PCTO Liceo Einstein 24 marzo 2026

6. Misure da aereo e da satellite per l’ambiente costiero marino

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… ma quali azioni di monitoraggio dovremmo implementare per gestire una zona costiera in un clima che cambia?

PROCESSI/TARGET ? PROBLEMATICHE

Processi/Target	Problematiche
Livello del mare; Subsidenza	Nuisance floods e "acqua alta"; livello di marea; onde; eventi estremi; salinizzazione acquiferi
Qualità dell'acqua	Eutrofizzazione (algal blooms, eventi di anossia, etc.) Inquinanti (alte temperature, sostanze chimiche, etc.)
Trasporto sedimenti; Batimetria; Topografia	Erosione/deposizione, morfologia, flusso dell'acqua, mobilità natanti
Vegetazione emersa/sommersa	Biodiversità, condizioni del habitat, stabilità di suoli/fondali, accrezione, bilancio del blue carbon
Morfologia dei lidi	Protezione lagune, difesa da eventi estremi

PROCESSI ? METODI DI MONITORAGGIO

- **Livello del mare** → Mareografi; remote sensing
- **Subsidenza** → DGPS; reti GPS; radar remote sensing (Interferometria)
- **Qualità dell'acqua**, **Trasporto sedimenti** → Campagne di misura; sonde multiparametriche; remote sensing
- **Batimetria**, **Topografia** → Multi- and single-beam; remote sensing (LiDAR)
- **Vegetazione emersa/sommersa**, **Morfologia dei lidi** → Campagne di misura; remote sensing

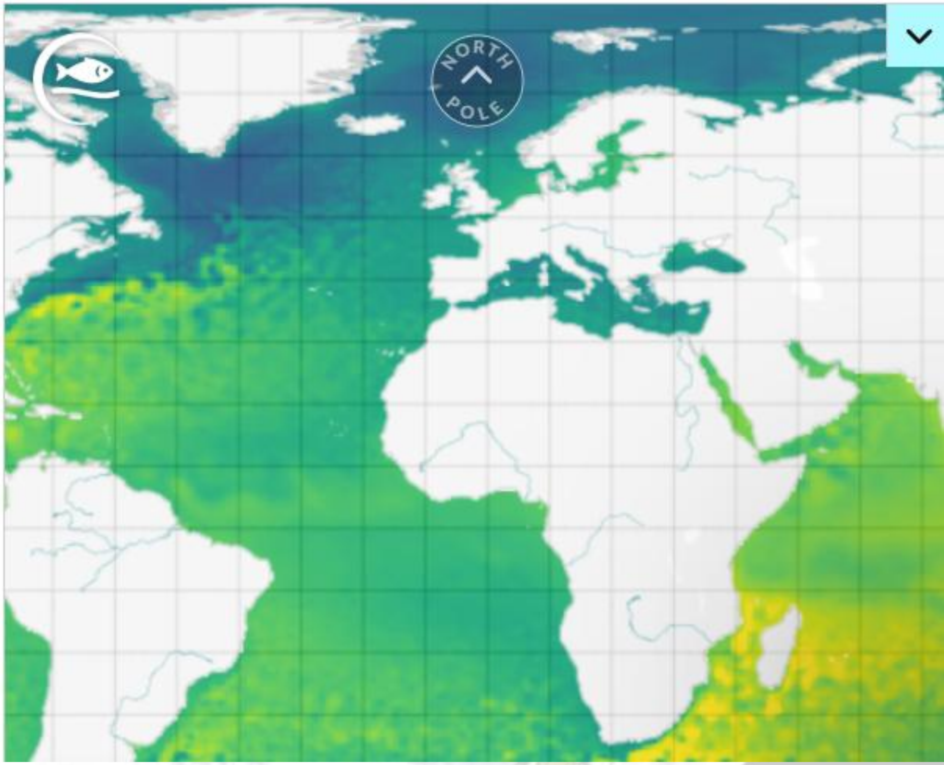
Copernicus monitoring: Sea Level

https://data.marine.copernicus.eu/product/SEALEVEL_GLO_PHY_L4_MY_008_047/description

Overview

Altimeter satellite gridded Sea Level Anomalies (SLA) computed with respect to a twenty-year [1993, 2012] mean. The SLA is estimated by Optimal Interpolation, merging the L3 along-track measurement from the different altimeter missions available. Part of the processing is fitted to the Global ocean. (see QUID document or http://duacs.cls.fr pages for processing details). The product gives additional variables (i.e. Absolute Dynamic Topography and geostrophic currents (absolute and anomalies)). It serves in delayed-time applications. This product is processed by the DUACS multimission altimeter data processing system.

DOI (product):
https://doi.org/10.48670/moi-00148



PROCESSI ? METODI DI MONITORAGGIO

PROCESSI		METODI DI MONITORAGGIO
Livello del mare	→	Mareografi; remote sensing
Subsidenza	→	DGPS; reti GPS; radar remote sensing (Interferometria)
Salinizzazione acquifero		
Qualità dell'acqua Trasporto sedimenti	→	Campagne di misura; sonde multiparametriche; remote sensing
Batimetria Topografia	→	Multi- and single-beam; remote sensing (LiDAR)
Vegetazione emersa/sommersa Morfologia dei lidi	→	Campagne di misura; remote sensing

Global Positioning System

The GPS constellation

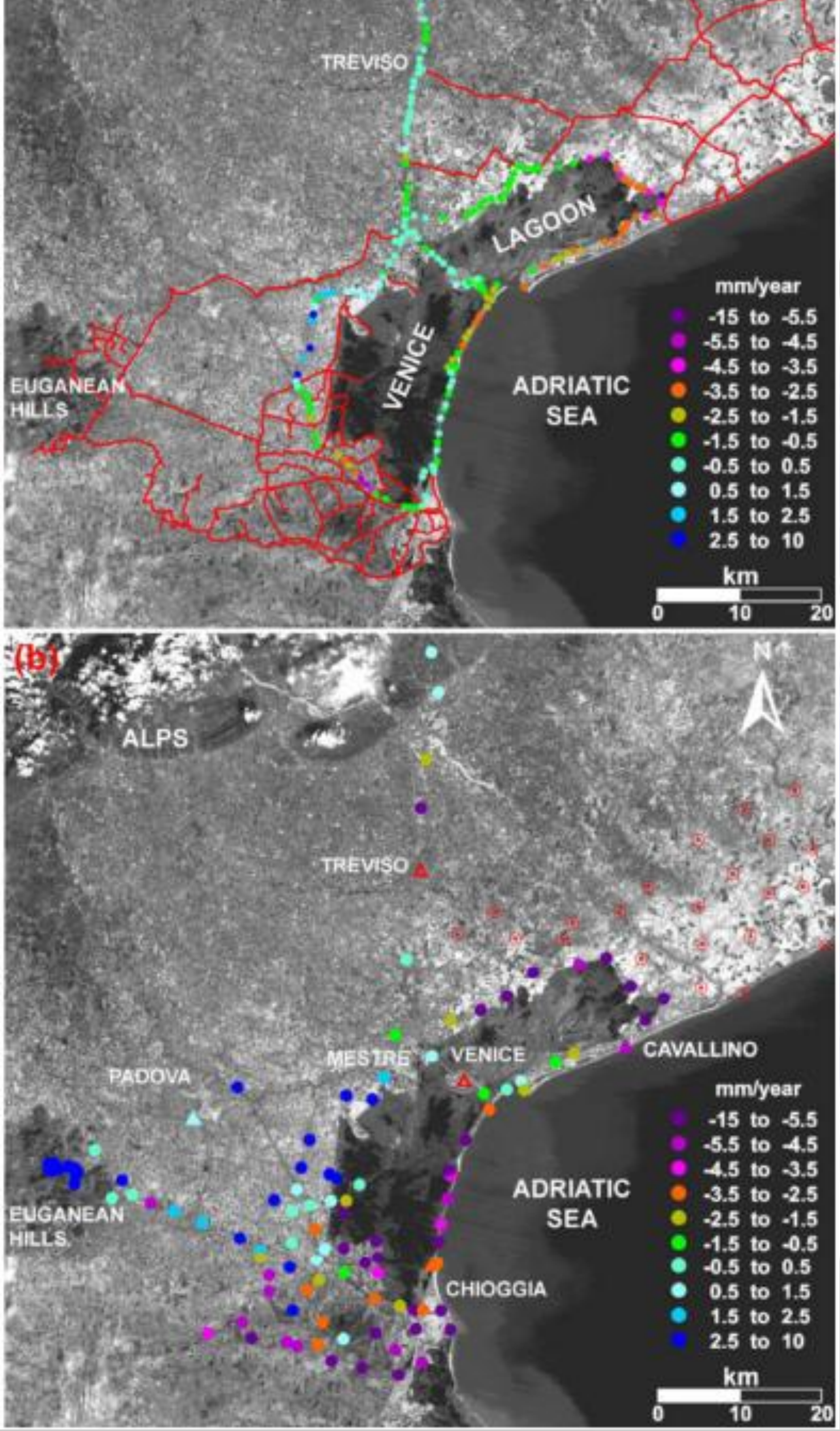
The **Global Positioning System (GPS)** is a space-based satellite navigation system with **24 satellites** that are distributed equally among **six circular orbital planes**.

Each satellite continually transmits messages that include:

- **the time the message was transmitted**,
- **satellite position at time of message transmission**.

Signal velocity = speed of light

Each GPS device calculates the **distance** between the device and each satellite based on the **delay between the time the signal was sent and the time when it was received**.



Subsidence in Venice

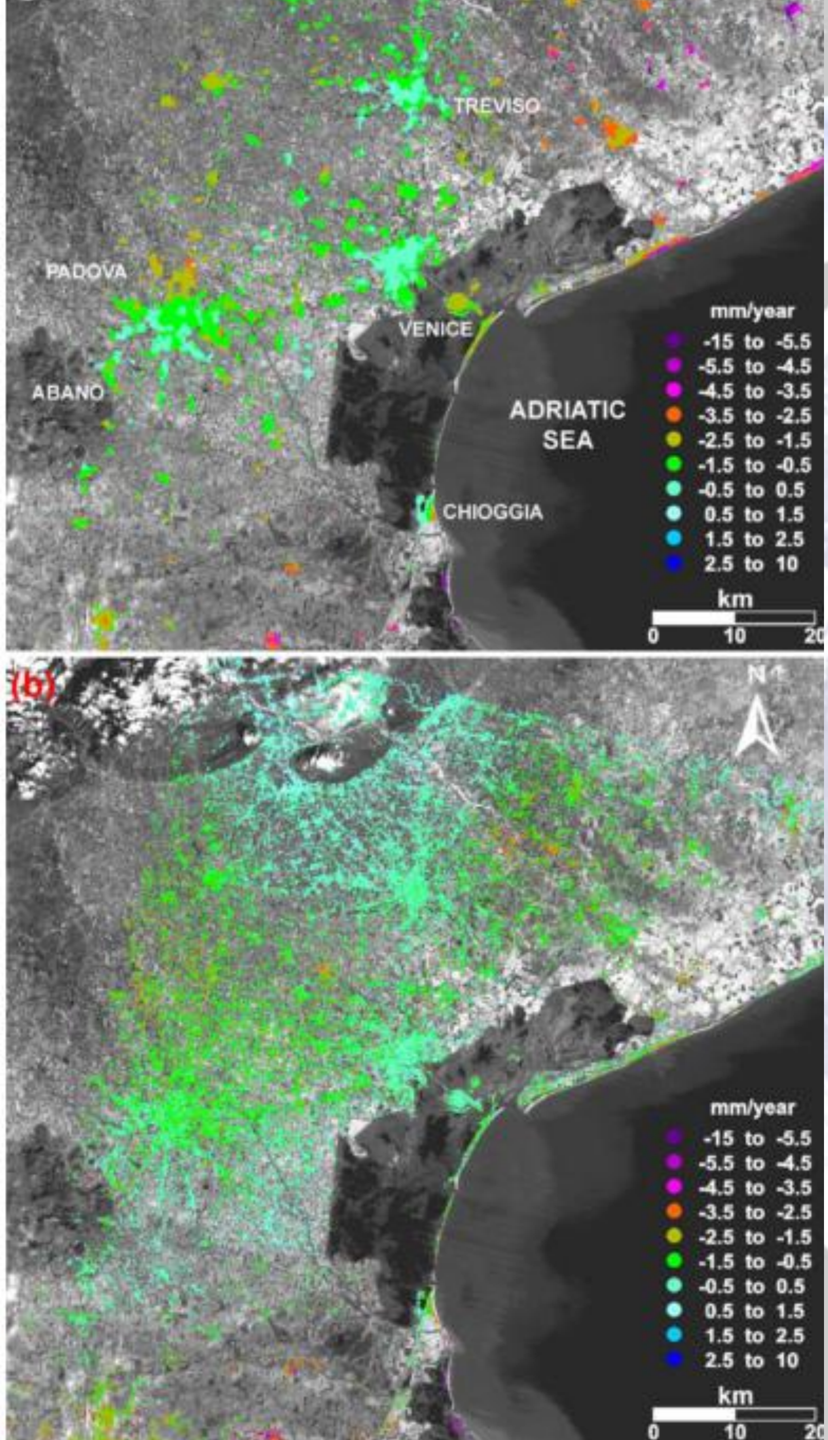
(a) is the **leveling network** available in 2005. Benchmarks established before 2000 are colored according to displacement rates (mm/year) recorded from 1993 to 2000.

