Safeguard CO2 Storage Site with Optical Satellite Remote Sensing

应用光学卫星遥感监测二氧化碳封存区的安全

Never Stand Still

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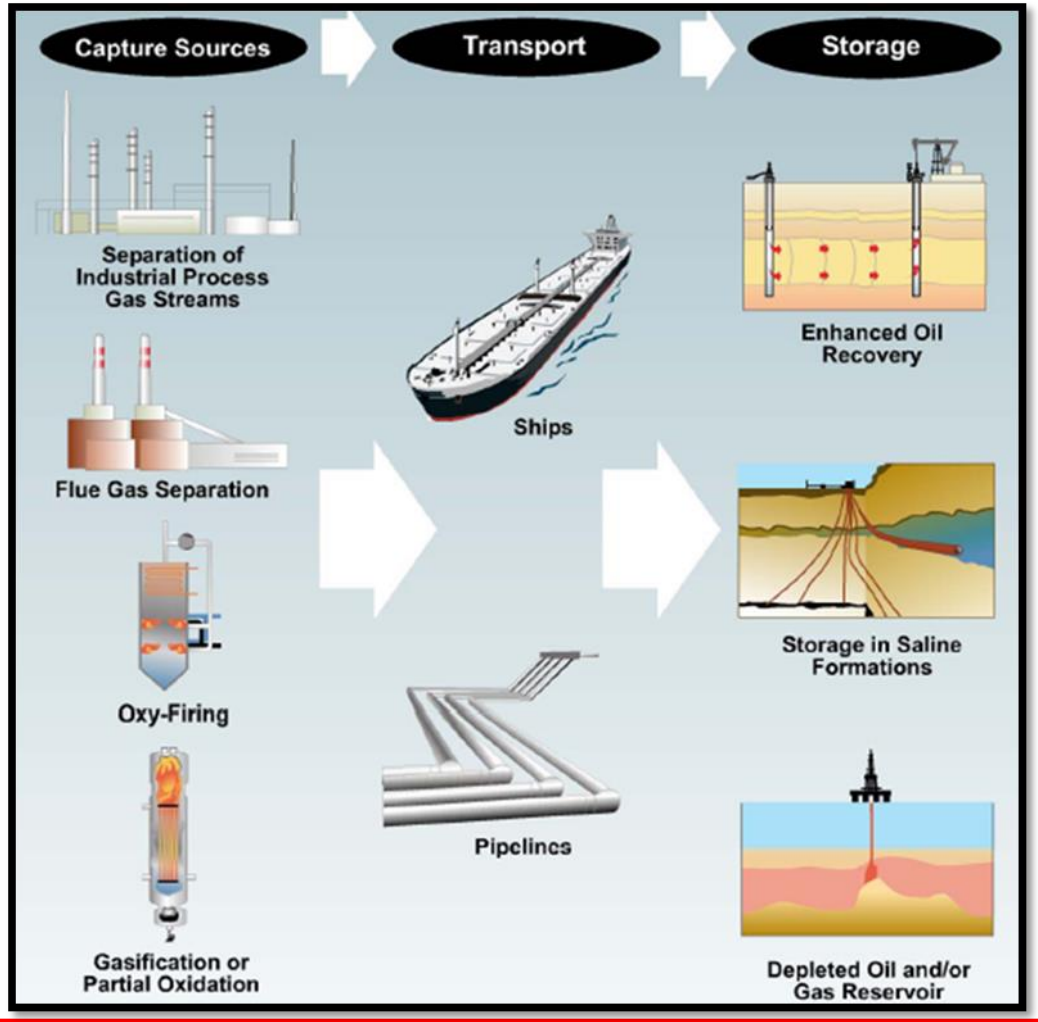
Outline 提纲

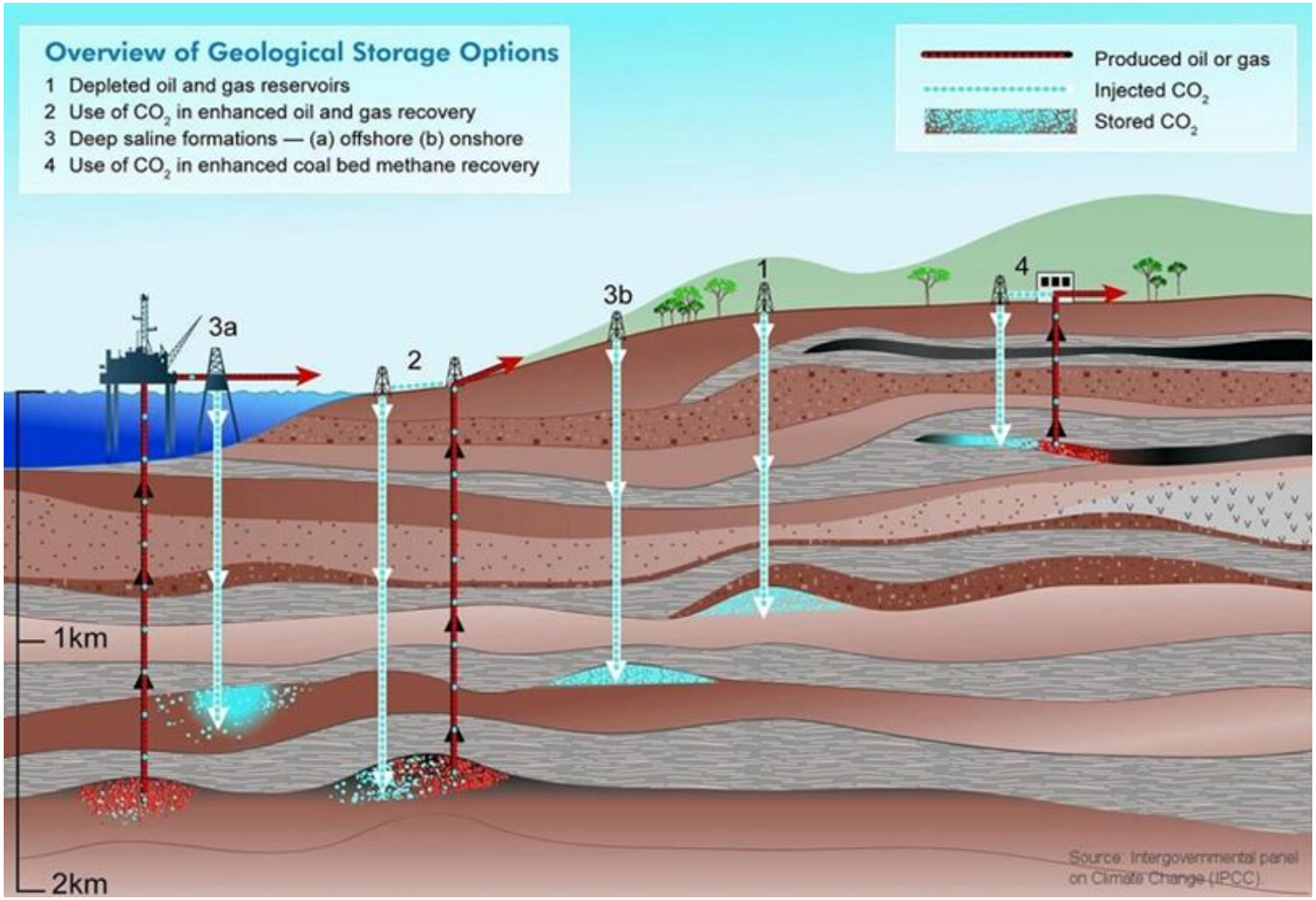
- CCS introduction CO2捕集与封存简介
- CO2 storage site monitoring CO2封存区监测技术
- Optical satellite monitoring – natural CO2 leakage analogue 光学卫星监测自然CO2泄漏
- Optical satellite monitoring – CO2 storage sites 光学卫星监测自然CO2封存区
- Concluding remarks 结语

