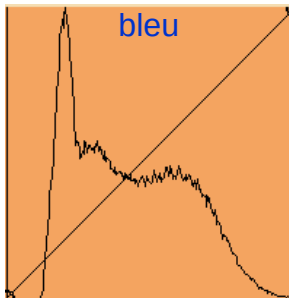
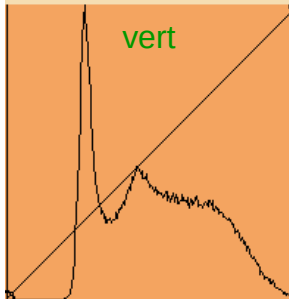
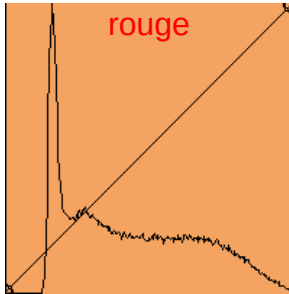
■ Egalisation uniforme et distributions multi-modales



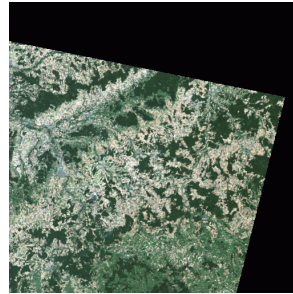


■ modèle image

image de référence



Landsat 7 198-27 01/08/2000



Landsat 7 197-27 11/09/2000

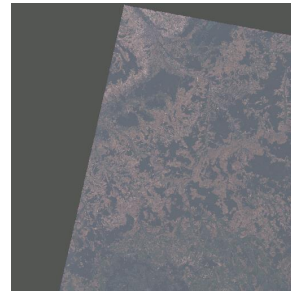


image de travail

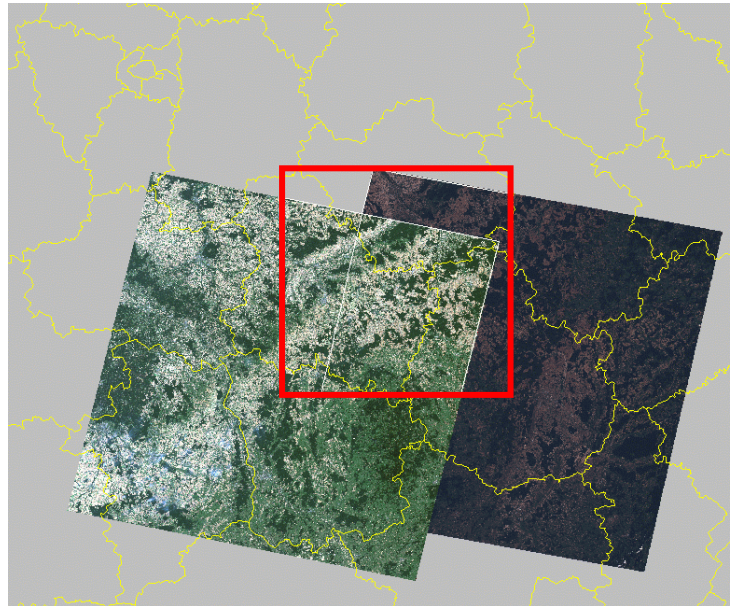
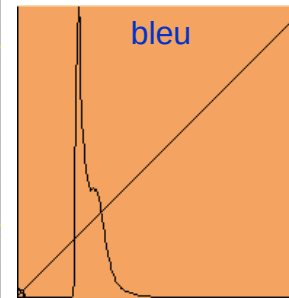
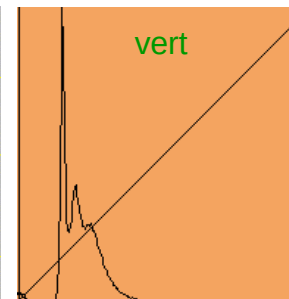
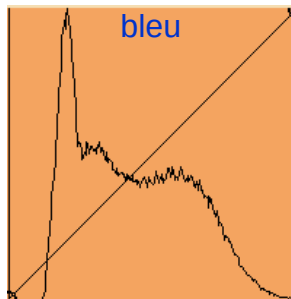
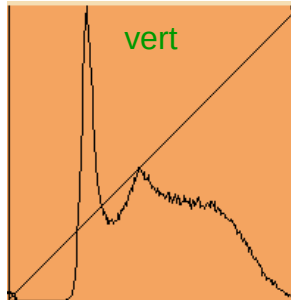
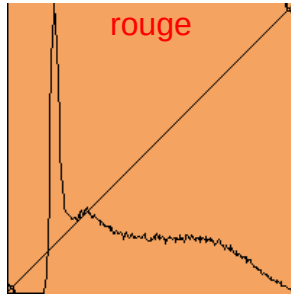


image de référence



histogrammes de
l'image modèle

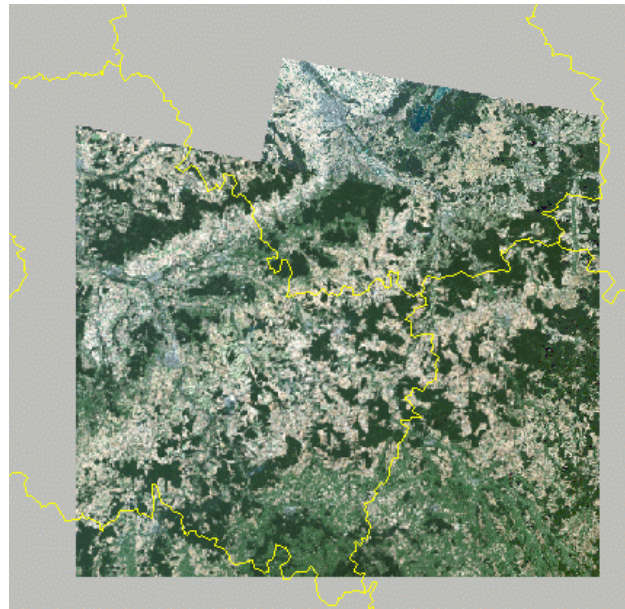
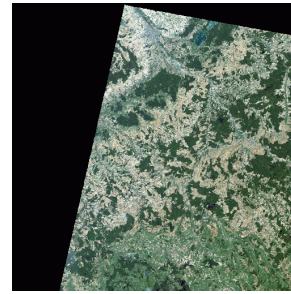
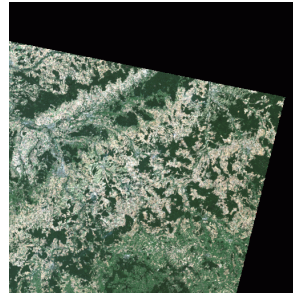
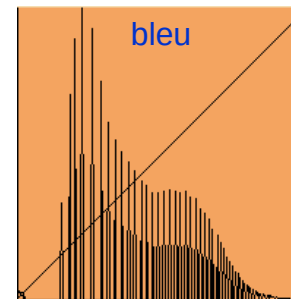
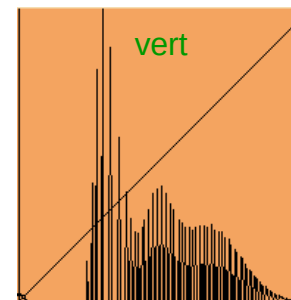
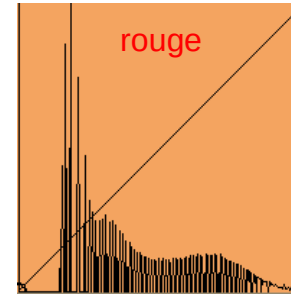
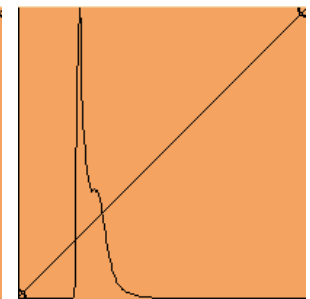
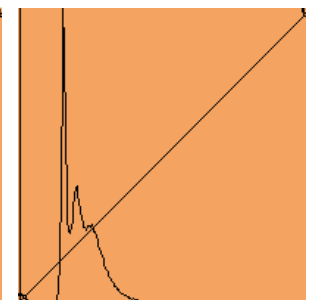
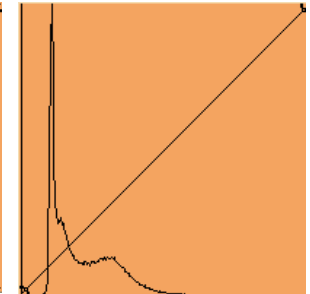


image de travail



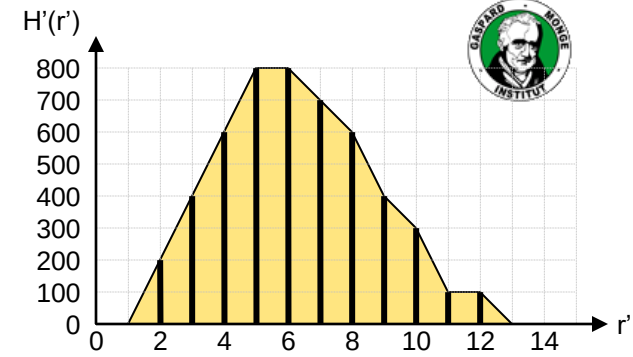
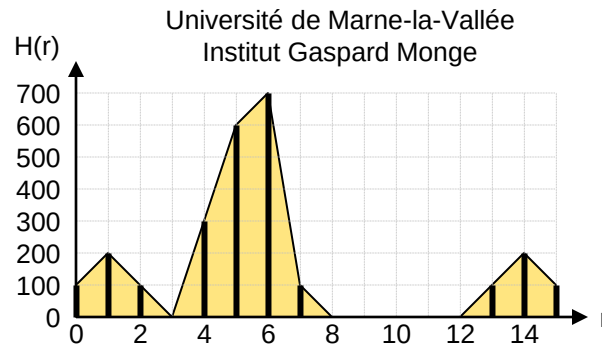
histogrammes de
l'image adaptée au modèle



histogrammes de
l'image originale



Algorithm



Soient

- . $H(r)$, $r=0..15$, l'histogramme de l'image originale,
- . $H_C(r)$, $r=0..15$, l'histogramme cumulé de l'image originale,
- . N le nombre de pixels de l'image originale,
- . $H'(r')$, $r'=0..15$, l'histogramme de l'image modèle,
- . $H_C'(r')$, $r'=0..15$, l'histogramme cumulé de l'image modèle,
- . N' le nombre de pixels de l'image modèle (N' peut être différent de N)

. $r' \leftarrow 0$

. Pour ($r \leftarrow 0$; $r \leq 15$; $r++$) **Faire**

- . Tant que ($(r' < 15)$ et $(H_C'(r')/N' < H_C(r)/N)$ **Faire**
- . $r' \leftarrow r' + 1$

FinFaire

. $LUT[r] \leftarrow r'$

FinFaire

$p(r) = H_C(r)/N$

100%

80%

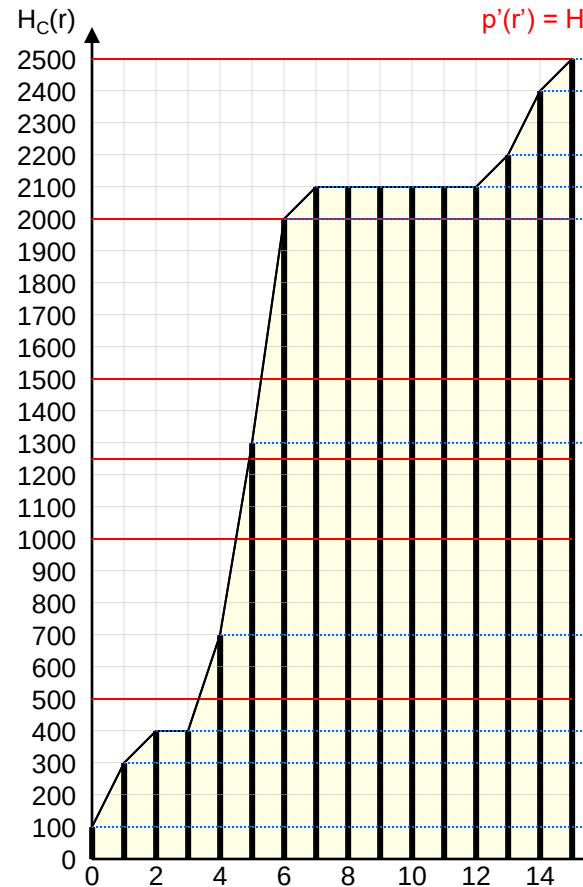
60%

50%

40%

20%

0%



$p'(r') = H_C'(r')/N'$

100%

80%

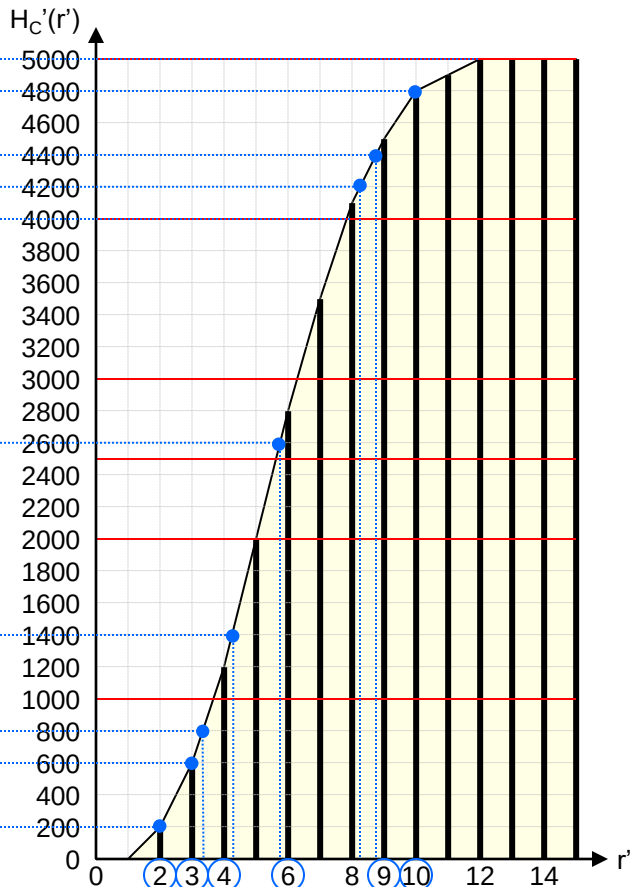
60%

50%

40%

20%

0%



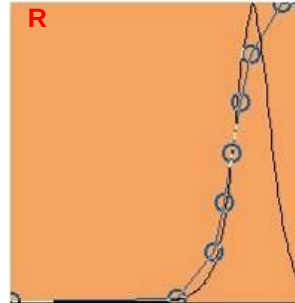
LUT [2 3 4 4 5 6 8 9 9 9 9 9 9 10 12]



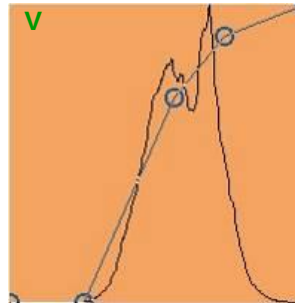
⊕ Fonctions différentes selon les canaux



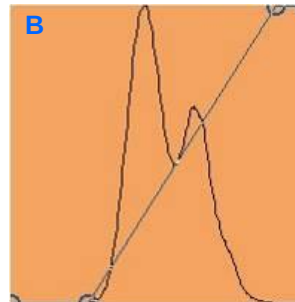
Landsat ETM+ du 26/08/2001 – Arabie saoudite



égalisation d'histogramme



stretching par morceaux

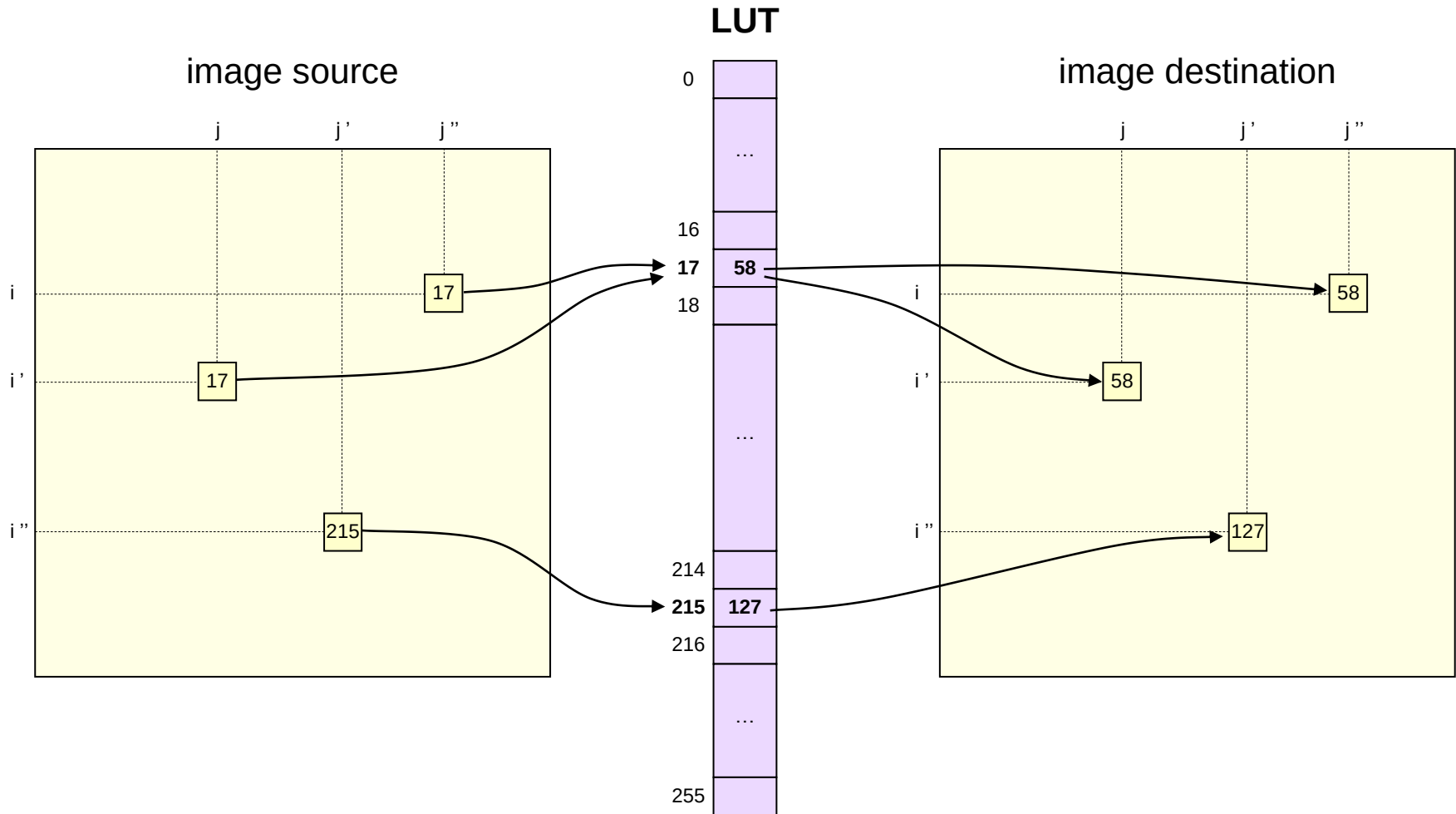


stretching linéaire





Traitement Radiométrique Global (TRG)





❁ Traitement radiométrique par filtrage

❁ Filtrages convolutifs

- introduction et formule de convolution
- traitement des bords
- filtres passe-bas / passe-haut / rehaussement des contours

❁ Mesures des variations - Analyse de Fourier

- image des écart-types
- Formule de Fourier - cas monodimensionnel / bidimensionnel – composantes réelle et imaginaire – Spectre de puissance

❁ Filtrages adaptatifs

- bruits additif / multiplicatif selon modèle – bruit des images SAR
- filtres de LEE / KUAN
- stretching linéaire imposé selon des statistiques locales

❁ Filtrages heuristiques

- filtre médian – influence de la largeur de la fenêtre statistique



Traitement radiométrique par filtrages

☼ Classes de filtrages

- ☒ Filtrages convolutifs
Ex.: lisser le défaut
- ☒ Filtrages adaptatifs
tenir compte des statistiques locales
- ☒ Filtrages morphologiques
dilater / éroder les formes
- ☒ Filtrages heuristiques
traitement spécifique
traitement non linéaire (ex.: filtre médian)

5	8	10	15	18
9	11	17	22	26
14	16	77	28	33
19	22	26	32	37
25	28	31	36	43

5	8	10	15	18
9	11	17	22	26
14	16	23	28	33
19	22	26	32	37
25	28	31	36	43



Filtrages convolutifs

⊕ Filtrage « Moyenne 3x3 »

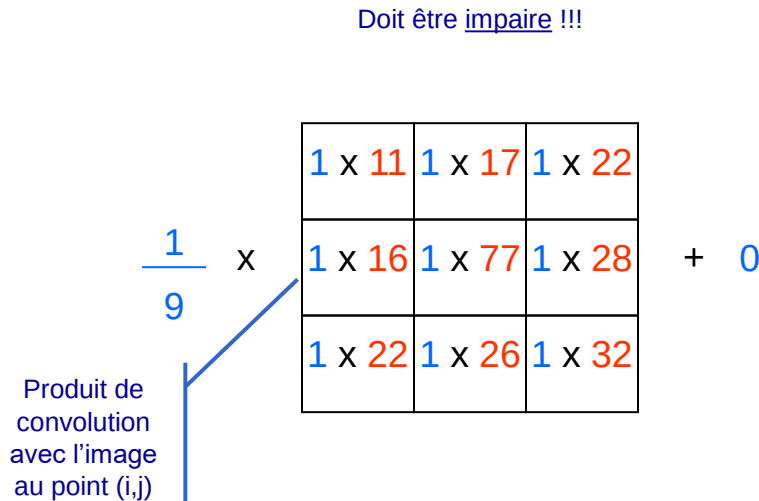
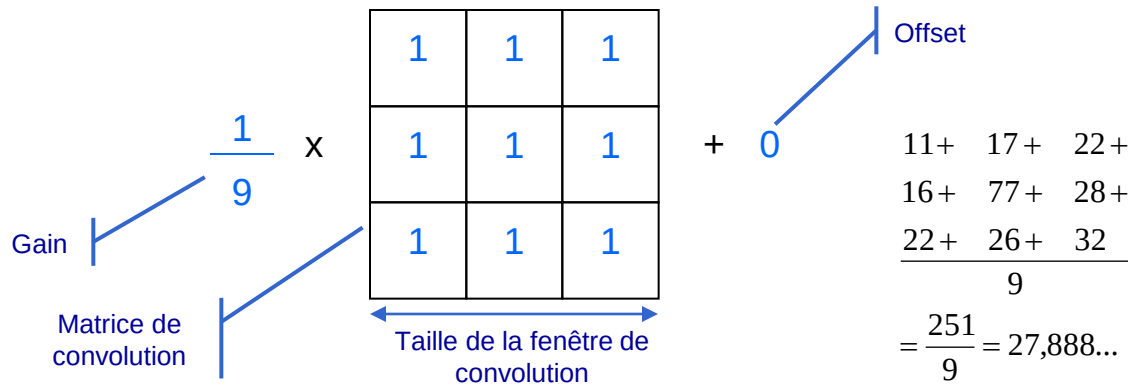


image en entrée

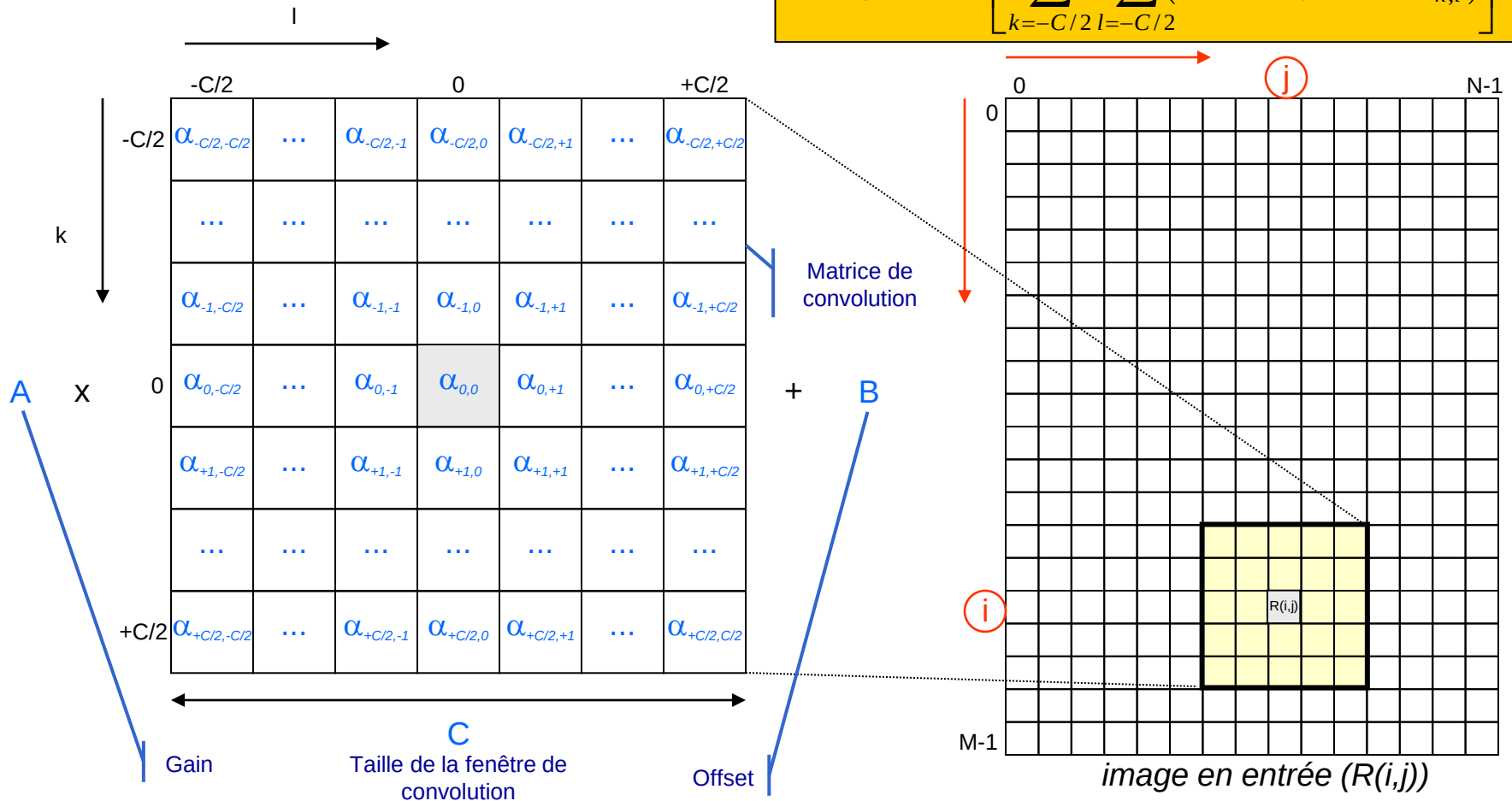
		i		
5	8	10	15	18
9	11	17	22	26
14	16	77	28	33
19	22	26	32	37
25	28	31	36	43

image en sortie

		j		
	18,55..	22,66..	27,33..	
	19	23	27	
i	23,44..	27,88..	33,11..	
	23	28	33	
	28,66..	32,88..	38,11..	
	29	33	38	

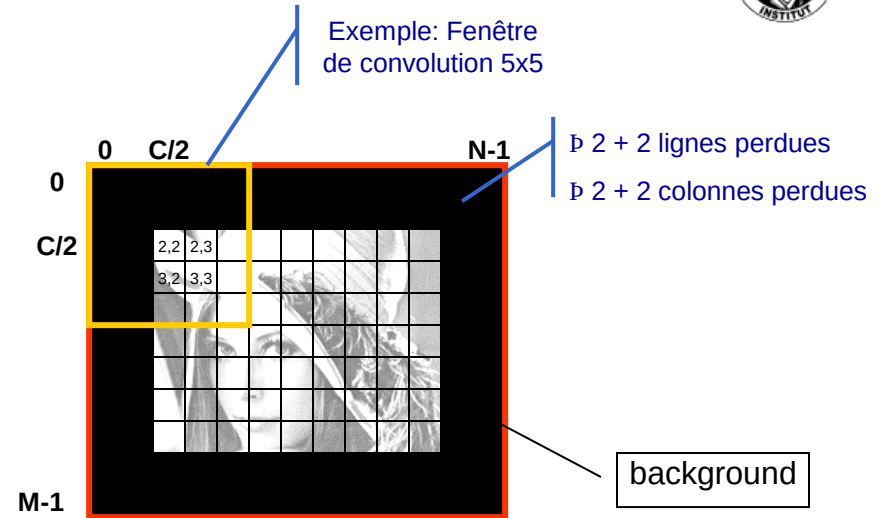
Formule de convolution

$$R'(i, j) = A \times \left[\sum_{k=-C/2}^{+C/2} \sum_{l=-C/2}^{+C/2} (R(i+k, j+l) \times \alpha_{k,l}) \right] + B$$



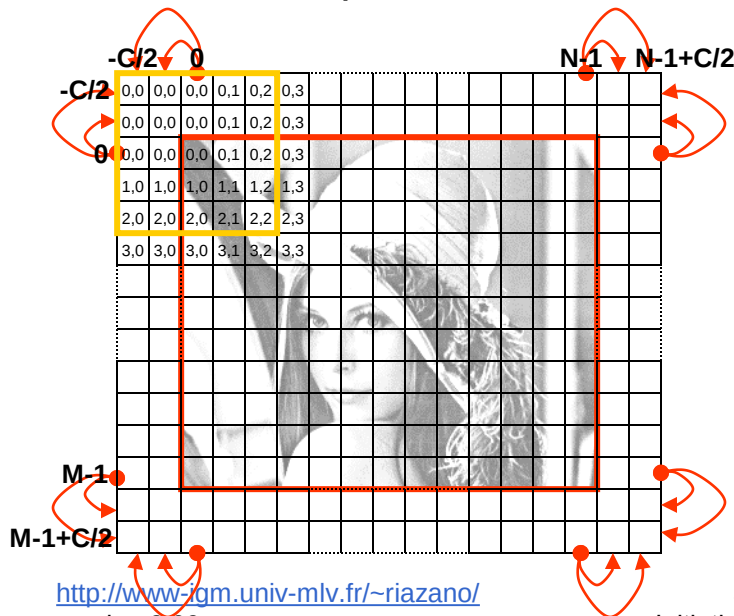
Traitement des bords

- Ne pas traiter les bords
 - Pixels en background
 - Restriction de l'image

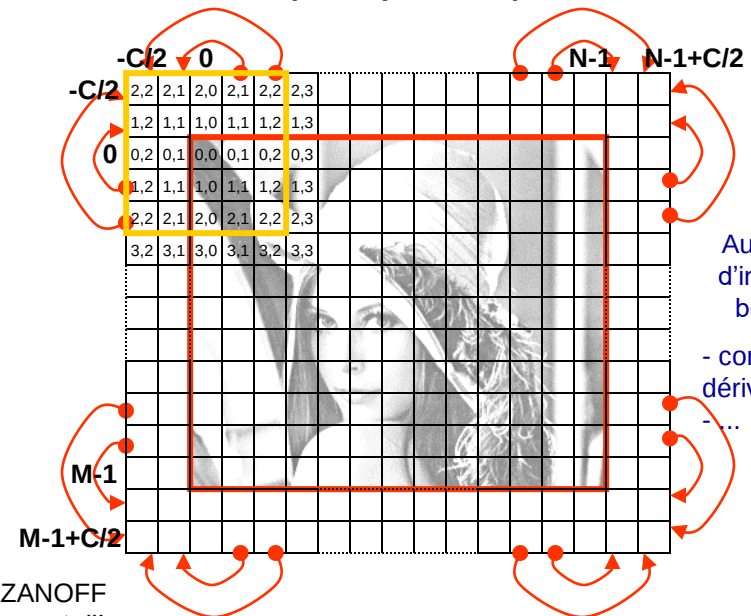


- Etendre l'image de $\pm C/2$ lignes / colonnes

Duplication



Copie symétrique



Autres méthodes d'initialisation des bords d'image:

- continuation de la dérivée première

⊕ Filtres passe-bas

⊞ « Moyenne 3x3 »

$$\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} + 0$$

Moyenne 3x3

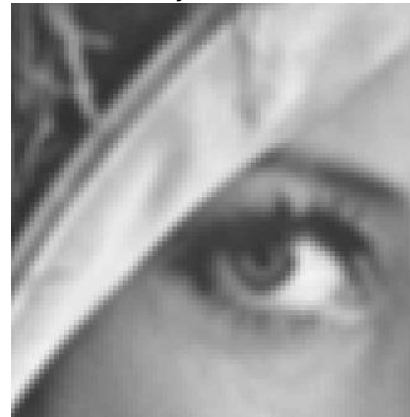


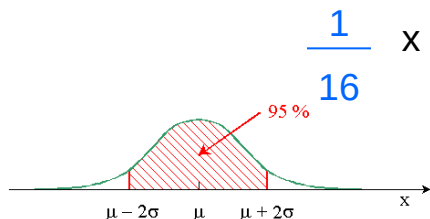
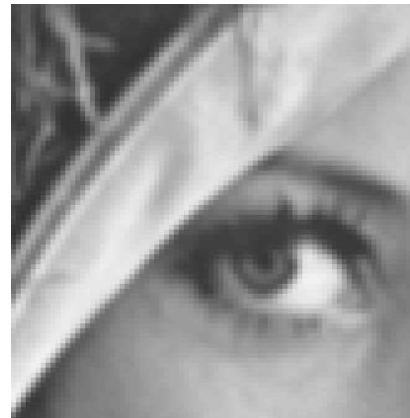
image originale
(léna, canal vert zoom x4)



⊞ « Gauss 3x3 »

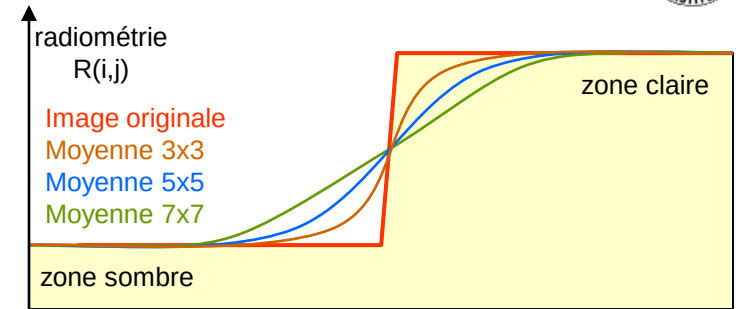
$$\frac{1}{16} \times \begin{bmatrix} 1 & 2 & 1 \\ 2 & 4 & 2 \\ 1 & 2 & 1 \end{bmatrix} + 0$$

Gauss 3x3



<http://www.astro.ulg.ac.be/cours/magain/stat/stat51.html>

- ❑ Profil radiométrique
- ❑ Influence de la largeur du filtre



« Moyenne 3x3 »

$$\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} + 0$$

« Moyenne 5x5 »

$$\frac{1}{25} \times \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 \end{bmatrix} + 0$$

« Moyenne 7x7 »

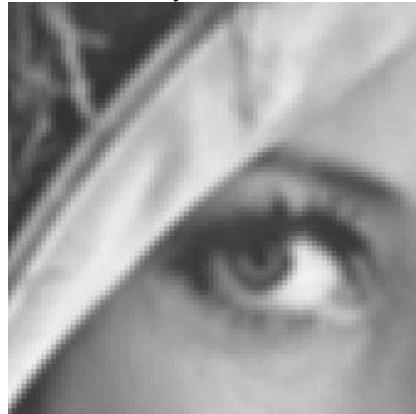
$$\frac{1}{49} \times \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} + 0$$

image originale

Moyenne 3x3

Moyenne 5x5

Moyenne 7x7



■ Influence des itérations du filtrage (exemple « Moyenne 3x3 »)

1 itération

$$\left[\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right]$$

2 itérations

$$\left[\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right] \square \left[\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right]$$

3 itérations

$$\left[\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right] \square \left[\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right] \square \left[\frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix} \right]$$

Matrice de convolution
équivalente sur 1 passage

$$\frac{1}{81} \times \begin{bmatrix} 1 & 2 & 3 & 2 & 1 \\ 2 & 4 & 6 & 4 & 2 \\ 3 & 6 & 9 & 6 & 3 \\ 2 & 4 & 6 & 4 & 2 \\ 1 & 2 & 3 & 2 & 1 \end{bmatrix} + 0$$