(b) The **DGPS network** is represented by circles and the **CGPS network** is represented in triangles. New DGPS benchmarks added to the network in 2004 are indicated with void red circles.

Treviso is assumed as a stable reference.

Teatini et al., 2005

Subsidence in Venice

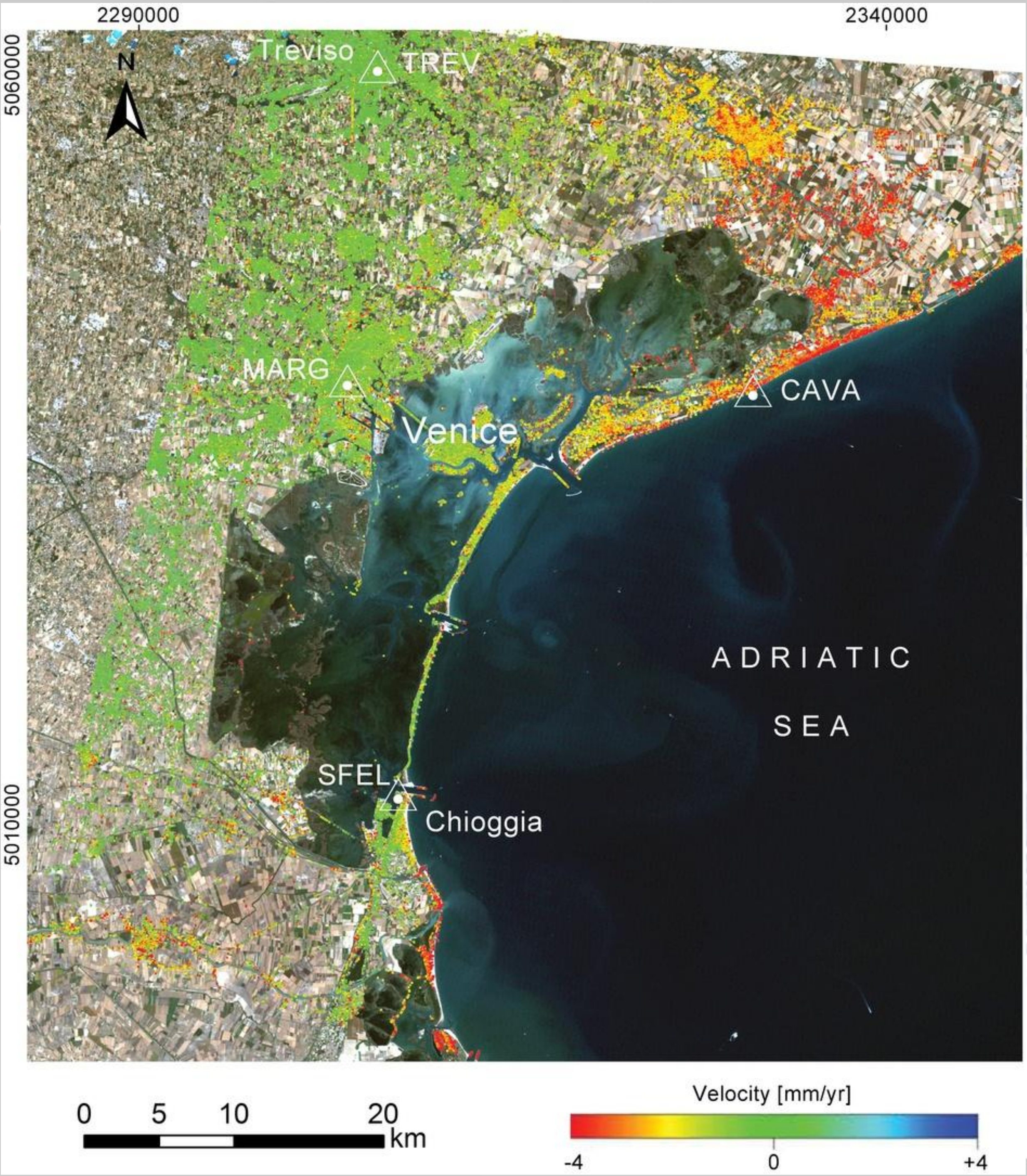


(a) InSAR (Interferometric Synthetic Aperture Radar) over the time interval 1993-2000

(b) IPTA (Interferometric Point Target Analysis) over the time interval 1992-2000.

Treviso is assumed as the stable reference

Teatini et al., 2005



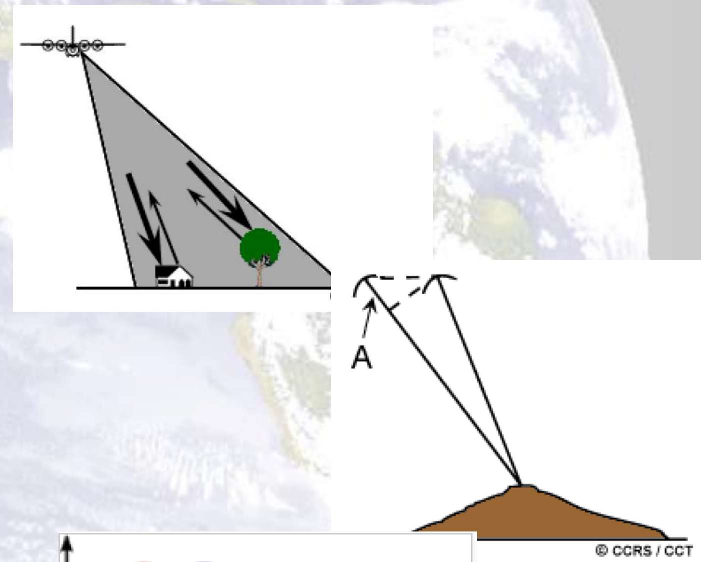
Subsidence in Venice (today largely natural)

Tosi et al., 2013: Velocity map (mm/yr) for the Venice coastland obtained by IPTA on ENVISAT images acquired between 2003 and 2010.

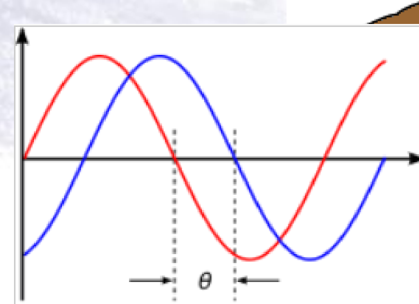
Radar Interferometry

Active microwave sensors provide their **own source of microwave radiation**. Active microwave sensors are **imaging** and **non-imaging**. **The most common** form of **imaging active microwave sensors** is **RADAR** (RAdio **D**etection **A**nd **R**anging).

Interferometric synthetic aperture radar, abbreviated **InSAR** uses two or more synthetic aperture radar (SAR) images to generate maps of surface deformation or digital elevation, using **differences in the phase of the waves** returning to the satellite or aircraft.



By **measuring** the exact **phase difference** between the two returns, the path length difference can be calculated to an **accuracy** that is on the order of the wavelength (i.e **centimetres**). Knowing the position of the antennas with respect to the **Earth's surface**, the position of the resolution cell, including its **elevation**, can be determined.



Phase difference

PROCESSI ? METODI DI MONITORAGGIO

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Livello del mare	Mareografi; remote sensing
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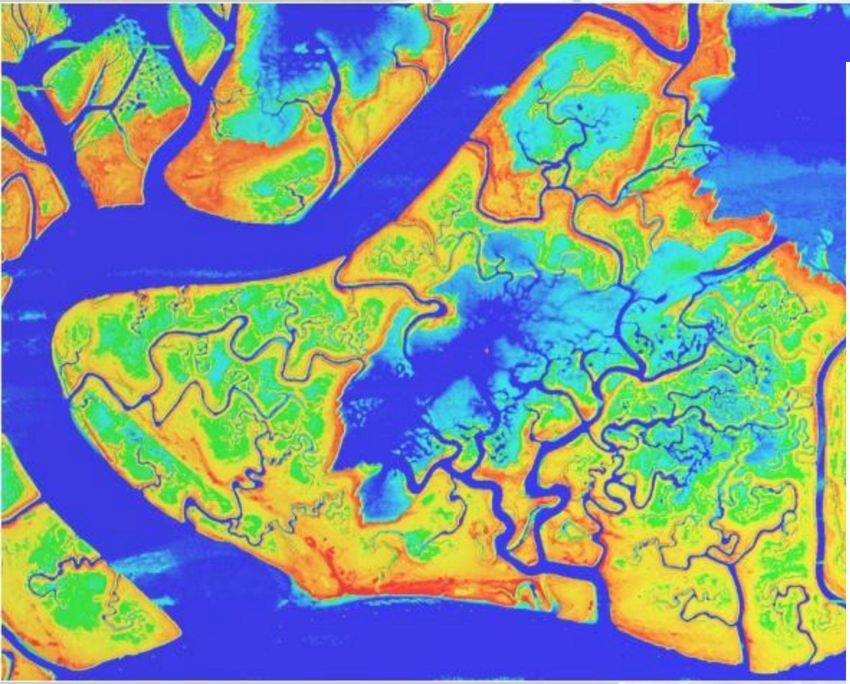
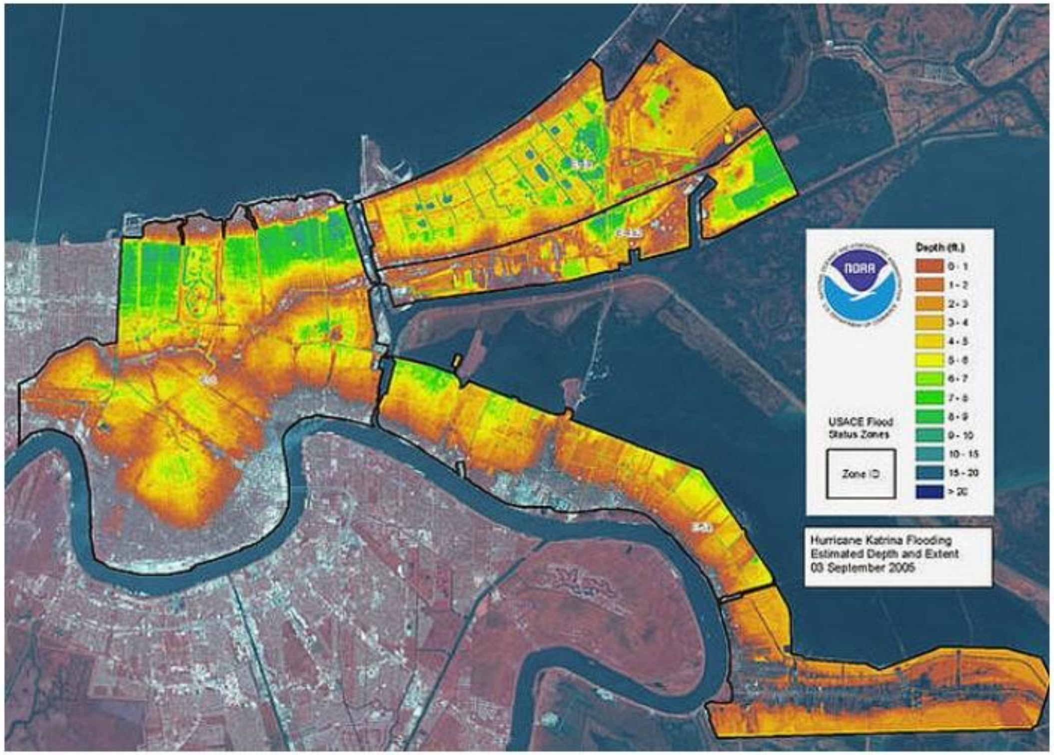
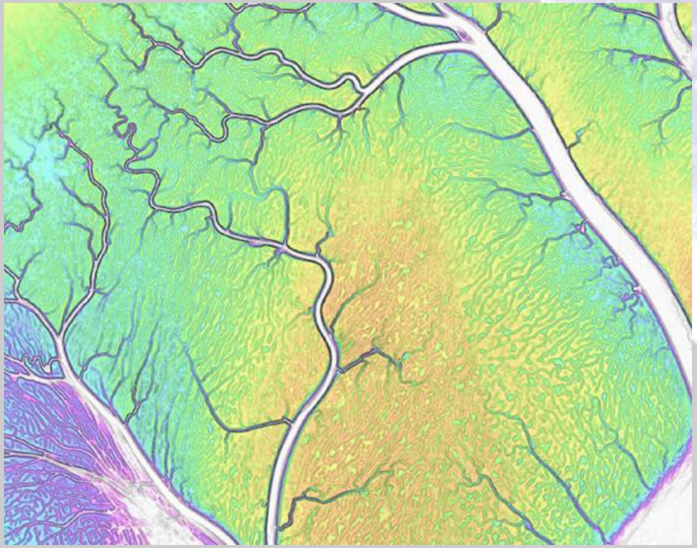
Vegetazione emersa/sommersa Morfologia dei lidi	Campagne di misura; remote sensing