CCS Process Chain（IEA, 2004）

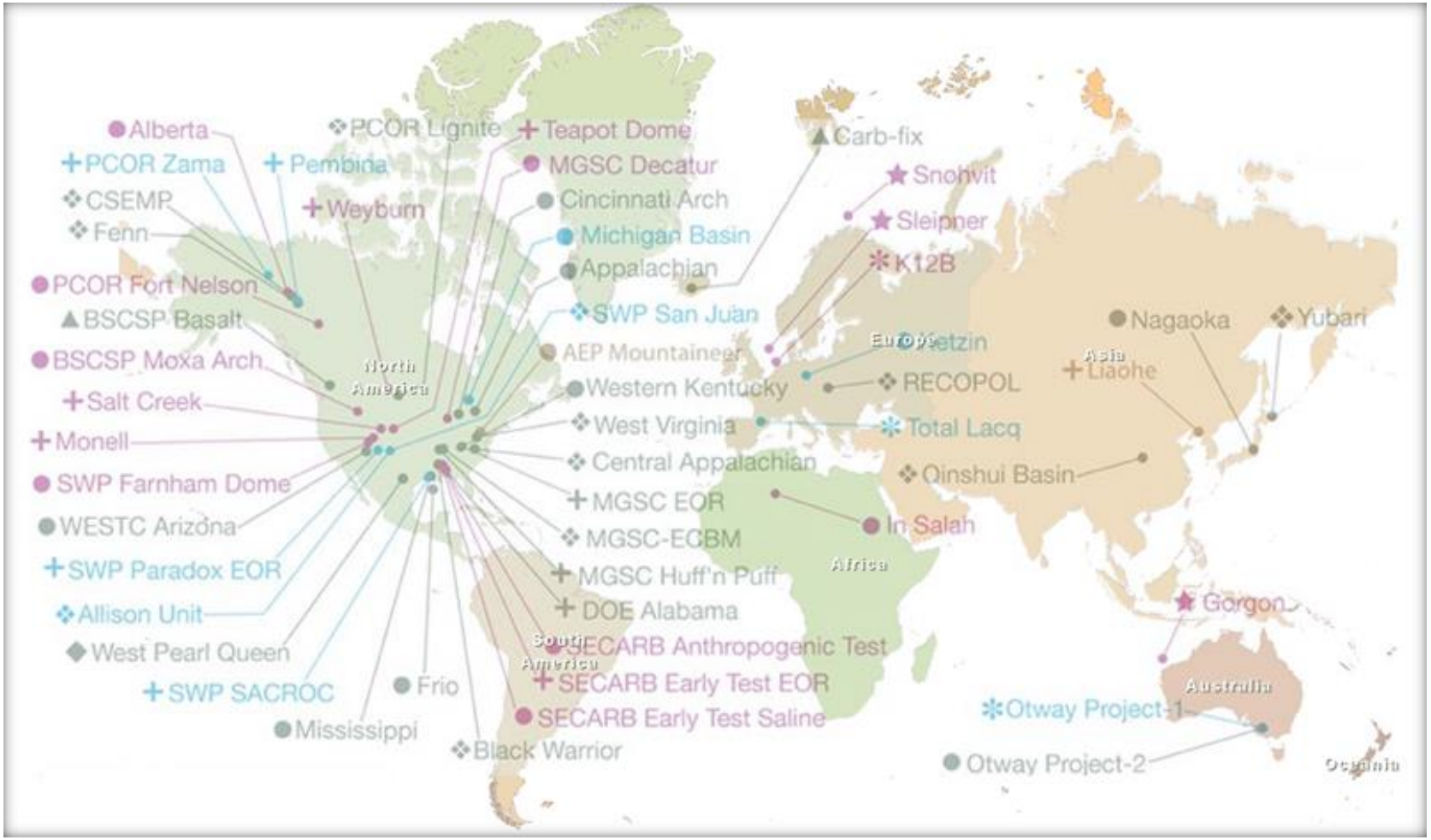
- CO2捕集与封存过程



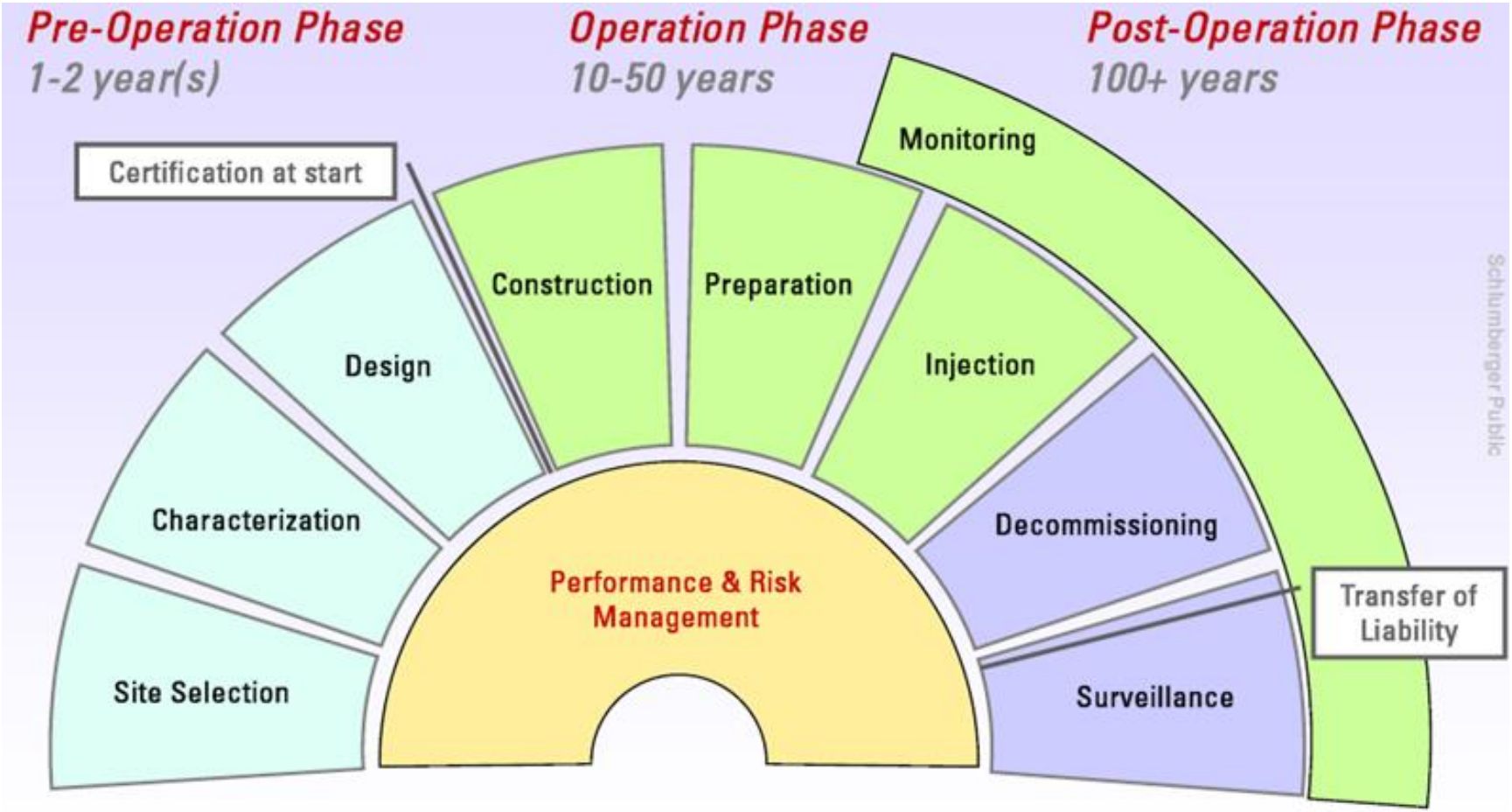
Overview of geological storage options (IPCC, 2005)
地质封存的途径



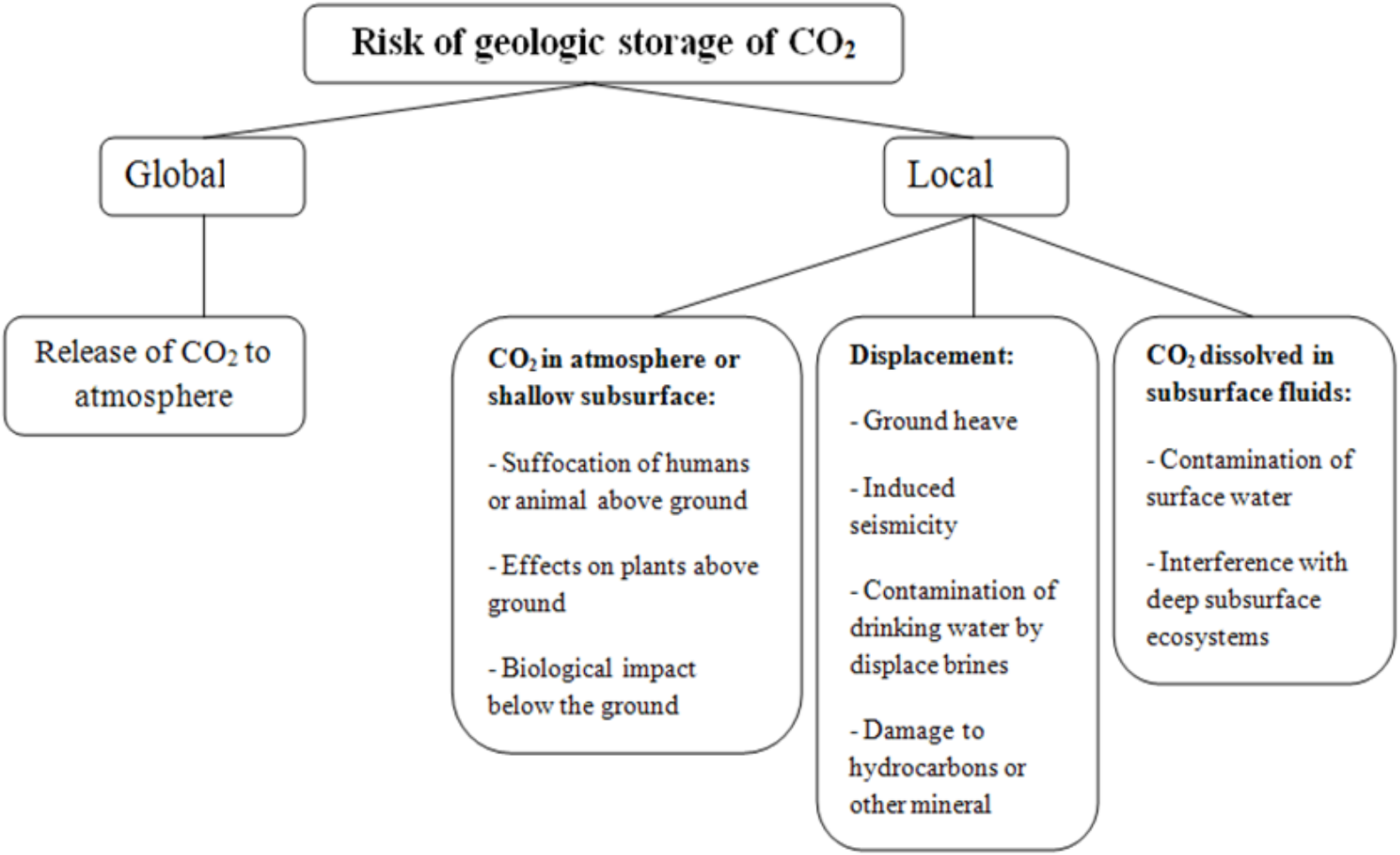
CO_2 storage operation across the world (CO2CRC, 2011)
全球CO2封存项目分布



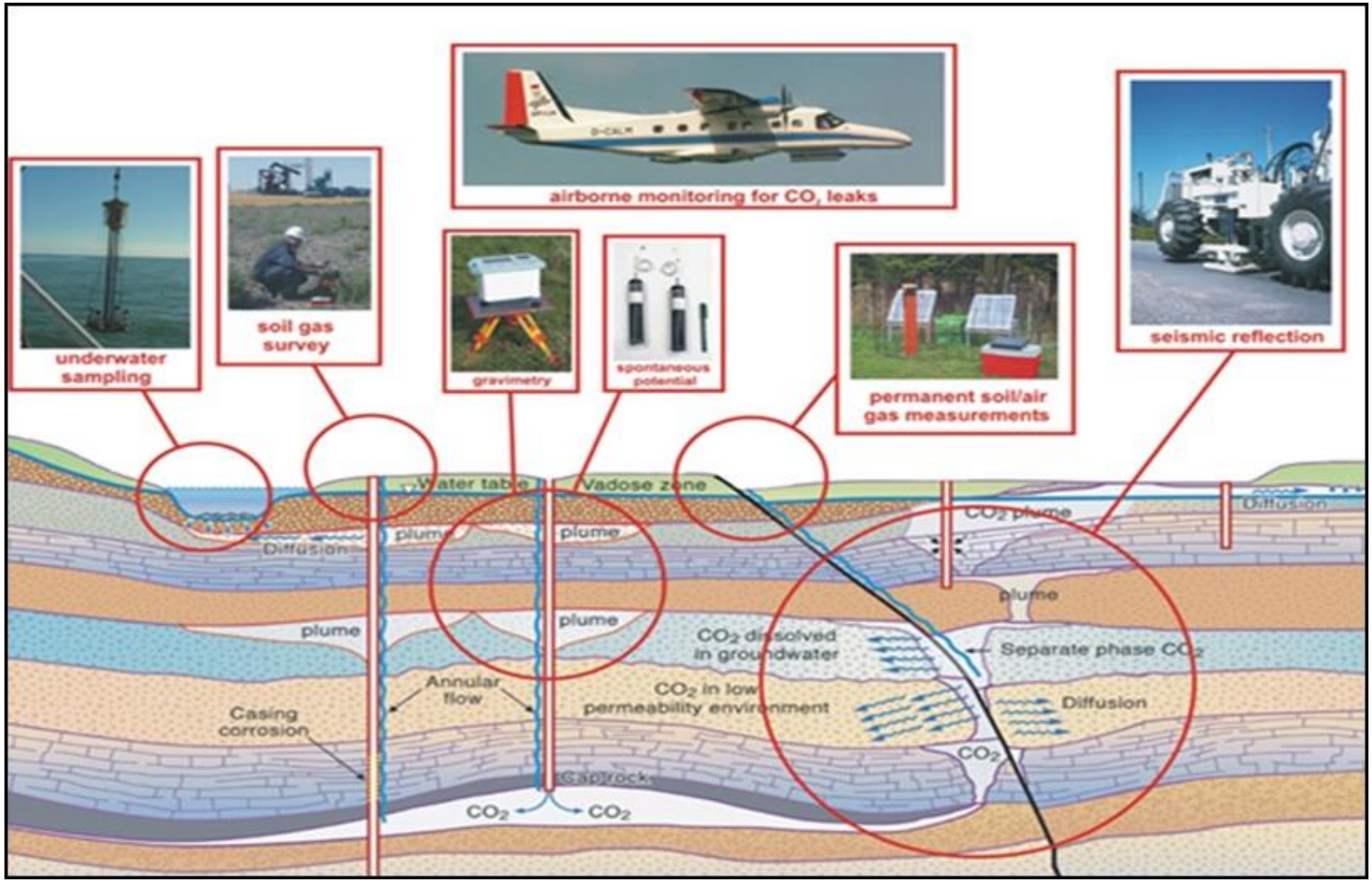
Geologic storage life cycle (Schlumberger, 2008)
地质封存项目周期



Risk of CO2 leakage (IPCC, 2005)
CO2泄漏的危害



CO2 monitoring and verification (BGS, 2009)
CO2监测和核查 - 现有技术



Satellite Optical Remote Sensing
光学卫星遥感

Key techniques developed
关键技术研发 - UNSW

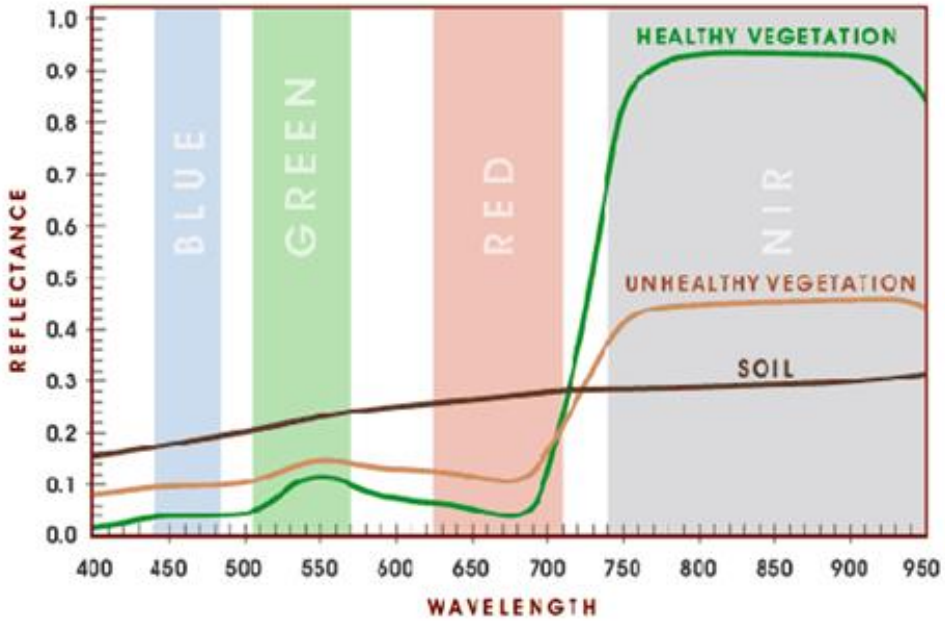
- Multispectral NDVI time series analysis
- Hyperspectral NDVI time series analysis