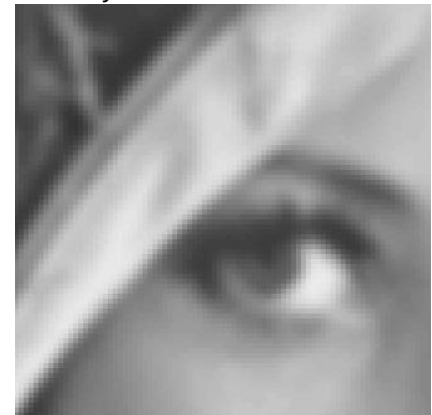
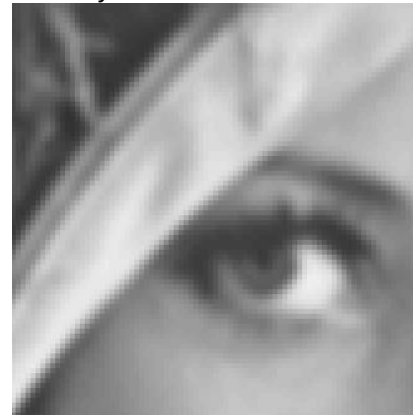
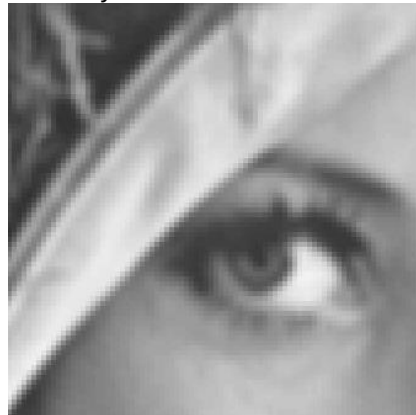
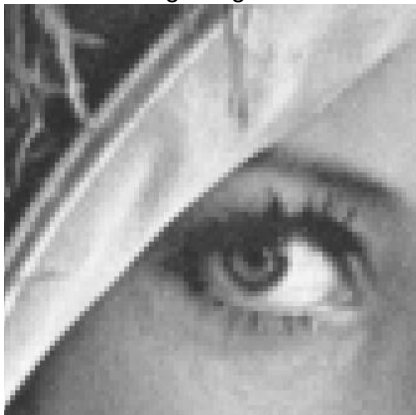
$$\frac{1}{729} \times \begin{bmatrix} 1 & 3 & 6 & 7 & 6 & 3 & 1 \\ 3 & 9 & 18 & 21 & 18 & 9 & 3 \\ 6 & 18 & 36 & 42 & 36 & 18 & 6 \\ 7 & 21 & 42 & 49 & 42 & 21 & 7 \\ 6 & 18 & 36 & 42 & 36 & 18 & 6 \\ 3 & 9 & 18 & 21 & 18 & 9 & 3 \\ 1 & 3 & 6 & 7 & 6 & 3 & 1 \end{bmatrix} + 0$$

image originale

Moyenne 3x3 – 1 itération

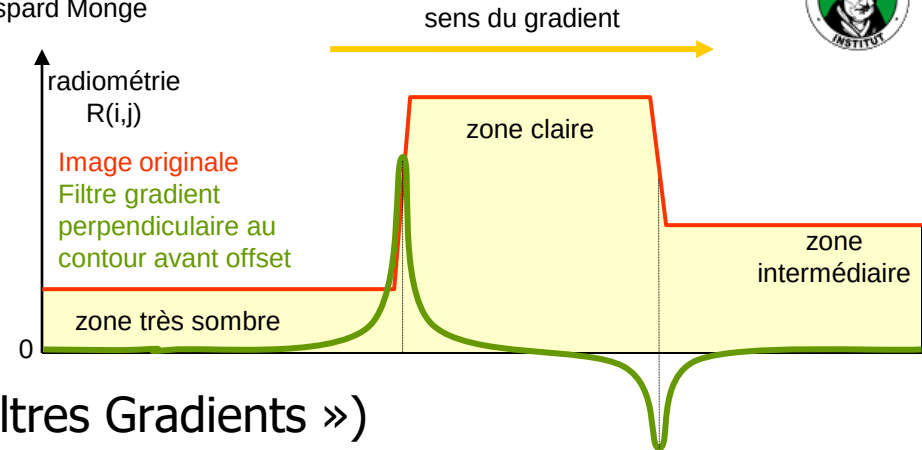
Moyenne 3x3 – 2 itérations

Moyenne 3x3 – 3 itérations



⊕ Filtres passe-haut

⊕ Filtres directionnels (« Filtres de Prewitt » ou « Filtres Gradients »)



« Gradient 3x3 N-S »

Facteur multiplicatif ($\alpha=10$)

distance d entre les pixels soustraits

nombre de différences pondérées

$$\frac{\alpha}{2 \times 3} \times \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} + 128$$

« Gradient 3x3 W-E »

$$\frac{\alpha}{2 \times 3} \times \begin{bmatrix} -1 & 0 & 1 \\ -1 & 0 & 1 \\ -1 & 0 & 1 \end{bmatrix} + 128$$

« Gradient 3x3 NW-SE »

$$\frac{\alpha}{\frac{4\sqrt{2}}{3} \times 3} \times \begin{bmatrix} -1 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} + 128$$

image originale

Gradient 3x3 N-S

Gradient 3x3 W-E

Gradient 3x3 NW-SE



■ Filtre « Gradient 3x3 N-S » - Influence du gain ·

$$\frac{\alpha}{2 \times 3} \times \begin{bmatrix} -1 & -1 & -1 \\ 0 & 0 & 0 \\ 1 & 1 & 1 \end{bmatrix} + 128$$

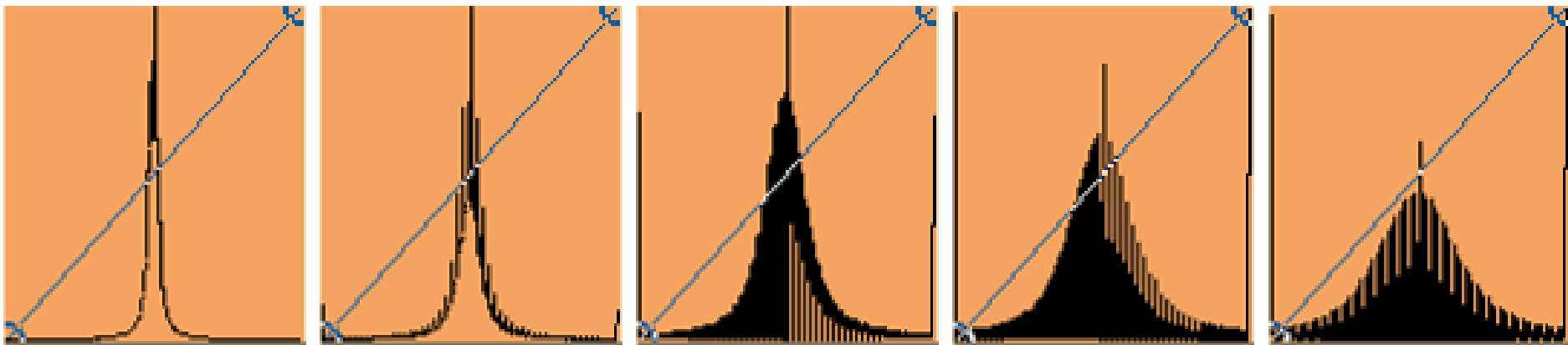
$\alpha = 2$

$\alpha = 5$

$\alpha = 10$

$\alpha = 15$

$\alpha = 20$



■ Filtre « Gradient » - Animations

image originale



gradients: N-S → NW-SE → W-E



■ Comparaison des filtres de « Sobel » et « Gradient »

« Sobel 3x3 N-S »

$$\frac{\alpha}{2 \times 4} \times \begin{bmatrix} -1 & -2 & -1 \\ 0 & 0 & 0 \\ 1 & 2 & 1 \end{bmatrix} + 128$$

Sobel 3x3 N-S



Gradient 3x3 N-S



« Sobel 3x3 W-E »

$$\frac{\alpha}{2 \times 4} \times \begin{bmatrix} -1 & 0 & 1 \\ -2 & 0 & 2 \\ -1 & 0 & 1 \end{bmatrix} + 128$$

Sobel 3x3 W-E



Gradient 3x3 W-E



« Sobel 3x3 NW-SE »

$$\frac{\alpha}{\frac{4\sqrt{2}}{3} \times 4} \times \begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix} + 128$$

Sobel 3x3 NW-SE



Gradient 3x3 NW-SE

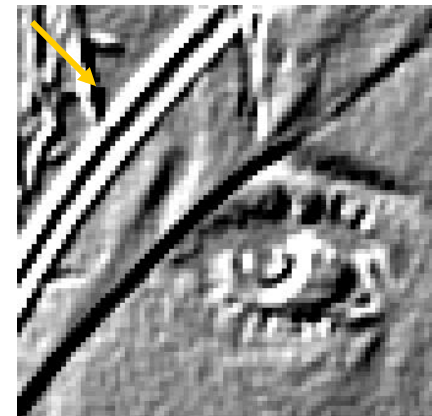
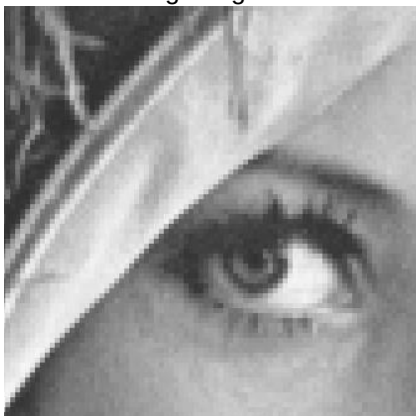
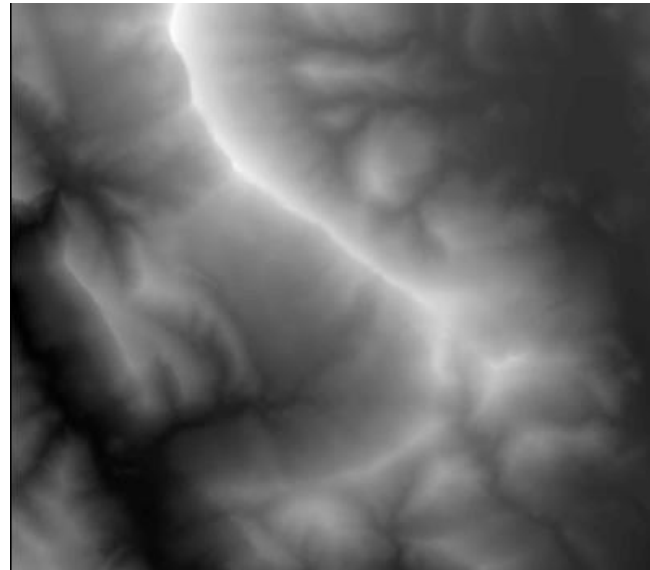


image originale





■ Application aux Modèles Numériques de Terrain



$$5 \times \begin{bmatrix} -1 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 1 \end{bmatrix} + 128$$

« Gradient 3x3 NW-SE »

$$5 \times \begin{bmatrix} 0 & -1 & -1 \\ 1 & 0 & -1 \\ 1 & 1 & 0 \end{bmatrix} + 128$$

« Gradient 3x3 NE-SW »

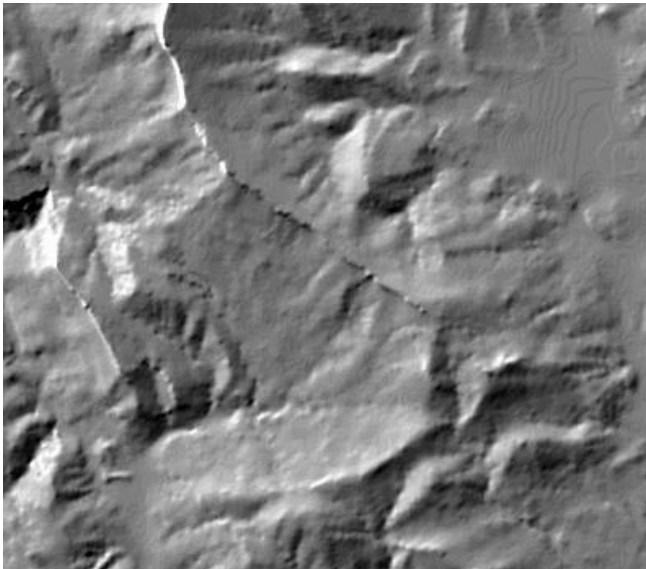
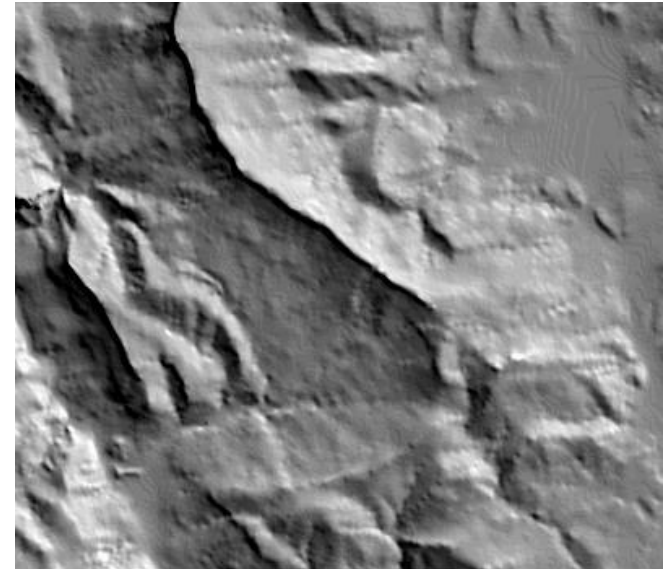


image originale

Montagne de Coupe – SE de Digne
résolution planimétrique 20 m
profondeur des données sur 8 bits

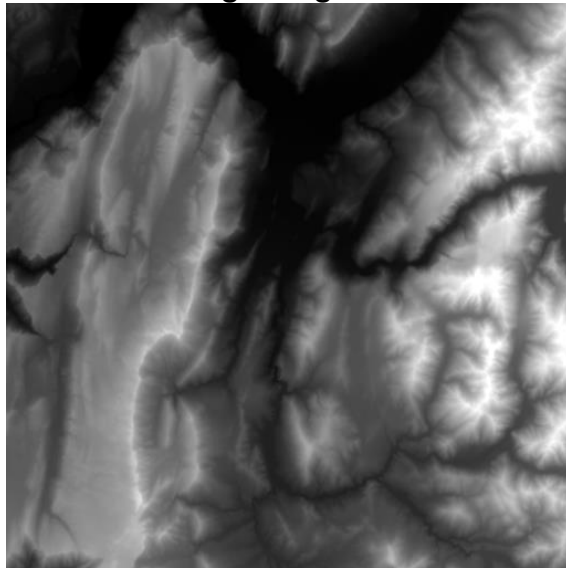




■ Application aux Modèles Numériques de Terrain - Composition de sources de lumière

$$2 \times \begin{bmatrix} -2 & -1 & 0 \\ -1 & 0 & 1 \\ 0 & 1 & 2 \end{bmatrix} + 32768$$

image originale

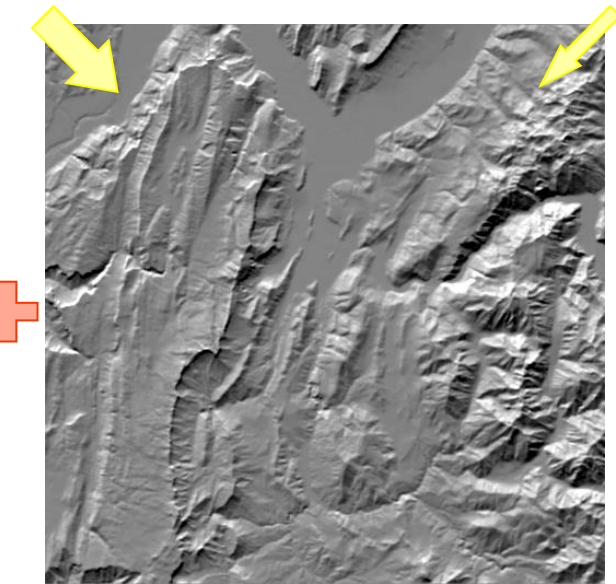
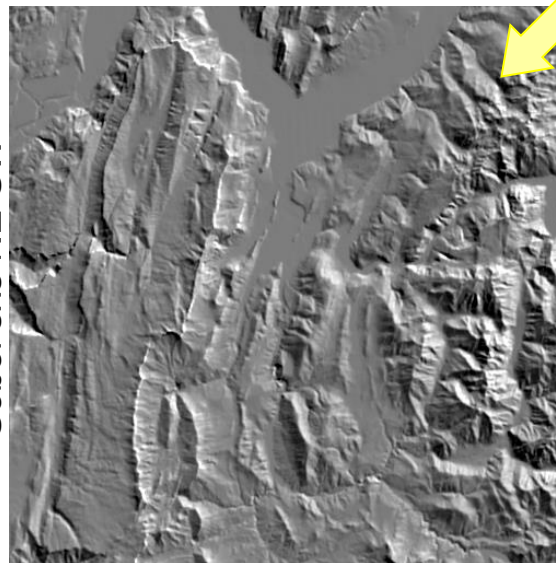
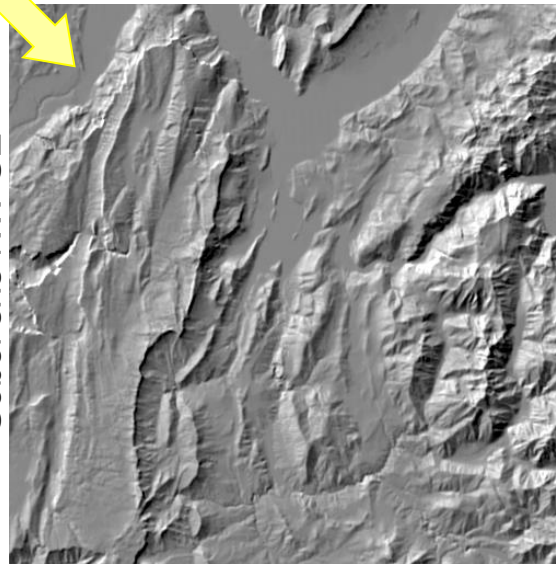


France – Isère - Grenoble
résolution planimétrique 90 m
profondeur des données sur 16 bits
stretching automatique sur 8 bits

$$1 \times \begin{bmatrix} 0 & -1 & -2 \\ 1 & 0 & -1 \\ 2 & 1 & 0 \end{bmatrix} + 32768$$

« Sobel 3x3 NW-SE »

« Sobel 3x3 NE-SW »

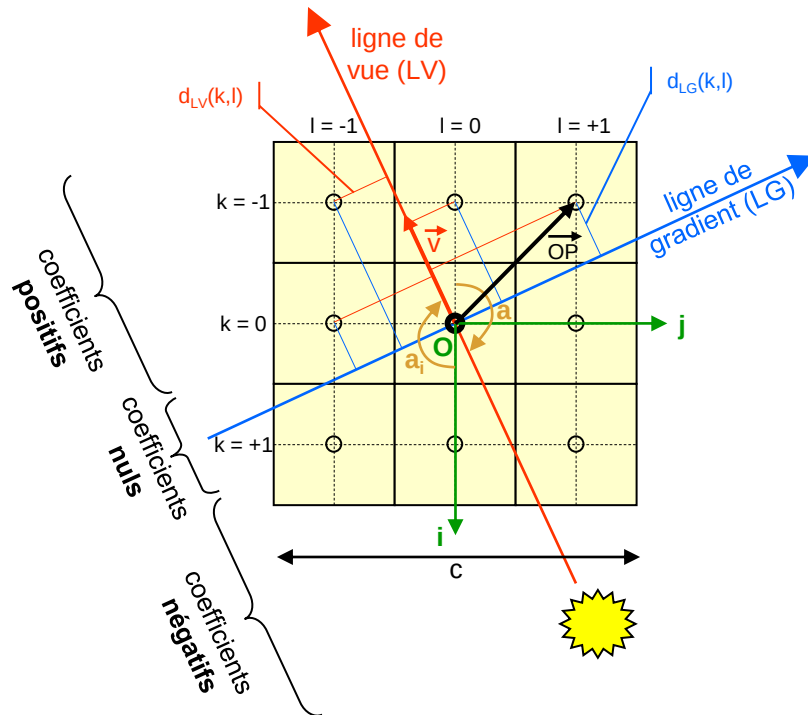


« Sobel 3x3 2xNW-SE + 1xNE-SW »

$$1 \times \begin{bmatrix} -4 & -3 & -2 \\ -1 & 0 & 1 \\ 2 & 3 & 4 \end{bmatrix} + 32768$$



❖ Filtre « Compass »



Intentions:

1. Trouver un filtre majorant le poids des points proches de la ligne de vue
→ facteur $(c/2+1-|d_{LV}|)$.
2. Rehausser les faibles variations à proximité de la ligne de gradient
→ $(c/2) / d_{LG}$. Ce rehaussement est cependant limité à proximité de la ligne de gradient sur un corridor (par exemple de largeur 2×0.5).

a : azimut de l'illumination dans le repère Nord géographique

a_i : azimut de l'illumination dans le repère image (O, i, j) . $a_i = -a$

$$d_{LG} = \vec{v} \cdot \vec{OP} = \cos(a).k - \sin(a).l$$

$$d_{LV} = \vec{v}^T \cdot \vec{OP} = -\sin(a).k - \cos(a).l$$

$$M_{Compass} = \sum_k \sum_l \frac{\alpha}{|\alpha(k, l)|} \times \begin{bmatrix} \alpha(k, l) = 0 & \text{si } |d_{LG}| < 0,5 \\ \alpha(k, l) = \frac{c/2}{d_{LG}} \times (c/2 + 1 - |d_{LV}|) & \text{si } |d_{LG}| \geq 0,5 \end{bmatrix} + 128$$

Exemple: $a = 155^\circ$ $c = 5$

+5.402	+6.569	+3.906	+1.735	+0.331
+2.820	+3.344	+2.336	0	0
+1.004	0	0	0	-1.004
0	0	-2.336	-3.344	-2.820
-0.331	-1.735	-3.906	-6.569	-5.402

■ Filtre « Compass » - Influence de la largeur de la fenêtre de convolution



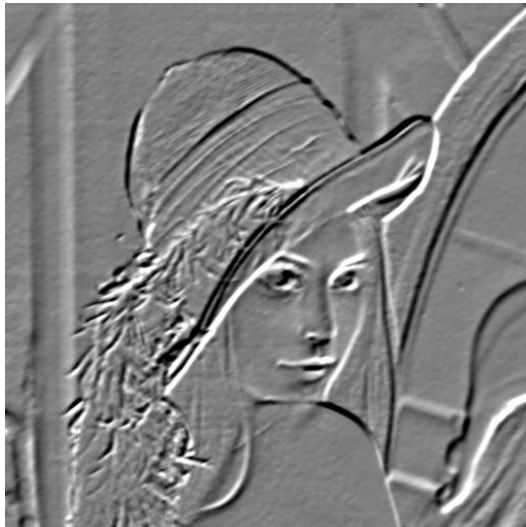
azimut = 155° - **c = 3**



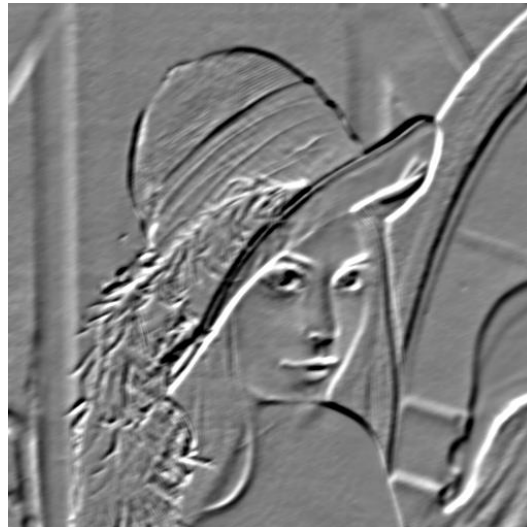
azimut = 155° - **c = 5**



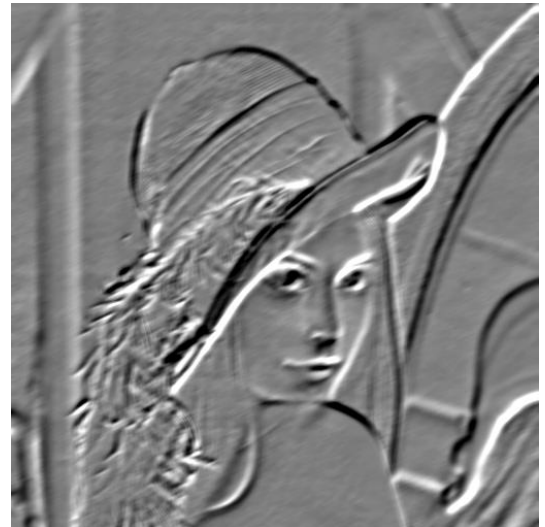
azimut = 155° - **c = 7**



azimut = 155° - **c = 9**



azimut = 155° - **c = 11**



azimut = 155° - **c = 13**



■ Filtre « Compass » - Exemples



000.00

Animation – girl – Compass 5x5 – 32 vues $\Delta\alpha=11,25^\circ$

[SR-ITI-COURS\anim_girl_compass_5x5_11.25deg.gif](http://www-igm.univ-mlv.fr/~riazano/SR-ITI-COURS\anim_girl_compass_5x5_11.25deg.gif)

■ Filtres gradients non-directionnels

« Gradient 3x3 4-connexe » « Gradient 3x3 8-connexe »

$$\frac{\alpha}{1 \times 4} \times \begin{bmatrix} 0 & -1 & 0 \\ -1 & 4 & -1 \\ 0 & -1 & 0 \end{bmatrix} + 128$$

Gradient 3x3 4-connexe

$$\frac{\alpha}{\frac{(4+4\sqrt{2}) \times 8}{8}} \times \begin{bmatrix} -1 & -1 & -1 \\ -1 & 8 & -1 \\ -1 & -1 & -1 \end{bmatrix} + 128$$

Gradient 3x3 8-connexe

image originale

Histogramme gradient 4-connexe

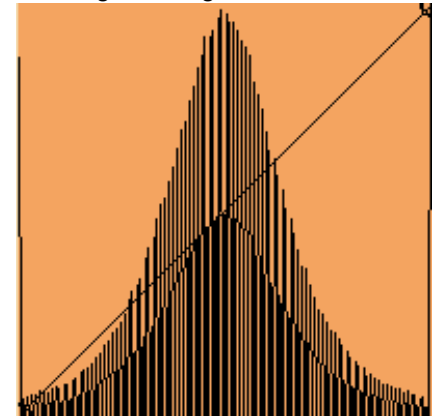
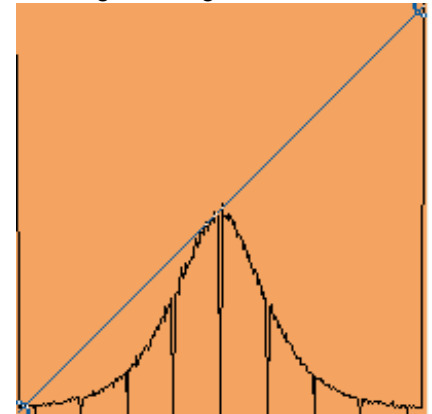
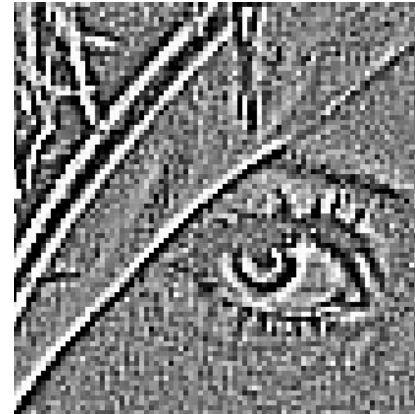


image originale (zoom x4)

Gradient 3x3 4-connexe

Gradient 3x3 8-connexe

Histogramme gradient 8-connexe

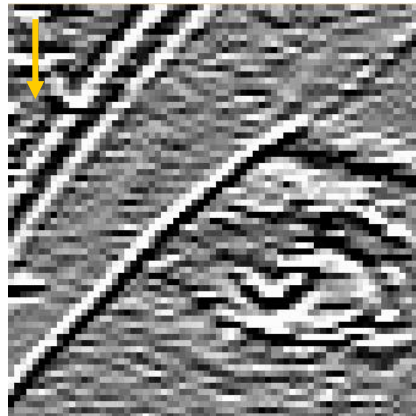


■ Comparaison des filtres de détection des dérivées premières et secondes

« Courbure 3x3 N-S » « Courbure 3x3 W-E » « Courbure 3x3 NW-SE »

$$\frac{\alpha}{3} \times \begin{bmatrix} -1 & -1 & -1 \\ 2 & 2 & 2 \\ -1 & -1 & -1 \end{bmatrix} + 128$$

Courbure 3x3 N-S



Gradient 3x3 N-S



$$\frac{\alpha}{3} \times \begin{bmatrix} -1 & 2 & -1 \\ -1 & 2 & -1 \\ -1 & 2 & -1 \end{bmatrix} + 128$$

Courbure 3x3 W-E

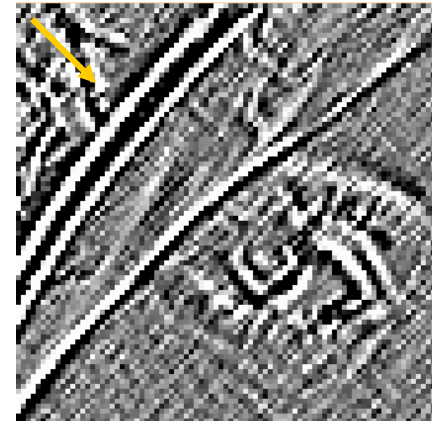


Gradient 3x3 W-E



$$\frac{\alpha}{3} \times \begin{bmatrix} -1 & -1 & 2 \\ -1 & 2 & -1 \\ 2 & -1 & -1 \end{bmatrix} + 128$$

Courbure 3x3 NW-SE



Gradient 3x3 NW-SE



image originale



■ Filtres de dérivées secondes non-directionnels

« Laplacien 3x3 »

$$\frac{\alpha}{4} \times \begin{bmatrix} 1 & -2 & 1 \\ -2 & 4 & -2 \\ 1 & -2 & 1 \end{bmatrix} + 128$$

« Laplacien 5x5 »

$$\frac{\alpha}{4} \times \begin{bmatrix} 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & -2 & 0 & 0 \\ 1 & -2 & 4 & -2 & 1 \\ 0 & 0 & -2 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \end{bmatrix} + 128$$

image originale

Laplacien 3x3

Laplacien 5x5

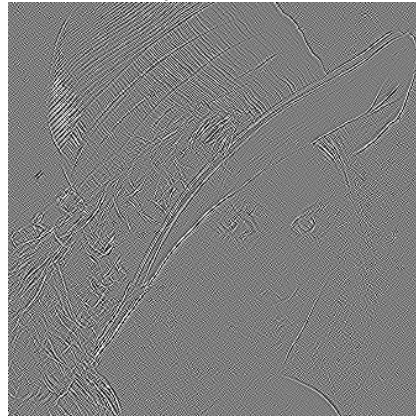
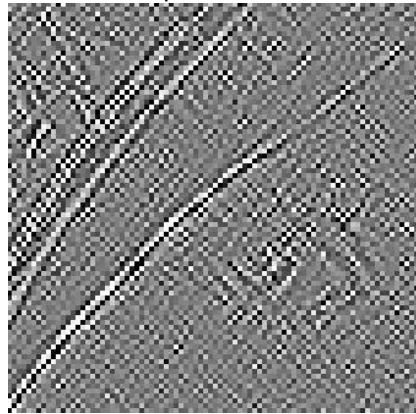


image originale (zoom x4)

Laplacien 3x3

Laplacien 5x5





Filtres de rehaussement des contours

« Pratt 3x3 » (« Ajouter à l'image initiale sa différence à la moyenne locale »)

$$\frac{1}{9} \times \begin{bmatrix} -1 & -1 & -1 \\ -1 & 17 & -1 \\ -1 & -1 & -1 \end{bmatrix} + 0 \quad \text{Gain du rehaussement} \quad R'(i, j) = R(i, j) + \beta \times [R(i, j) - \overline{m_{\text{CXC}}}] \rightarrow \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} + \begin{bmatrix} 0 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} - \frac{1}{9} \times \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{bmatrix}$$

image originale

Pratt 3x3

Pratt 7x7 pondéré à 0.5

Pratt 7x7 pondéré à 1.5

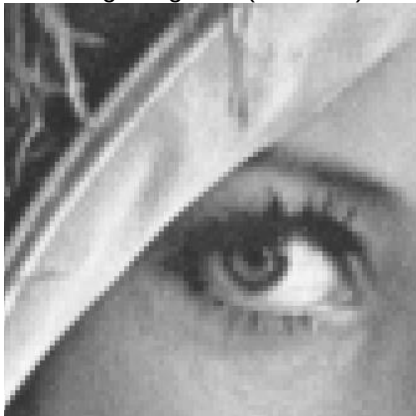


image originale (zoom x4)

Pratt 3x3

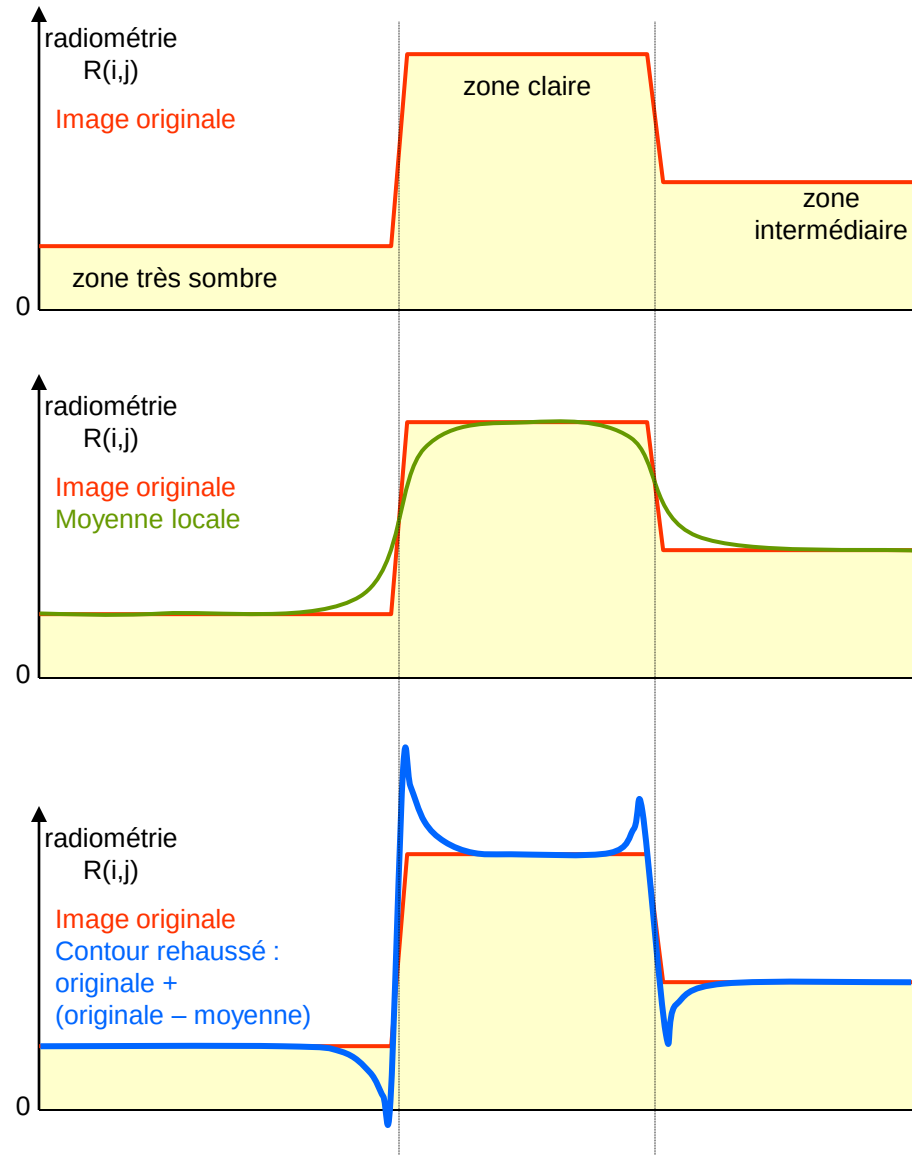
Pratt 7x7 pondéré à 0.5

Pratt 7x7 pondéré à 1.5





• Étude du profil de rehaussement d'un contour



✚ Mesurer les variations – Image des écart-types locaux

Image originale



Fenêtre d'analyse 3x3



Fenêtre d'analyse 7x7



Zones à fort gradient
(hautes fréquences)

Zones à faible gradient
(basses fréquences)

Zones homogènes
(fréquences nulles)



Fenêtre d'analyse 55x55

Mesurer les variations - Espace des fréquences – Analyse de Fourier

Théorie – Cas monodimensionnel

Théorie de Fourier: « Tout signal peut être considéré comme étant la somme de sinusoides élémentaires ».