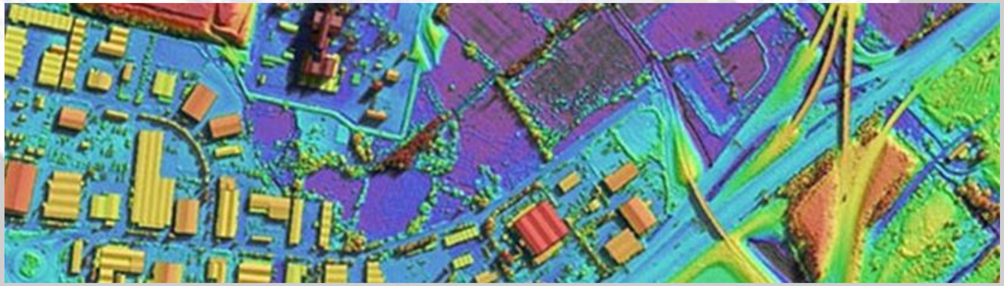
TOPOGRAFIA





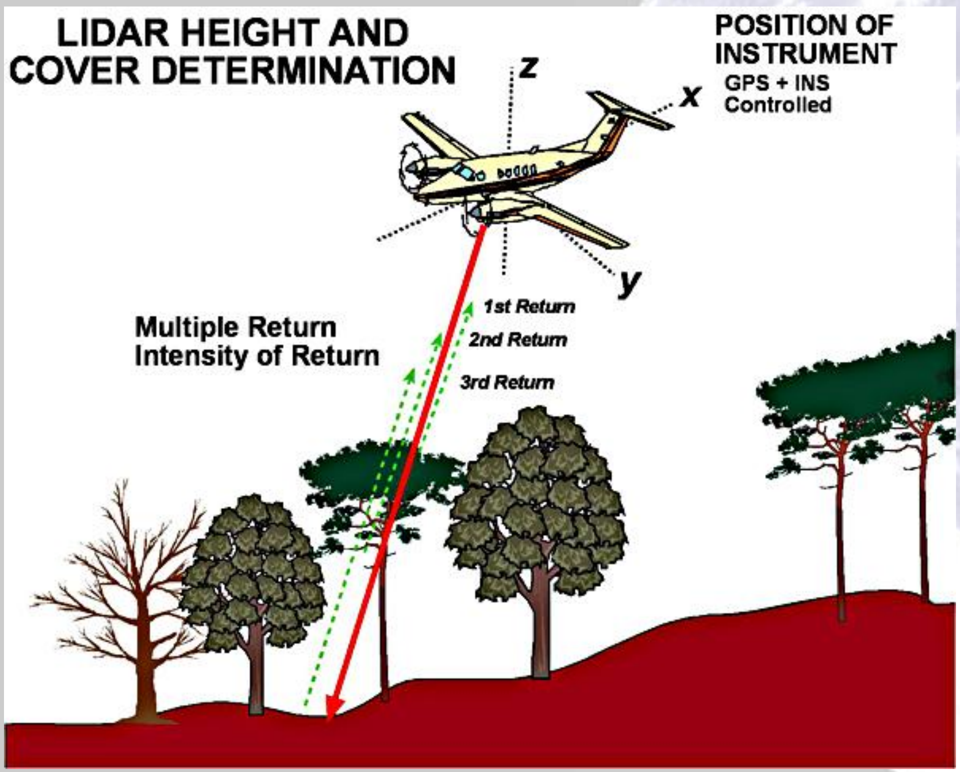
LIDAR map of New Orleans flooding from Hurricane Katrina





LIDAR REMOTE SENSING

Light Detection And Ranging (LIDAR) instruments emit a pulse of coherent light (laser) out to a target. The transmitted light interacts with atmosphere and target. Some of this light is reflected / scattered back to the instrument where it is recorded.



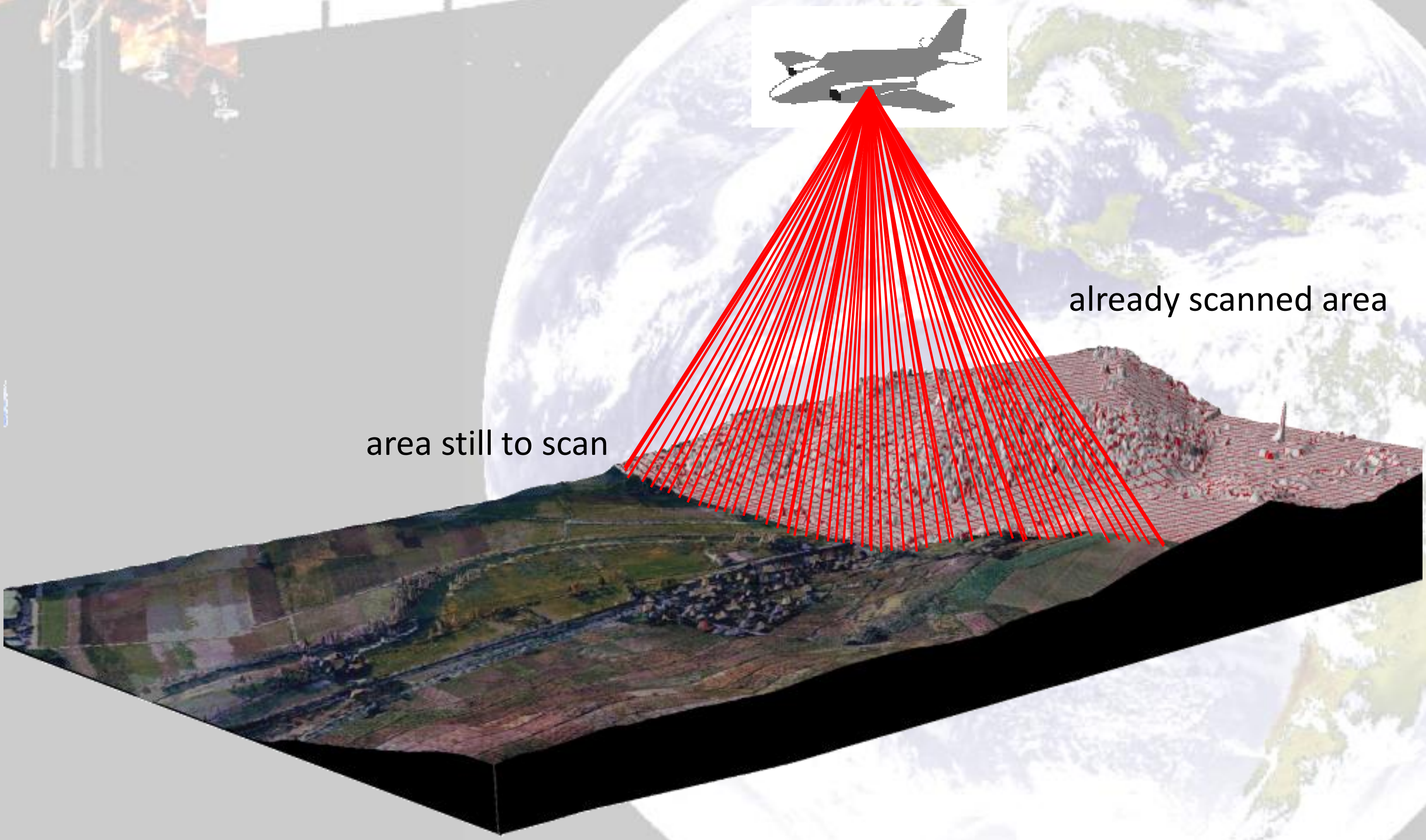
LIDAR can use UV, visible (VIS), or Near Infrared (NIR) light

LIDAR systems used **for topographic mapping** use eye-safe near-infrared laser light, in the region **from 1040 to 1060 nm.**

LIDAR systems for **bathymetric mapping** use blue-green lasers centered at approximately **532 nm (water penetration).**

LIDAR REMOTE SENSING

System



Airborne laserscanning to survey the Earth`s surface

LIDAR REMOTE SENSING

LIDAR systems can emit pulses at rates > 100,000 **pulses** per sec.

A pulse of laser light travels at **c, the speed of light**.

LIDAR technology is based on the accurate measurement of the **travel time** from the transmitter to the target and back to the receiver:

$$t = 2\,s/c$$

where:

s = distance between the LIDAR and the object

c = the speed of light

$$s = \tfrac{1}{2}\,tc$$

Steps in the Lidar Process:

