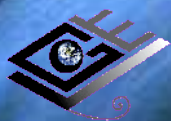


遙測原理簡介

蔡富安 教授
國立中央大學
太空及遙測研究中心 暨
土木工程學系
ftsai@csrsr.ncu.edu.tw



GeoComputing
Laboratory



國立中央大學太空及遙測研究中心

遙測之定義

To learn *something* about *something*
without touching it.

以非接觸式方式獲取目標物之資訊

- 方式：透過感測器
- 媒介：電磁波、聲波
- 對象：物體表面物理特性（溫度、溼度、粗糙度、顏色等）、幾何資訊（位置、方向、大小、形狀、速度）、或目標區的各種現象 (phenomena)

遙測之目的與定位

To learn *more, more quickly, or more economically.*

- 遙測的目的非取代地面或傳統量測
- 輔助資料
 - 更多
 - 更快
 - 更廣
 - 更經濟

遙測之類別

■ 以感測器 (sensor) 類別區分

□ 主動式遙測

- 遙測儀器發射電磁波或其他感測媒介，並接收目標物反射回波
- 例如：合成孔徑雷達影像、氣象雷達、光達 (LiDAR)、多普勒雷達等

□ 被動式遙測

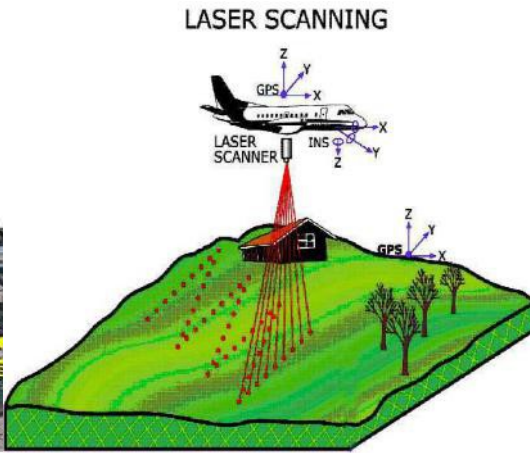
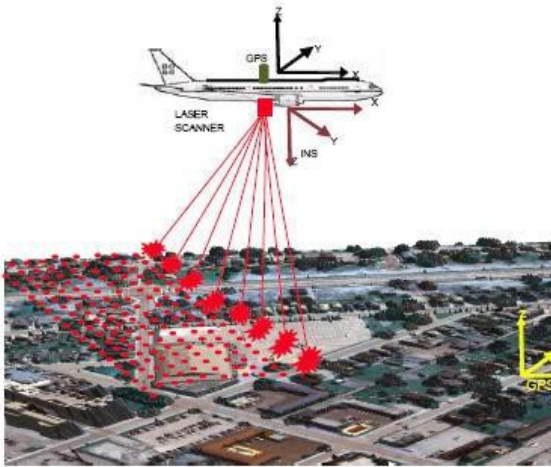
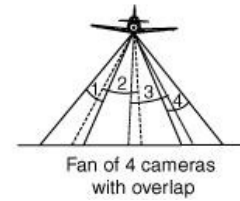
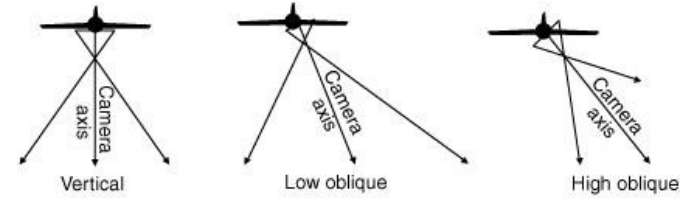
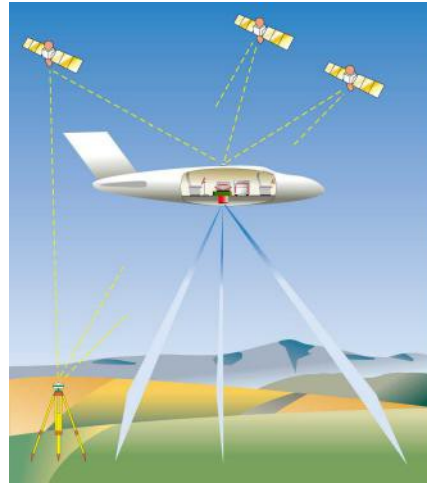
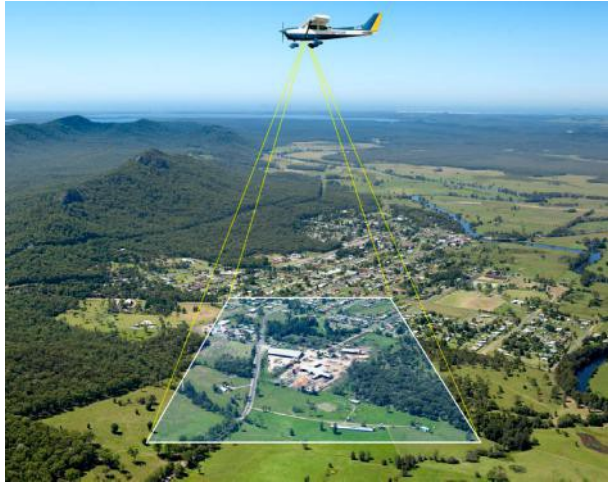
- 遙測儀器並不發射電磁波，能量來自目標物本身放出的電磁波或目標物對其他能量來源的反射
- 例如：光學衛星影像、航空攝影測量等

遙測之類別

■ 以載具 (platform) 類別區分

- 衛載 (space-borne) : 衛星
- 空載 (airborne) : 飛機、直昇機、氣球、無人載具 (UAV)
- 地面遙測 (ground-based) : 車、船、手持式、固定式...

空載遙測

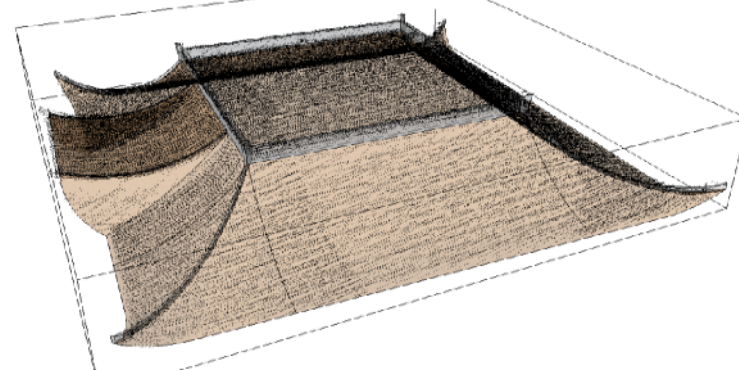


地面遙測

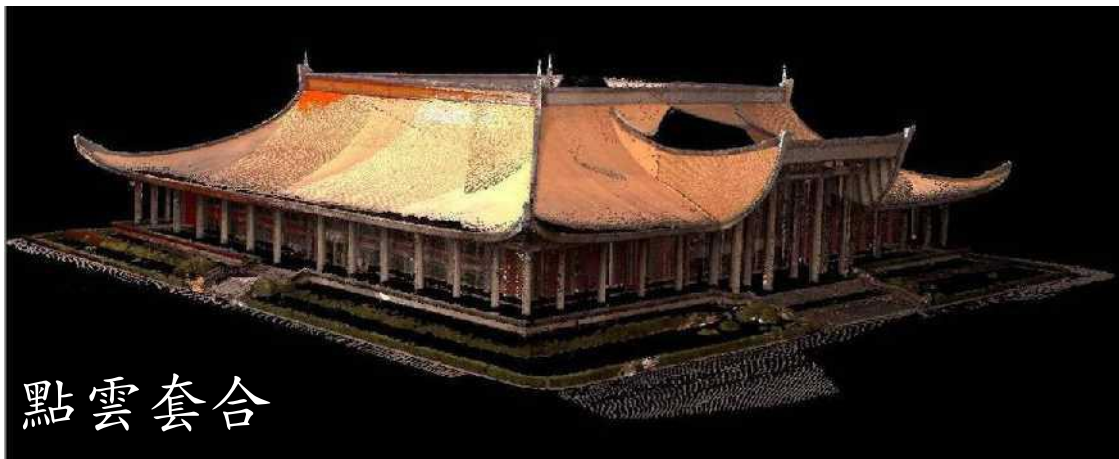


高精度地面光達重建

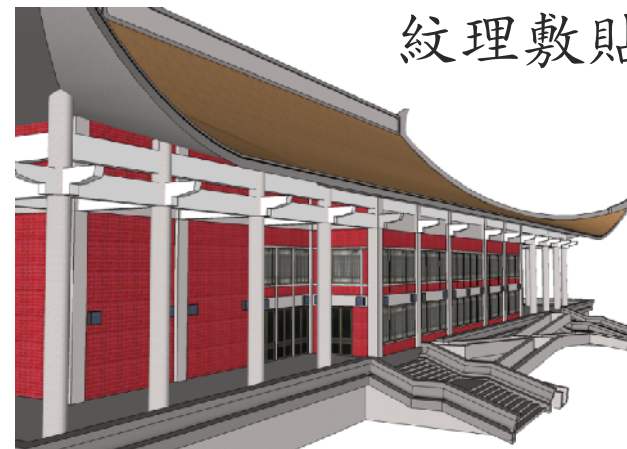
點雲曲面彌合



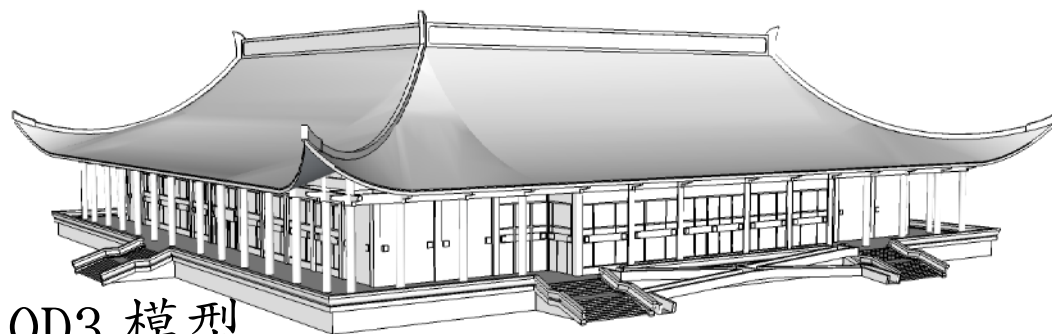
點雲套合



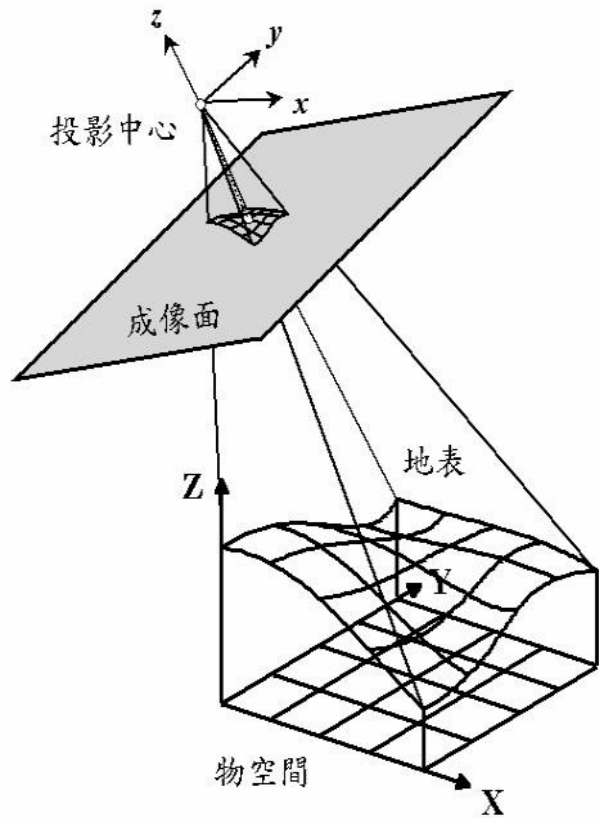
紋理敷貼



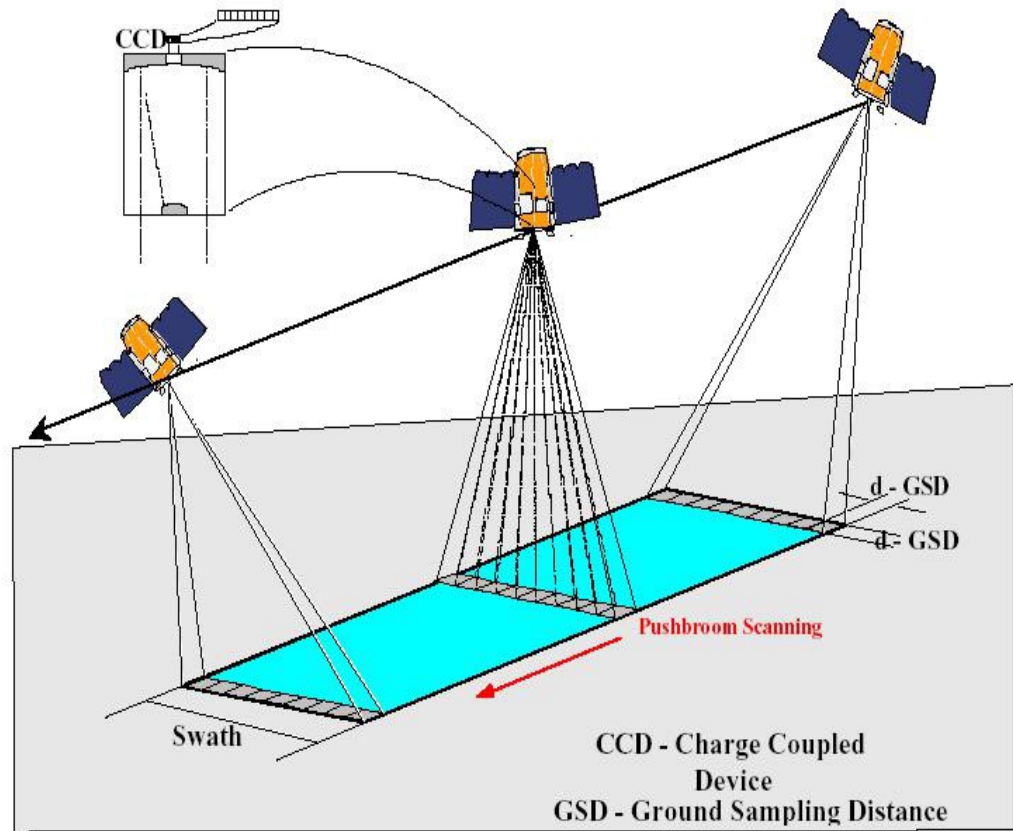
LOD3 模型



光學影像成像原理

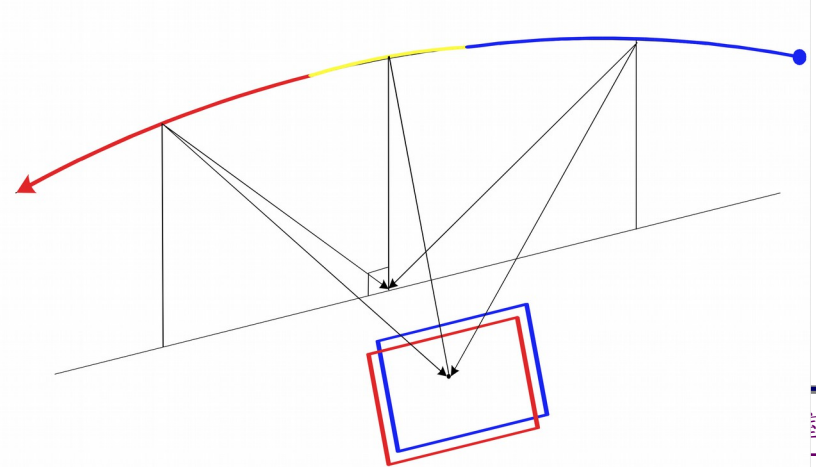
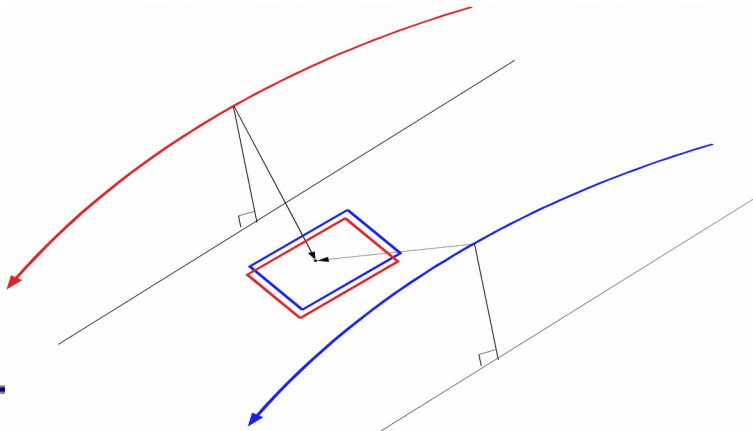
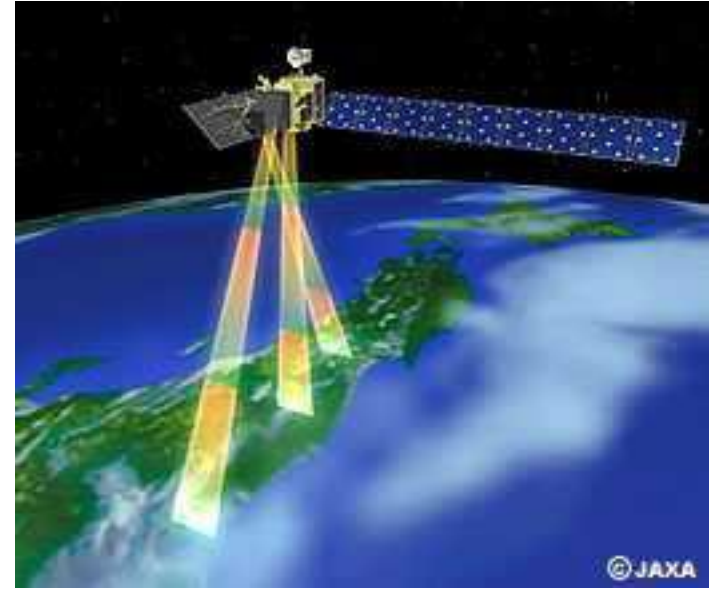
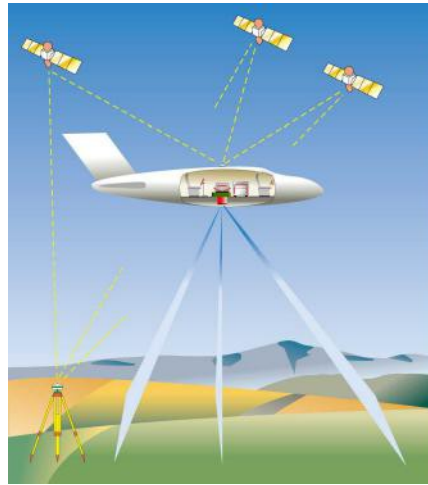
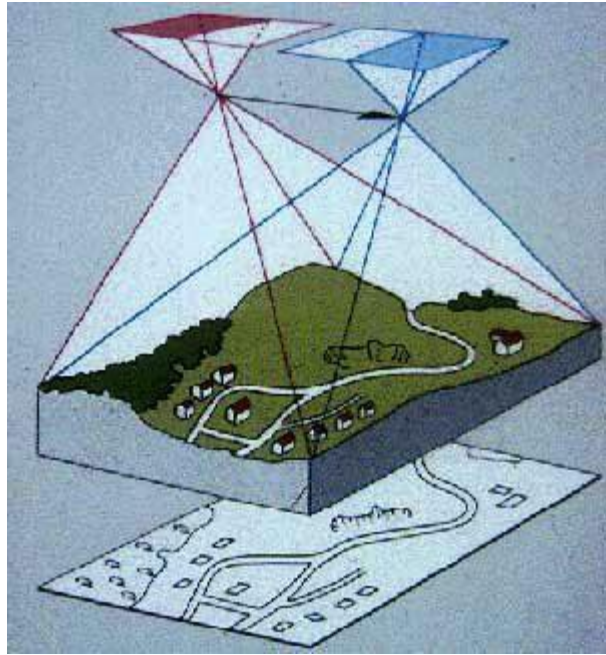


全透視投影

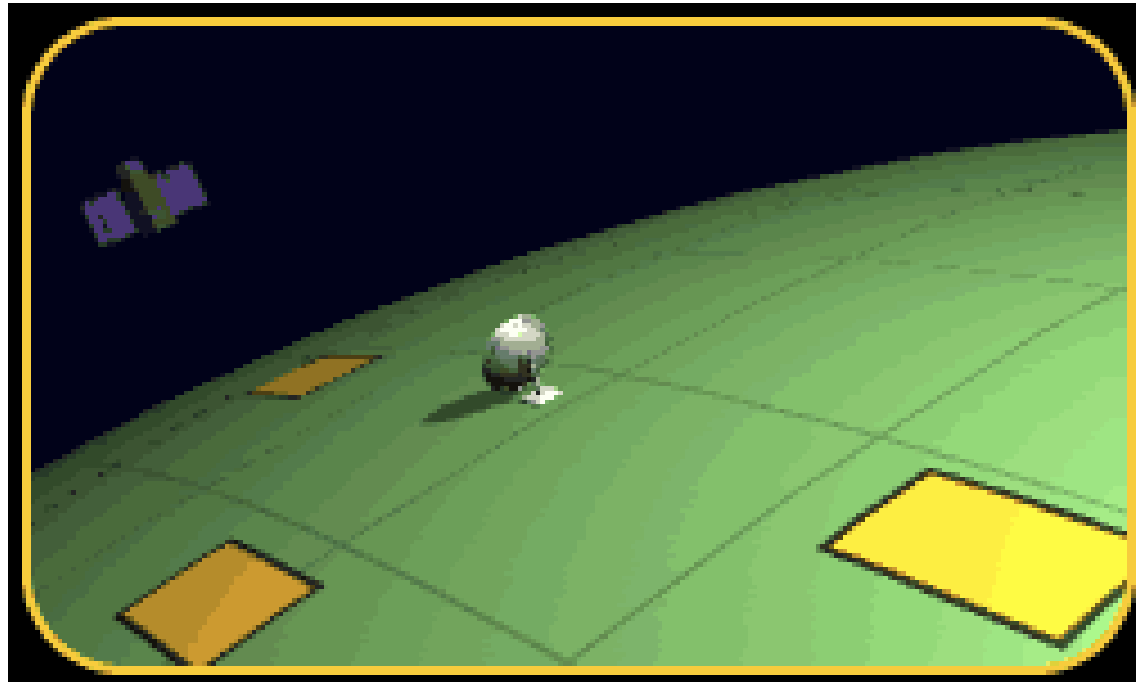


半透視投影

立體觀測



衛星立體觀測 (Body Rotation)



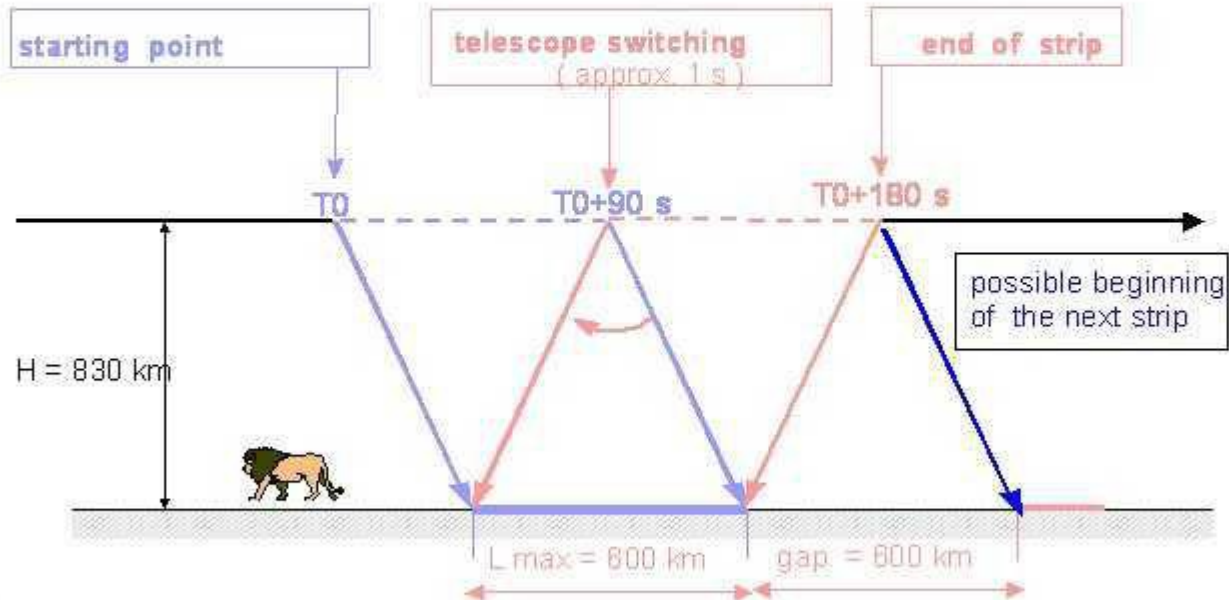
©2000 ImageSat International

衛星立體觀測 (Telescope Rotation)

A unique offer of orthoimagery and DTM

SPOT
IMAGE

HRS : the acquisition process



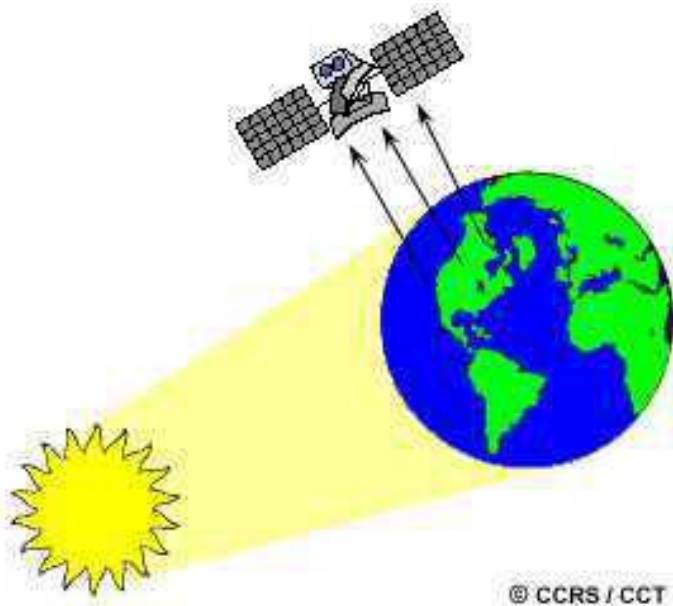
SPOT 5 INTERNATIONAL CONFERENCE

Author: Marc Bernard

Page 12

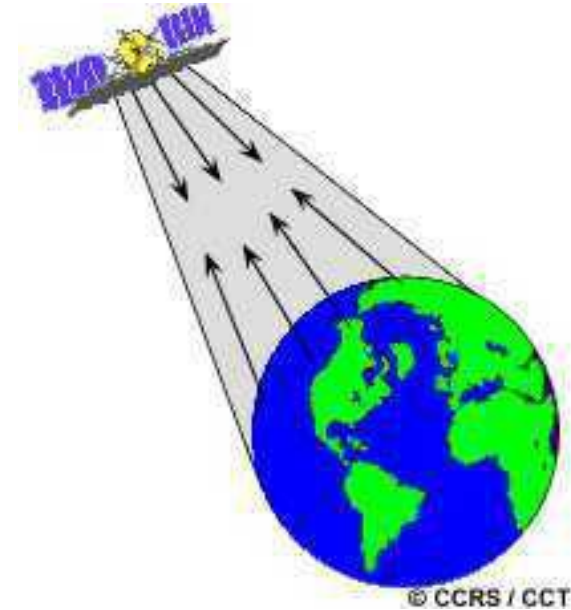
■ 被動式 (Passive)

- 電磁波能量來自太陽
- SPOT
- FORMOSAT-2



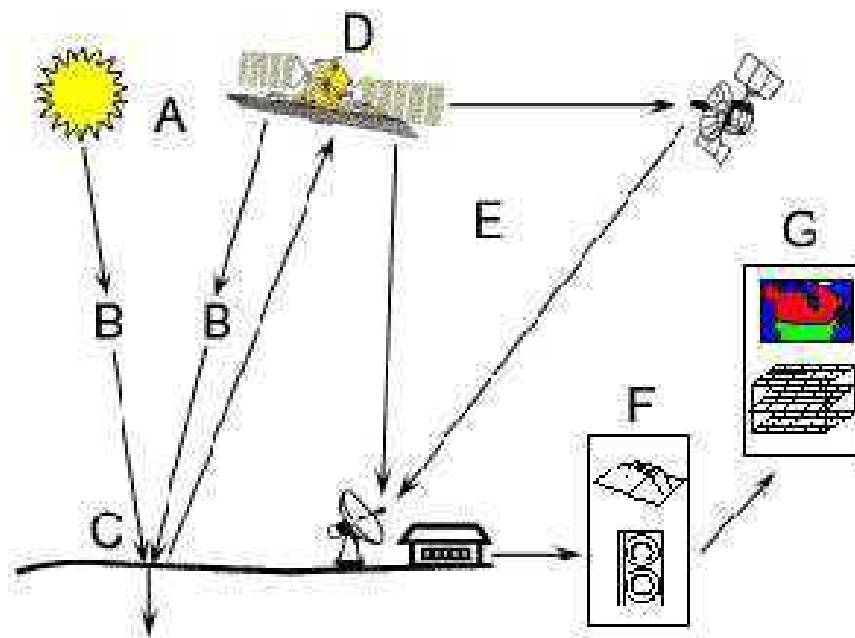
■ 主動式 (Active)

- 電磁波能量來自載體本身
- ERS
- Radarsat



遙測技術七大要素

- A. 能量來源
- B. 輻射與大氣
- C. 電磁波與地表交互作用
- D. 感測器
- E. 資料傳輸, 接收與處理
- F. 判釋與分析
- G. 應用

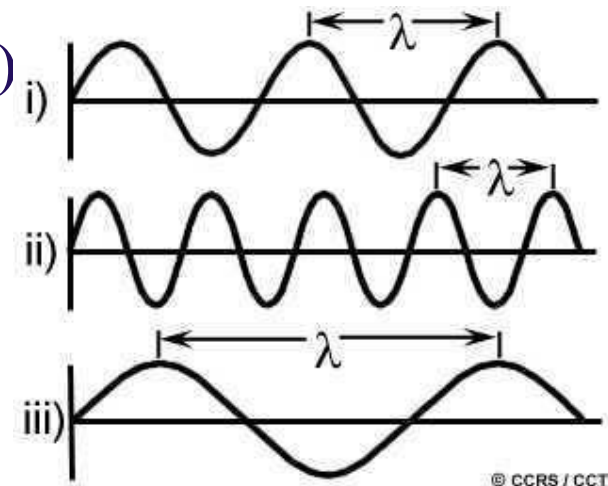
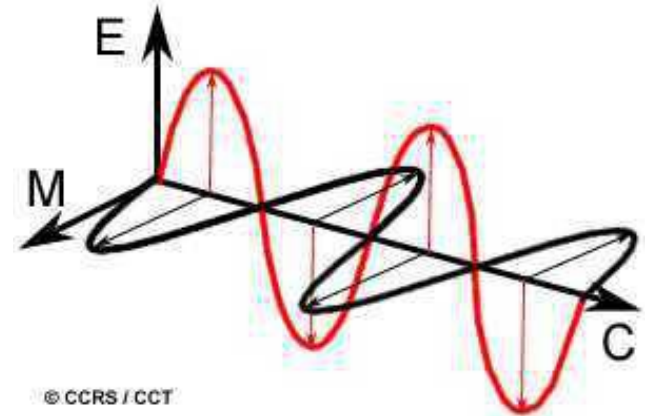