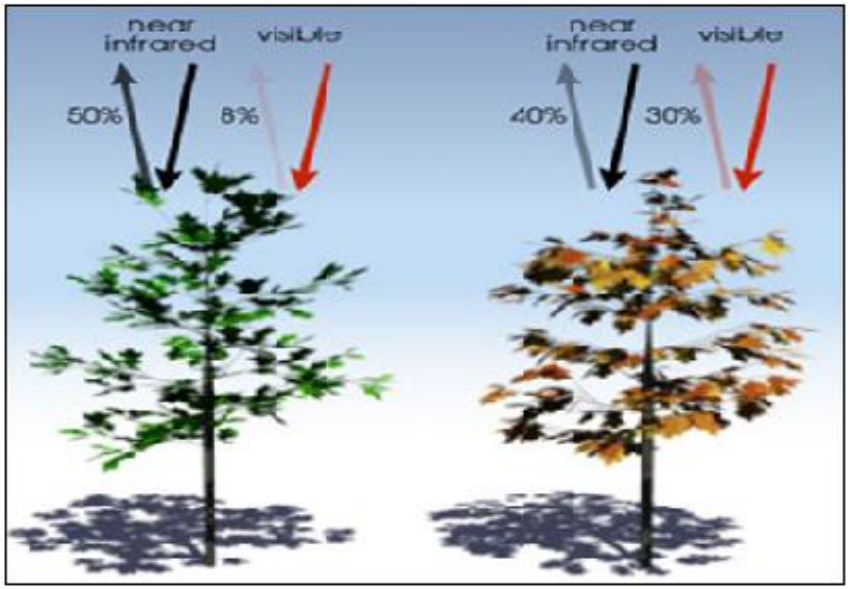
- 多光谱植被指数时间序列分析
- 高光谱植被指数时间序列分析

Selected results
代表性结果

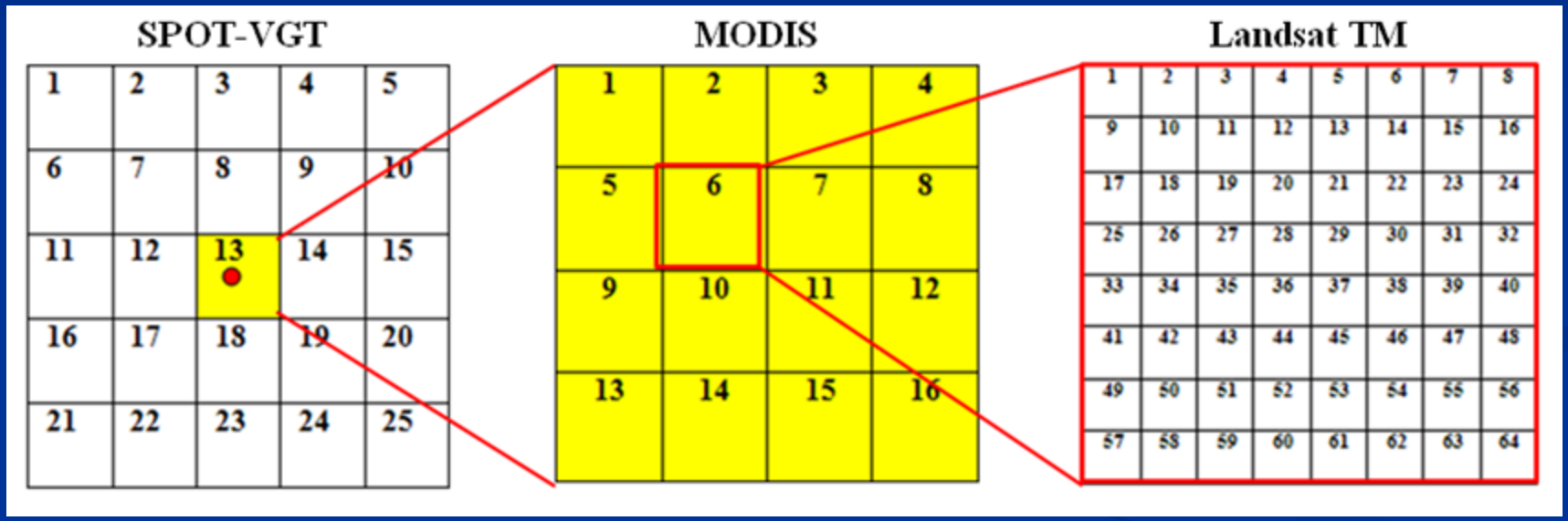
Principle – NDVI – Vegetation: distributed sensors
监测原理 – NDVI –“植被就是分布式CO2传感器”

- Normalized Difference Vegetation Index 归一化植被指数
- NDVI = (NIR – VIS)/ (NIR + VIS)
  - NIR = near-infrared light (0.76μm) 近红外
  - VIS = visible light (0.6μm) 可见光
- Close to +1 (e.g. 0.8 - 0.9) – dense and healthy vegetation
- Close to 0 – dead / no vegetation


HEALTHY VEGETATION
UNHEALTHY VEGETATION
SOIL
BLUE
GREEN
RED
NIR
REFLECTANCE
WAVELENGTH
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
400
450
500
550
600
650
700
750
800
850
900
950


near infrared
visible
50%
8%
near infrared
visible
40%
30%

Satellite Optical Remote Sensing
光学卫星遥感 – 高、中、低结合



Low (1,000m) Medium (250m) High (30m)

Image resolution

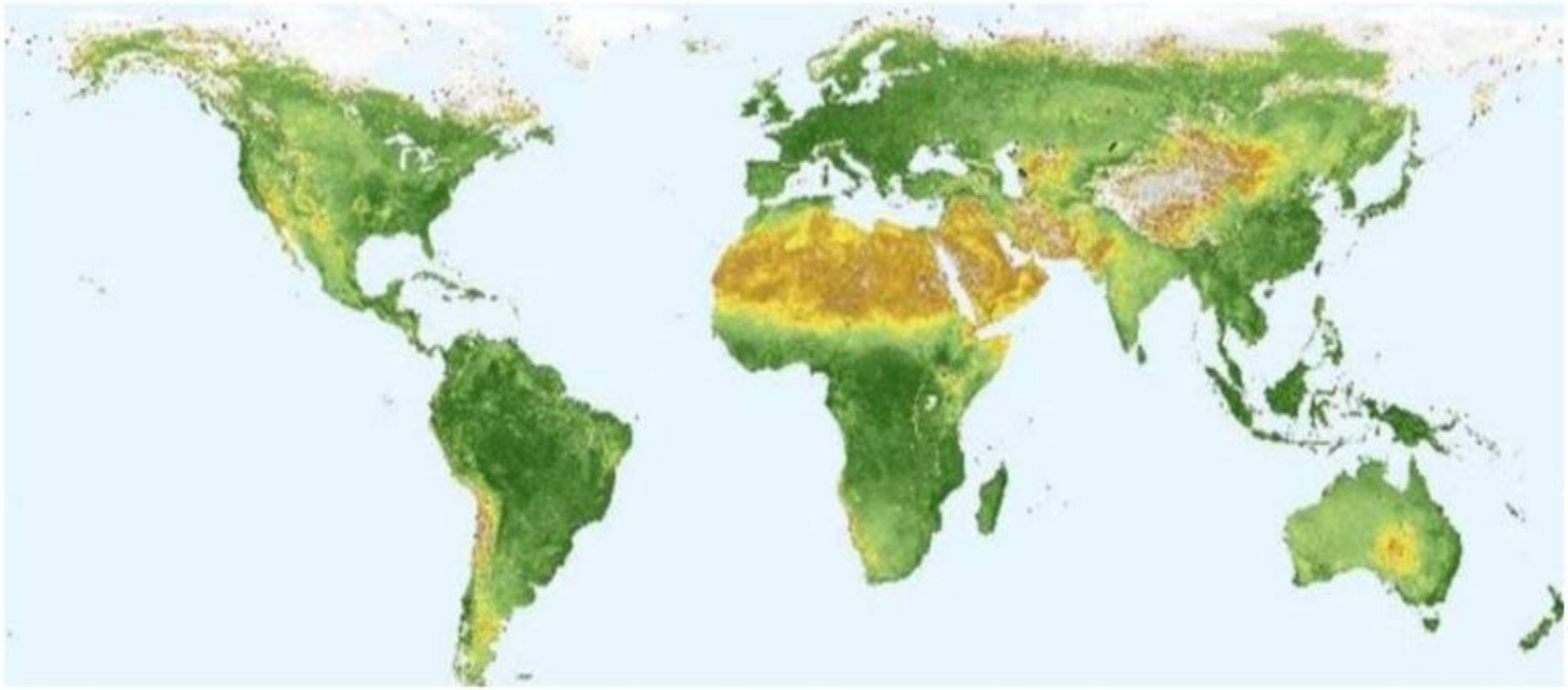
SPOT-VGT S10 法国SPOT卫星

- The French Centre National d'Etudes Spatiales (CNES), in cooperation with Belgium and Sweden

- Two Vegetation instruments on SPOT satellites
  - Vegetation 1 on SPOT 4
  - Vegetation 2 on SPOT 5

- 10-day NDVI synthesis from SPOT Vegetation (CNES website, 2009)

10-day NDVI synthesis from SPOT vegetation (May 2009, CNES)



SPOT-VGT 4 & 5

SPOT卫星参数

Satellite	SPOT-VGT 4	SPOT-VGT 5
Altitude	822 km	822 km
Inclination	98.7 degrees	98.7 degrees
Orbit	sun-synchronous polar	sun-synchronous polar
Period of revolution	101 minutes	101 minutes
Swath width	60 x 60 to 80 km	60 x 60 to 80 km
Repeat cycle	1 day	1 day
Band	B0, B2, B3 and MIR	B0, B2, B3 and MIR
Spectral band	0.43 – 0.47µm (blue) 0.61 – 0.68 µm (red) 0.79 – 0.89 µm (near IR) 1.58 – 1.75 µm (mid-IR)	0.43 – 0.47µm (blue) 0.61 – 0.68 µm (red) 0.79 – 0.89 µm (near IR) 1.58 – 1.75 µm (mid-IR)
Period	24/03/1998 – still operational	04/05/2002 – still operational

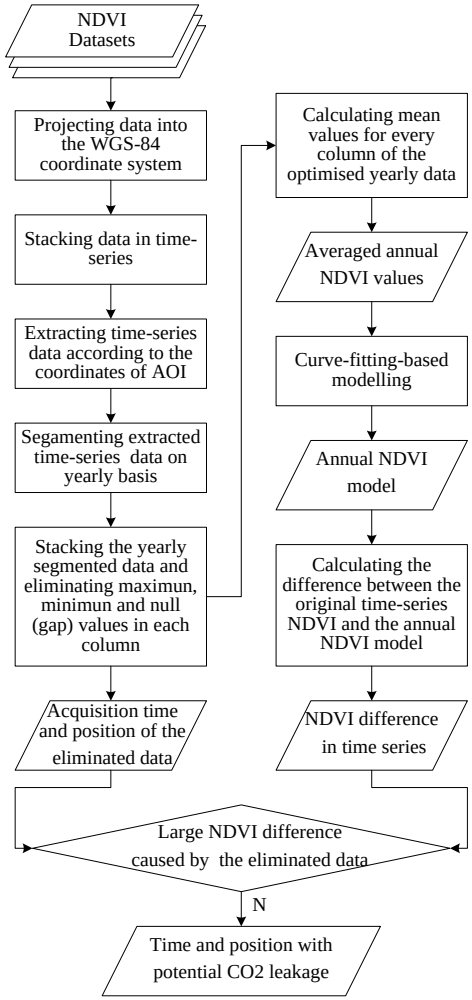
MODIS

- Onboard the Terra (EOS AM) and Aqua (EOS PM) satellites
- 36 spectral bands ranging in wavelength from 0.4µm to 14.4µm
- Resolution of 250m
- 8 and 16 day MODIS NDVI composite images

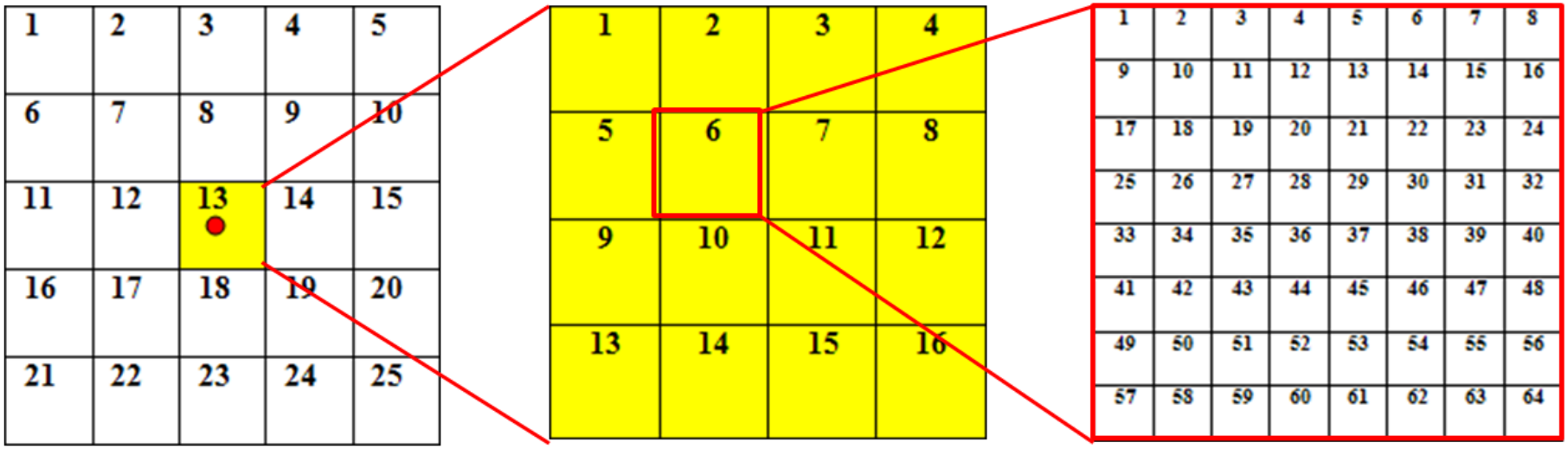
Landsat-5 Thematic Mapper (TM)　Landsat-5卫星参数