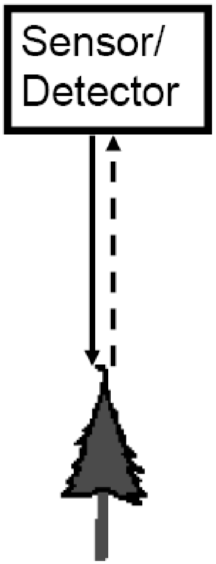
Creation of the Lidar pulse

Lidar pulse travels to the target

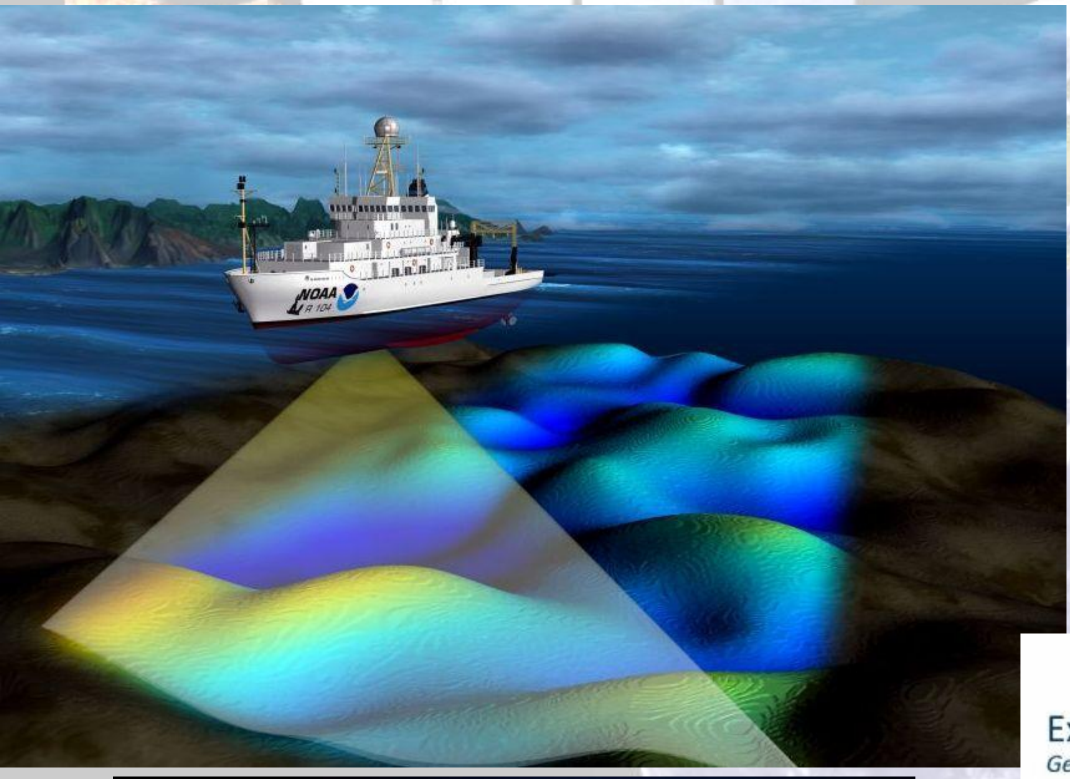
Interaction with the target

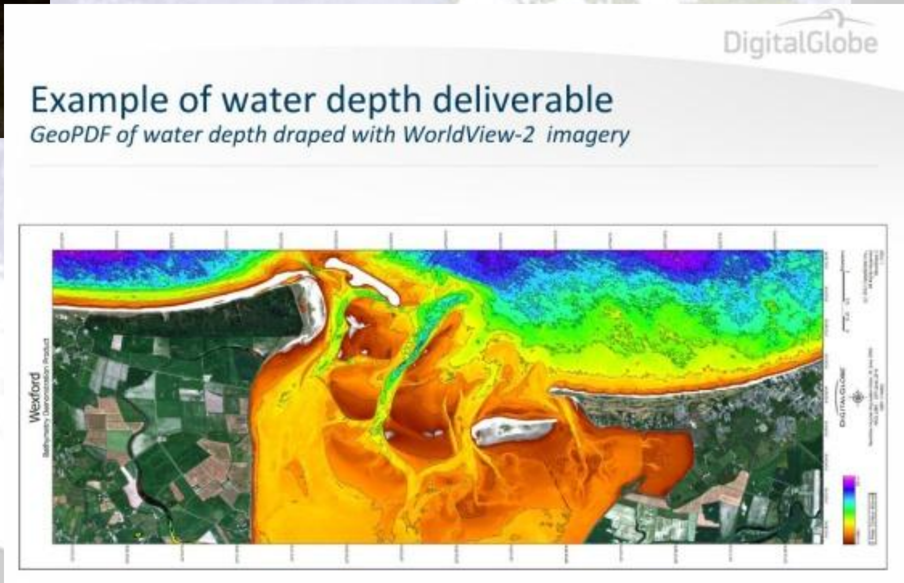
Lidar pulse travels back to sensor

Sensor processes return signal

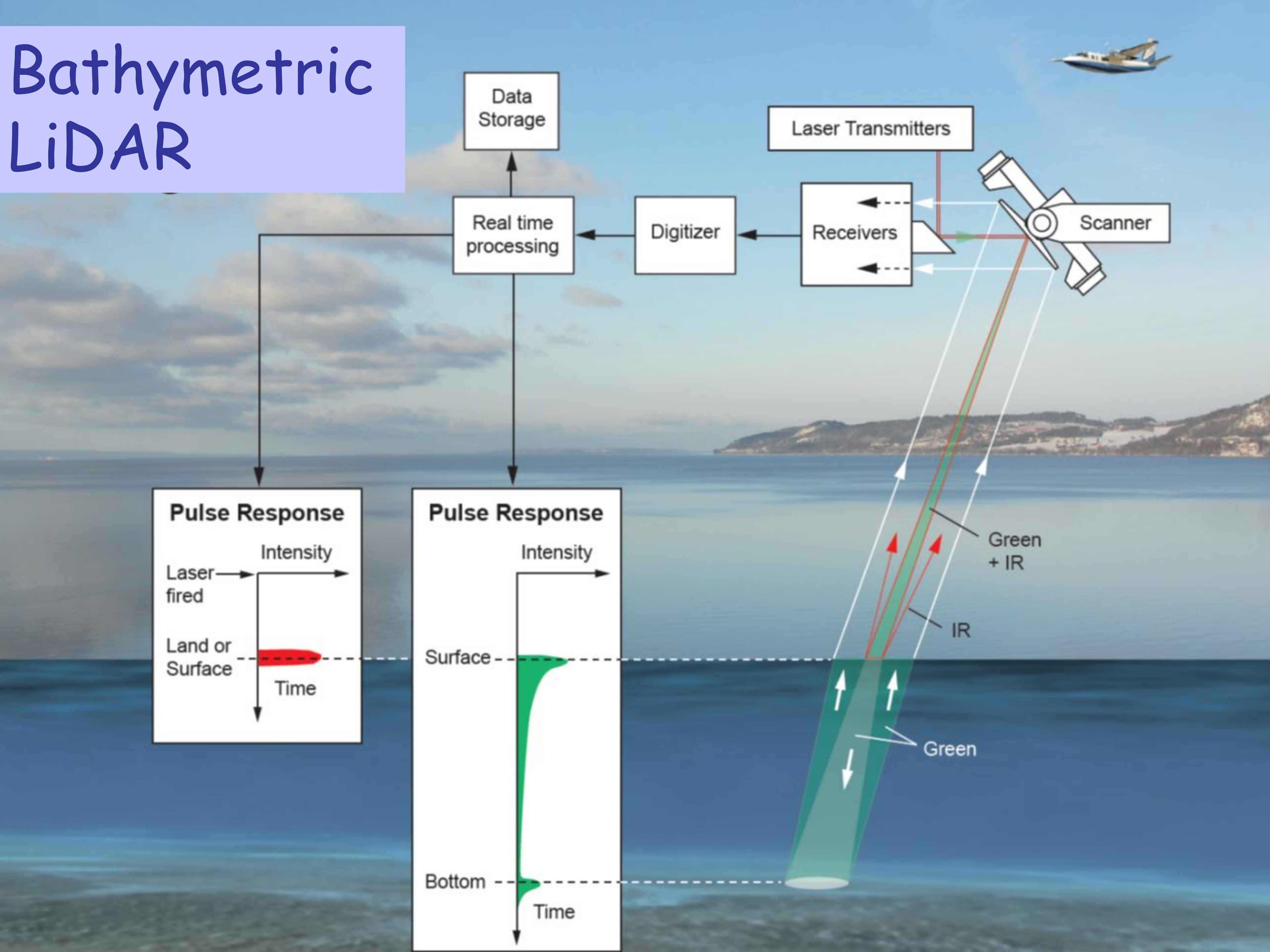


BATIMETRIA


NOAA
R 104

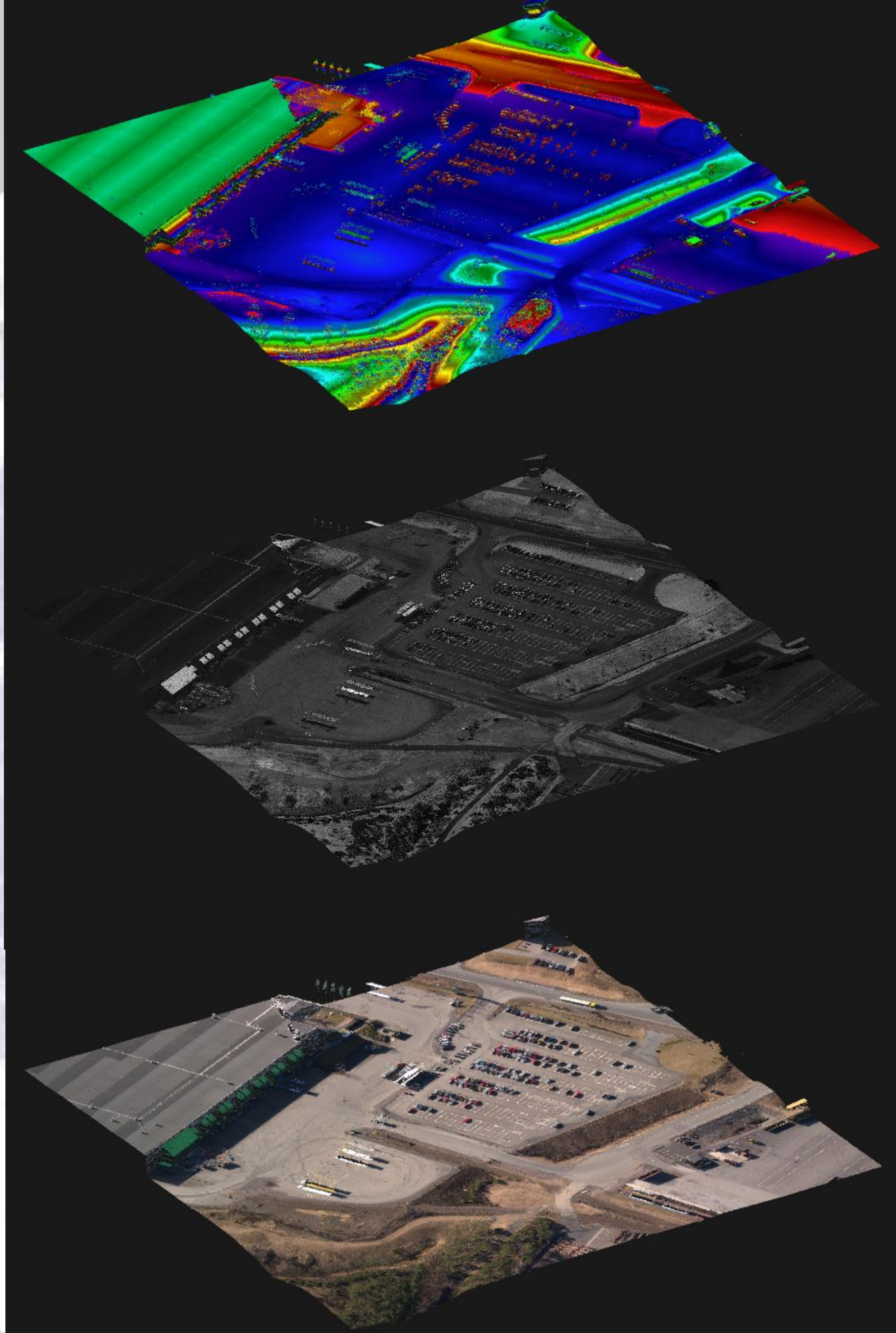

DigitalGlobe
Example of water depth deliverable
GeoPDF of water depth draped with WorldView-2 imagery

Bathymetric LiDAR



Summary
Modern bathymetric LIDAR

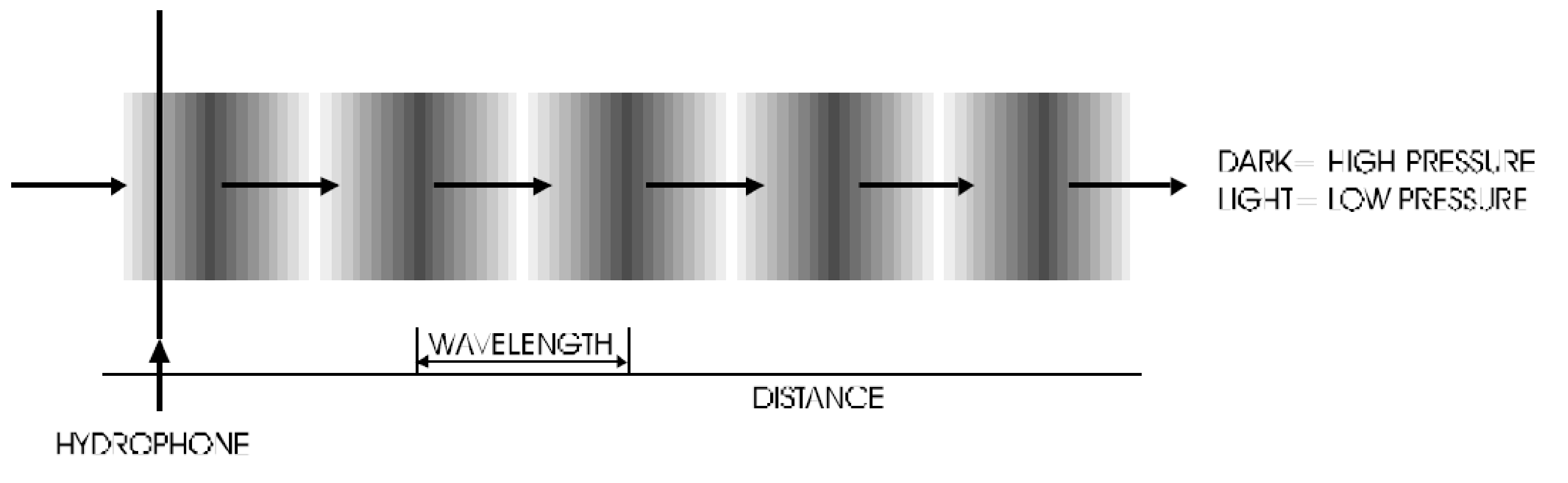
- Simultaneous capture of topography and bathymetry
  - Full waveform in both topo and bathy
- Reasonable depth penetration
  - > 20 meter in clear waters
  - > 10 meters in less clear water
- High data density
  - Typical
    - Topo > 10 points per square meter
    - Bathy > 1 point per square meter



ECHO SOUNDING

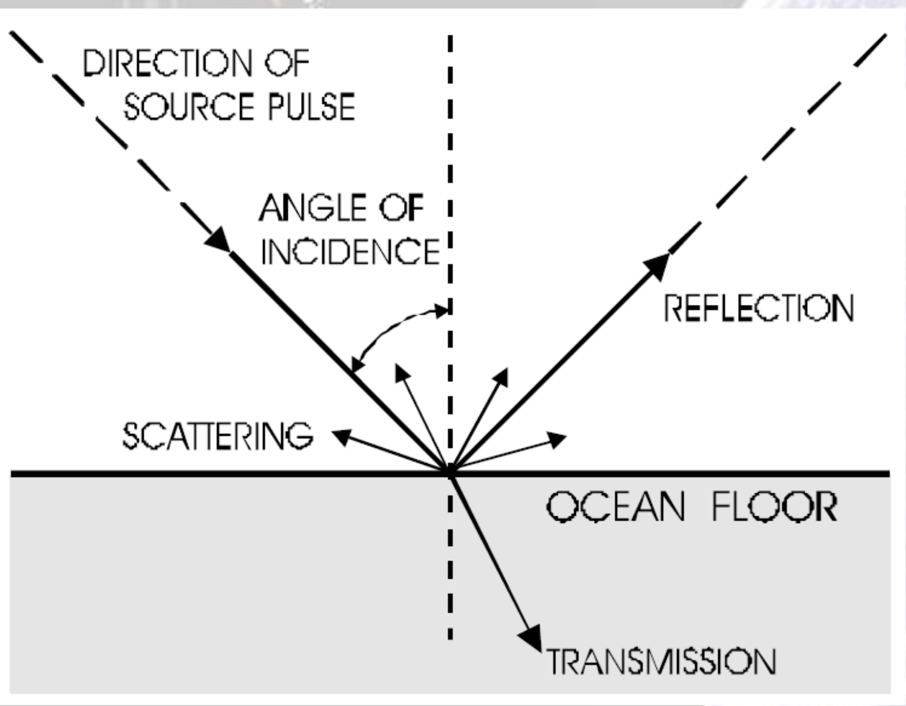
Echo sounding is a type of SONAR used to determine the depth of water by transmitting sound pulses into water.

The ability of sound to travel over great distances allows the detection of obstacles in a water environment.
Sound travels in water in a moving series of **pressure fronts known as a *compressional wave*.**



ECHO SOUNDING

Sound waves with low frequency can travel for hundreds of kilometers without significant attenuation.