Transformée directe

$$F(u) = \int_{-\infty}^{+\infty} f(x) \times e^{-j.2\pi.u.x} . dx$$

$$F(u) = R(u) + j.I(u)$$

Formule d'Euler

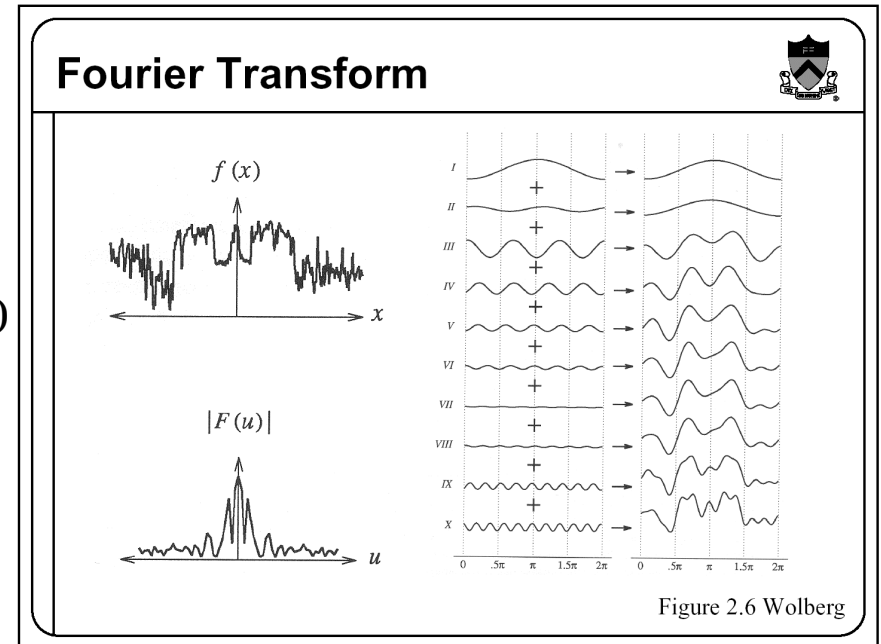
$$e^{-j.2\pi.u.x} = \cos(2\pi.u.x) - j \times \sin(2\pi.u.x)$$

$$P(u) = |F(u)|^2$$

Spectre de puissance

Transformée inverse

$$f(x) = \int_{-\infty}^{+\infty} F(u) \times e^{+j.2\pi.u.x} . du$$



<http://www.cs.princeton.edu/courses/archive/fall00/cs426/lectures/sampling/sampling.pdf>



❖ Cas bidimensionnel

Transformée directe

Cas 2D continu

$$F(u,v) = \int_{-\infty}^{+\infty} \int_{-\infty}^{+\infty} f(x,y) \times e^{-j.2\pi.u.x} \times e^{-j.2\pi.v.y} .dx.dy$$

Cas 2D discret

$$F(u,v) = \frac{1}{M \times N} \cdot \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} f(x,y) \times e^{-j.2\pi \left(\frac{u.x}{M} + \frac{v.y}{N} \right)}$$

Transformée inverse

$$f(x,y) = \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} F(u,v) \times e^{+j.2\pi \left(\frac{u.x}{M} + \frac{v.y}{N} \right)}$$

<http://astronomy.swin.edu.au/~pbourke/analysis/dft/>

```

/*****
/* Direct fourier transform */
/*****
int DFT(
    int dir, /* transform sens -direct (+1) -inverse (-1) */
    int m, /* sample number */
    double *x1, /* input/output array - real component */
    double *y1 /* input/output array - imaginary component */
)
{
    long i,k;
    double arg;
    double cosarg,sinarg;
    double *x2=NULL,*y2=NULL;

    /*-----*/
    /* Allocate local buffers */
    /*-----*/
    x2 = malloc(m*sizeof(double));
    y2 = malloc(m*sizeof(double));
    if (x2 == NULL || y2 == NULL)
        return(FALSE);

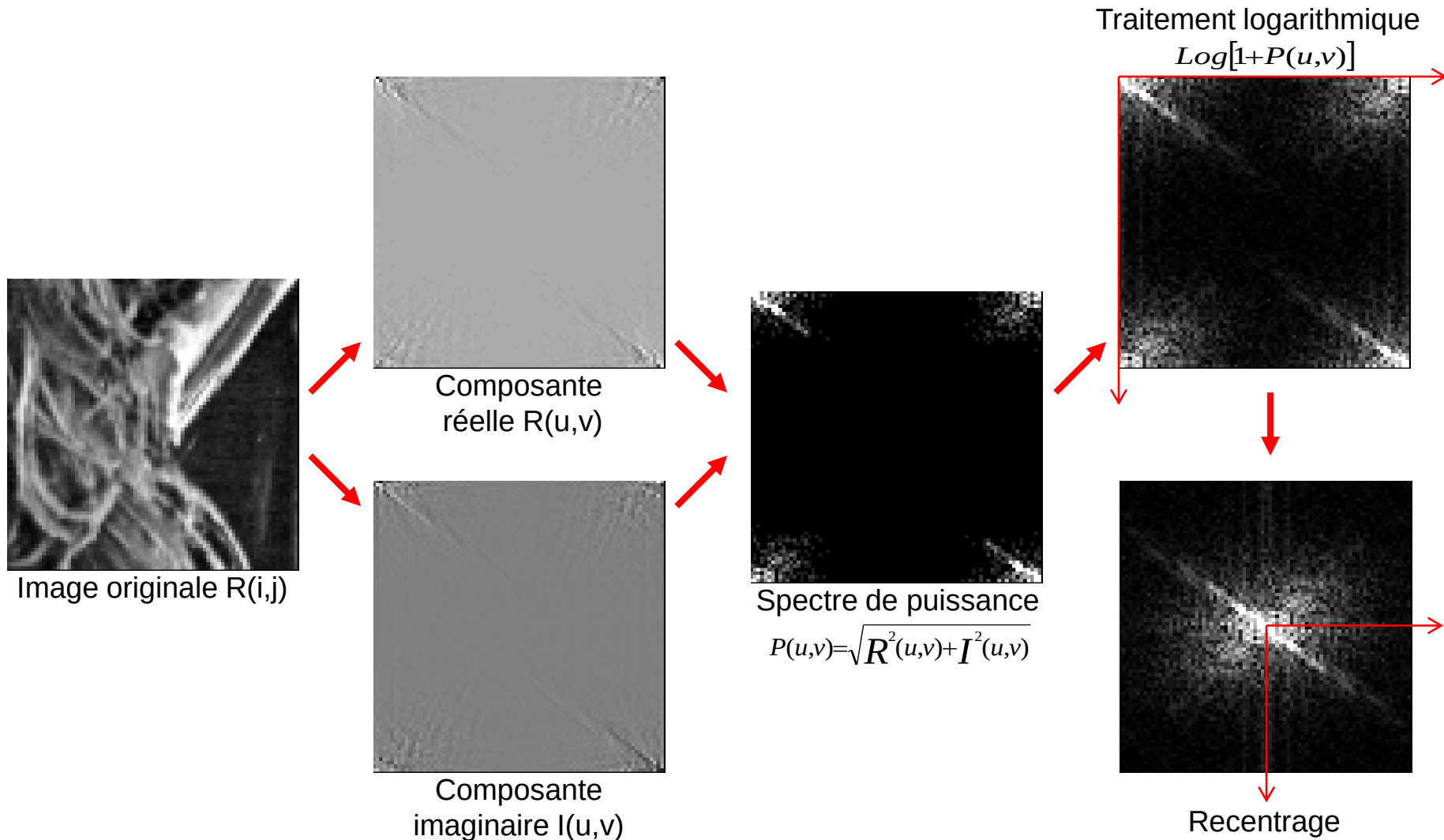
    /*-----*/
    /* Loop on samples */
    /*-----*/
    for (i=0;i<m;i++) {
        x2[i] = 0;
        y2[i] = 0;
        arg = - dir * 2.0 * 3.141592654 * (double)i / (double)m;
        for (k=0;k<m;k++) {
            cosarg = cos(k * arg);
            sinarg = sin(k * arg);
            x2[i] += (x1[k] * cosarg - y1[k] * sinarg);
            y2[i] += (x1[k] * sinarg + y1[k] * cosarg);
        }
    }

    /*-----*/
    /* Copy the data back */
    /*-----*/
    if (dir == 1) {
        for (i=0;i<m;i++) {
            x1[i] = x2[i] / (double)m;
            y1[i] = y2[i] / (double)m;
        }
    } else {
        for (i=0;i<m;i++) {
            x1[i] = x2[i];
            y1[i] = y2[i];
        }
    }

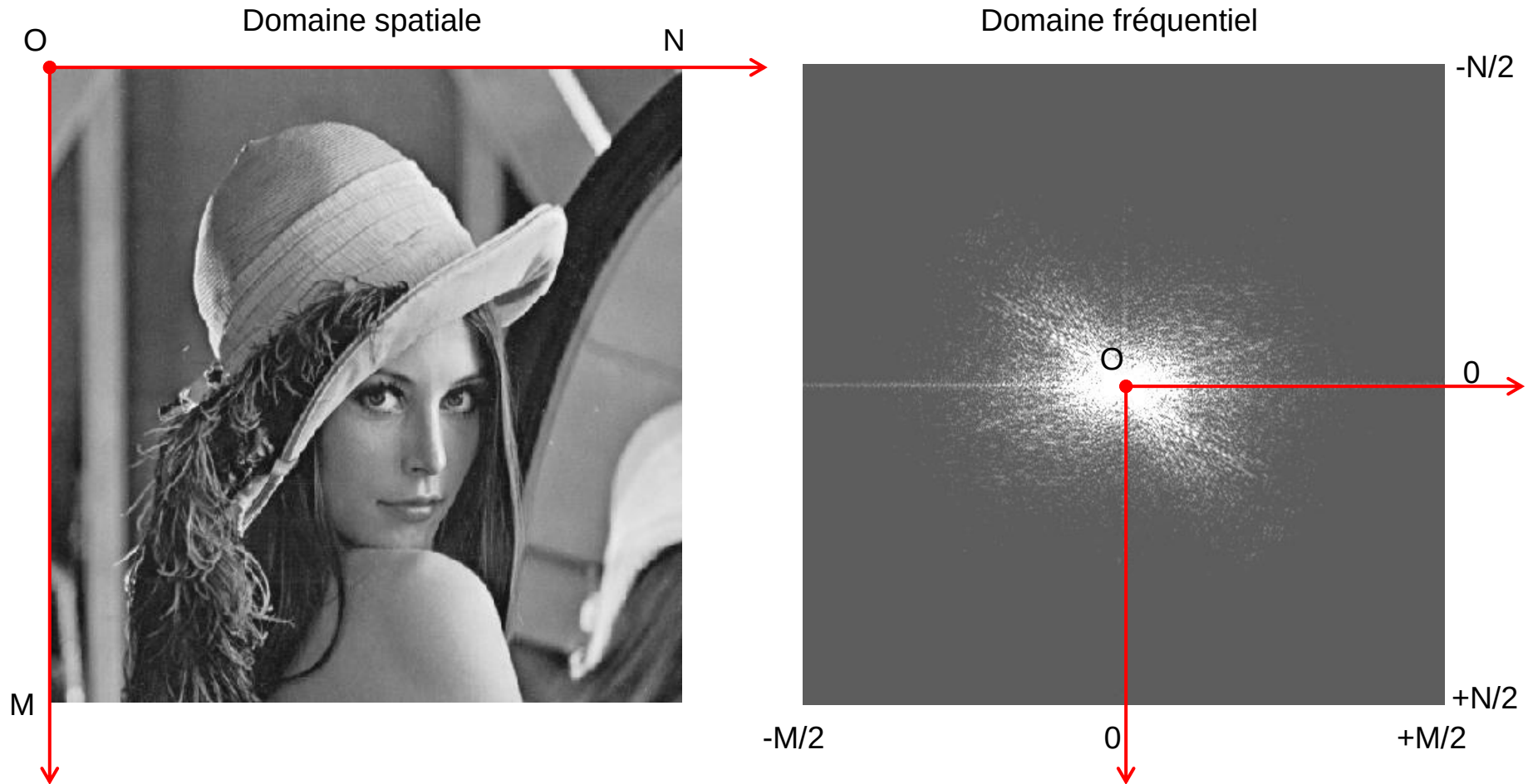
    /*-----*/
    /* Release memory and return */
    /*-----*/
    free(x2);
    free(y2);
    return(TRUE);
}

```

■ Composantes réelle et imaginaire – Spectre de puissance

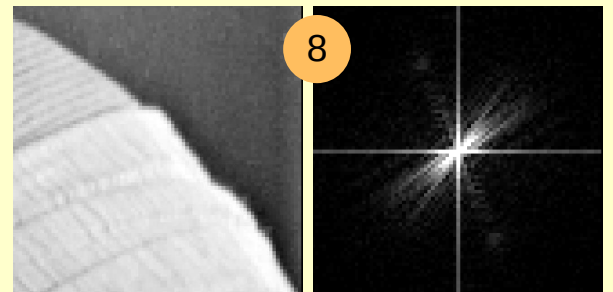
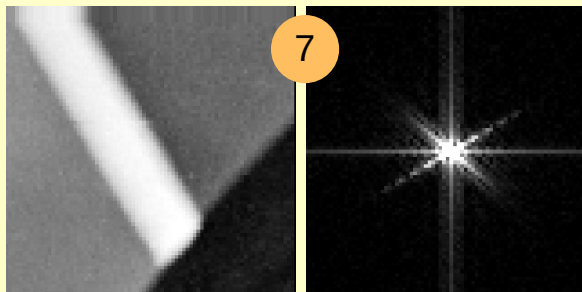
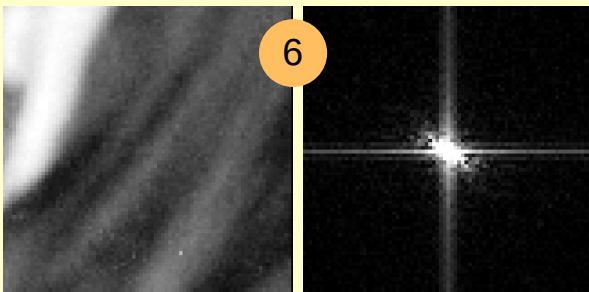
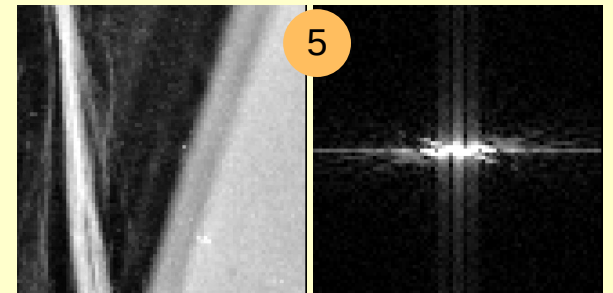
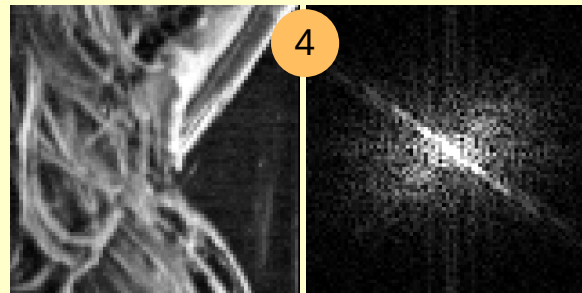
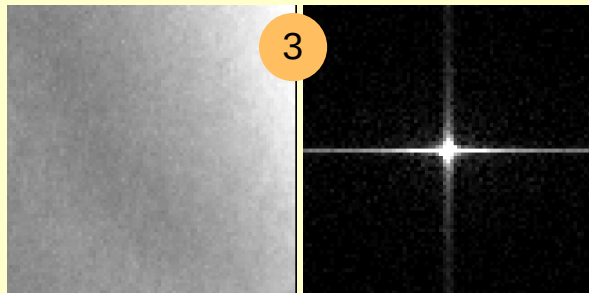
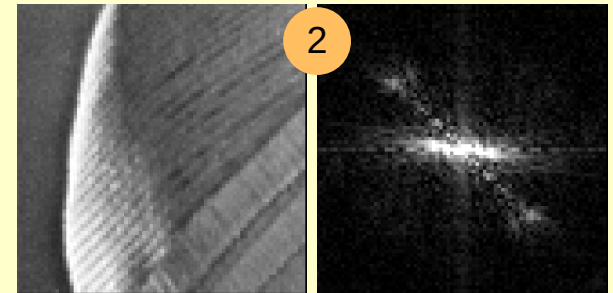
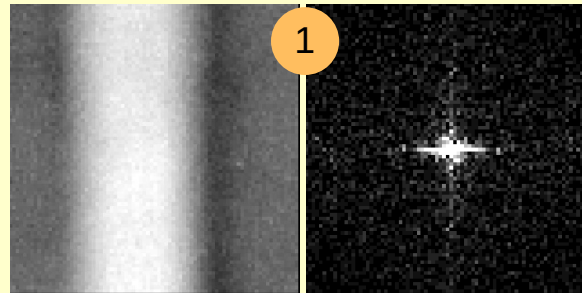
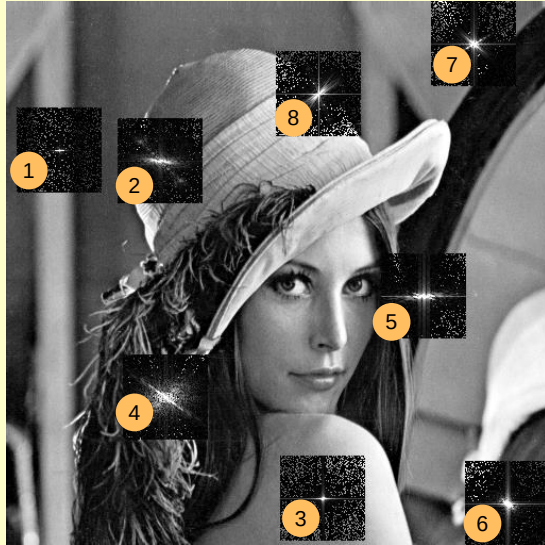


■ Spectre d'énergie des fréquences d'une image – Mesure globale



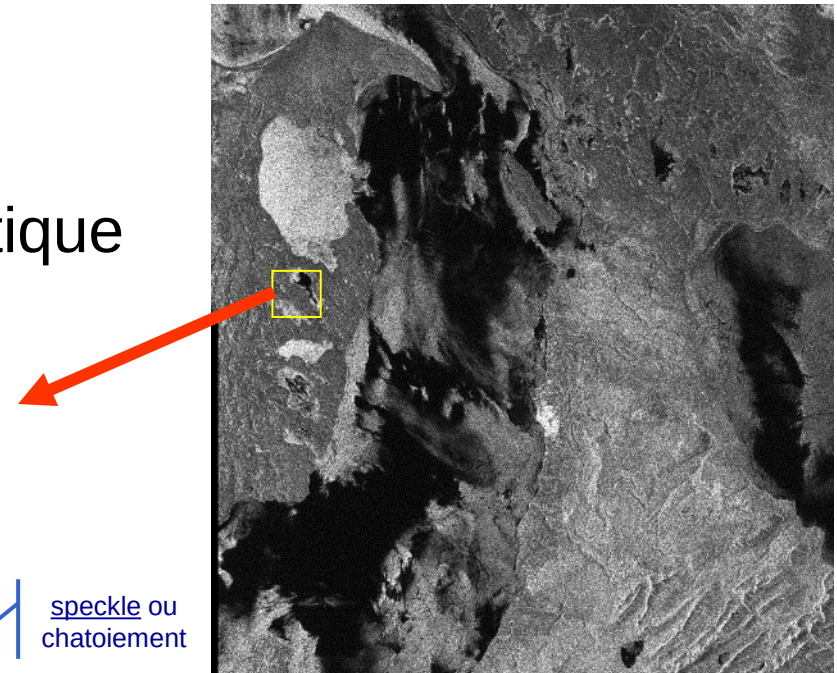
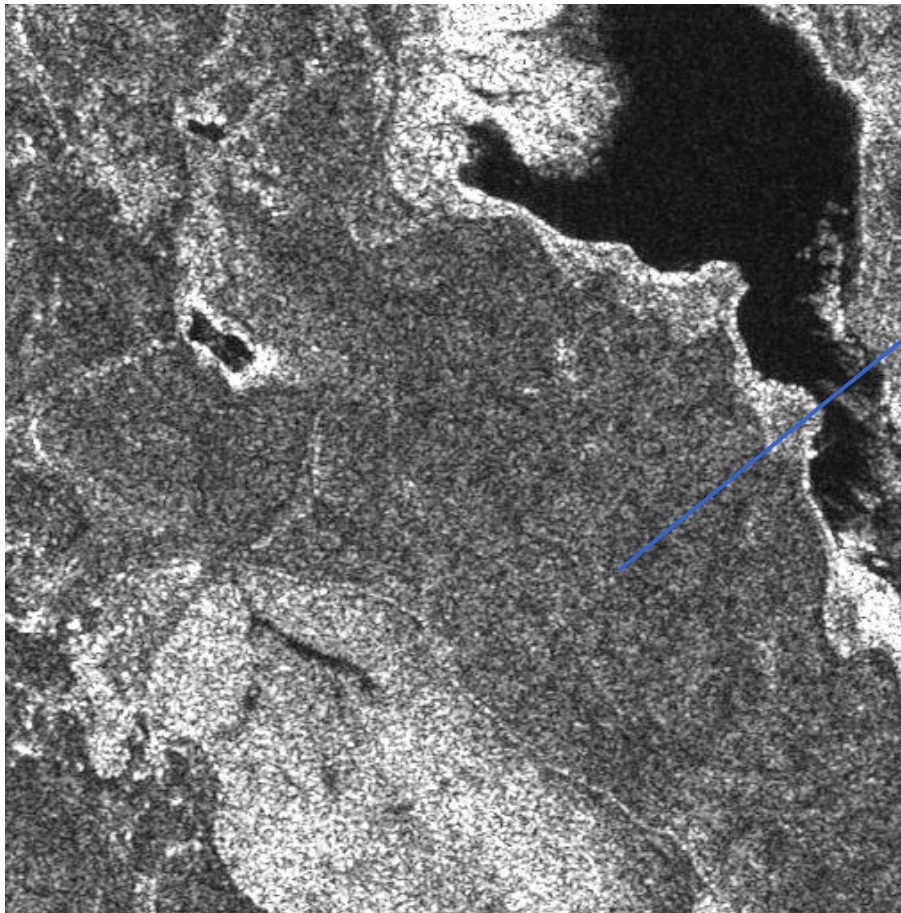


Mesures locales



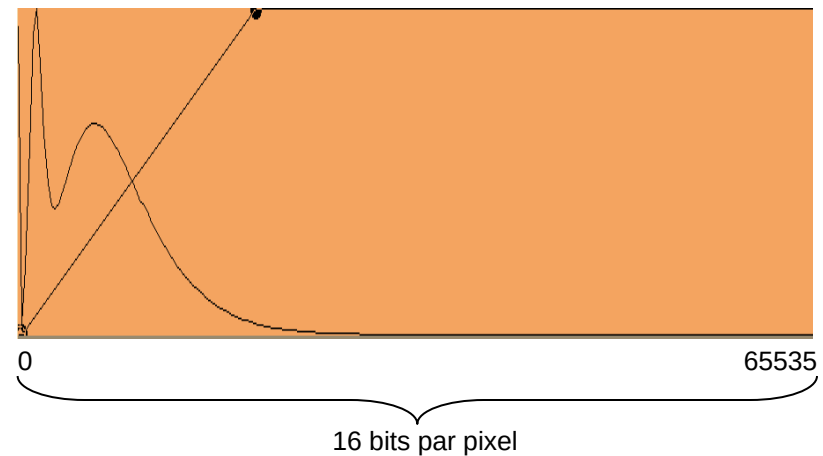
Images bruitées

⊕ RADAR à ouverture synthétique



speckle ou
chatolement

image originale – ERS1 SAR 29/11/1992 - Patagonie

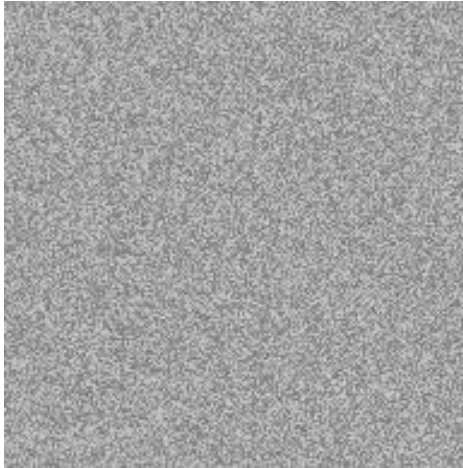




⊕ Bruit additif selon un modèle

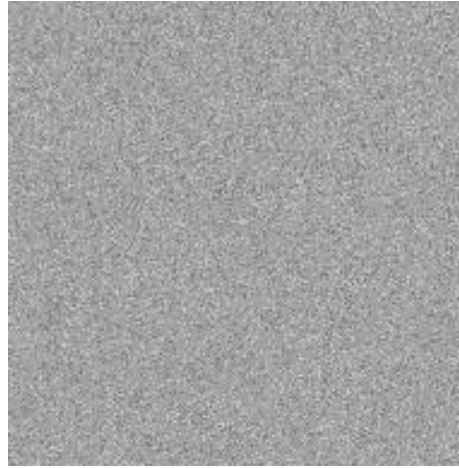
bruit uniforme

densité 100% - amplitude 100



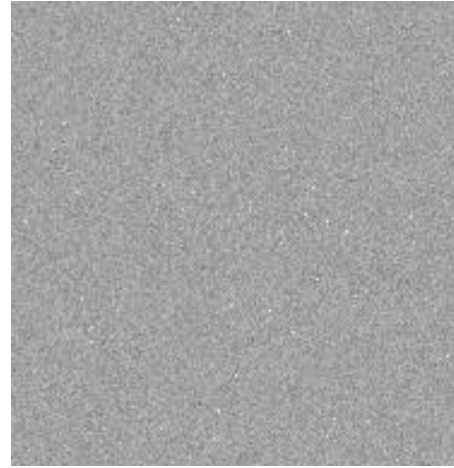
bruit uniforme

densité 50% - amplitude 100



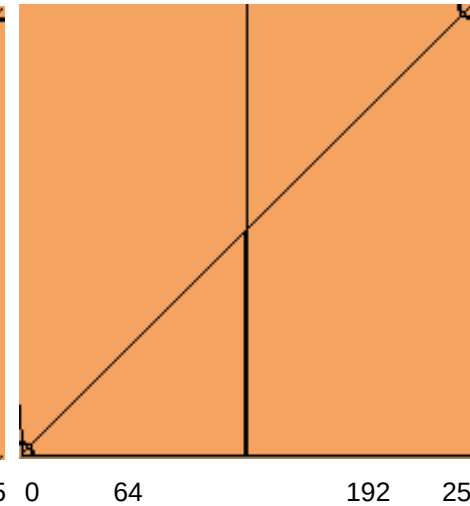
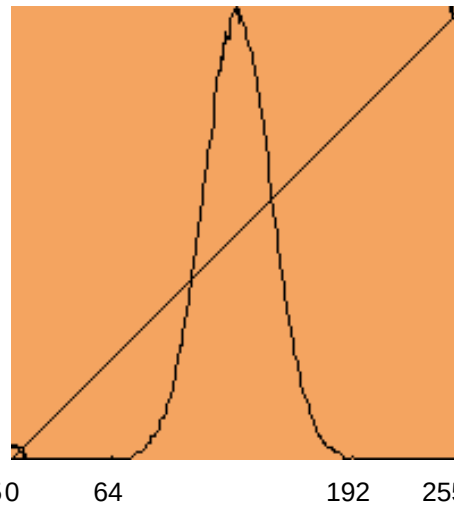
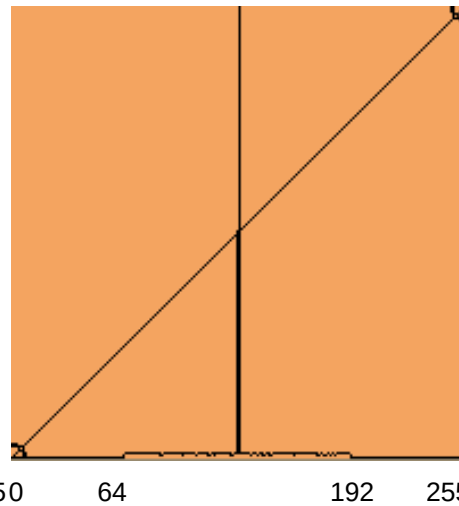
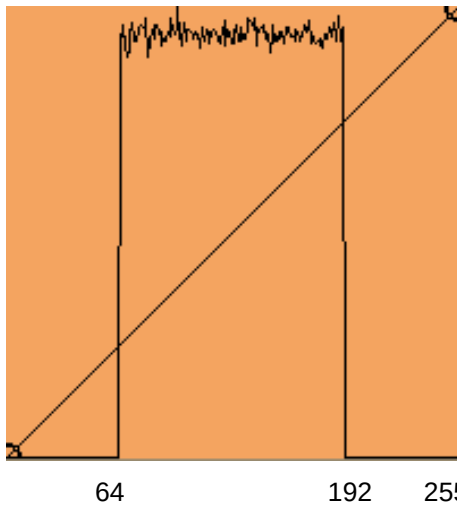
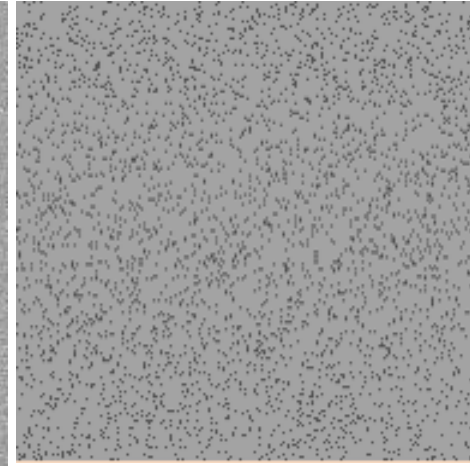
bruit gaussien

densité 100% - $\sigma=0,2$ - amplitude 150



bruit impulsionnel

densité 10%



Filtrages adaptatifs

⊕ Filtre de LEE

- ▣ Modèle de « bruit multiplicatif »

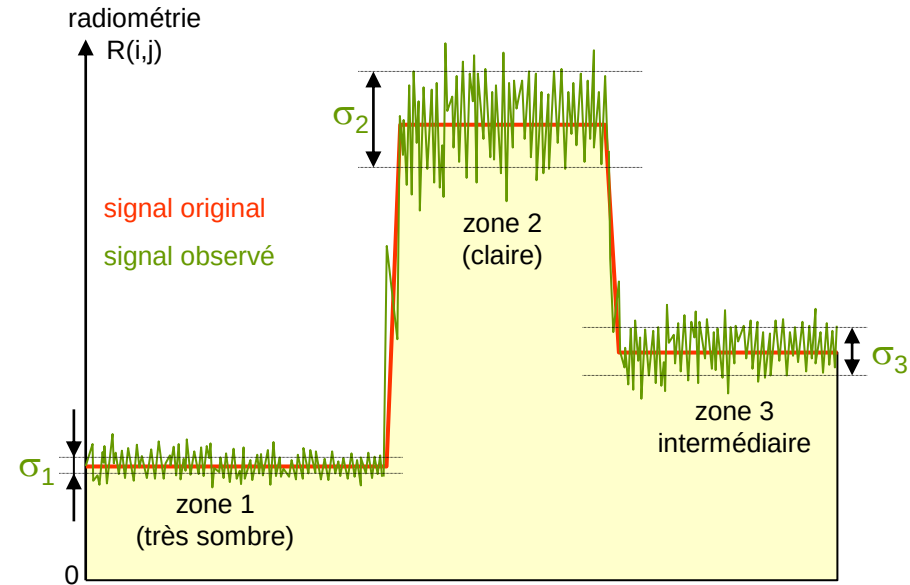
$$r(i, j) = r_0(i, j) \times n(i, j)$$

avec:

$r_0(i, j)$ image originale avant corruption par le bruit

$r(i, j)$ image observée corrompue par le bruit

$n(i, j)$ bruit multiplicatif



- ▣ Filtre de restauration de l'image originale

$$r'(i, j) = \bar{m}(i, j) + \frac{\sigma^2(i, j)}{\sigma^2(i, j) + \sigma_n^2} \times [r(i, j) - \bar{m}(i, j)]$$

avec:

$r(i, j)$ image observée corrompue par le bruit

$r'(i, j)$ image restaurée

$m(i, j)$ moyenne mesurée dans la fenêtre autour de (i, j)

$\sigma(i, j)$ écart-type mesuré dans la fenêtre autour de (i, j)

σ_n écart-type centré réduit du bruit

Fenêtre 7x7

$\sigma_n = 0 \rightarrow$ image originale

$\sigma_n = \infty \rightarrow$ moyennes locales

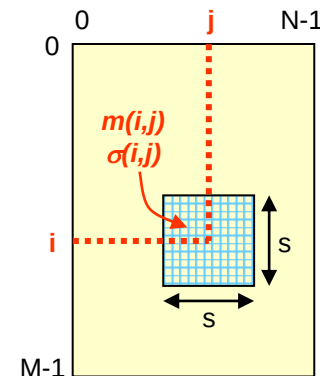
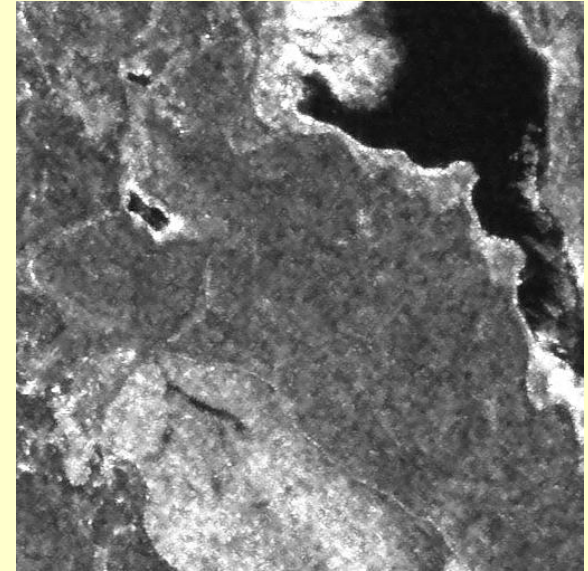
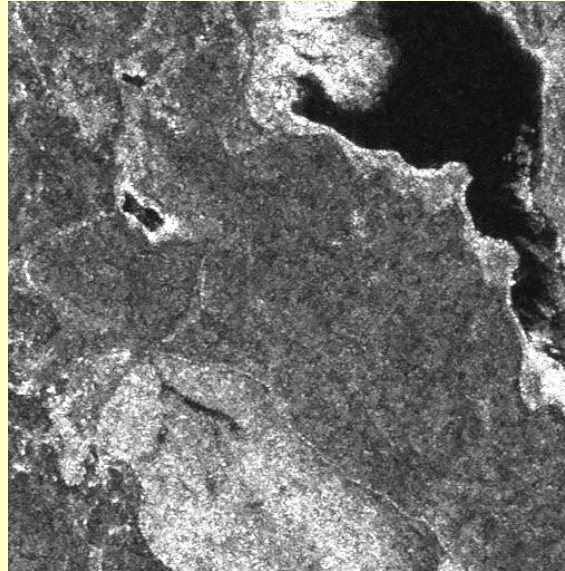
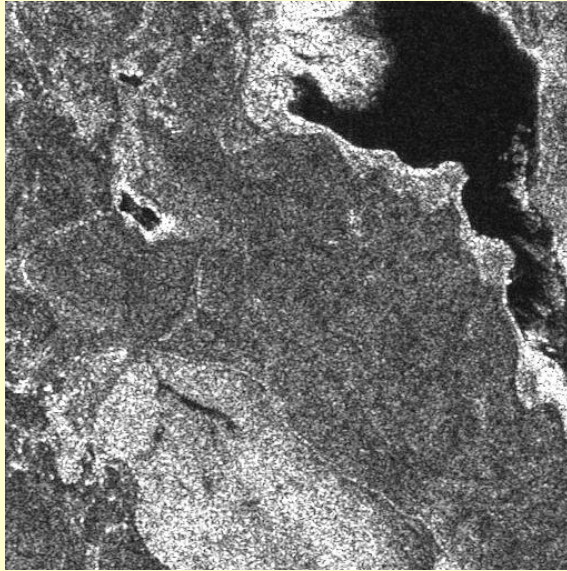




image originale – ERS1 29/11/1992

LEE - $\sigma_n=0,2$

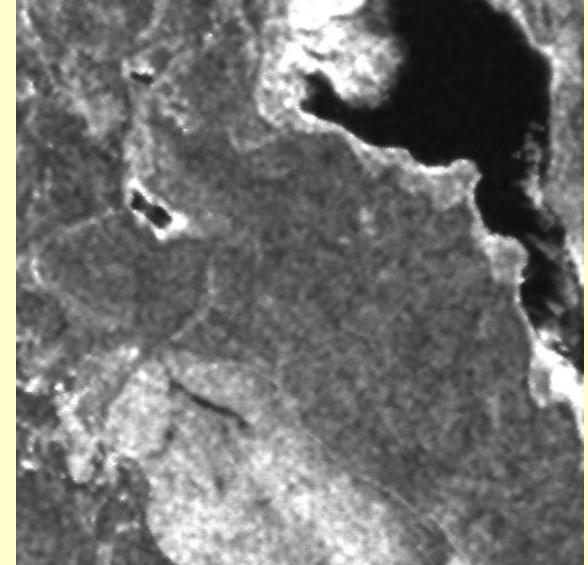
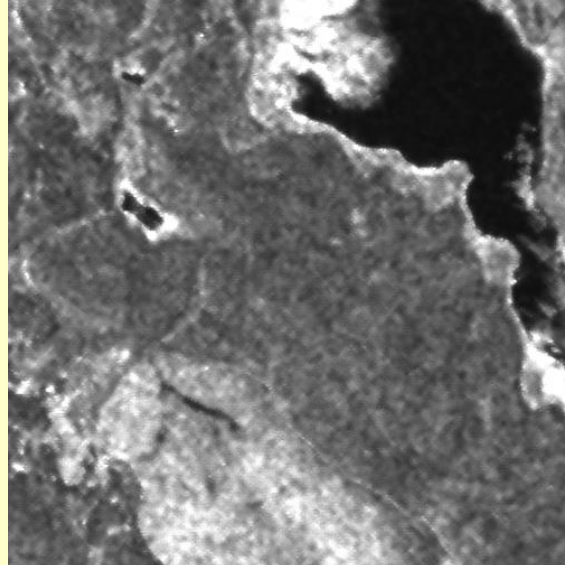
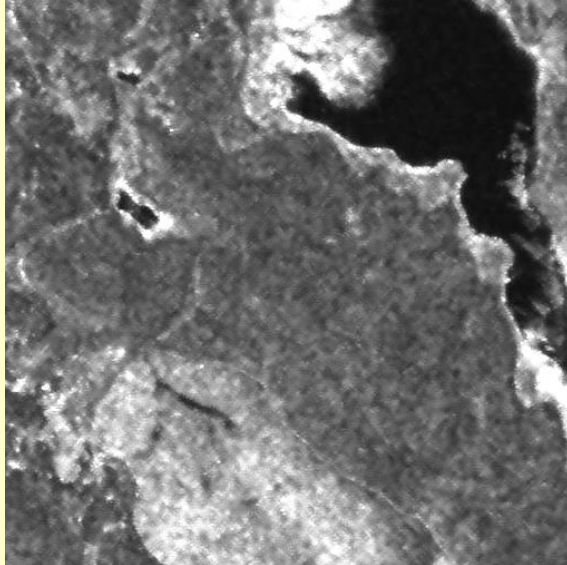
LEE - $\sigma_n=0,4$



