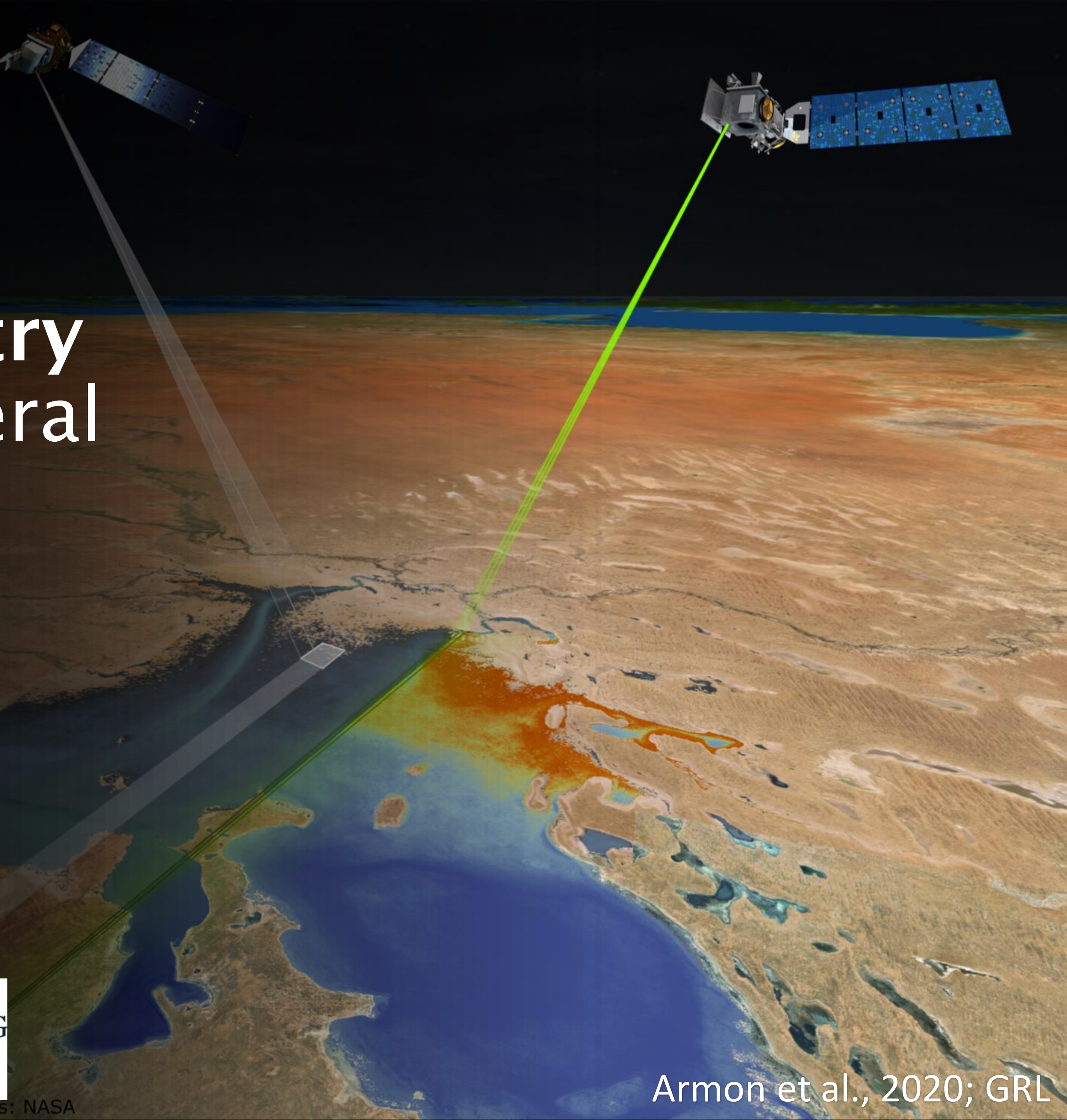
Determining **bathymetry** of shallow and ephemeral desert lakes using **satellite imagery and altimetry**



Moshe Armon, Elad Dente, Yuval Shmilovitz, Amit Mushkin, Efrat Morin, Tim J. Choen, and Yehouda Enzel

האוניברסיטה העברית בירושלים
THE HEBREW UNIVERSITY OF JERUSALEM
الجامعة العبرية في اورشليم القدس