When a moving sound pulse encounters the ocean floor, some fraction of its energy is transmitted, some is reflected and some scattered.

Scattered en.+ reflected en.= echo

Echo sounders measure depth by generating a short pulse of sound, or *ping*, and then listening for the echo of the pulse from the bottom.

Distance → range = (1/2) x velocity x echo time

BATHYMETRY IN THE LAGOON OF VENICE: EQUIPEMENT

Multibeam System Kongsberg EM 2040D-C

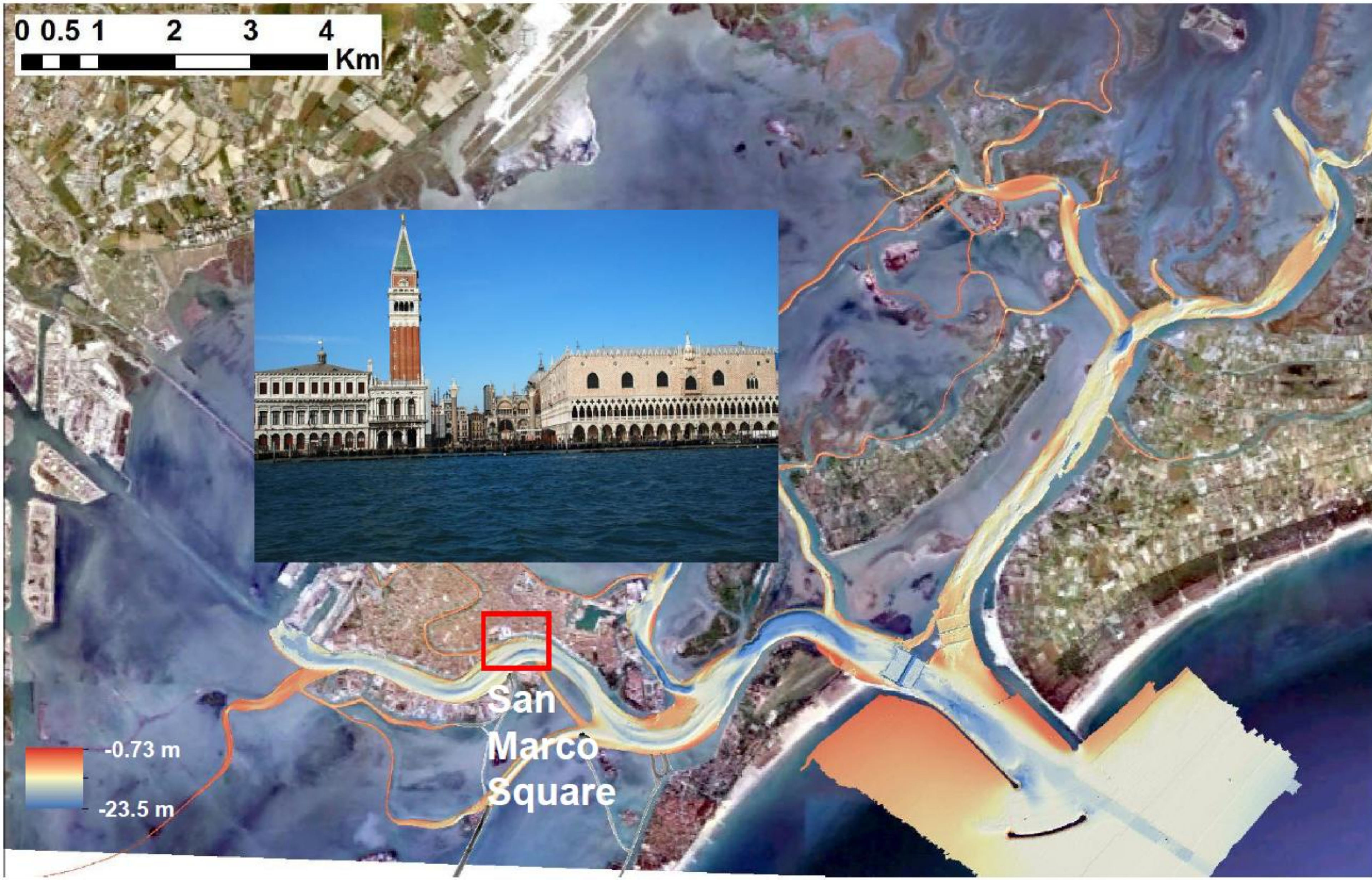
Positioning system Kongsberg Seapath 300

Motion sensor Kongsberg Seatex MRU 5

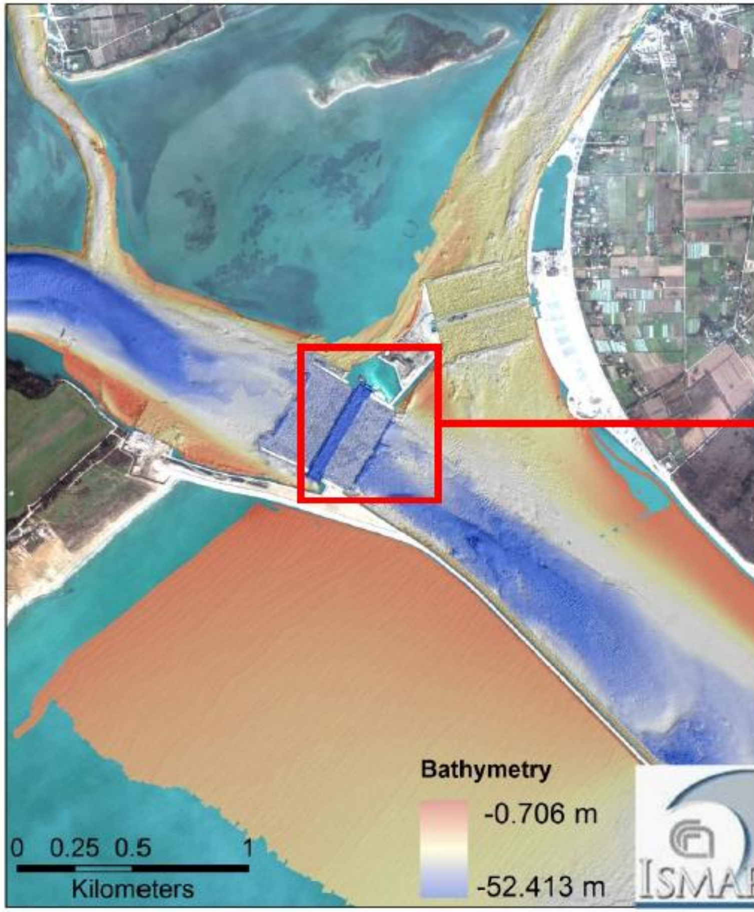
Valeport Mini SVS and AML Ocenographic SV Profiler

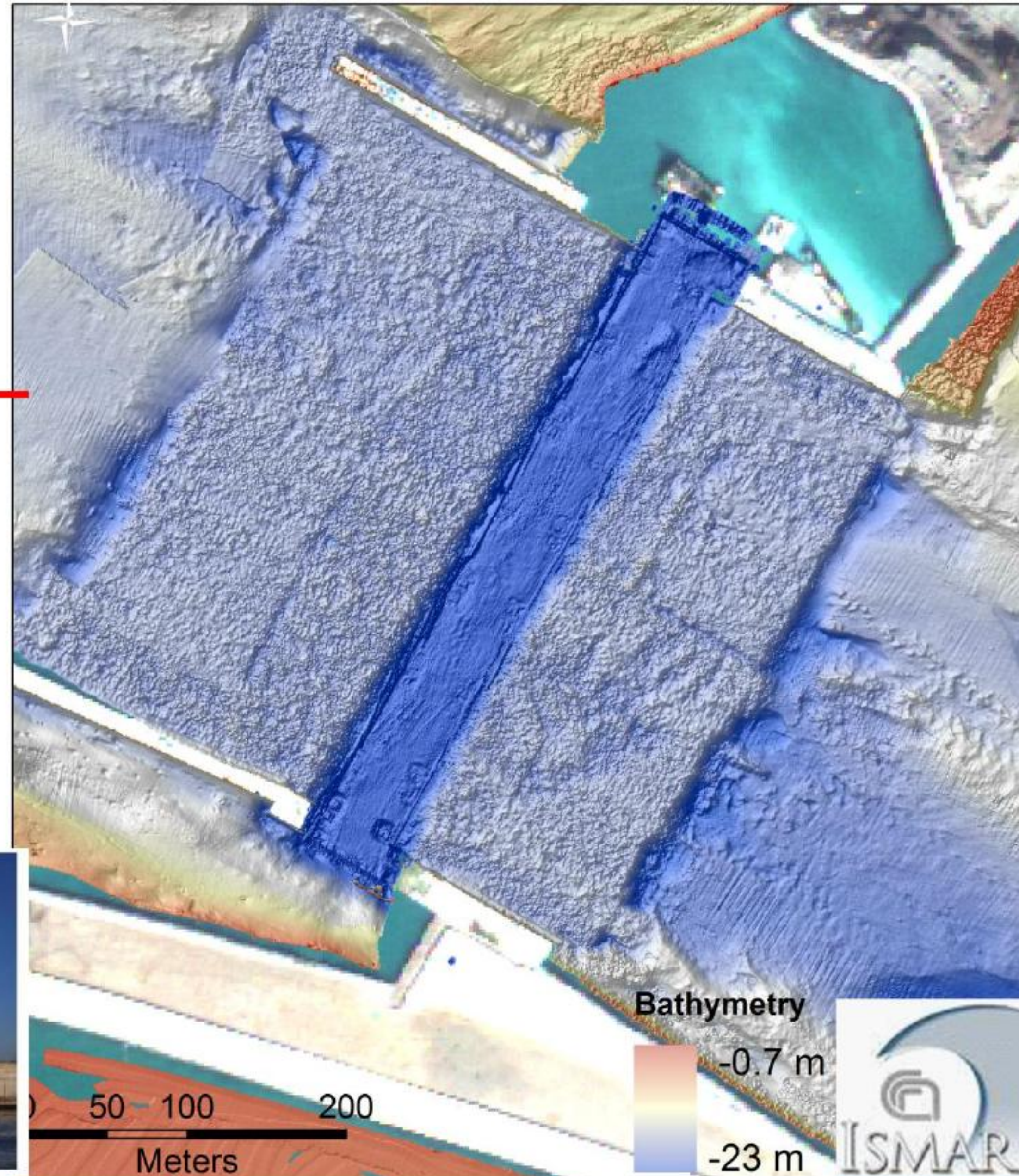
(Foglini et al., CNR)

An updated bathymetry of the Venice Lagoon (Foglini et al., CNR, 2014)