LEE - $\sigma_n=0,6$

LEE - $\sigma_n=0,8$

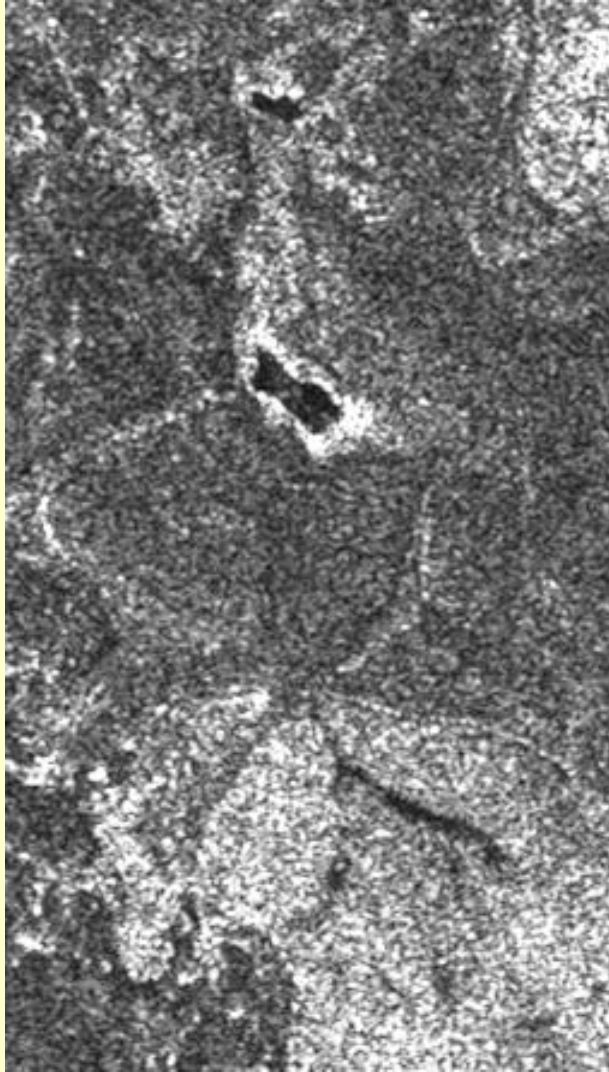
LEE - $\sigma_n=1,0$



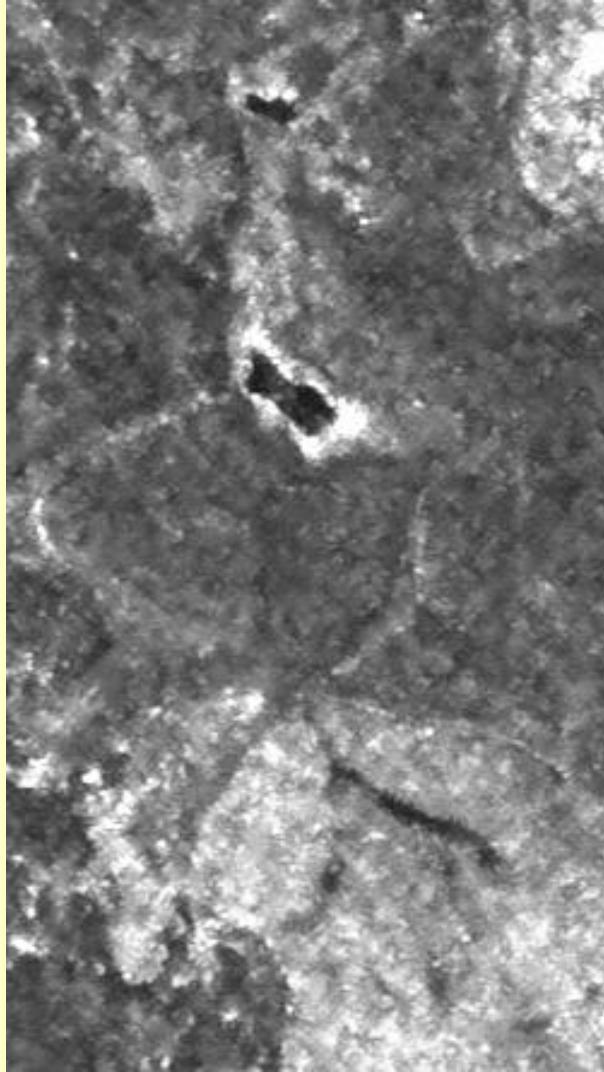


■ Filtre de LEE – Comparaison avec l'original et la moyenne 7x7

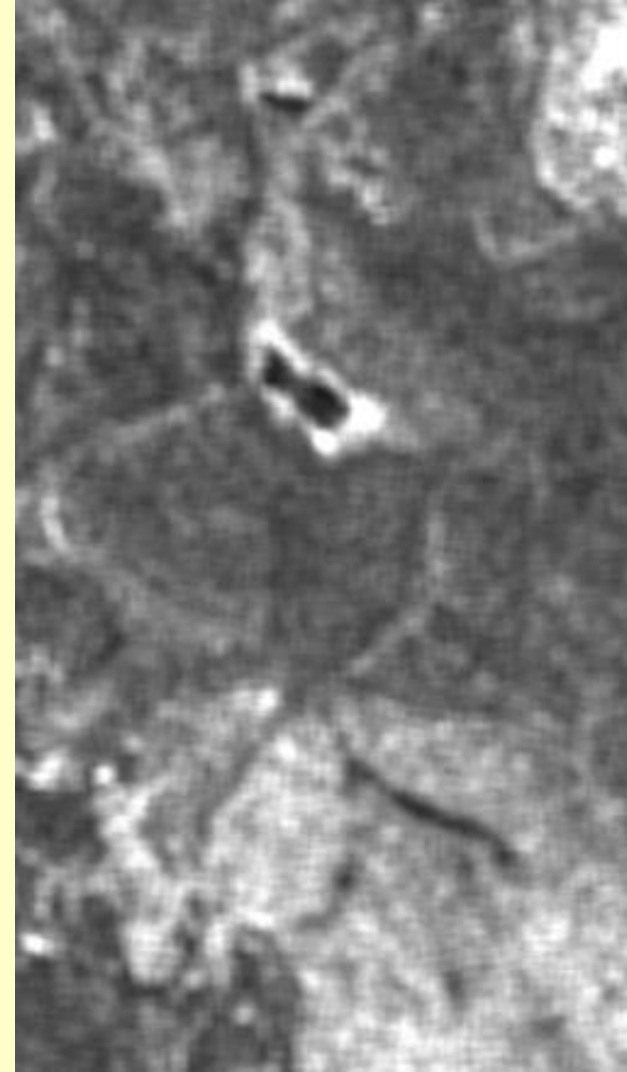
image originale



Filtre de LEE - $\sigma_n=0,4$



Filtre moyenne 7x7



❖ Filtre de KUAN

❖ Modèle de « bruit additif »

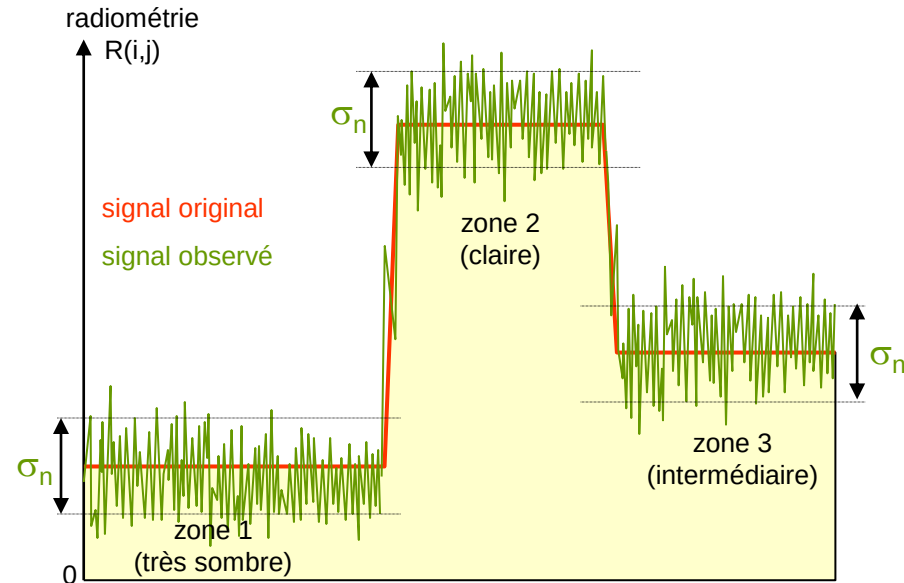
$$r(i, j) = r_0(i, j) + n(i, j)$$

avec:

$r_0(i, j)$ image originale avant corruption par le bruit

$r(i, j)$ image observée corrompue par le bruit

$n(i, j)$ bruit additif



❖ Filtre de restauration de l'image originale

$$r'(i, j) = \bar{m}(i, j) + \frac{\sigma^2(i, j) - \sigma_n^2}{\sigma^2(i, j)} \times [r(i, j) - \bar{m}(i, j)]$$

avec:

$r(i, j)$ image observée corrompue par le bruit

$r'(i, j)$ image restaurée

$m(i, j)$ moyenne mesurée dans la fenêtre autour de (i, j)

$\sigma(i, j)$ écart-type mesuré dans la fenêtre autour de (i, j)

σ_n écart-type du bruit

Fenêtre 7x7

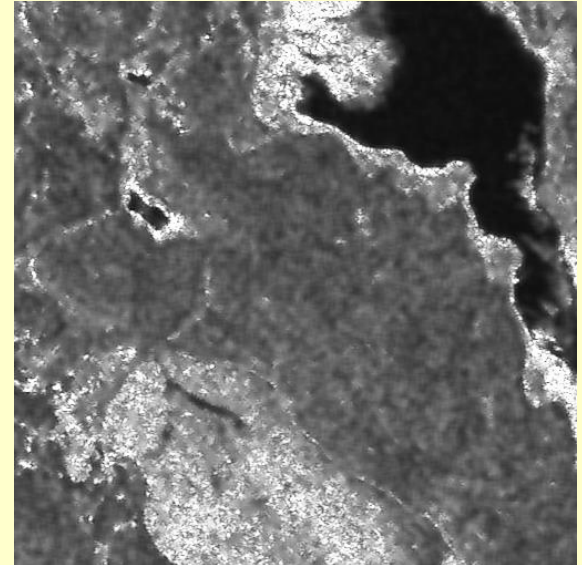
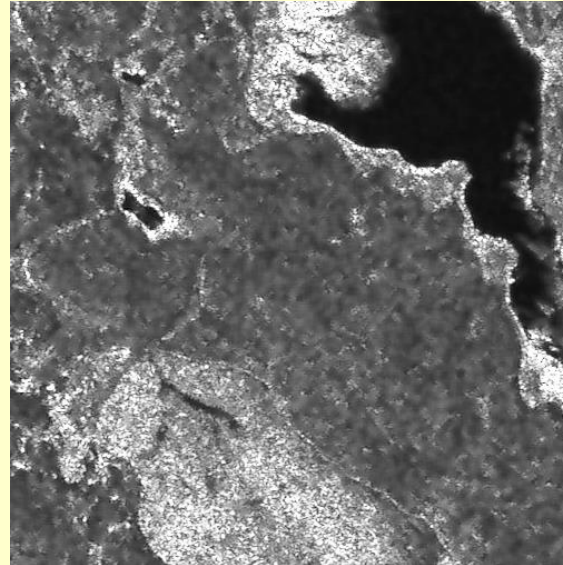
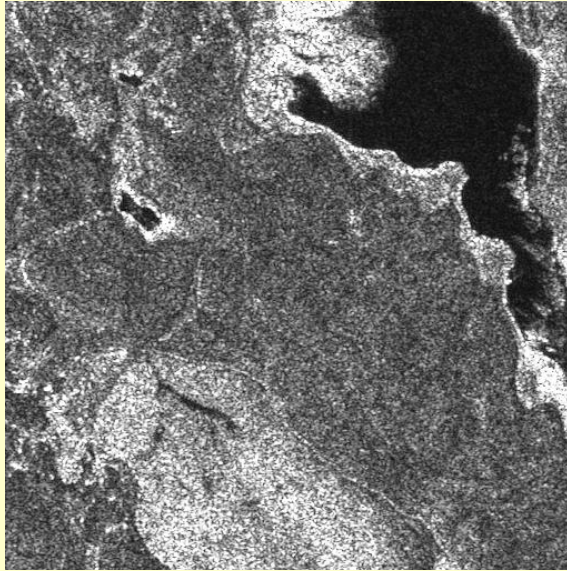
$\sigma_n = 0 \rightarrow$ image originale
 $\sigma_n > \sigma(i, j) \rightarrow$ numérateur forcé à 0
 $\rightarrow$ moyennes locales



image originale – ERS1 29/11/1992

KUAN - $\sigma_n=50$

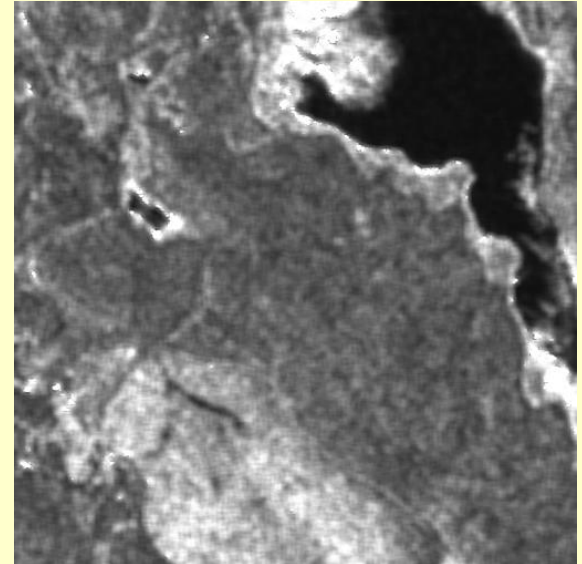
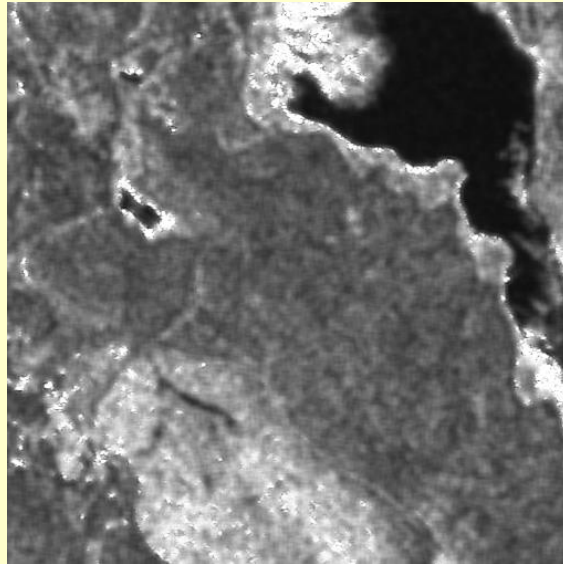
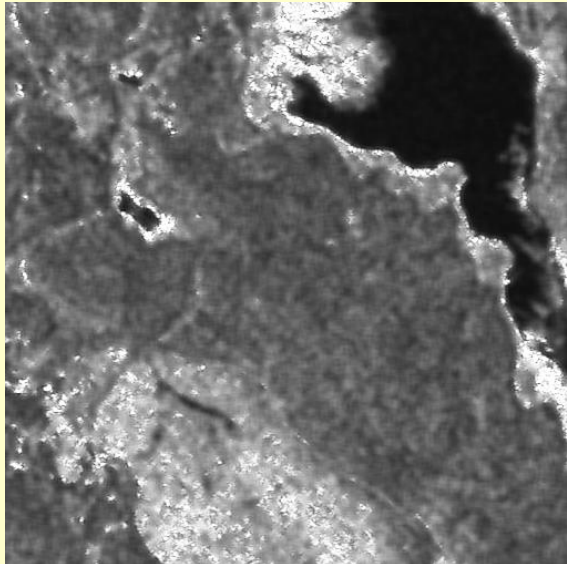
KUAN - $\sigma_n=70$



KUAN - $\sigma_n=90$

KUAN - $\sigma_n=110$

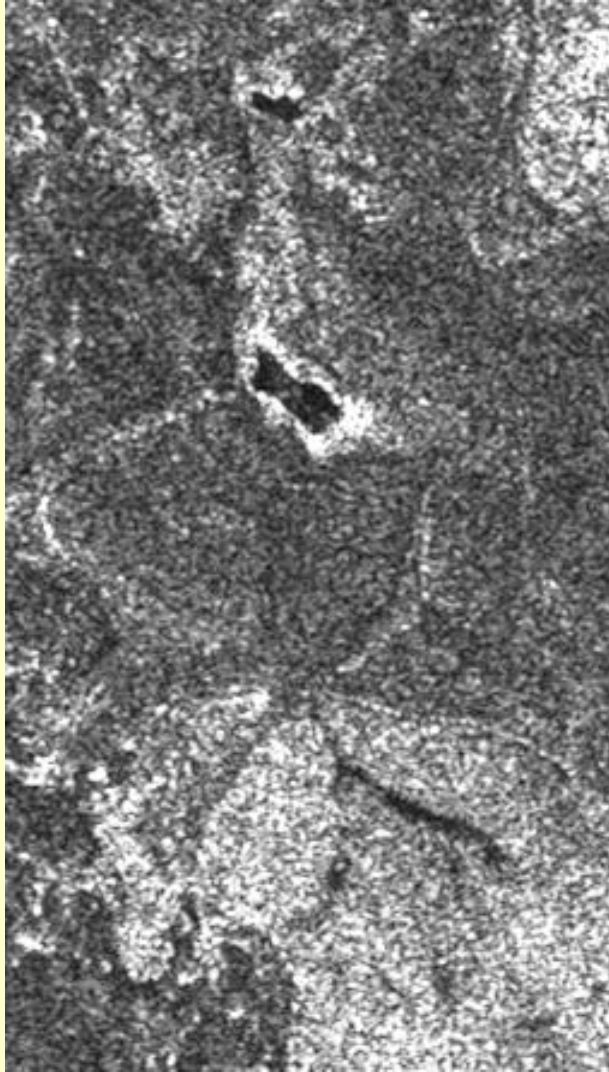
KUAN - $\sigma_n=150$



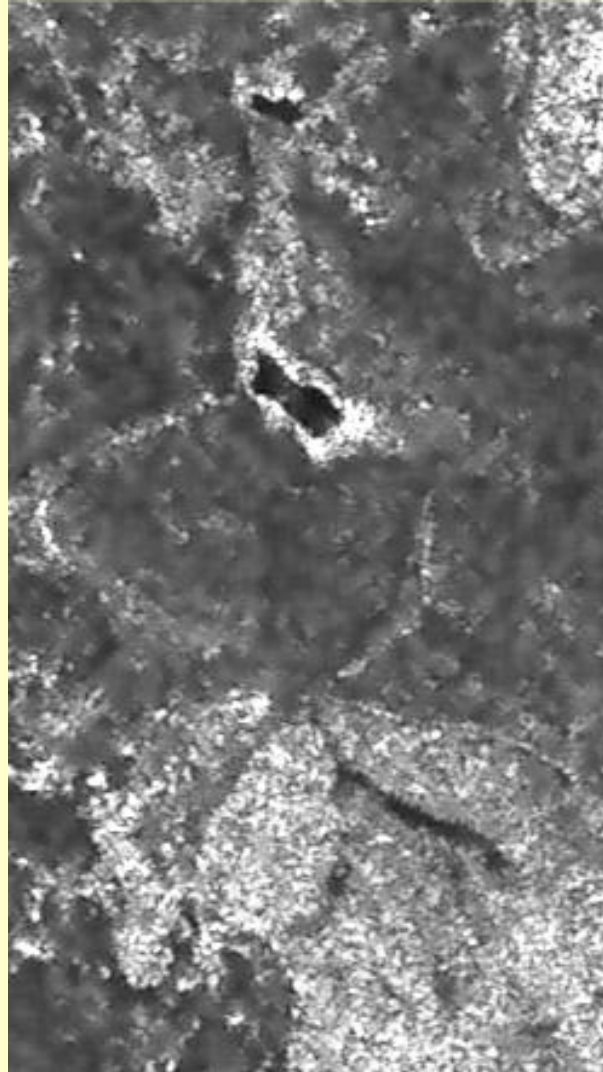


■ Filtre de KUAN – Comparaison avec le filtre de LEE

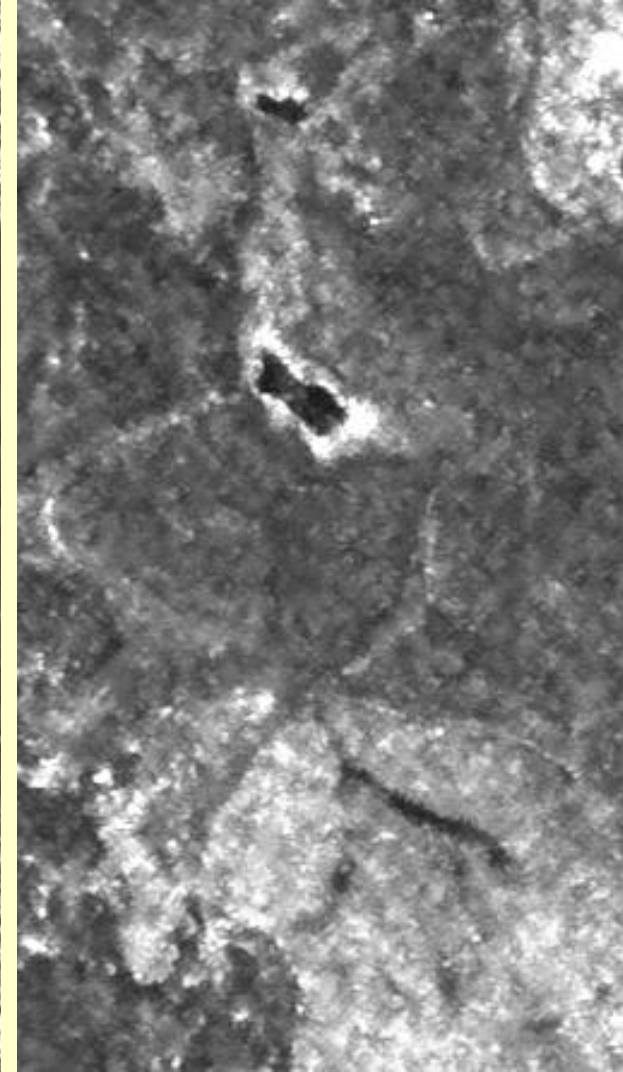
image originale



Filtre de KUAN - $\sigma_n=50$



Filtre de LEE - $\sigma_n=0,4$





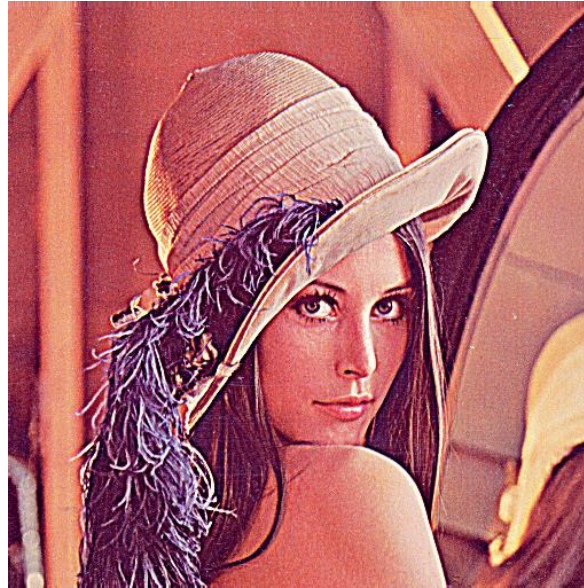
Application au post-traitement de rehaussement des contours

Image originale



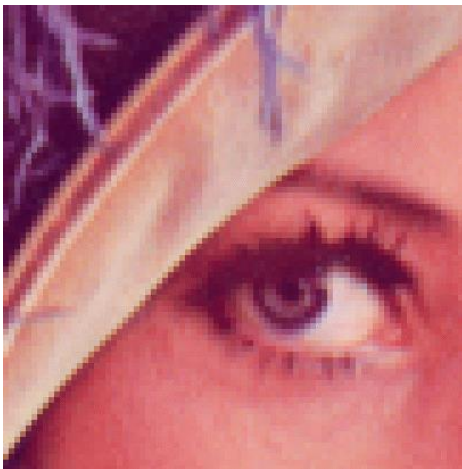
Image rehaussée (gain $\beta = 3$)

$$R'(i, j) = R(i, j) + \beta \times [R(i, j) - \overline{m_{\text{CC}}}]$$



Filtre de KUAN ($\sigma_{\text{bruit}} = 15$)

Idée de Sylvain DUMAZET (mars 2005)



✚ Stretching linéaire imposé selon les statistiques locales

$$r'(i, j) = \frac{\sigma_0}{\sigma(i, j)} \times r(i, j) + \left[\bar{m}_0 - \frac{\sigma_0}{\sigma(i, j)} \times \bar{m}(i, j) \right]$$

avec:

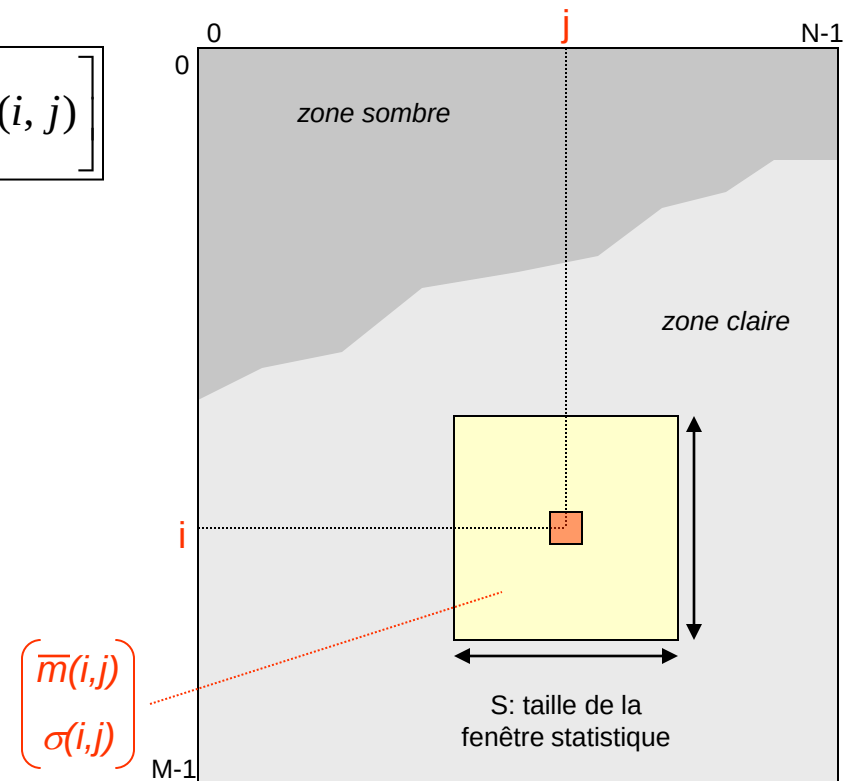
$\bar{m}_0$ moyenne imposée en sortie

σ_0 écart-type imposée en sortie

$\bar{m}(i, j)$ moyenne mesurée dans la fenêtre autour de (i, j)

$\sigma(i, j)$ écart-type mesuré dans la fenêtre autour de (i, j)

⇐ Lien « [Stretching global imposé par des statistiques de sortie](#) »





■ new-york – $m_0=128$ – $\sigma_0=40$ – **S=101**

Application Language Display Deformation model Options Help

Reference image Work image

Add new point Zoom
Modify point 2
Remove point 2

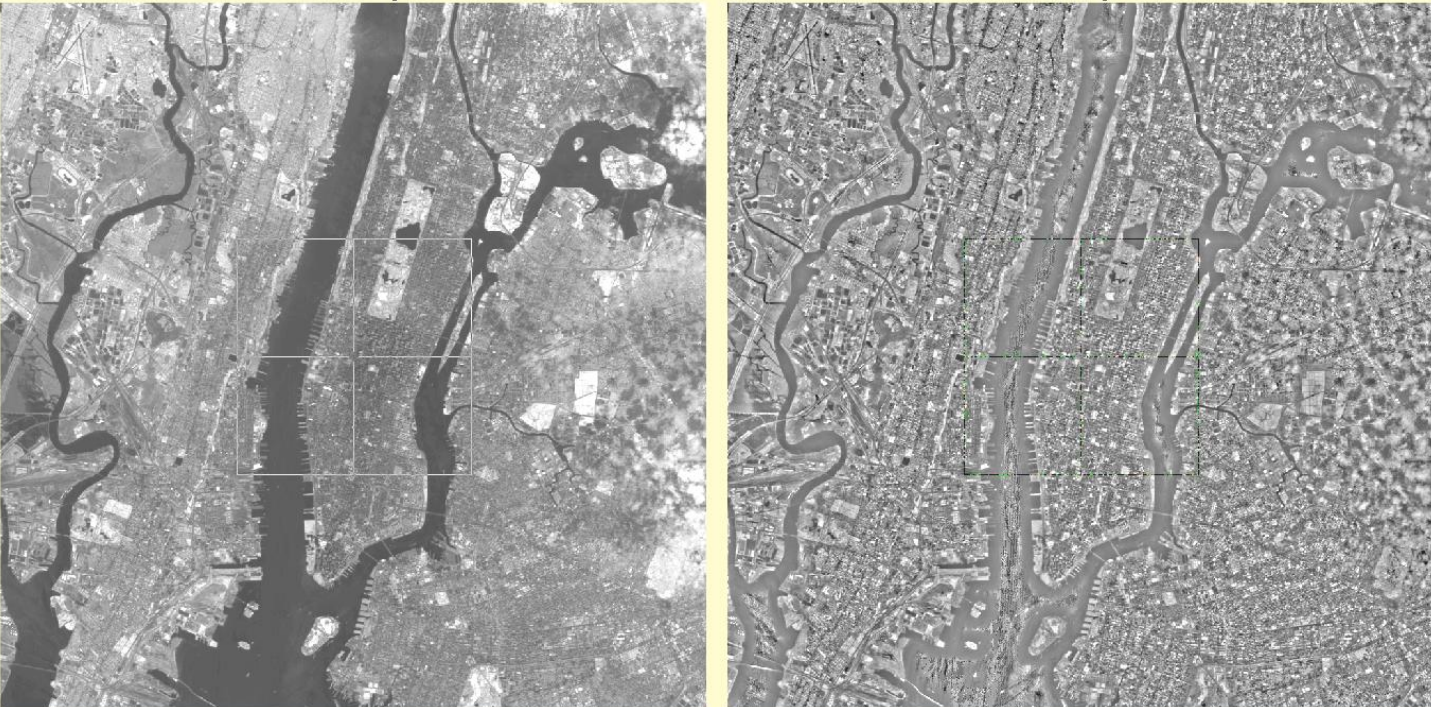
Ok Predict
Cancel Best fit



new-york – $m_0=128$ – $\sigma_0=40$ – **S=31**

Application Language Display Deformation model Options Help

Reference image Work image



Add new point Zoom

Modify point 1

Remove point 1

OK Predict

Cancel Best fit





new-york – $m_0=128$ – $\sigma_0=40$ – **S=11**

Application Language Display Deformation model Options Help

Reference image

Work image

Add new point

Modify point

Remove point

Zoom

1

1

Ok

Cancel

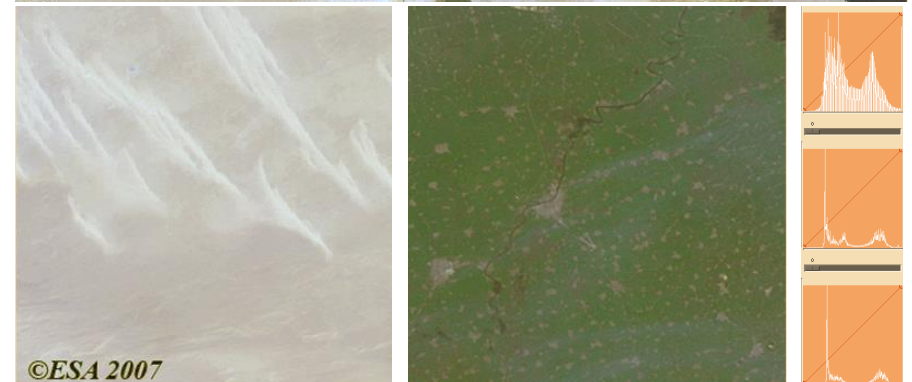
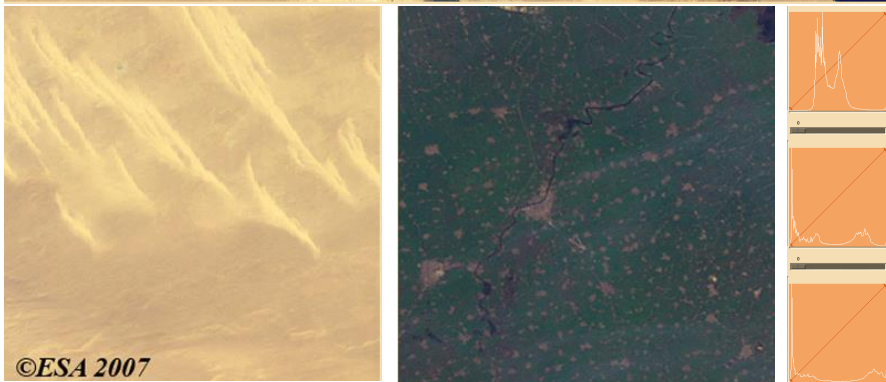
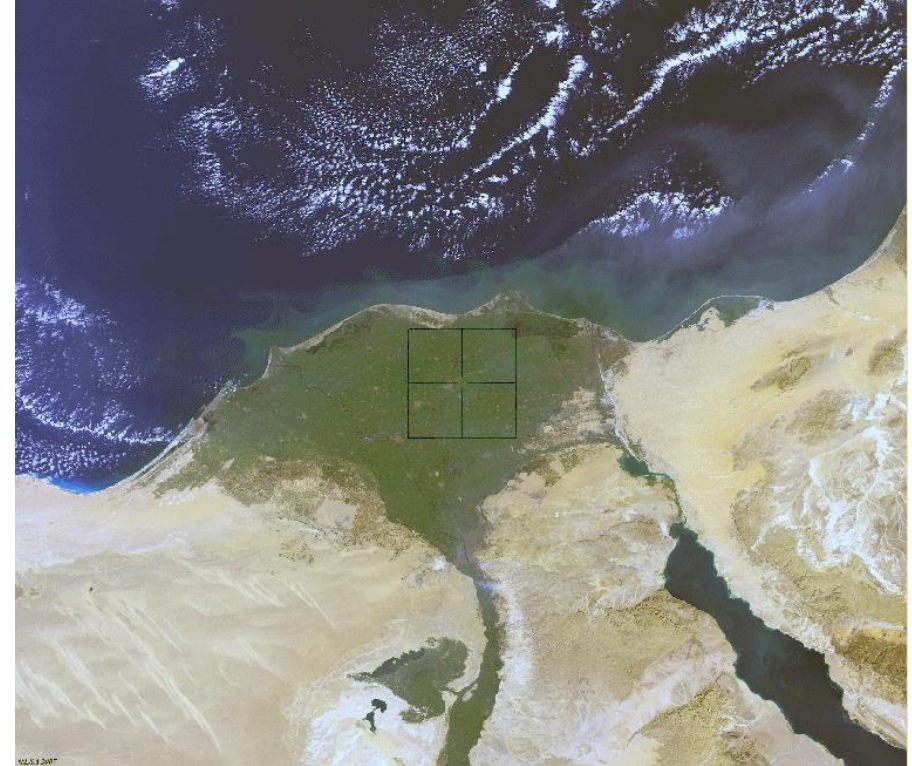
Predict

