Satellite-Derived Bathymetry

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Objectives

Understand the rationale and assumptions underlying the depth of penetration zone for mapping bathymetry

Derive maximum depth of penetration estimates for Landsat OLI bands

Combine satellite and field data to define depth of penetration (DOP) zones and display a crude bathymetry map

Refine the bathymetry map by interpolation using DOP zone

Investigate the limitations of the method

Theory of bathymetry mapping using remote sensing

Different wavelengths of light penetrate water to varying degrees

When light passes through water it becomes attenuated by interaction with the water column

The intensity of light, I_d, remaining after passage length p through water, is given by:

$$I_d = I_0 \, e^{-pKd}$$

I_0 = intensity of the incident light and Kd = attenuation coefficient, which varies with wavelength

When light passe the length p and back to the surface, It determines the depth as:

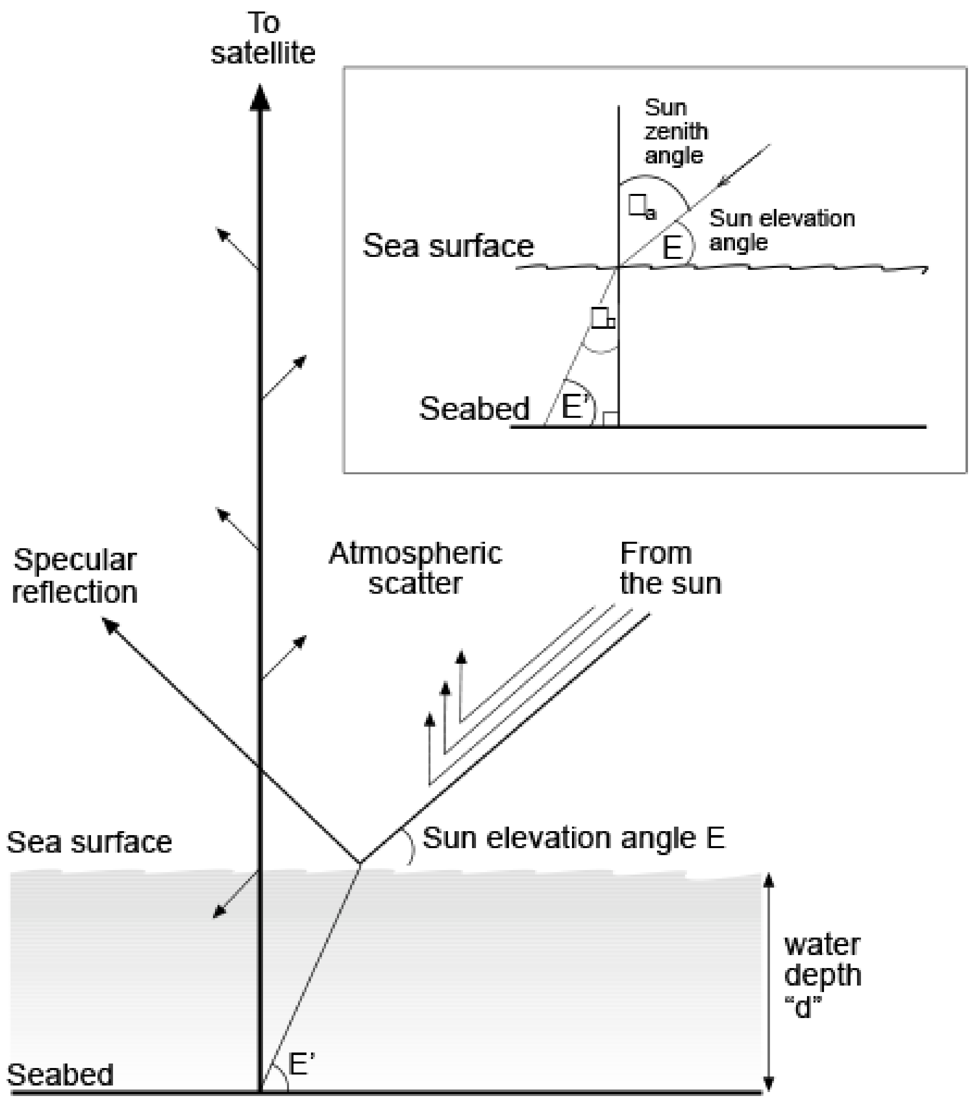
$$Ln(I_d) = Ln(I_0) - 2dKd$$

d = Depth, for vertical view above water

Longer wavelength light (red) has a higher attenuation coefficient than short wavelengths (blue)