© CCRS / CCT

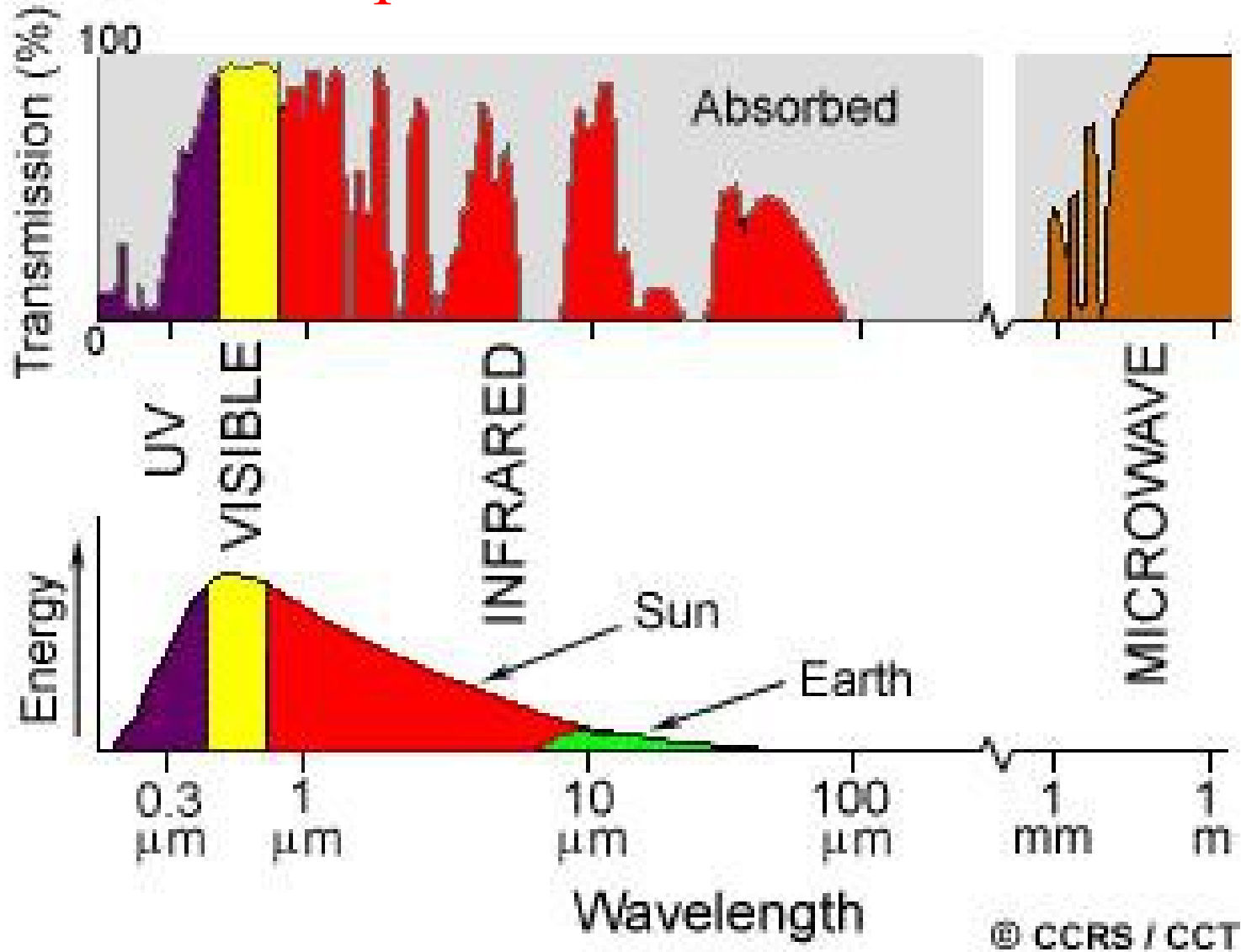
A. 能量來源

■ 電磁波

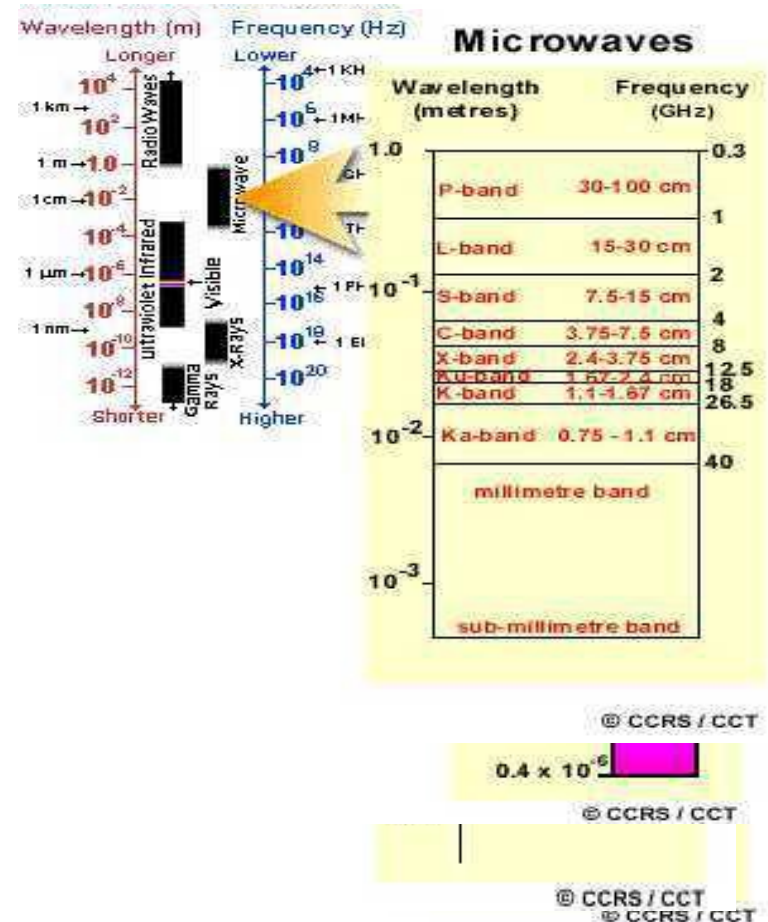
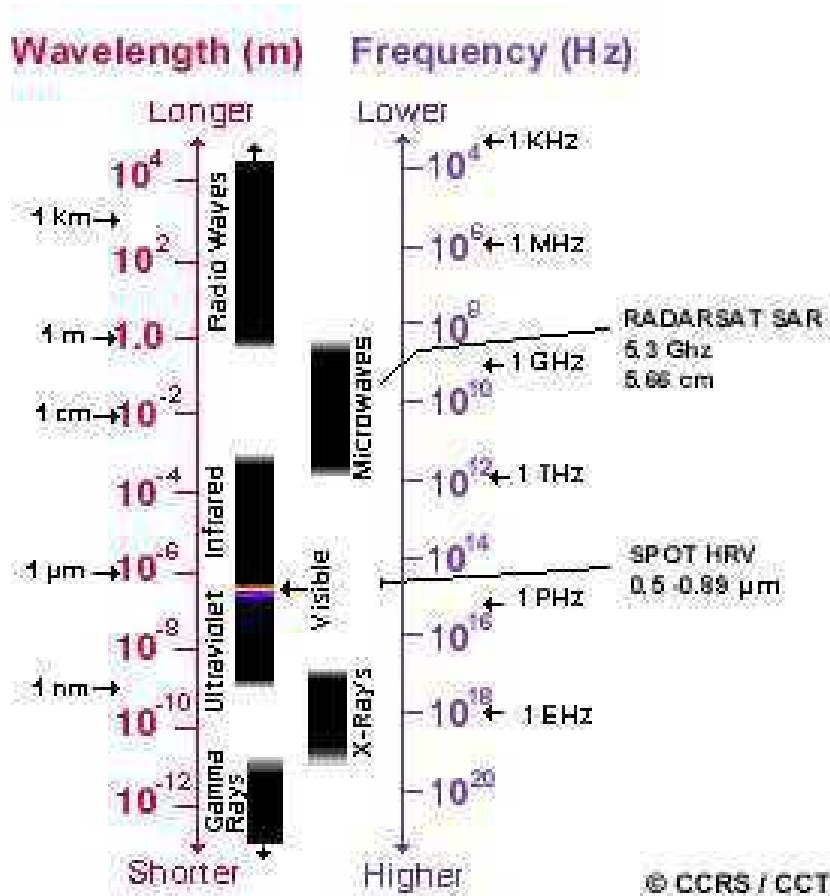
- 遙測的基本元素
- 遙測相關理論或模式的基礎
- 包括電波 (E) 與磁波 (M)
 - 相互垂直
 - 以光速 (c) 前進
- 波長 (λ)
 - Nanometers (nm, 10^{-9} meters)
 - Micrometers (μm , 10^{-6} meters)
 - Centimeters (cm, 10^{-2} meters)
- 頻率 (ν)
 - Hertz (Hz)
- 光速 (c) = 波長 (λ) x 頻率 (ν)



Solar EM Spectrum



A. 電磁波譜



A. 電磁波譜

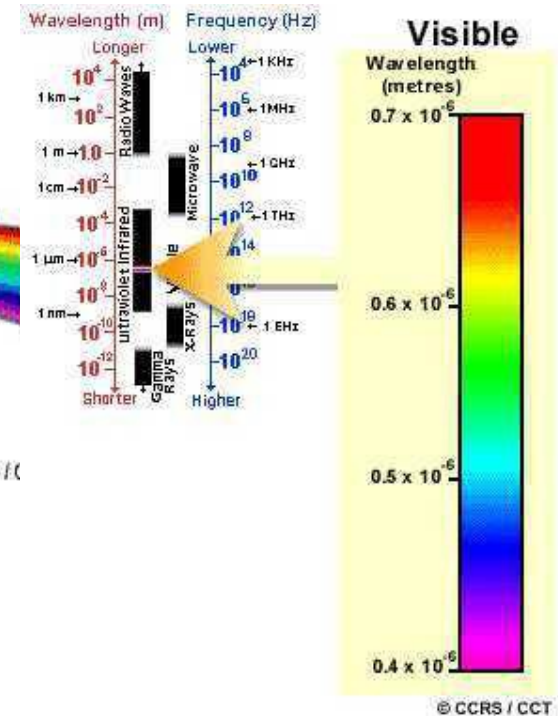
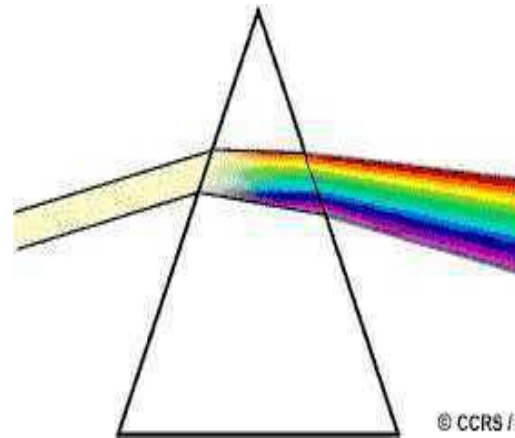
■ 紫外線 (Ultraviolet or UV)

- 岩石、礦石等在紫外線照射下會發出螢光 (近可見光)

■ 可見光 (Visible)

- 0.4-0.7 μm

■ 紫 \rightarrow 紅



A. 電磁波譜

■ 紅外光 (Infrared, IR)

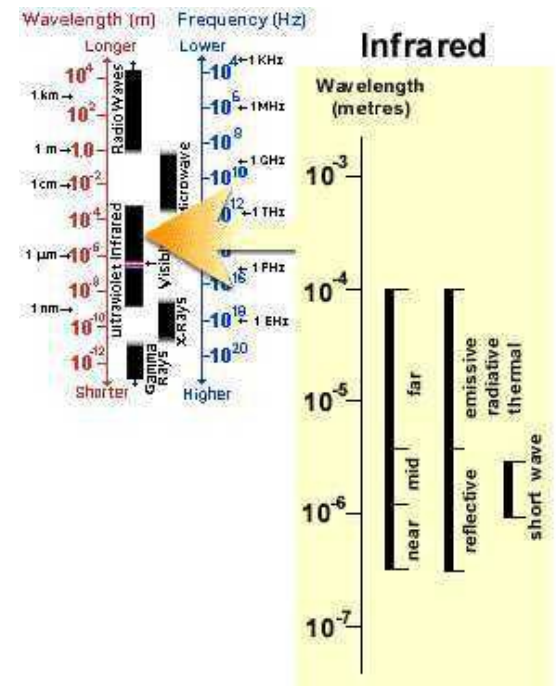
□ 反射性 NIR-SWIR(0.7-3 μm)

□ 輻射性 Thermal-IR(熱紅外光, 3-100 μm)

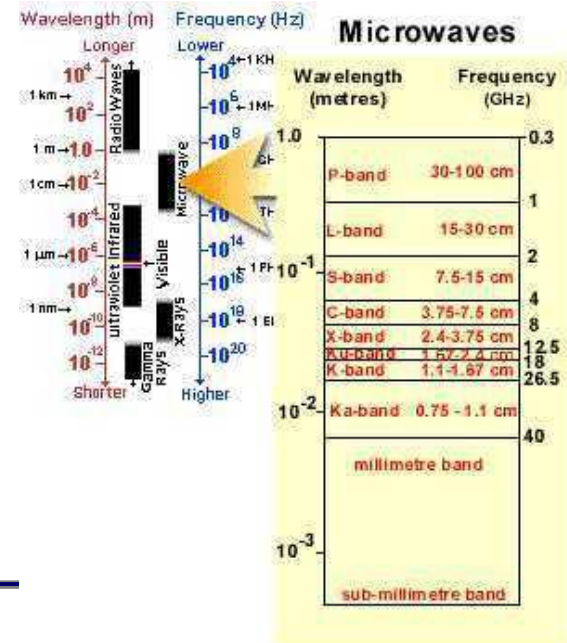
■ 由地物本身所輻射出之熱能

■ 微波 (Microwaves)

□ 1mm-1m



© CCRS / CCT



B. 輻射與大氣

■ 散射效應 (Scattering)

□ 因大氣中之氣體分子或微粒，導致電磁波路徑改變。

□ Rayleigh Scattering

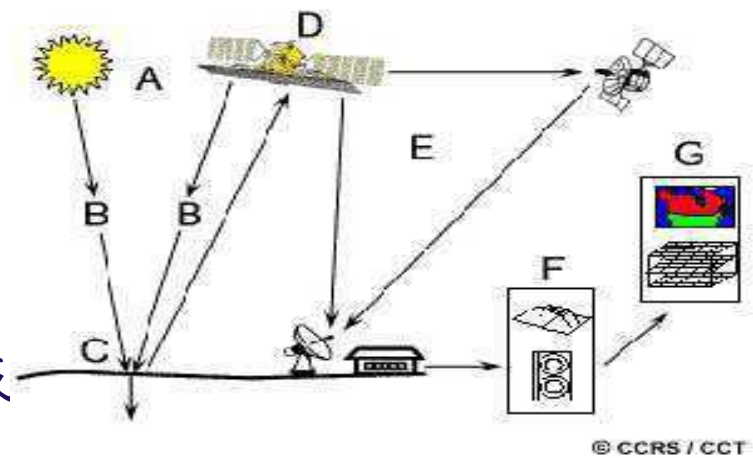
□ Mie Scattering

■ 吸收效應 (Absorption)

□ 電磁波能量被吸收

□ 主要因為以下三種大氣成

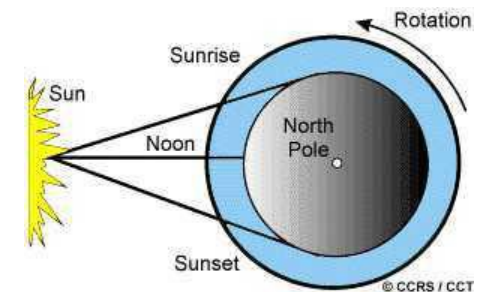
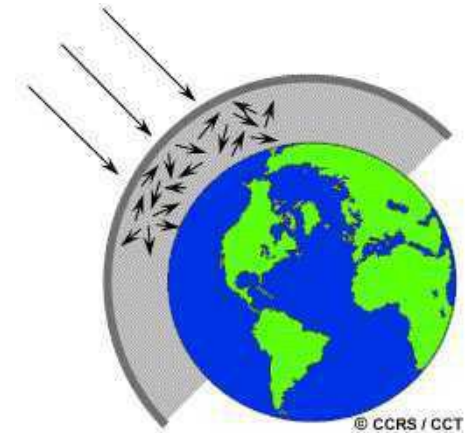
■ 臭氧、二氧化碳、水氣



B. 輻射與大氣 -- 散射效應

■ Rayleigh Scattering

- 大氣微粒直徑小於波長
 - 灰塵微粒、氮、氧分子
- 白天天空呈現藍色
 - 短波長較長波長容易散射
- 晨昏天空呈現橘紅色
 - 電磁波旅行之距離較遠
 - 短波被散射，剩下長波。



■ Mie Scattering

- 雲、霧呈現白色；霾 (haze)
 - 大氣微粒直徑大於波長
 - 所有波長都均勻散射

C. 電磁波與地表交互作用

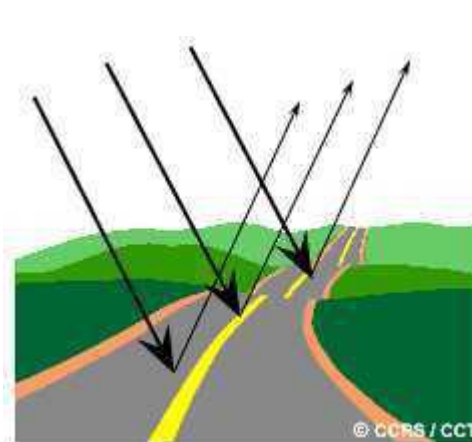
■ 入射 (Incident, I) 之電磁波與地表之交互作用

- 吸收 (Absorption, A)
- 傳遞 (Transmission, T)
- 反射 (Reflection, R)

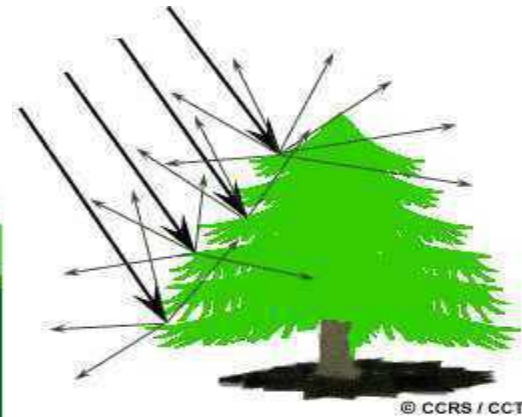


■ 反射形式及反射量

- 地表粗糙度 (Roughness)
- 電磁波波長
- 波長小於地表粗糙度
 - 漫射效應為主
- 範例
 - 目標物：細砂
 - 微波 -> 平滑
 - 可見光 -> 粗糙

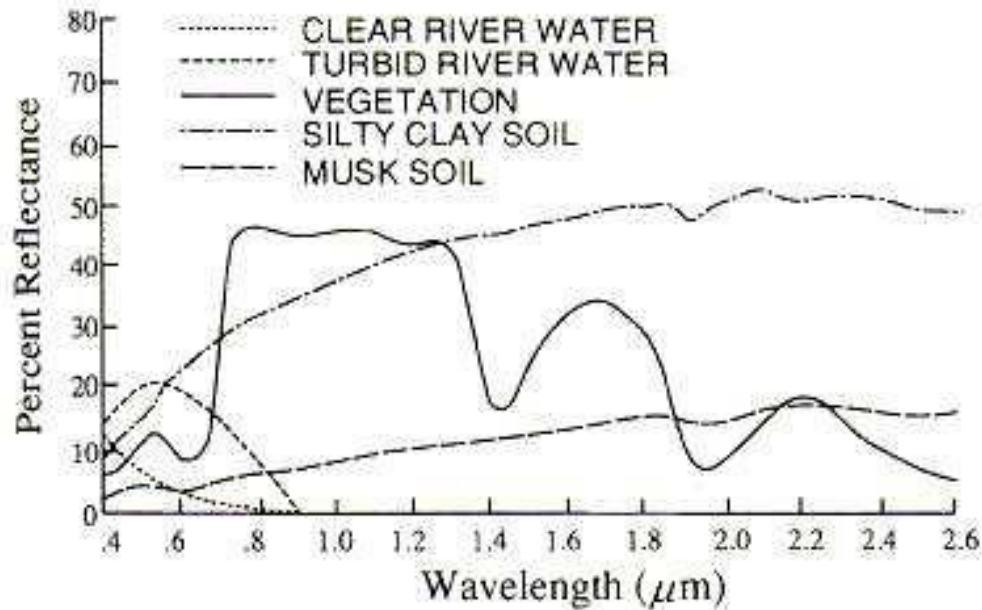


• 鏡面 (Specular) 反射
(Diffuse) 反射



• 漫射

地物光譜反射特性



Spectral reflectance of vegetation, soil and water

©JARS

應用範例

■ 綠色植物為何是綠色？

□ 植物的葉綠素

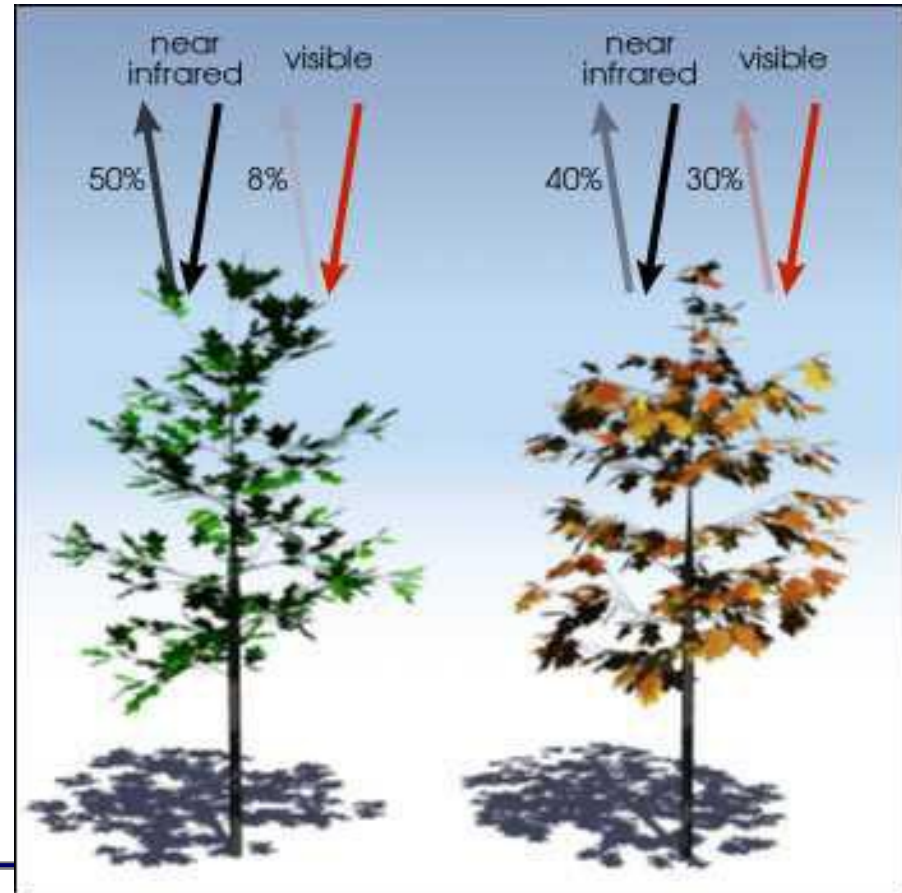
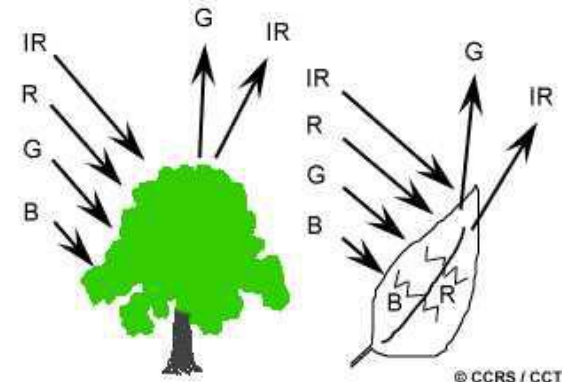
- 吸收紅光及藍光
- 反射綠光及近紅外光

■ 正規化差分植被指數

□ NDVI (Normalized Difference Vegetation Index)

□ $(IR-R)/(IR+R)$

■ 海水為何呈現藍色？

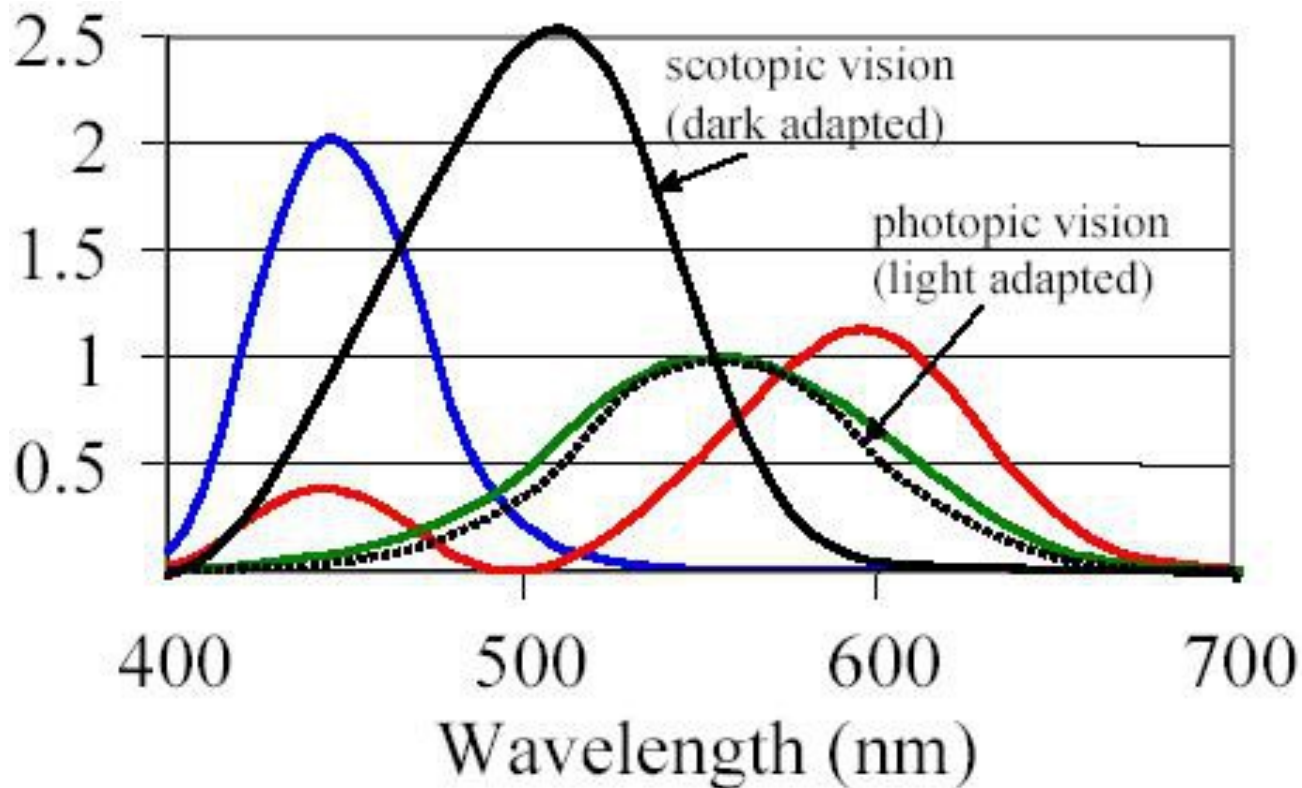


$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72$$

$$\frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

人眼視覺系統限制

- 僅能感應 0.4~0.7 μm
- 僅有 3 個顏色（波長）接收器 (color receptors)



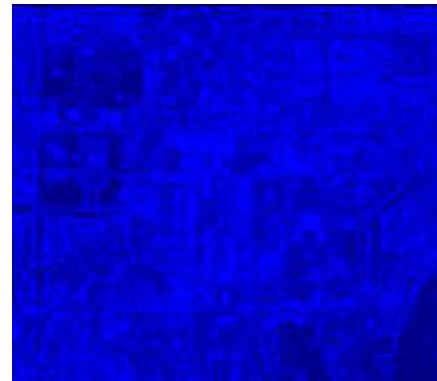
■ 數位影像色彩

◆ True color

Formosat-2 image



61
55
57
58
61
58
59
62
61
59
60
59
60
58
48
65
73
74
72
73
75
77
75
74
77
75
75
77
77
79
69
67
80
87
104
99
100
102
105
102
103
103
103
103
103
105
100
96
94
107
106



74
73
71
79
70
75
73
79
82
94
52
68
57
65
67
64
60
91
90
90
90
96
88
65
95
95
108
105
84
75
81
83
79
74
117
118
111
115
106
115
117
118
123
136
137
116
99
105
111
106
104

Red-Red

Green-Green

Blue-Blue

■ 數位影像色彩

◆ False color

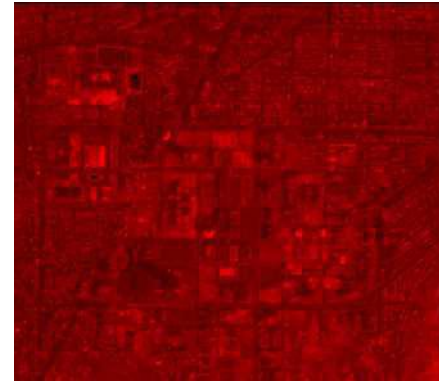
Formosat-2 image



64
67
67
67
68
72
70
73
66
66
68
64
58
68
85
84
82

74
72
73
75
77
75
74
77
75
75
77
77
79
69
67
80
87

104
99
100
102
105
102
103
103
103
103
103
105
100
96
94
107
106



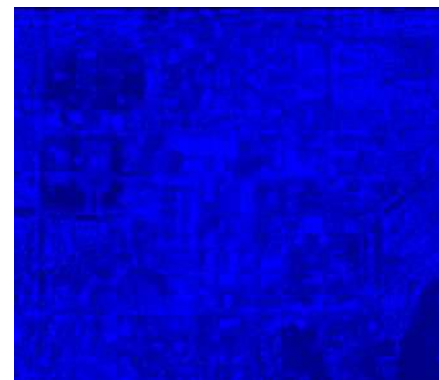
81
80
76
74
80
81
84
90
92
85
74
72
68
65
66
66
63