Parameters	Landsat-5 TM
Altitude	705 km
Orbit	Polar, sun synchronous
Inclination	98.2 degrees
Revisit cycle	16 days
Resolution	30 meter (TM)
Swath width	185 km
Spectral band	Band 1 : 0.45 - 0.52 (blue) Band 2 : 0.52 - 0.60 (green) Band 3 : 0.60 - 0.69 (red) Band 4 : 0.77 - 0.90 (near infrared) Band 5 : 1.55 - 1.75 (shortwave infrared) Band 6 : 10.40 - 12.50 (thermal infrared) Band 7 : 2.08 - 2.35 (reflective infrared)

Flowchart of GEOS-NDVI time-series analysis
NDVI 时间序列分析流程图（UNSW-GEOS）



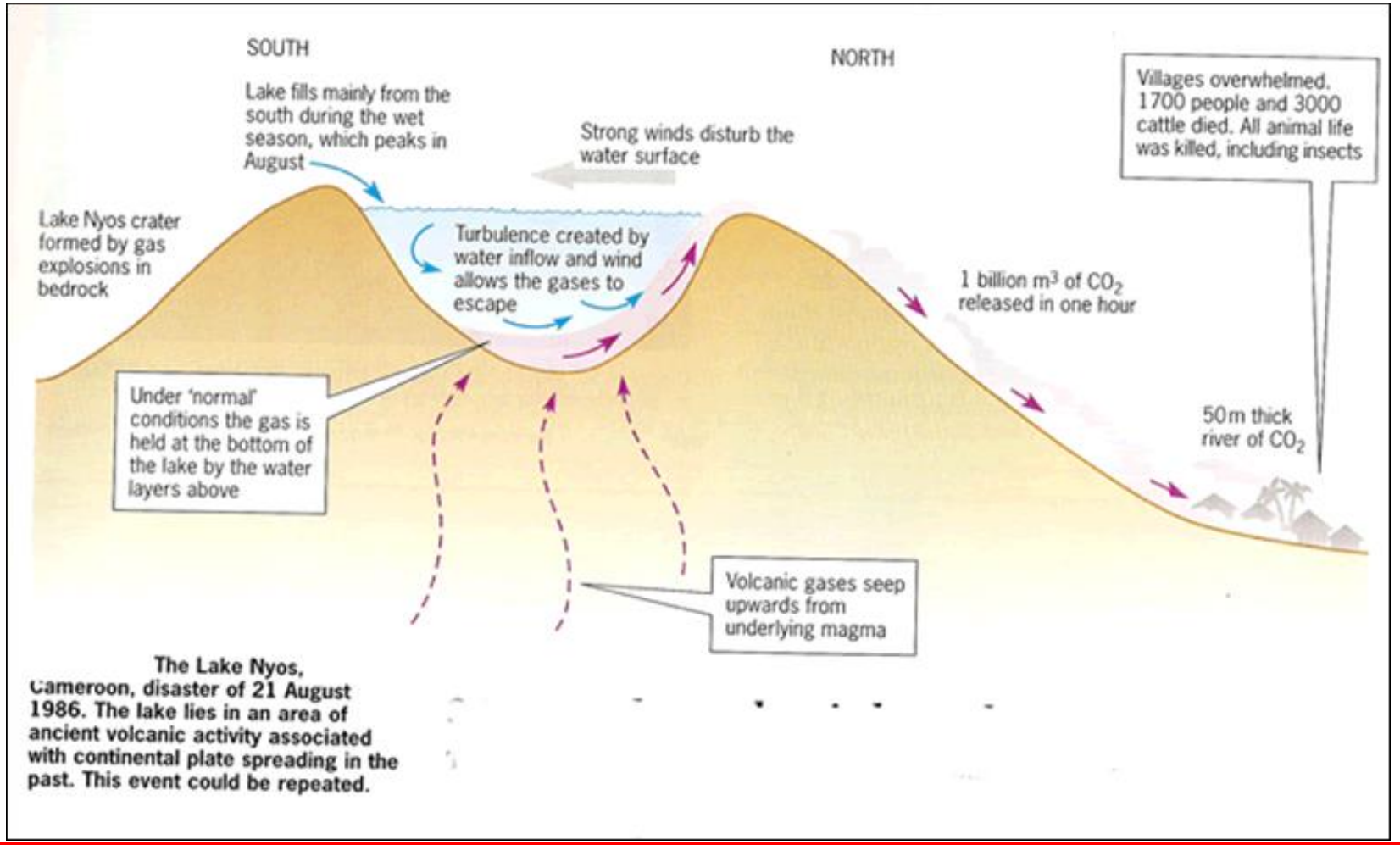
Nested: SPOT, MODIS and Landsat 多卫星结合



Natural analogue 自然CO2泄漏

- The consequences of CO2 eruptions from geologic reservoirs, such as volcanic and geothermal structures, can be devastating
- Lake Nyos, Cameroon
- Mammoth Mountain, California, USA

CO2 disaster at Lake Nyos, Cameroon, 21 August 1986 喀麦隆

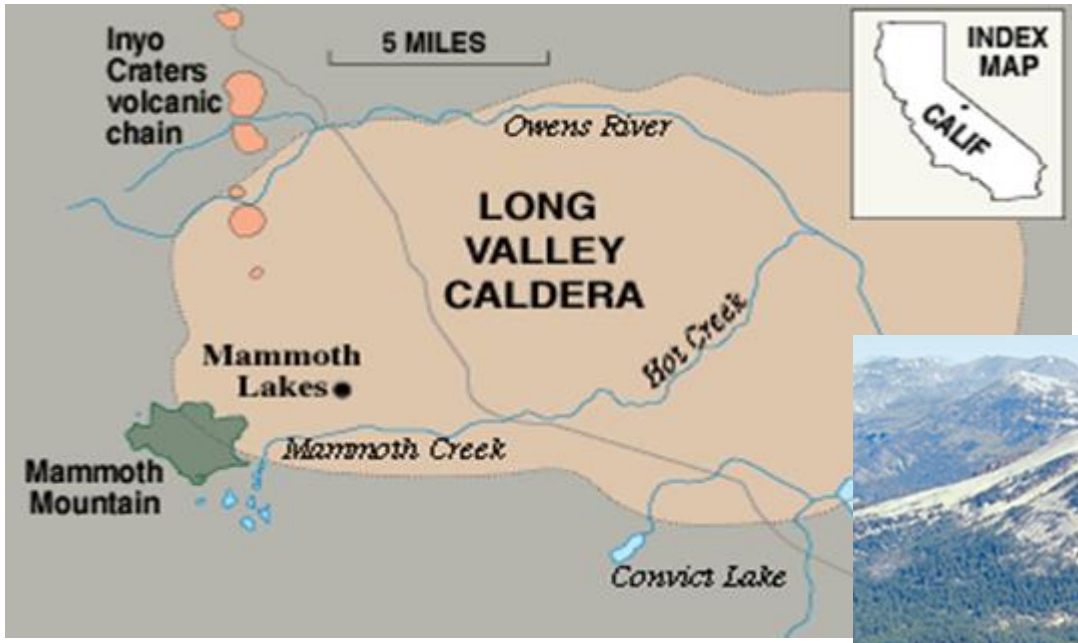


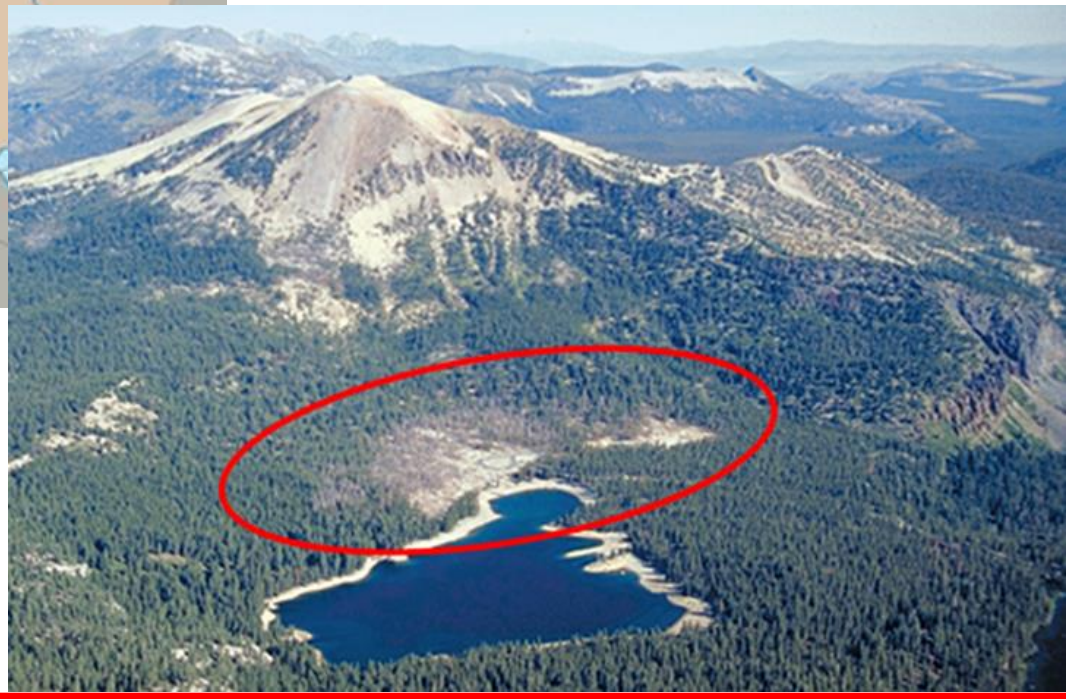
The Lake Nyos, Cameroon, disaster of 21 August 1986. The lake lies in an area of ancient volcanic activity associated with continental plate spreading in the past. This event could be repeated.

A chain of volcanoes

火山群

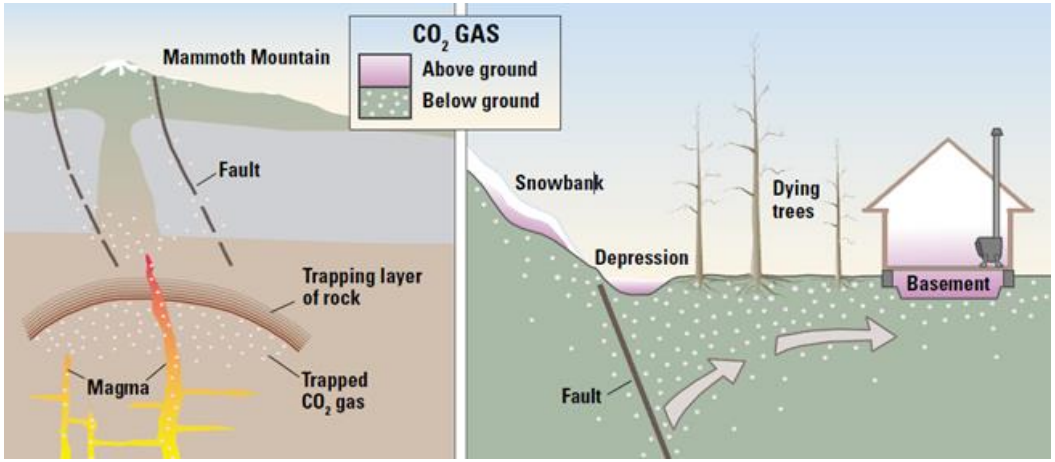
Mammoth Mountain, California, USA 美国加利福尼亚猛犸山

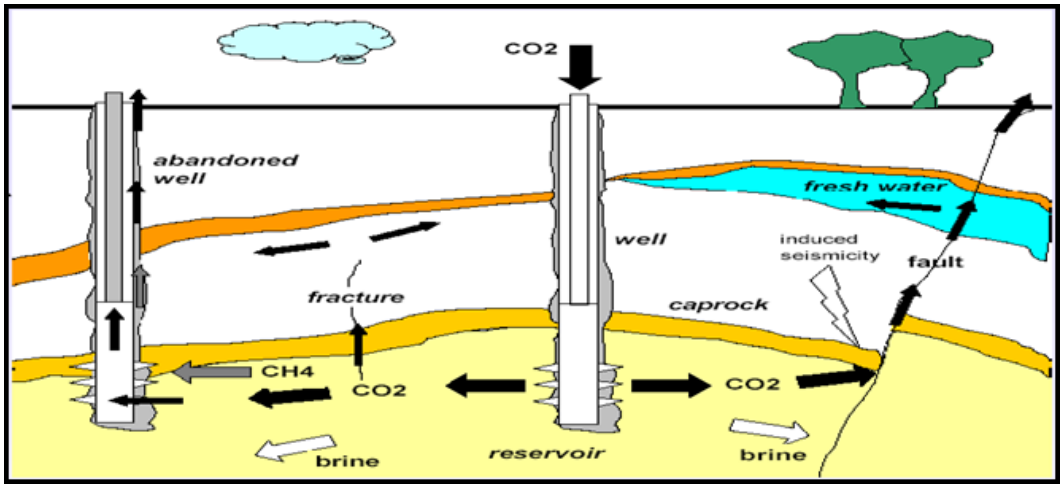




Natural leakage model (USGS, 2004) vs CO2 storage leakage model (Damen et al., 2005)