Red light attenuates rapidly in water and does not penetrate further than a few meters

Theory of bathymetry mapping using remote sensing



For water of depth *d*, the length of that path is equal to

$$d + d.cos(E')$$

$$I_d = R.I_0\, e^{-Kd\, *\, d(1\, +\, cos(E))}$$

where *R* is the proportion scattered upwards from the seabed

Theory of bathymetry mapping using remote sensing

The radiance from deep water (L_d), and shallow water will be:

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$$L = L_d + R.I_0\, e^{-Kd * d(1 + cos(E))}$$

The ratio of the radiance from two different depths, *x* and *y*, is:

$$\frac{L_x - L_d}{L_y - L_d} = \frac{R.I_0.e^{-k.x(1+cosec(E'))}}{R.I_0.e^{-k.y(1+cosec(E'))}}$$

In a very shallow water

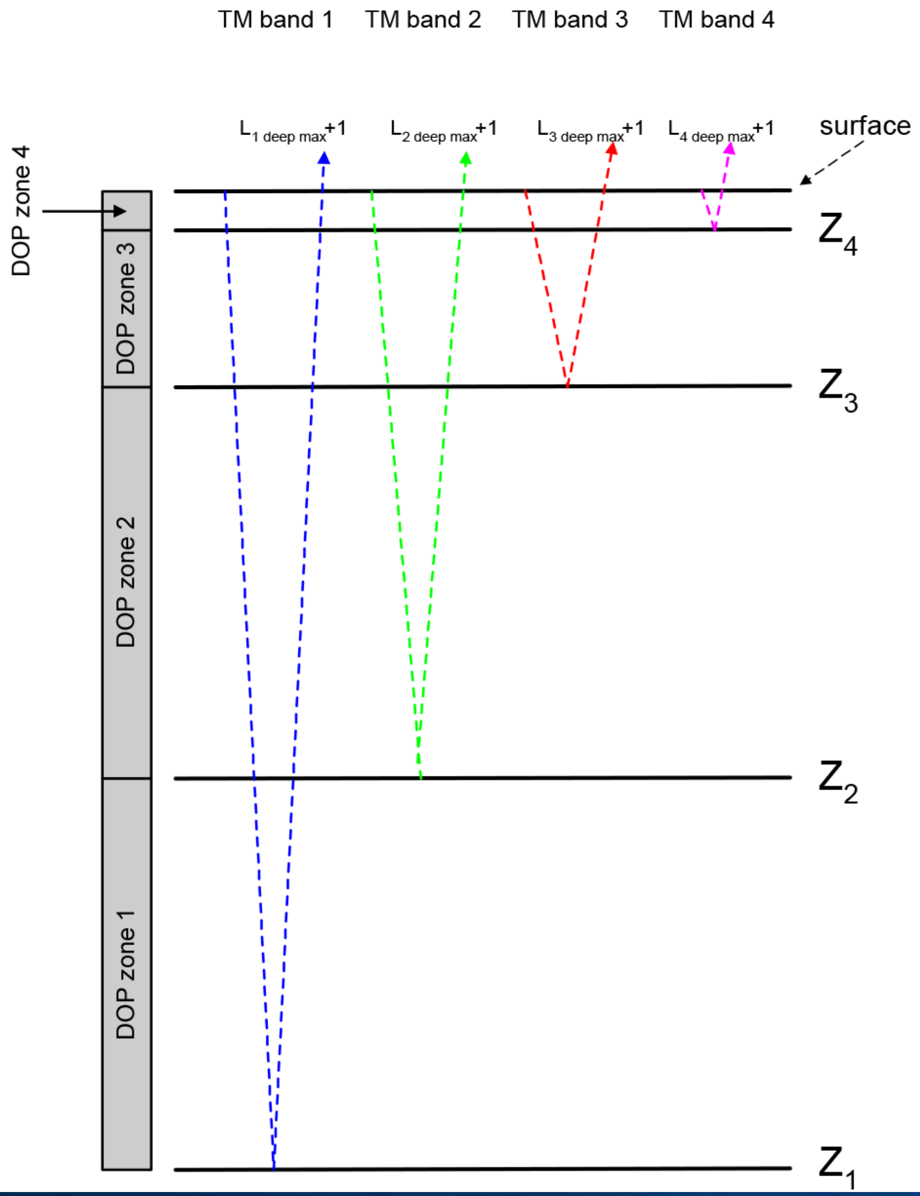
$$\frac{L_x - L_d}{L_0 - L_d} = e^{-k.x(1+cosec(E'))}$$