MOSE CONSTRUCTION SITE





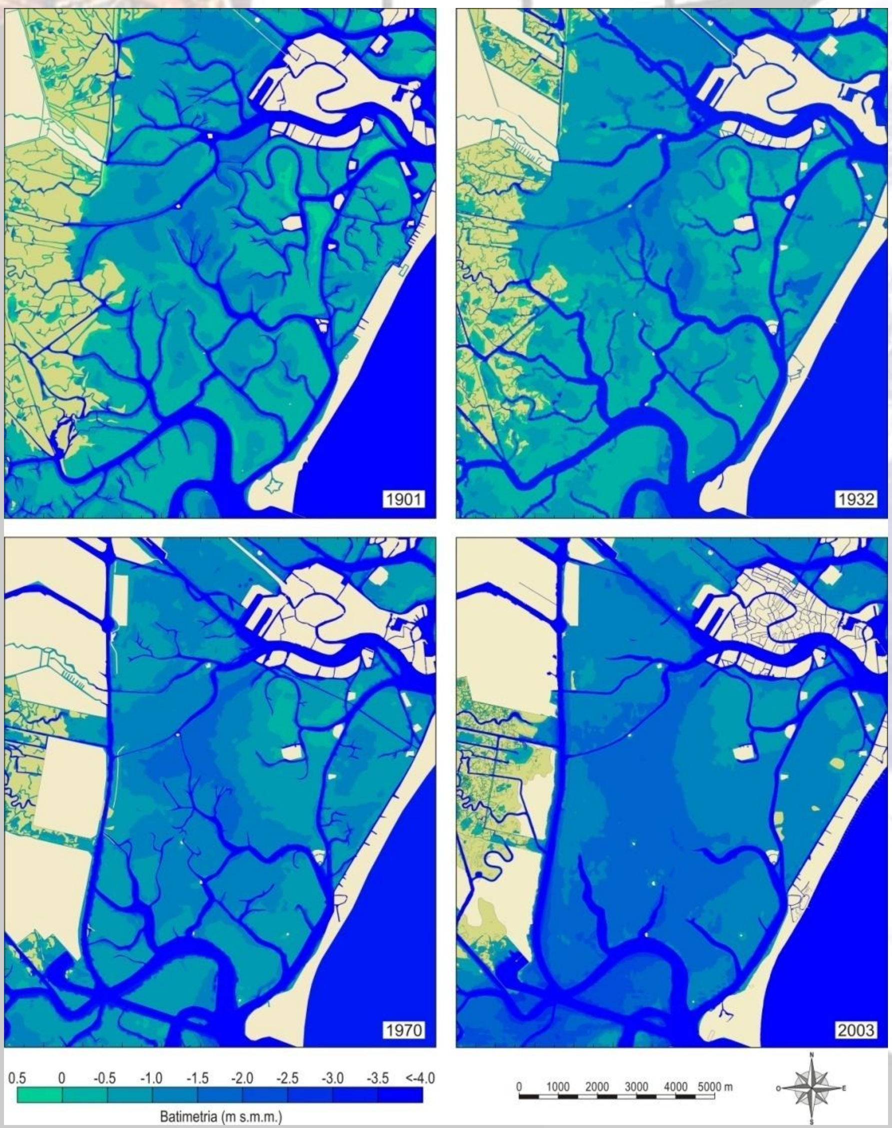
Resolution

0.5 M

V.E. 5X

ECHO SOUNDING

Lagoon floor erosion /deposition



Mean botton elevation

1901	**- 0.49 m**
1932	**- 0.60 m**
1970	**- 1.02 m**
2003	**- 1.46 m**

L. D'Alpaos & L. Carniello
University of Padova

PROCESSI ? METODI DI MONITORAGGIO

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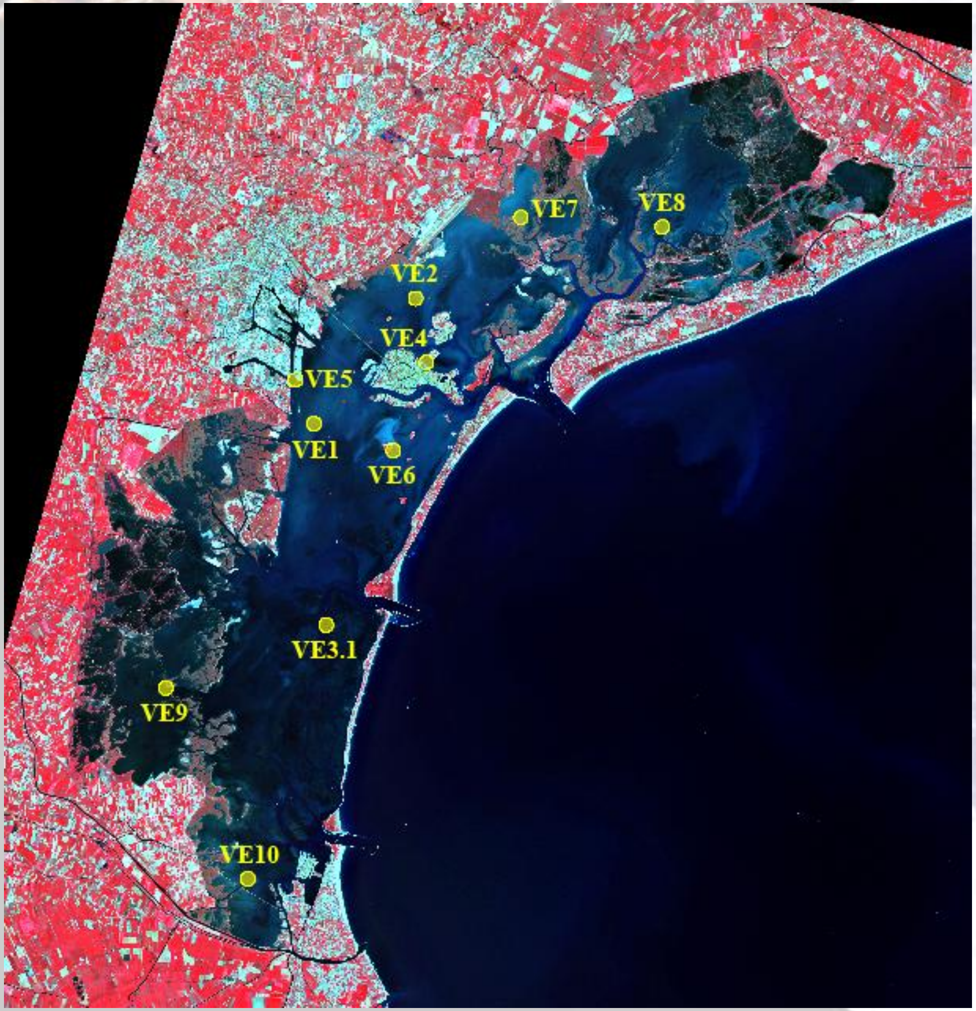
Qualità dell'acqua e trasporto dei sedimenti in laguna di Venezia

Misure puntuali di qualità dell’acqua

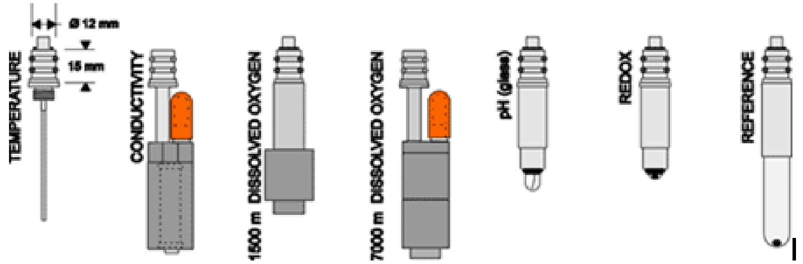


10 sonde multiparametriche ospitate in coffe registrano dati meteo e di qualità dell’acqua ogni 30 minuti. Il primo sito è stato installato nel 2001.

Misure puntuali di qualità dell'acqua

Idronaut's OCEAN SEVEN 316 CTD multiparameter probe:

IDRONAUT Sensors



SENSOR SPECIFICATIONS

	Range	Accuracy	Resolution	Time Constant
Pressure	0.. 1000 dbar*	0.05 %full scale	0.03 %	50 ms
Temperature	-3.. +50 °C	0.003 °C	0.0007 °C	50 ms
Conductivity	0.. 64 mS/cm	0.003 mS/cm	0.001 mS/cm	50 ms (at 1m/second flow rate)
Oxygen	0.. 25 ppm 0.. 250 % sat.	0.1 ppm 1 % sat.	0.01 ppm 0.1 % sat.	3 s (in air) 3 s
pH	0.. 14 pH	0.01 pH	0.001 pH	3 s
Redox	-1000.. +1000 mV	1 mV	0.1 mV	3 s
Auxiliary inputs	0.. 5000 mV	1 mV	0.076 mV	50 ms (6 auxiliary analogue inputs)

Misure puntuali di qualità dell'acqua

Seapoint Chlorophyll Fluorometer:

The SCF uses modulated blue LED lamps and a **blue excitation filter to excite chlorophyll *a*.**
The **fluorescent light emitted by chlorophyll *a* passes through a red emission filter** and is detected by a silicon photodiode. The low level signal is then processed using synchronous demodulation circuitry which generates an **output voltage proportional to chlorophyll *a* concentration.**
Excitation Wavelength = 470nm
Emission Wavelength = 685nm

Misure puntuali di qualità dell'acqua

Seapoint Turbidity Meter:

The Seapoint Turbidity Meter detects light scattered by particles suspended in water, generating an **output voltage proportional to turbidity or suspended solids.**
Light Source Wavelength = 880nm

Misure puntuali di qualità dell'acqua

A121 | f_x 9/1/2009

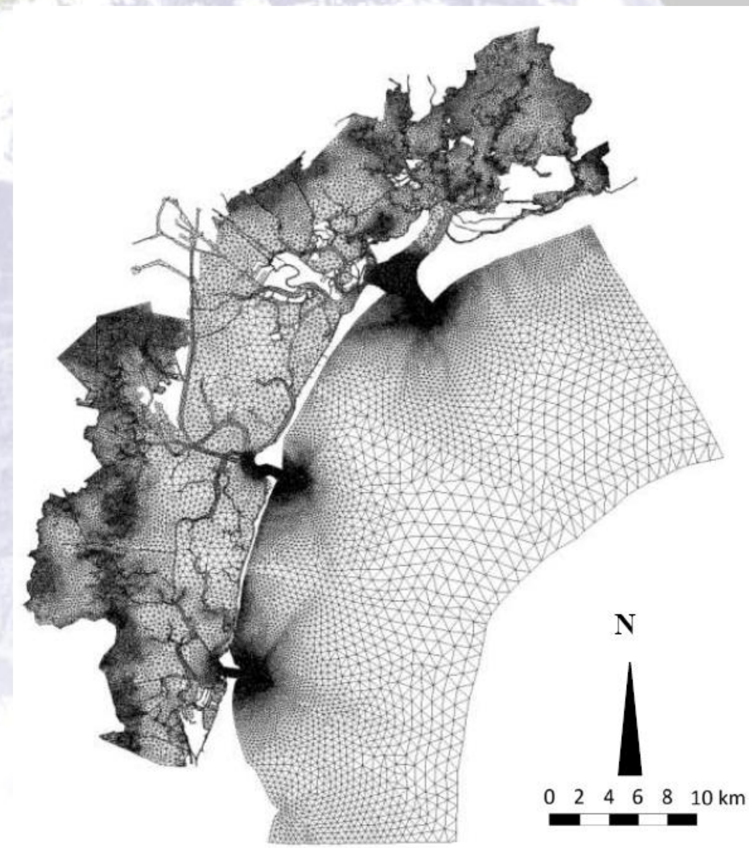
	A	B	C	D	E	F	G	H	I	J	K	L
1	Data	Ora	Press	Temp	Cond	Sal	O2 perc	O2 ppm	pH	Eh	Chla	Torb
2			m	°C	mS/cm	PSU	%	mg/L	pH Unit	mV	microg/L	FTU
3	7/24/2009	12:00:00 AM	0.79	28.0936	50.1927	30.7525	96.64	6.34	8.023	287.33	4.48	18.47
4	7/24/2009	12:30:00 AM	0.77	28.0463	50.3285	30.8762	91.9	6.03	8.004	286.26	3.35	18.26
5	7/24/2009	1:00:00 AM	0.72	27.8906	49.3269	30.2888	99.6	6.575	8.068	282.83	4.7	15.84
6	7/24/2009	1:30:00 AM	0.664	27.8235	49.1632	30.2196	95.4	6.31	8.056	284.51	3.97	15.84
7	7/24/2009	2:00:00 AM	0.59	27.4814	44.8422	27.4678	95.9	6.478	8.125	282.82	11.29	29.75
8	7/24/2009	2:30:00 AM	0.5	27.5102	45.3693	27.8111	94.24	6.35	8.115	283.62	10.65	182.9
9	7/24/2009	3:00:00 AM	0.43	27.5837	45.028	27.5347	89.3	6.02	8.105	285.07	10.96	30.67
10	7/24/2009	3:30:00 AM	0.35	27.5911	45.2808	27.7029	85.7	5.77	8.093	284.71	9.07	31.08
11	7/24/2009	4:00:00 AM	0.26	27.449	44.2795	27.1026	84.82	5.742	8.104	283.07	9.54	36.3
12	7/24/2009	4:30:00 AM	0.18	27.4528	44.524	27.2673	84.9	5.74	8.092	282.19	9.23	33.8
13	7/24/2009	5:00:00 AM	0.09	27.2002	43.7001	26.8501	78	5.31	8.058	278.19	8.63	51.7
14	7/24/2009	5:30:00 AM	0.0485	27.58375	44.3644	27.0828	75.67	5.11	8.066	269.305	6.28	62.255
15	7/24/2009	6:00:00 AM	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
16	7/24/2009	6:30:00 AM	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
17	7/24/2009	7:00:00 AM	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
18	7/24/2009	7:30:00 AM	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
19	7/24/2009	8:00:00 AM	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999
20	7/24/2009	8:30:00 AM	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999	-9999

from the Venice Water Authority data base

Per la qualità dell'acqua, integriamo misure puntuali e dati satellitari in un MODELLO MATEMATICO