Red-NIR



91
90
90
90
86
88
85
95
95
108
105
84
75
81
83
79
74

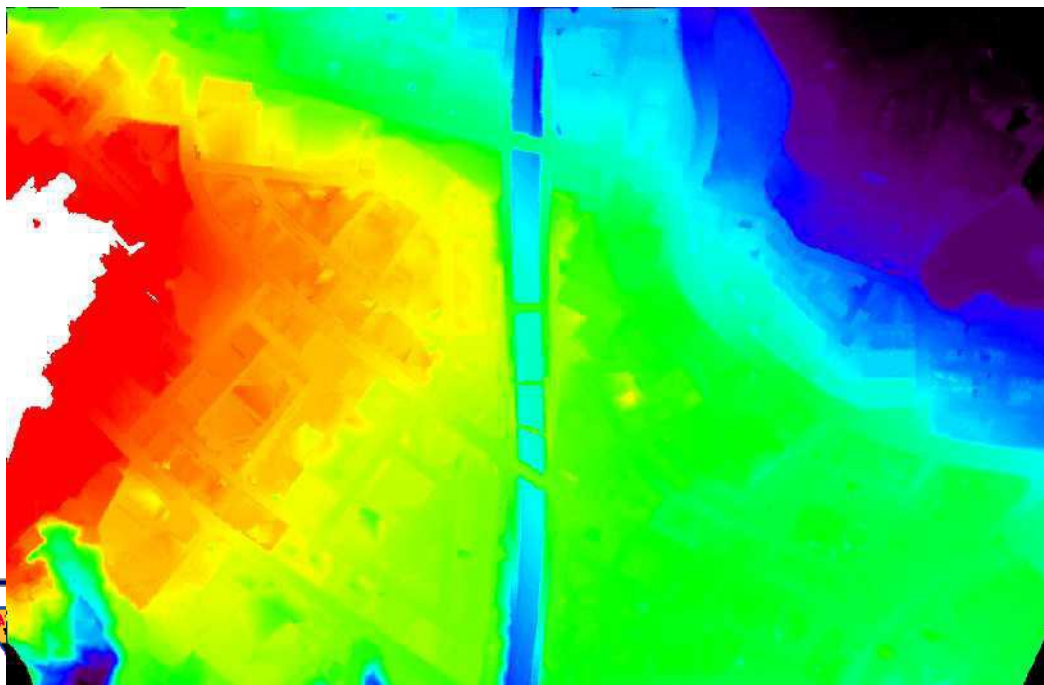
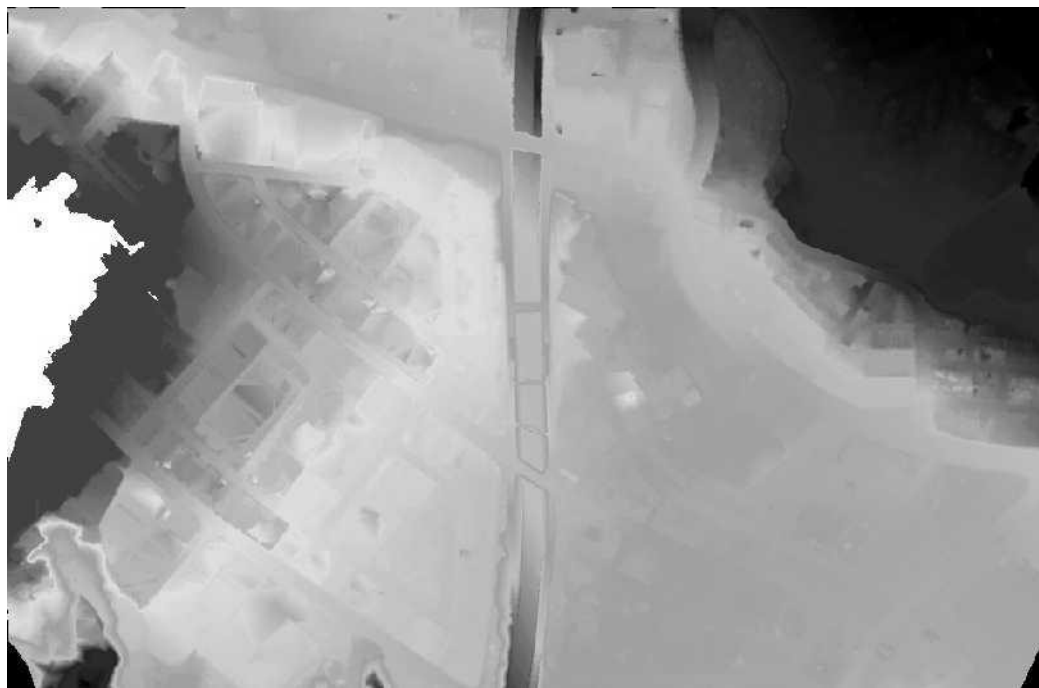
Green-Green



117
118
111
115
108
115
117
118
123
136
137
116
99
105
111
106
104

Blue-Blue

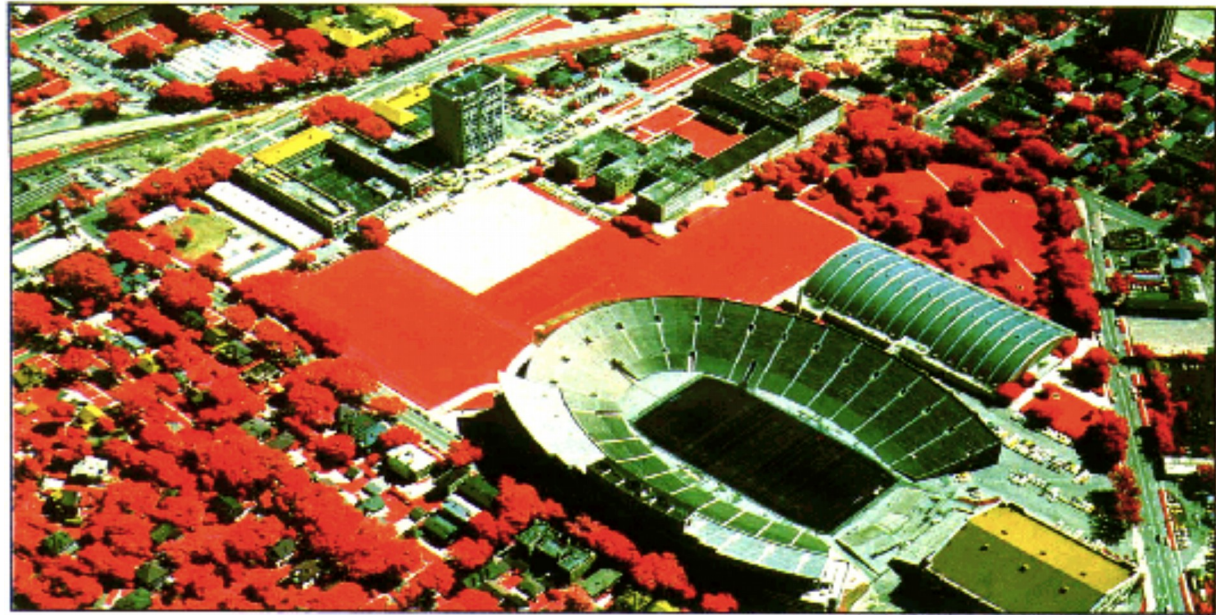
■ 數位影像色彩
◆ Pseudo color

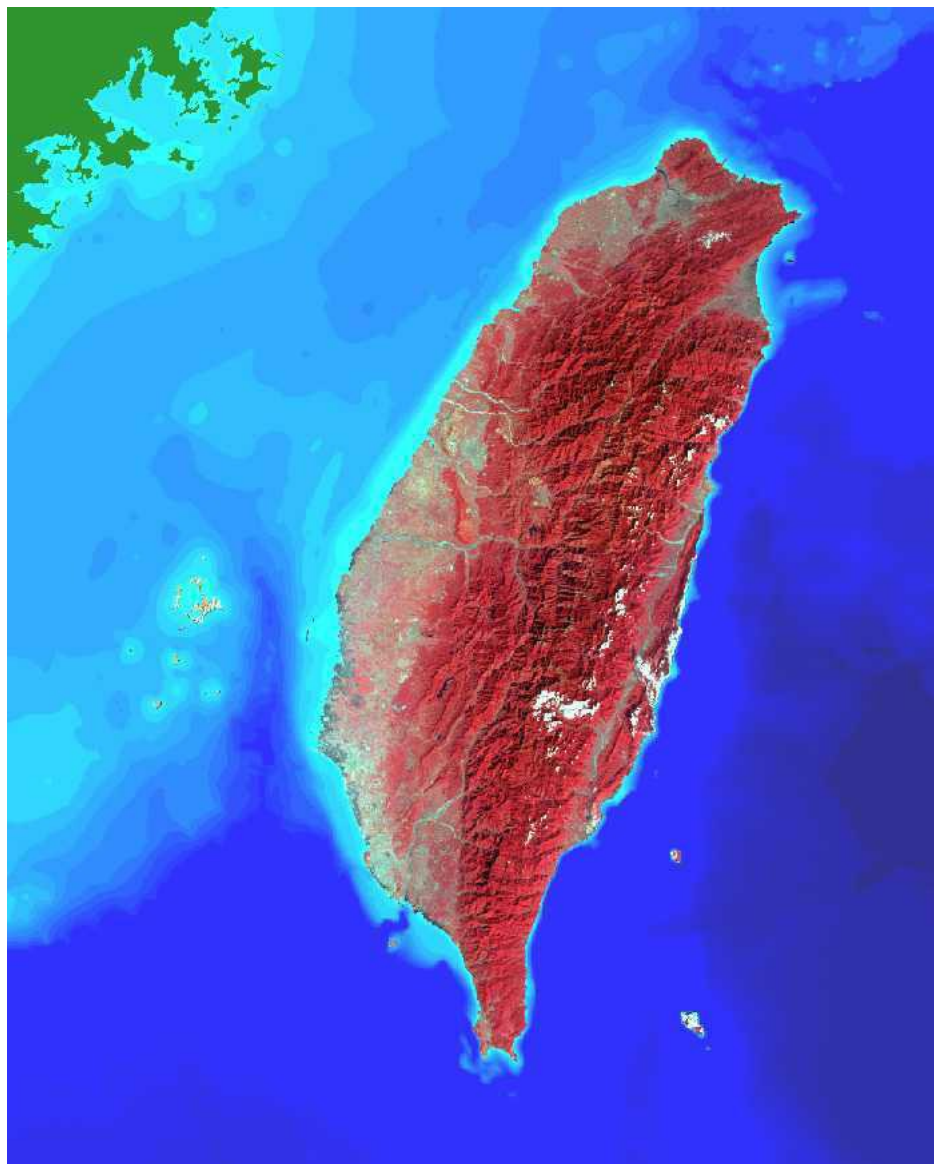


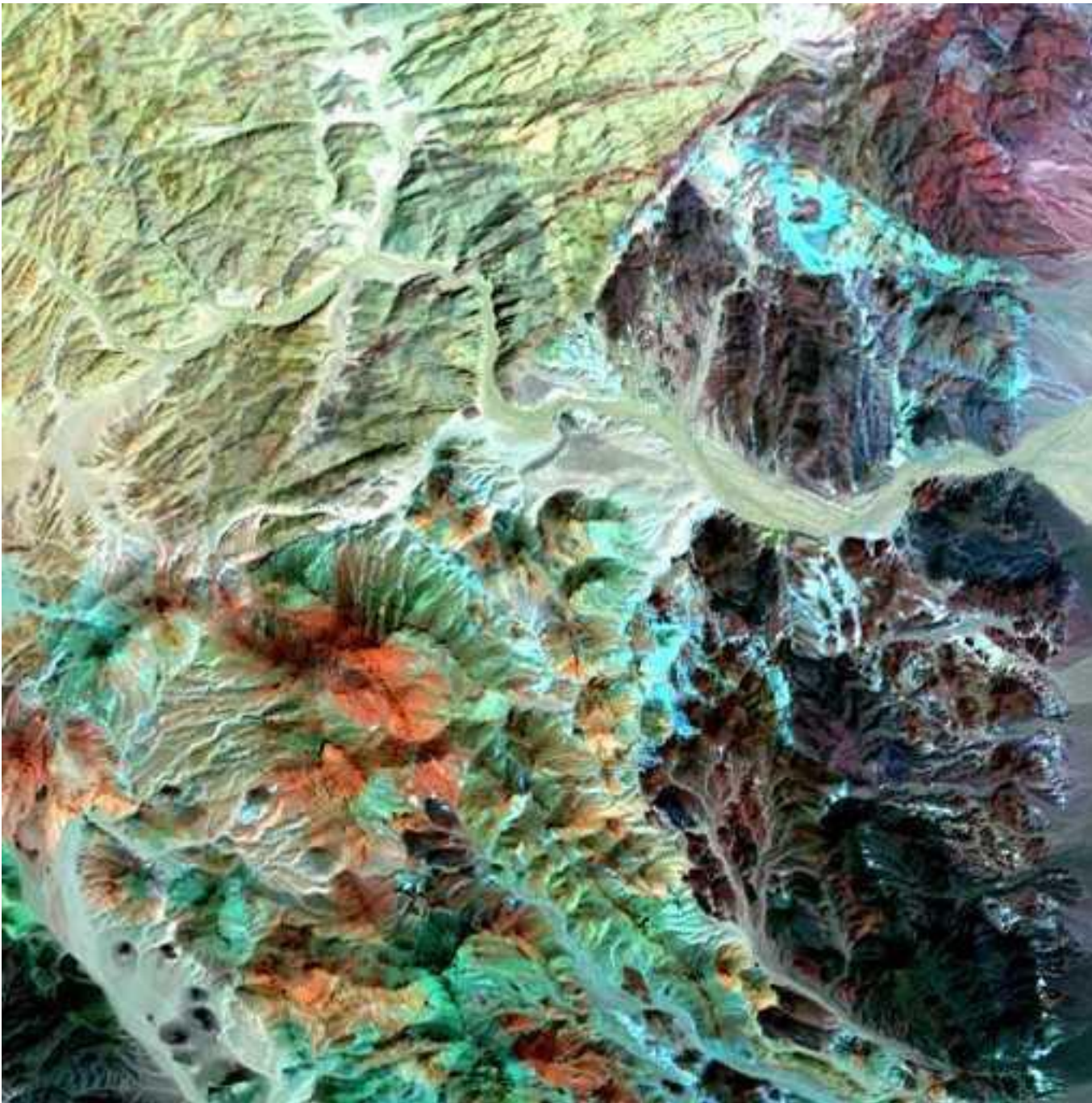
R+G+B



IR+R+G

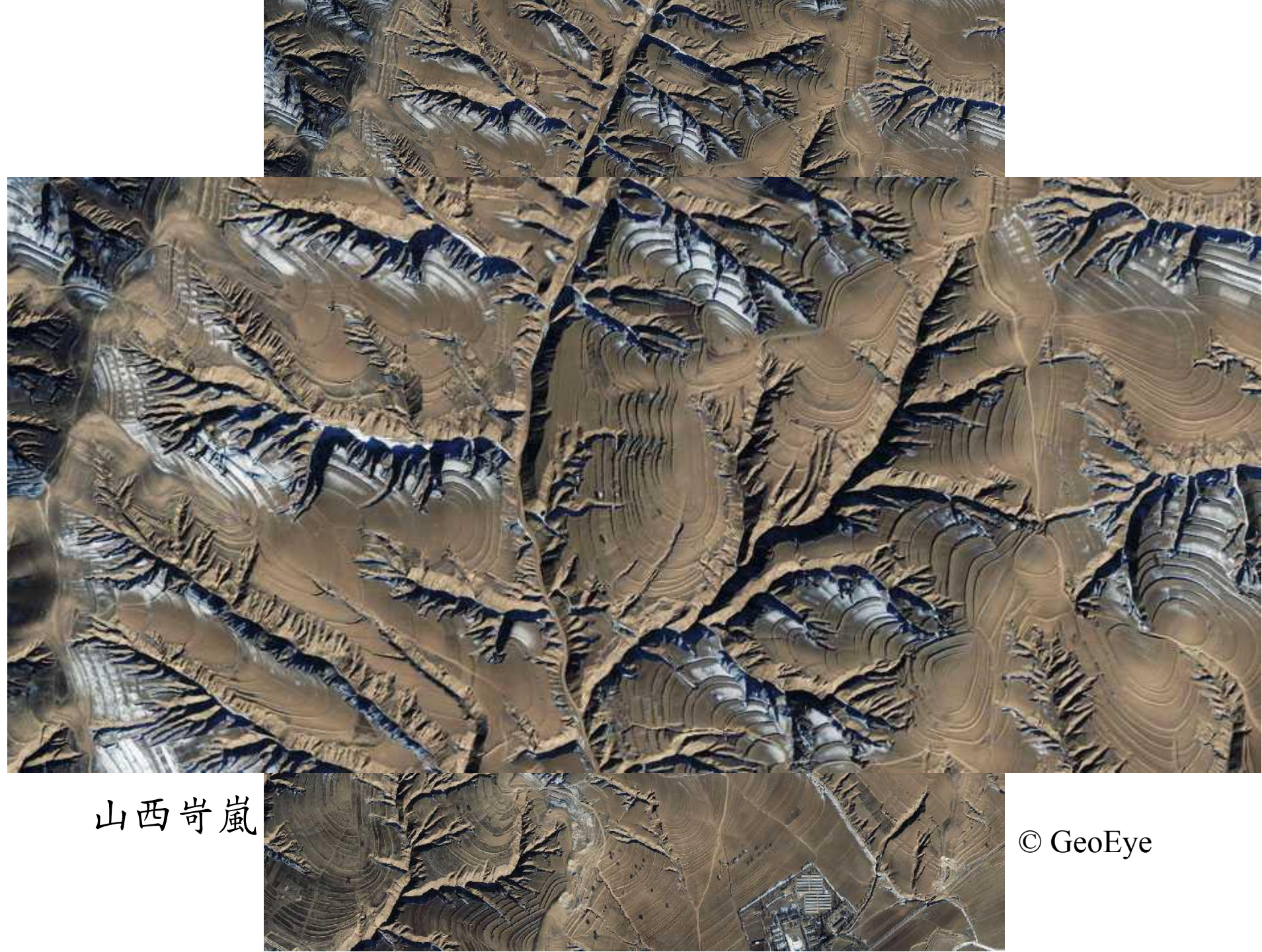






Gobi Desert,
Mongolia

© HyVISTA Co.



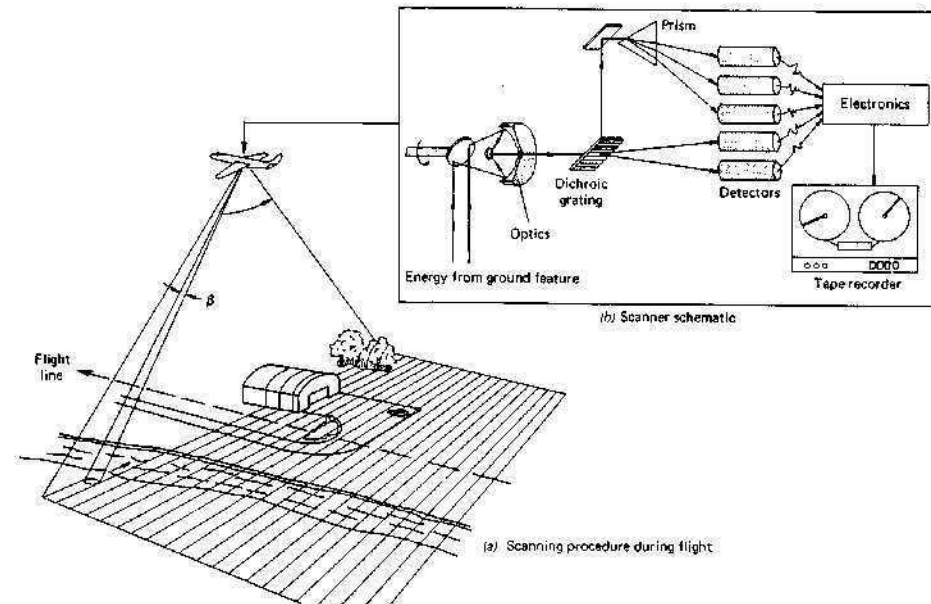
山西峽嵐

© GeoEye

光學感測器

跨徑掃描儀 (Across-Track, 或 Wisk-broom Scanner)

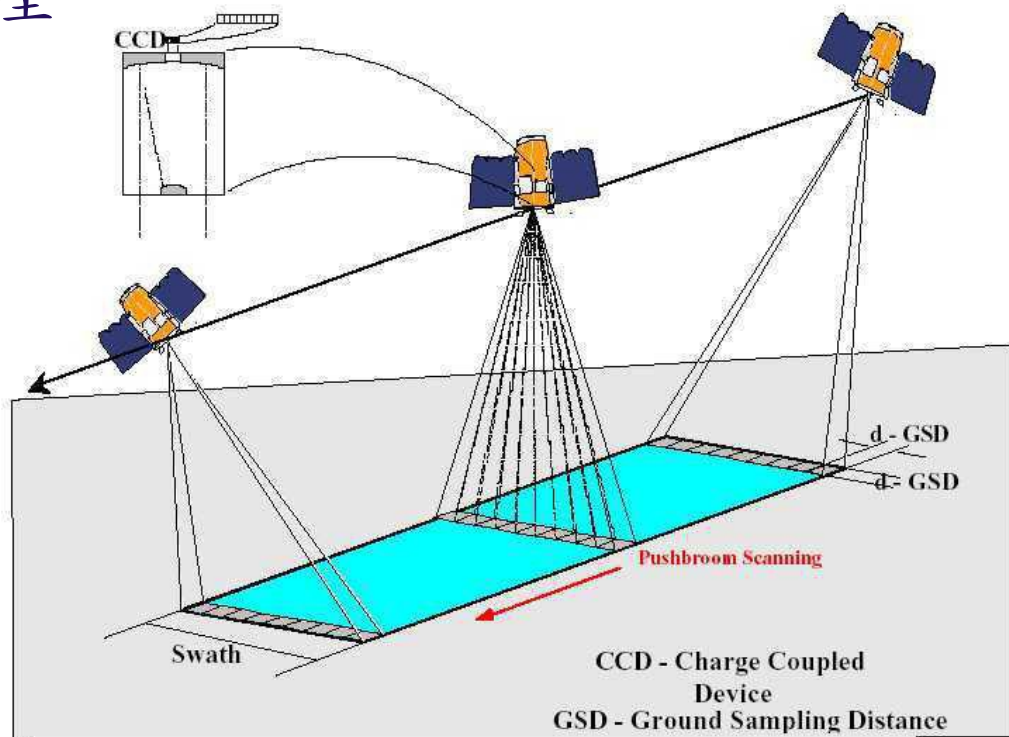
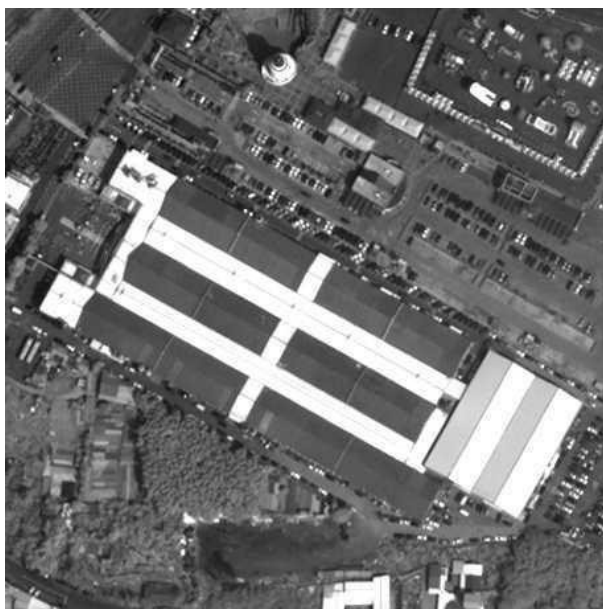
- 垂直於飛行方向掃描
- 探測元件多樣化
- 影像幾何品質較差



光學感測器

沿徑掃描儀 (Along-Track 或 Push-broom Scanner)

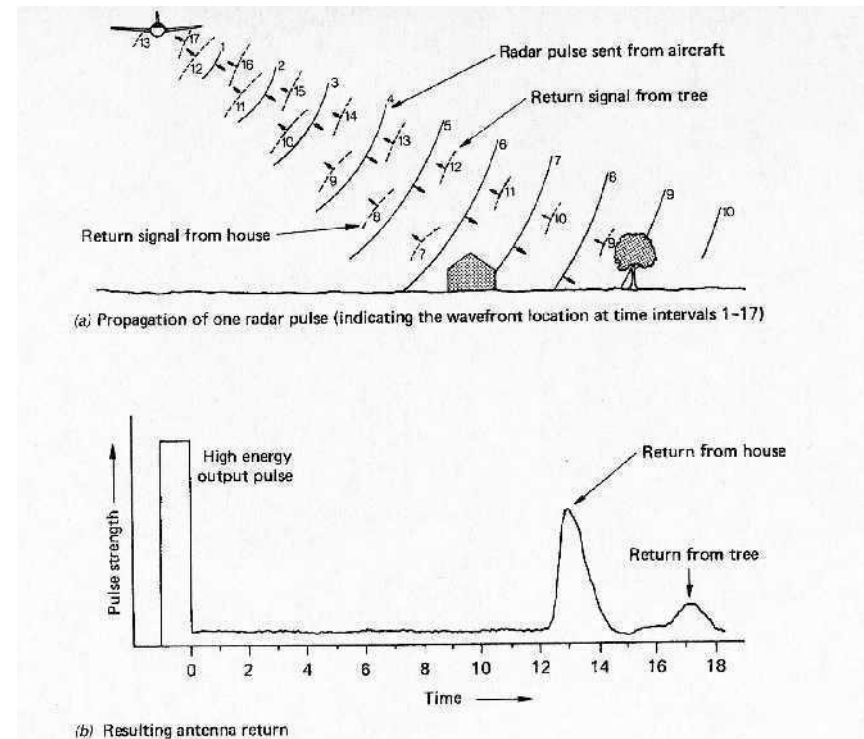
- 一系列探測元件同時沿飛行方向掃描
- 探測波段較受限制
- 影像幾何品質較佳



雷達感測器

■ 真實孔徑雷達 (Real Aperture Radar, RAR)