GEOLOGICAL SURVEY OF ISRAEL

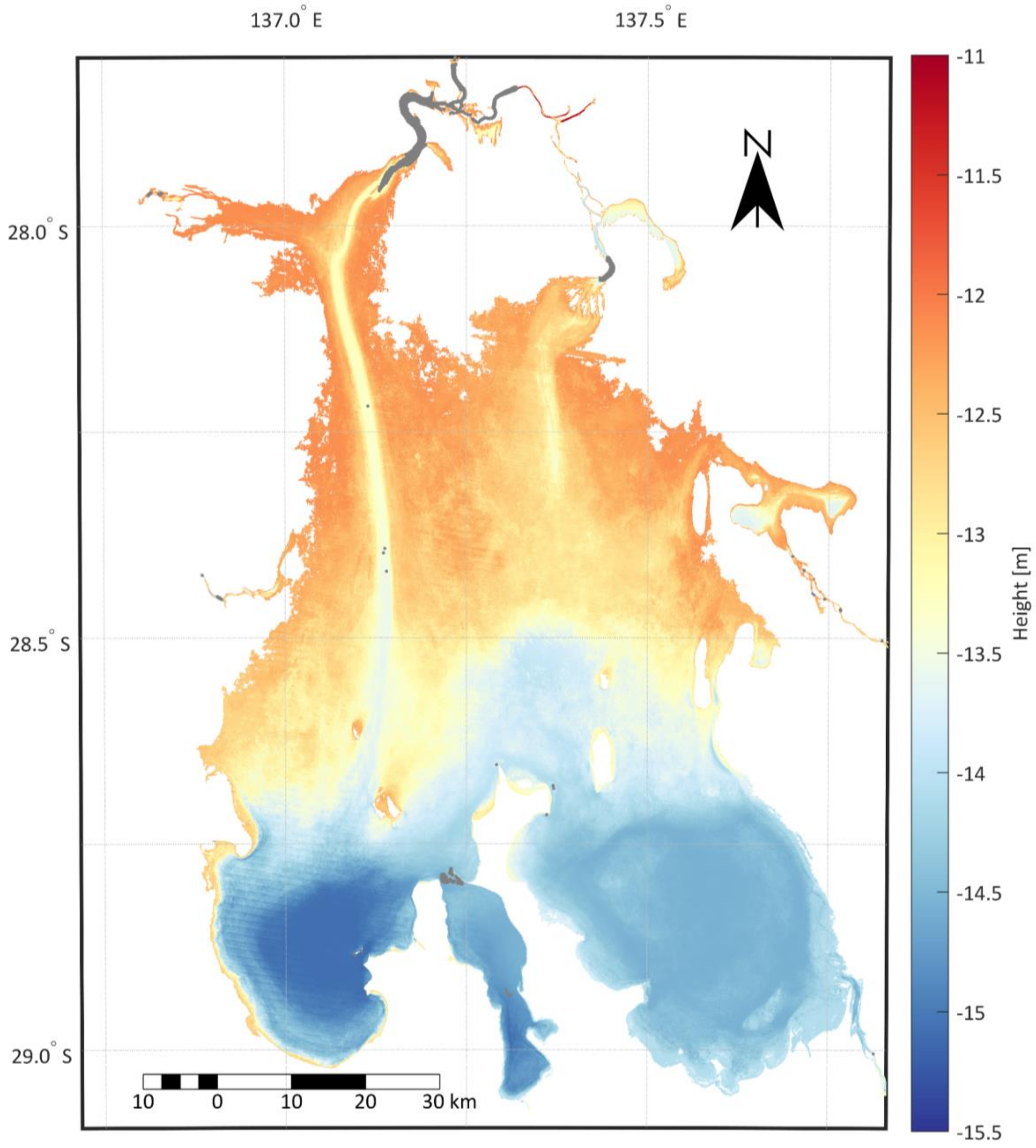
UNIVERSITY OF WOLLONGONG AUSTRALIA

italGlobe ; Satellite illustrations: NASA

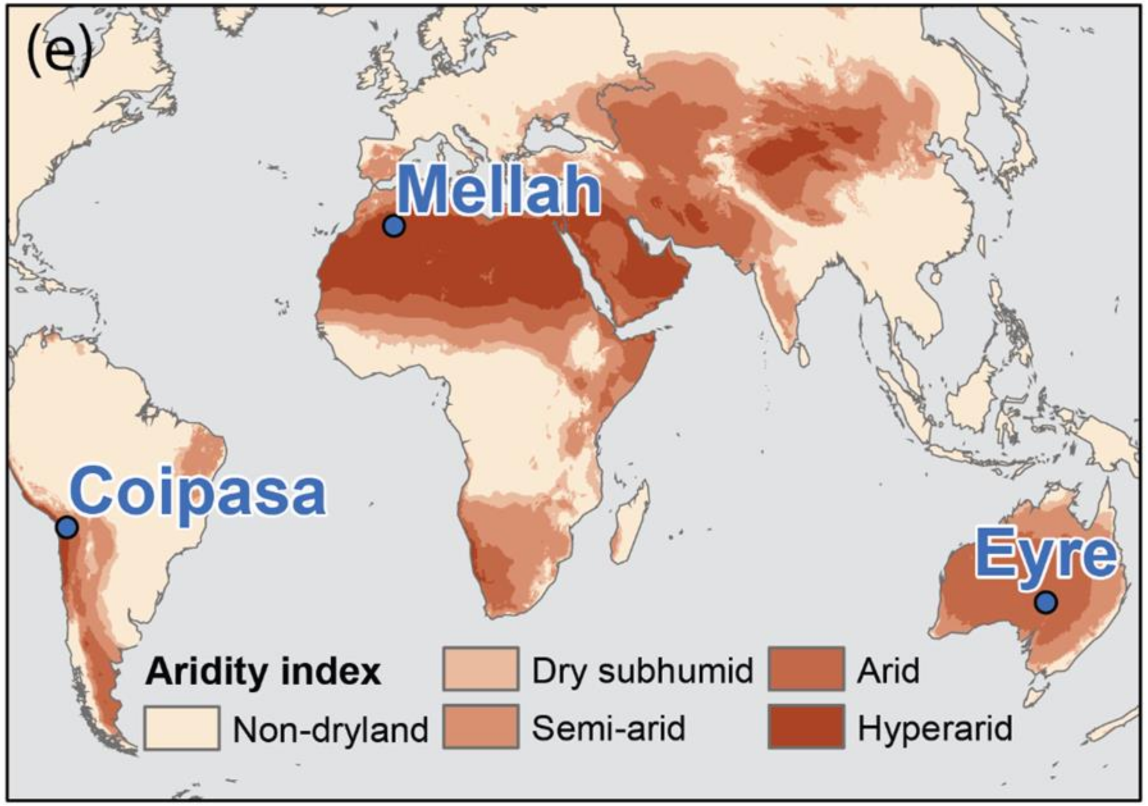
Armon et al., 2020; GRL

In short

- We developed a new methodology to produce **bathymetry maps of shallow desert lakes**, **based on globally available data sets**
- Our method enables mapping the bathymetry of **lakes partially flooded or consisting of subbasins**, both major limitations of other methods
- The derived bathymetry **error is ~30 cm**, rather than ~2.5 m for other globally available data



Contents



- Desert lakes
  - Bathymetry of desert lakes
- Methodology
  - ICESat-2
  - Water frequency maps
  - Relating water occurrence and elevation
- Results
  - Example #1: Multiple subbasins lake - Lake Eyre
  - Example #2: Non-surveyed lake - Sabkhat El-Mellah
  - Example #3: Inundated lake – Lago Coipasa
- Discussion and conclusions
- Appendix
- References

Desert lakes

- **Deserts** around the globe are characterized by **internal drainage systems**
- The inner part of these basins is often occupied by **ephemeral shallow desert lakes** (playas)
- These lakes are home to numerus opportunistic **species** and may serve as **water resources**
- They are also important in deciphering **paleohydrology**