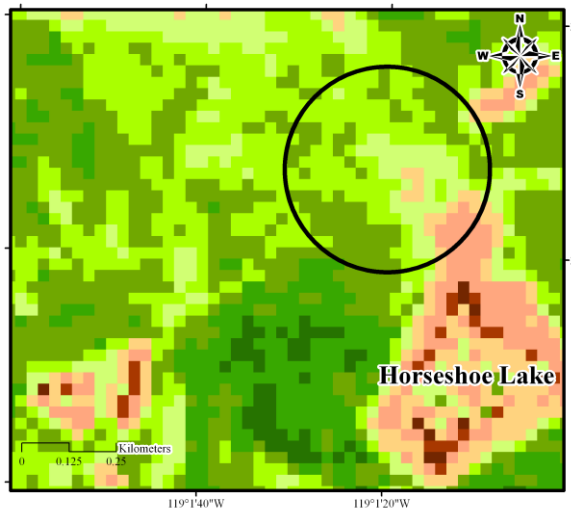
- CO2泄漏解译模型

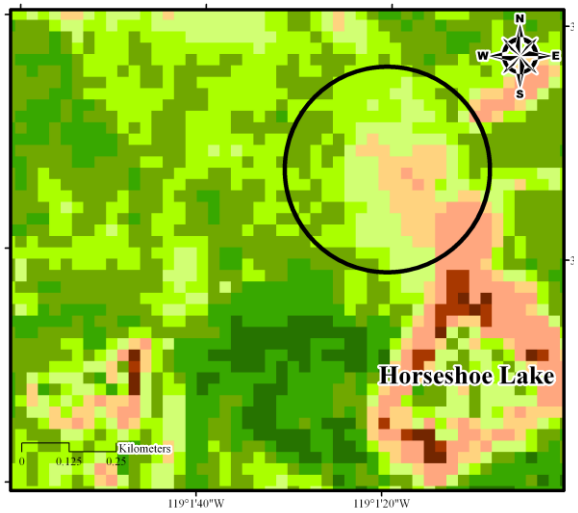


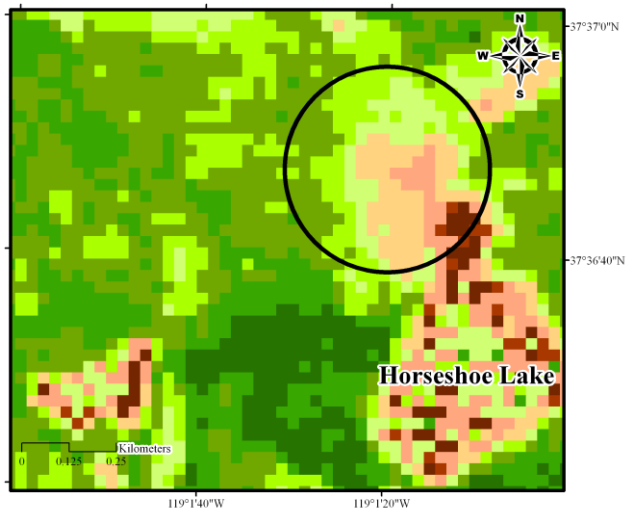


Landsat 5 TM result

猛犸山结果



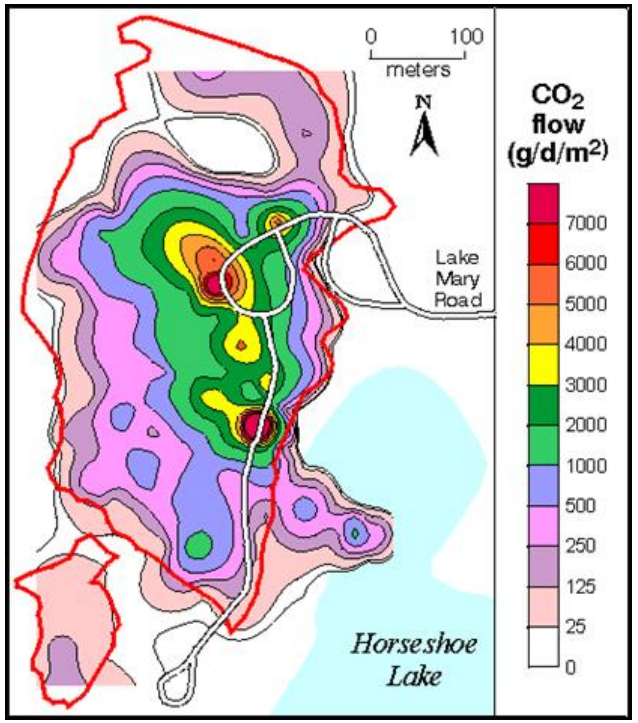




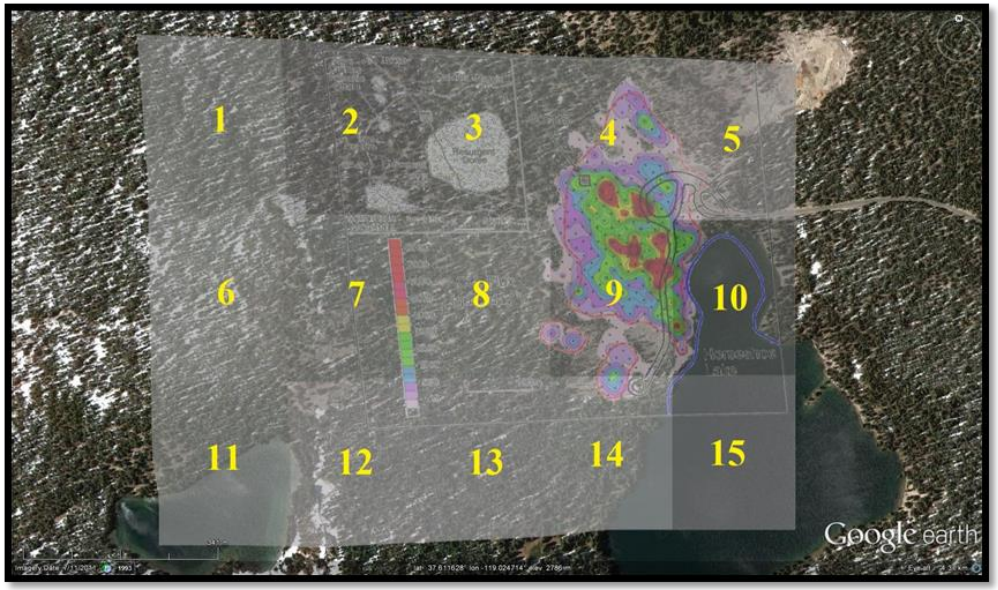
- 4th September 1988
- 5th September 1994
- 1st April 2010

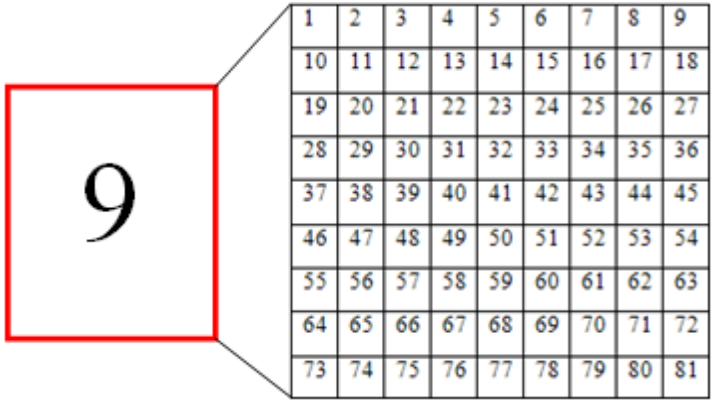
CO2 concentration – USGS field survey
美国地质调查局实地调查