High temporal resolution

Hydrodynamic and transport /resuspension model

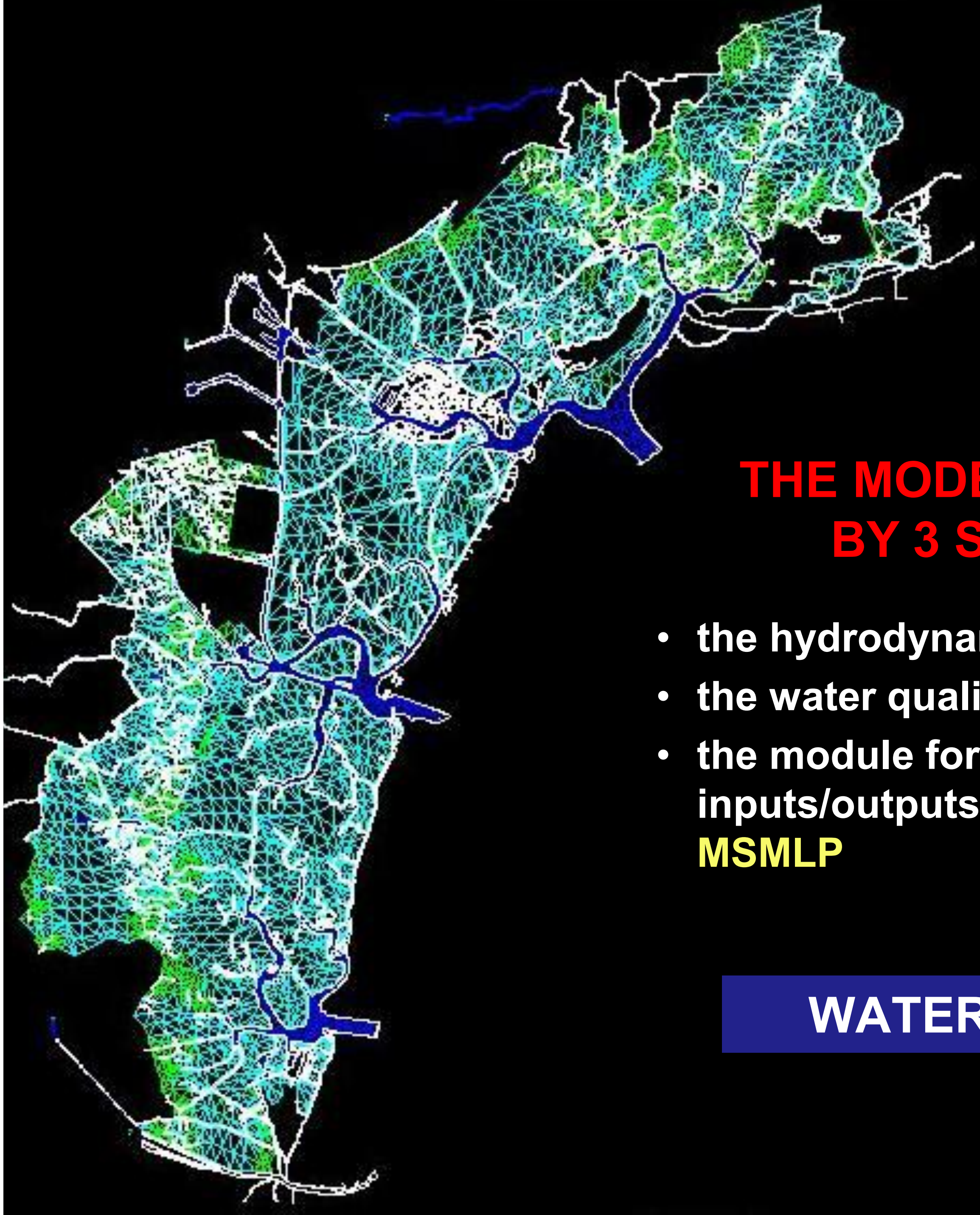


High spatial resolution

Esempio di utilizzo di:

- Modello idrodinamico
- Osservazione da sonde
- Dato satellitare

per simulare la dinamica della temperatura dell'acqua



2D FINITE ELEMENT HYDRODYNAMIC MODEL (Garzon, 2003) 15, 000 elements

THE MODEL IS COMPOSED BY 3 SUB-MODELS:

- the hydrodynamic sub-model: MEFHP
- the water quality sub-model: MEFDP
- the module for the integration of inputs/outputs with remotely sensed data: MSMLP

WATER TEMPERATURE

Landsat 5 TM 19/09/2001 9:39 GMT: initial water temperature conditions

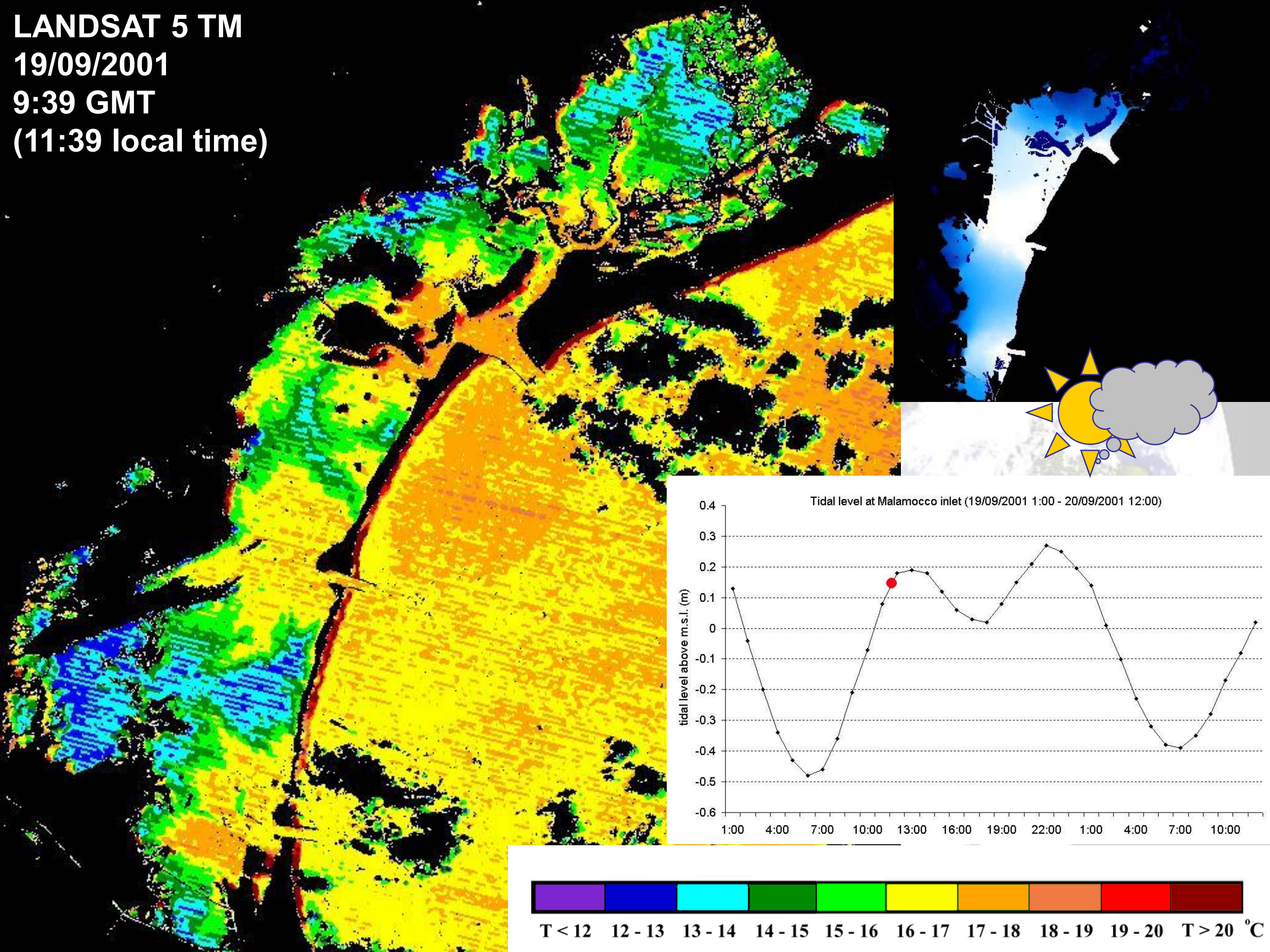
Landsat 7 ETM+ 20/09/2001 9:41 GMT: final condition

Radiometric calibration

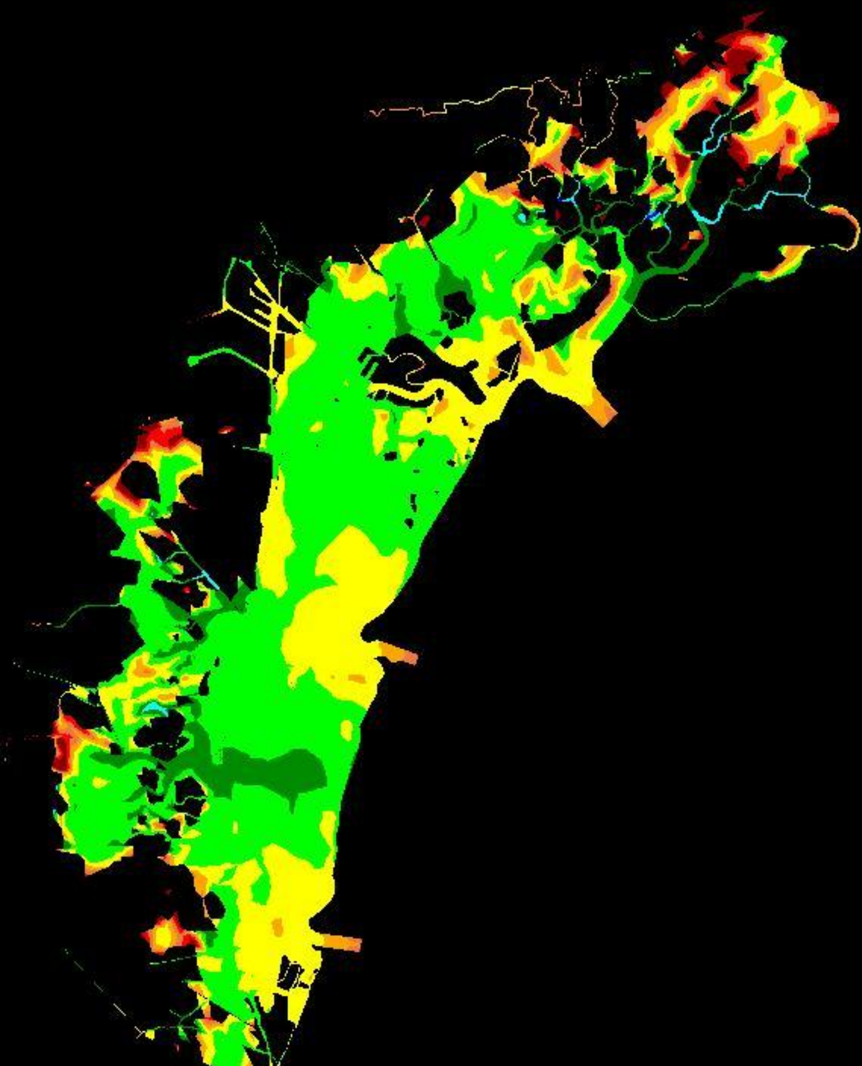
Atmospheric correction (ATCOR 2 based on MODTRAN 4.2)

Geocoding

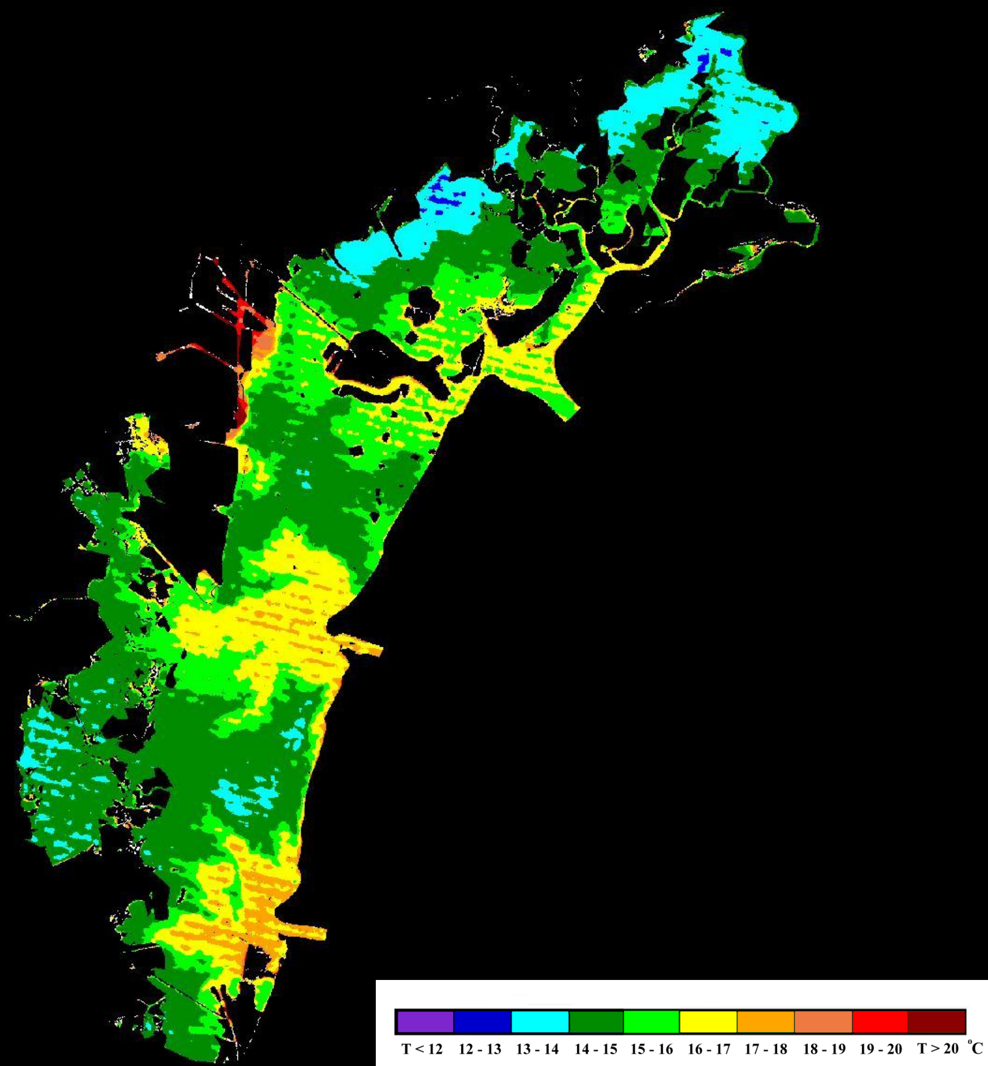
Intervallo di lunghezza d'onda delle bande TM ed ETM+ (µm) (da ltpwww.gsfc.nasa.gov/IAS/handbook/handbook_htmls/chapter8/chapter8.html, 2001)								
Sensor	**Band 1**	**Band 2**	**Band 3**	**Band 4**	**Band 5**	**Band 6**	**Band 7**	**Band 8**
TM	0.45 - 0.52	0.52 - 0.60	0.63 - 0.69	0.76 - 0.90	1.55 - 1.75	10.4 - 12.5	2.08 - 2.35	N/A
ETM+	0.45 - 0.52	0.53 - 0.61	0.63 - 0.69	0.78 - 0.90	1.55 - 1.75	10.4 - 12.5	2.09 - 2.35	.52 - .90