Desert lakes

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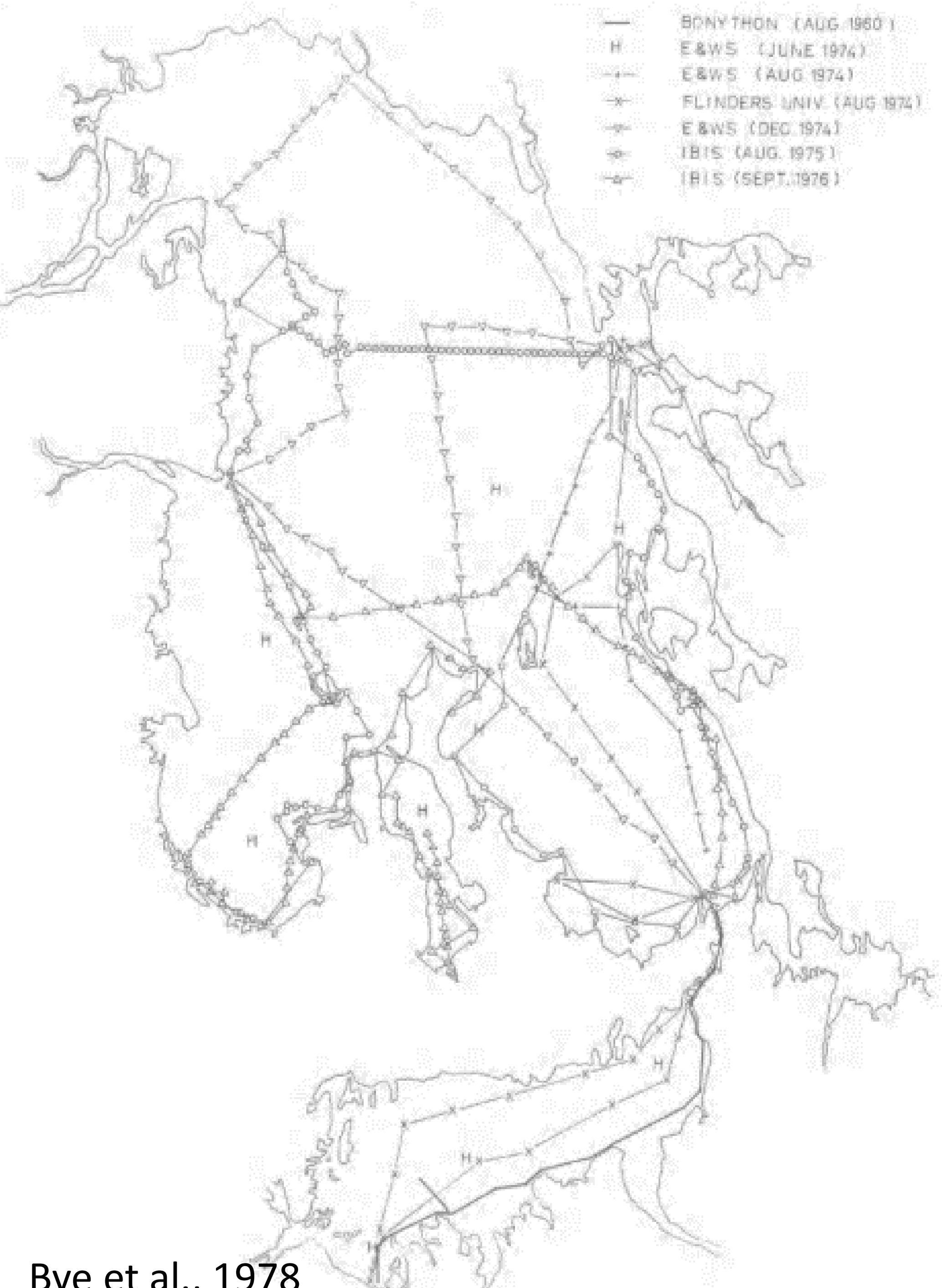
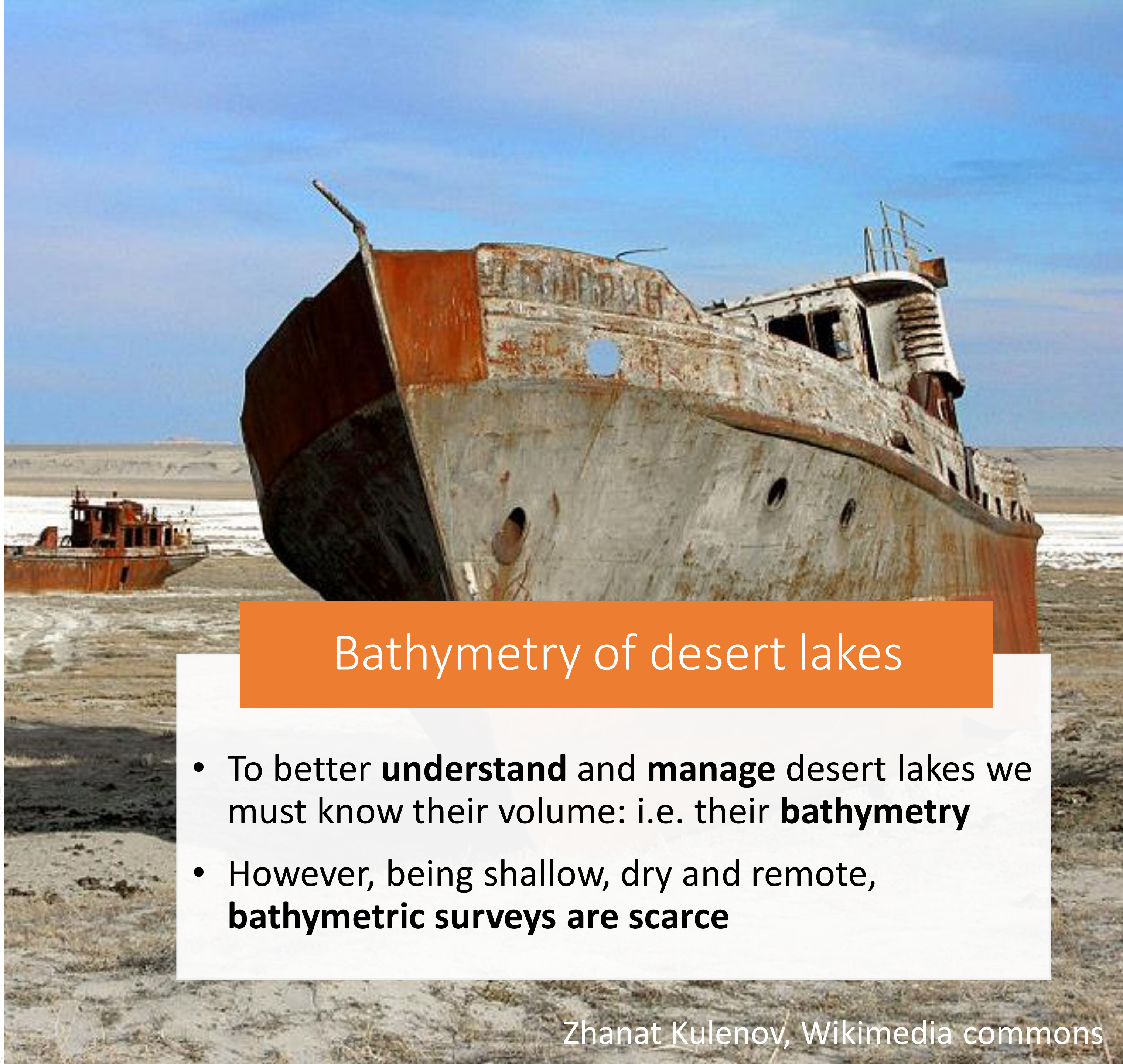