USGS tree kill maps at Mammoth mountain CA, USA

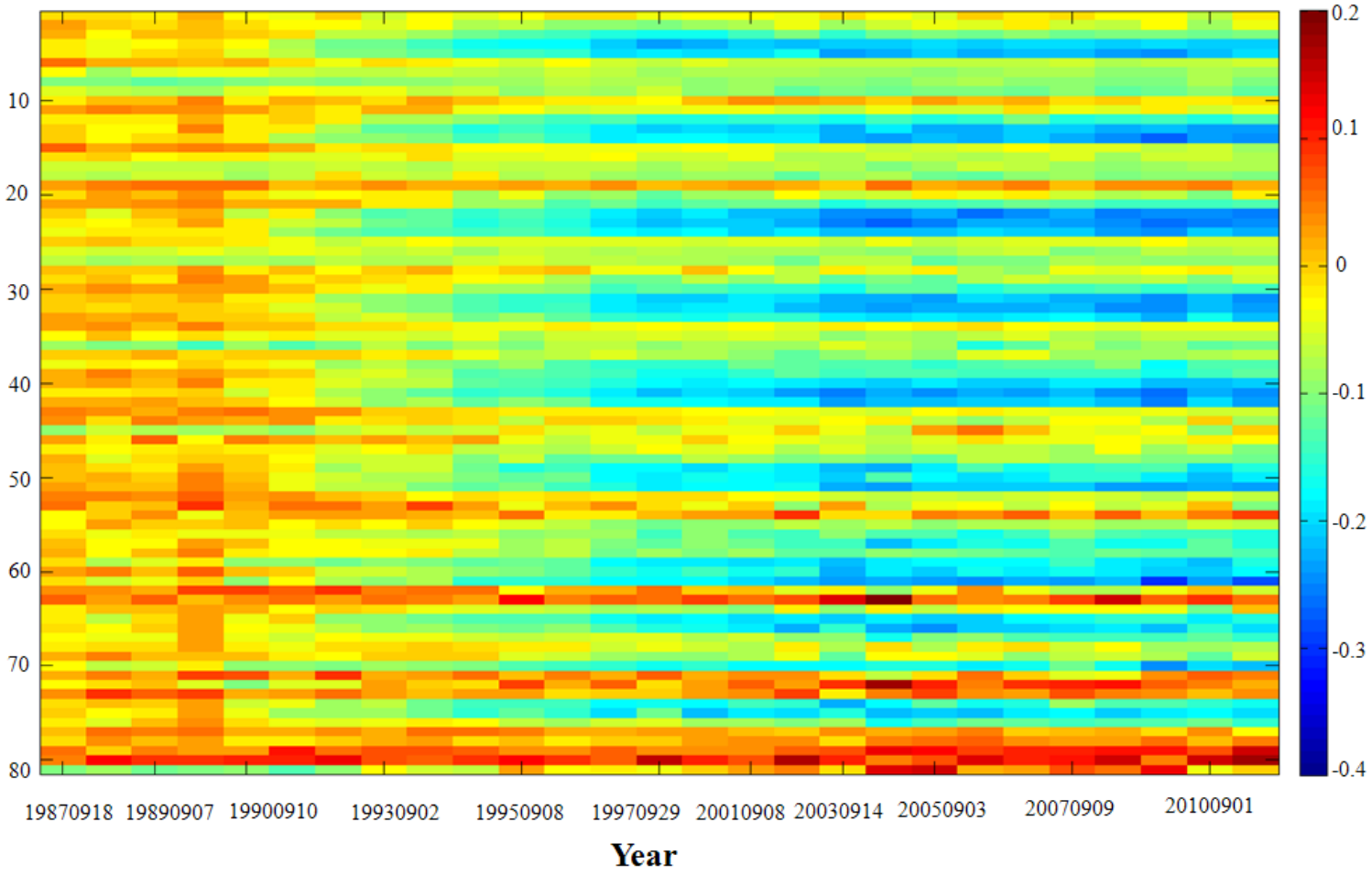


MODIS to Landsat





Mammoth Mountain NDVI time series result - Landsat

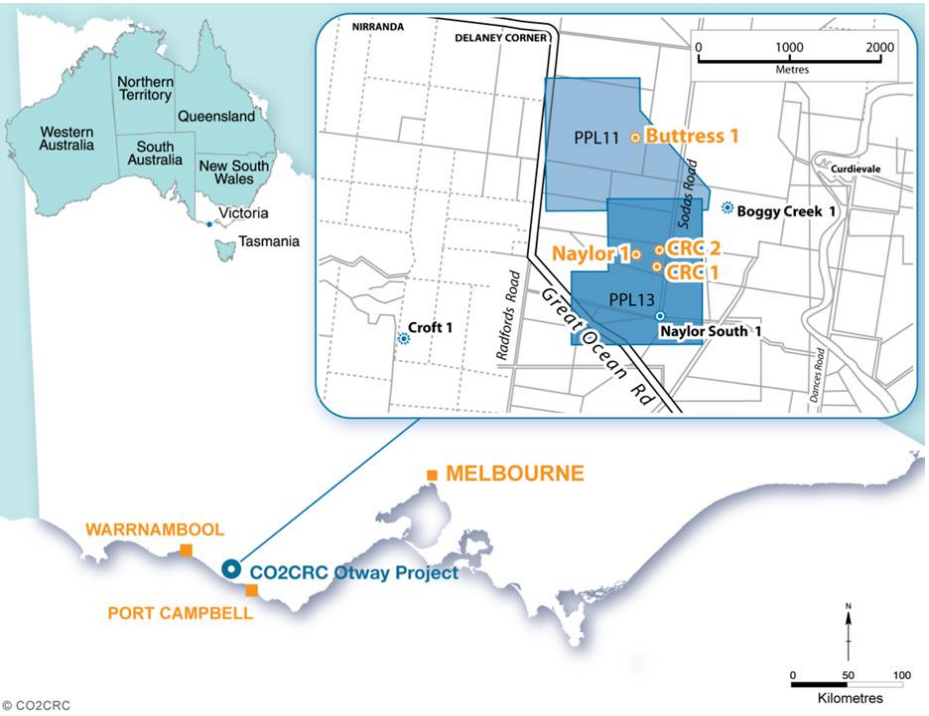


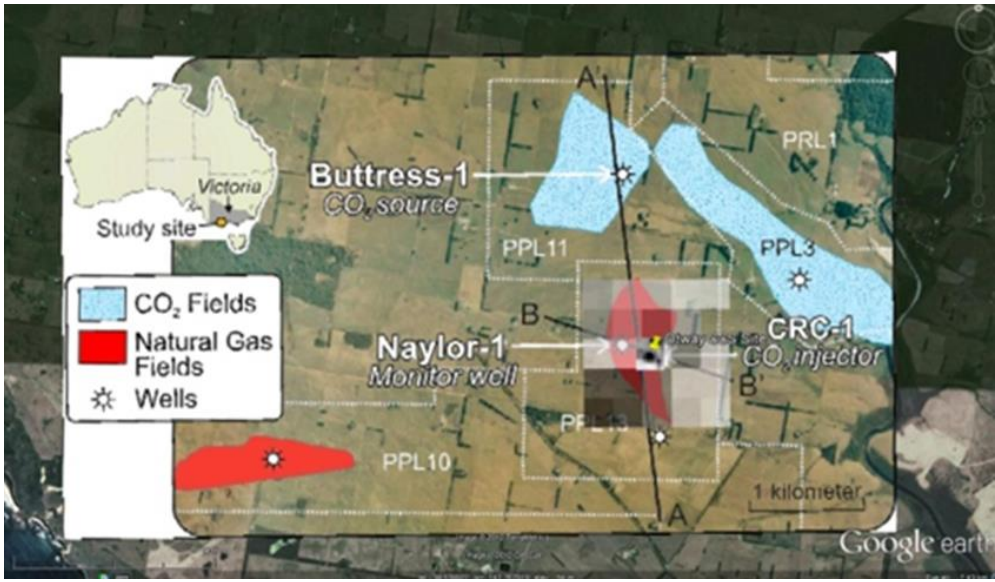
CCS sites　　CO2封存监测试验区

- Australia　　澳大利亚
  - Otway　　奥特维
  - Iona　　埃文娜
- China　　中国
  - Ordos　　鄂尔多斯
  - Liulin　　柳林

CO2CRC Otway site

澳大利亚CO2封存区





Construction phase at Otway CO2CRC
施工阶段

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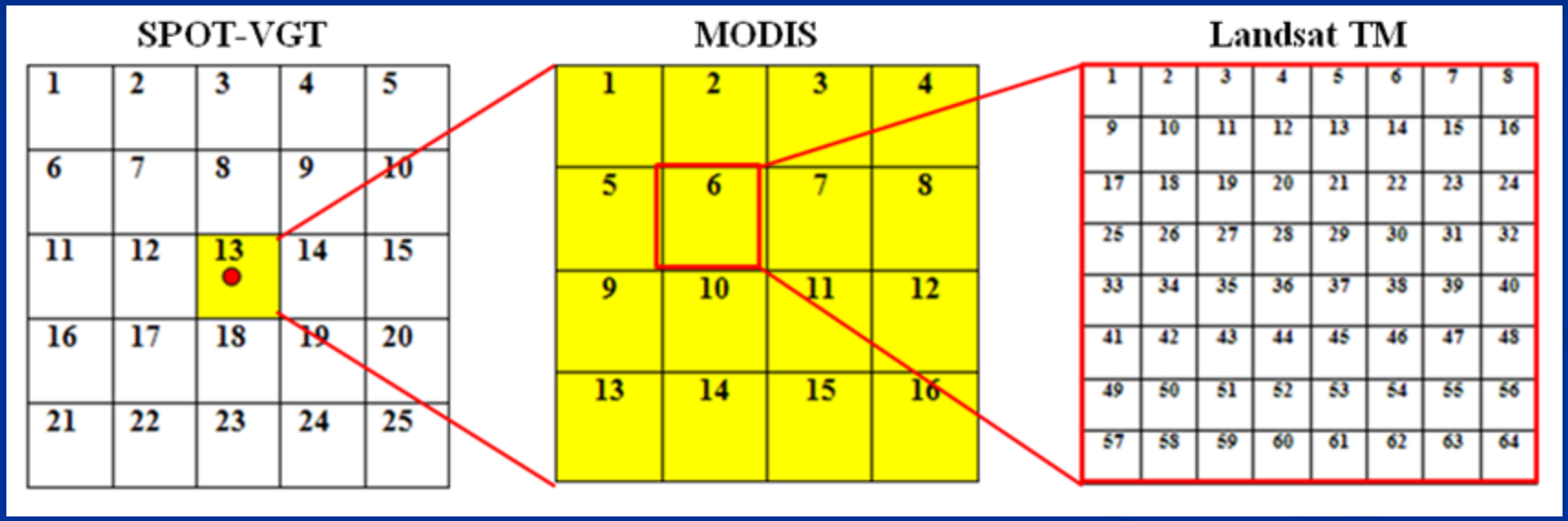
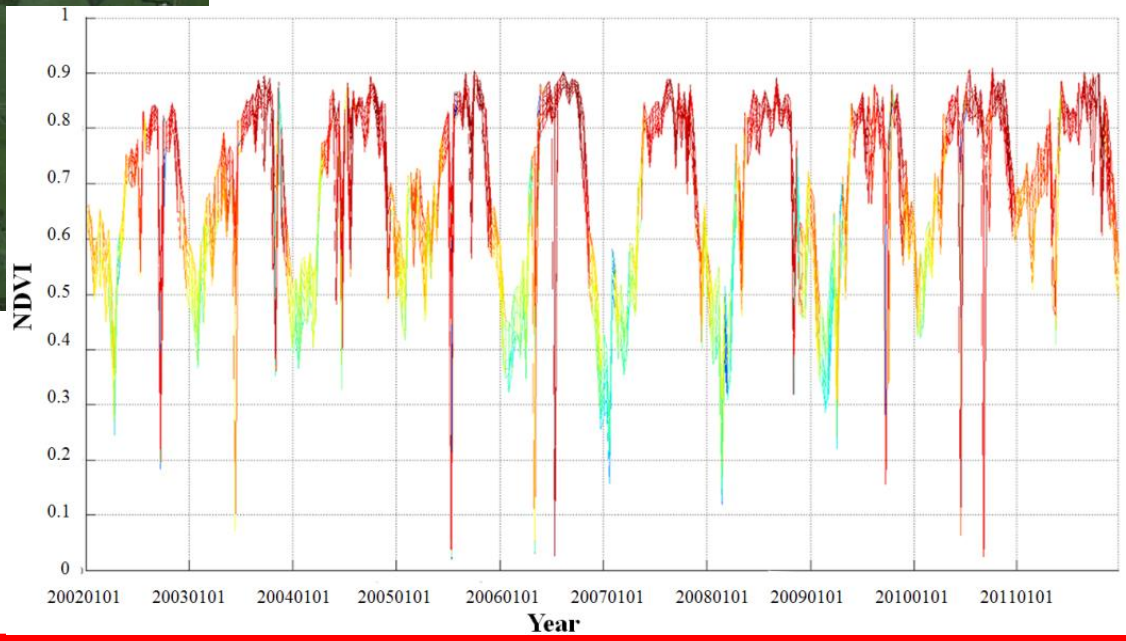


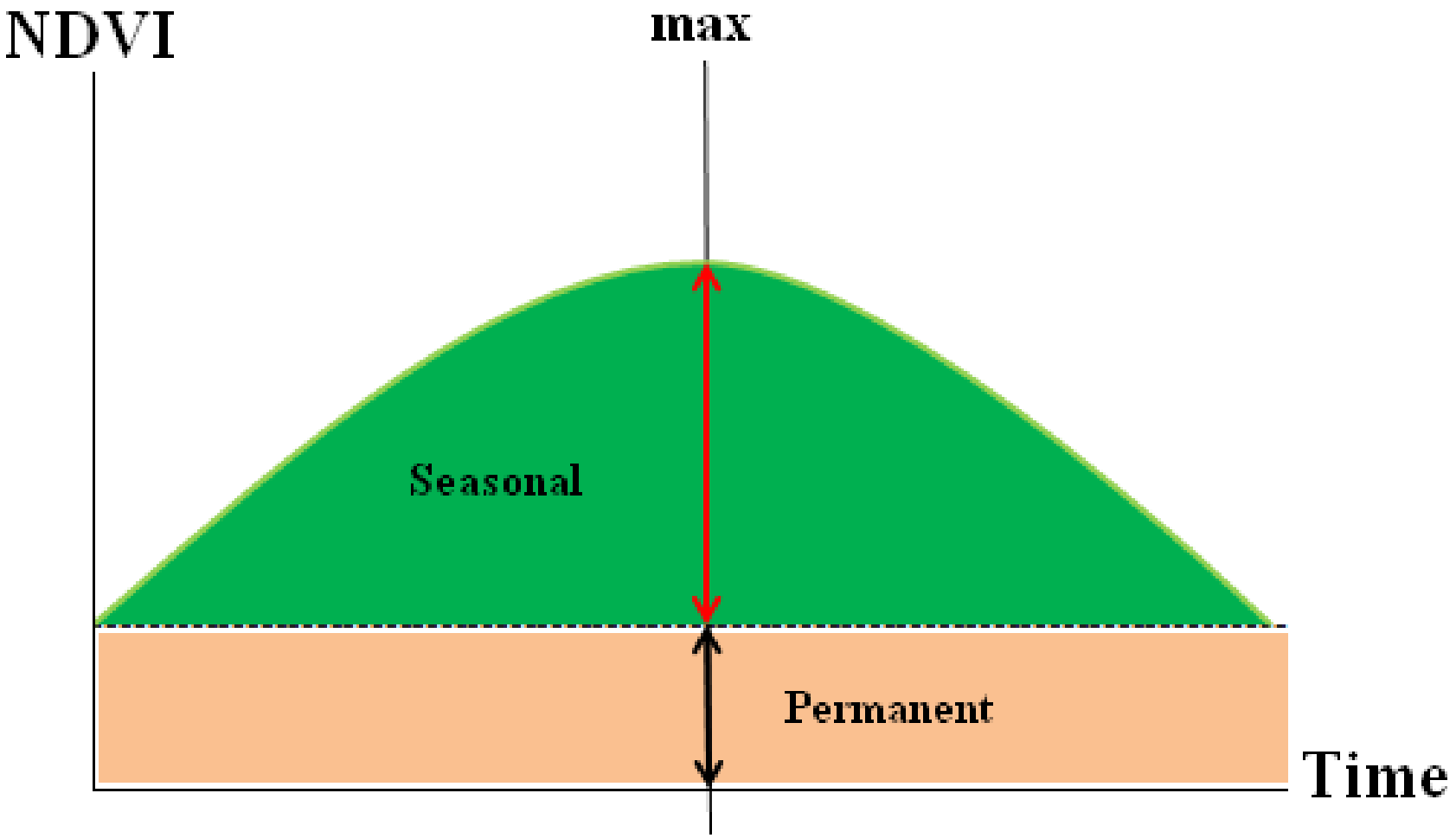
Low (1,000m) Medium (250m) High (30m)

Image resolution

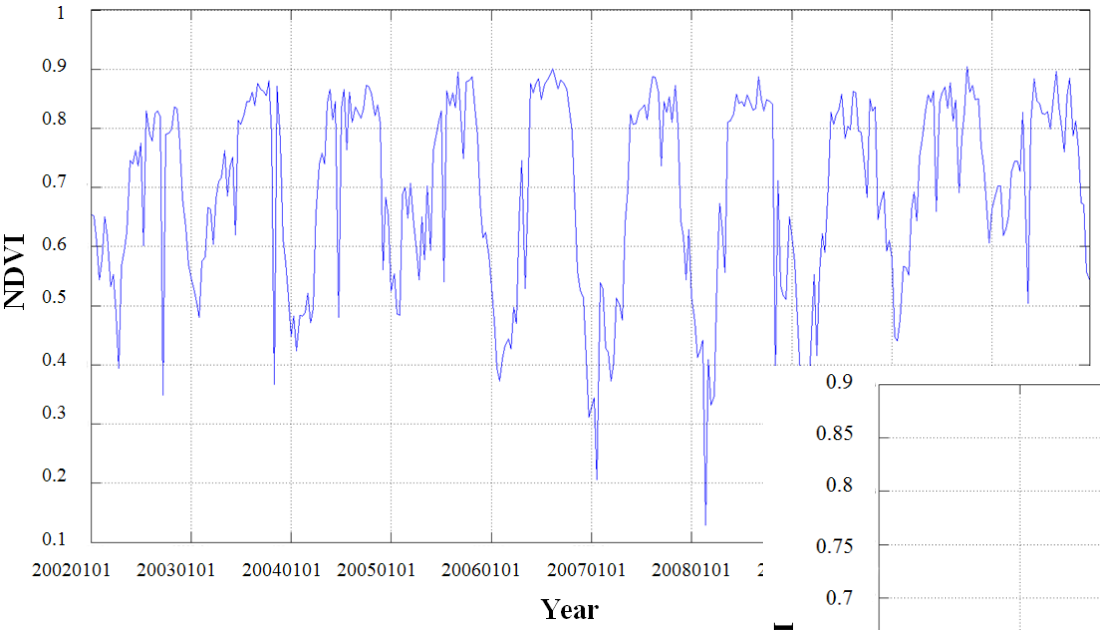
SPOT VGT 10-year NDVI time-series plot
十年期NDVI时间序列