Best fit



❏ Nil – $m_0=128$ - $\sigma_0=60$ – **Stretching imposé global (sur toute l'image)**

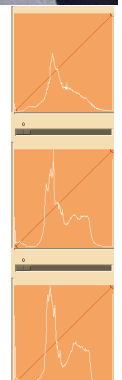
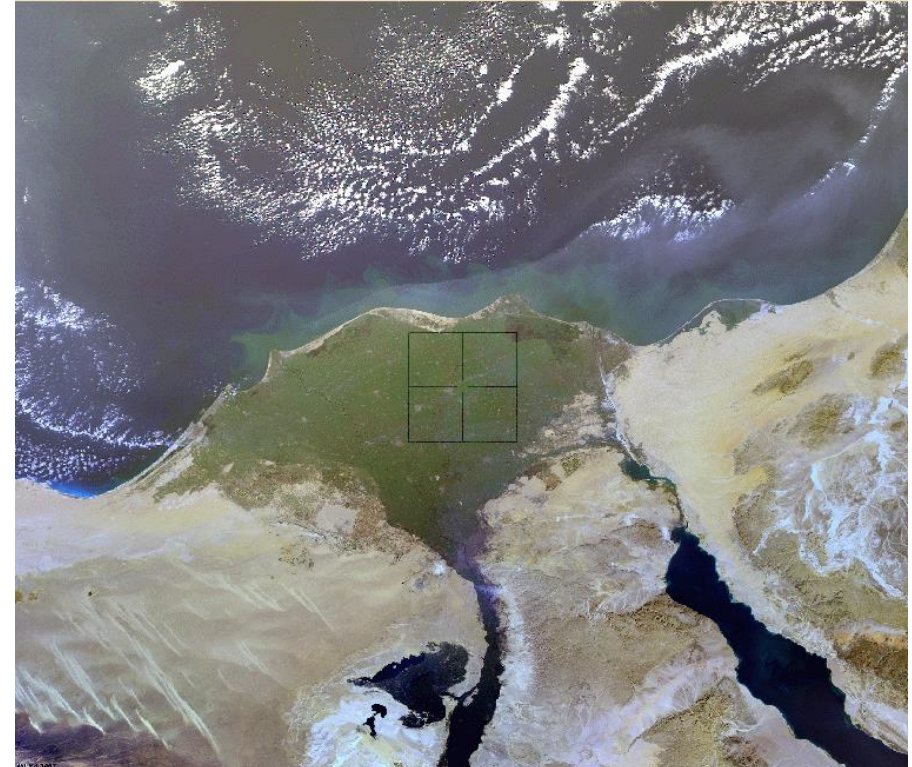
image originale (2417 x 2807)





❏ Nil – $m_0=128$ – $\sigma_0=60$ – **S=1501**

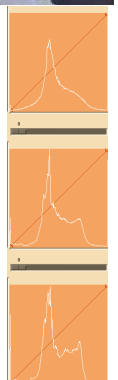
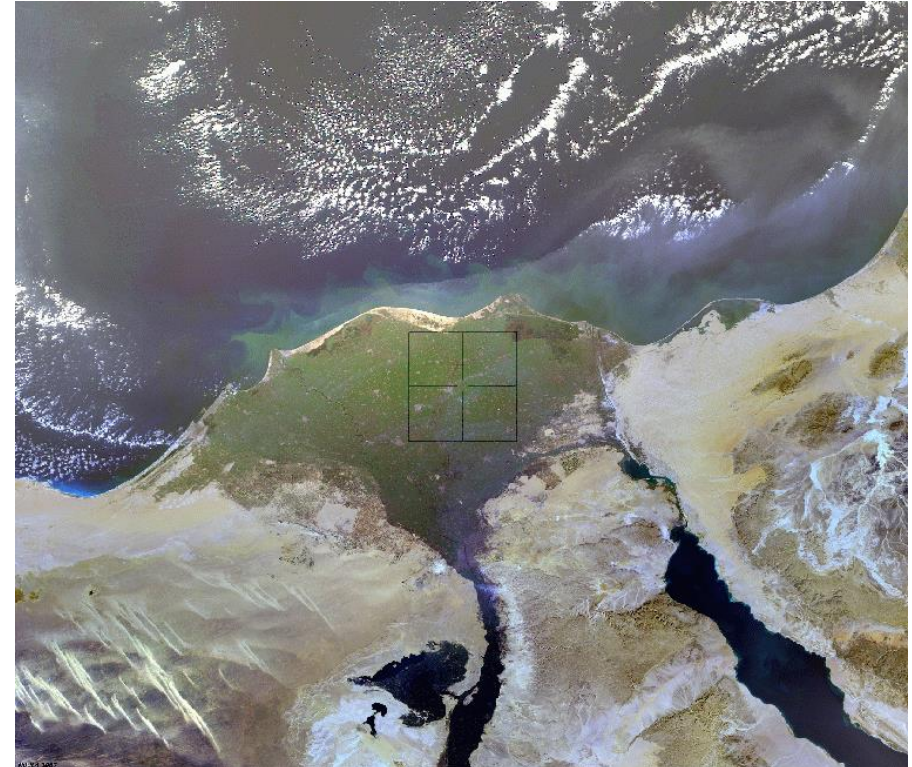
image originale (2417 x 2807)





❏ Nil – $m_0=128$ – $\sigma_0=60$ – **S=1001**

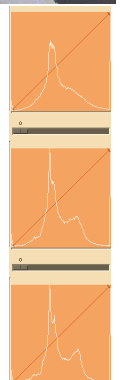
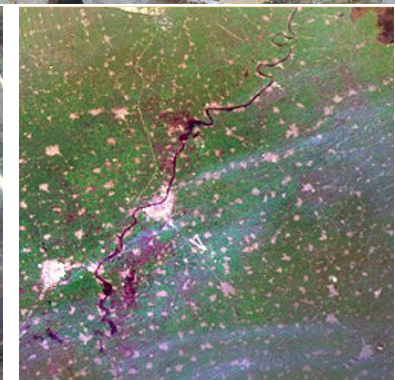
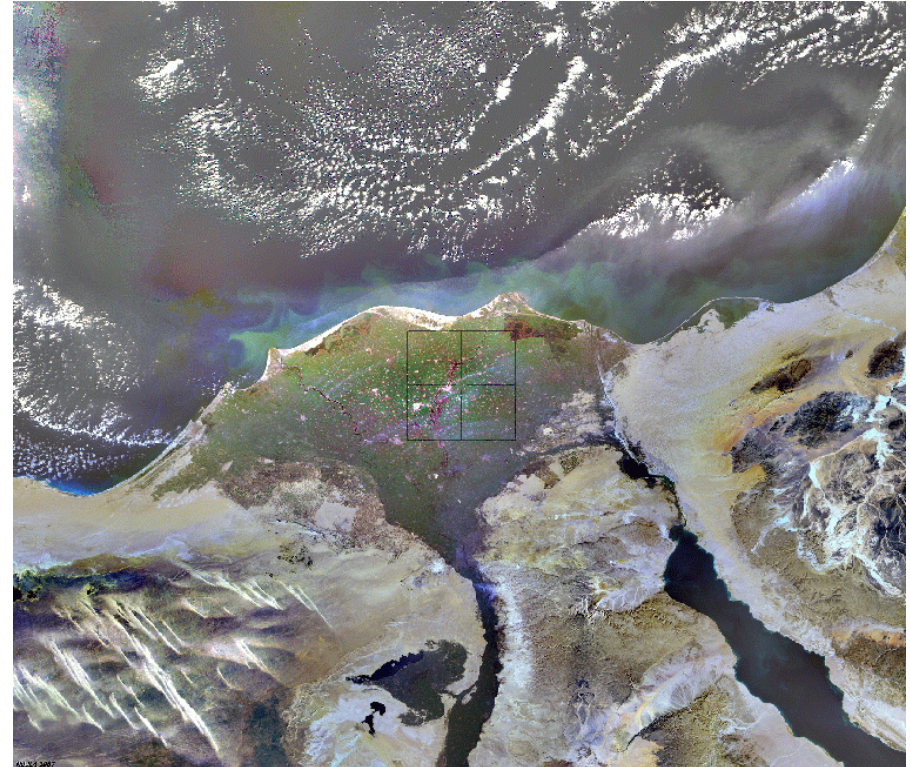
image originale (2417 x 2807)





❏ Nil – $m_0=128$ – $\sigma_0=60$ – **S=501**

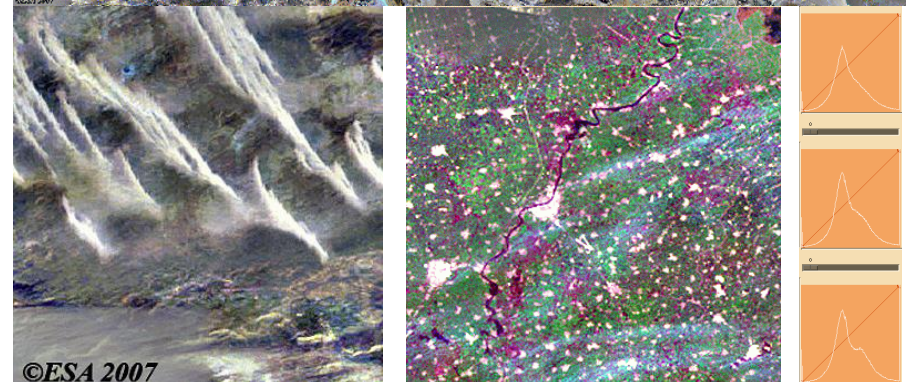
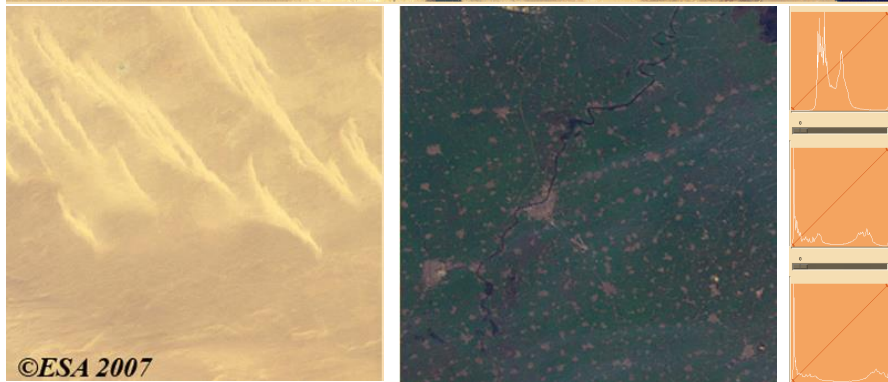
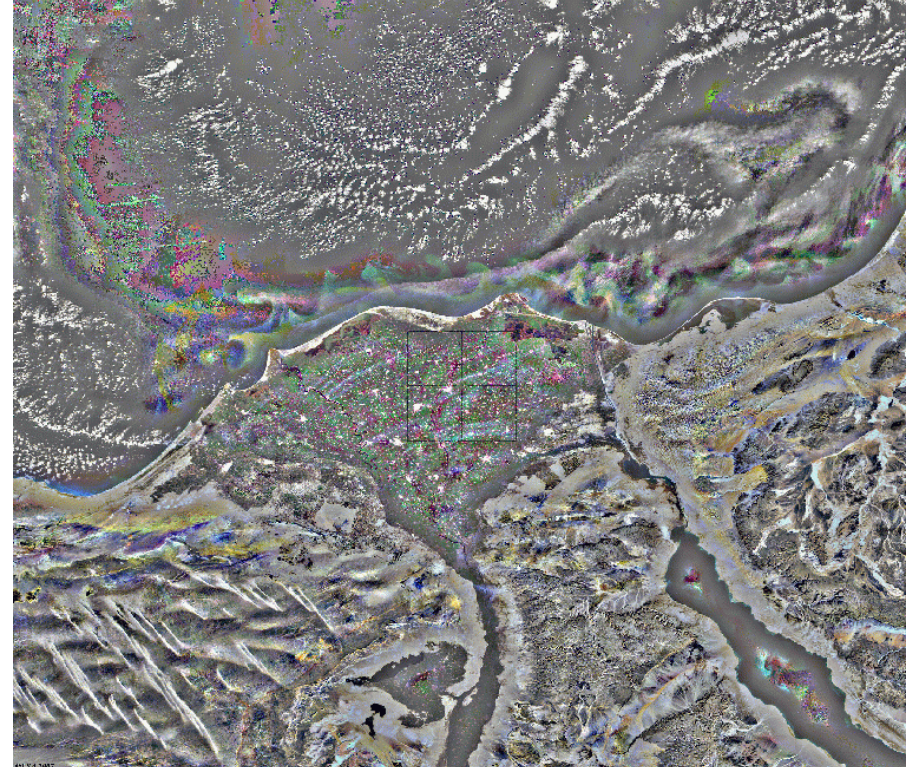
image originale (2417 x 2807)





❏ Nil – $m_0=128$ – $\sigma_0=60$ – **S=101**

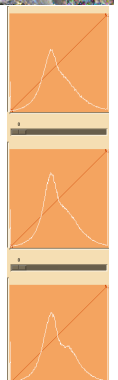
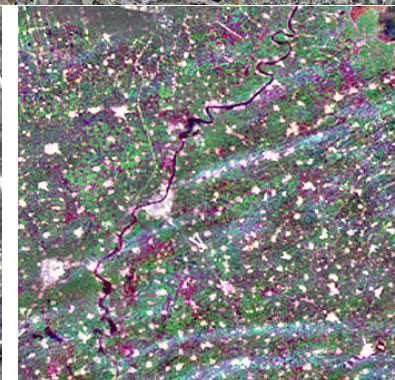
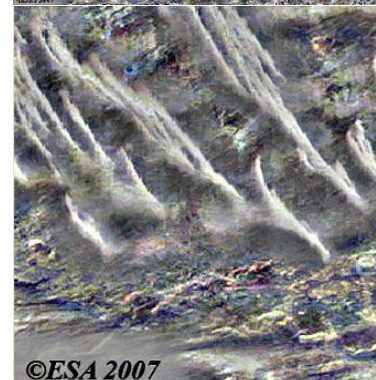
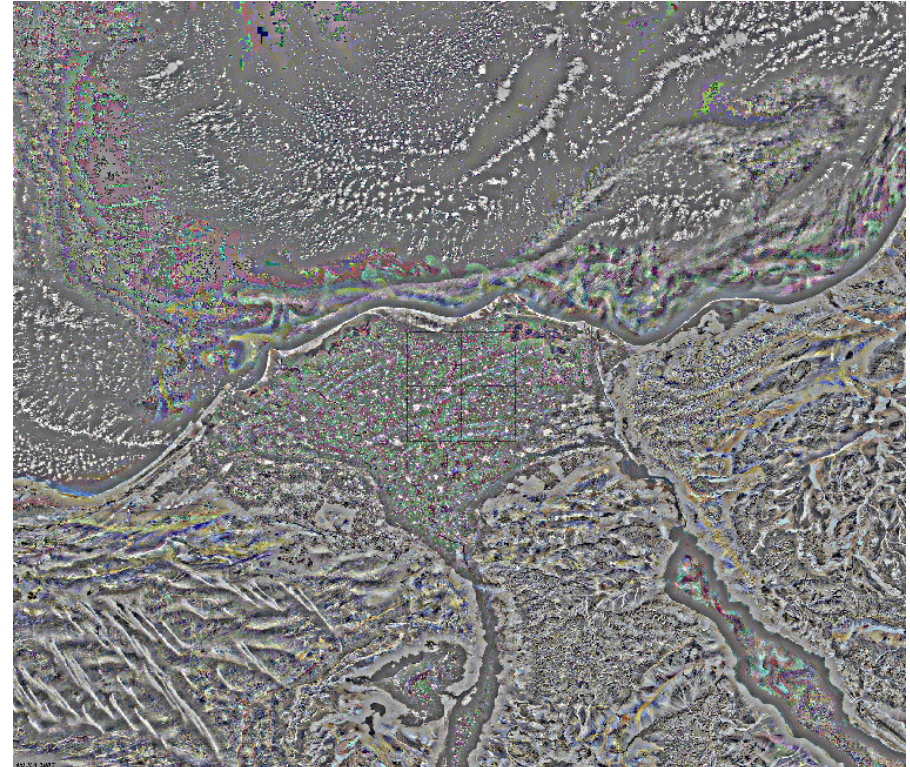
image originale (2417 x 2807)





❏ Nil – $m_0=128$ – $\sigma_0=60$ – **S=51**

image originale (2417 x 2807)





■ Stretching local appliqué aux images Radar

Scène Envisat ASAR WSM acquise le 20/05/2008 au large du Mozambique

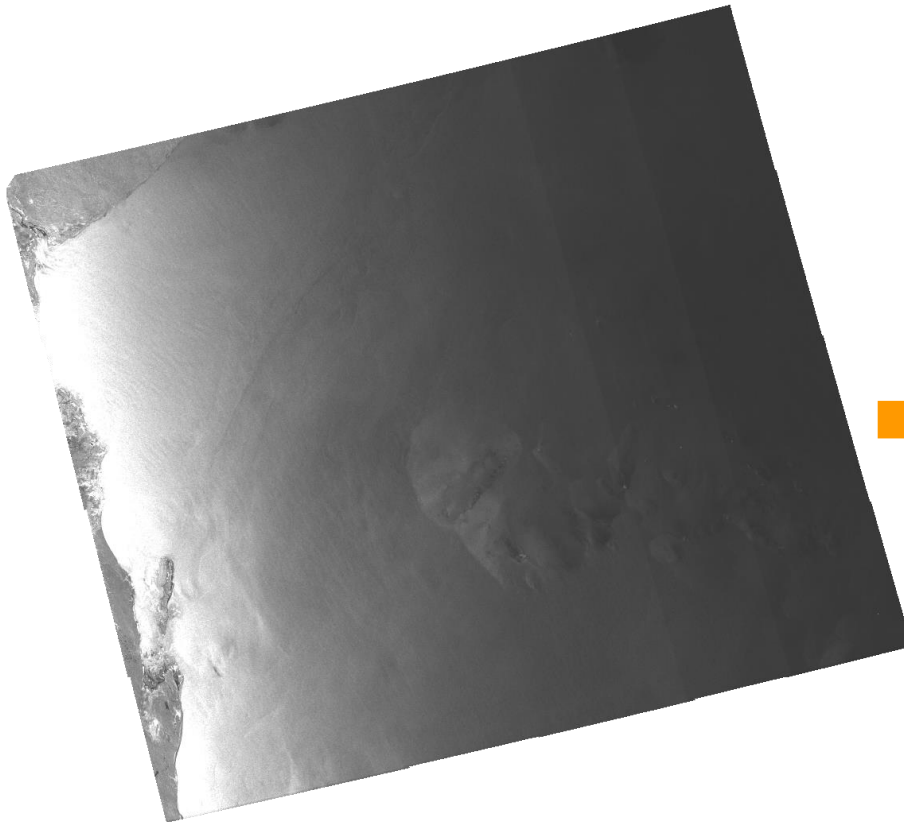
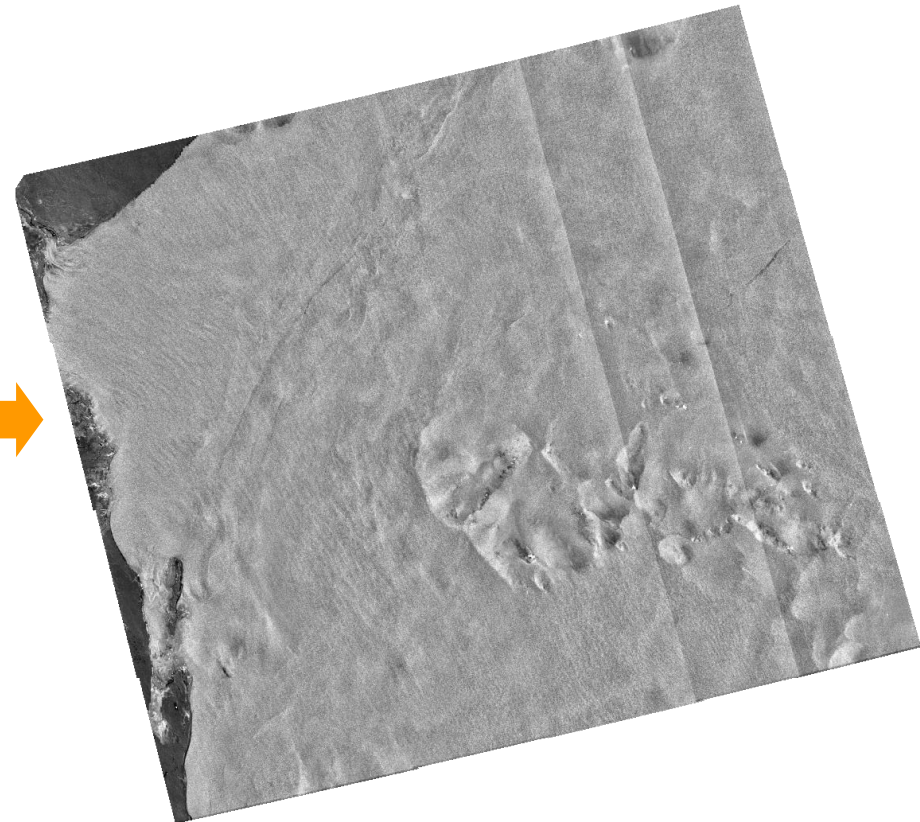


image originale



résultat du stretching local
($m_0=160$ - $\sigma_0=50$ - $S=301$)

Filtrages heuristiques

⊕ Filtre médian

■ Valeur médiane dans une fenêtre 3x3

0	1	2	3	4	5	6	7	8
11	16	17	21	22	26	28	32	77

■ Valeur médiane dans une fenêtre 5x5

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
5	8	9	10	11	14	15	16	17	18	19	21	22	25	26	27	28	28	31	32	33	36	37	43	77

5	8	10	15	18
9	11	17	21	27
14	16	77	28	33
19	22	26	32	37
25	28	31	36	43

	11	16	21	
	17	22	28	
	25	28	33	

■ Bruit Gaussien additif



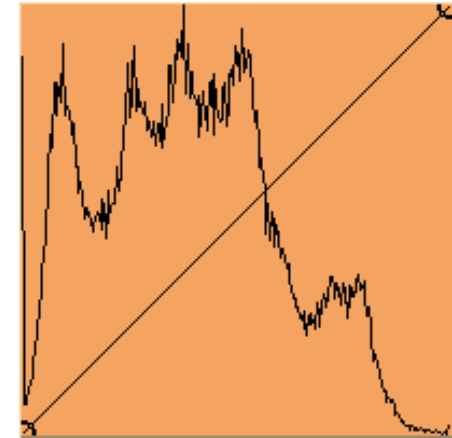
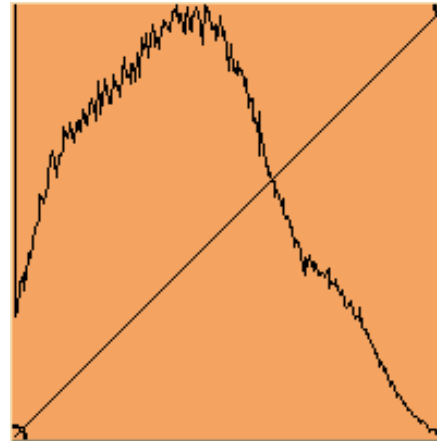
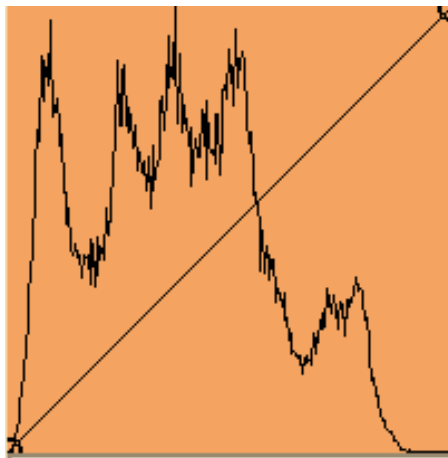
image originale



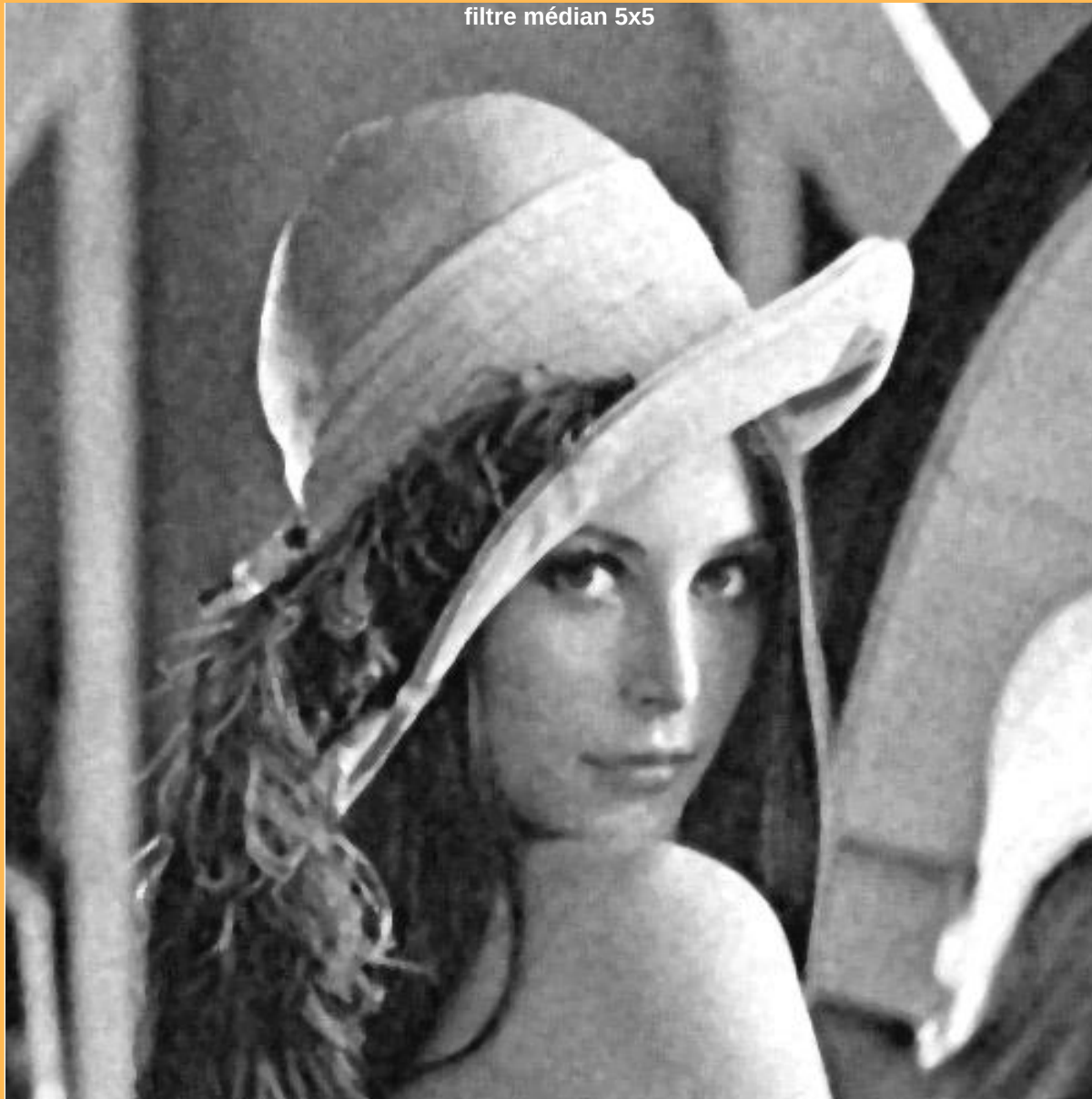
bruit gaussien $\sigma=0,4$ amplitude=150 densité=100%



bruit gaussien $\sigma=0,4$ amplitude=150 densité=30%



filtre médian 5x5



bruit gaussien $\sigma=0,4$ amplitude=150 densité=10



filtre médian 5x5



filtre médian 3x3



bruit gaussien $\sigma=0,4$ amplitude=150 densité=10



filtre médian 3x3



filtre médian 5x5



bruit gaussien $\sigma=0,4$ amplitude=150 densité=30



filtre médian 5x5



filtre médian 3x3



bruit gaussien $\sigma=0,4$ amplitude=150 densité=30



filtre médian 3x3





✱ Traitement géométrique

- ✱ transformations mathématiques simples
- ✱ modèles de déformation direct / inverse
- ✱ méthodes d'interpolation (PPV / bi-linéaire / bi-cubique / moyenne / majoritaire)
- ✱ transformations polynomiales: influence du degré – estimation par moindres carrés – résolution de systèmes d'équations linéaires
- ✱ transformations locales: l'orthorectification

Traitement géométrique

Quelques transformations mathématiques simples

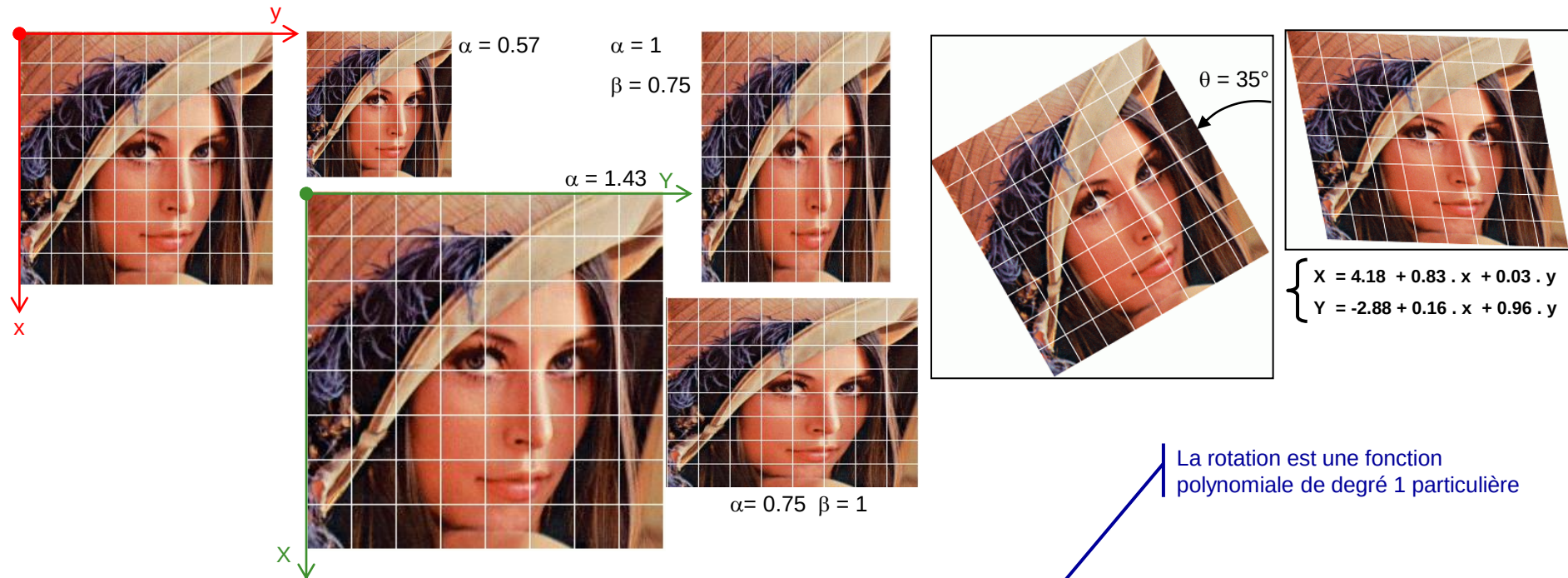
image originale

homothétie isotrope

homothétie anisotrope

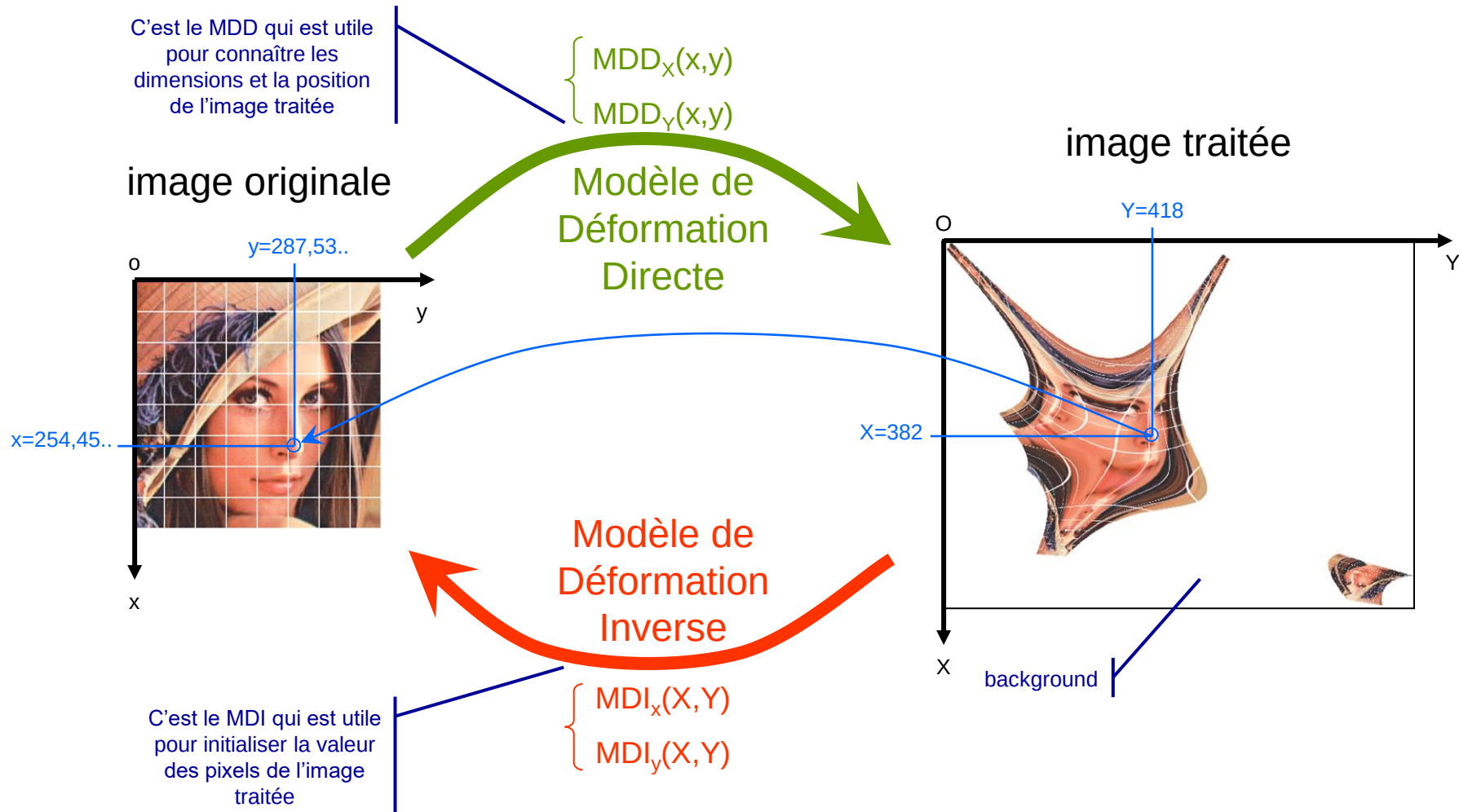
rotation

polynomiale (degré 1)



MDD Modèle de Déformation Directe	$\begin{cases} X = MDD_X(x,y) = \alpha \times x \\ Y = MDD_Y(x,y) = \alpha \times y \end{cases}$	$\begin{cases} X = \alpha \times x \\ Y = \beta \times y \end{cases}$	$\begin{cases} X = X_0 + \cos(\theta) \times x - \sin(\theta) \times y \\ Y = Y_0 + \sin(\theta) \times x + \cos(\theta) \times y \end{cases}$	$\begin{cases} X = a_0 + a_1 \times x + a_2 \times y \\ Y = b_0 + b_1 \times x + b_2 \times y \end{cases}$
--------------------------------------	--	---	--	--

Modèles de déformation directe (MDD) et inverse (MDI)



Quelques transformations mathématiques simples

Le modèle de déformation inverse

image originale

y

homothétie isotrope

$$\alpha = 0.57$$

$$a = 1$$

$$\beta = 0.75$$

homothétie anisotrope

$$\alpha = 1.43$$



$$a = 0.75 \quad \beta = 1$$

rotation

$$\theta = 35^\circ$$

polynomiale (degré 1)

$$\begin{cases} X = 4.18 + 0.83 \cdot x + 0.03 \cdot y \\ Y = -2.88 + 0.16 \cdot x + 0.96 \cdot y \\ x = -5.18 + 1.21 \cdot X - 0.04 \cdot Y \\ y = 3.87 - 0.20 \cdot X + 1.05 \cdot Y \end{cases}$$

$$\text{MDI} \stackrel{?}{=} \text{MDD}^{-1}$$

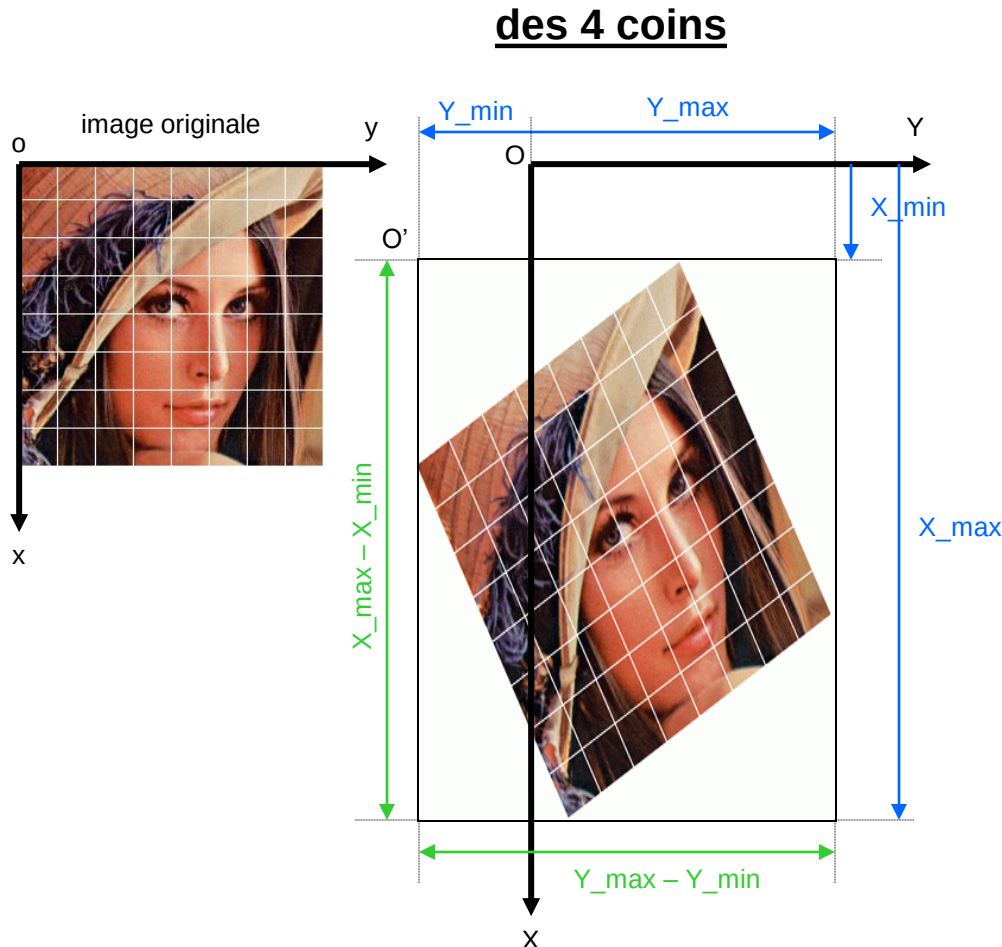
Attention: Toutes les transformations ne sont pas toujours inversibles.