Bye et al., 1978



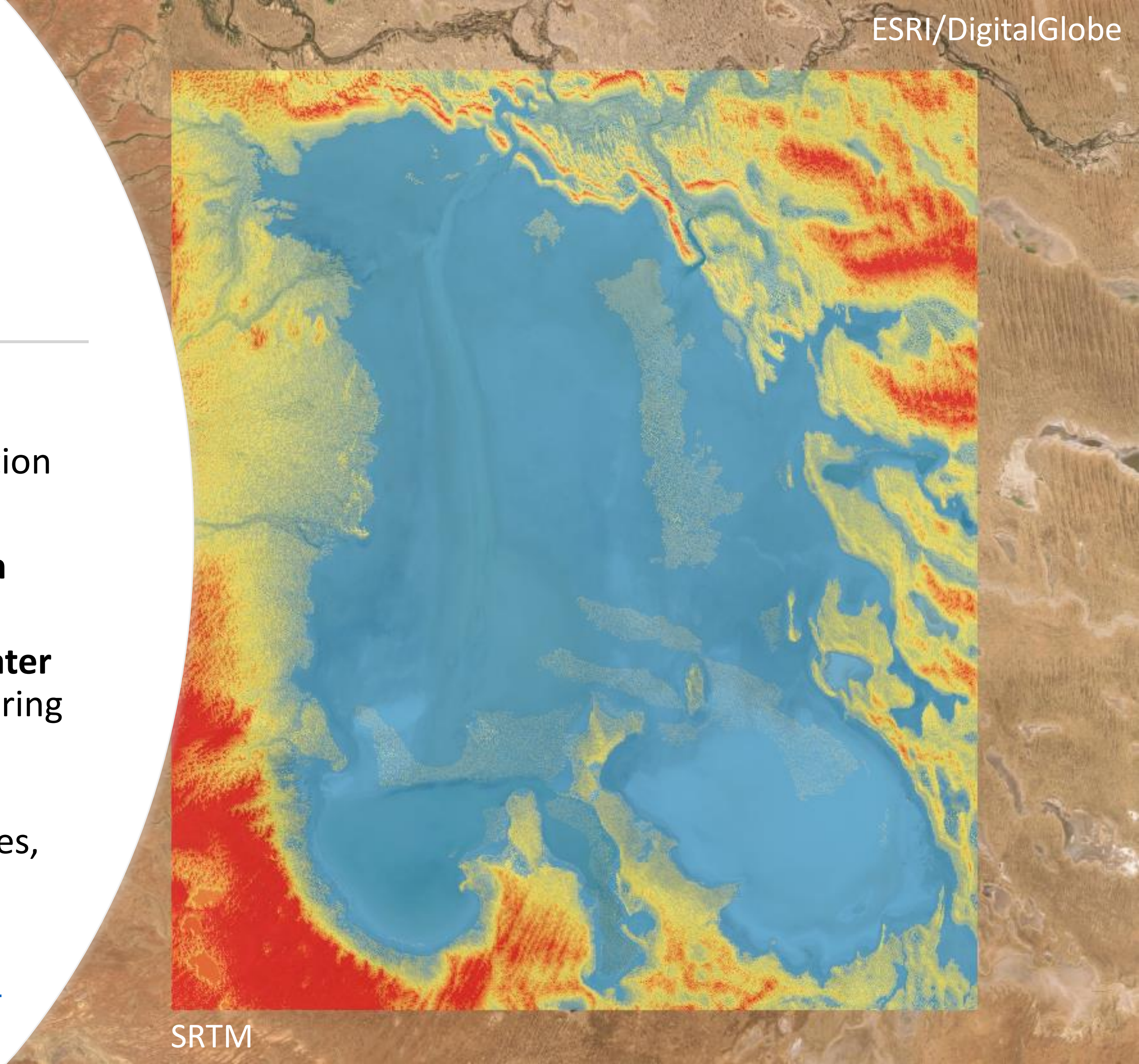
Bathymetry of desert lakes

- To better **understand** and **manage** desert lakes we must know their volume: i.e. their **bathymetry**
- However, being shallow, dry and remote, **bathymetric surveys are scarce**

Zhanat Kulenov, Wikimedia commons

Desert lakes' bathymetry from remote sensing

- The Shuttle Radar Topography Mission (**SRTM**) offers ~30 m global digital elevation models (DEMs)
- However, these have some **limitations in desert lakes**:
  - Radar signal could not penetrate **water** and thus lakes that were flooded during the SRTM DEM acquiring are misrepresented
  - Exceptionally bright and smooth lakes, as commonly observed in deserts, exhibit a large signal to noise ratio
  - Alternative methods described [here]



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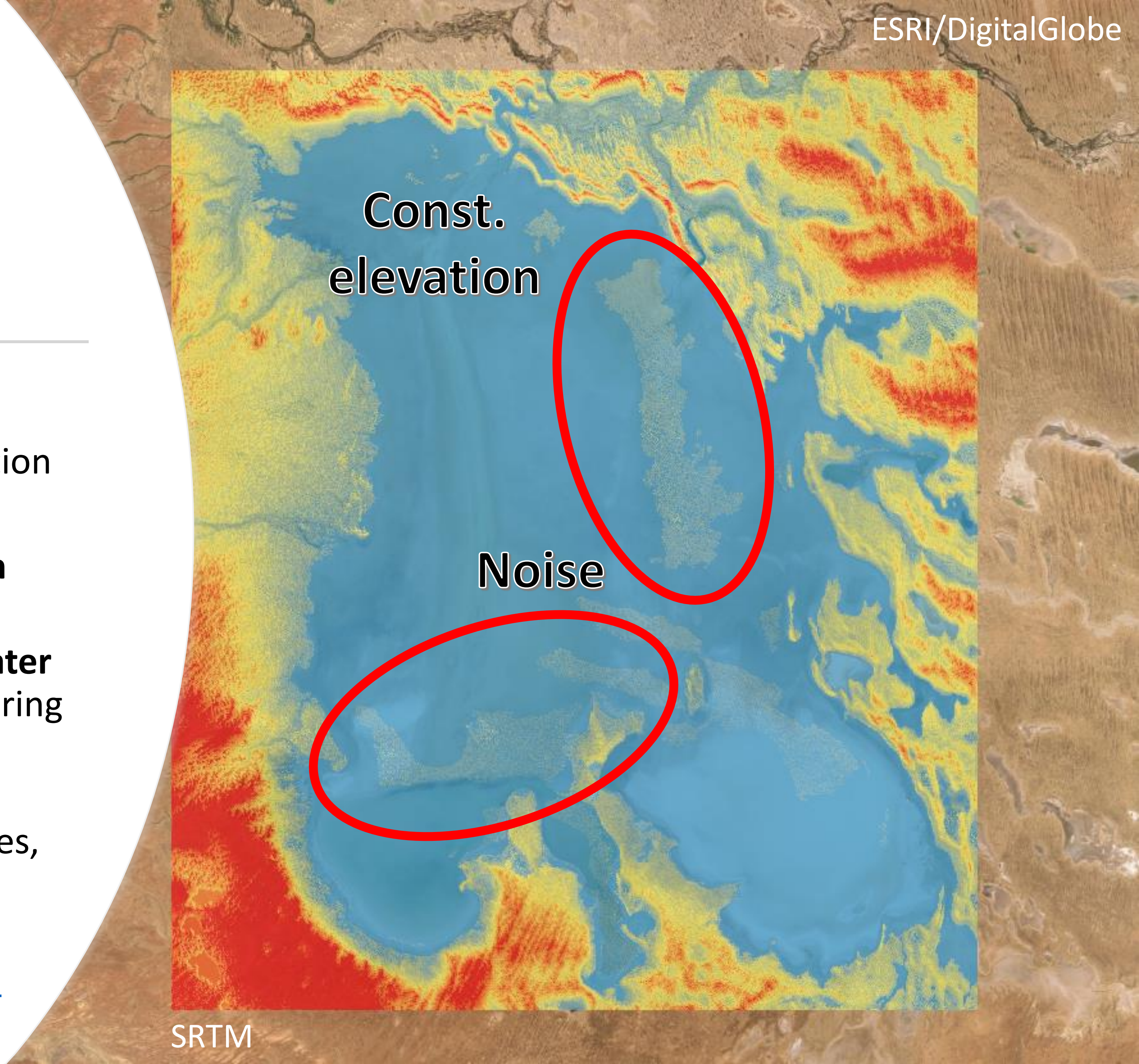
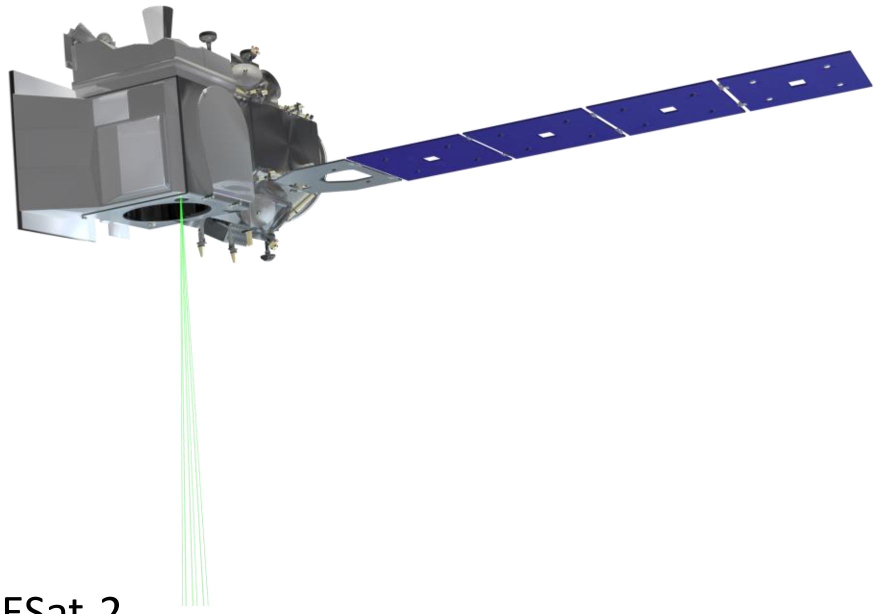
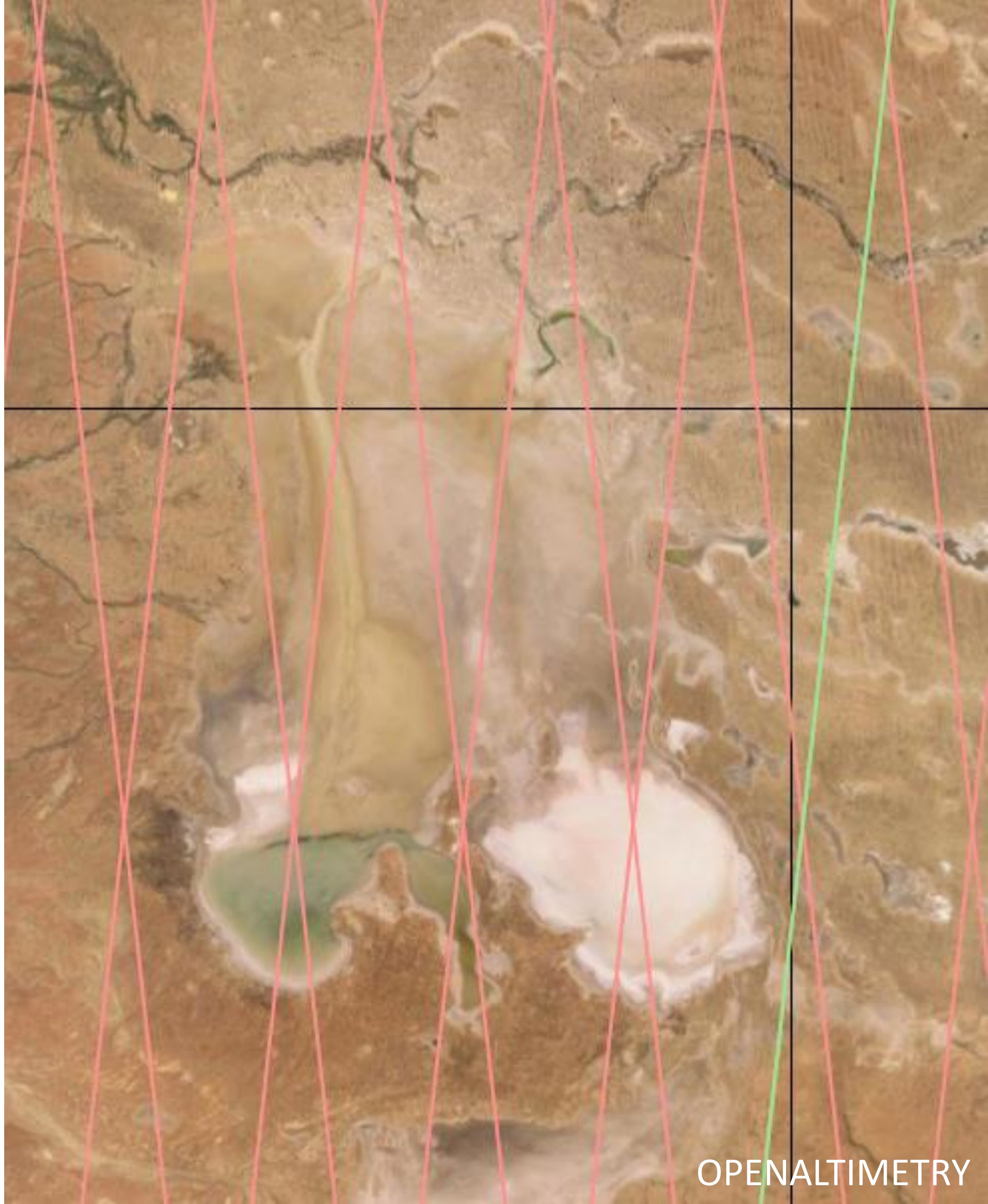