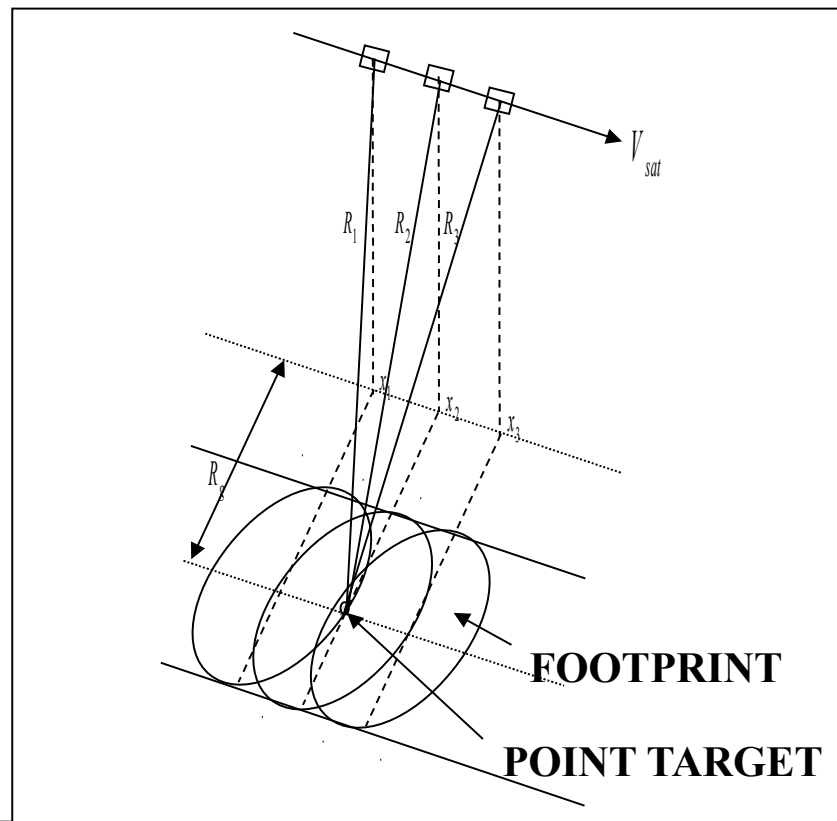
- 天線直徑較大
- 資料處理較簡



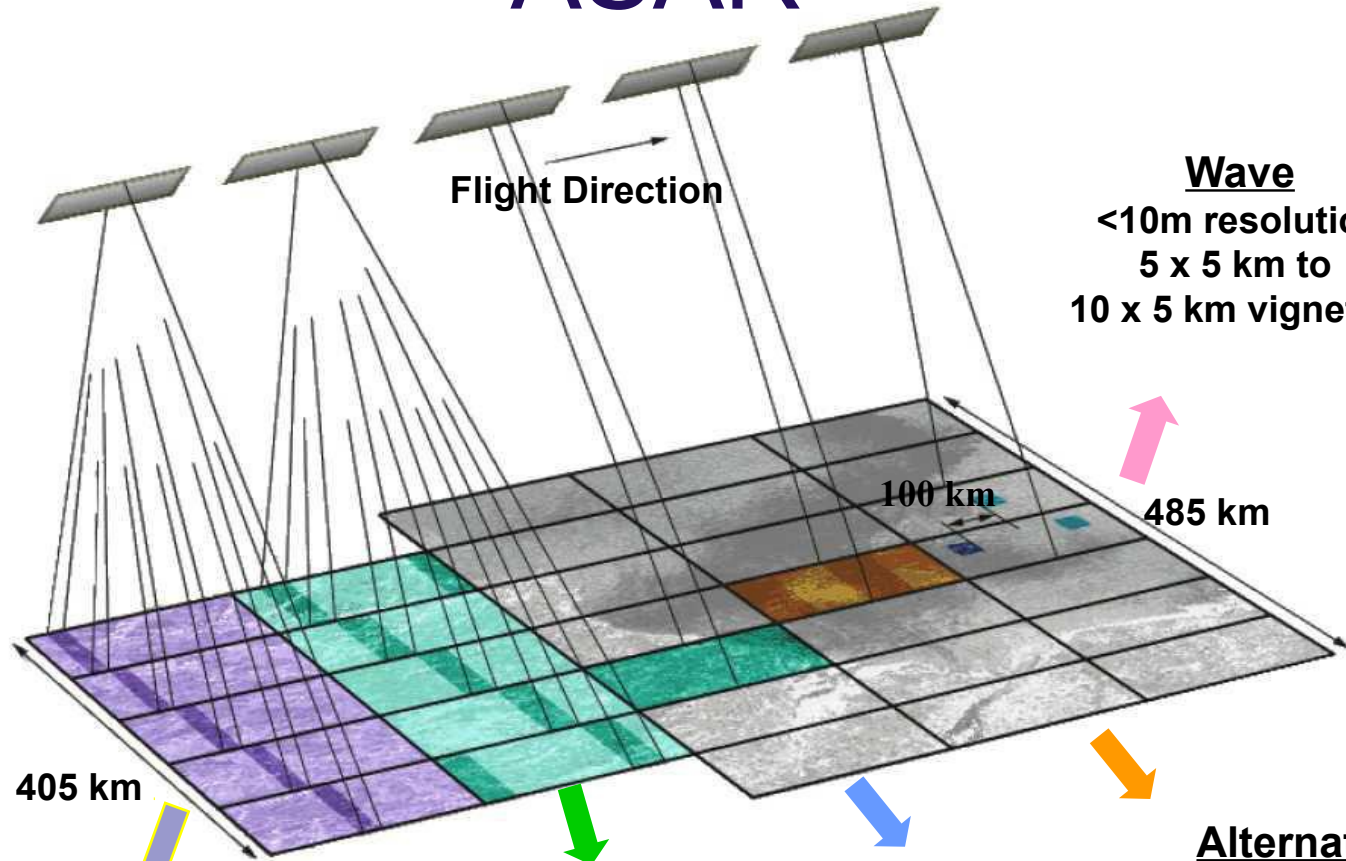
雷達操作示意圖

雷達感測器

- 合成孔徑雷達 (Synthetic Aperture Radar, SAR)
 - 天線直徑較小
 - 資料處理較繁



ASAR



Global Monitoring
 1000 m resolution
 405 km swath

Wide Swath
 150 m resolution
 405 km swath

Image
 25 m resolution
 up to 100 km swath

Alternating Polarisation
 25 m resolution
 up to 100 km swath

HH or VV

HH or VV

VV+HH, HV+VH, VH+HV

光學影像與雷達影像之比較



SPOT

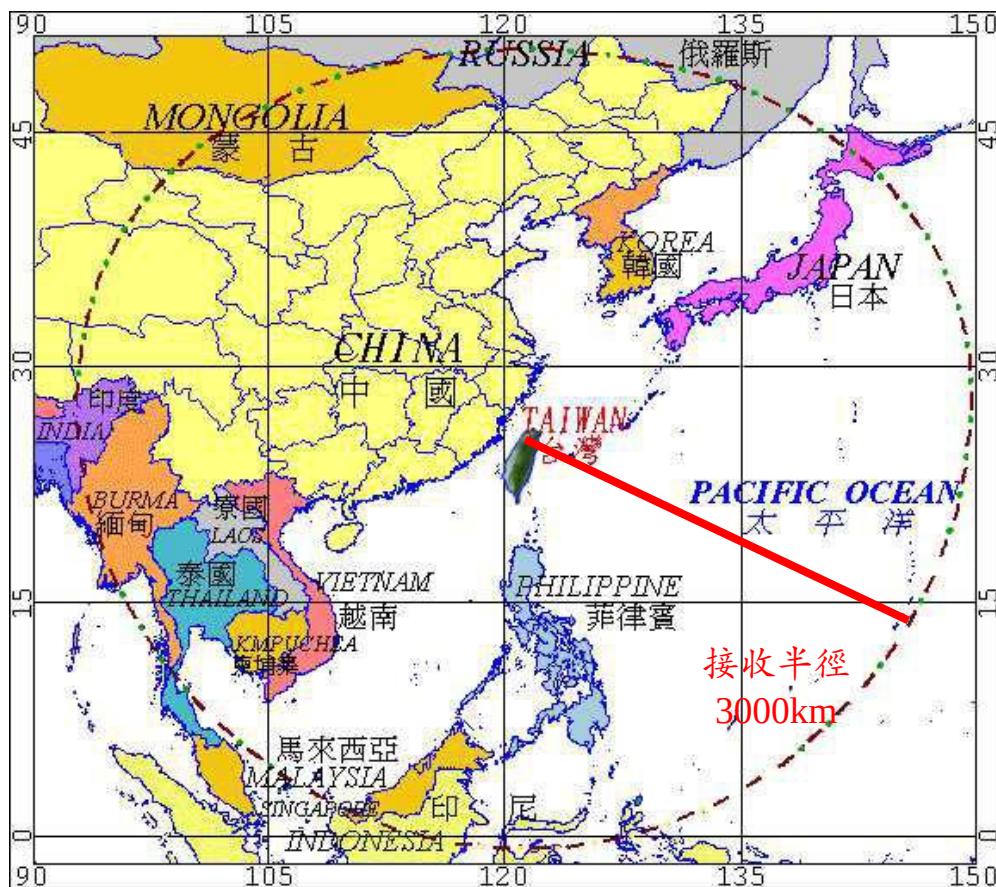


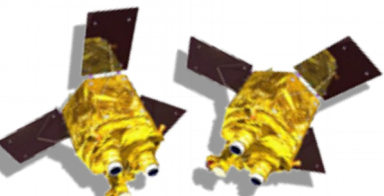
Radarsat

E. 資料傳輸，接收與處理

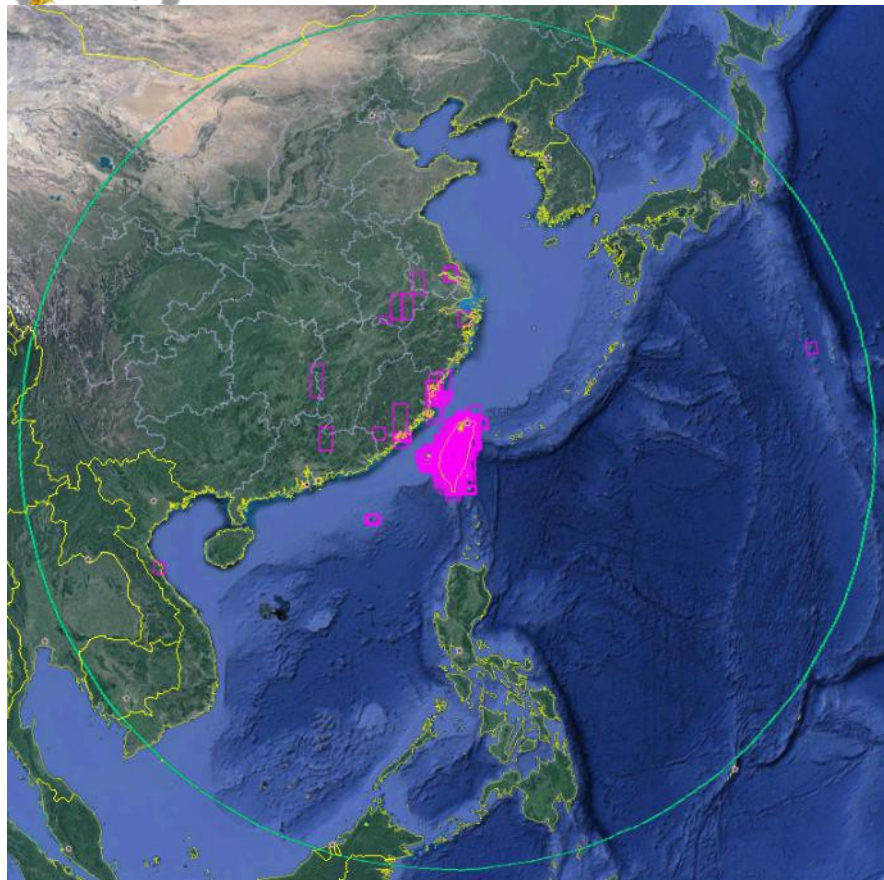
- 資料傳輸與接收
 - 資源衛星接收站
- 資料前處理
 - 輻射改正 (Radiometric Correction)
 - 相對輻射改正
 - 絕對輻射改正 (大氣校正)
 - 幾何改正 (Geometric Correction)
 - 可與地理資訊系統整合

中央大學太遙中心資源衛星接收站

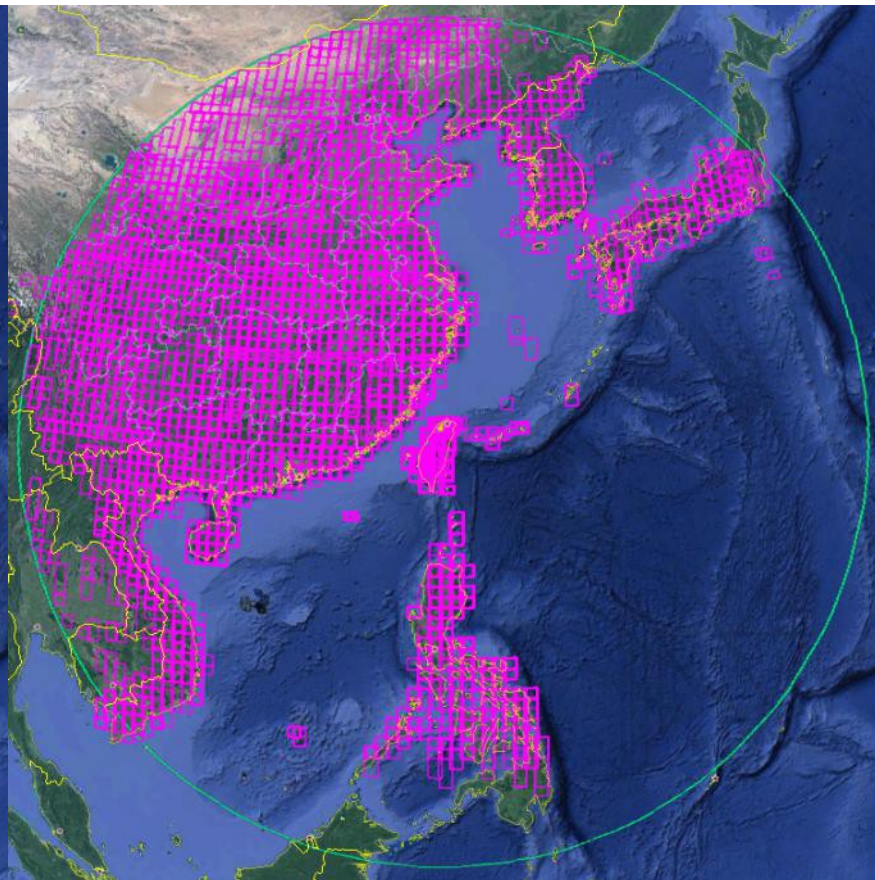




VRS v.s. DRS



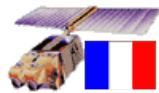
2017年01/01至09/06 虛擬接收取像



2018年01/01至09/06 直接接收取像

2018/01/01至2018/09/06，日平均取像約29組(60 Km*60 Km) PAN+MS，相較虛擬接收的同期，大幅提昇影像接收能量約為過去11倍，產品處理能量約為過去30倍

SPOT 1-7



ERS-2



EROS-A



Earth Resources Satellite Receiving Station

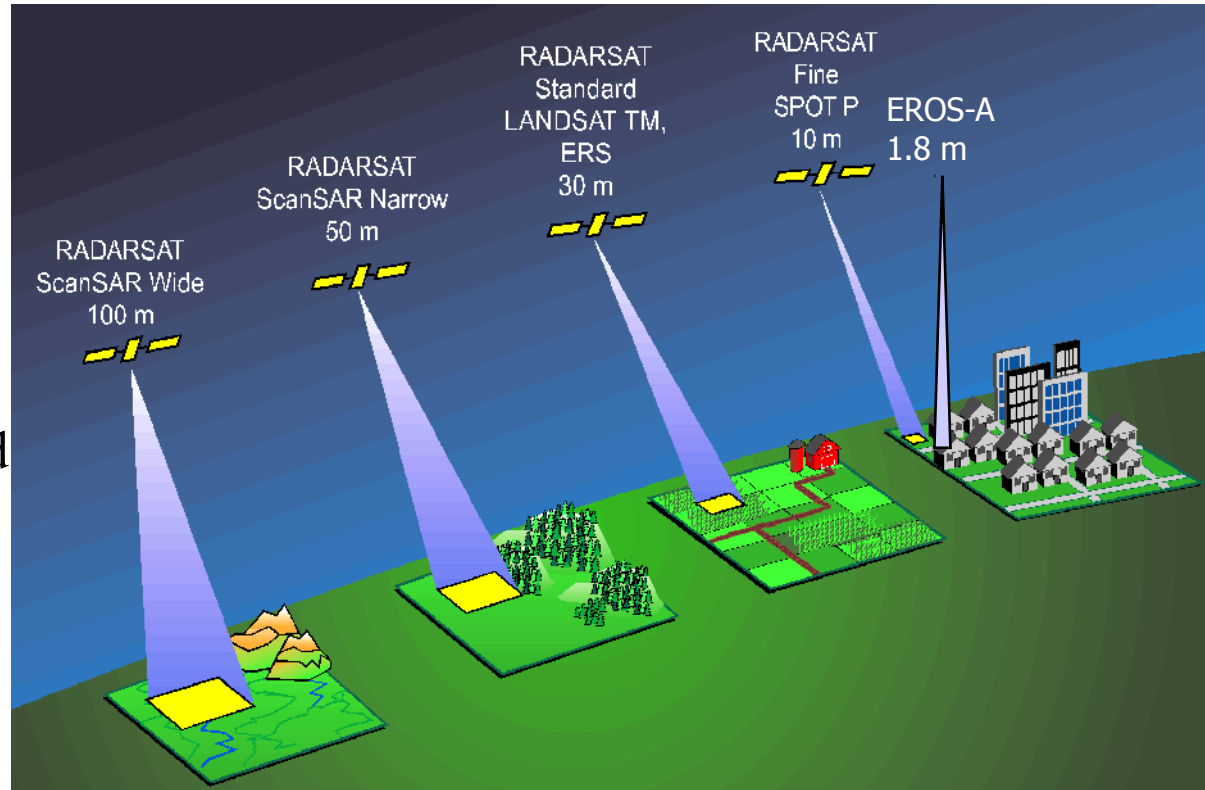
Comparison of image resolutions

TERRA, AQUA

Formosat-2, 5

Major products

- Standard products :
bulk, system & orthorectified
- Value-added products :
6.25 m/1.5 m color images,
3D perspective view,
flight simulation



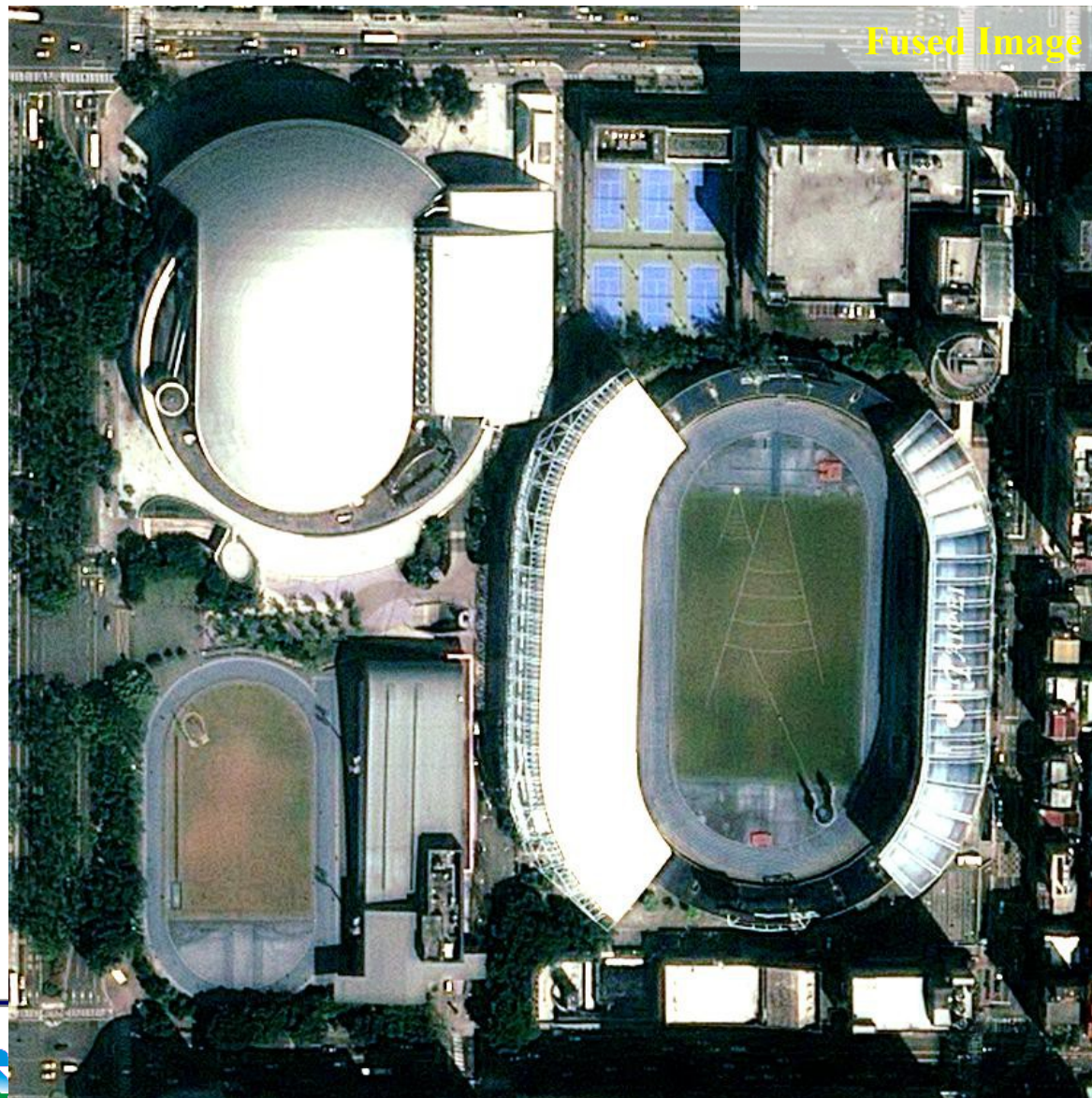
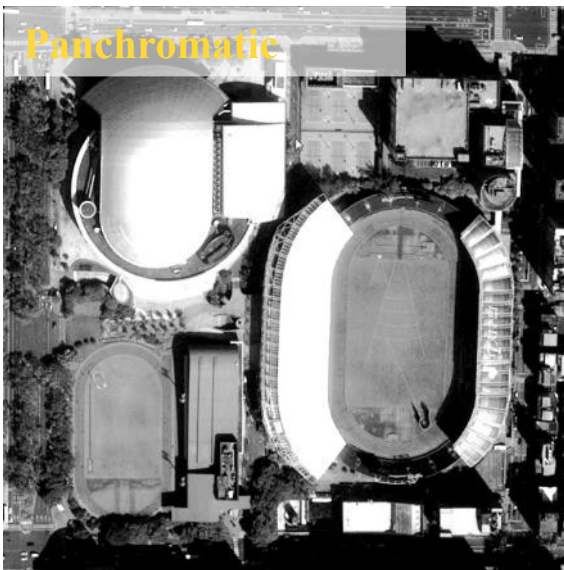
@RSI

加值產品 (融合影像)

SPOT 1.5/6 m

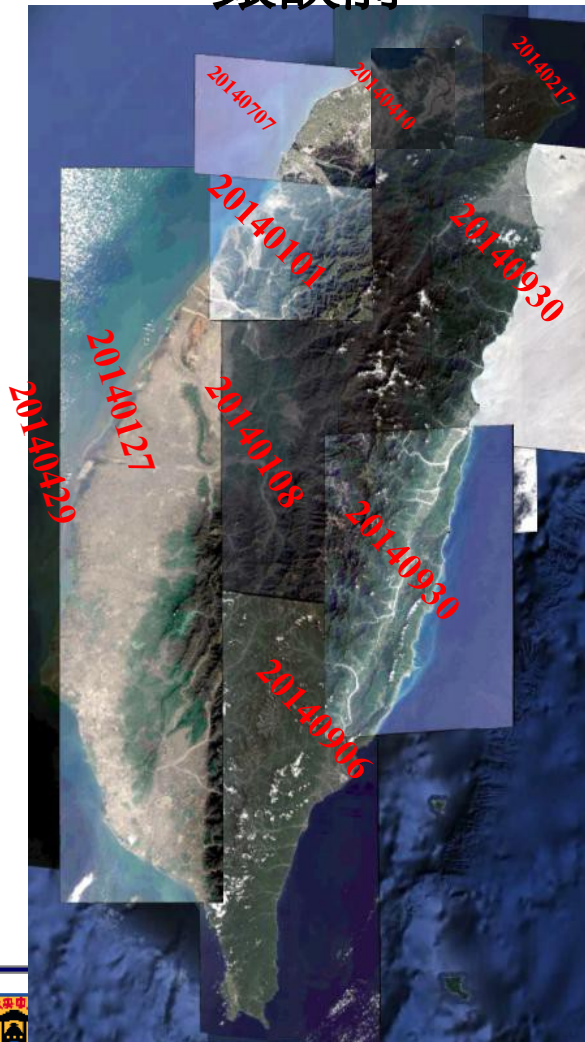


Pleiades 0.5/2 m 超高解析融合影像



加值產品 -- 無雲鑲嵌影像

鑲嵌前



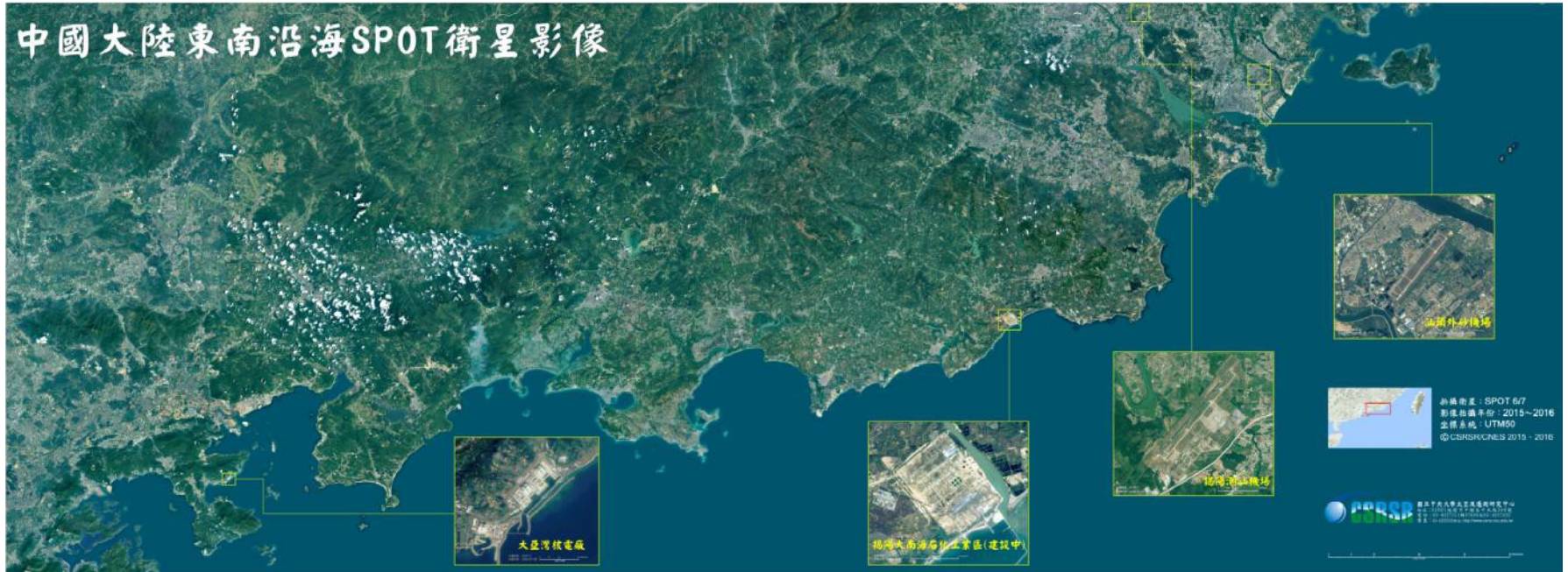
鑲嵌後



鑲嵌 / 填海

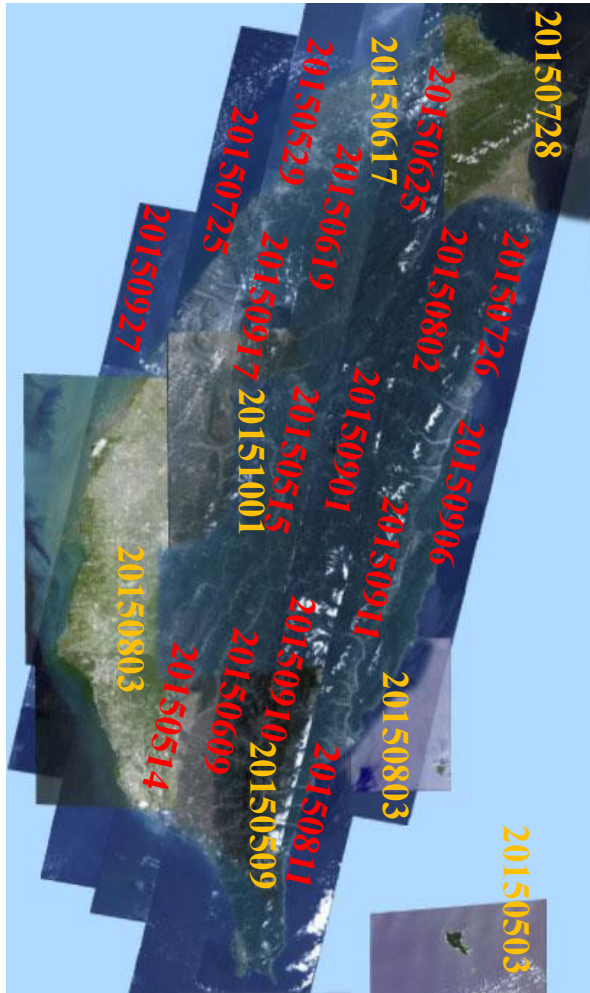


SPOT6/7 衛星影像鑲嵌 (343 km x 126 km)



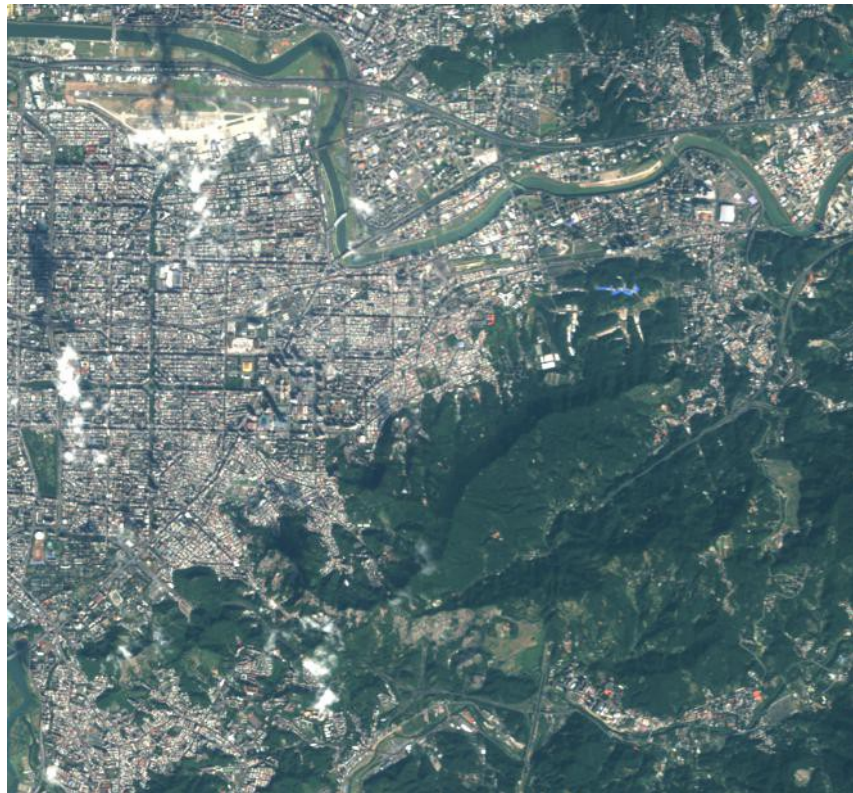
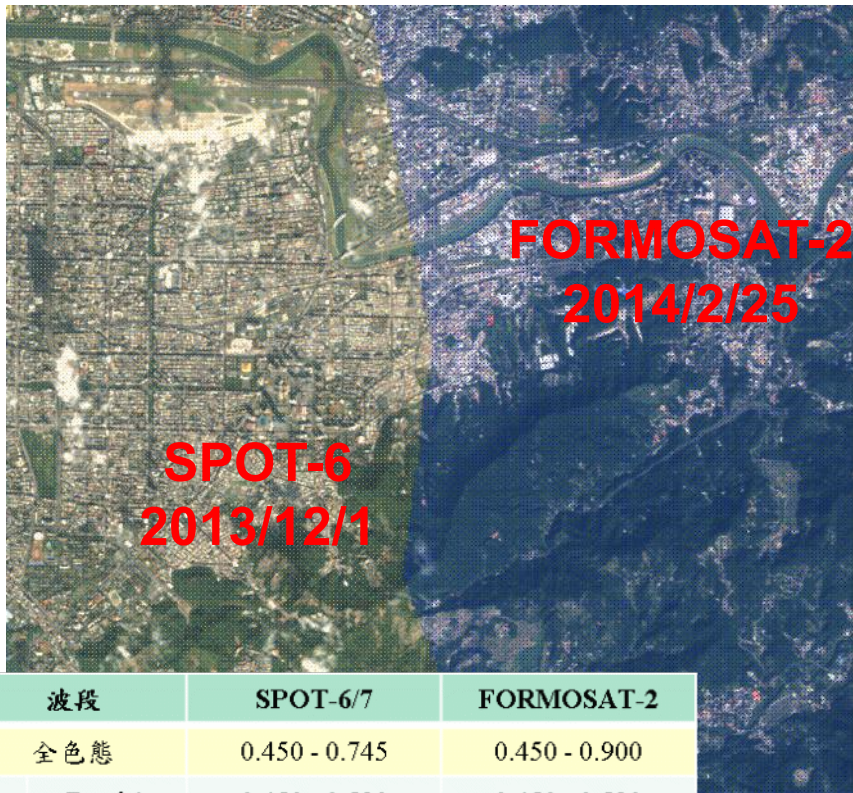
跨影像拼接

SPOT-6 與 FORMOSAT-2 拼接



福衛二號與 SPOT6 影像鑲嵌之接合線

台北地區鑲嵌成果



波段		SPOT-6/7	FORMOSAT-2
全色態		0.450 - 0.745	0.450 - 0.900
多光譜	Band 1	0.450 - 0.520	0.450 - 0.520
	Band 2	0.530 - 0.590	0.520 - 0.600
	Band 3	0.625 - 0.695	0.630 - 0.690
	Band 4	0.760 - 0.890	0.760 - 0.900