Par exemple, les polynômes de degré supérieur à 1 le sont rarement.

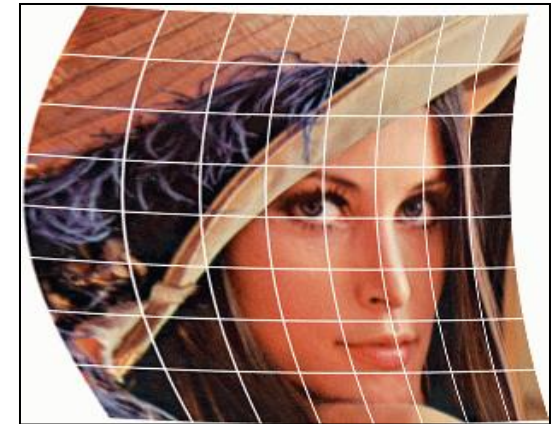
MDD Modèle de Déformation Directe	$\begin{cases} X = \text{MDD}_x(x,y) = \alpha \times x \\ Y = \text{MDD}_y(x,y) = \alpha \times y \end{cases}$	$\begin{cases} X = \alpha \times x \\ Y = \beta \times y \end{cases}$	$\begin{cases} X = X_0 + \cos(\theta) \times x - \sin(\theta) \times y \\ Y = Y_0 + \sin(\theta) \times x + \cos(\theta) \times y \end{cases}$	$\begin{cases} X = a_0 + a_1 \times x + a_2 \times y \\ Y = b_0 + b_1 \times x + b_2 \times y \end{cases}$
MDI Modèle de Déformation Inverse	$\begin{cases} x = \text{MDI}_x(X,Y) = 1/\alpha \times X \\ y = \text{MDI}_y(X,Y) = 1/\alpha \times Y \end{cases}$	$\begin{cases} x = 1/\alpha \times X \\ y = 1/\beta \times Y \end{cases}$	$\begin{cases} x = \cos(\theta) \times (X - X_0) + \sin(\theta) \times (Y - Y_0) \\ y = -\sin(\theta) \times (X - X_0) + \cos(\theta) \times (Y - Y_0) \end{cases}$	$\begin{cases} x = \frac{(X - a_0) \cdot b_2 - (Y - b_0) \cdot a_2}{a_1 \cdot b_2 - a_2 \cdot b_1} \\ y = \frac{-(X - a_0) \cdot b_1 + (Y - b_0) \cdot a_1}{a_1 \cdot b_2 - a_2 \cdot b_1} \end{cases}$

❖ Calculer la taille et la position de l'image traitée

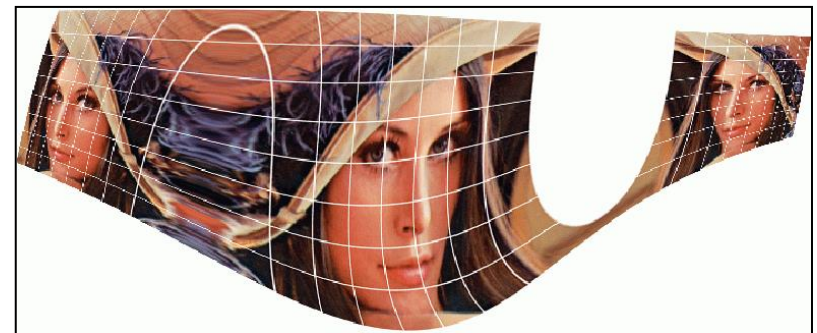
à partir des valeurs $X_{\min}$, $X_{\max}$, $Y_{\min}$, $Y_{\max}$ des transformées directes



des points du périmètre



de tous les points de l'image



Quelques transformations – « Best of MDI étudiants (1) »

« Sinus »

Serge RIAZANOFF - 2006



$$\begin{cases} x = X + 64 \times \sin\left(2\pi \times \frac{Y}{256}\right) \\ y = Y \end{cases}$$

« La Mesquine »

Maryline TRAN VAN BUU - 2008



$$\begin{cases} x = X + 64 \times \sin\left(2\pi \times \frac{Y+150}{256}\right) \\ y = Y \end{cases}$$

« Vagues à l'âme » (A=5 T=20)

Grégory MAZABRAUD - 2006



$$\begin{cases} x = X + A \times \sin\left(2\pi \times \frac{Y}{T}\right) \\ y = Y + A \times \sin\left(2\pi \times \frac{X}{T}\right) \end{cases}$$

« Spirale à l'œil »

Larry GEROMEGNACE - 2007



$$\begin{cases} x_2 = X - 256 \\ y_2 = Y - 256 \end{cases} \begin{cases} x_1 = \cos(\theta) \cdot x_2 + \sin(\theta) \cdot y_2 \\ y_1 = -\sin(\theta) \cdot x_2 + \cos(\theta) \cdot y_2 \end{cases} \begin{cases} x = x_1 + 259 \\ y = y_1 + 265 \end{cases}$$

$$\theta = \frac{50}{\sqrt{x_2^2 + y_2^2}}$$

« Vitre de salle de bains »

Guillaume ROUSSEL - 2006



$$\begin{cases} x = [X + (X \% 30)] \% 512 \\ y = [Y + (Y \% 30)] \% 512 \end{cases}$$

« Persiennes » (A=3 T=20)

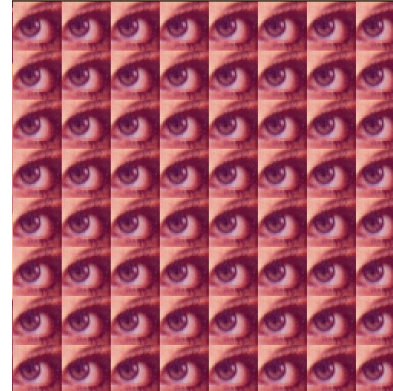
Yannis JULIENNE - 2006



$$\begin{cases} x = X \\ y = Y + A \times \tan\left(2\pi \times \frac{x}{T}\right) \end{cases}$$

« Modulo des yeux »

Julien LEROY - 2008



$$\begin{cases} x = 258 + \frac{X}{2} \% 32 \\ y = 317 + \frac{Y}{2} \% 32 \end{cases}$$



Photo de Vico déconvoluée par Interpol (octobre 2007)
<http://afp.google.com/article/ALeqM5hpWnb9TTBQK3z3LnsjdJXdt1UGg>

Quelques transformations – « Best of MDI étudiants (2) »

« Reflets amortis »

Emmanuel THOMAS - 2006



$$\begin{cases} x = \frac{|X + 100 \times \sin(\sqrt{X})| + 170}{1.5} - 50 \\ y = \frac{Y}{1.5} + 75 \end{cases}$$

« Lèvres en coin »

Jacques POULAIN - 2007



$$\begin{cases} x = 100 \times \log[2 \times \sqrt{X}] \\ y = 100 \times \log[2 \times \sqrt{Y}] \end{cases}$$

« Presque de face »

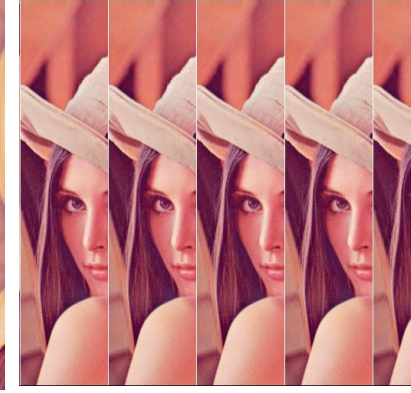
Etienne SCHROEDER - 2007



$$\begin{cases} x = \frac{X \times \left[1 + \frac{|X - 333|}{60} - X\right]}{5.5} + 222 \\ y = \frac{Y \times \left[1 + \frac{|Y - 333|}{60} - Y\right]}{5.5} + 222 \end{cases}$$

« Léna et ses sœurs »

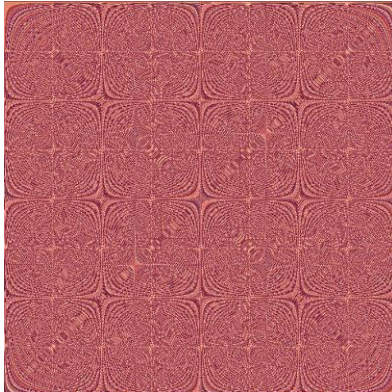
Daniel DA COSTA - 2008



$$\begin{cases} x = X \\ y = [(512 - (Y \% 115)) - 110] \end{cases}$$

« Modulo du produit » (□=1)

Gérard TAN - 2007



$$\begin{cases} x = \left[\frac{X \times \frac{Y}{\alpha}}{\alpha} \right] \% 512 \\ y = \left[\frac{Y \times \frac{X}{\alpha}}{\alpha} \right] \% 512 \end{cases}$$

« Modulo du produit » (□=60)

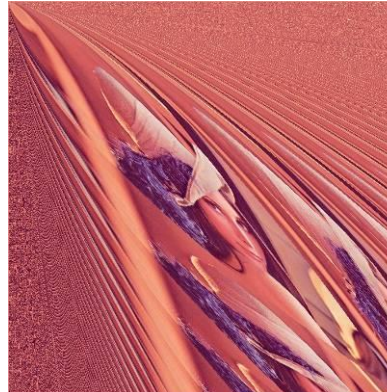
Jean-Félix TRAN - 2007



$$\begin{cases} x = \left[\frac{X \times \frac{Y}{\alpha}}{\alpha} \right] \% 512 \\ y = \left[\frac{Y \times \frac{X}{\alpha}}{\alpha} \right] \% 512 \end{cases}$$

« Dunes »

Guillaume ROUSSEL - 2006



$$\begin{cases} x = \text{Arrondi}\left(\frac{X^3}{Y^2}\right) \% 512 \\ y = \text{Arrondi}\left(\frac{Y^3}{X^2}\right) \% 512 \end{cases}$$

« Degré 2 »

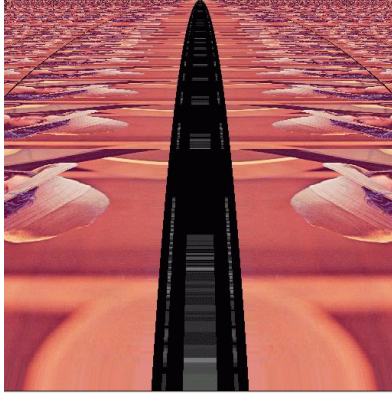
Frédéric DELABOT - 2007



$$\begin{cases} x = \frac{X^2}{512} + \frac{Y}{2} \\ y = \frac{X}{2} + \frac{Y^2}{512} \end{cases}$$

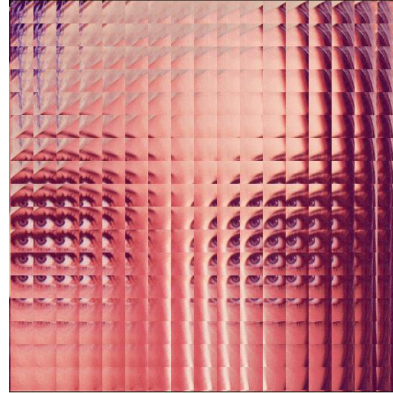
Quelques transformations – « Best of MDI étudiants (3) »

« Avenue Léna »
Vincent COUBRAY - 2006



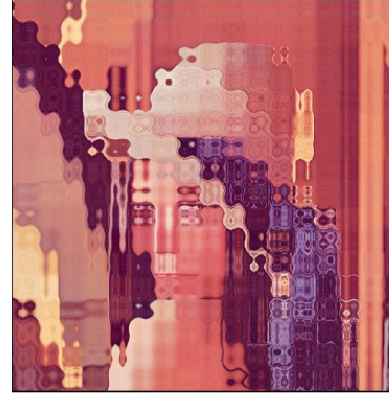
$$\begin{cases} x = \frac{(Y-256)^2}{X} \% 512 \\ y = \frac{(X-512)^2}{X} \% 512 \end{cases}$$

« T'as d'beaux yeux »
Xavier MALAC - 2008



$$\begin{cases} x = \frac{X+4 \times [251+(X \% 30)]}{5} \\ y = \frac{Y+4 \times [312+(Y \% 30)]}{5} \end{cases}$$

« Effet cire »
Carl RENGOUWA - 2008



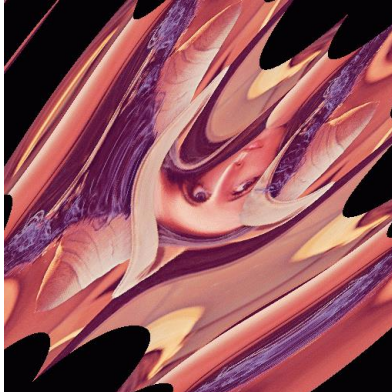
$$\begin{cases} x = X + 10 \times \sin\left(\pi \times \frac{X}{15}\right) \\ y = (512 - Y) + 10 \times \cos\left(\pi \times \frac{512 - Y}{15}\right) \end{cases}$$

« Léna module modulo »
Mohamed MOUNIROU - 2008



$$\begin{cases} x = \left\lfloor \frac{\sqrt{X^2 + Y^2} + X}{\sqrt{X^2 + Y^2} + Y} \% 70 \right\rfloor \% 512 \\ y = \left\lfloor \frac{\sqrt{X^2 + Y^2} + Y}{\sqrt{X^2 + Y^2} + X} \% 70 \right\rfloor \% 512 \end{cases}$$

« Fantôme »
Maxime GOURDON - 2009



$$\begin{cases} x_2 = X - 256 \\ y_2 = Y - 256 \end{cases} \begin{cases} x_1 = \cos(\theta).x_2 + \sin(\theta).y_2 \\ y_1 = -\sin(\theta).x_2 + \cos(\theta).y_2 \end{cases} \begin{cases} x = x_1 + 266 \\ y = y_1 + 327 \end{cases}$$

$$\theta = (X + Y) \times \frac{\pi}{180}$$

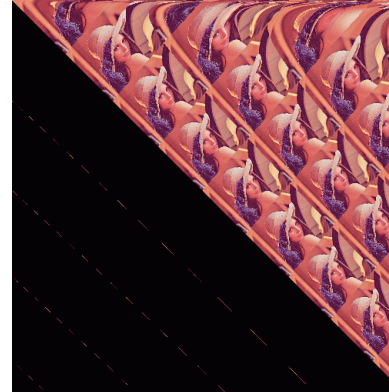
« Biche »
Nicolas CARRIER - 2009



$$\begin{cases} x = X + \frac{10240}{\sqrt{2}} \times d \times \cos\left(\frac{d}{15}\right) \\ y = Y + \frac{10240}{\sqrt{2}} \times d \times \sin\left(\frac{d}{15}\right) \end{cases}$$

$$d = |X - 256| + (Y - 256)^2$$

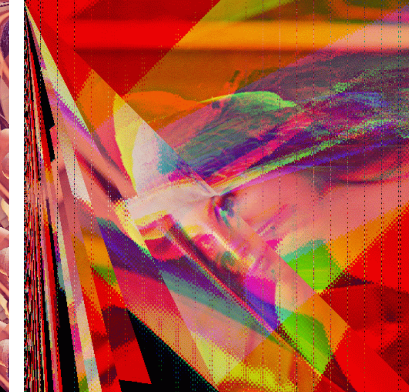
« Arc en ciel »
Mathieu MAZZOLINI - 2009



$$\begin{cases} x_1 = \cos(\theta).X + \sin(\theta).Y \\ y_1 = -\sin(\theta).X + \cos(\theta).Y \end{cases} \begin{cases} x = E[x_1 / 2 \times \log(500 \times Y)] \% X \\ y = E[y_1 / 2 \times \log(500 \times X)] \% Y \end{cases}$$

$$\text{Récursif : } \theta \leftarrow 0 \quad \text{boucle : } \theta \leftarrow E(\theta + 45) \times \frac{\pi}{180}$$

« Arc en ciel »
Mathieu MAZZOLINI - 2009



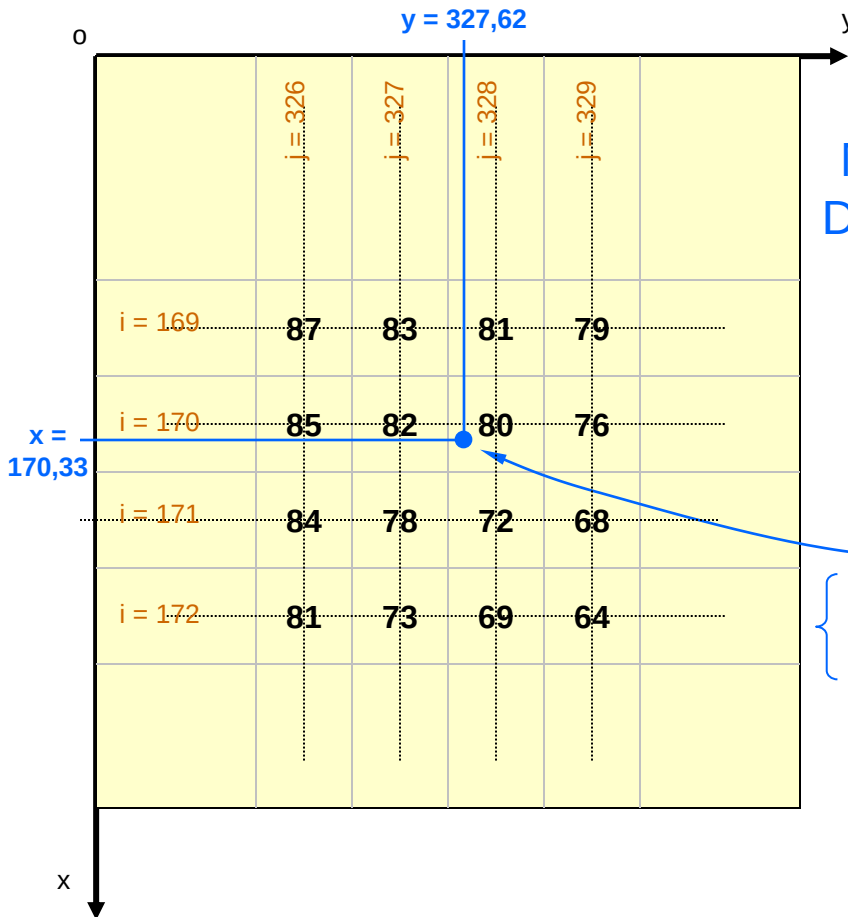
$$\begin{cases} x_2 = X - 256 \\ y_2 = Y - 256 \end{cases} \begin{cases} x_1 = \cos(\theta).x_2 + \sin(\theta).y_2 \\ y_1 = -\sin(\theta).x_2 + \cos(\theta).y_2 \end{cases} \begin{cases} x = x_1 \cdot \cos\left(\frac{X}{Y+1}\right) + Y \\ y = y_1 \cdot \sin\left(\frac{X}{Y+1}\right) + X \end{cases}$$

$$\theta = \frac{\cos(X)}{\sin(Y+1)} \times \frac{\pi}{180}$$



❁ Méthodes d'interpolation

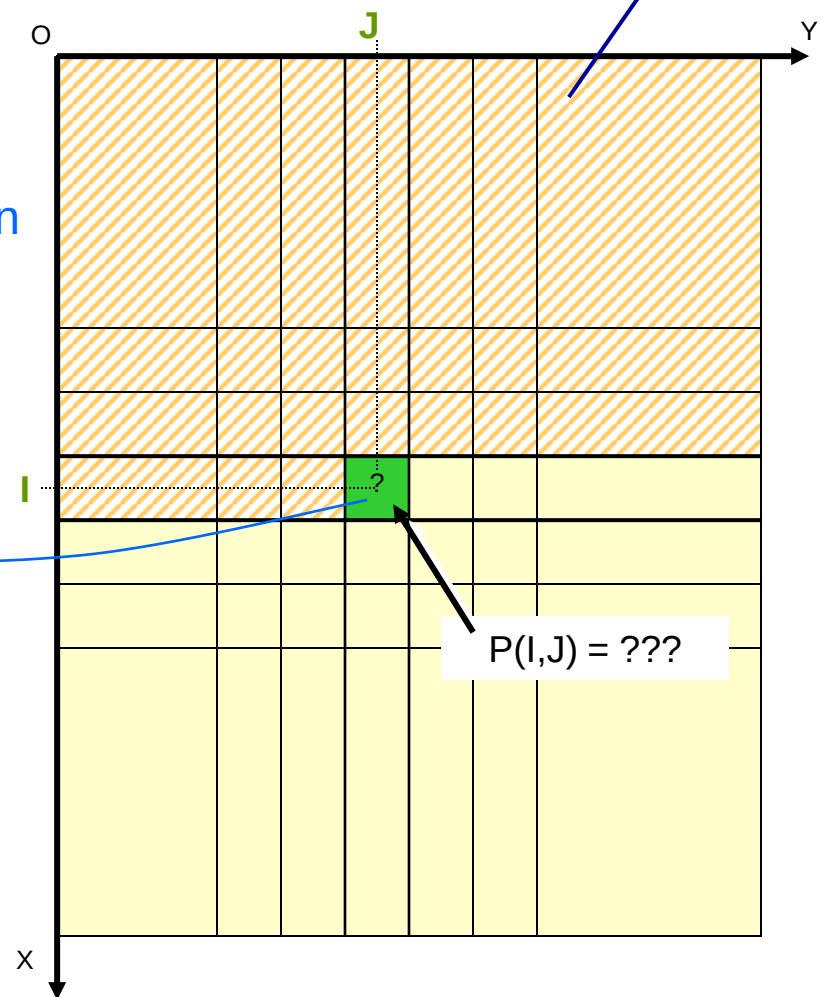
image originale $O(i,j)$



Modèle de
Déformation
Inverse

$$\begin{cases} x = MDI_x(I,J) \\ y = MDI_y(I,J) \end{cases}$$

image traitée $P(I,J)$

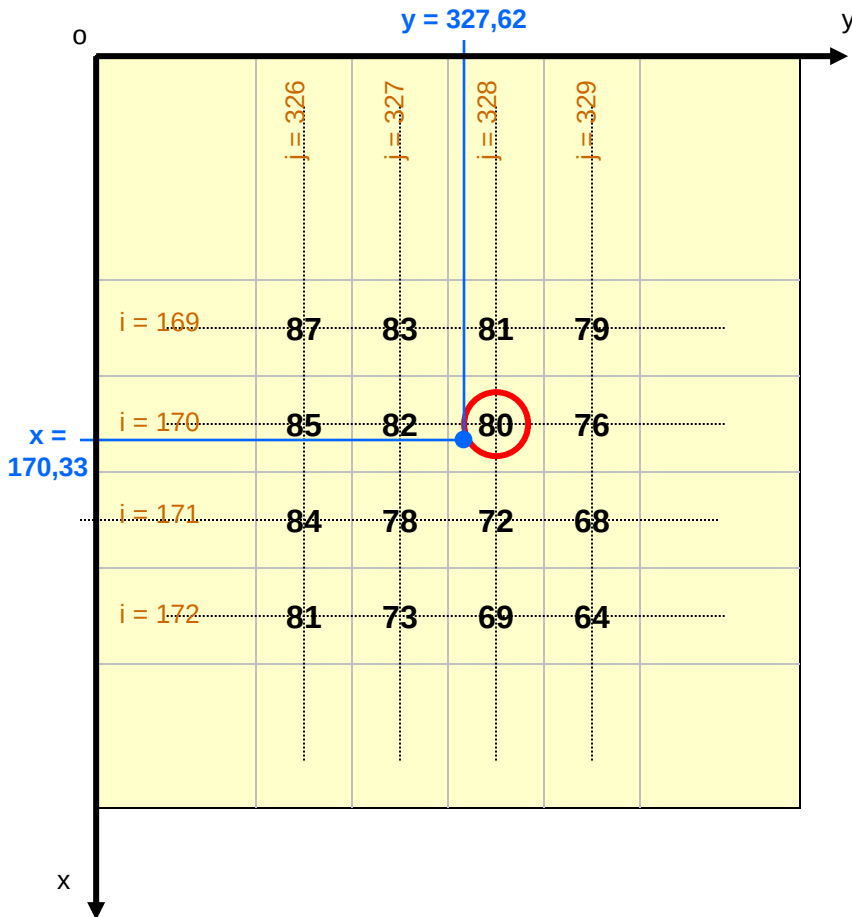


partie déjà
traitée



■ Plus proche voisin (PPV) – « Nearest neighbour (NN) »

image originale $O(i,j)$

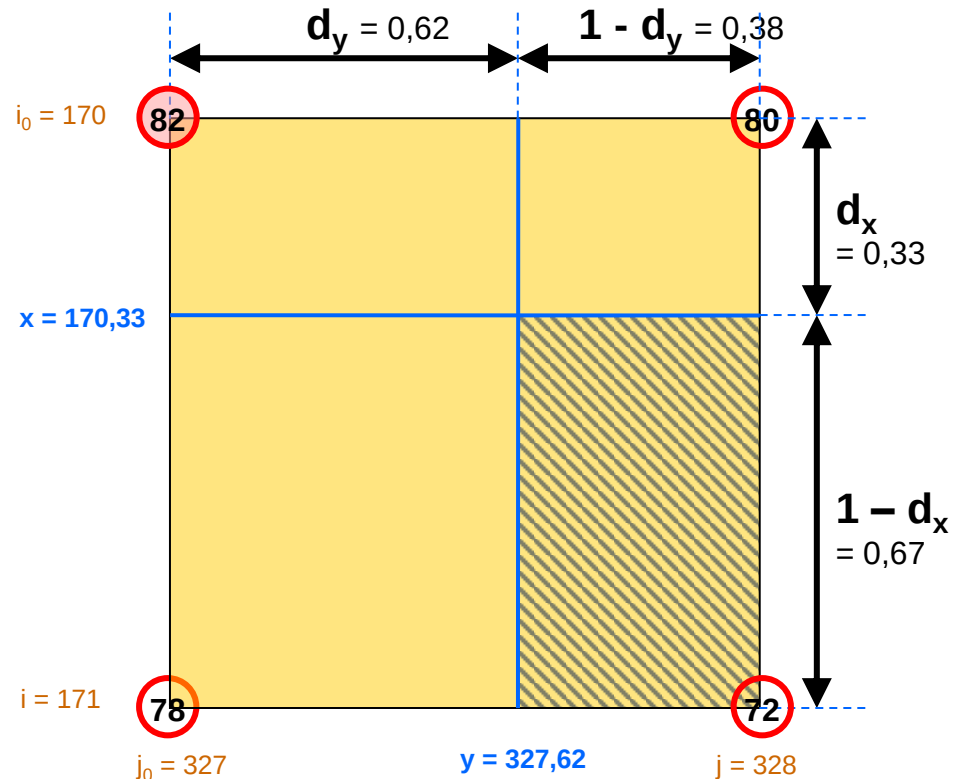
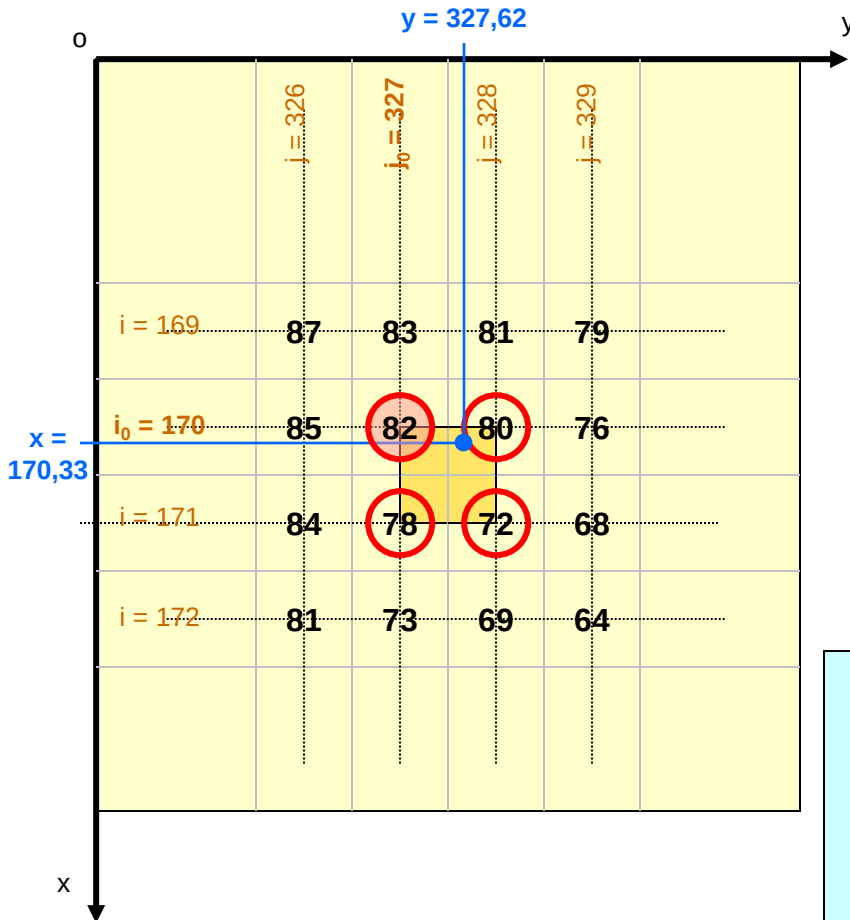


$$P(I, J) \leftarrow O[\text{Arrondi}(x), \text{Arrondi}(y)]$$



• Interpolation bilinéaire (BL)

image originale $O(i,j)$

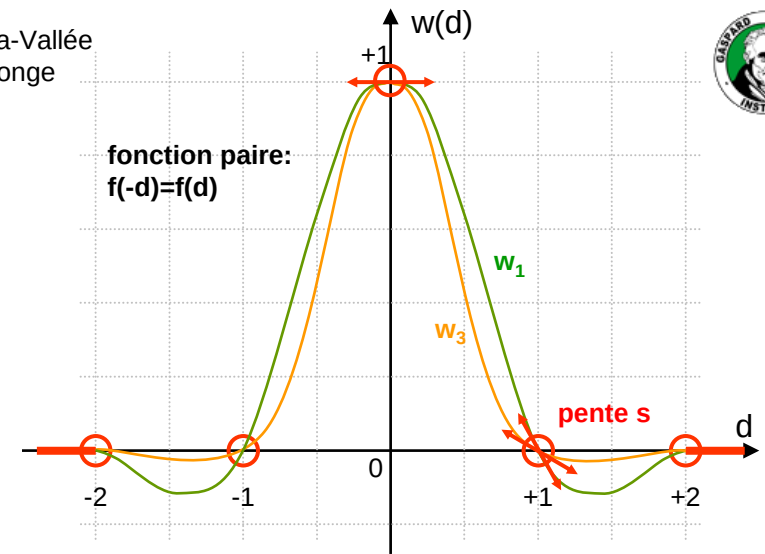
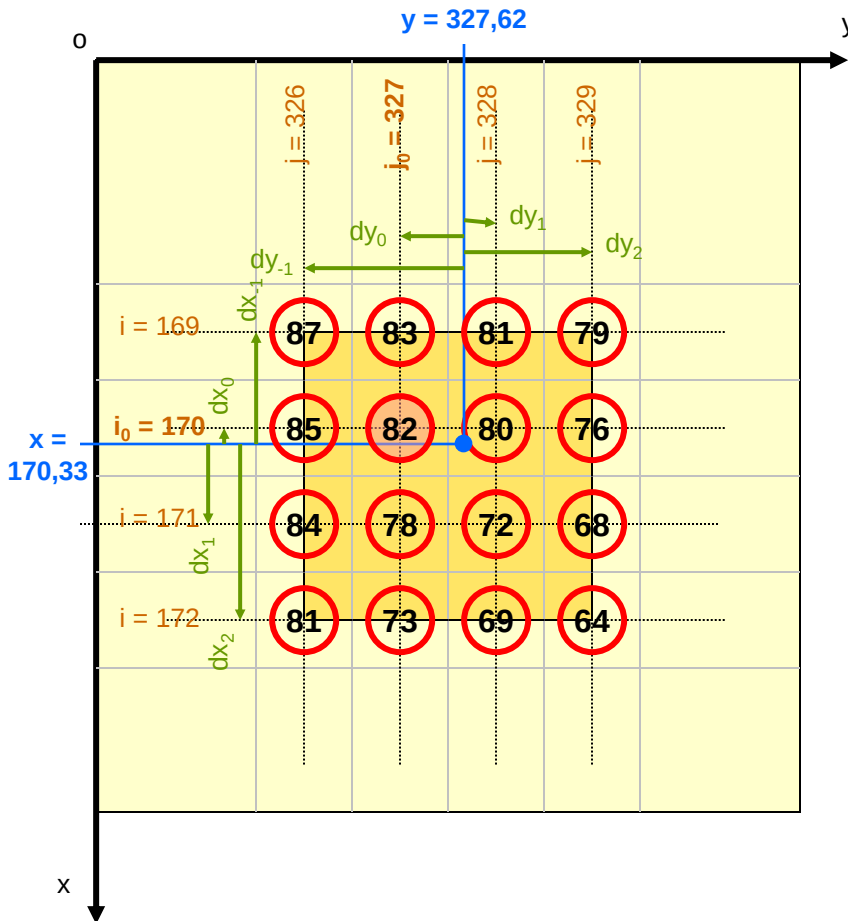


$$\begin{aligned}
 P(I, J) \leftarrow & O(i_0, j_0) \times (1 - d_x) \times (1 - d_y) \\
 & + O(i_0 + 1, j_0) \times d_x \times (1 - d_y) \\
 & + O(i_0, j_0 + 1) \times (1 - d_x) \times d_y \\
 & + O(i_0 + 1, j_0 + 1) \times d_x \times d_y
 \end{aligned}$$



■ Interpolation bi-cubique (BC)

image originale $O(i,j)$



$$w_1(d) = \begin{cases} 1 - (s+3).d^2 + (s+2).|d^3| & 0 \leq |d| \leq 1 \\ -4s + 8s.|d| - 5s.d^2 + s.|d^3| & 1 < |d| \leq 2 \\ 0 & 2 < |d| \end{cases}$$

Forme générique (splines)

[Feuille de calcul \(tableur\)](#)

$$w_1(d) = \begin{cases} 1 - 2.d^2 + |d^3| & 0 \leq |d| \leq 1 \\ 4 - 8.|d| + 5.d^2 - |d^3| & 1 < |d| \leq 2 \\ 0 & 2 < |d| \end{cases}$$

pente $s = -1$

$$w_2(d) = \begin{cases} 1 - 1/2.[5.d^2 - 3.|d^3|] & 0 \leq |d| \leq 1 \\ 1/2.[4 - 8.|d| + 5.d^2 - |d^3|] & 1 < |d| \leq 2 \\ 0 & 2 < |d| \end{cases}$$

pente $s = -1/2$

$$w_3(d) = \begin{cases} 1 - 11/4.d^2 + 7/4.|d^3| & 0 \leq |d| \leq 1 \\ 1 - 2.|d| + 5/4.d^2 - 1/4.|d^3| & 1 < |d| \leq 2 \\ 0 & 2 < |d| \end{cases}$$

pente $s = -1/4$

$$P(I, J) \leftarrow \frac{\sum_{k=-1}^{+2} w(dx_k) \times \left[\sum_{l=-1}^{+2} [w(dy_l) \times O(i_0 + k, j_0 + l)] \right]}{\sum_{k=-1}^{+2} [w(dx_k)] \times \sum_{l=-1}^{+2} [w(dy_l)]}$$