ICESat-2 laser altimetry

- The Ice, Cloud, and Land Elevation Satellite-2 (ICESat-2) measures dense and **accurate elevation measurements** over specific **narrow profiles**
- Global elevation data for these profiles are **freely available** at: OPENALTIMETRY

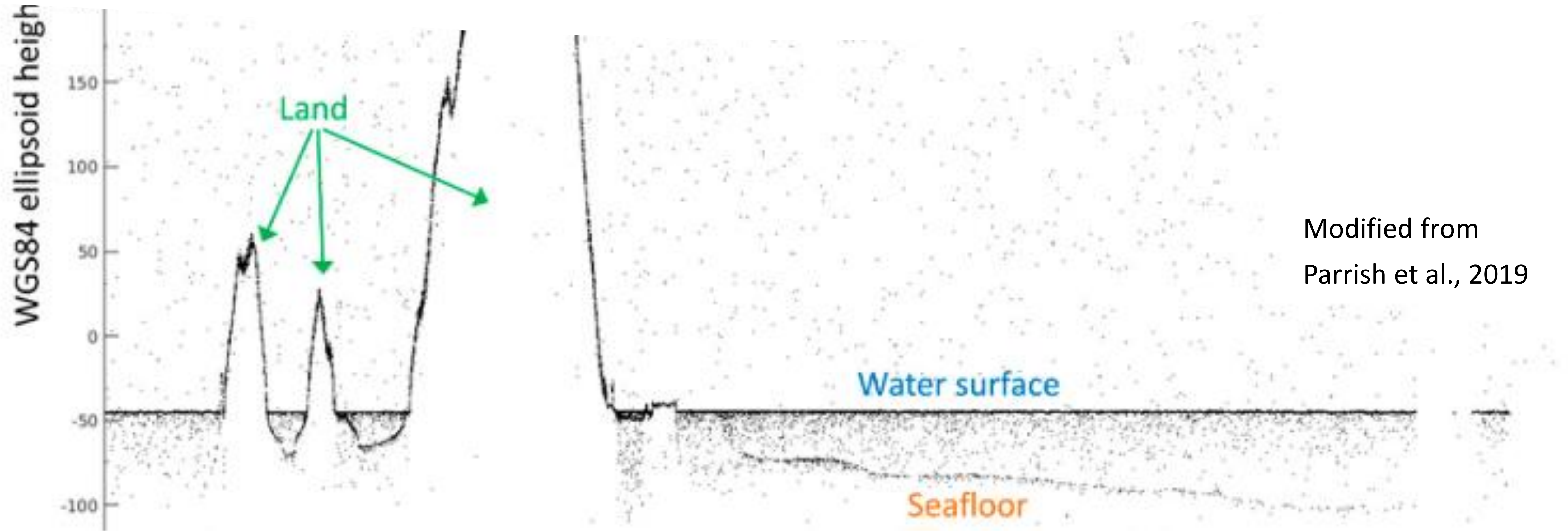


NASA: ICESat-2



ICESat-2 underwater measurements

- Green laser photons can **penetrate water** and give underwater measurements up to few or even **few dozens of meters**
- However, they are only measured over **specific profiles**