單位：μm

如何選取資料

Rule of Thumb: 依照應用需求及資料特性選擇最合適的產品

■ 幾個思考方向

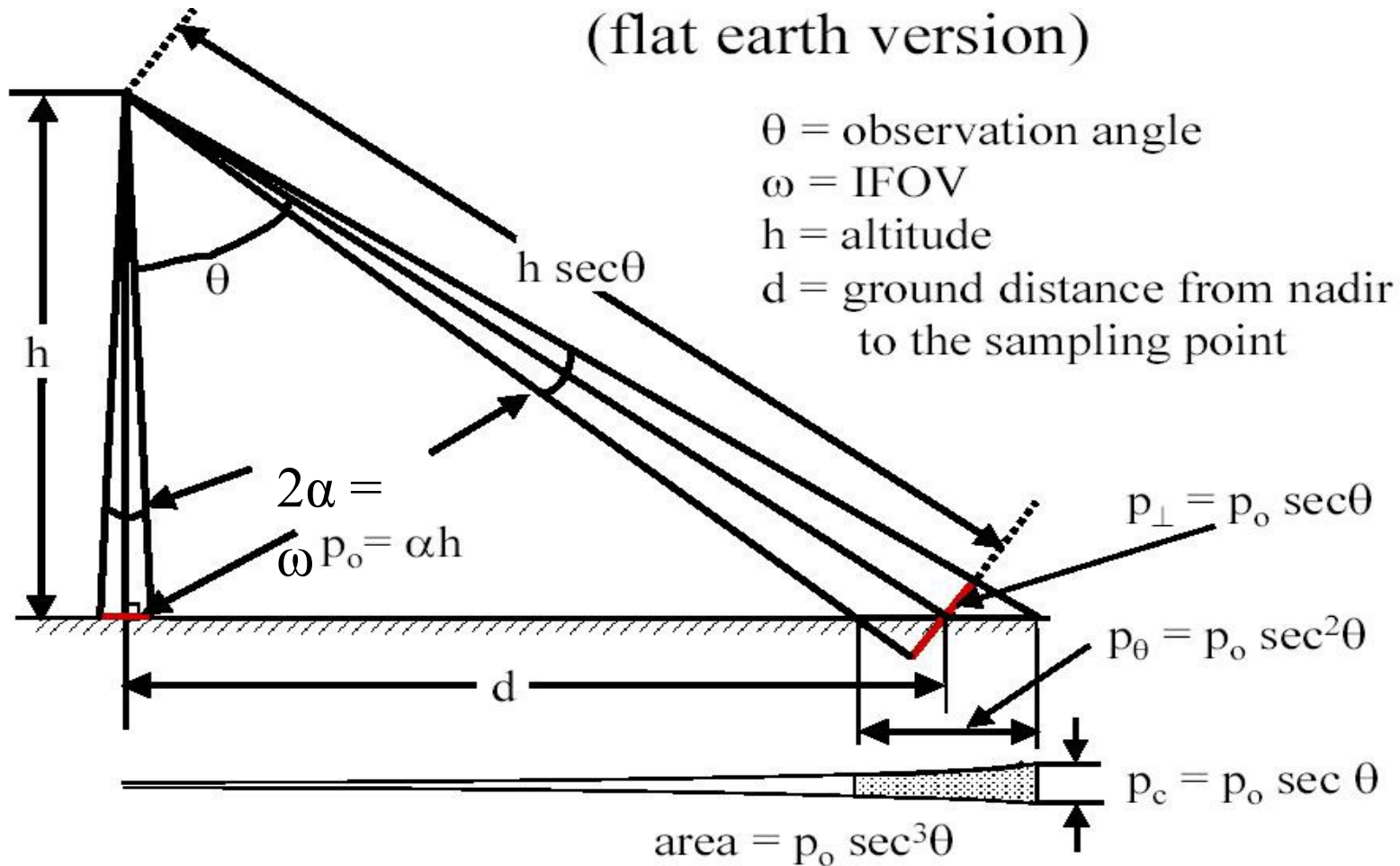
- 所須要之影像細緻程度為何？
- 地面涵蓋範圍？
- 幾何定位準確度？
- 從影像上想獲取何種資訊？
- 需要多久拿到影像？
- 多久需要一張影像？
- 預算有多少？

幾何改正

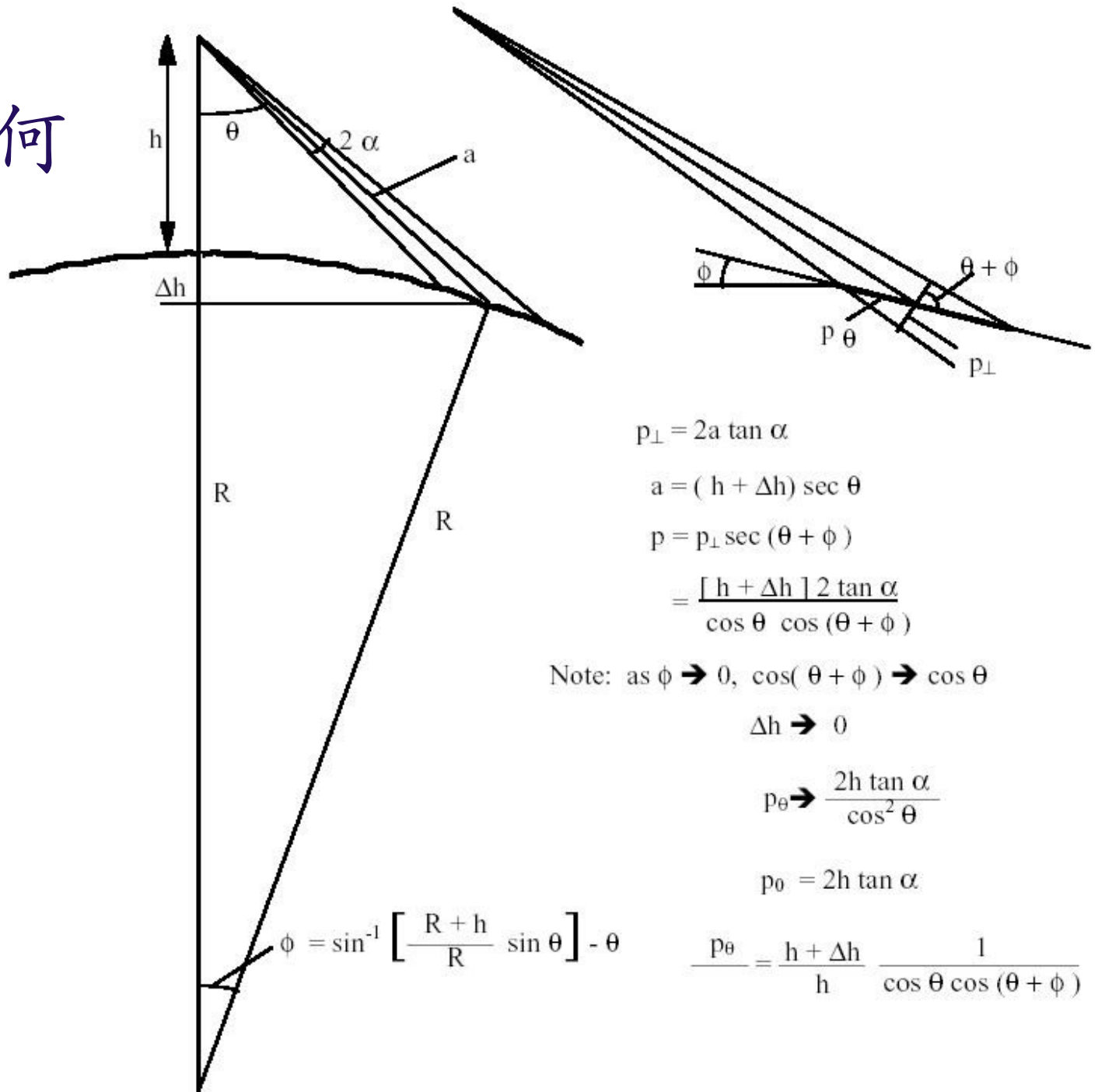
- 回復 (restore) 或補償 (compensate) 影像在幾何上的變形
- 變形的原因：
 - ◆ 感測器的特性 (sensor characteristics)
 - ◆ 觀測的幾何關係 (viewing geometry)
 - ◆ 載具移動 (platform motion)
 - ◆ 目標物移動 (target motion)

觀測幾何

(flat earth version)



觀測幾何



$$p_{\perp} = 2a \tan \alpha$$

$$a = (h + \Delta h) \sec \theta$$

$$p = p_{\perp} \sec(\theta + \phi)$$

$$= \frac{[h + \Delta h] 2 \tan \alpha}{\cos \theta \cos(\theta + \phi)}$$

Note: as $\phi \rightarrow 0$, $\cos(\theta + \phi) \rightarrow \cos \theta$

$$\Delta h \rightarrow 0$$

$$p_{\theta} \rightarrow \frac{2h \tan \alpha}{\cos^2 \theta}$$

$$p_{\theta} = 2h \tan \alpha$$

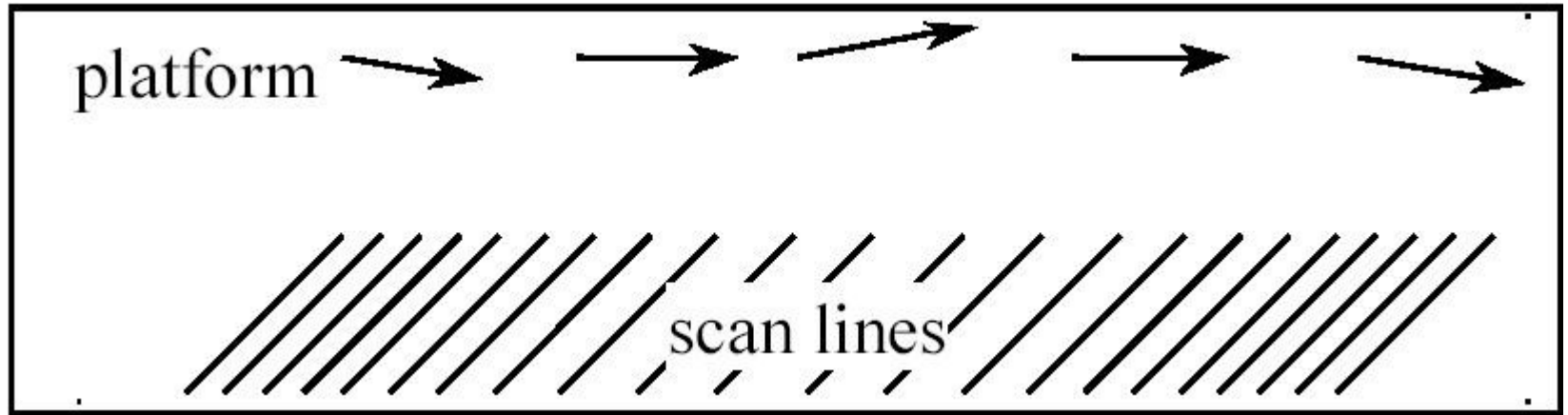
$$\frac{p_{\theta}}{h} = \frac{h + \Delta h}{h} \frac{1}{\cos \theta \cos(\theta + \phi)}$$

$$\phi = \sin^{-1} \left[\frac{R + h}{R} \sin \theta \right] - \theta$$

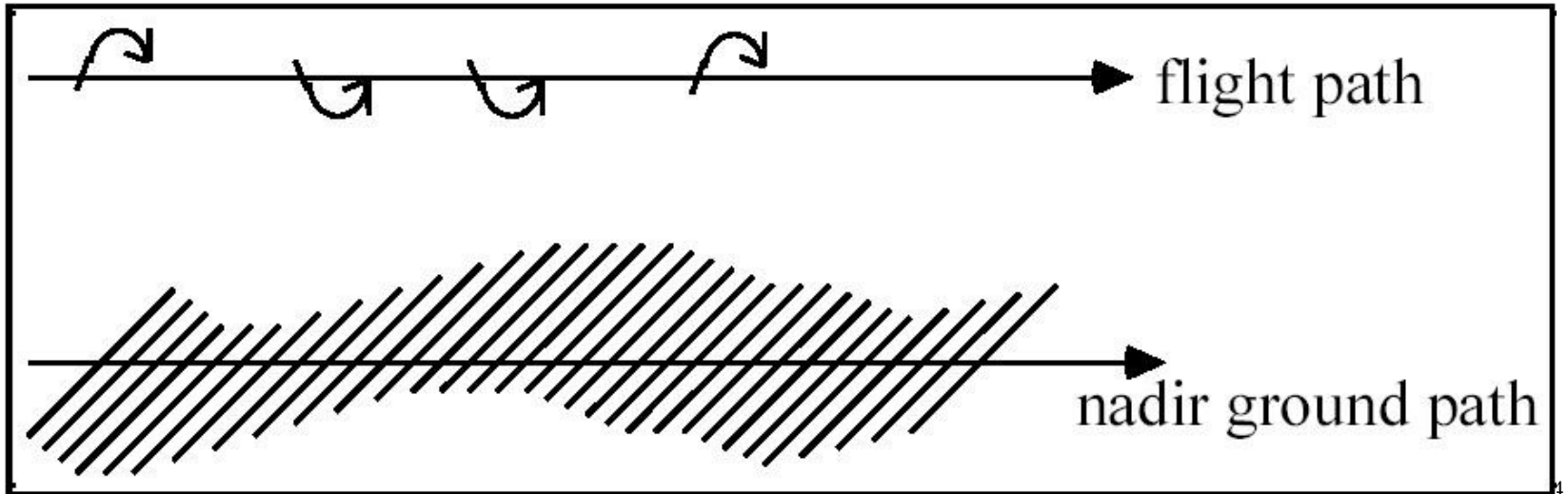


載具移動

Pitch

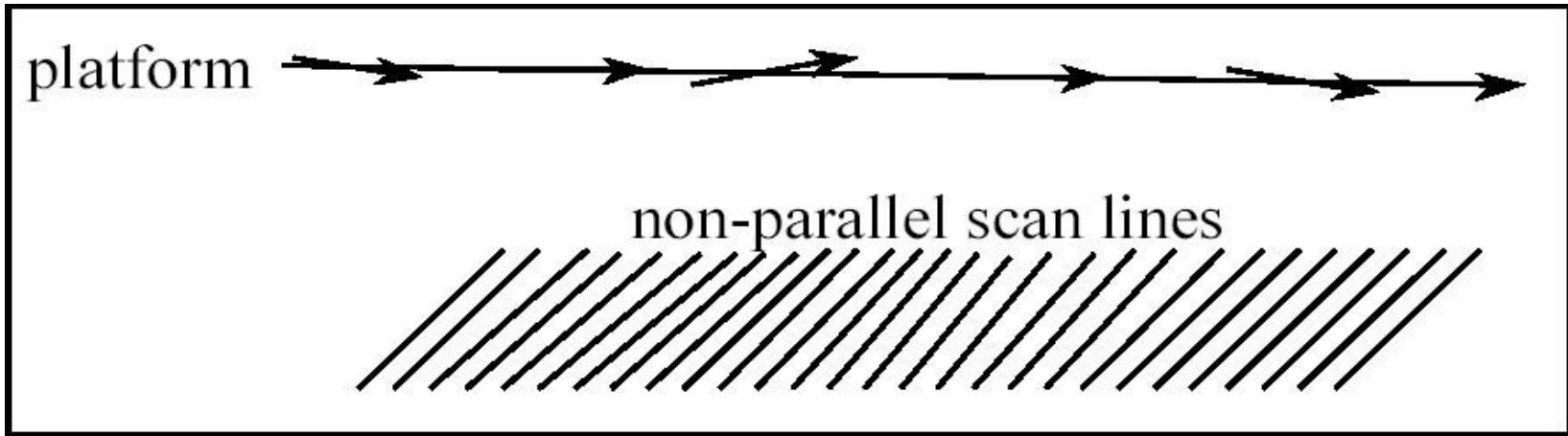


Roll

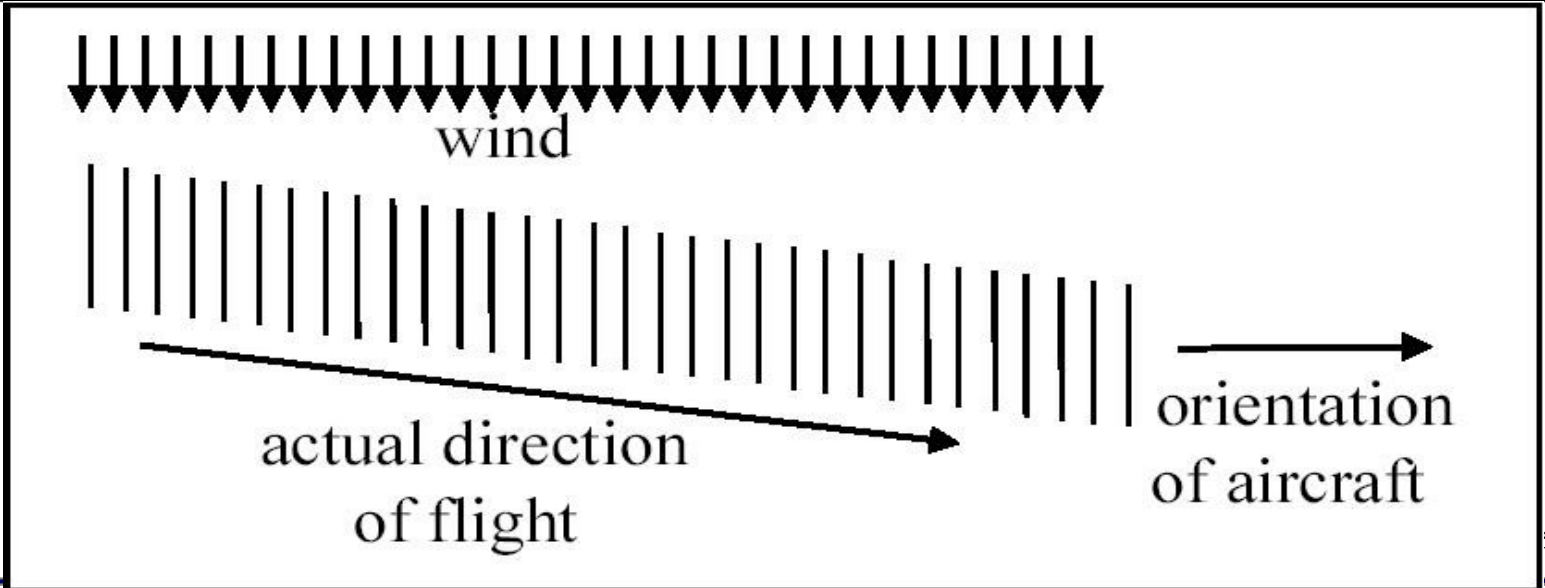


載具移動

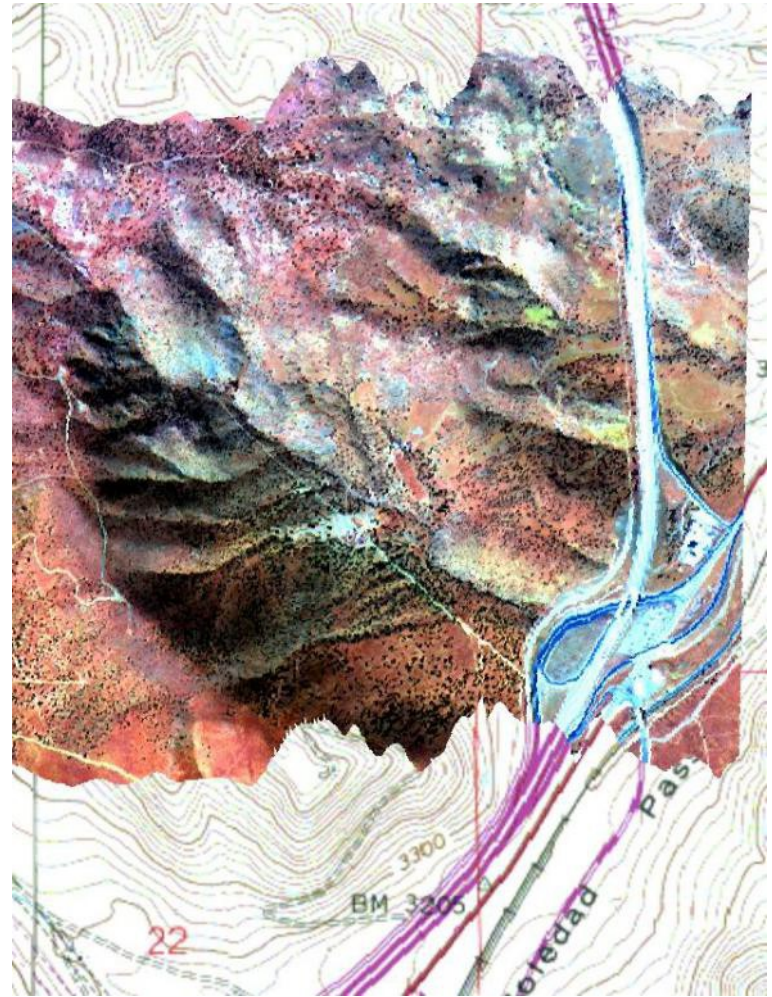
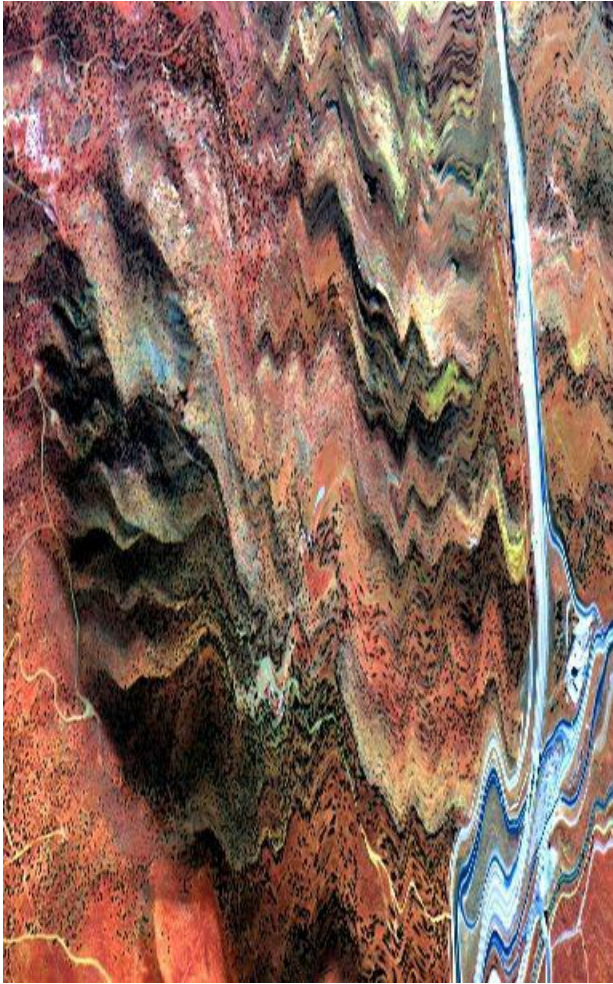
Yaw



Altitude and slew



空載影像幾何校正



56

SPOT 及福衛影像產品等級

Level 0	原始影像 (未進行輻射改正)
Level 1A	原始影像 (僅相對輻射改正)
Level 2	系統幾何改正
Level 2C	系統幾何改正 (適用大區域多航帶鑲嵌融合 , 僅進行一次灰度值重新取樣)
Level 3	嚴密幾何改正 (使用控制點 , 未使用 DTM)
Level 4	嚴密幾何改正正射影像 (使用控制點 +DTM)
彩色融合	使用 Level 2C 以上產品 (多光譜 + 全色態)

不同產品等級之比較



原始資料 (L1A)



系統改正影像 (L2)



精密幾何改正 (正射影像)(L4)

套疊 1:5000 向量圖比較



系統改正影像 (L2)

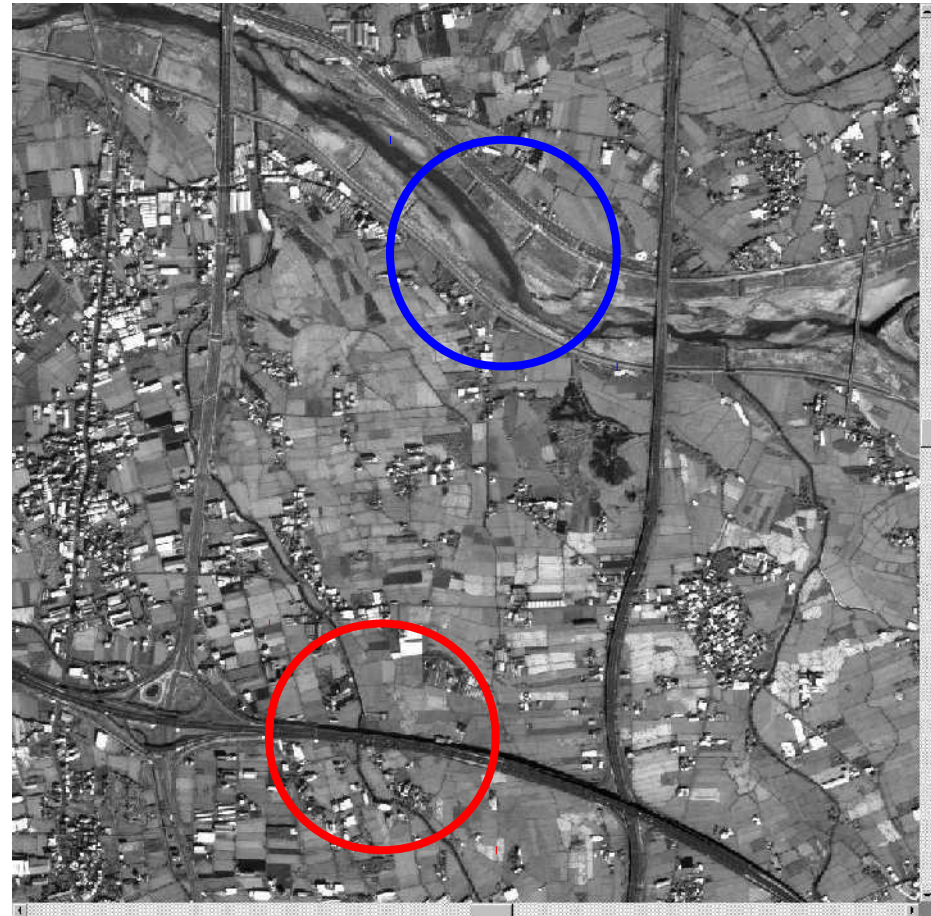
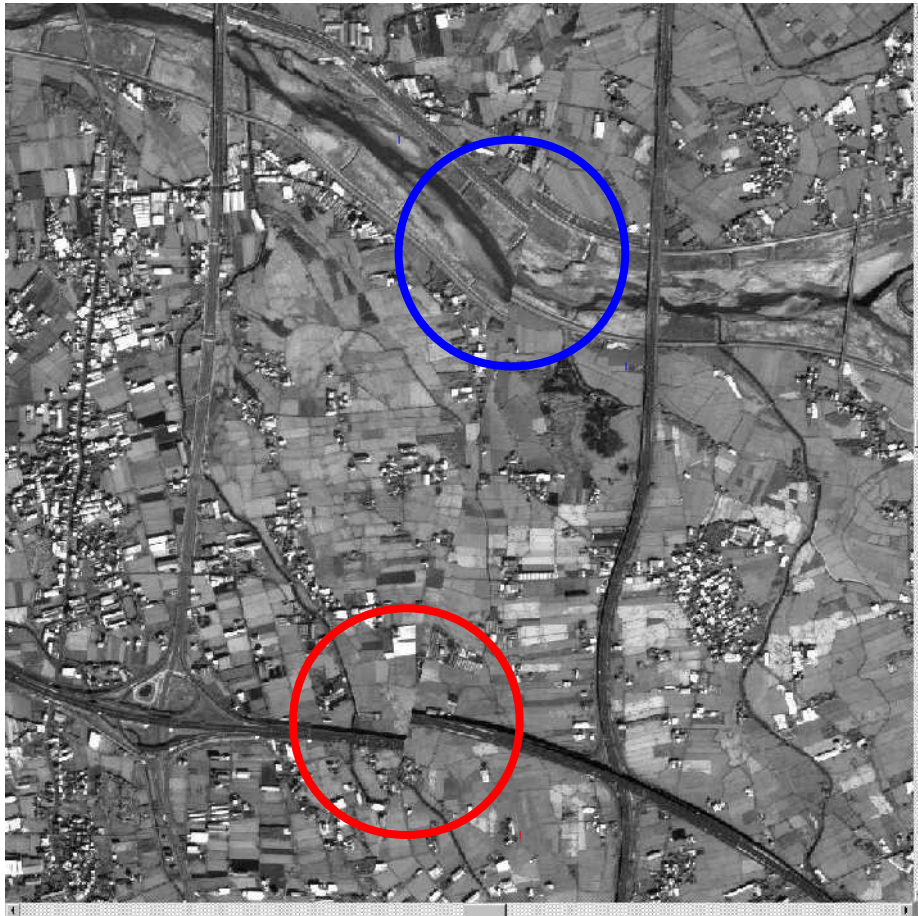


精密幾何改正 (正射影像) (L4)

精密幾何改正正射影像套疊向量圖



Level-2 與 Level-2C 之比較



輻射校正

Operations intended to remove systematic or random noise affecting the amplitude (brightness) of an image.

- Radiometric defects may be introduced during:
 - imaging (atmosphere, optics, detector,)
 - digitization or
 - transmission.

Goal: to restore an image to the condition it would have been in if the imaging process were flawless.