■ Comparaison des méthodes d'interpolation - Résultats

Plus Proche Voisin (NN)



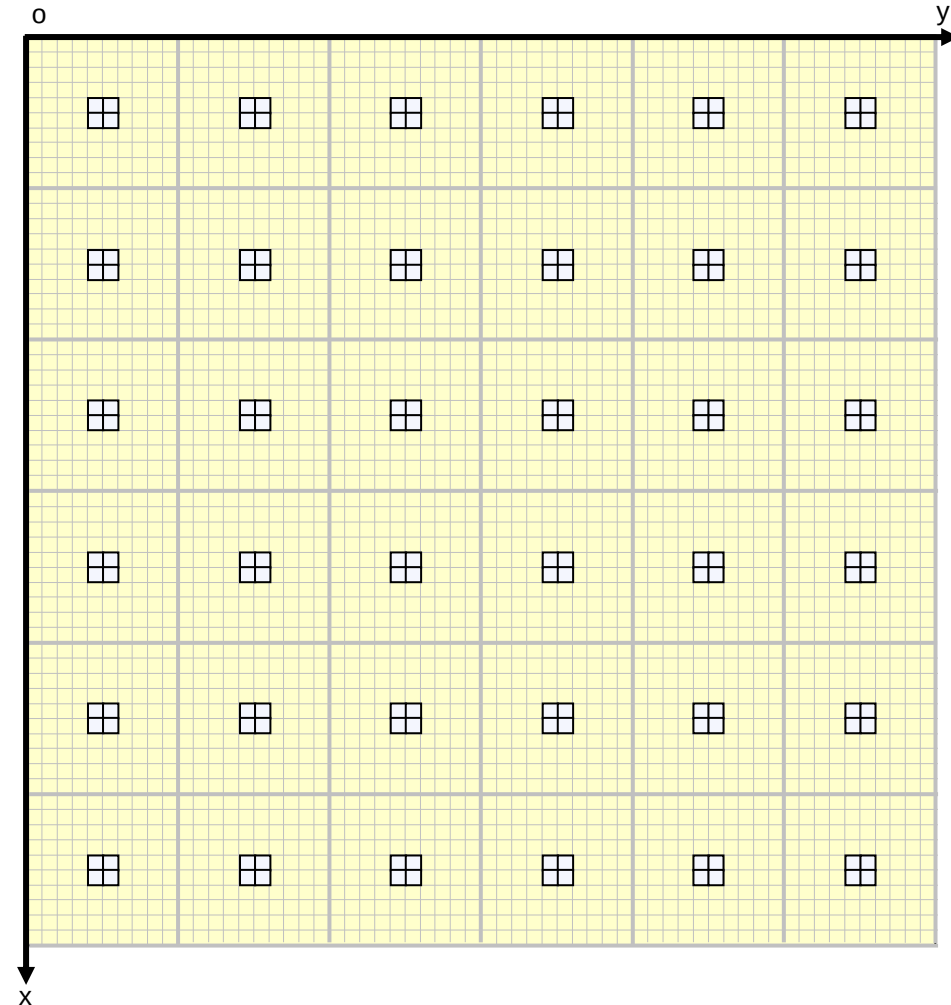
Bi-Linéaire (BL)



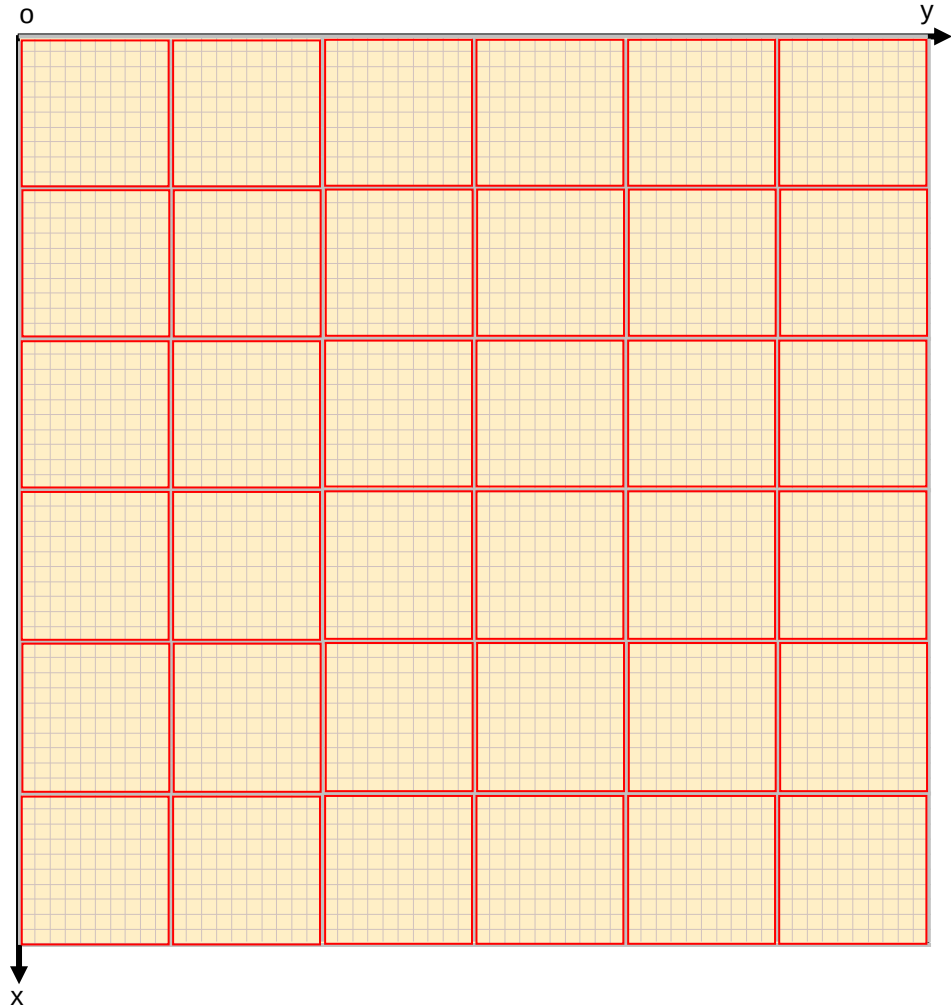


■ Interpolation moyenne

Exemple d'interpolation bi-linéaire (2x2)
pour un facteur de ré-échantillonnage de 0,1



Exemple d'interpolation moyenne (10x10)
pour un facteur de ré-échantillonnage de 0,1



■ Interpolation moyenne – Exemple

Mosaïque du Darfour – Instrument DMC, acquisition décembre 2009 – Echantillonnage à 0,02

Plus proche voisin



Bi-cubique



Moyenne

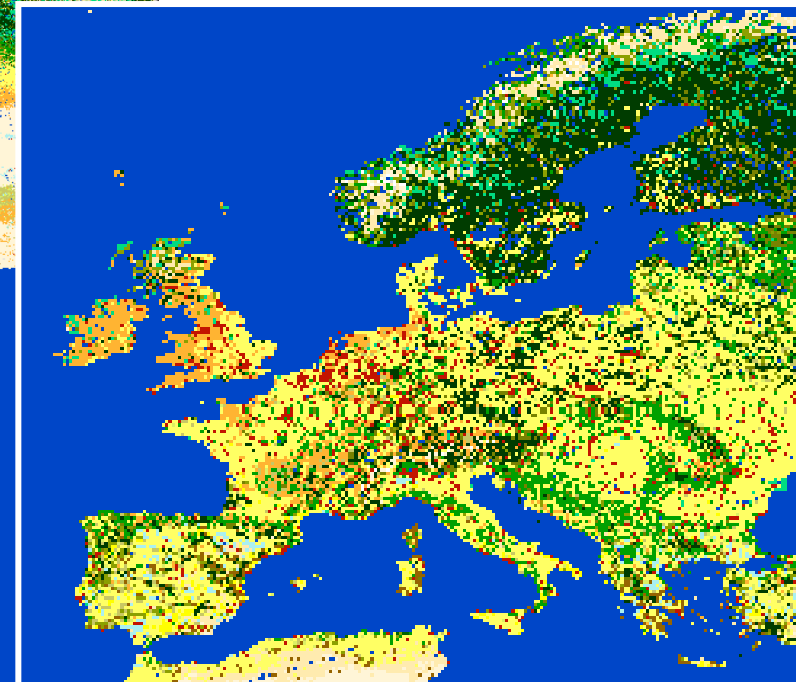
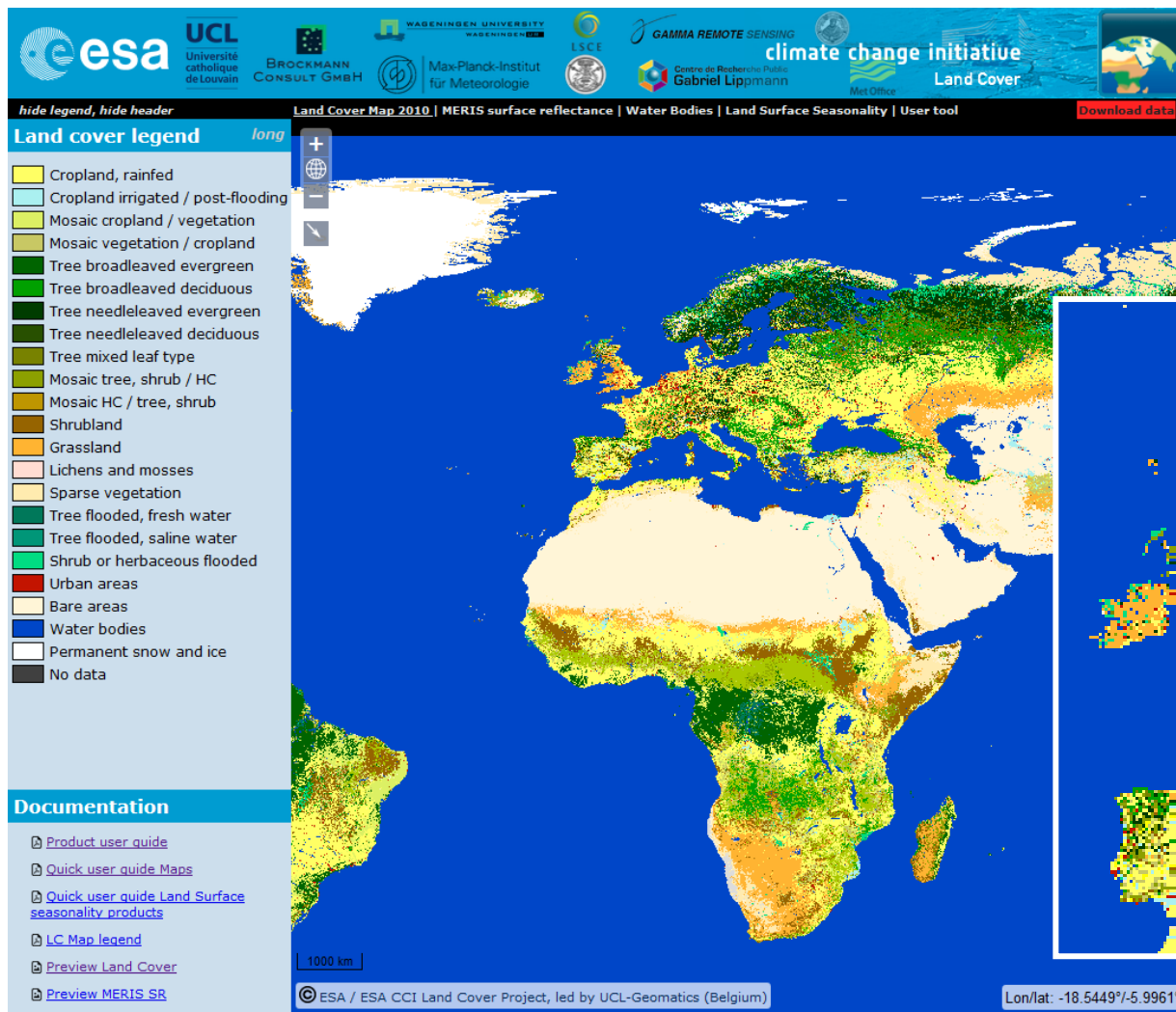




■ Interpolation majoritaire – Le plus proche voisin

Image thématique et LUT associée – Le problème de l'interpolation numérique

<http://maps.elie.ucl.ac.be/CCI/viewer/index.php>

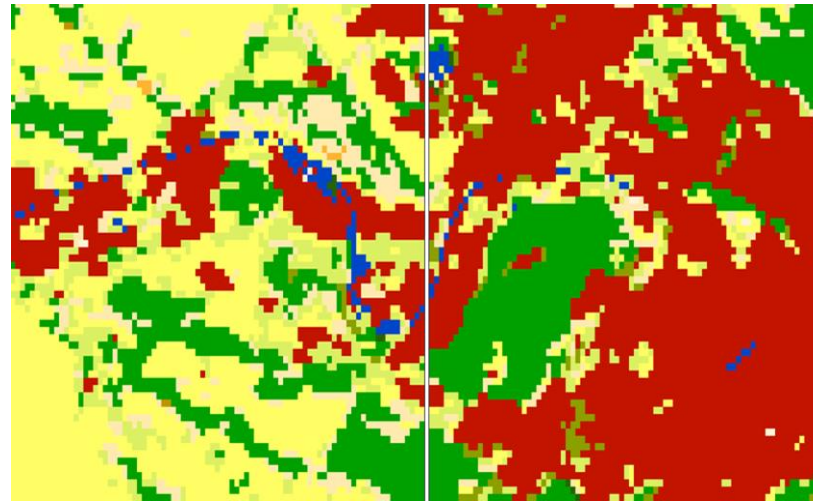




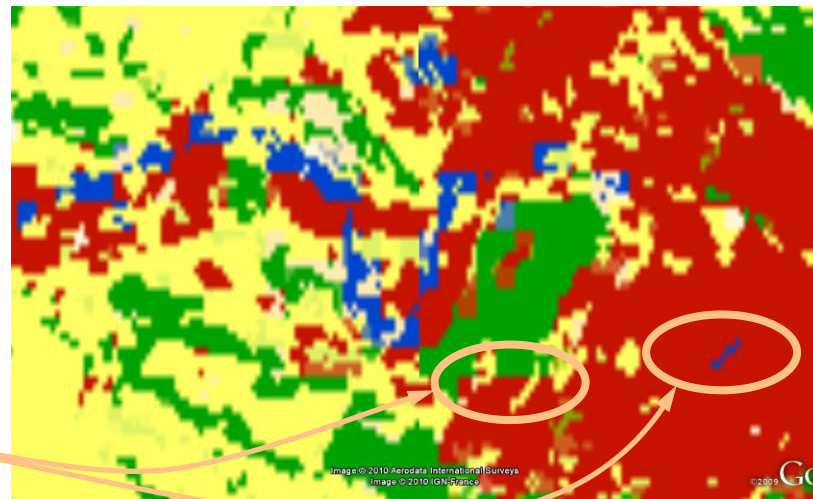
■ Interpolation majoritaire – La somme d'indices ?

Image thématique et LUT associée – Le problème de l'interpolation numérique

Tuiles de la collection
GlobCover illustrant
l'occupation du sol



Vue de GlobCover
dans Google Earth



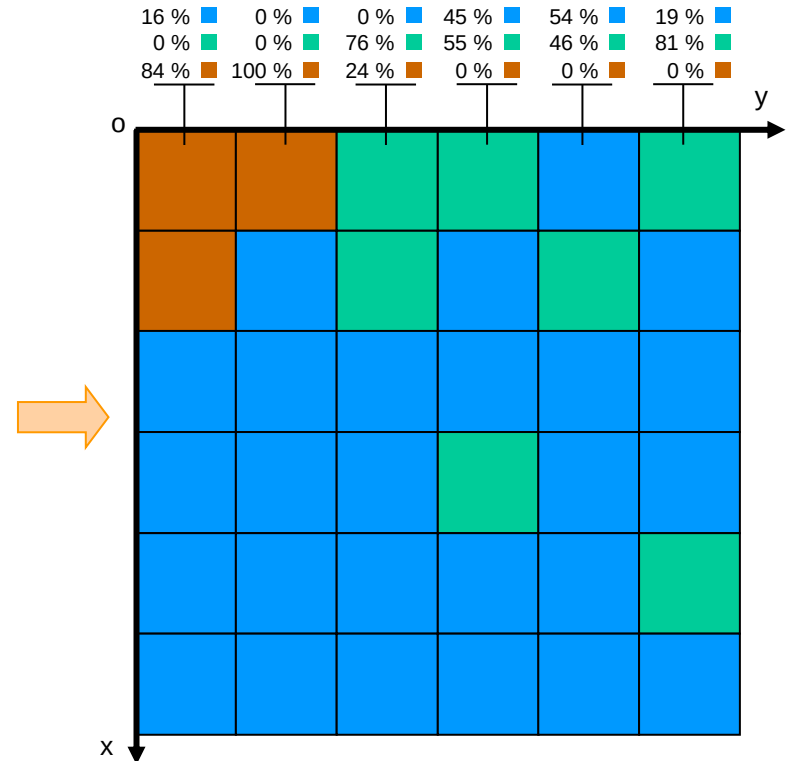
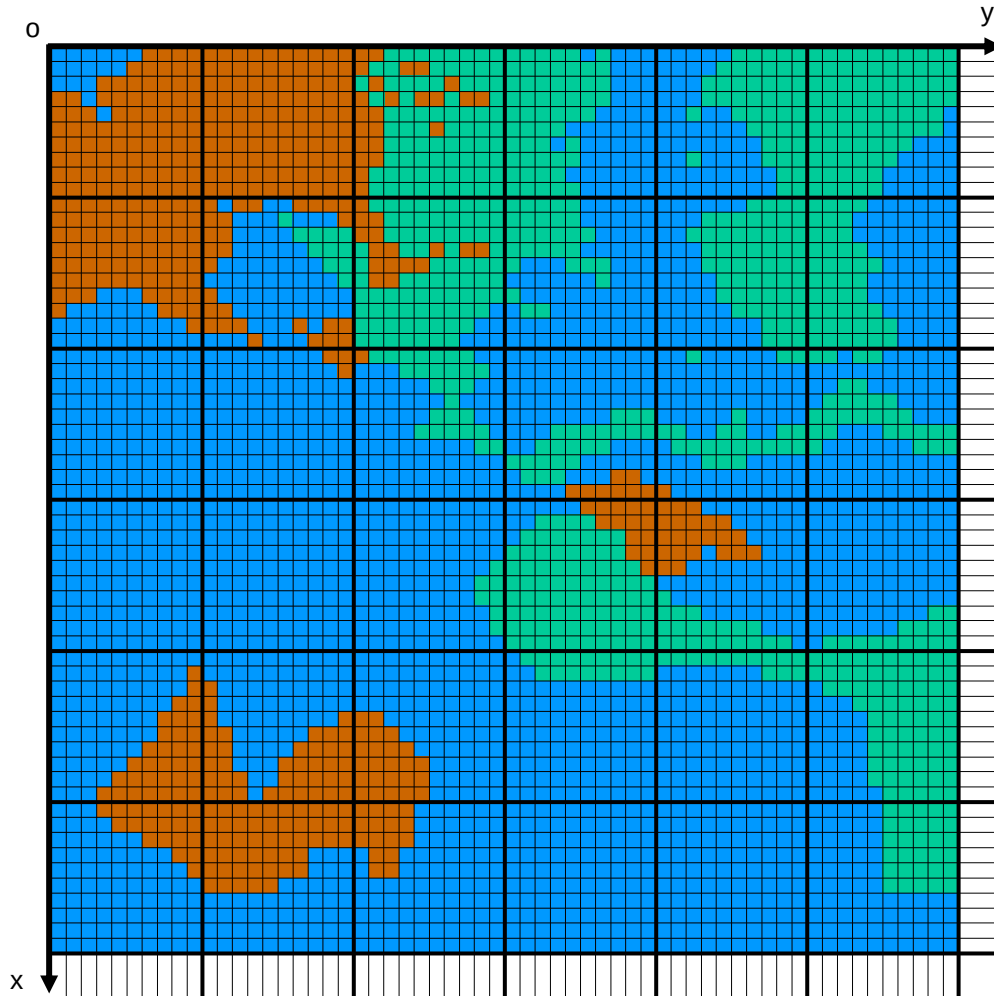
couleurs interpolées
erronées

	R	G	B
0	0	255	100
1	0	0	100
2	0	0	100
3			
4			
5	255	255	255
6			
7	80	0	0
8	80	60	230
9			
10	0	200	0
...	...	...	...
...	...	...	...
246	45	0	0
247	0	0	0
248	250	0	50
249	30	170	200
250			
251			
252			
253	255	255	255
254	255	255	255
255	255	255	255



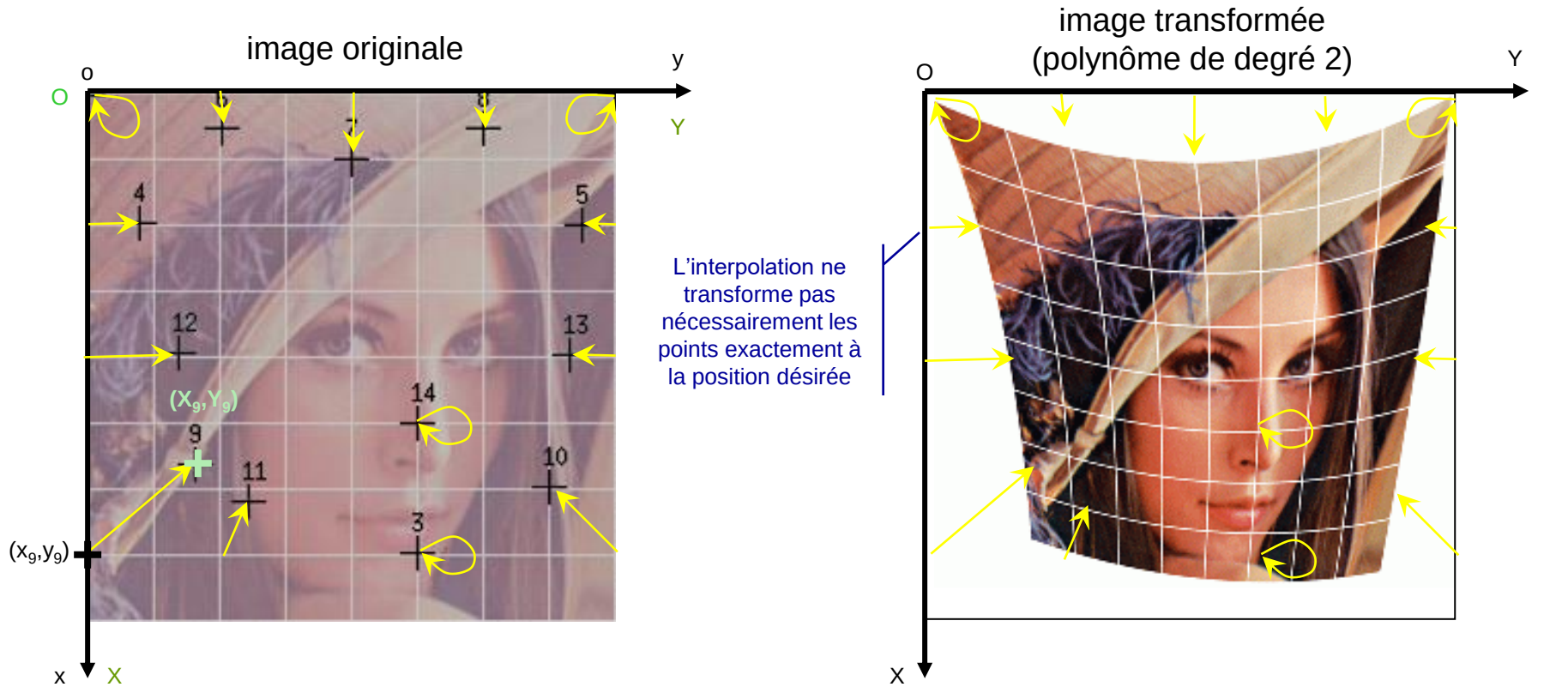
■ Interpolation majoritaire

Exemple d'interpolation moyenne (10x10) pour un facteur de ré-échantillonnage de 0,1



Transformation géométrique contrôlée par des points d'appui

Saisie des couples de points



Points d'appui: $((x_i, y_i), (X_i, Y_i)), i=1...N$

$$\begin{cases} X = a_0 + a_1 \times x + a_2 \times y + a_3 \times x^2 + a_4 \times xy + a_5 \times y^2 \\ Y = b_0 + b_1 \times x + b_2 \times y + b_3 \times x^2 + b_4 \times xy + b_5 \times y^2 \end{cases}$$

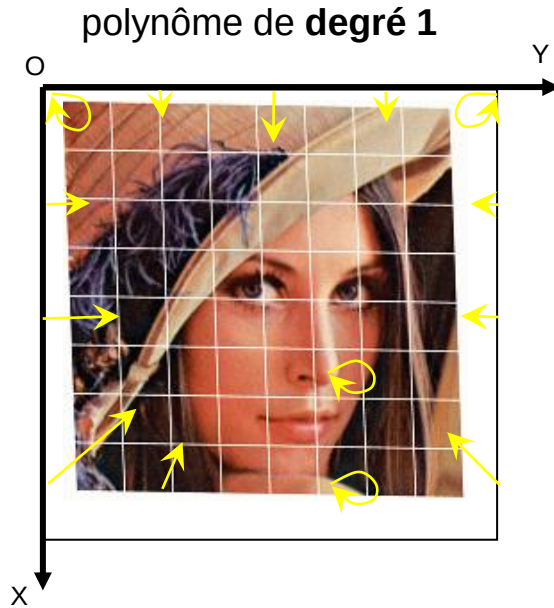
Pour chaque axe, 6 inconnues □ 6 points d'appui minimum

ou « points de contrôle »

Position originale

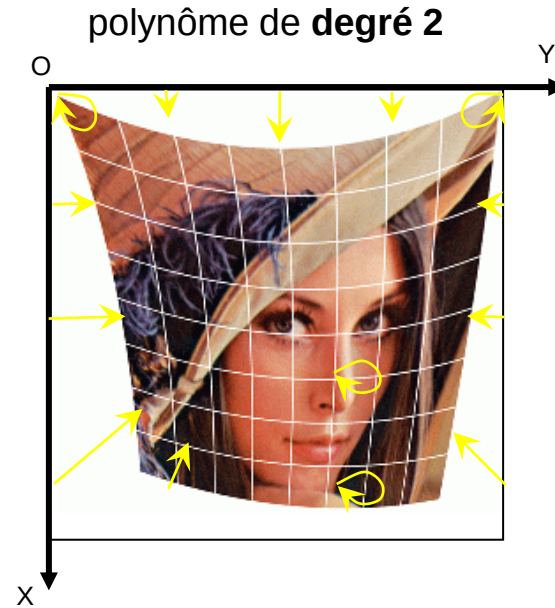
Position désirée

■ Influence du degré des transformations polynômiales



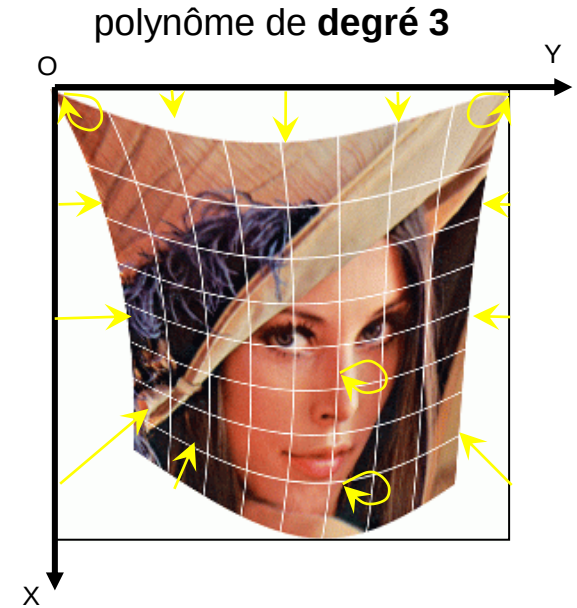
Pour chaque axe, **3 inconnues**

$$\begin{cases} X = a_0 + a_1 \times x + a_2 \times y \\ Y = b_0 + b_1 \times x + b_2 \times y \end{cases}$$



Pour chaque axe, **6 inconnues**

$$\begin{cases} X = a_0 + a_1 \times x + a_2 \times y + a_3 \times x^2 + a_4 \times xy + a_5 \times y^2 \\ Y = b_0 + b_1 \times x + b_2 \times y + b_3 \times x^2 + b_4 \times xy + b_5 \times y^2 \end{cases}$$



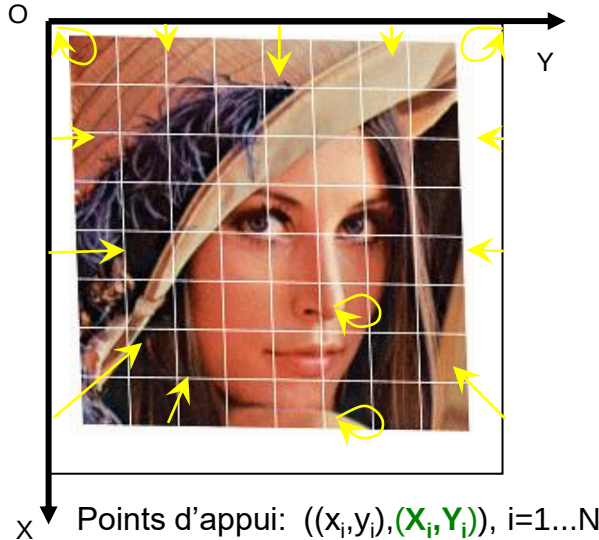
Pour chaque axe, **10 inconnues**

$$\begin{cases} X = a_0 + a_1 \times x + a_2 \times y + a_3 \times x^2 + a_4 \times xy + a_5 \times y^2 + a_6 \times x^3 + a_7 \times x^2y + a_8 \times xy^2 + a_9 \times y^3 \\ Y = b_0 + b_1 \times x + b_2 \times y + b_3 \times x^2 + b_4 \times xy + b_5 \times y^2 + b_6 \times x^3 + b_7 \times x^2y + b_8 \times xy^2 + b_9 \times y^3 \end{cases}$$



Estimation de la transformation par la méthode des « moindres carrés »

Exemple: polynôme de **degré 1**



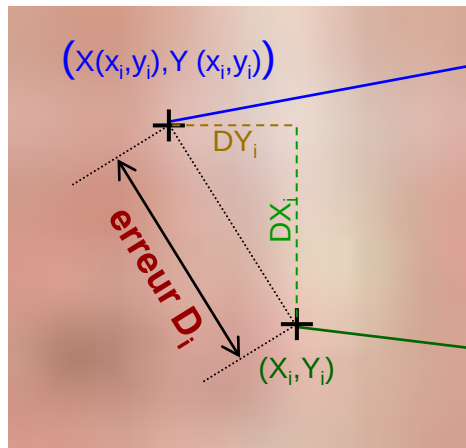
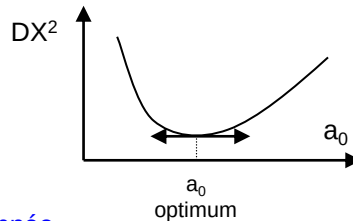
$$D_i = \sqrt{DX_i^2(a_0, a_1, a_2) + DY_i^2(b_0, b_1, b_2)}$$

Minimiser $D_i \Rightarrow$ minimiser DX_i et minimiser DY_i

$$\begin{aligned} DX_i^2(a_0, a_1, a_2) &= [X(x_i, y_i) - X_i]^2 \\ &= [(a_0 + a_1 x_i + a_2 y_i) - X_i]^2 \\ &= [a_0^2 + a_1^2 x_i^2 + a_2^2 y_i^2 + X_i^2 + 2a_0 a_1 x_i + 2a_0 a_2 y_i - 2a_0 X_i + 2a_1 a_2 x_i y_i - 2a_1 x_i X_i - 2a_2 y_i X_i] \end{aligned}$$

Trouver (a_0, a_1, a_2) minimisant l'erreur quadratique moyenne

$$\begin{aligned} DX^2(a_0, a_1, a_2) &= \frac{1}{N} \times \sum_{i=1}^N DX_i^2(a_0, a_1, a_2) \\ &= \frac{1}{N} \times \sum_{i=1}^N [a_0^2 + a_1^2 x_i^2 + a_2^2 y_i^2 + X_i^2 + 2a_0 a_1 x_i + 2a_0 a_2 y_i - 2a_0 X_i + 2a_1 a_2 x_i y_i - 2a_1 x_i X_i - 2a_2 y_i X_i] \end{aligned}$$



Position donnée
par le modèle

$$\begin{cases} X(x, y) = a_0 + a_1 x + a_2 y \\ Y(x, y) = b_0 + b_1 x + b_2 y \end{cases}$$

Position
désirée

$$\frac{\partial(DX^2(a_0, a_1, a_2))}{\partial a_0} = \frac{1}{N} \times \sum_{i=1}^N [2a_0 + 2a_1 x_i + 2a_2 y_i - 2X_i] = 0$$

$$\Rightarrow a_0 \times N + a_1 \sum_{i=1}^N x_i + a_2 \sum_{i=1}^N y_i = \sum_{i=1}^N X_i$$

$$\frac{\partial(DX^2(a_0, a_1, a_2))}{\partial a_1} = \frac{1}{N} \times \sum_{i=1}^N [2a_1 x_i^2 + 2a_0 x_i + 2a_2 x_i y_i - 2x_i X_i] = 0$$

$$\Rightarrow a_0 \sum_{i=1}^N x_i + a_1 \sum_{i=1}^N x_i^2 + a_2 \sum_{i=1}^N x_i y_i = \sum_{i=1}^N x_i X_i$$

$$\frac{\partial(DX^2(a_0, a_1, a_2))}{\partial a_2} = \frac{1}{N} \times \sum_{i=1}^N [2a_2 y_i^2 + 2a_0 y_i + 2a_1 x_i y_i - 2y_i X_i] = 0$$

$$\Rightarrow a_0 \sum_{i=1}^N y_i + a_1 \sum_{i=1}^N x_i y_i + a_2 \sum_{i=1}^N y_i^2 = \sum_{i=1}^N y_i X_i$$



❖ Résolution du système d'équations linéaires

Système de 3 équations à 3 inconnues

Notation matricielle: $A \otimes x = b$

$$\begin{cases} a_0 \times N + a_1 \times \sum_{i=1}^N x_i + a_2 \times \sum_{i=1}^N y_i = \sum_{i=1}^N X_i \\ a_0 \times \sum_{i=1}^N x_i + a_1 \times \sum_{i=1}^N x_i^2 + a_2 \times \sum_{i=1}^N x_i y_i = \sum_{i=1}^N x_i X_i \\ a_0 \times \sum_{i=1}^N y_i + a_1 \times \sum_{i=1}^N x_i y_i + a_2 \times \sum_{i=1}^N y_i^2 = \sum_{i=1}^N y_i X_i \end{cases} \Rightarrow \begin{pmatrix} N & \sum_{i=1}^N x_i & \sum_{i=1}^N y_i \\ \sum_{i=1}^N x_i & \sum_{i=1}^N x_i^2 & \sum_{i=1}^N x_i y_i \\ \sum_{i=1}^N y_i & \sum_{i=1}^N x_i y_i & \sum_{i=1}^N y_i^2 \end{pmatrix} \otimes \begin{pmatrix} a_0 \\ a_1 \\ a_2 \end{pmatrix} = \begin{pmatrix} \sum_{i=1}^N X_i \\ \sum_{i=1}^N x_i X_i \\ \sum_{i=1}^N y_i X_i \end{pmatrix}$$

Une des méthodes de résolution est la décomposition LU (*Lower Upper, Numerical recipes*) en deux matrices triangulaires (Méthode de Crout).

$$L \otimes U = A$$

$$\begin{pmatrix} \alpha_{11} & 0 & 0 \\ \alpha_{21} & \alpha_{22} & 0 \\ \alpha_{31} & \alpha_{32} & \alpha_{33} \end{pmatrix} \otimes \begin{pmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ 0 & \beta_{22} & \beta_{23} \\ 0 & 0 & \beta_{33} \end{pmatrix} = \begin{pmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{pmatrix}$$