Modified from

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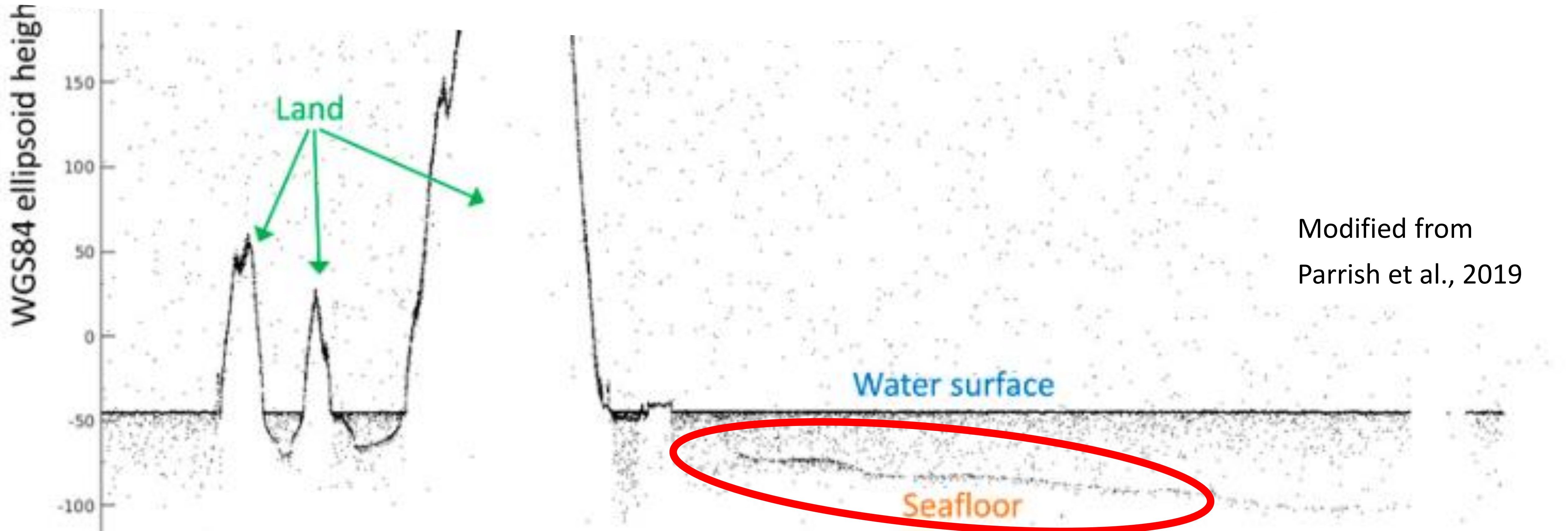


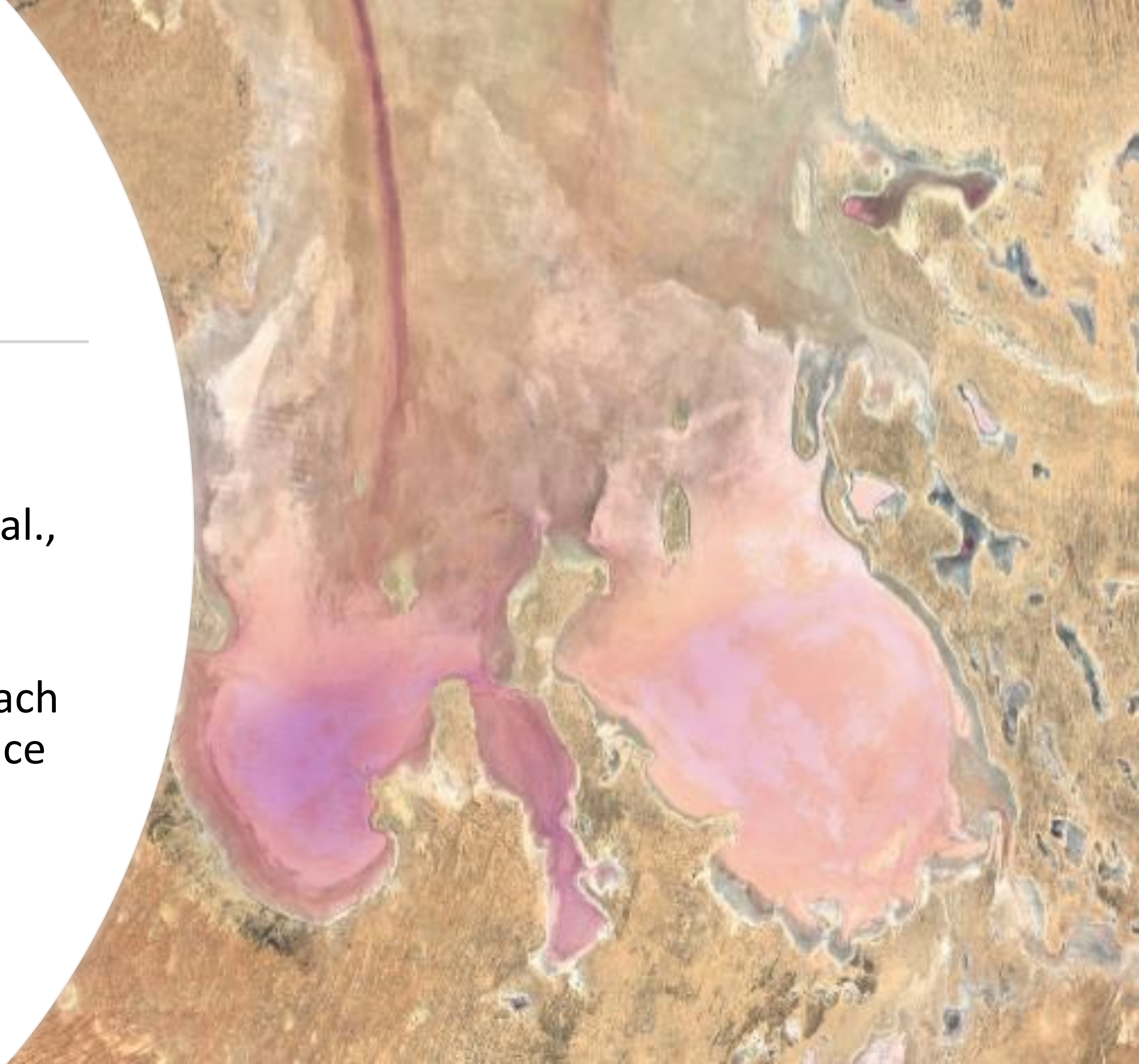
Modified from

Parrish et al., 2019

So how can we derive spatial lake bathymetry maps?