$$depth\ x = \frac{log_e(L_x - L_d) - log_e(L_0 - L_d)}{-k(1 + cosec(E'))}$$

Theory of bathymetry mapping using remote sensing

- Blue light penetrates much further and in clear water
- The seabed can reflect enough light to be detected by a satellite sensor
- The depth of penetration is dependent on water turbidity, Suspended sediment particles, phytoplankton and dissolved organic Matters
- Water constituents absorb light, thus increasing attenuation
- SAR imagery has provided information on bathymetry, although the highly specific conditions of sea state and currents necessary

Theory of bathymetry mapping using remote sensing



Depth of penetration zones (DOP zones)

DOP zones does not assign a depth to each pixel

DOP assigns a pixel to a depth range

For Landsat sensors

Landsat TM band *i*	Depth of penetration z_i
1	25 m
2	15 m
3	5 m
4	1 m

Major applications of satellite-derived bathymetry

Planning hydrographic surveys

Mapping transportation corridors

Updating/augmenting existing charts

Coastal sediment accumulation/loss

Mapping shipping hazards

Assisting interpretation of underwater features

Satellite-derived bathymetry maps have not been used as a primary source of bathymetric data for navigational purposes

Interactive Lecture

Interactive Lecture

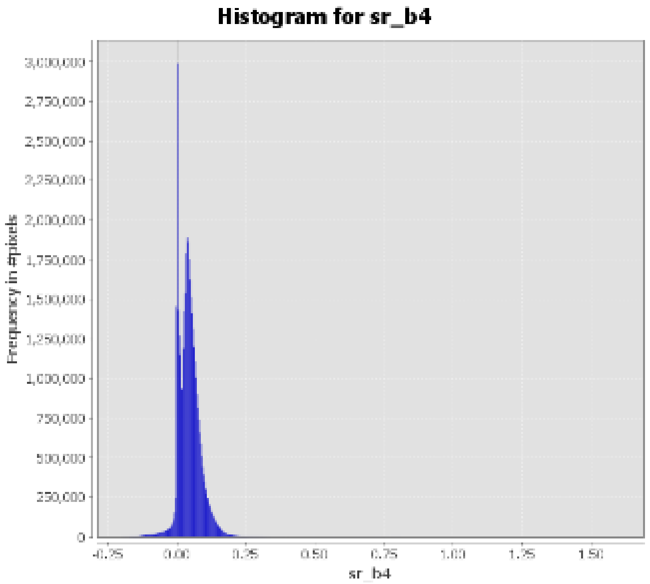
Open ArcGIS Project, review data

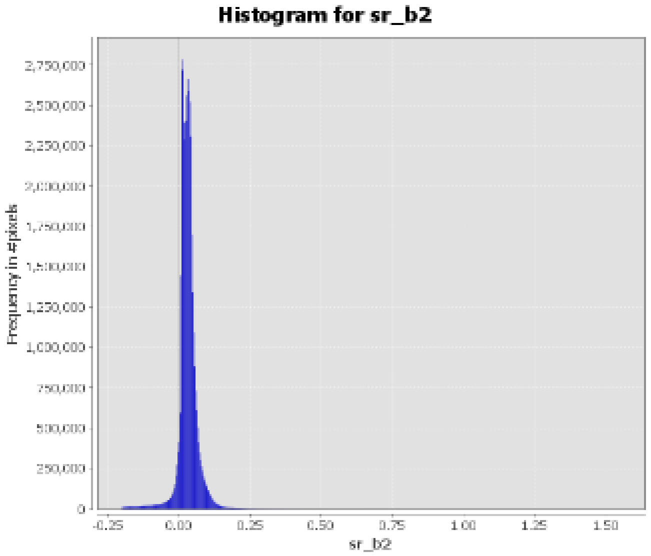
Open Landsat OLI L2, Review bands and masks