Digitized Image: $I(x, y)$



$$\textit{Illumination: } M(x, y) = E_d$$



Path Radiance: $A(x, y) = L_$*



Corrected Image: $F(x, y)$



F. 判釋與分析

目的

- 判釋與分析
- 辨識與量測

處理程序

- 原始資料
- 處理模式
- 地真資料
- 產物

方式

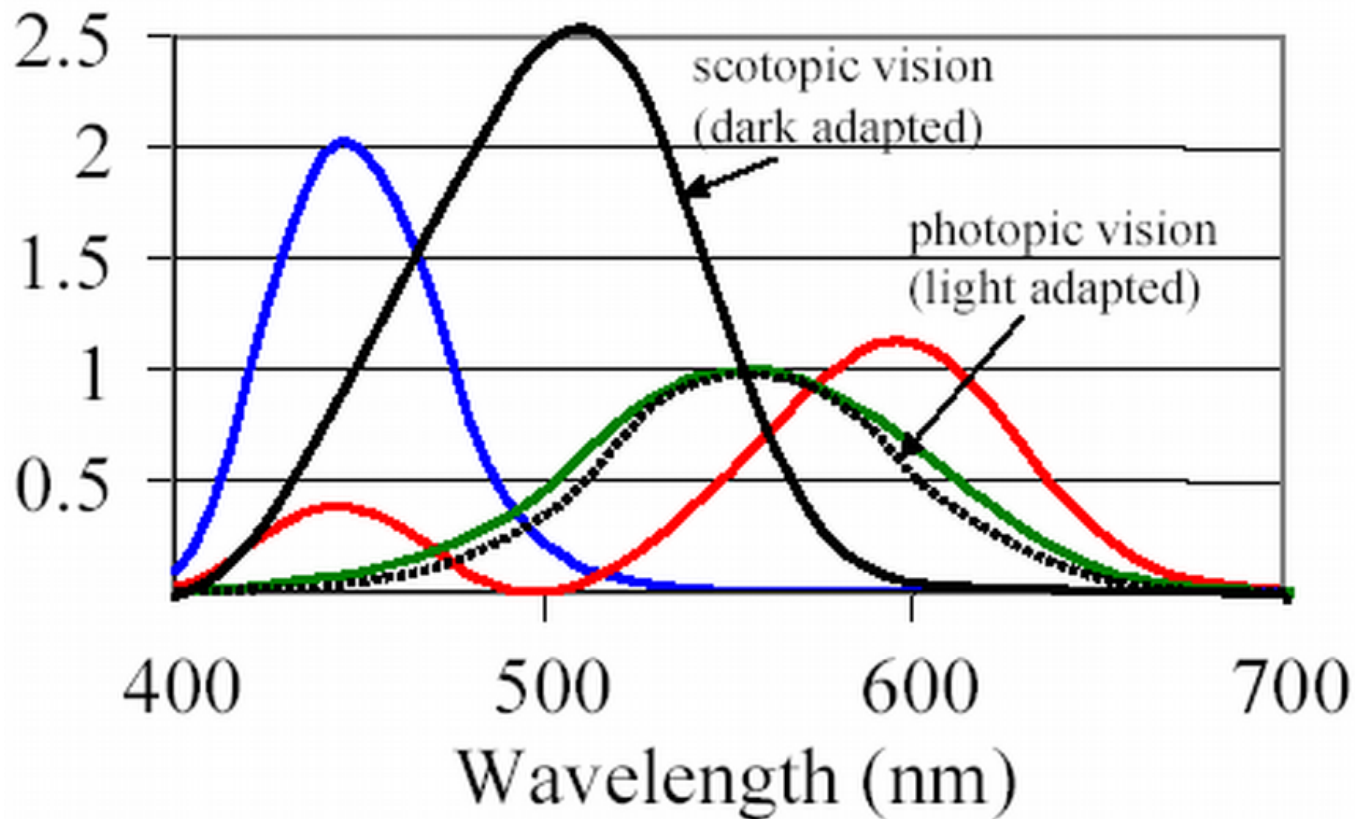
- 人工與數位處理
- 相互依存

類比或數位	數位
人工判釋	數位影像處理
對硬體需求低	通常需要特殊軟體或硬體
同一時間僅能處理一或少數個波段或單一影像	可同時處理多波段及大量影像資料
判釋結果因人，因時不同（主觀）品質可能有差距	處理結果一致結果須經嚴密驗證

人類視覺限制

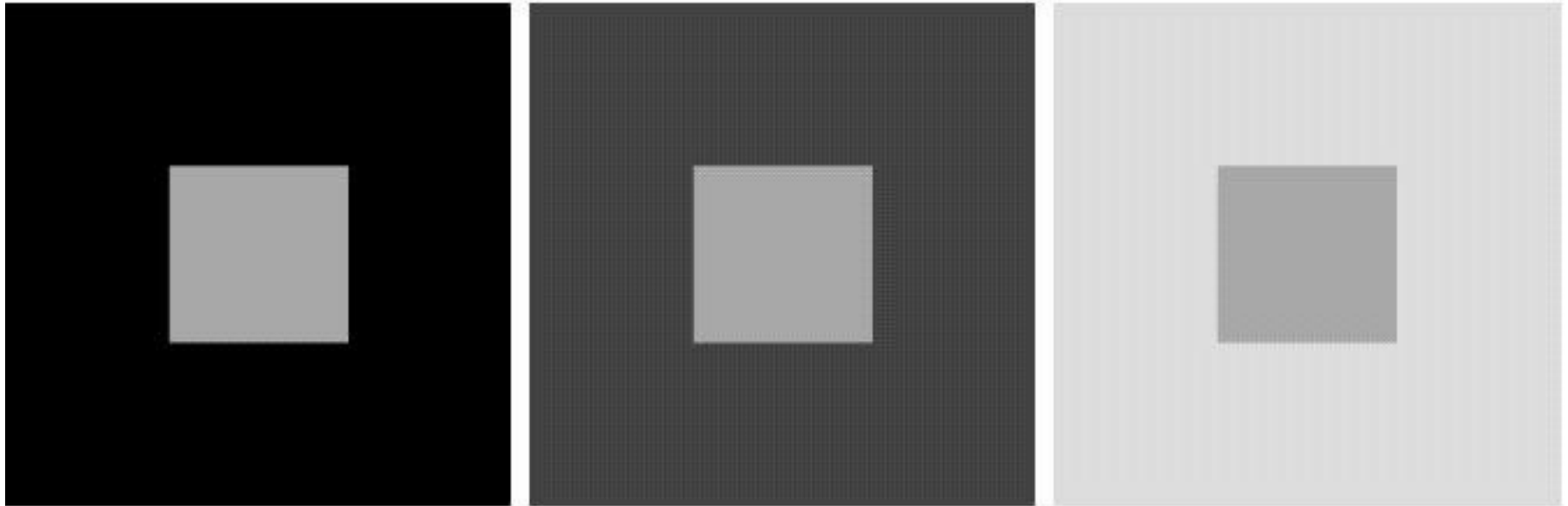
有限的光譜波長 (400~700 nm)

只有三個顏色感測器 (color receptor)



人類視覺限制

對比與絕對灰度值



人類視覺限制

對比與絕對灰度值



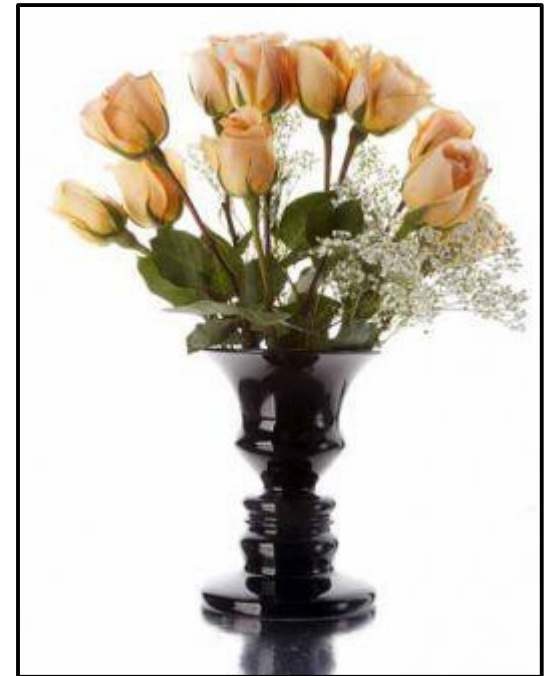
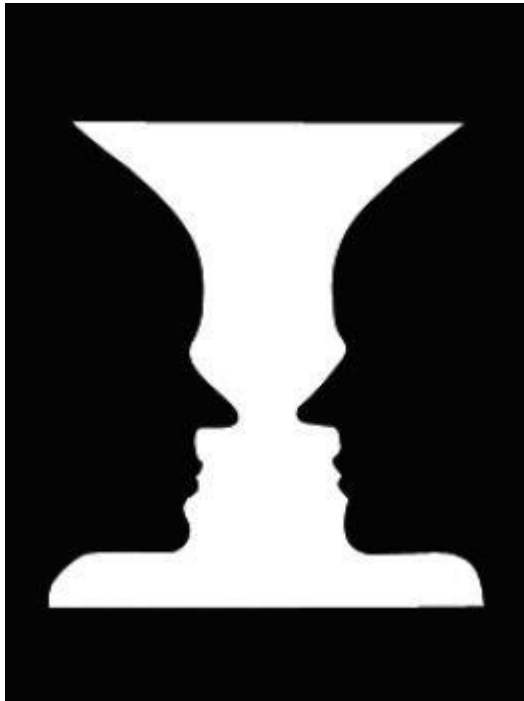
人類視覺限制

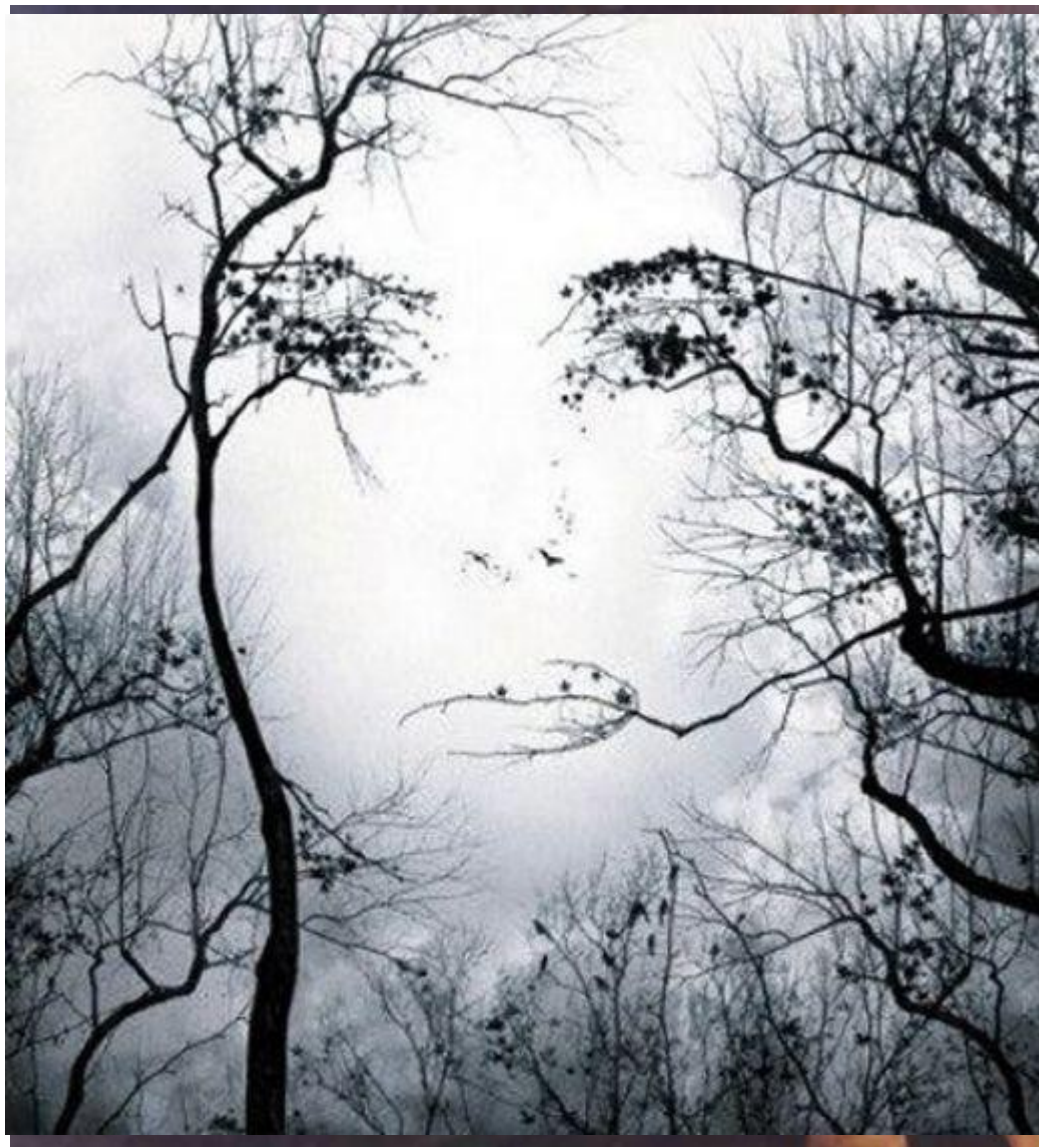
對比與絕對灰度值



Purves, Lotto and Nundy
(2002) American Scientist,
90(3):236-243.

影像判釋 (Human Perception)





半自動化影像判釋分析系統

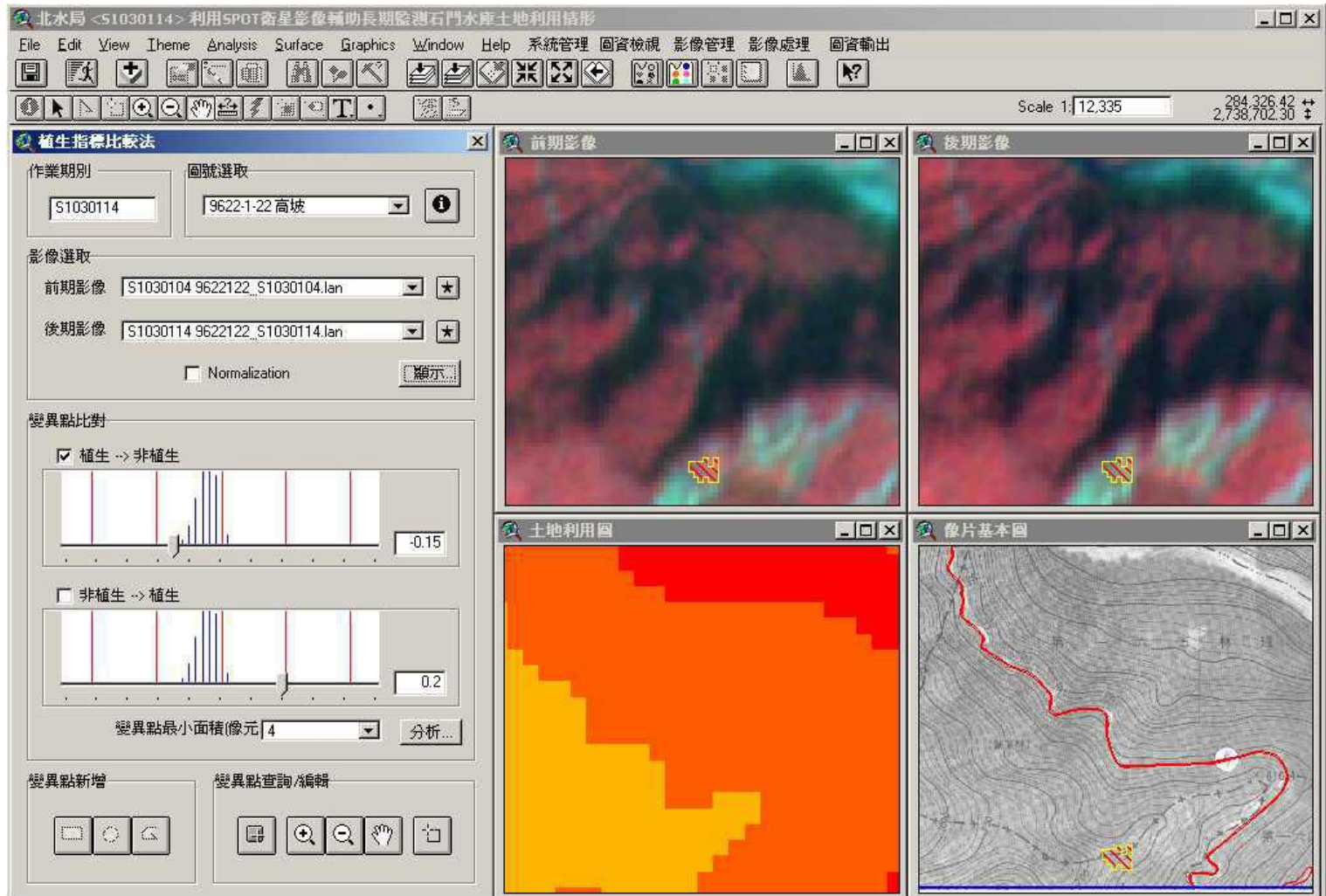
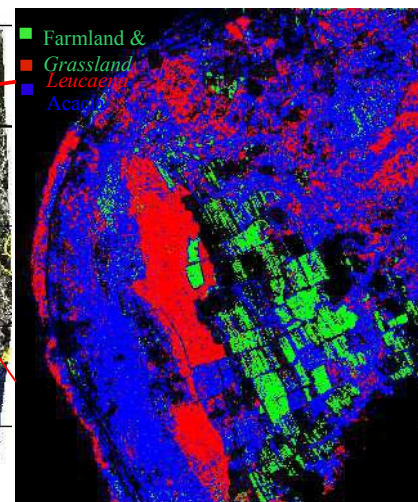
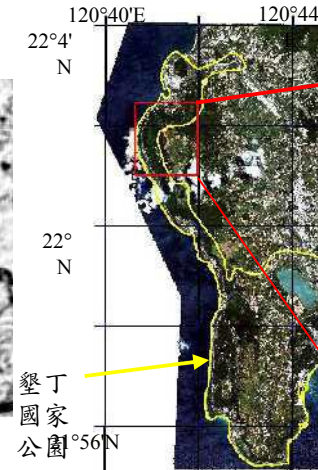
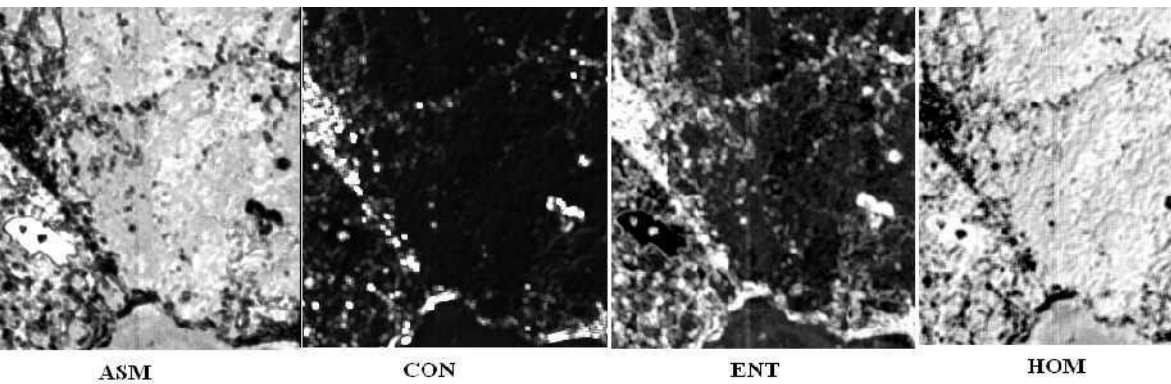
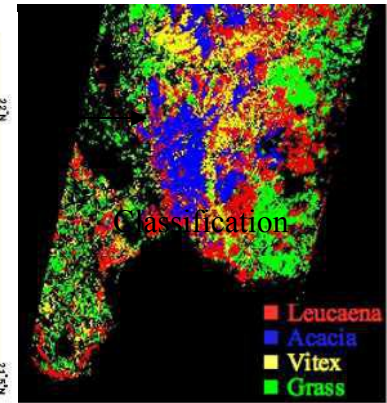
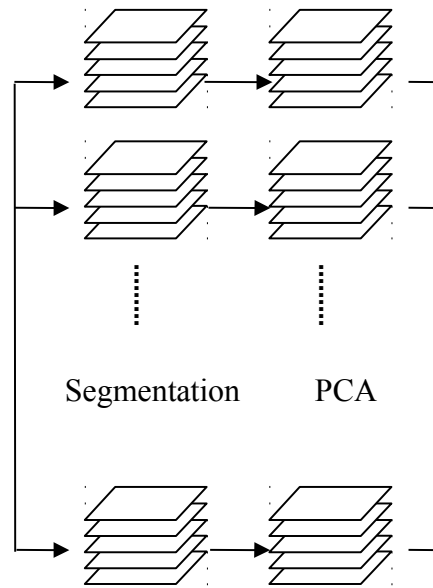
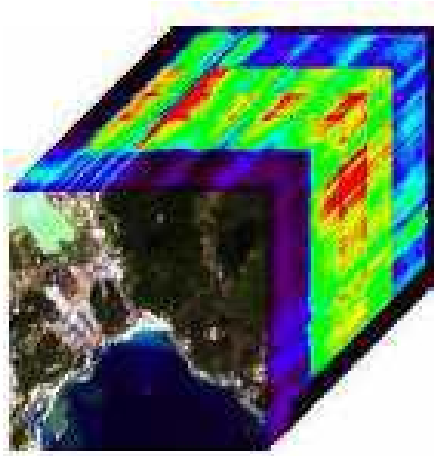


Fig. 3: User interface of the developed change detection system.

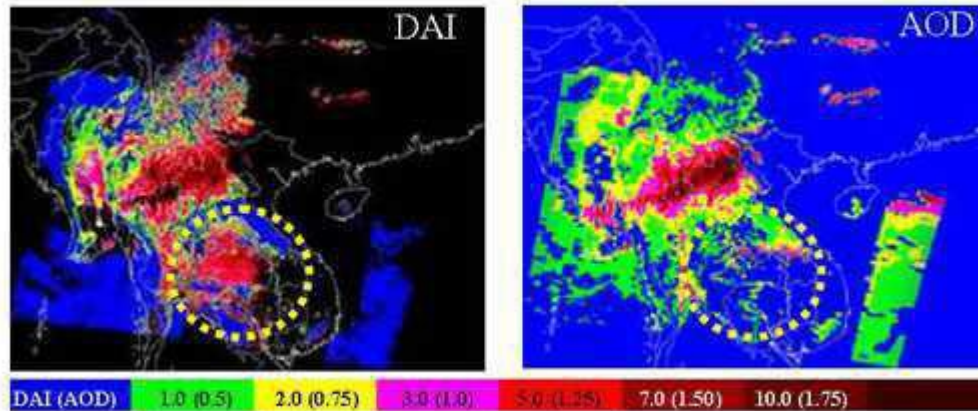
遙測影像分析應用範例



生質燃燒及沙塵暴監測

► MODIS在生質燃燒煙塵之監測

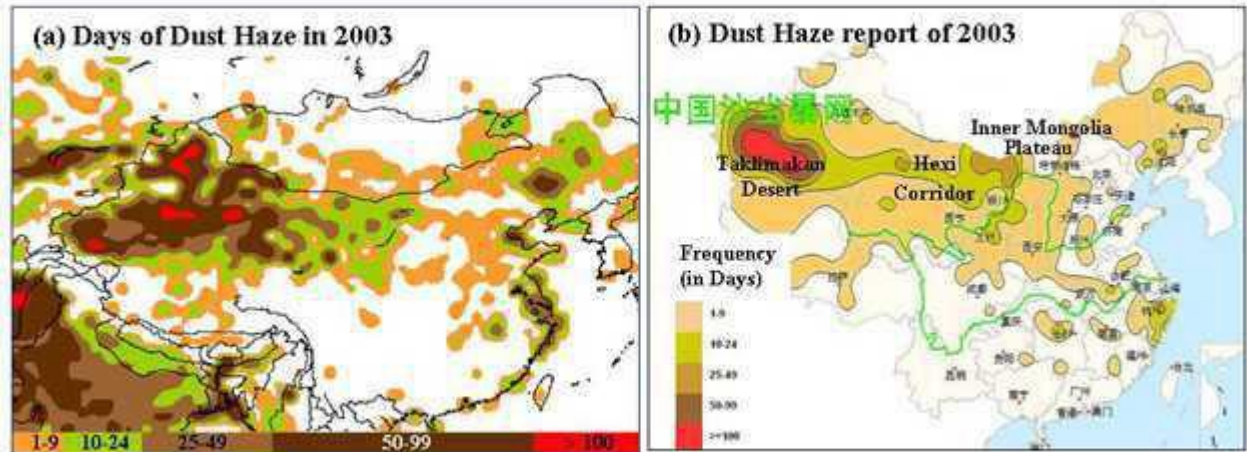
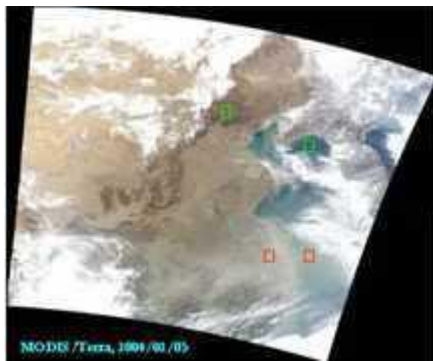
Biomass burning : smoke plume in DAI, MODIS/Terra 03:45 UTC, 27 Mar 2004.



(DAI: Deep-blue Aerosol Index; AOD: Aerosol Optical Depth)

► 衛星遙測沙塵天氣之空間分布- MODIS/Aqua

Remote sensing of spatial frequency distribution of dust weather from MODIS/Aqua.



Dust haze spatial frequency distribution in 2003. (a) From MODIS/Aqua products, (b) Dust weather reports (from <http://www.duststorm.com.cn>).

小林村



小林村變遷 (莫拉克颱風前後)





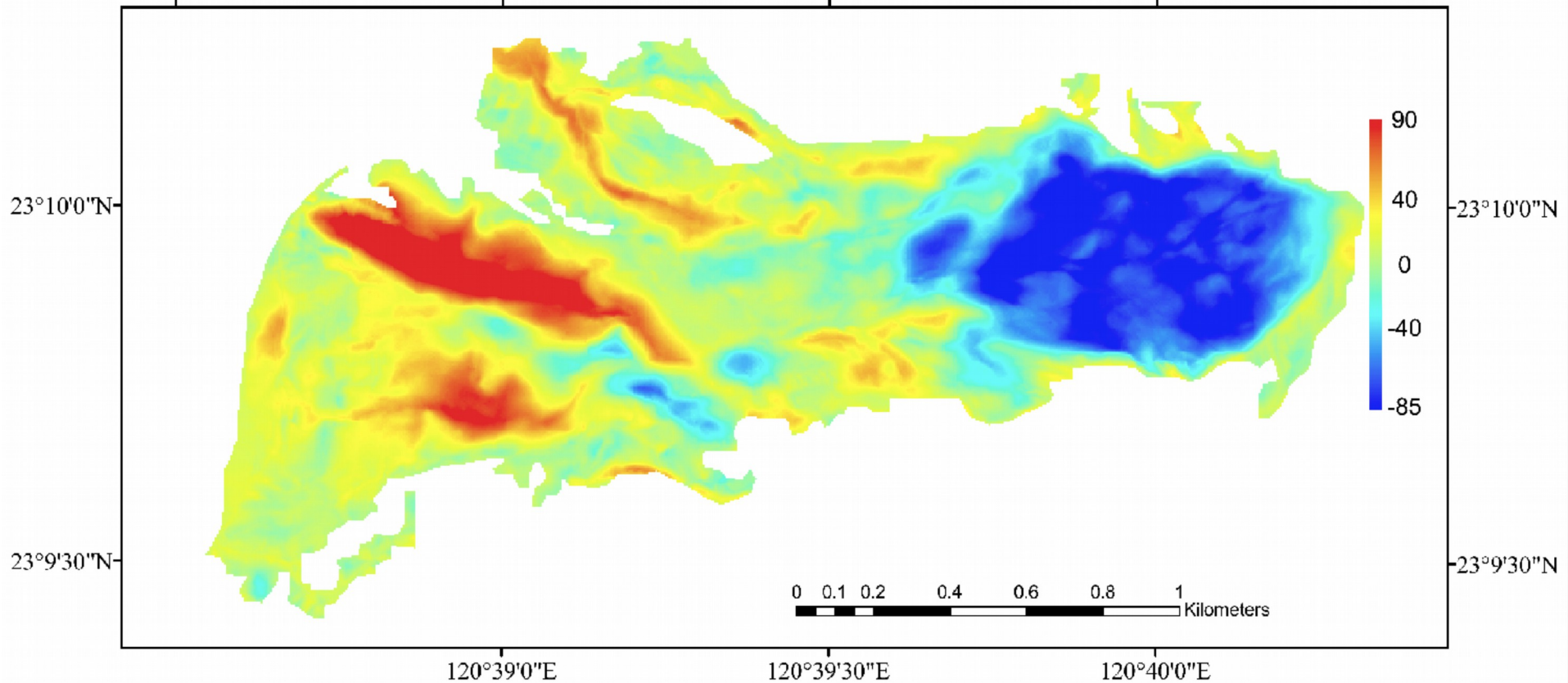


120°38'30"E

120°39'0"E

120°39'30"E

120°40'0"E



23°10'0"N

23°10'0"N

23°9'30"N

23°9'30"N

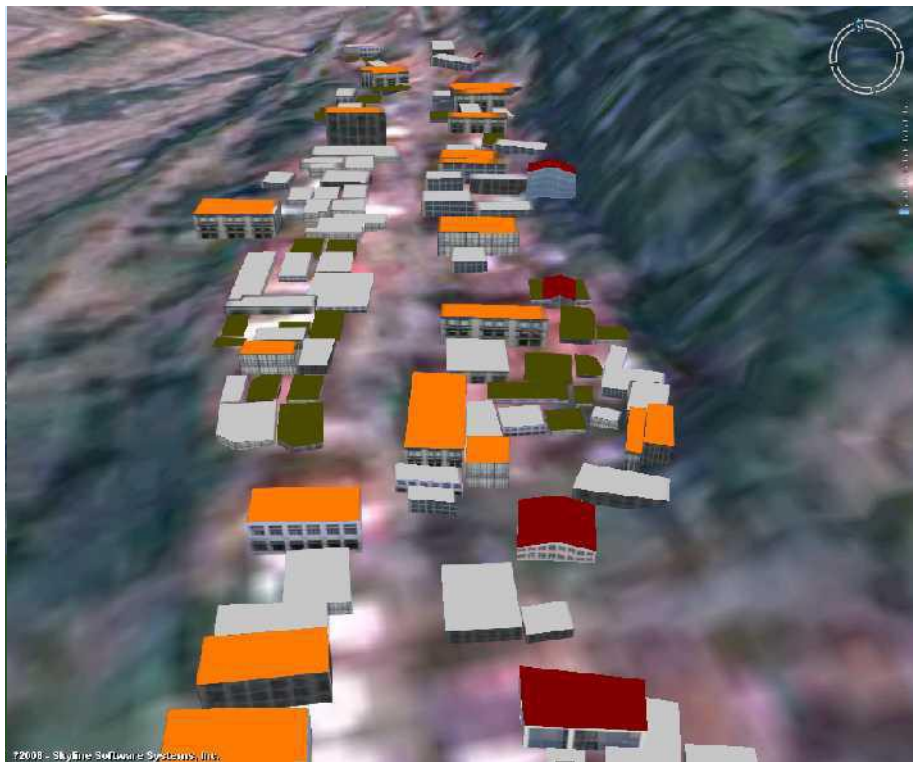
0 0.1 0.2 0.4 0.6 0.8 1 Kilometers

120°39'0"E

120°39'30"E

120°40'0"E





Before

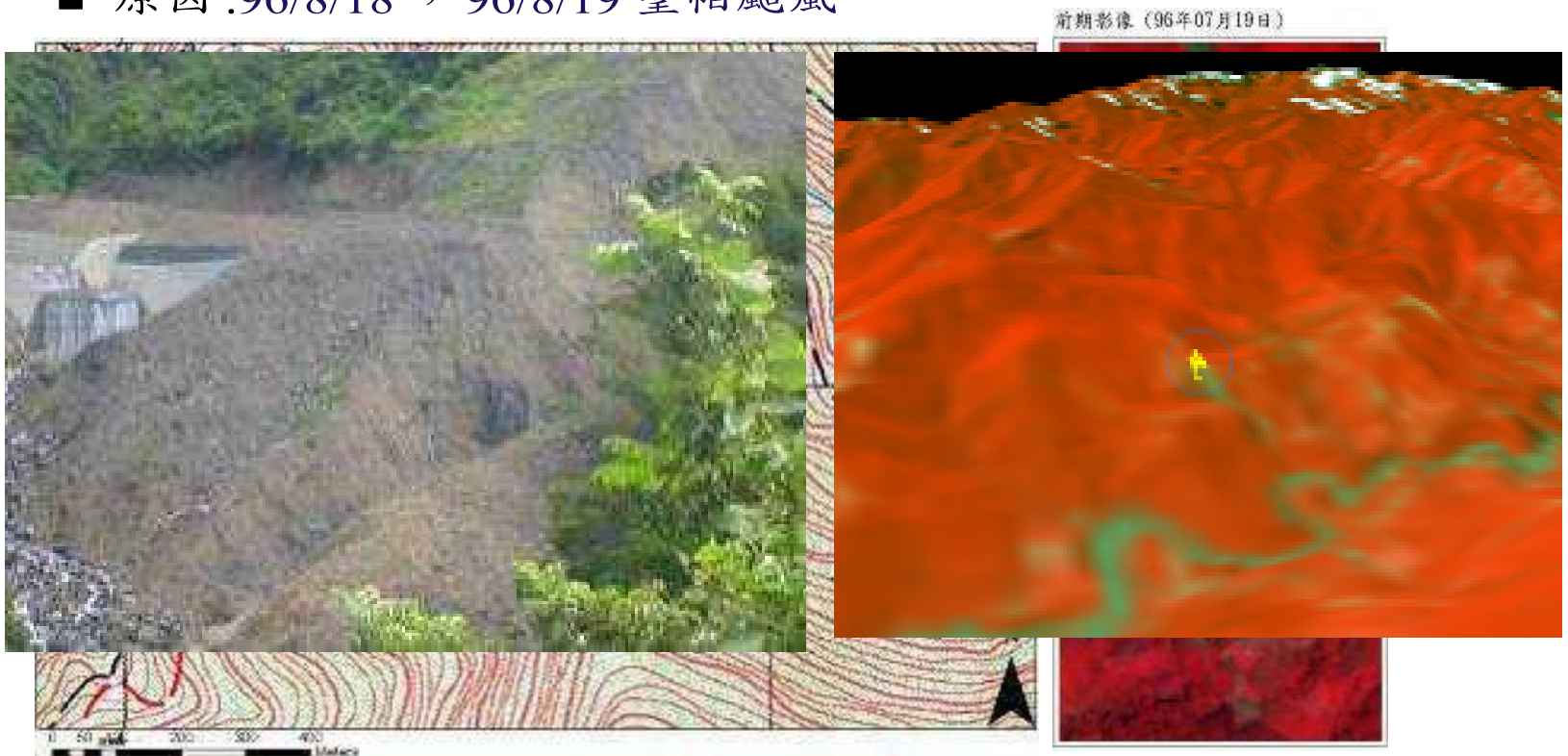
- Building models reconstructed from aerial stereopairs
- Generic texture