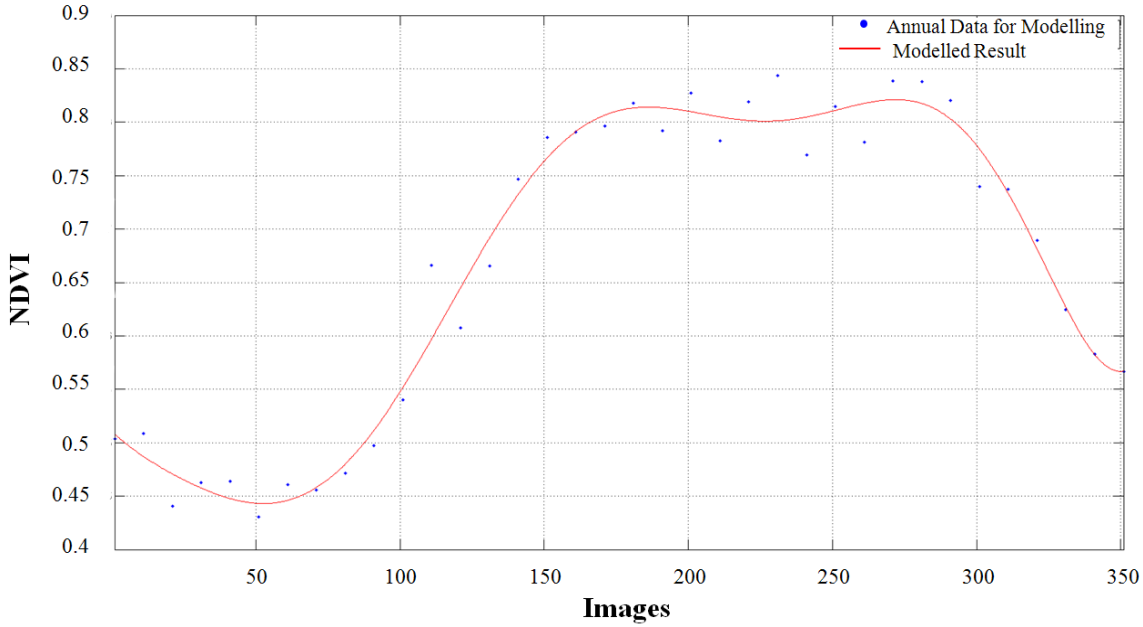


Vegetation cycle 植被生长周期

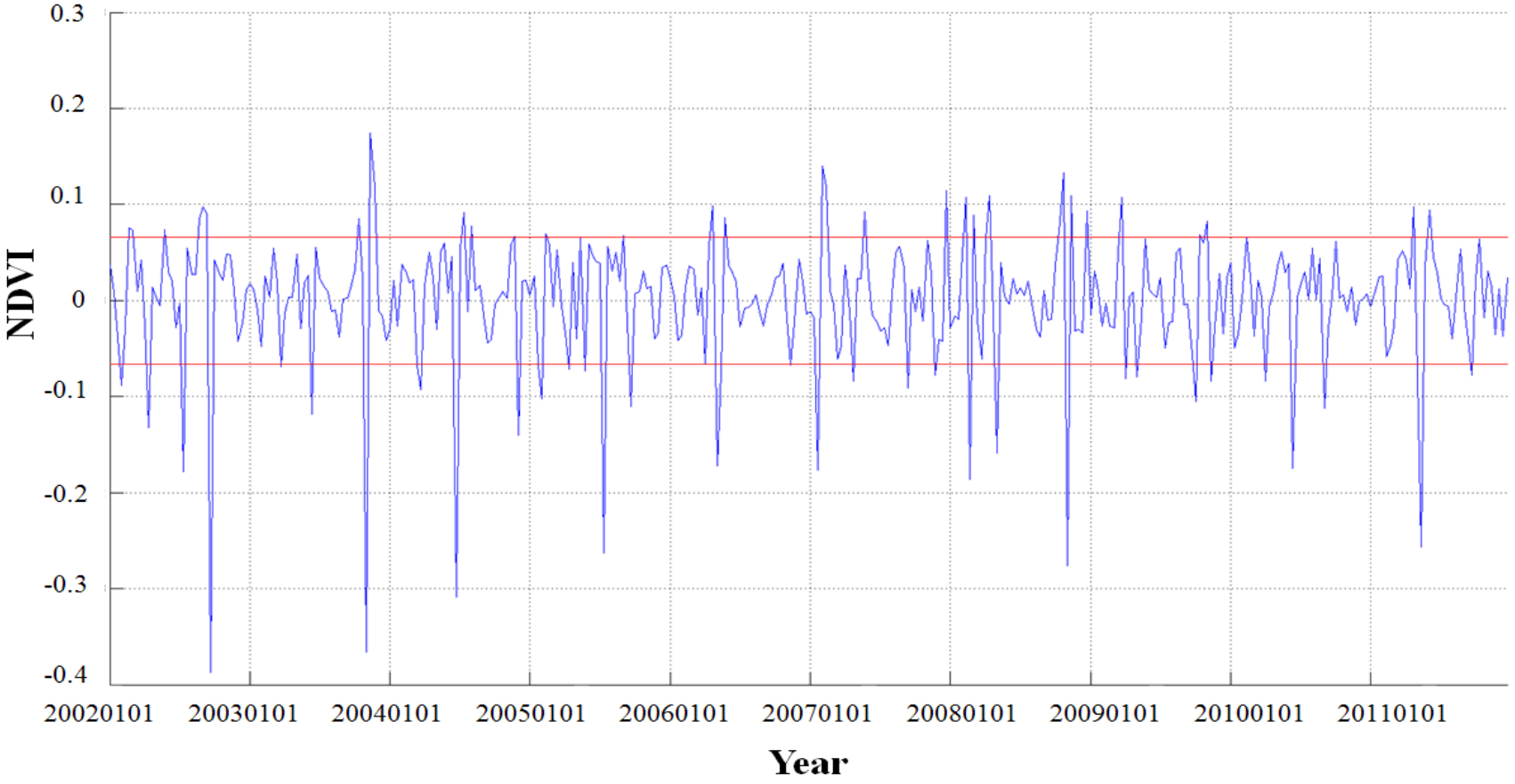


Pixel No. 13: 10-year NDVI time series and annual growth model
NDVI时间序列及年生长模型

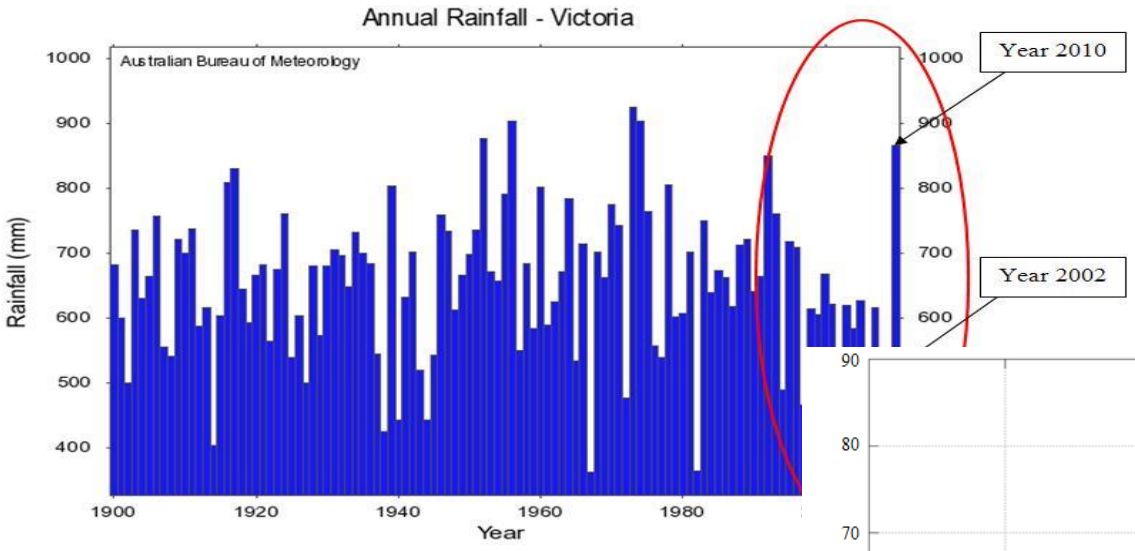


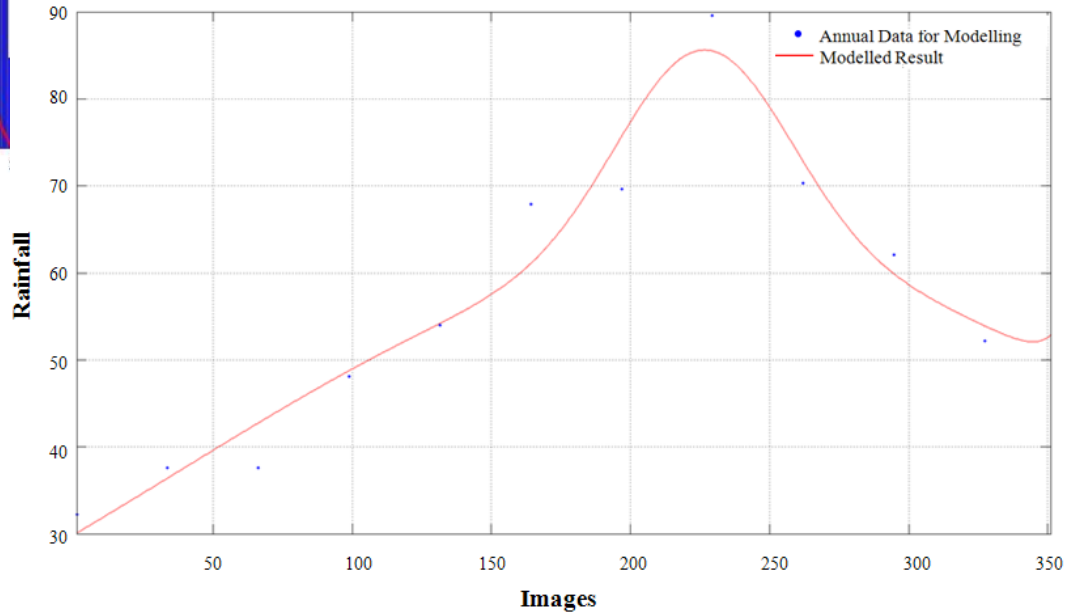


ΔNDVI time series plot for pixel No.13
差分NDVI时间序列



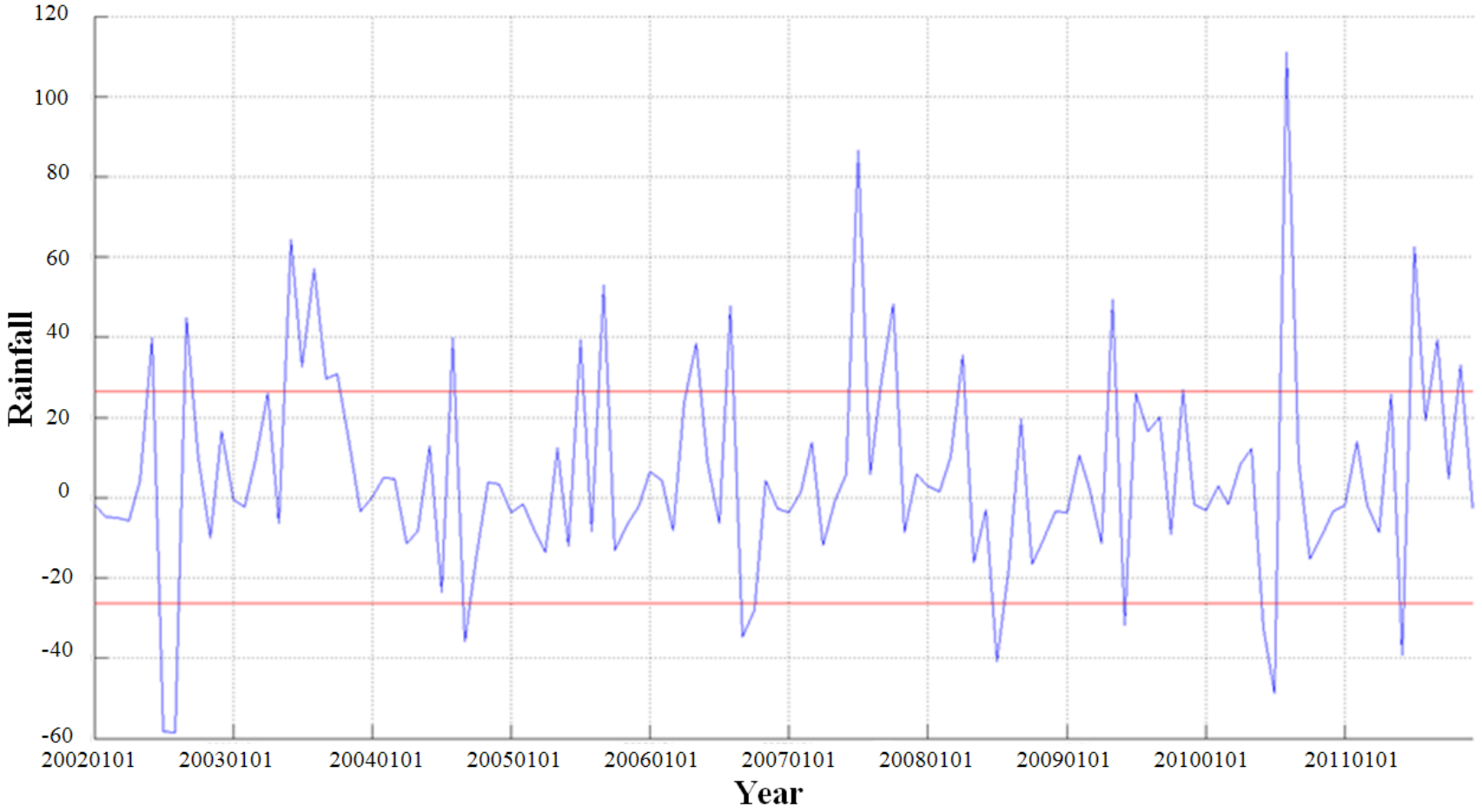
Annually Rainfall data and model for Victoria
年降雨数据及模型