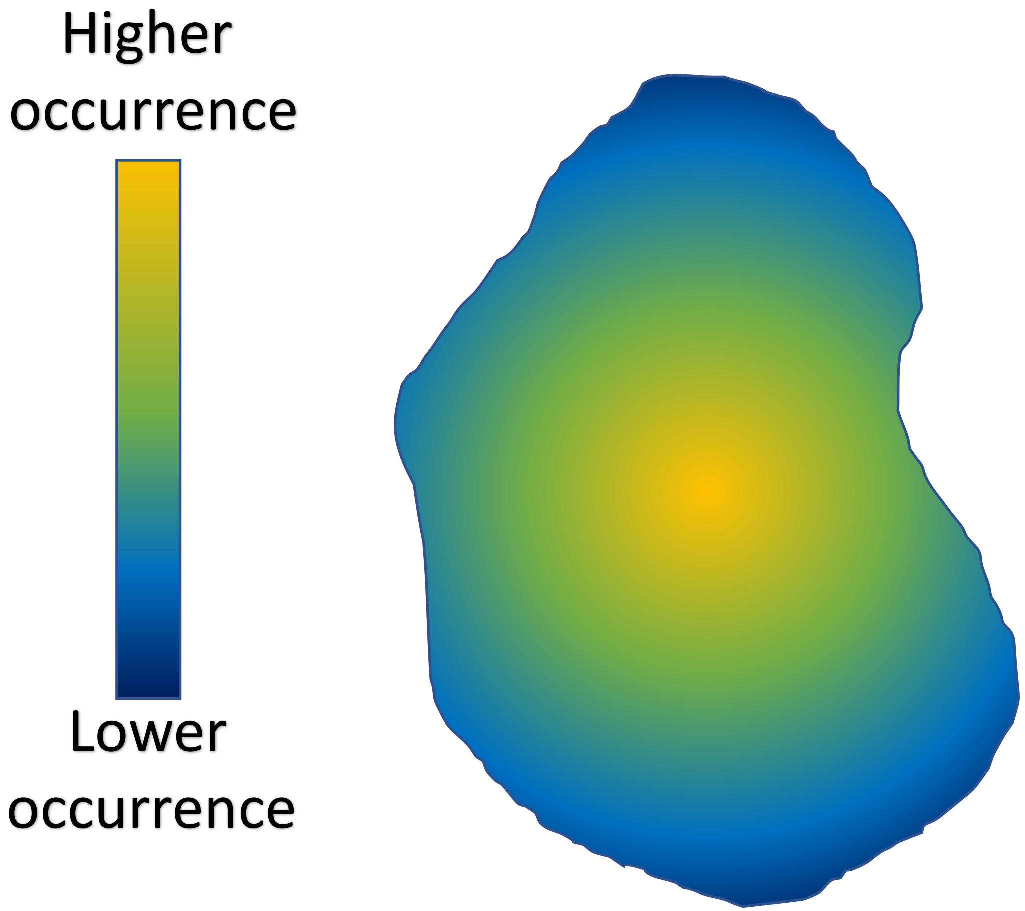
Water frequency maps

- The global surface water explorer offers global and freely available **water occurrence maps** (Pekel et al., 2016)
- These are composed of the frequency of water occurring in each Landsat program pixel (**~30 m**) since 1984



Relating water occurrence and elevation

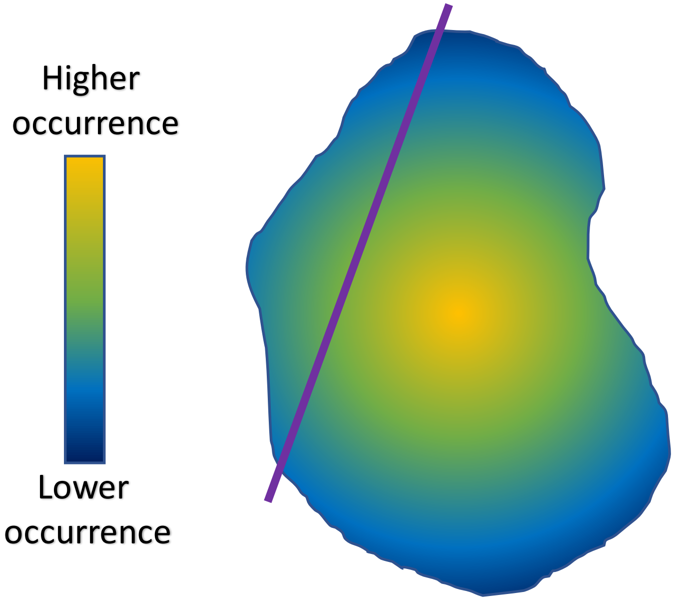
- Being ephemeral, desert lakes exhibit **highest water frequency in their deepest regions** and the lowest frequency in their outskirts



Relating water occurrence and elevation

- If we find the **relation** between **water occurrence** along the laser profiles and **elevation (WOLP)**, we can **generate bathymetry maps** for the entire lake

1. Determining water occurrence and acquiring laser profiles



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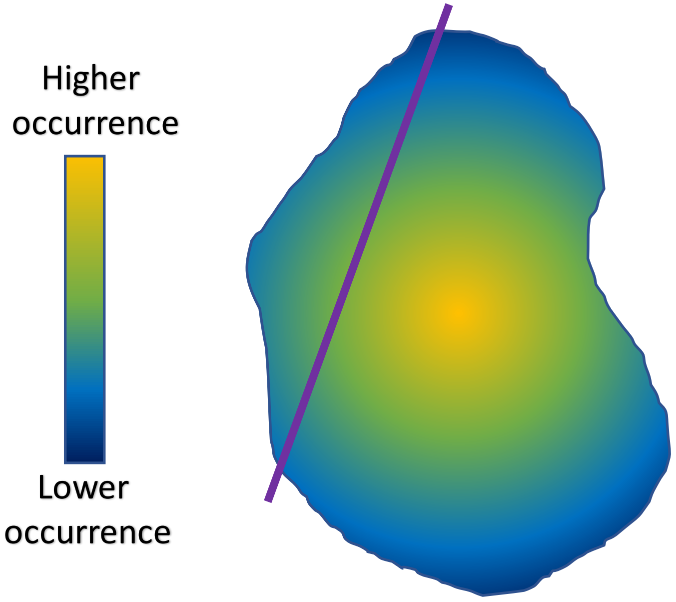
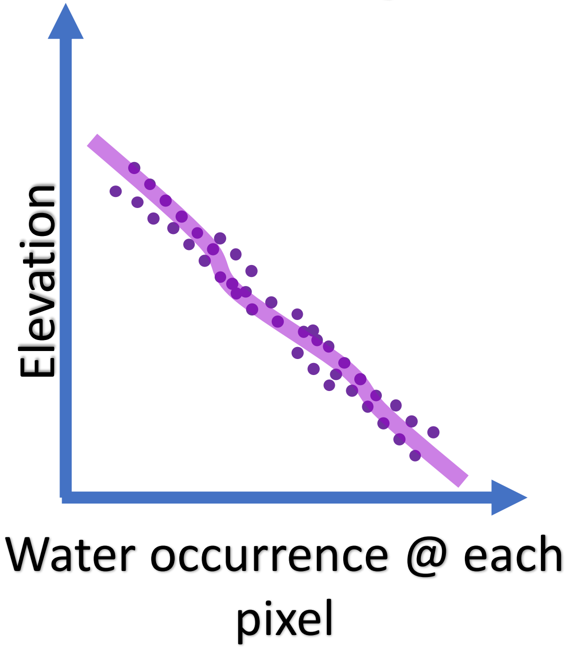


2. Water occurrence-elevation curve fitting



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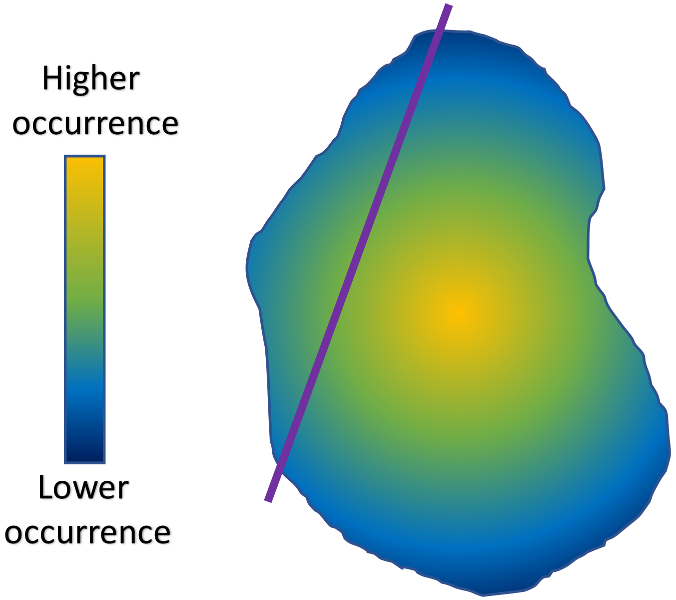