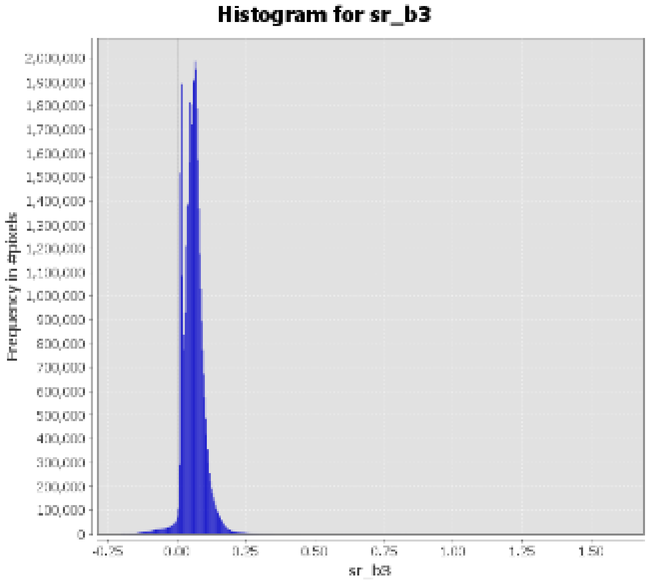
Calculating depth of penetration zones

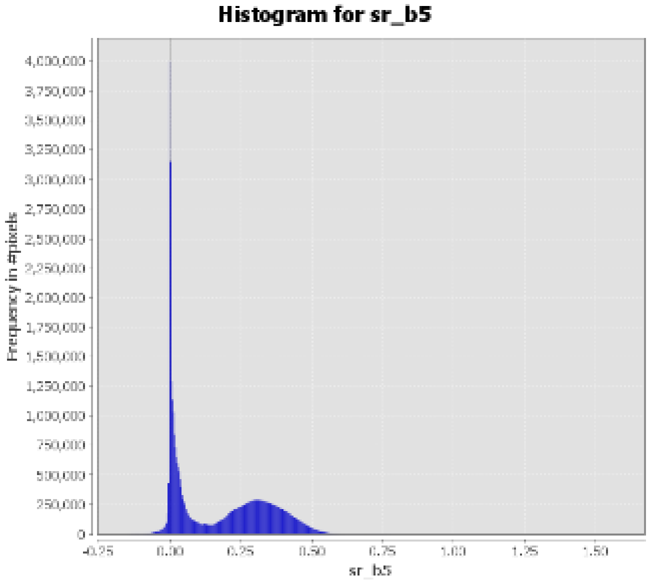
- The reflectance from deep water would be close to zero
- But because it has not although no light is being reflected back from the deep ocean the sensors will be
- Recording significant radiance values because of atmospheric scattering
- The highest radiance values over deep water provides a baseline
- For each waveband, if radiance values are greater than the maximum deep water values then we assume the sensor is detecting light reflected from the seabed
- Maximum and minimum pixel values over deep water are examined using histogram of deepwater pixels
- The maximum deepwater ($L_{deep\ max}$), minimum deepwater ($L_{deep\ min}$) and modal deepwater ($L_{deep\ mean}$) radiance values for bands 1-4

Interactive Lecture









Open Excel Field data, Review it

Pixels with DN values > 57 should thus be at less than the maximum depth of penetration

The deepest site was recorded as 25.35 m deep and has a radiance value of 61 which is greater than 57 indicating some bottom reflectance