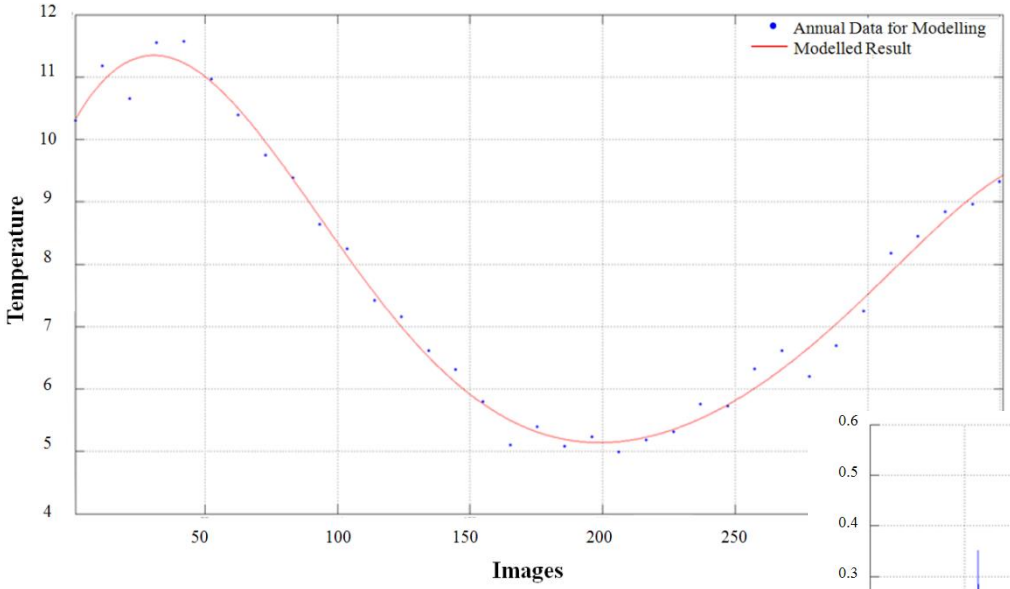
Rainfall differential result

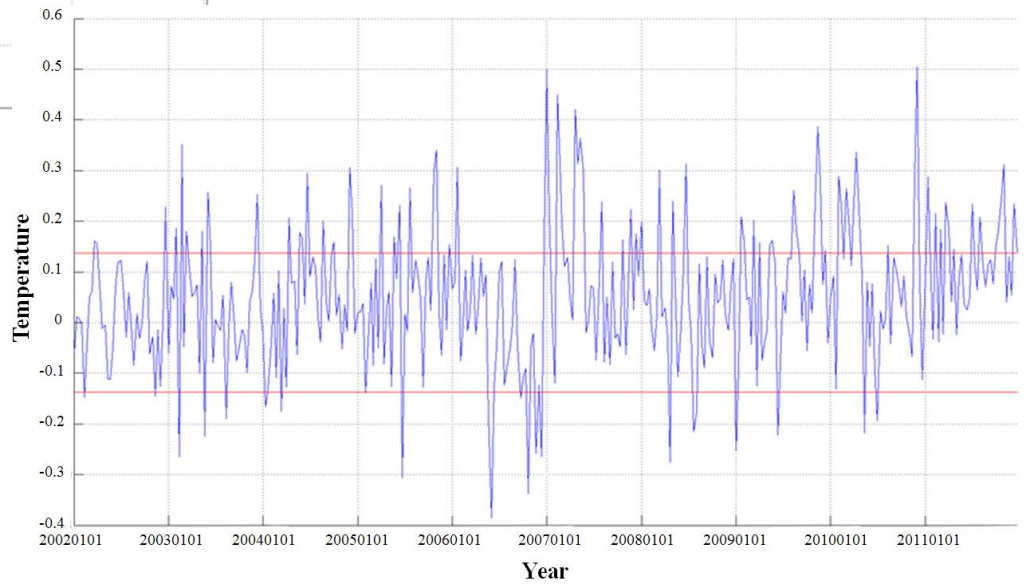
降雨差分时间序列



Temperature

年温度数据及模型





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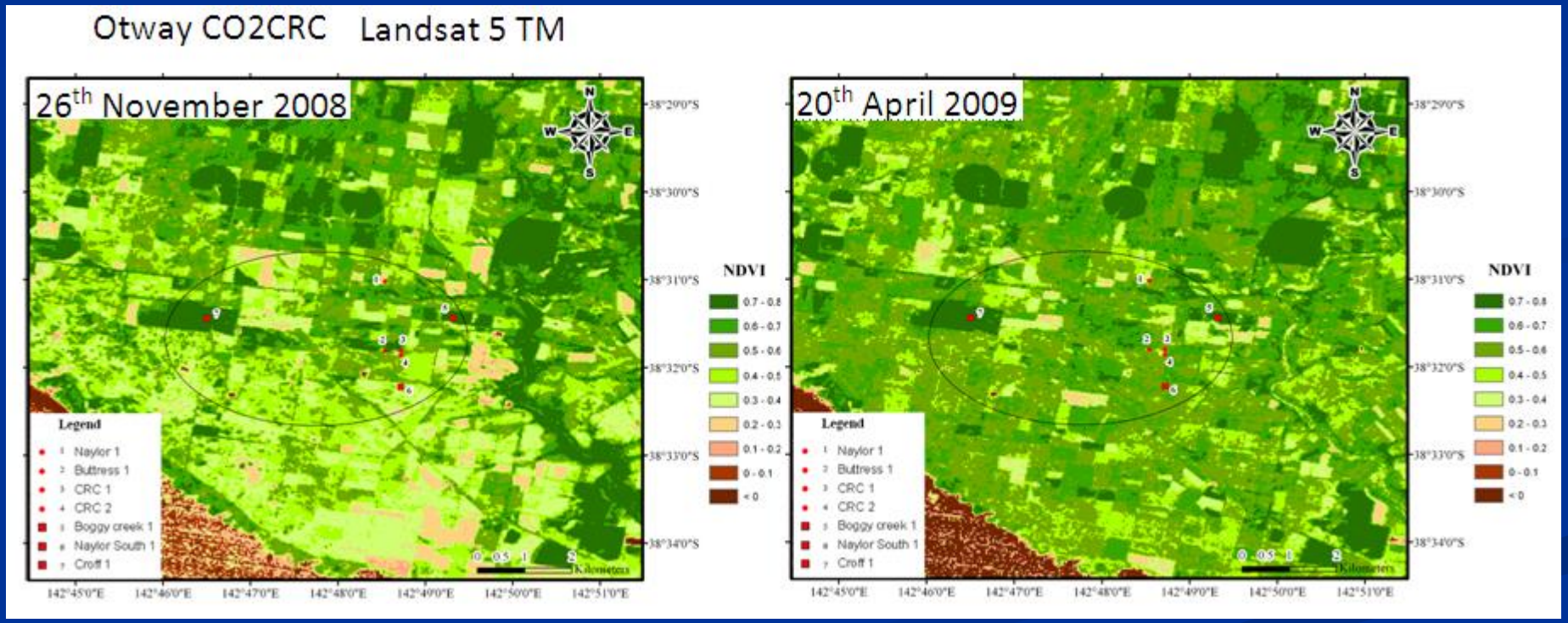
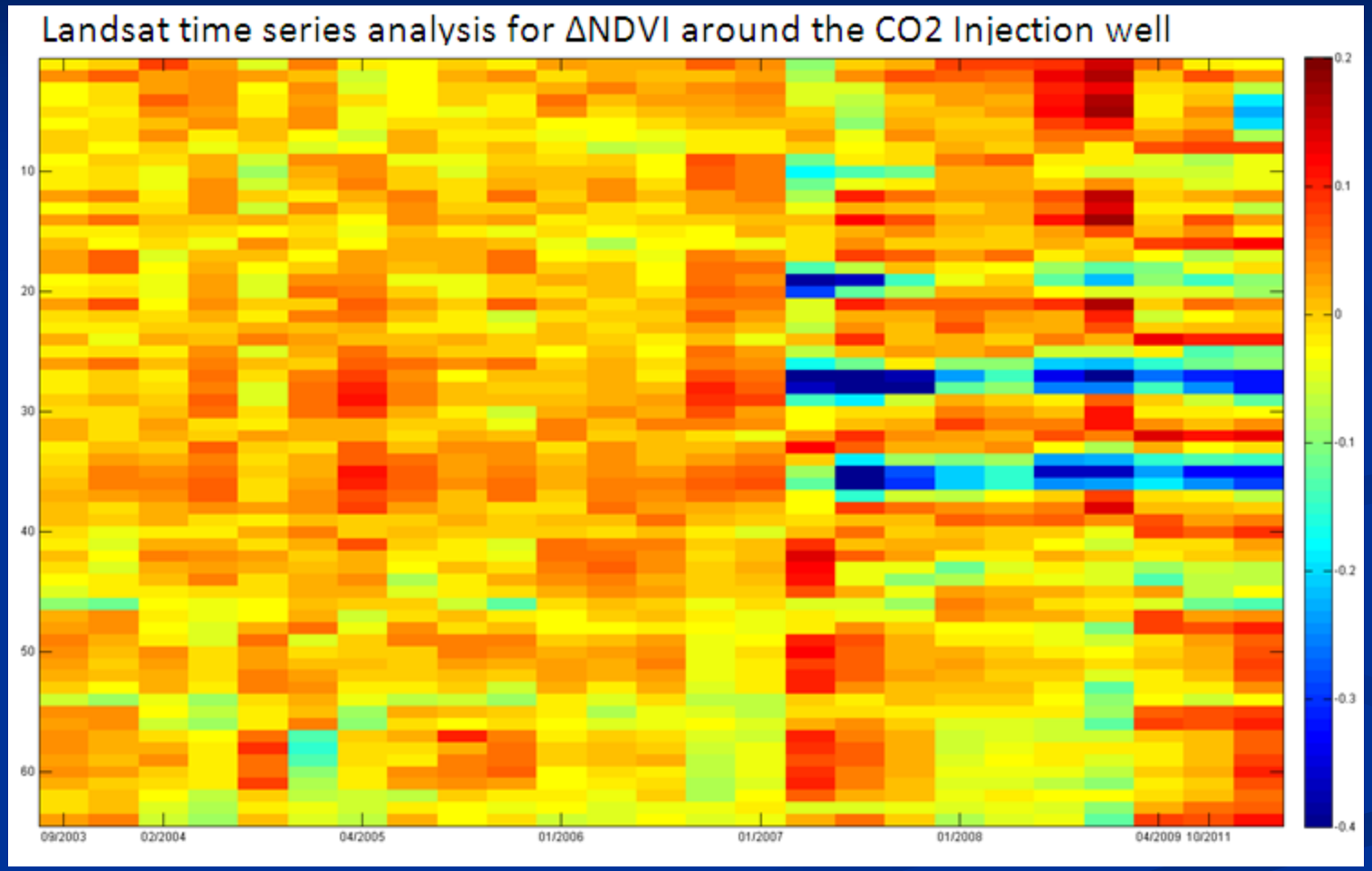


Satellite Optical Remote Sensing
光学卫星遥感



Vegetation Stress: Otway (2003-2012)

Concluding remarks 结语

- Potential CO2 leakage has to be carefully monitored

  我们应该密切监测封存区潜在的CO2泄漏
- Wherever possible, vegetation can be used as “distributed sensors” of CO2

  封存区的地表植被能巧妙地用作分布式CO2传感器
- Vegetation dynamics needs to be thoroughly understood with multi-year optical satellite remote sensing data

  必须使用多年期光学卫星遥感数据弄清植被动态特征
- Integration of optical satellites of low, medium and high resolution can be used to detect vegetation stress due to CO2 contamination

  高、中、低分辨率光学卫星的结合能用NDVI有效检测CO2泄漏

Acknowledgement 致 谢

- DRET / JCG
- 澳大利亚资源、能源及旅游部 -中澳清洁煤协调小组

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- 澳大利亚研究基金会会

- Cooperative Research Centre program
- 澳大利亚合作研究中心计划

- Geoscience Australia
- 澳大利亚地球科学组织

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- Cholathat, R., X. Li, L. Ge, H.T. Chu, 2010. Hyperspectral remote sensing for geologic carbon sequestration field monitoring. 31st Asian Conf. on Remote Sensing, Hanoi, Vietnam, 1-5 November, paper TS31-5, CD-ROM procs.