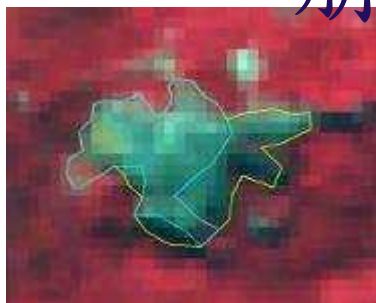
After

Landslide Detection

- 原因 :96/8/18 , 96/8/19 聖帕颱風



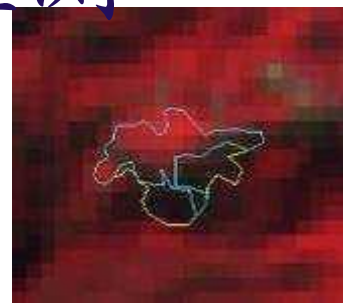
崩塌地長期監測



93/10/12



95/10/20



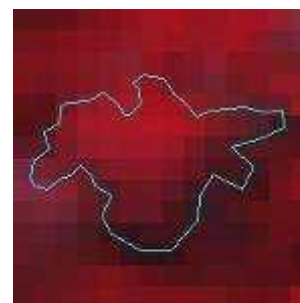
96/11/15



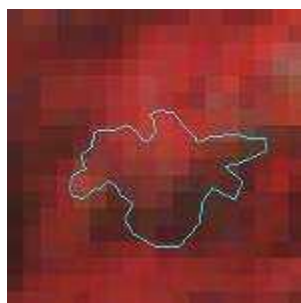
97/02/21



97/06/21



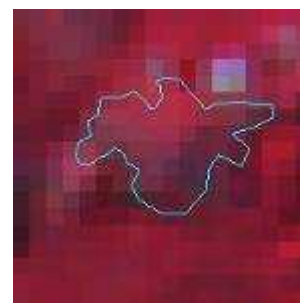
97/10/10



98/02/11



98/06/09



98/09/26

非法變異點回報成果

變異點編號

R18961000016

變異類型

新增建物

查證結果

非法

圖幅名稱

新化鎮(東部)

前期影像日期

02/04/2007

後期影像日期

08/16/2007

前期影像

後期影像

變異點
現地描述

正在大興土木，外觀已具雛型，判斷是蓋寺廟，正面大殿，三面環有大廂房，惟僅佔本地號三分之一面積，其實主體結構大半為 395-1 地號上

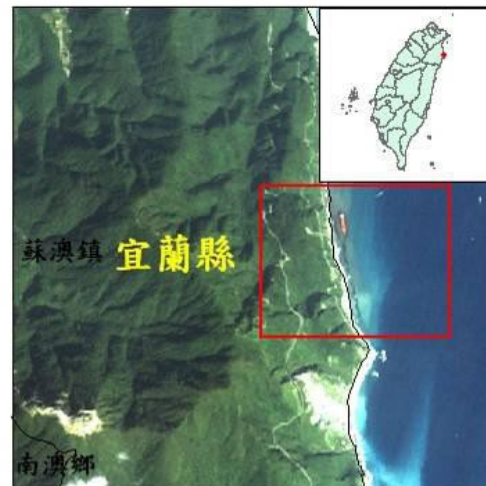
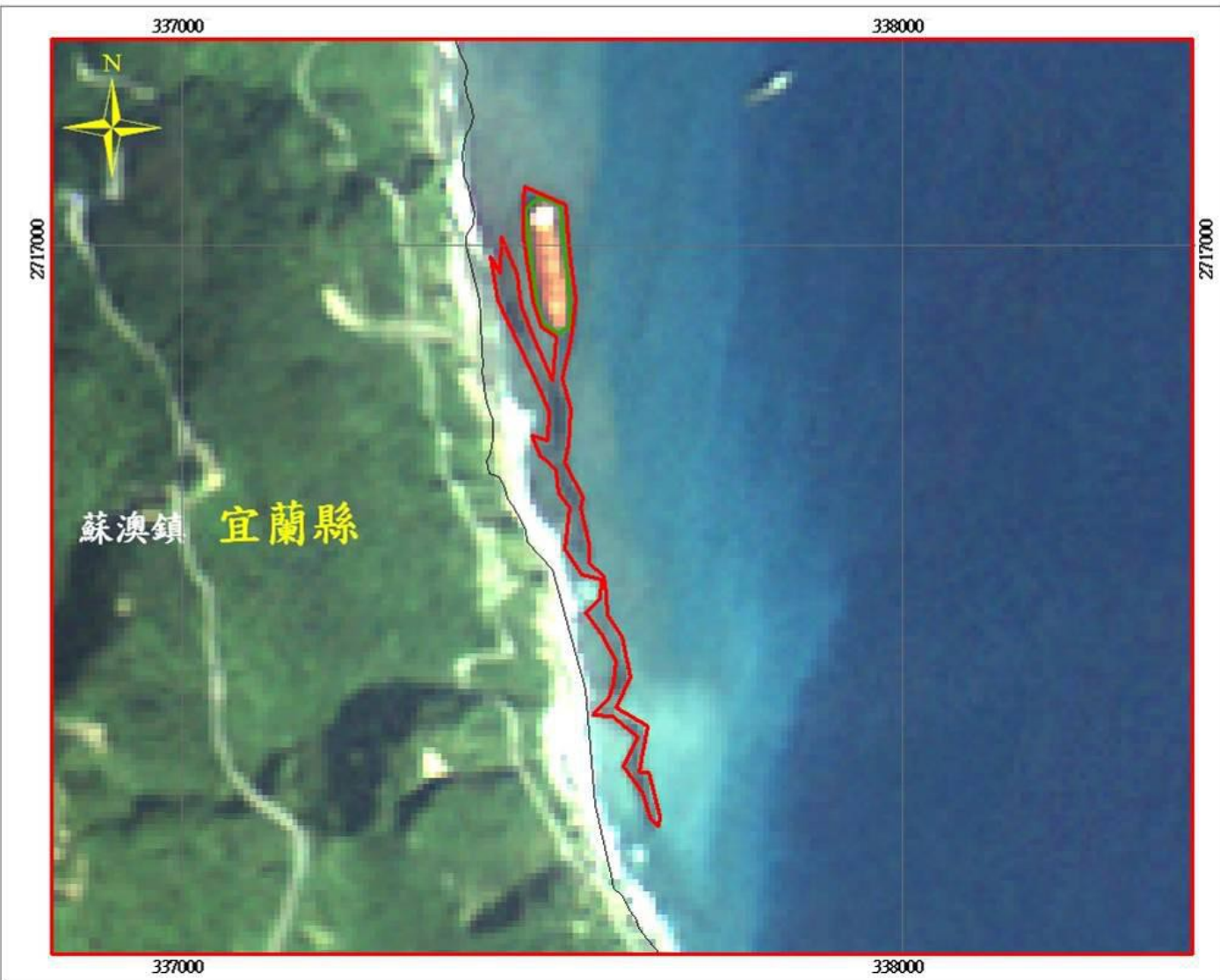
現 場 照 片



宜蘭縣蘇澳鎮外海吉尼號 擱淺漏油評估

根據12/25/2006 福衛二號衛星影像

本台灣海域油污評估圖係根據衛星影像，由國立中央大學太空及遙測研究中心地理資訊系統實驗室製作。影響區域係由12/25/2006拍攝之福衛二號多光譜衛星影像(解析度8m)作出判釋，範圍約為31,343平方公尺。此為尚未經過現地調查驗證之初步評估。



圖例

- 鄉鎮邊界
- 事故船隻
- 污染範圍
- Red: Kand_3
- Green: Kand_2
- Blue: Kand_1

衛星影像判釋範例

- 正常船行軌跡
- 海域污染
- 海面
- 海岸線

0 90 180 360 540
Meters

拍攝日期及時間: 12/25/2006(陰曆11/06/2006) 10:04:32

衛星影像: 福衛二號 多光譜(8m)

經緯度: 東經: 121°52'32.5" 北緯: 24°31'58"

坐標(TWD67) E: 337897 N: 271443

船艙航向: 西 船艙大小: 160公尺

與台灣本島距離: <100公尺

風速風向資料

風向: 船北轉東北風 風速: 5至6哩風8級

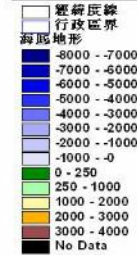
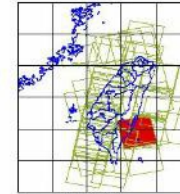
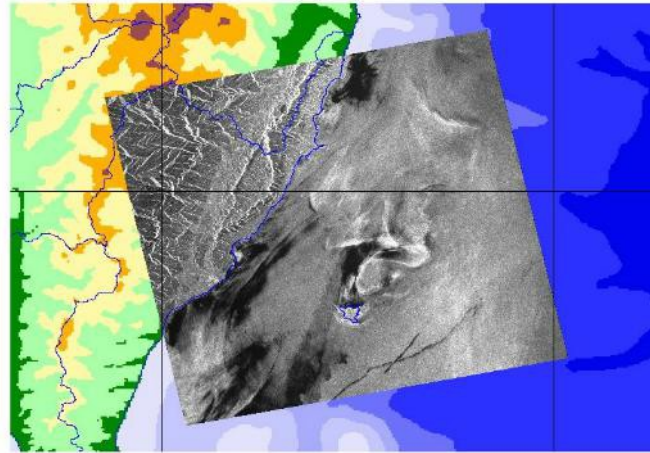
潮汐資料(蘇澳燈測站)

第一次乾潮		第一次滿潮		第二次乾潮		第二次滿潮	
時間	高度(CH)	時間	高度(CH)	時間	高度(CH)	時間	高度(CH)
03:30	-97	10:00	10	15:05	-38	21:04	42

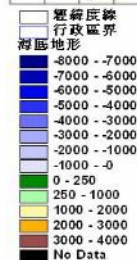
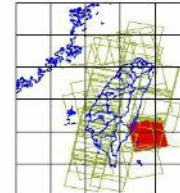
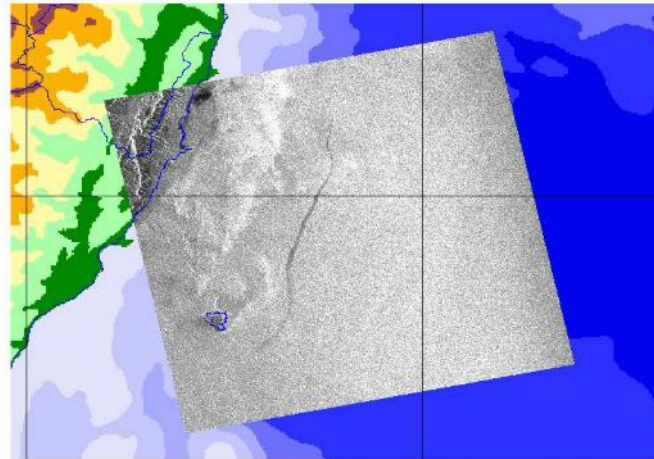


雷達影像海洋油污監測

s02022(1995/05/01)



s00708(1994/05/20)

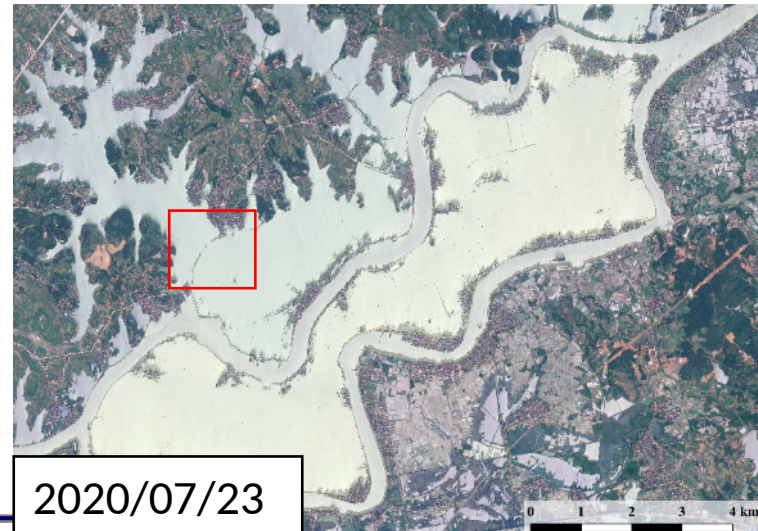
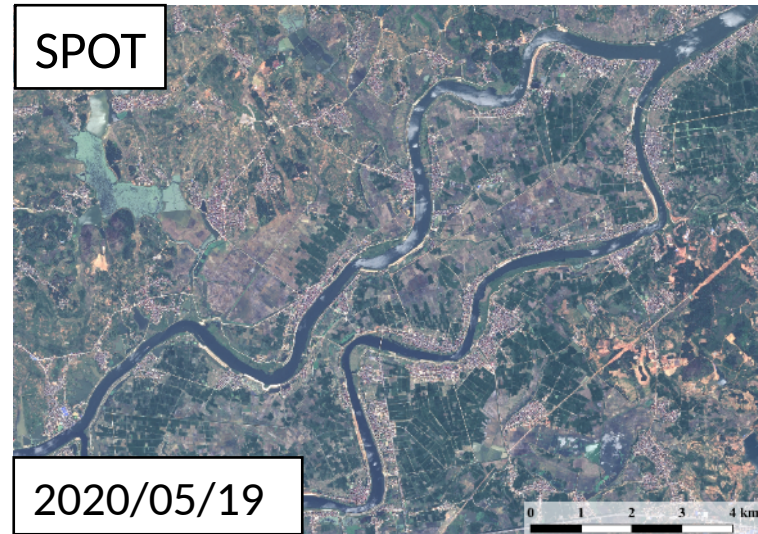
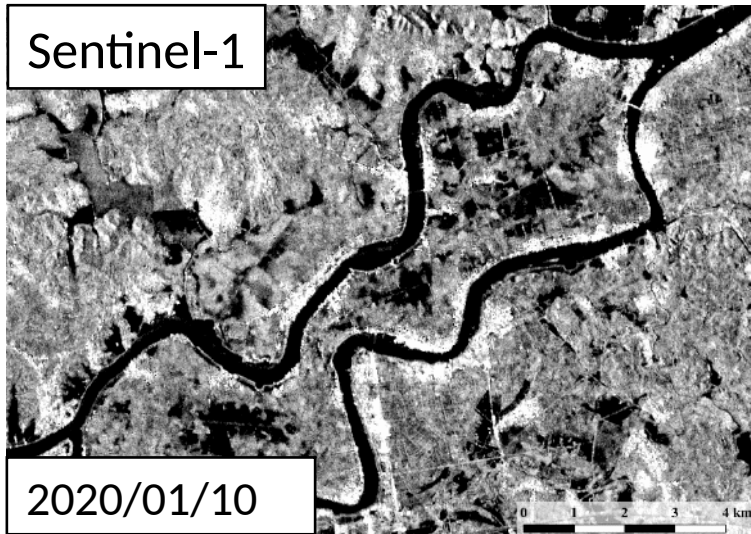


30 0 30 Kilometers

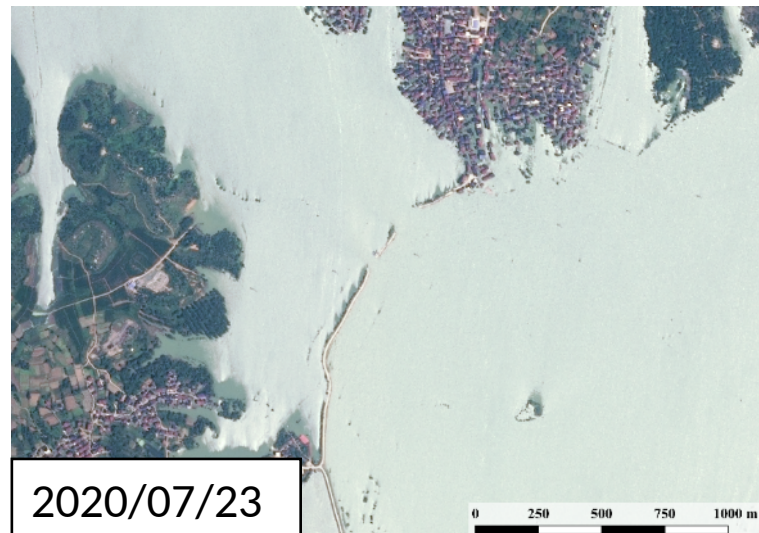
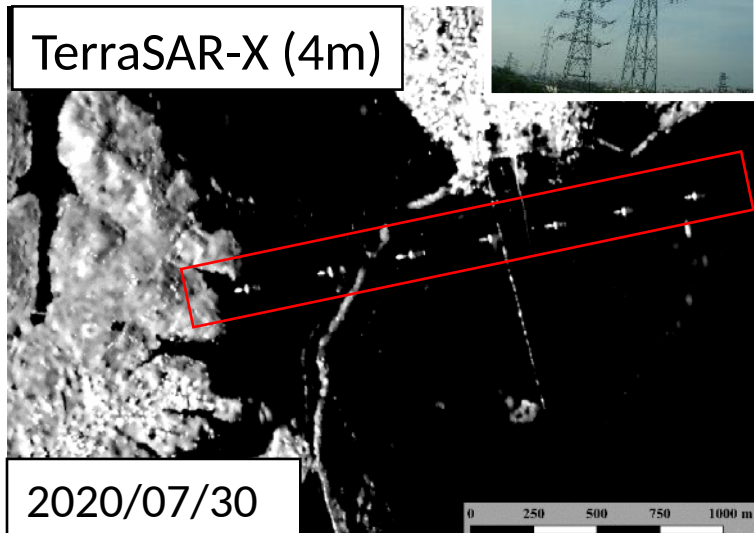
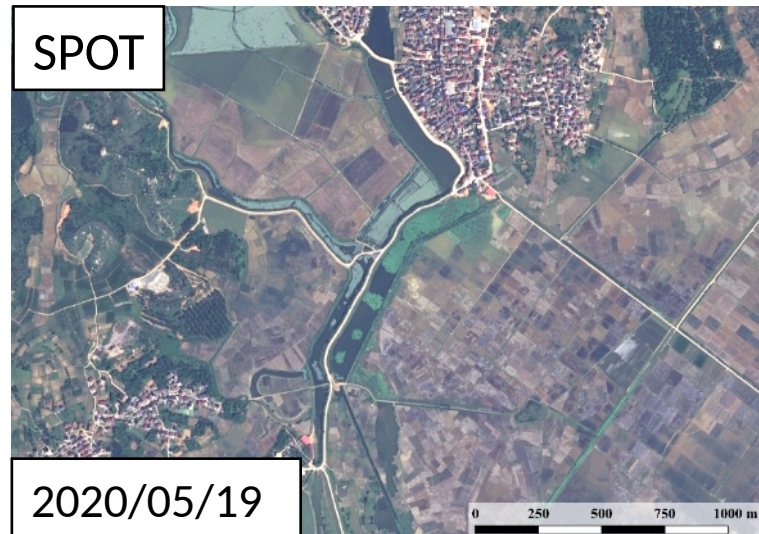
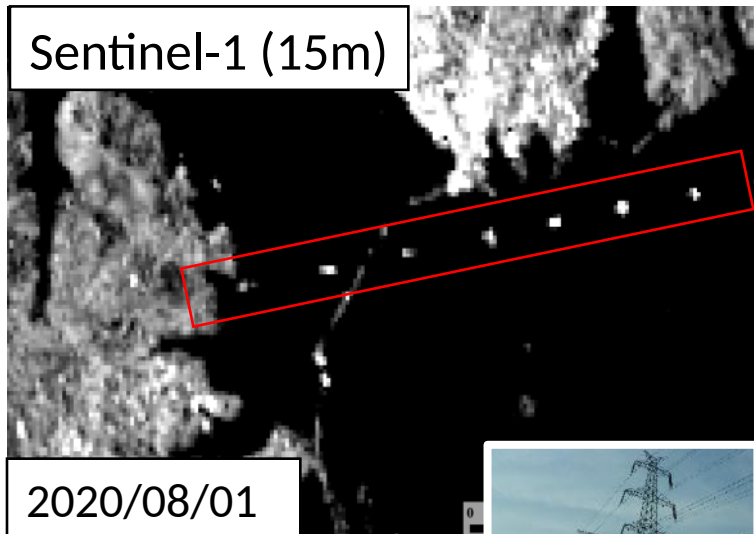


國立中央大學太空及遙測研究中心
 國立中央大學(興隆路)
 電話: (02)29523471-1217151 X 701P K004-1107770
 傳真: 02-29523471

淹水監測

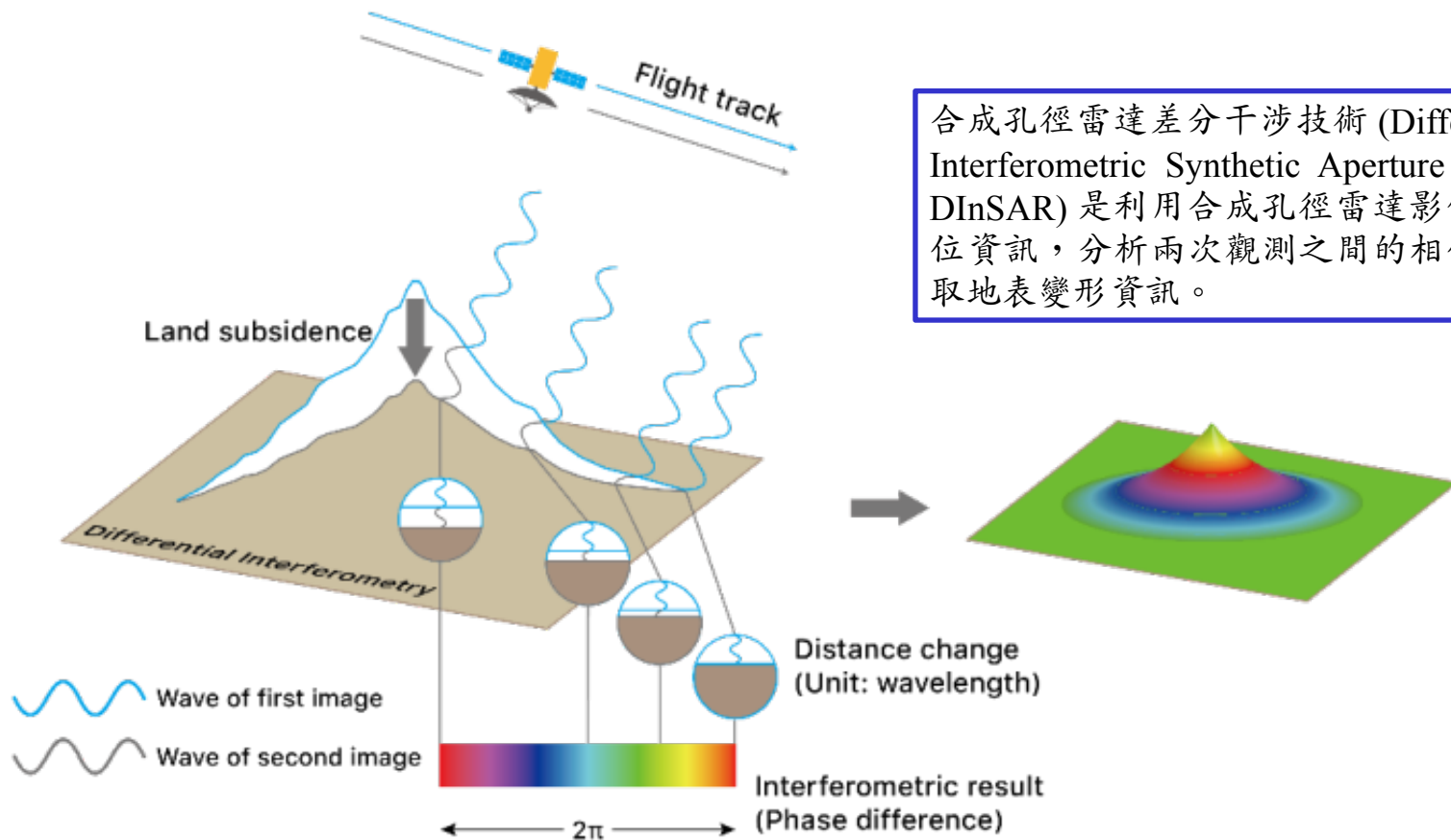


淹水監測

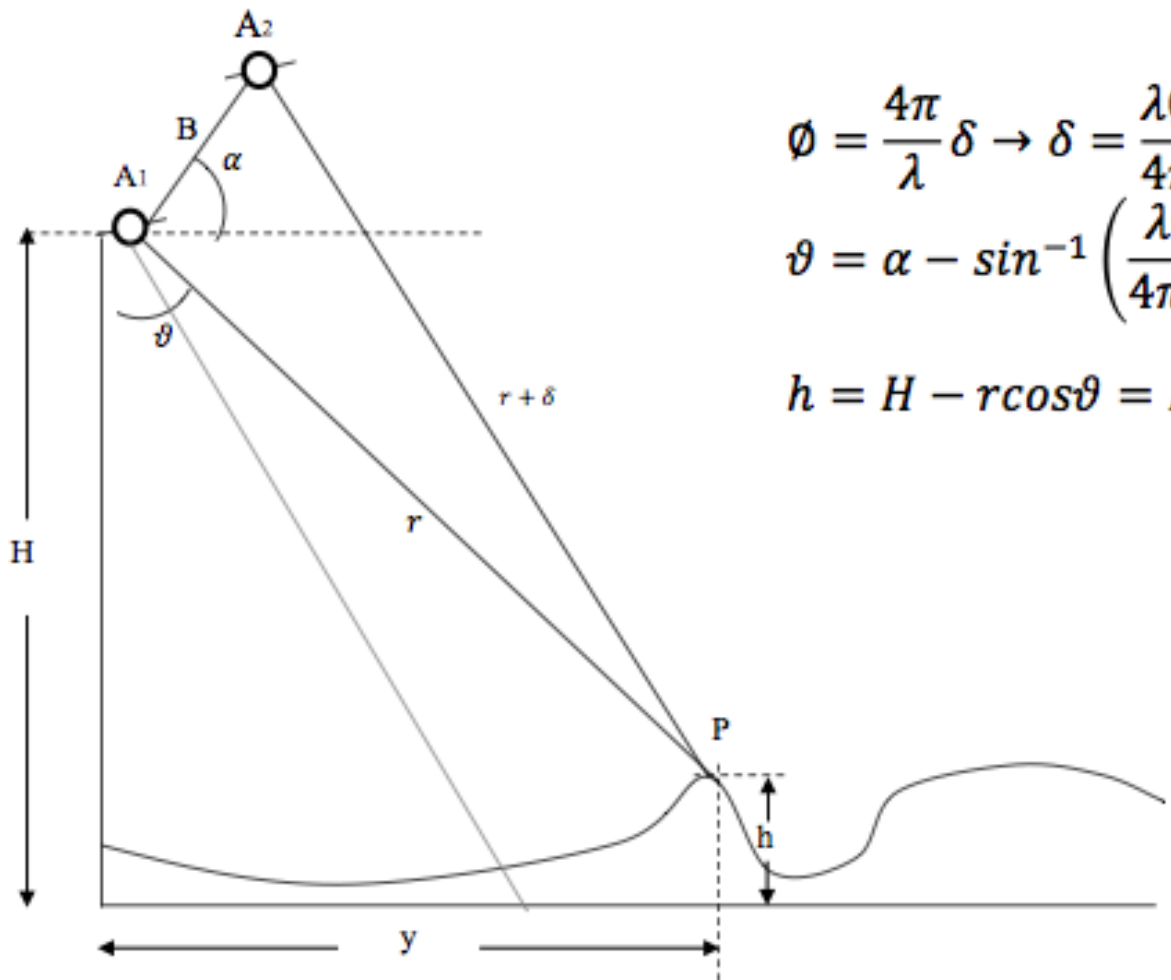


雷達差分干涉

Differential Interferometric SAR (DInSAR)



合成孔徑雷達差分干涉技術 (Differential Interferometric Synthetic Aperture Radar, DInSAR) 是利用合成孔徑雷達影像之相位資訊，分析兩次觀測之間的相位差獲取地表變形資訊。



$$\phi = \frac{4\pi}{\lambda} \delta \rightarrow \delta = \frac{\lambda\phi}{4\pi} = -B \sin(\vartheta - \alpha)$$