LANDSAT 5 TM
19/09/2001
9:39 GMT
(11:39 local time)
Tidal level at Malamocco inlet (19/09/2001 1:00 - 20/09/2001 12:00)
tidal level above m.s.l. (m)
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
1:00
4:00
7:00
10:00
13:00
16:00
19:00
22:00
1:00
4:00
7:00
10:00
T < 12
12 - 13
13 - 14
14 - 15
15 - 16
16 - 17
17 - 18
18 - 19
19 - 20
T > 20
°C

Model output after 24h
20/09/2001
9:40 GMT (11:40 local time)



LANDSAT 7 ETM+
20/09/2001
9:41 GMT (11:41 local time)

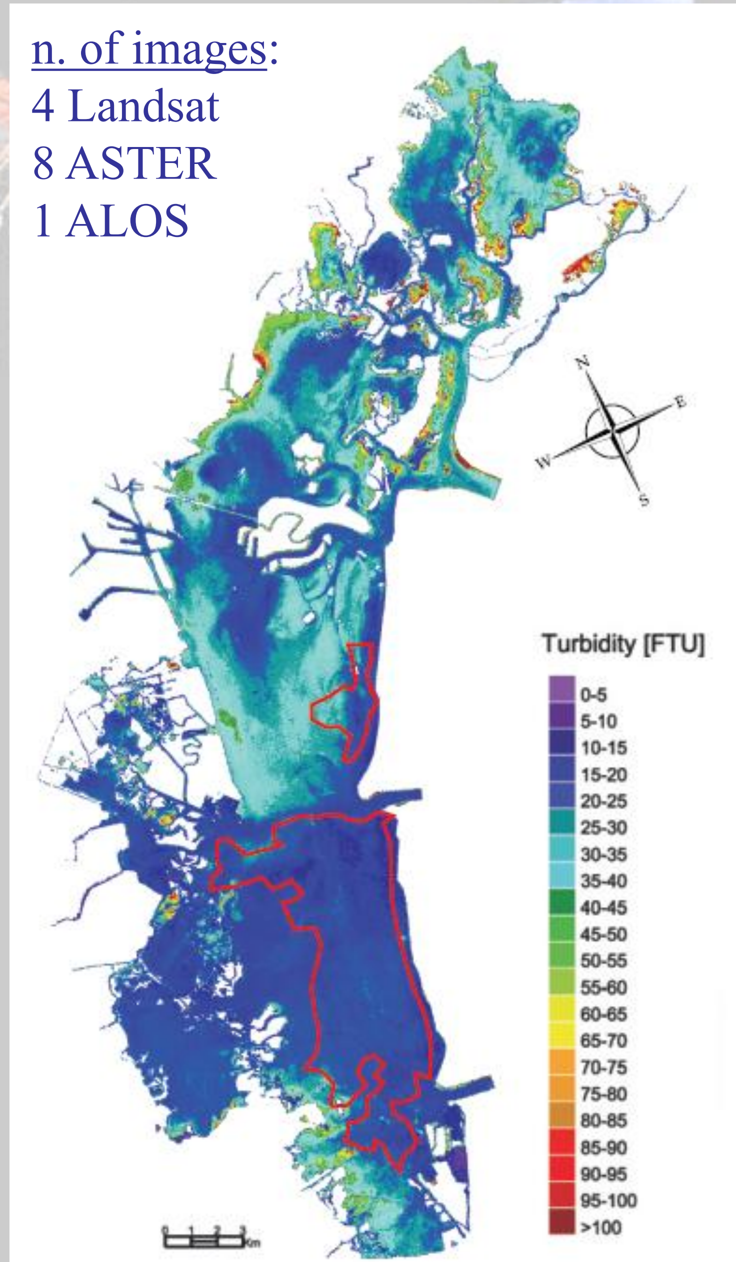


PROCESSI	?	METODI DI MONITORAGGIO
Livello del mare	→	Mareografi; remote sensing
Subsidenza	→	DGPS; reti GPS; radar remote sensing (Interferometria)
Qualità dell'acqua Trasporto sedimenti	→	Campagne di misura; sonde multiparametriche; remote sensing
Batimetria Topografia	→	Multi- and single-beam; remote sensing (LiDAR)
Vegetazione emersa/sommersa Morfologia dei lidi	→	Campagne di misura; remote sensing

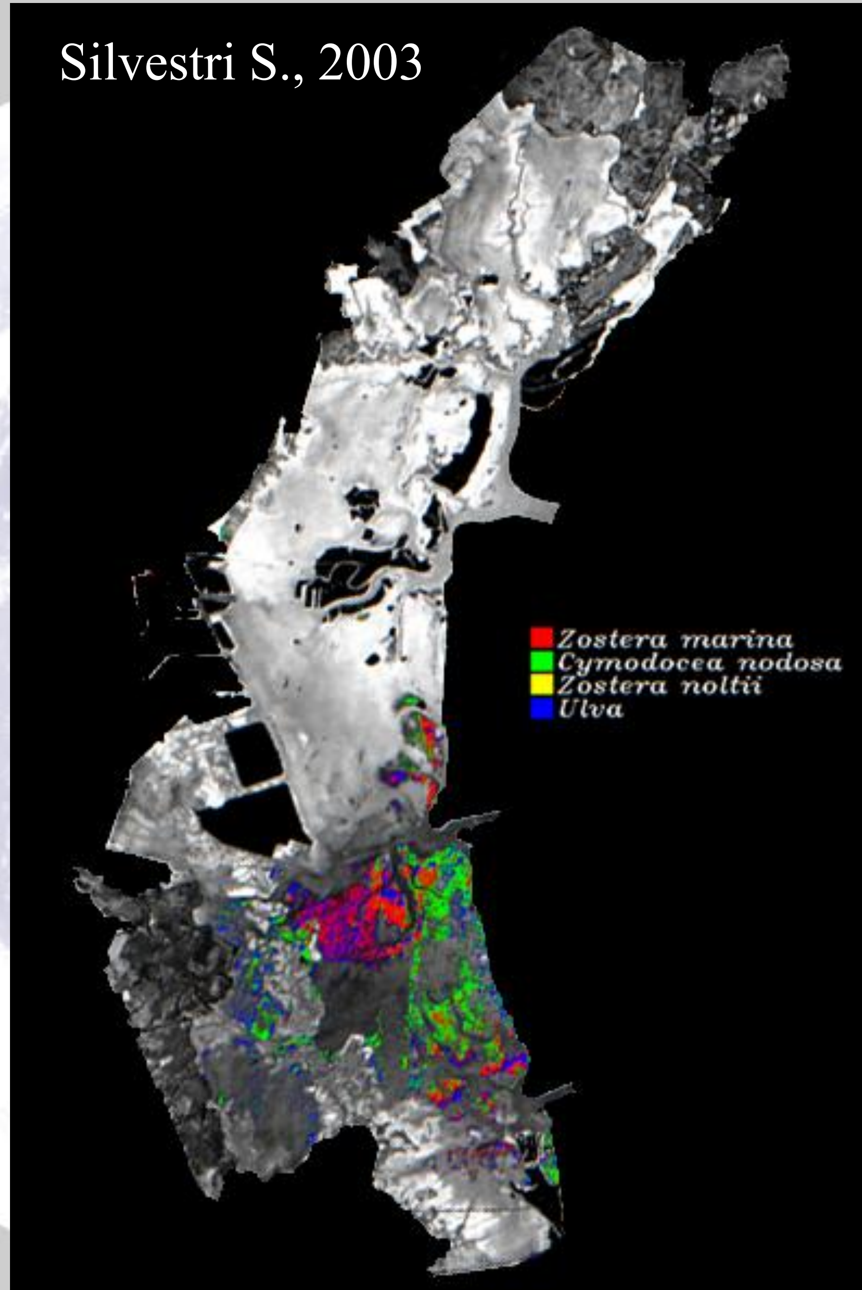
REMOTE SENSING AND MODELS

Mean turbidity

Landsat 7 ETM 18 May 2002



Volpe et al. RSE 2011



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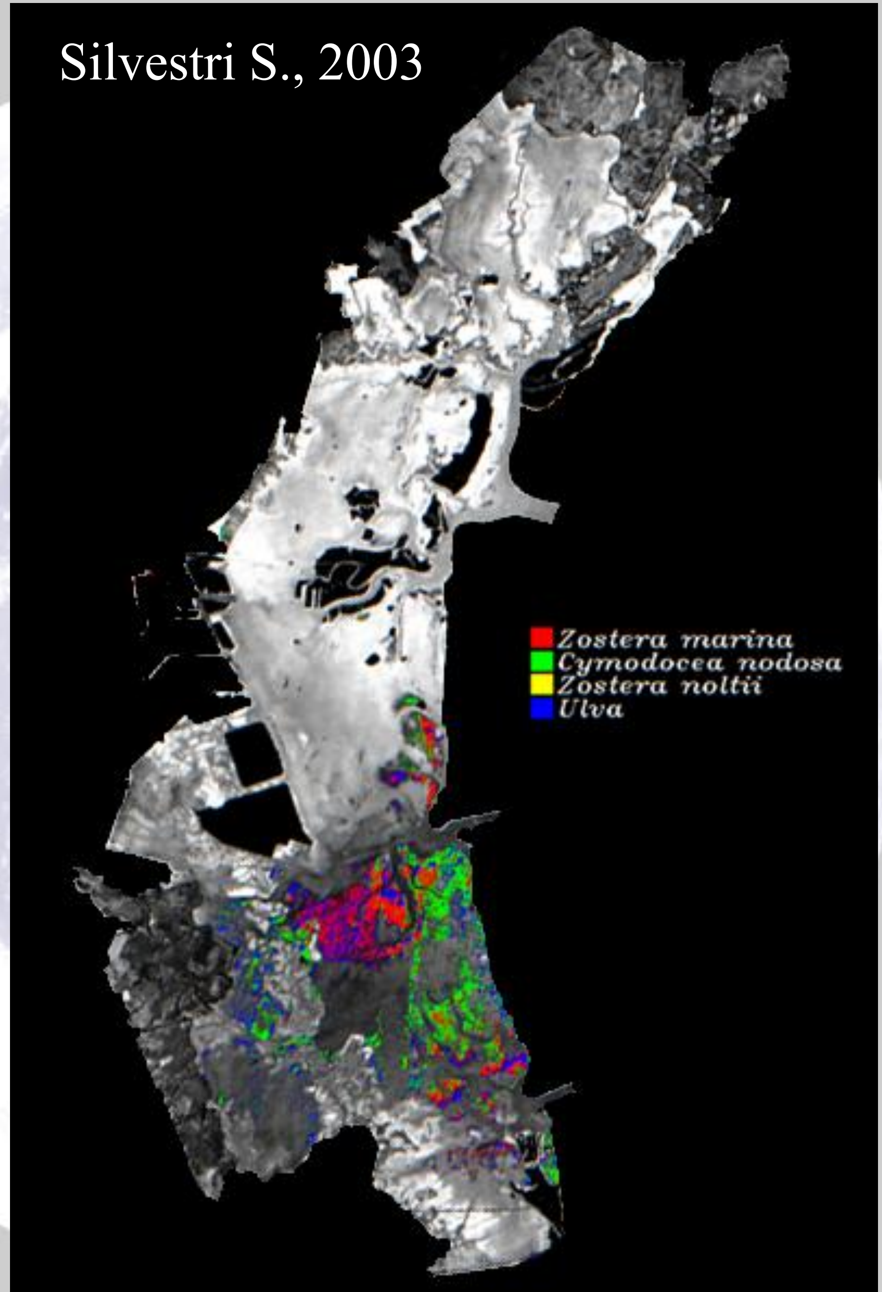

Messaggi da portare con te…

- Il **sea level rise** sta già avendo forte impatto sulle nostre coste, esacerbato dall'azione umana di **estrazione di acqua** dagli acquiferi
- **Ci dobbiamo adattare** spostandoci verso l'interno. Alcune città vanno protette con opere di ingegneria
- Il **MONITORAGGIO** delle coste è fondamentale, e va effettuato con **misure puntuali accoppiate all'osservazione da remoto**
- Solo integrando misure puntuali e dati da remoto **con i modelli matematici** siamo in grado di studiare i fenomeni costieri e prevedere cosa accadrà in futuro

Grazie dell’attenzione !!

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