Find the first pixel in the waveband with a radiance value > $L_{deep\ max}$ for that waveband.
Move down the column until you find the last pixel which has a value < $L_{deep\ max}$.
This determines a range of depths between which *zi* must lie

Decision tree to assign pixels to depth zones

Landsat TM band	1	2	3	4	DOP zones
Deepwater maximum DN	57	16	11	5	
If DN value (L_i) of pixel	≤57	≤16	≤11	≤5	then depth > 20.8 m
If DN value (L_i) of pixel	>57	≤16	≤11	≤5	then depth = 13.5-20.8 m (zone 1)
If DN value (L_i) of pixel	>57	>16	≤11	≤5	then depth = 4.2-13.5 m (zone 2)
If DN value (L_i) of pixel	>57	>16	>11	≤5	then depth = 1.0-4.2 m (zone 3)
If DN value (L_i) of pixel	>57	>16	>11	>5	then depth = 0-1.0 m (zone 4)

If none of these conditions apply, then pixels are coded to 0

DOP zones does not assign a depth to each pixel, instead it assigns a pixel to a depth range (e.g; z1-z2)

Next, interpolating depths for each pixel within each DOP zone

$$L_i = L_{i\ deep\ mean} + (L_{i\ surface} - L_{i\ deep\ mean}) * e^{-2Kd_i \cdot Z}$$

$$L_i - L_{i\ deep\ mean} = (L_{i\ surface} - L_{i\ deep\ mean}) * e^{-2Kd_i \cdot Z}$$

If we define: $$X_2 = \mathrm{Ln}(L_i - L_{i\ deep\ mean})$$

Then: $$X_2 = \mathrm{Ln}(\underbrace{L_{i\ surface} - L_{i\ deep\ mean}}_{\text{Constant}}) - 2Kd_i \cdot Z$$

$$X_i = A_i - 2Kd_i \,.\, Z_i$$

If a pixel is only just inside DOP zone 2 as opposed to DOP zone 1 (the zone with the next lowest coefficient of attenuation 0:

$$X_{i\ min} = A_i - 2Kd_i \,.\, Z_i$$

$$X_{i\ max} = A_i - 2Kd_i \,.\, Z_{i+1}$$

Then

$$Kd_i = [X_{i\ max} - X_{i\ min}] \,/\, [2 * (Z_i - Z_{i+1})]$$

$$A_i = X_{i\ min} + 2Kd_i \,.\, Z_i$$

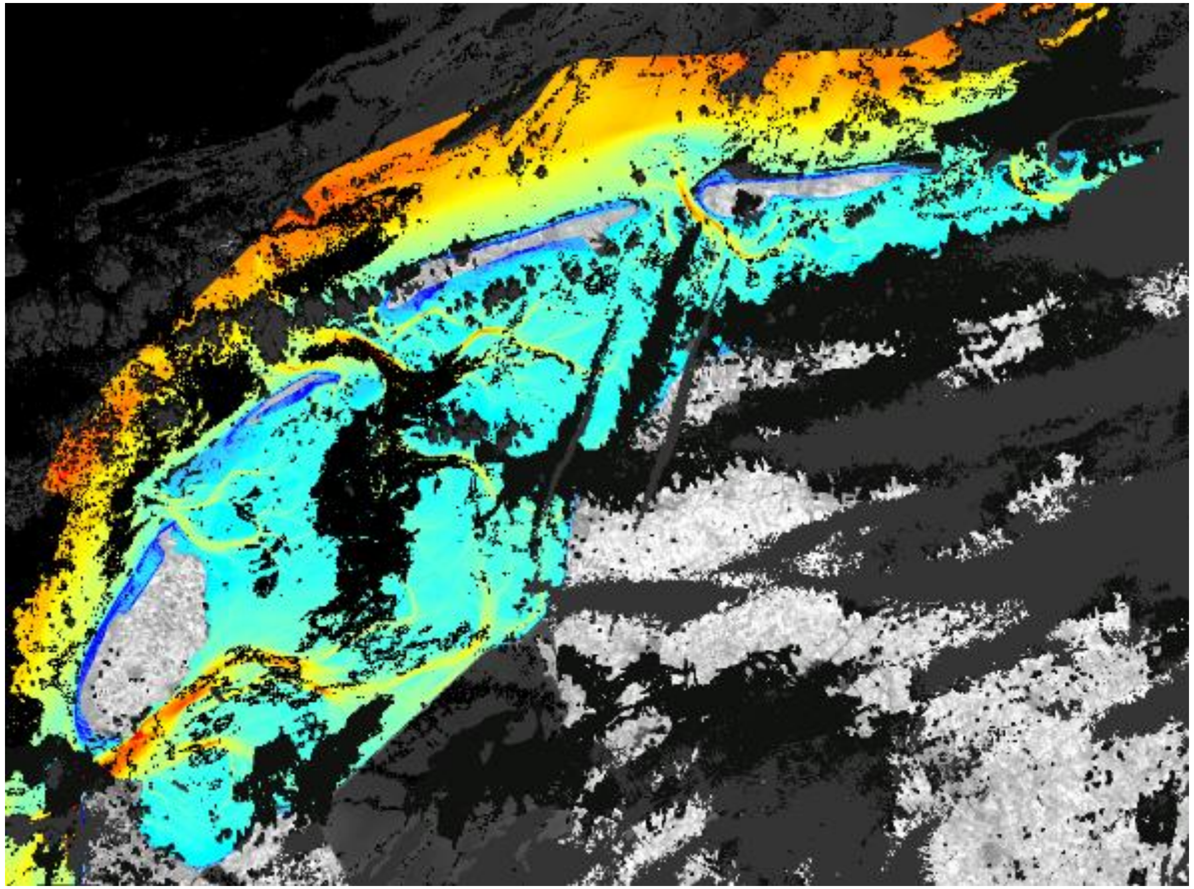