La résolution du système s'effectue en deux passes :

$$A \otimes x = (L \otimes U) \otimes x = L \otimes (U \otimes x) = b$$

1. rechercher la solution telle que

$$L \otimes y = b$$

2. Puis résoudre

$$U \otimes x = y$$



Programmes – TimMatrixLuDecomposition

```
/*=====*/
/* NAME */
/* TimMatrixLuDecomposition performs the Lower Upper triangular decomposition */
/* of a matrix. */
/*=====*/
/* SYNOPSIS */
/* int TimMatrixLuDecomposition (<matrix_dimension>, */
/* <matrix_to_be_processed>, */
/* <permutation_array_to_be_initialized>, */
/* <parity_of_permutation_order>) */
/*=====*/
/* DESCRIPTION */
/* TimMatrixLuDecomposition implements the Crout's method with partial pivoting. */
/* ting for matrix decomposition. */
/* Given a NxN matrix this routine replaces it by the LU decomposition of */
/* rowwise permutation of itself. */
/* The first two parameters are in input, and describes the matrix to be processed. This matrix must be square and already initialized with double elements. In the case matrix includes one row full of zeros, function TimMatrixLuDecomposition returns an error. */
/* Third parameter (<permutation_array_to_be_initialized>) is an output vector which records the row permutation affected by the partial pivoting. Memory of this vector must have been previously allocated by caller. */
/* TimMatrixLuDecomposition is to be used just before TimMatrixLuSubstitution in order to solve linear equation system. */
/* Last parameter (<parity_of_permutation_order>) is initialized by function */
/* to 1 if the number of row exchanges is even, and 0 otherwise */
/* BIBLIOGRAPHY : W.H. PRESS et al. - Numerical Recipes - Cambridge University Press - 3rd edition - pp.33-36. */
/* TimMatrixLuDecomposition returns 0 on succes, and -1 otherwise. */
/*=====*/
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/*=====*/
/* ADMINISTRATION */
/* David DE NARDI | 09.10.92 | v00.01 | Creation of the SW component */
/* Giorgio FANARI | 09.10.92 | v00.01 | Creation of the SW component */
/* Serge RIAZANOFF | 15.01.93 | v01.01 | Tests, comments and validation */
/* David LE CORFEC | 04.03.98 | v02.01 | Added ANSI C support */
/* Serge RIAZANOFF | 17.02.00 | v02.02 | free C -> TimFree C */
/* Serge RIAZANOFF | 17.02.00 | v02.03 | call to TimAlloc(NULL) */
/* Serge RIAZANOFF | 02.03.03 | v03.01 | Version without Timb */
/*=====*/
/* ANSI C inclusion files */
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

/*=====*/
/* TimMatrixLuDecomposition core */
/*=====*/
int TimMatrixLuDecomposition
(
    int n, /* matrix dimension */
    double *matrix, /* matrix to be decomposed */
    int *index, /* permutation array to be initialized */
    int *even_flag_p /* permutation number is even flag */
)
{
    /* Local variables */
    int ili; /* index among lines in matrix */
    int ipx; /* index among pixels in matrix */
    int k; /* auxiliary index in matrix */
    int imax; /* pivot index */
    double *scale_factor; /* scaling factor per line */
    double sum; /* sum of matrix elements */
    double value; /* auxiliary variable used for swap */
    double max_value; /* pivot value */
    double scaled_sum; /* pivot value after scaling */
}
```

```
/* Check parameters */
if ((matrix == NULL) ||
    (n <= 0) ||
    (index == NULL) ||
    (even_flag_p == NULL))
{
    fprintf(stderr, "TimMatrixLuDecomposition : Wrong parameters \n");
    return (-1);
}

/* Look for maximum, line per line */
*even_flag_p = 1;
if ((scale_factor=(double*)calloc(n,sizeof(double))) == NULL)
{
    fprintf(stderr, "TimMatrixLuDecomposition : Cannot allocate memory for scale factor\n");
    return (-1);
}
for (ili=0; ili<n; ili++)
{
    scale_factor[ili] = 0.0;
    for (ipx=1; ipx<n; ipx++)
        if (fabs(matrix[ili*n+ipx]) > scale_factor[ili])
            scale_factor[ili] = fabs(matrix[ili*n+ipx]);
    if (scale_factor[ili] == 0.0)
    {
        fprintf(stderr, "TimMatrixLuDecomposition: Passed matrix is singular \n");
        if (scale_factor) free (scale_factor); scale_factor=NULL;
        return(-1);
    }
    scale_factor[ili] = 1.0 / scale_factor[ili];
}

/* Loop on columns in Crout's method */
for (ipx=0; ipx<n; ipx++)
{
    /* Initialize the upper part of the column */
    for (ili=0; ili<ipx-1; ili++)
    {
        sum = matrix[ili*n+ipx];
        for (k=0; k<ili-1; k++)
            sum = sum - matrix[ili*n+k] * matrix[k*n+ipx];
        matrix[ili*n+ipx] = sum;
    }

    /* Initialize the lower part of the column and get pivot position */
    max_value = 0.0;
    imax = ipx;
    for (ili=ipx; ili<n; ili++)
    {
        sum = matrix[ili*n+ipx];
        for (k=0; k<ipx-1; k++)
            sum = sum - matrix[ili*n+k] * matrix[k*n+ipx];
        matrix[ili*n+ipx] = sum;
        scaled_sum = scale_factor[ili] * fabs(sum);
        if (scaled_sum >= max_value)
        {
            max_value = scaled_sum;
            imax = ili;
        }
    }

    /* Permutates elements between lines imax and ipx */
    if (ipx != imax)
    {
        for (k=0; k<n; k++)
        {
            value = matrix[imax*n+k];
            matrix[imax*n+k] = matrix[ipx*n+k];
            matrix[ipx*n+k] = value;
        }
        if (*even_flag_p) *even_flag_p = 0;
        else *even_flag_p = 1;
        scale_factor[imax] = scale_factor[ipx];
    }
    index[ipx] = imax;
}
```

```
/* When diagonal elemnt is zero, replace it by tiny value */
if (matrix[ipx*n+ipx] == 0.0) matrix[ipx*n+ipx] = 1.0e-20;

/* Divide line elements by the pivot */
if (ipx != n-1)
{
    value = 1.0 / matrix[ipx*n+ipx];
    for (ili=ipx+1; ili<n; ili++)
        matrix[ili*n+ipx] = matrix[ili*n+ipx] * value;
} /* loop on columns */

/* Release memory */
if (scale_factor) free (scale_factor);
scale_factor = NULL;

/* Return */
return(0);
}
```




Programmes – TimMatrixLuSubstitution

```

/*=====
/* NAME
/* TimMatrixLuSubstitution substitutes the right hand B of N equations A.X=B */
/* with the solution X of the system.
/*=====
/* SYNOPSIS
/* int TimMatrixLuSubstitution (<matrix_dimension>,
/* <LU_decomposed_matrix>,
/* <permutation_array>,
/* <right_hand_side_vector>)
/*=====
/* DESCRIPTION
/* TimMatrixLuSubstitution implements the Crout's method to solve system of
/* N linear equation A.X=B.
/*
/* The first two parameters describes the matrix result of the LU decomposi-
/* tion (see function TimMatrixLuDecomposition). This matrix must not be
/* singular (pivot value on the diagonal less than 1.0e-20).
/*
/* Third parameter (<permutation_array>) is input as the permutation vector
/* returned by TimMatrixLuDecomposition.
/*
/* Last parameter (<right_hand_side_vector>) is input as right-hand side vector*/
/* (B), and returns with the solution vector (X).
/*
/* TimMatrixLuSubstitution is to be used just after TimMatrixLuDecomposition
/* in order to solve linear equation system.
/*
/* BIBLIOGRAPHY : W.H. PRESS and al. - Numerical Recipes - Cambridge
/* University Press - 3rd edition - pp.36-37.
/*
/* TimMatrixLuSubstitution returns 0 on success, and -1 otherwise.
/*=====
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/* TELESPAZIO S.p.A.
/*=====
/* ADMINISTRATION
/* David DE NARDI | 09.10.92 | v0.0.1 | Creation of the SW component
/* Giorgio FANARI | 09.10.92 | v0.0.1 | Creation of the SW component
/* Serge RIAZANOFF | 15.01.93 | v0.1.0 | Tests, comments and validation
/* David LE CORFEC | 04.03.98 | v0.2.0.1 | Added ANSI C support
/* Serge RIAZANOFF | 02.03.03 | v0.3.0.1 | Version without Tim.h
/*=====
/* ANSI C inclusion files
/*=====
#include <stdio.h>
#include <stdlib.h>
#include <math.h>

/*=====
/* TimMatrixLuSubstitution core
/*=====
int TimMatrixLuSubstitution
(
    int n, /* matrix dimension */
    double *matrix, /* matrix to be decomposed */
    int *index, /* permutation array to be initialized */
    double *right_hand /* vector in input and output */
)
{
/*=====
/* Local variables
/*=====
int ili; /* index among lines in matrix */
int ili2; /* index among lines in matrix */
int ili3; /* index among lines in matrix */
int ipx; /* index among pixels in matrix */
double sum; /* sum of matrix elements */

```

```

/*=====
/* Check parameters
/*=====
if ((matrix == NULL)
    (n <= 0)
    (index == NULL)
    (right_hand == NULL))
{
    fprintf(stderr, "TimMatrixLuSubstitution : Wrong parameters \n");
    return (-1);
}
/*=====
/* Check that the matrix is not singular
/*=====
for (ili=0; ili<n; ili++)
    if (fabs(matrix[ili*n+ili]) <= 1.0e-20)
    {
        fprintf(stderr,
            "TimMatrixLuSubstitution : Matrix is singular (matrix[%d,%d]=%e\n",
            ili,ili,matrix[ili*n+ili]);
        return (-1);
    }
/*=====
/* Loop on lines forward
/*=====
ili2 = -1;
for (ili=0; ili<n; ili++)
{
    ili3 = index[ili];
    sum = right_hand[ili3];
    right_hand[ili3] = right_hand[ili];
    if (ili2 != -1)
        for (ipx=ili2; ipx<=ili-1; ipx++)
            sum = sum - matrix[ili*n+ipx] * right_hand[ipx];
    else
        if (sum != 0.0)
            ili2 = ili;
    right_hand[ili] = sum;
} /* loop on lines forward */
/*=====
/* Loop on lines backward
/*=====
for (ili=n-1; ili>=0; ili--)
{
    sum = right_hand[ili];
    if (ili < n-1)
        for (ipx=ili+1; ipx<n; ipx++)
            sum = sum - matrix[ili*n+ipx] * right_hand[ipx];
    right_hand[ili] = sum / matrix[ili*n+ili];
} /* loop on lines backward */
/*=====
/* Return
/*=====
return (0);
}

```



Programmes – TimMatrixSolveSystem - TestMatrixSolveSystem

```

=====
/* NAME
/* TimMatrixSolveSystem solves a system of N equations A.X=B.
=====
/* SYNOPSIS
/* int TimMatrixSolveSystem (<matrix_dimension>,
/*                          <system_matrix>,
/*                          <right_hand_side_vector>,
/*                          <solution_vector>)
/*
/* DESCRIPTION
/* TimMatrixSolveSystem implements the Crout's method to solve system of N
/* linear equation A.X=B.
/*
/* The first three parameters describes the system to be solved.
/*
/* Second parameter (<system_matrix>) is the NN square matrix including the
/* coefficients of linear equations (A). Coefficients (all) must be arranged
/* in the following order :
/* 0 1 N N+1 N+2 2N 2N+1 ...
/* a00,a01,...,a0N,a10,a11,...,a1NaN0,aN1,...,aNnN where i represents the
/* line index, and j represents the coefficient index per line.
/*
/* Third parameter (<right_hand_side_vector>) is the known right-hand side
/* vector (B).
/*
/* Last parameter (<solution_vector>) returns the values of the unknowns (X).
/*
/* Note :
/* 1. Third and fourth parameters can points on the same vector.
/* 2. <system_matrix> will be altered after TimMatrixSolveSystem completion.
/*
/* BIBLIOGRAPHY : W.H. PRESS and al. - Numerical Recipes - Cambridge
/* University Press - 3rd edition - pp.33-37.
/*
/* TimMatrixSolveSystem returns 0 on success, and -1 otherwise.
=====
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/* TELESPIAZIO S.p.A.
=====
/* ADMINISTRATION
/* David DE NARDIO | 09.10.92 | v00.01 | Creation of the SW component
/* Giorgio FANARI | 09.10.92 | v00.01 | Creation of the SW component
/* Serge RIAZANOFF | 15.01.93 | v01.01 | Tests, comments and validation
/* David I.E. CORFEC | 04.03.98 | v02.01 | Added ANSI C support
/* Serge RIAZANOFF | 17.02.00 | v02.02 | free() -> TimFree()
/* Serge RIAZANOFF | 17.02.00 | v02.03 | calloc() -> TimAlloc(NULL)
/* Serge RIAZANOFF | 02.03.03 | v03.01 | Version without Timb
=====
/* ANSI C inclusion files
=====
#include <stdio.h>
#include <stdlib.h>

=====
/* TimMatrixSolveSystem core
=====
int TimMatrixSolveSystem
(
    int n, /* matrix dimension */
    double *matrix, /* matrix to be decomposed */
    double *right_hand, /* system known vector */
    double *solution /* vector of unknown solutions */
)
{
    /* Local variables
    =====
    int *index; /* permutation array */
    int even_flag; /* permutation number is even flag */
    int i; /* vector index */

```

```

=====
/* Check parameters
=====
if ((matrix == NULL)
    ||
    (n <= 0)
    ||
    (right_hand == NULL)
    ||
    (solution == NULL))
{
    fprintf(stderr, "TimMatrixSolveSystem : Wrong parameters \n");
    return (-1);
}
=====
/* Allocate memory for permutation array
=====
if ((index=(int *)calloc(n,sizeof(int))) == NULL)
{
    fprintf(stderr,
        "TimMatrixSolveSystem : Cannot allocate memory for permutation array\n");
    return (-1);
}
=====
/* Perform the LU decomposition
=====
if (TimMatrixLuDecomposition(n,matrix,index,&even_flag) != 0)
{
    fprintf(stderr,
        "TimMatrixSolveSystem : Cannot compute LU decomposition\n");
    if (index) free (index); index=NULL;
    return (-1);
}
=====
/* Copy right-hand values into solution vector
=====
if (solution != right_hand)
{
    for (i=0; i<n; i++)
        solution[i] = right_hand[i];
}
=====
/* Perform the LU substitution
=====
if (TimMatrixLuSubstitution(n,matrix,index,solution) != 0)
{
    fprintf(stderr,
        "TimMatrixSolveSystem : Cannot compute LU substitution\n");
    if (index) free (index); index=NULL;
    return (-1);
}
=====
/* Release memory
=====
if (index) free (index);
index = NULL;
=====
/* Return
=====
return (0);
}

```

```

=====
/* NAME
/* TestMatrixSolveSystem tests the TimMatrixSolveSystem function.
=====
/* SYNOPSIS
/* TestMatrixSolveSystem
=====
/* DESCRIPTION
/* TestMatrixSolveSystem tests the resolution of a system of N linear
/* equations of N unknown variables.
/*
/* No arguments are given on the command line. The example system to be
/* solved has values given as constants.
/*
/* TestMatrixSolveSystem returns 0 upon success and 1 upon failure.
=====
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/* GAEL Consultant.
=====
/* ADMINISTRATION
/* Serge RIAZANOFF | 02.03.03 | v00.01 | Creation of the SW component
=====
/* ANSI C inclusion files
=====
#include <stdio.h>
#include <stdlib.h>

=====
/* Constant values
=====
#define N 3
double matrix[] = { 3, 5, 4,
                    4, 2, 1,
                    8, 1, 5 };

double right_hand[] = { 41,
                       19,
                       44 };

=====
/* TestMatrixSolveSystem core
=====
int main
(
    int argc, /* number of arguments on command line */
    char *argv[] /* values of arguments on command line */
)
{
    /* Local variables
    =====
    double solution[N]; /* solution to be computed */
    int i; /* vector index */

    /* Call the TimMatrixSolveSystem function
    =====
    if (TimMatrixSolveSystem(N,matrix,right_hand,solution) != 0)
    {
        fprintf(stderr, "TestMatrixSolveSystem : Cannot solve system.\n");
        exit (1);
    }

    /* Print out the solution values
    =====
    fprintf (stdout, "SOLUTION: \n");
    for (i=0; i<N; i++)
        fprintf (stdout, "%2d : %d\n", i, solution[i]);

    /* Return
    =====
    exit (0);
}

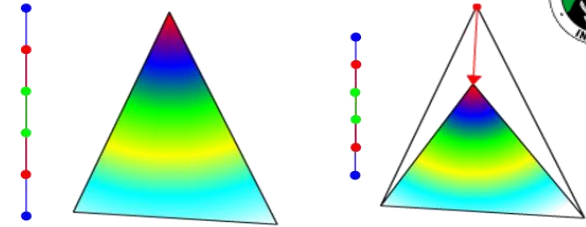
```

Vecteur solution: (2,3,5)



Transformations par facettes (*piecewise*)

- Saisie des points d'appui
- Triangulation de Delaunay



D'après les résultats du projet
de Marc MEYNIER et Benoit NEIL (2004)

⊕ Transformations par facettes (*piecewise*)

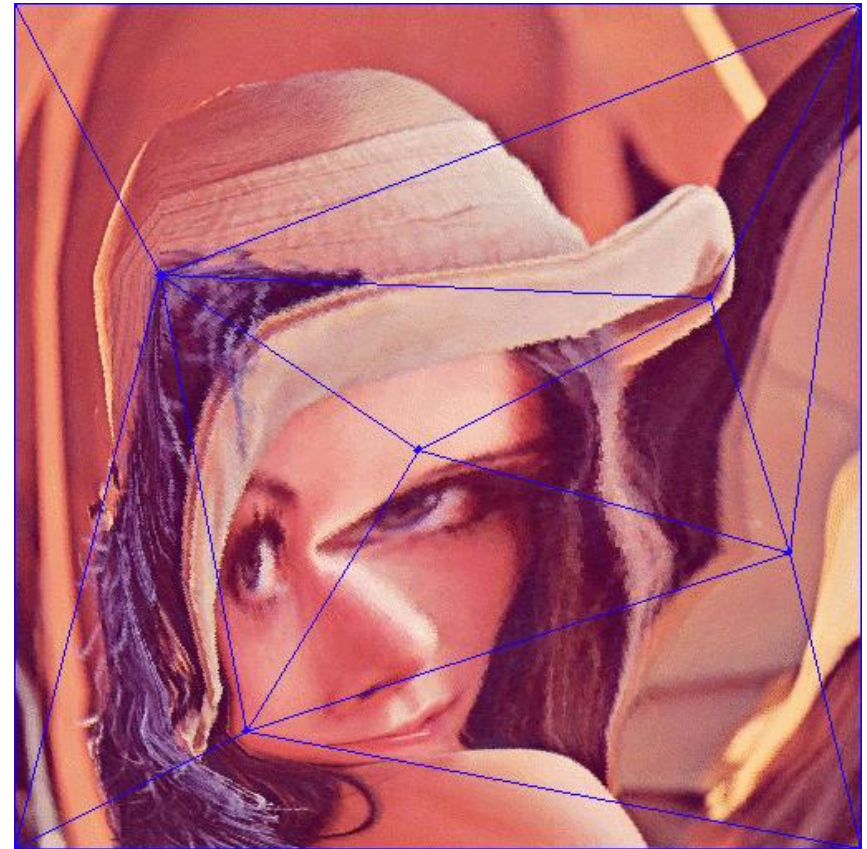
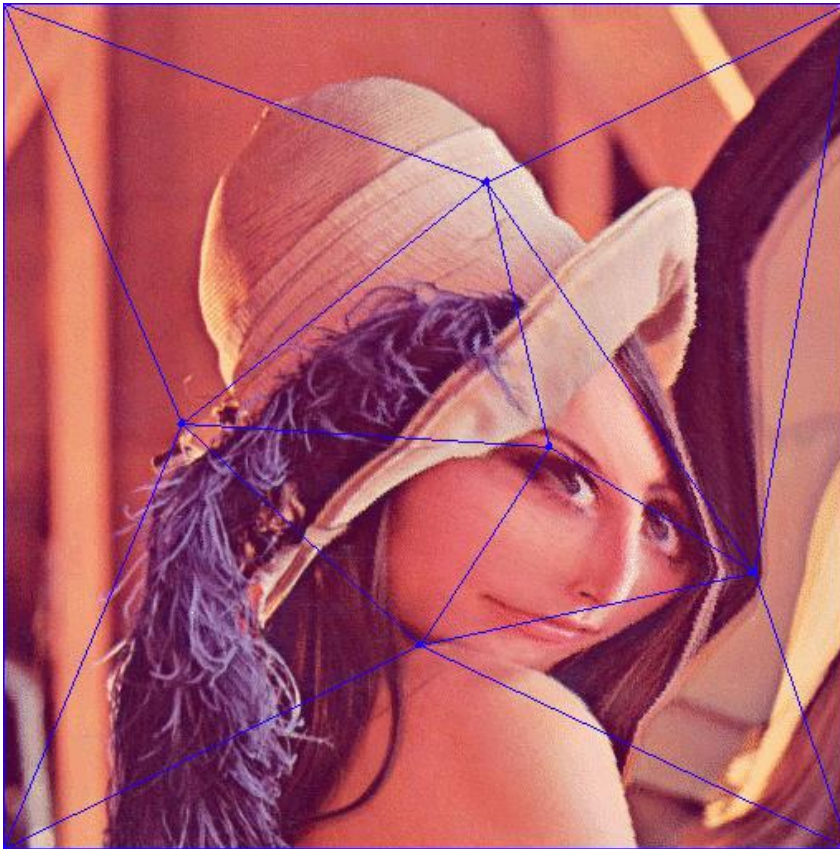
▣ Animations



D'après les résultats du projet
de Marc MEYNIER et Benoit NEIL (2004)

✚ Transformations par facettes (*piecewise*)

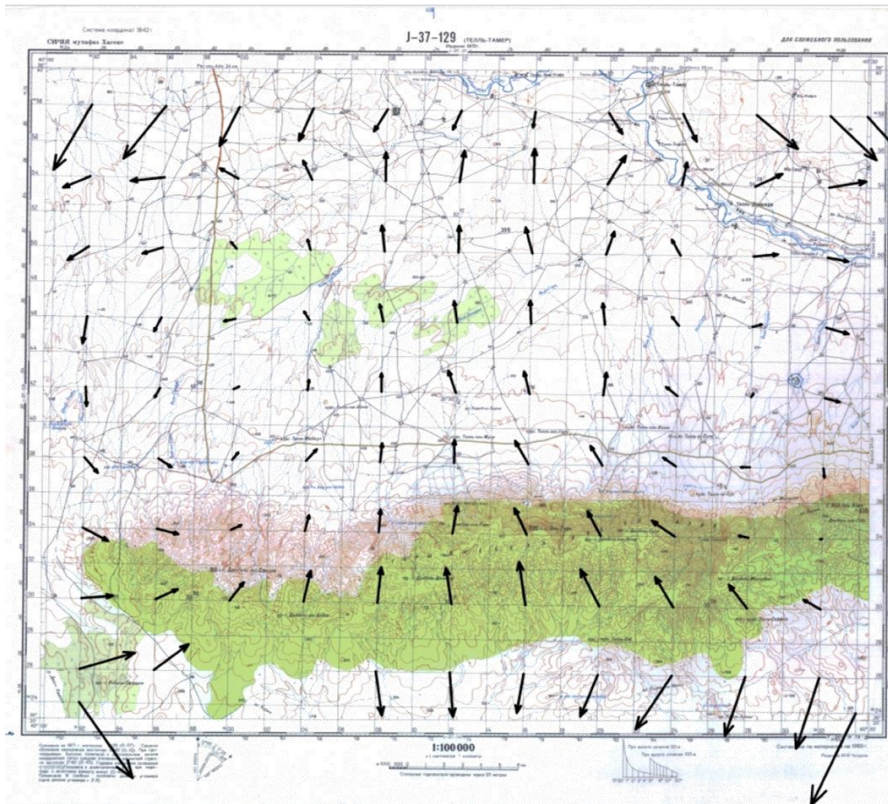
▣ Autres exemples



D'après les résultats du projet
de Victor VERRIERE et Daugoh TIVOLI (2004)

Transformations par facettes (*piecewise*)

- Application possible au recalage des cartes scannées



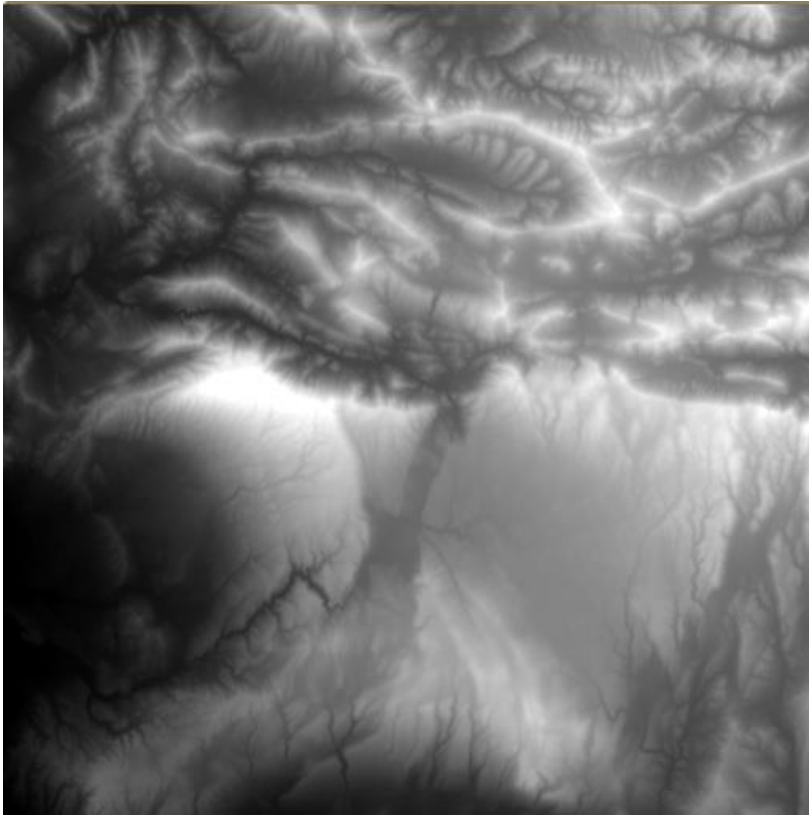
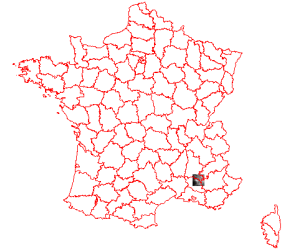
Résultats du contrôle qualité d'une image géocodée par une transformation polynomiale de degré 1



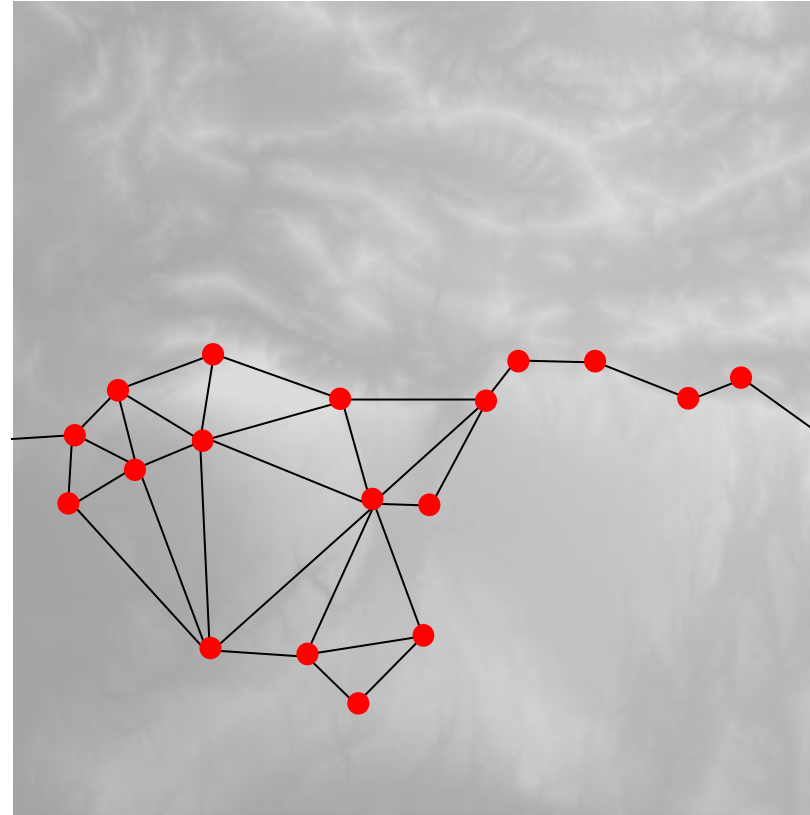
- Saisir un réseau hexagonal de points d'appui
→ **attention l'EQM est nécessairement nulle**
- Après traitement réaliser un contrôle qualité dans le réseau entrelacé
→ **l'EQM est significative.**

⊕ Transformations par facettes (*piecewise*)

- ⊞ Application très approximative sur une image présentant des erreurs de parallaxe

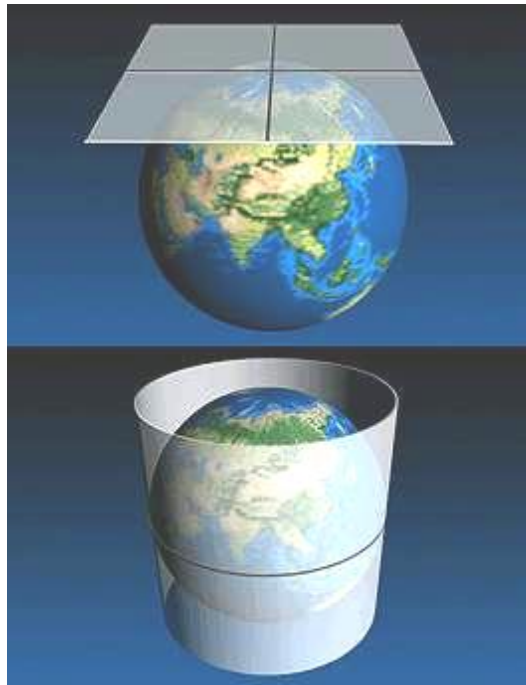


représentation maillée (grille, matrice, *raster*)



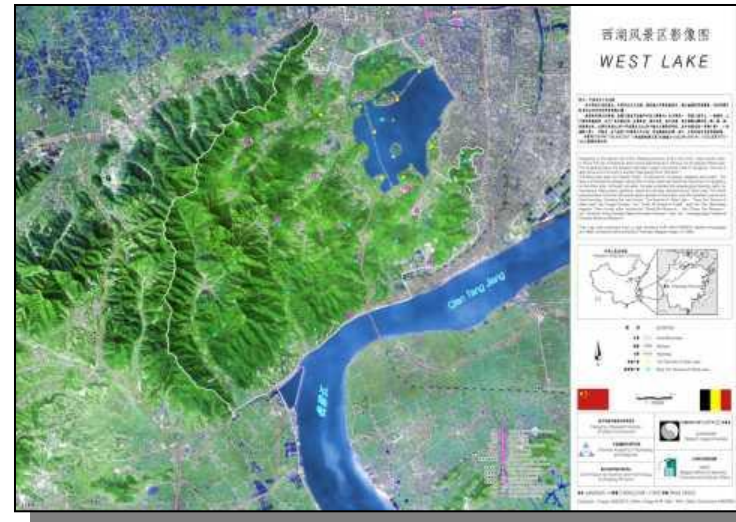
TIN (*Triangular Irregular Network*)

Exemples de transformation géométrique globale – Les changements de projection cartographique

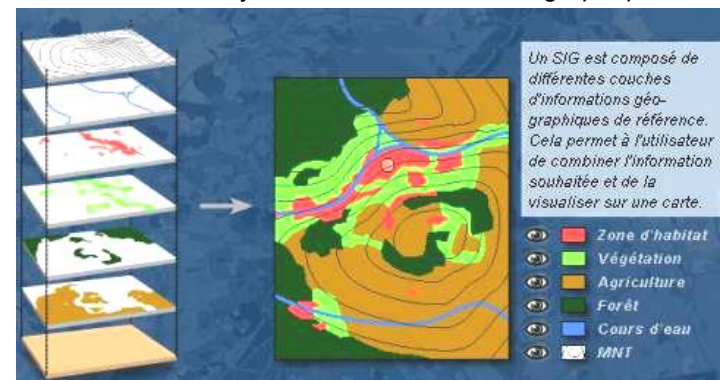


<http://telsat.belspo.be/beo/fr/guide/index.htm>

Spatiocarte

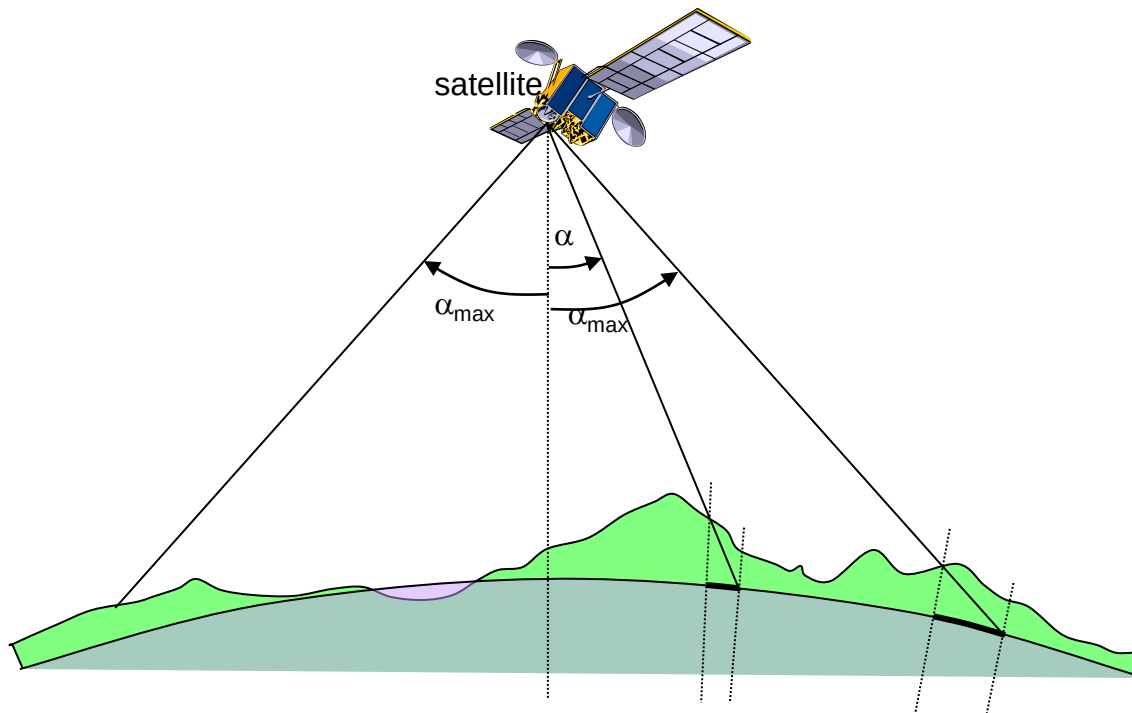


SIG : Système d'Information Géographique



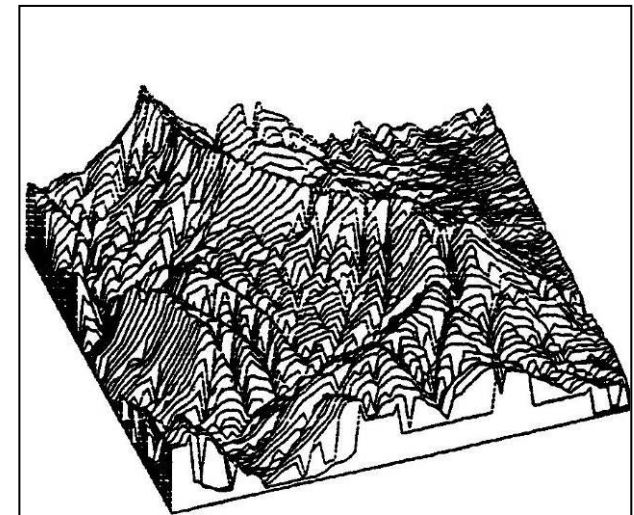
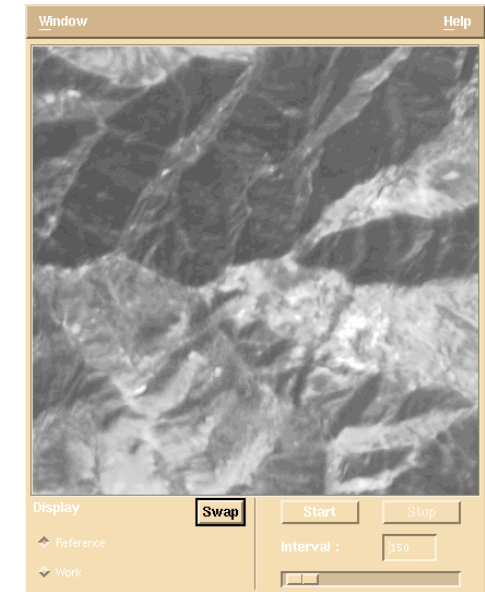
❖ Déformations locales

- ❖ Exemple de déformation locale –
⇒ L'orthorectification



Erreur de parallaxe

$$e_p \approx \tan(\alpha) \times h$$



❏ Défaut de parallaxe – Mosaïque de vues aériennes (New-York, Google Earth)





⊕ Morphologie mathématique

- ⊞ notions de topologie / voisinage
- ⊞ ouverture / fermeture / élément structurant



❖ Bibliographie

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