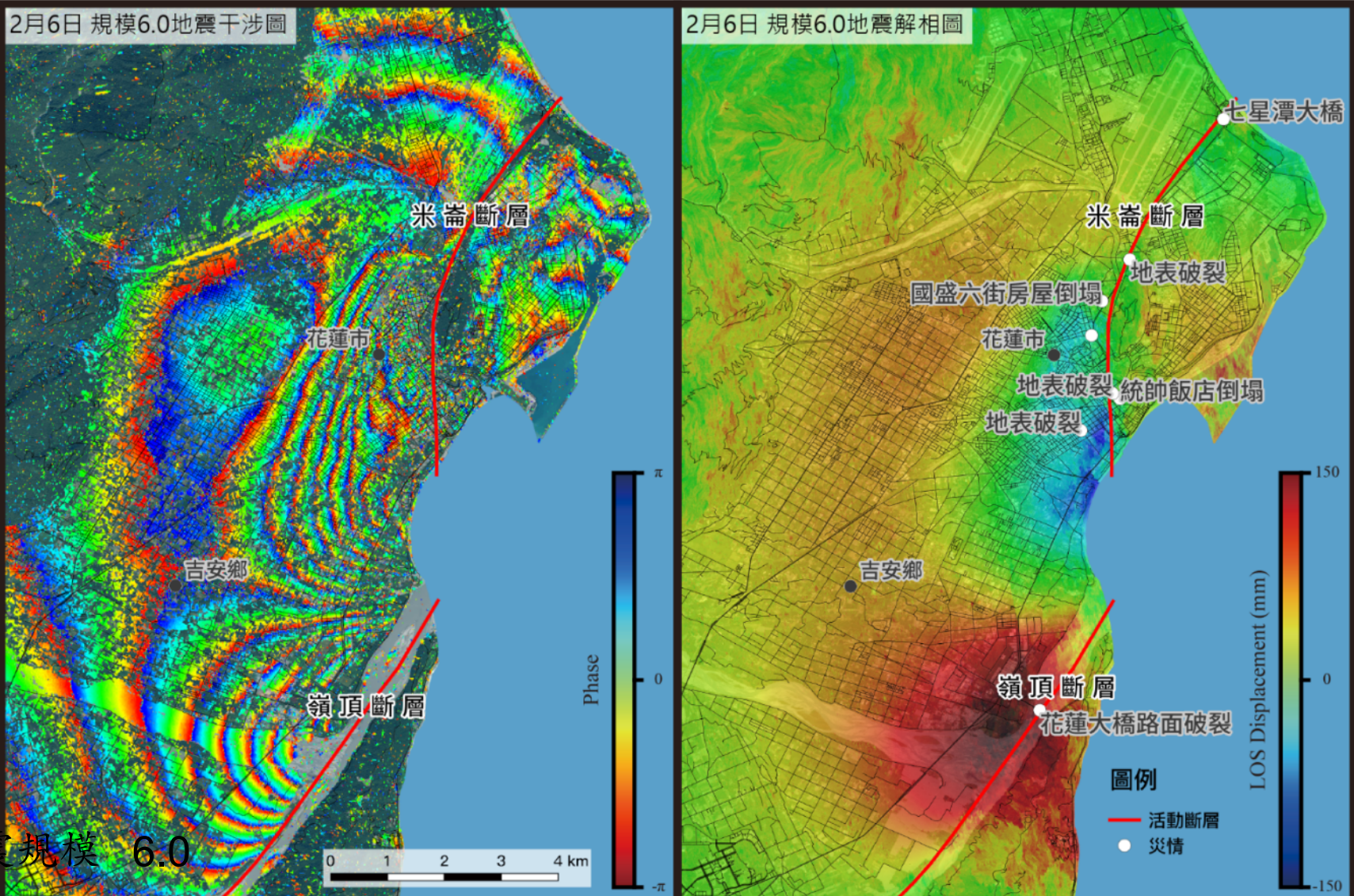
$$\vartheta = \alpha - \sin^{-1} \left(\frac{\lambda\phi}{4\pi B} \right)$$

$$h = H - r \cos\vartheta = H - r \cos \left[\alpha - \sin^{-1} \left(\frac{\lambda\phi}{4\pi B} \right) \right]$$

2019 花蓮地震 DInSAR 分析

2月6日 規模6.0地震干涉圖

2月6日 規模6.0地震解相圖

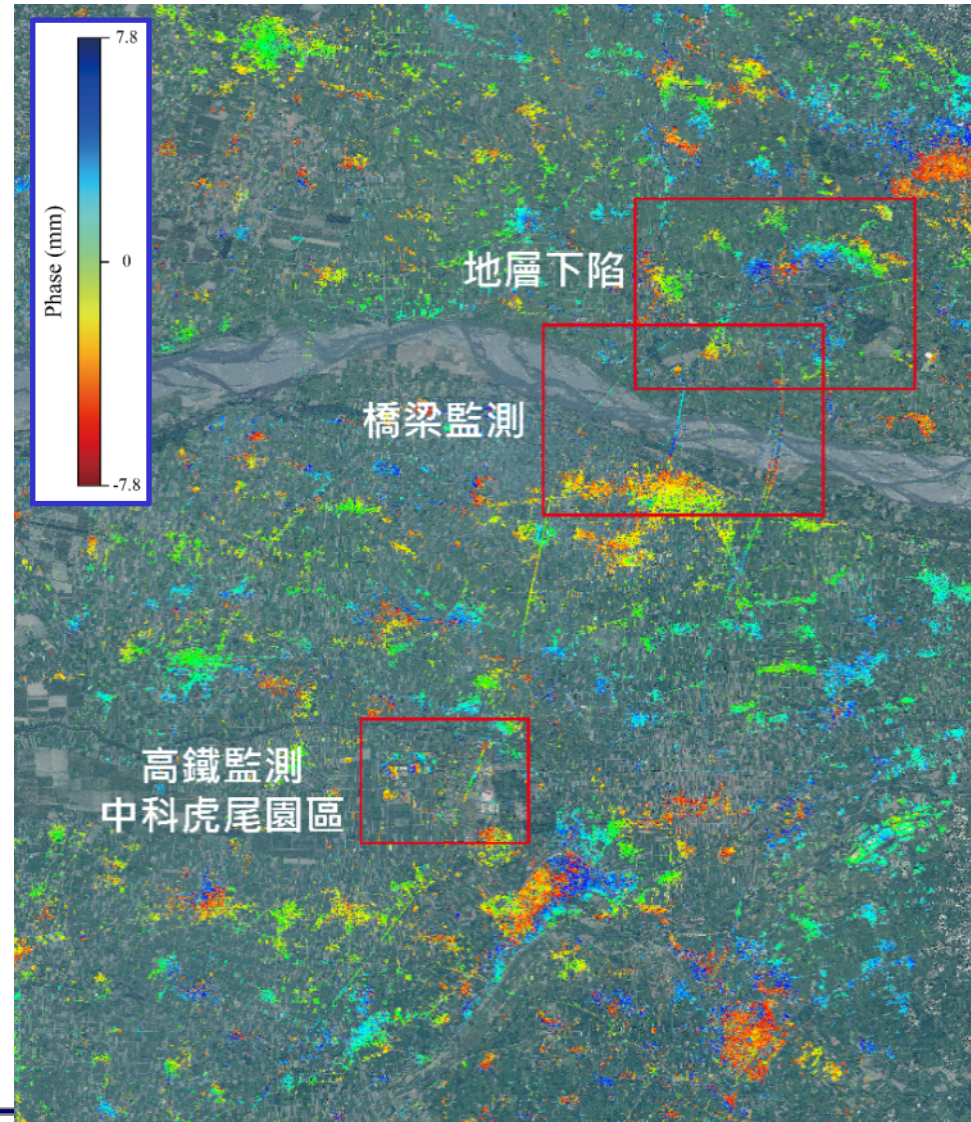


地震規模 6.0

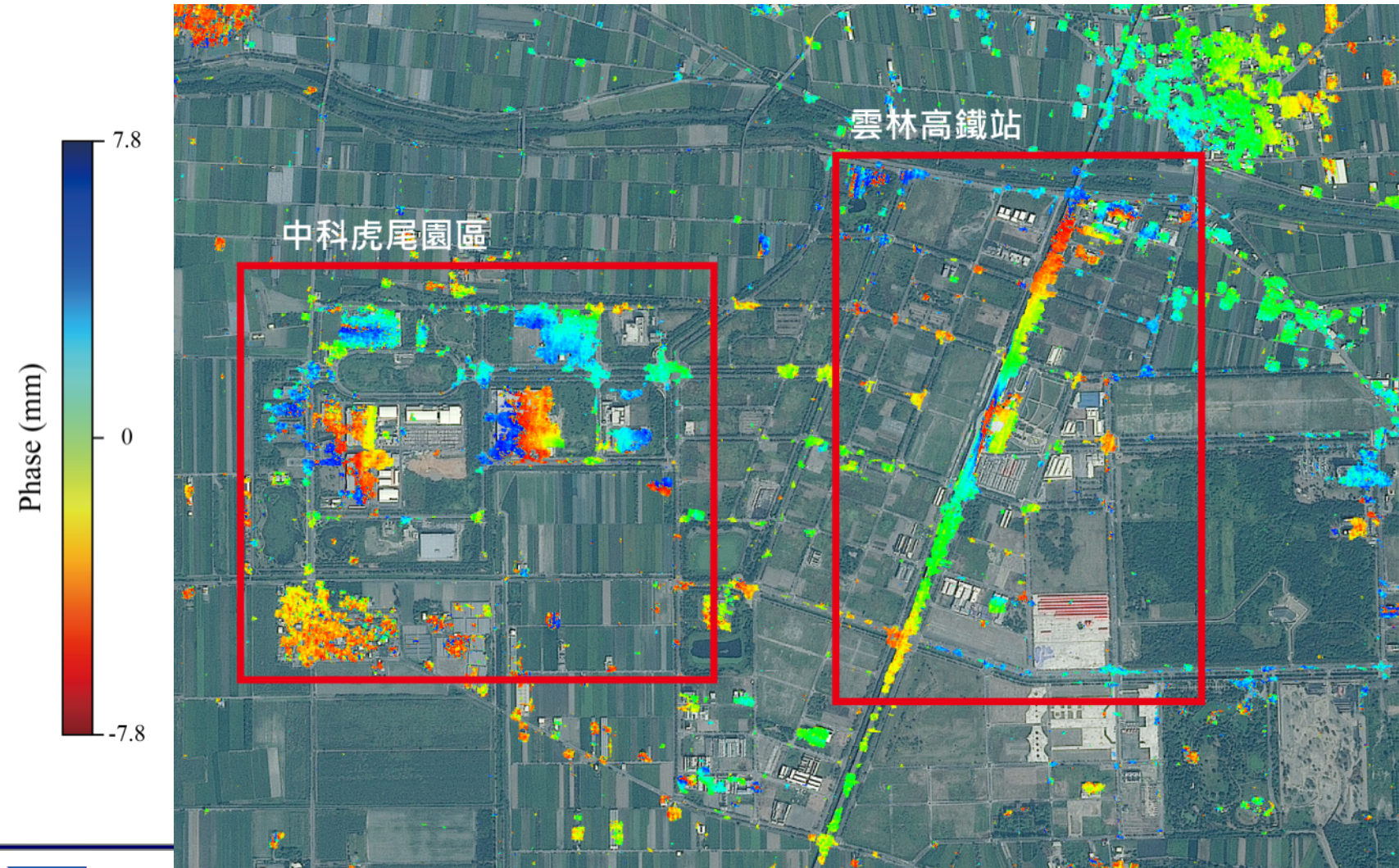


地表變形 PSInSAR 分析

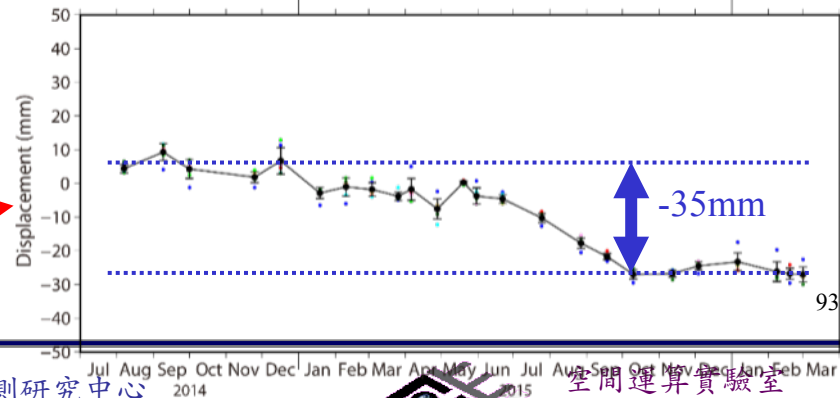
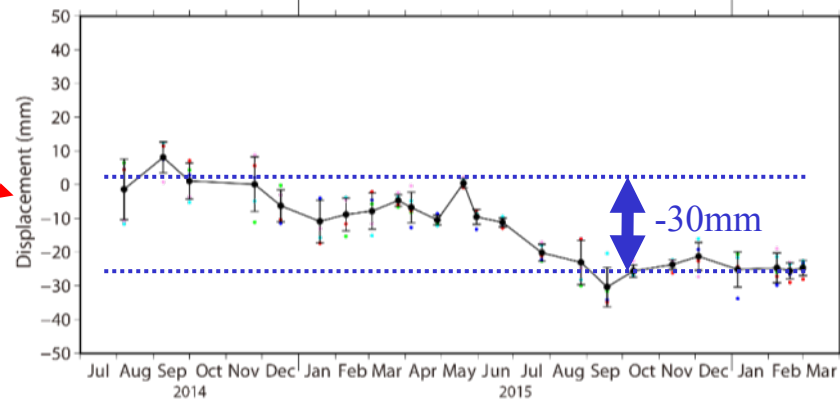
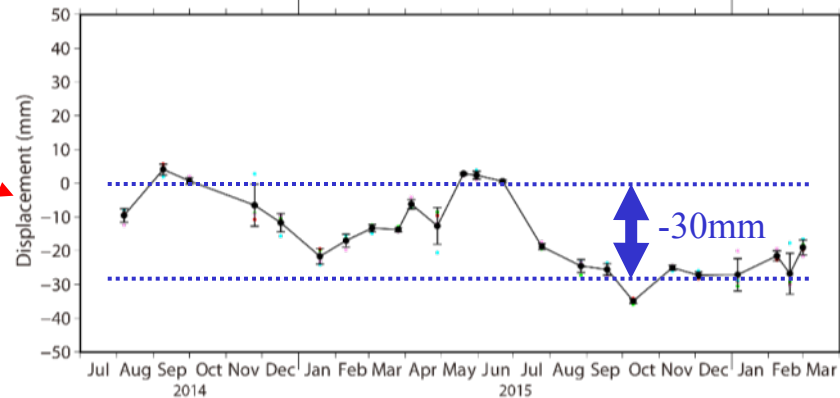
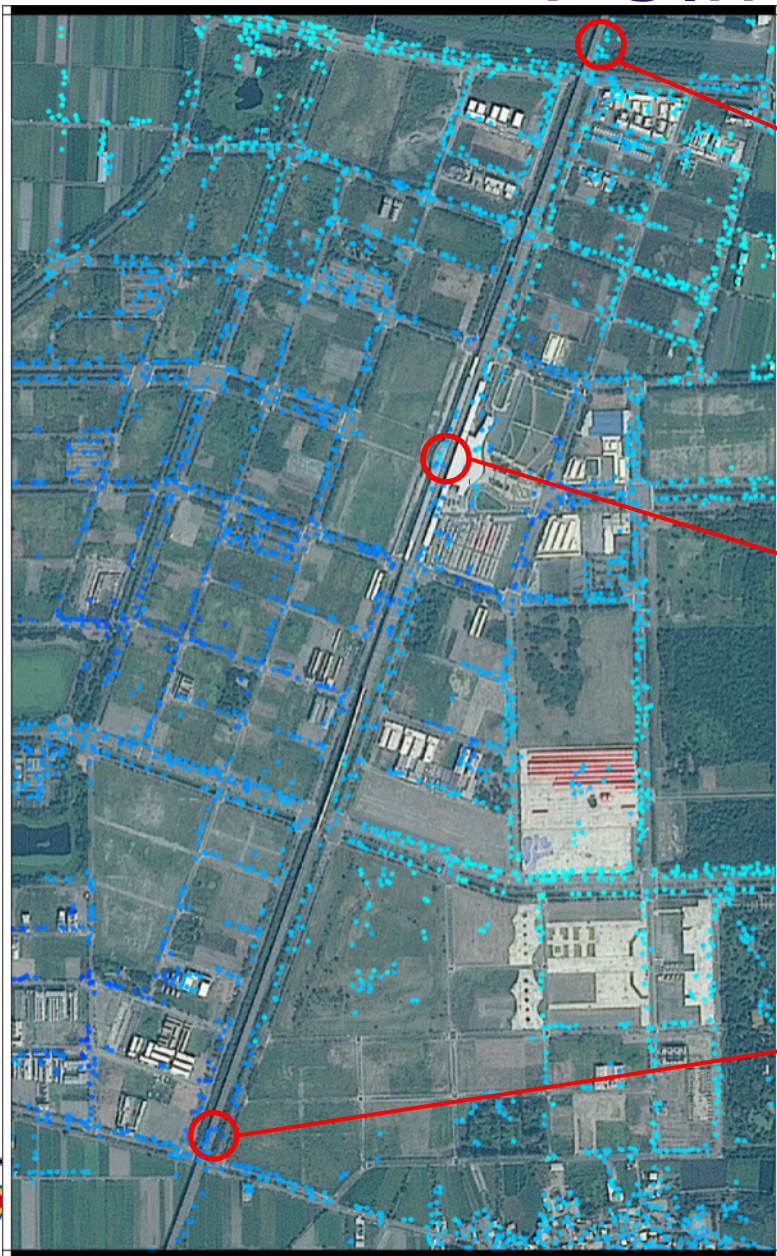
- TerraSAR-X: 2.2m
- 2015/04/28 ~ 2016/03/01



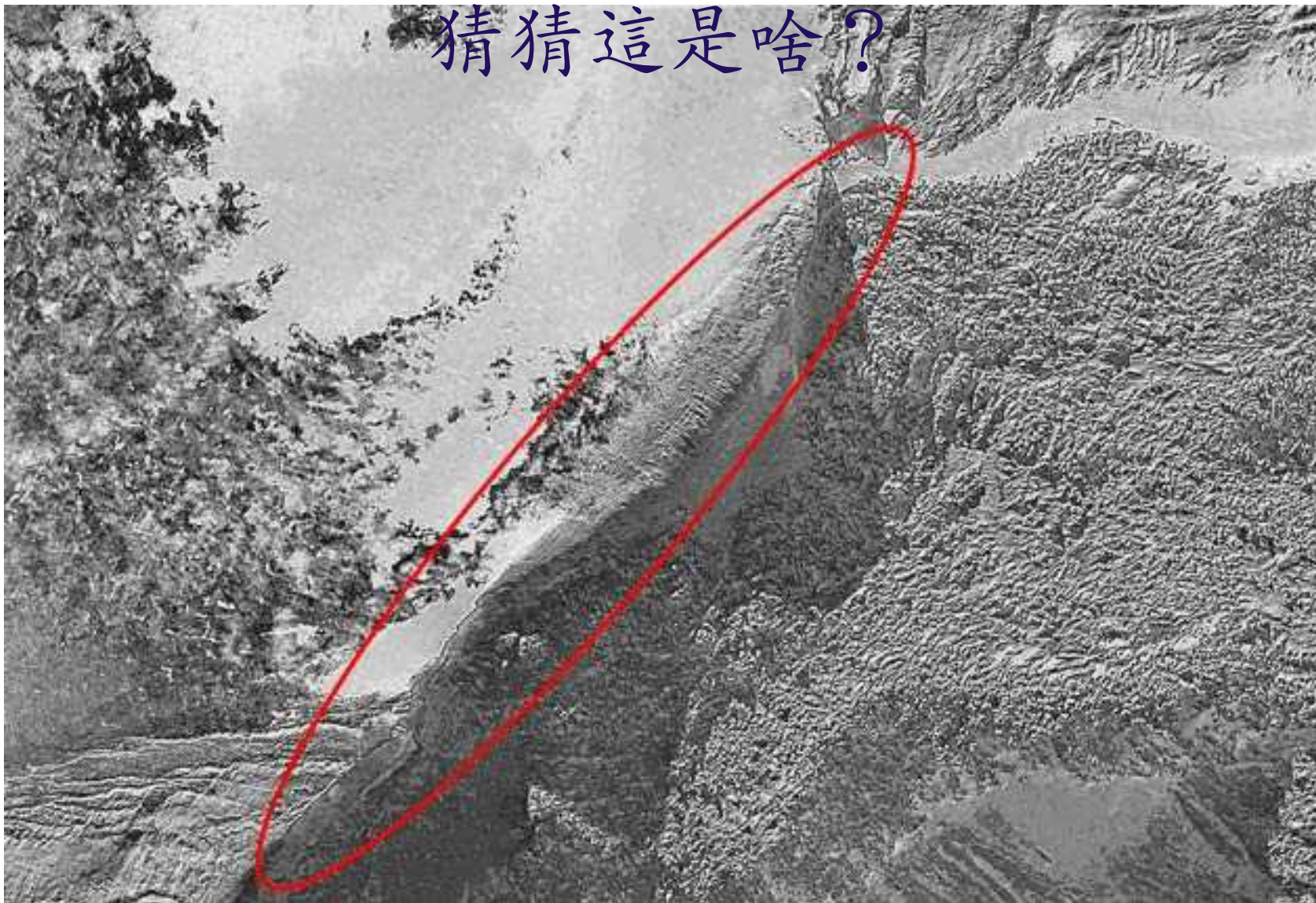
PSInSAR 分析



PSInSAR 分析



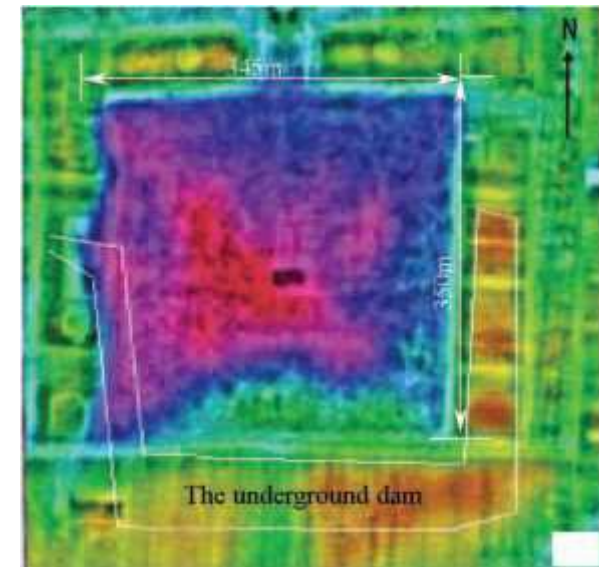
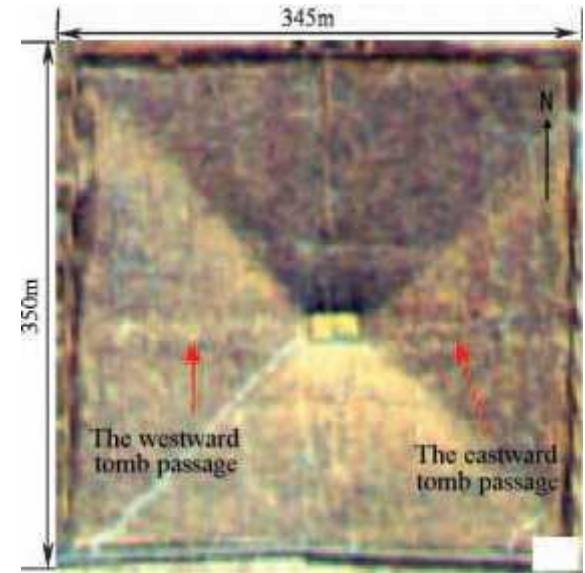
猜猜這是啥？



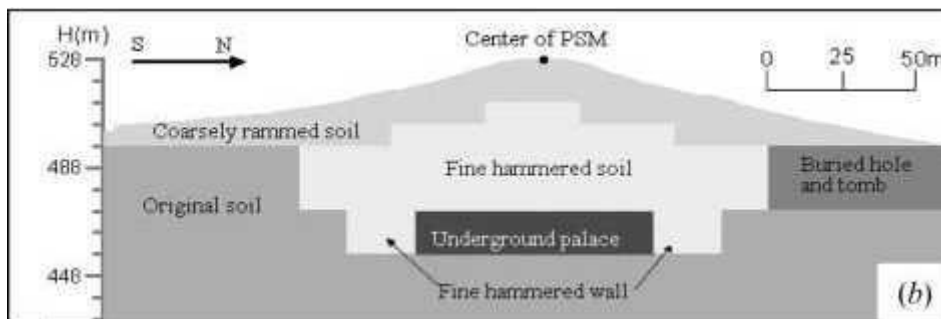
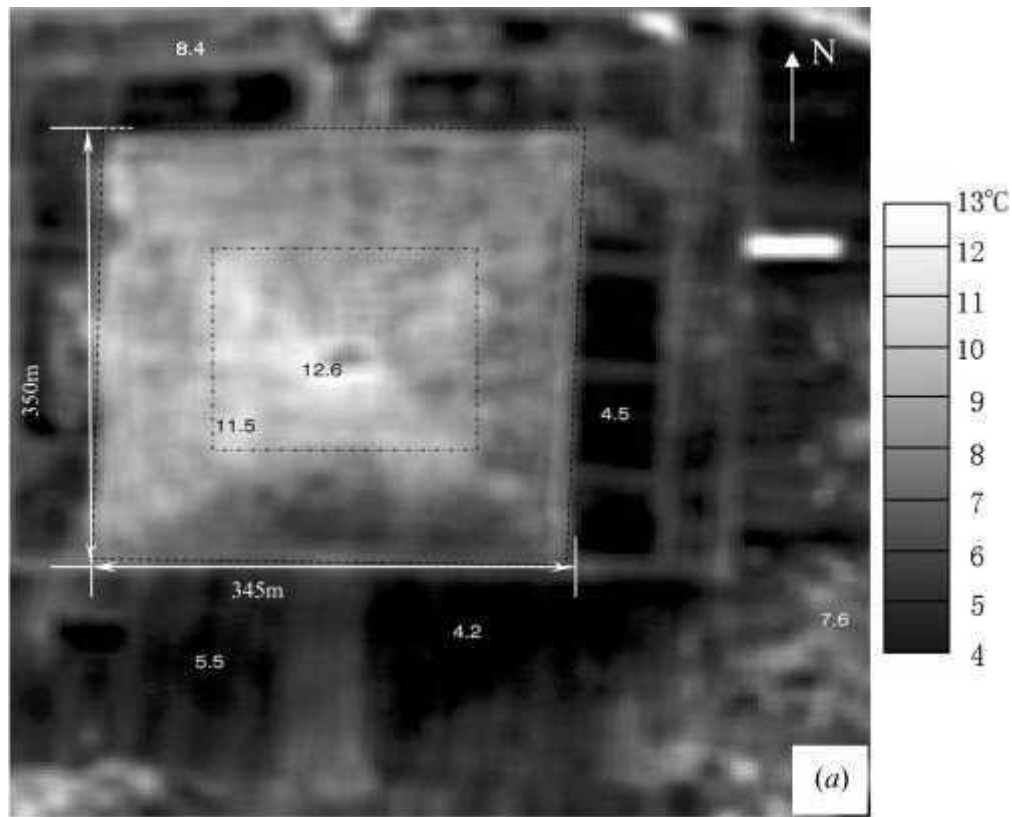
考古應用



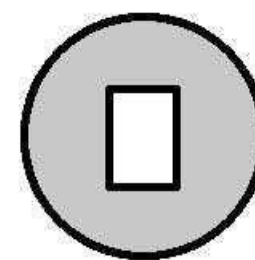
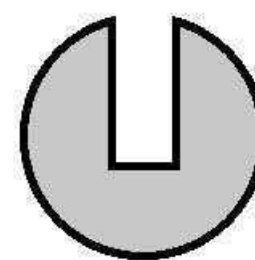
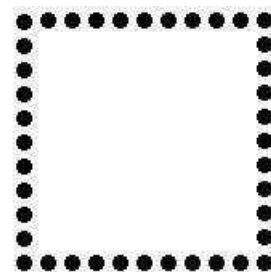
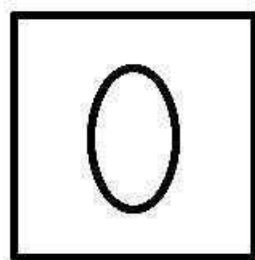
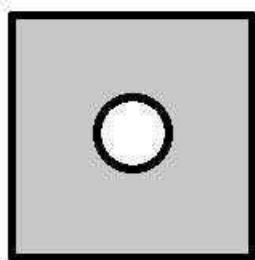
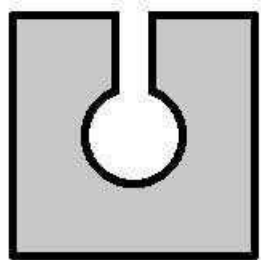
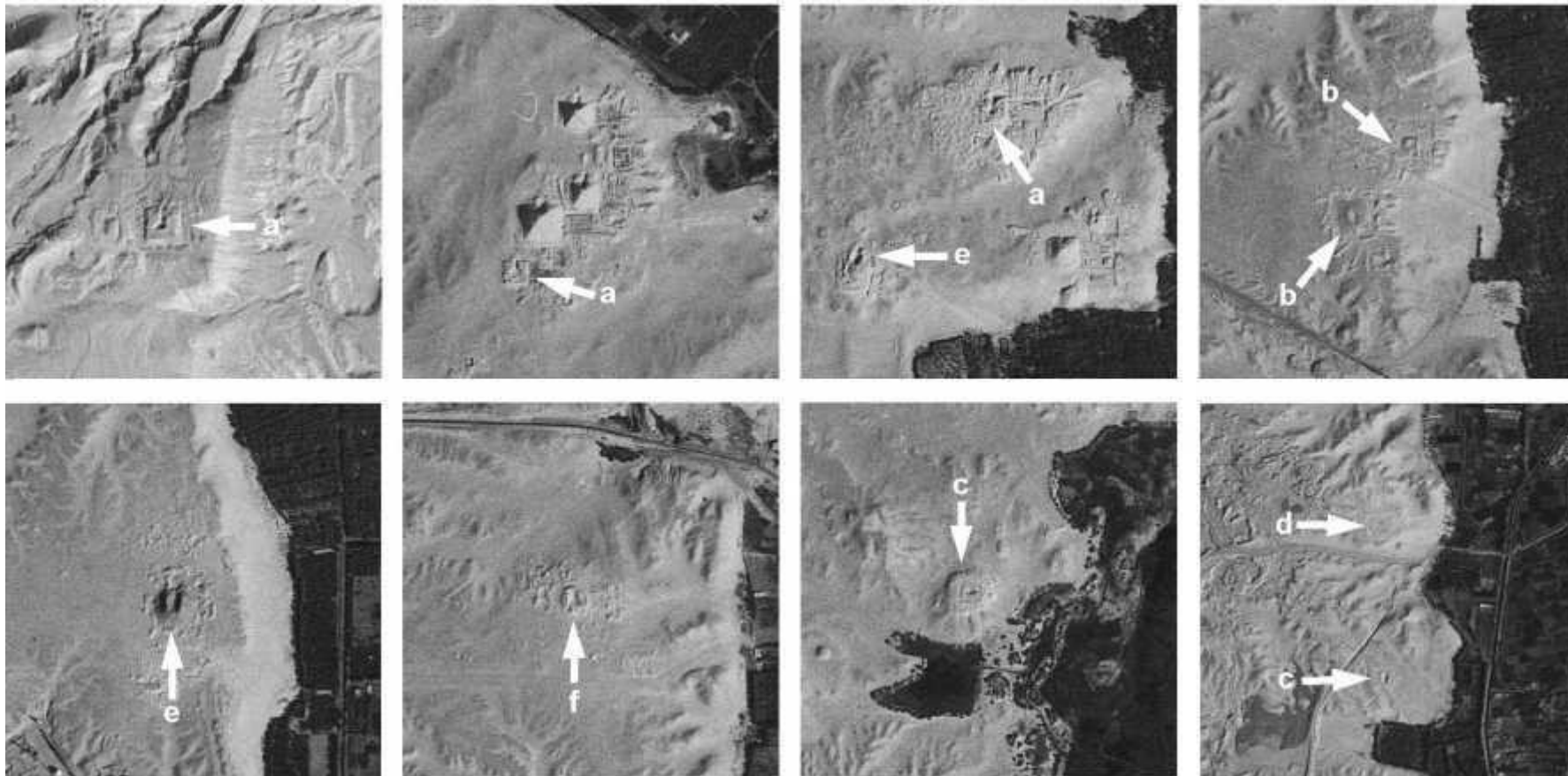
OMISSI Hyperspectral Image



(Source: Tan et al., 2006)



(Source: Tan et al., 2006)



遙測影像之限制

- 空間解析度
- 時間解析度
- 光譜解析度
- 輻射解析度
- 感測器特性
- 像幅大小
- 幾何準確度
 - 控制點, 數值地形模型, 隨機誤差, 人眼辨識, 等等
- 遙測影像之定位
 - 地理資訊來源
 - 地表資訊來源
 - 輔助資料