finally

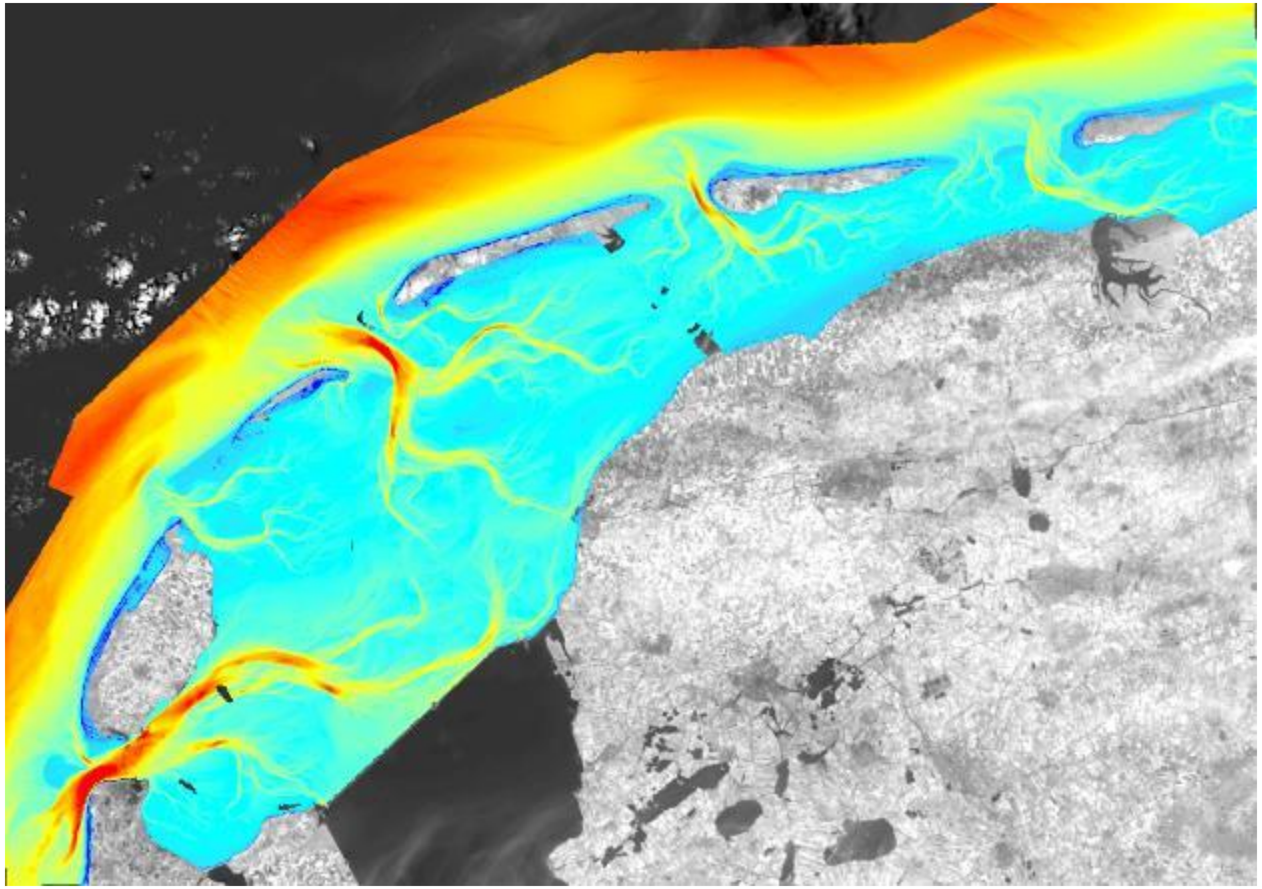
$$depth = [A_i - X_i] \,/\, 2 * Kd_i$$

Open the table of Li min and Li max in Excel, Review it

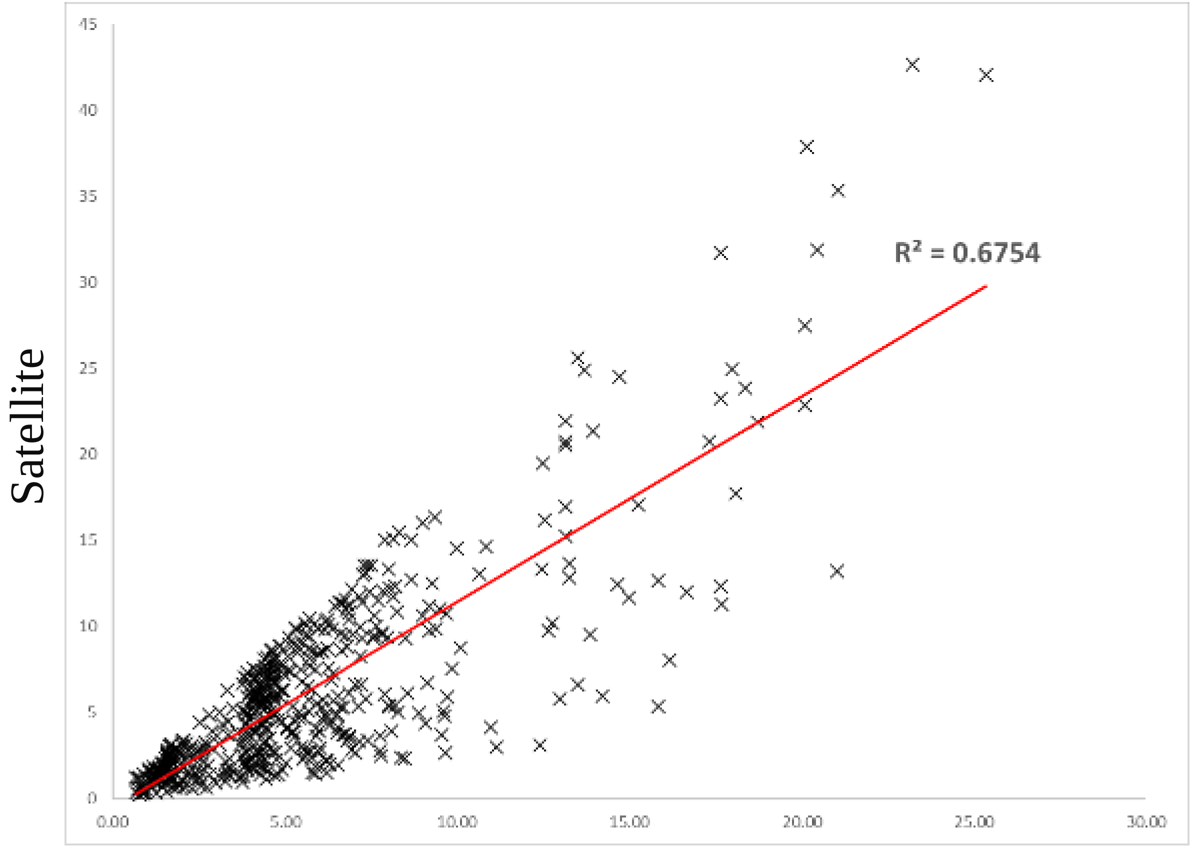
Interactive Lecture

Satellite-Derived Bathymetry





Accuracy assessment of the crude bathymetric map



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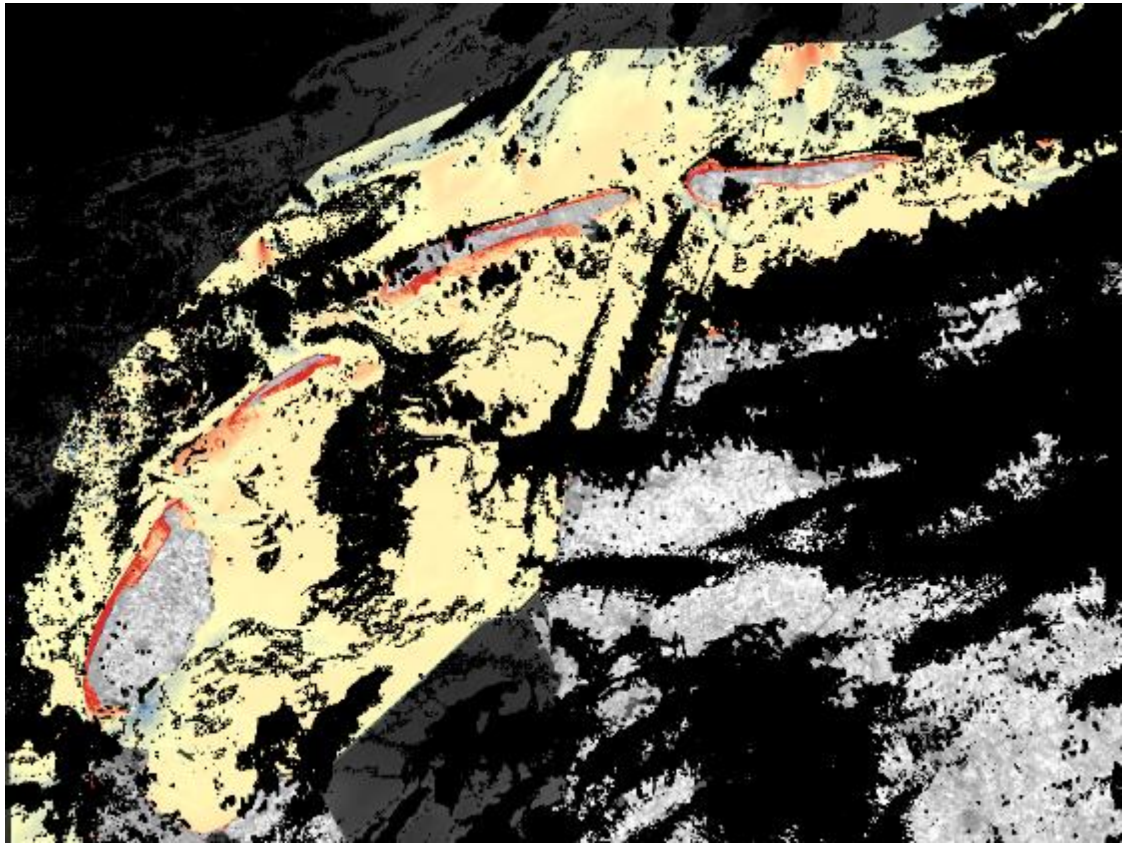

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Thank you