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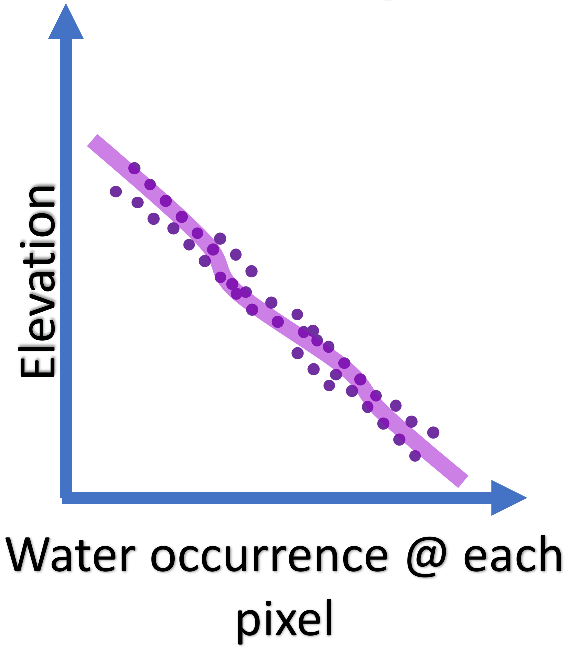
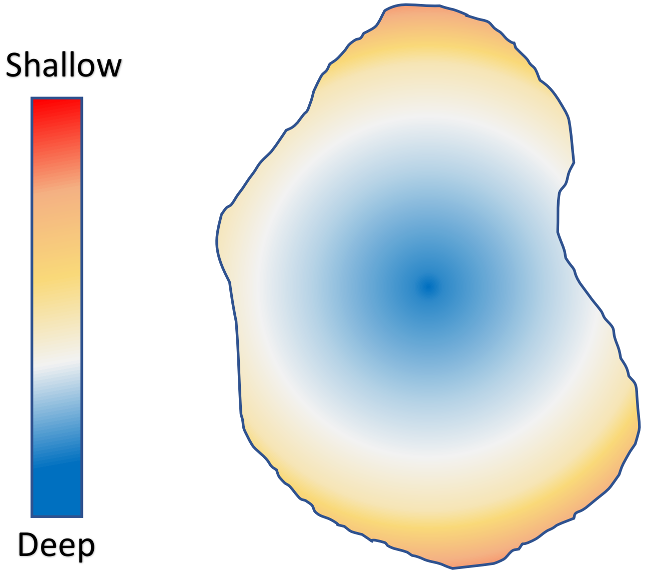
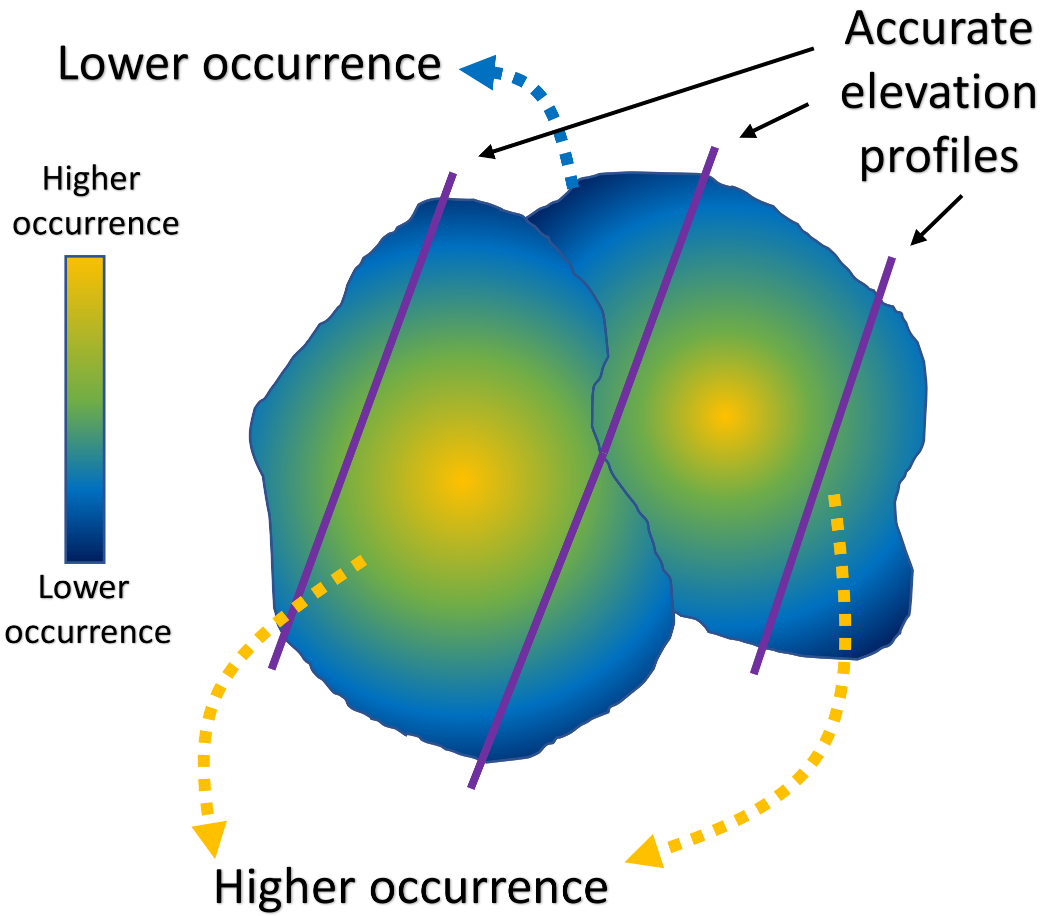


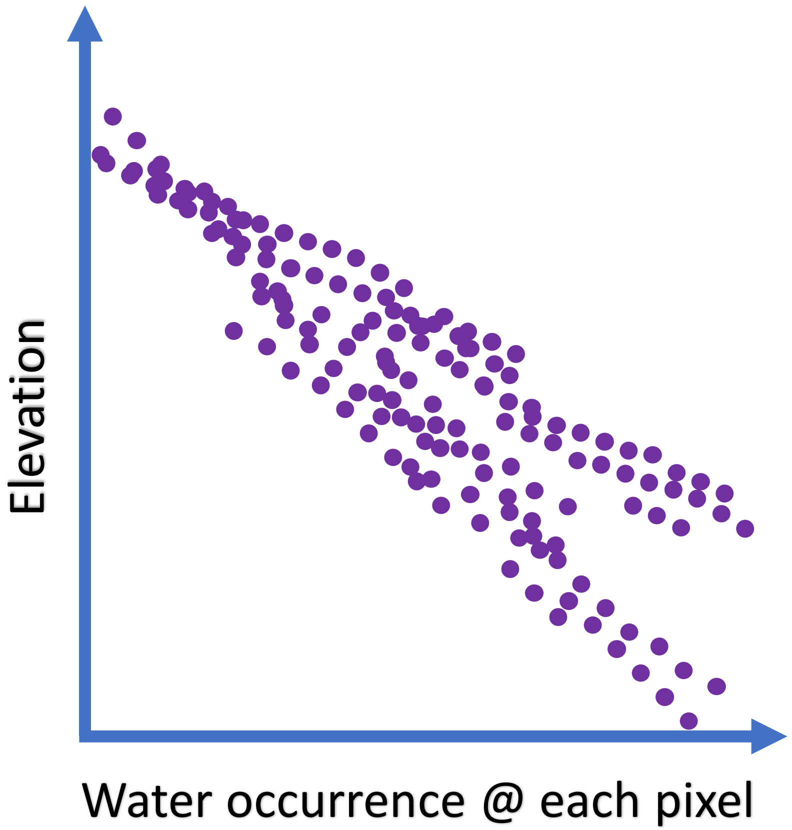
3. Generating bathymetry map



Adaptation to multiple subbasin lakes

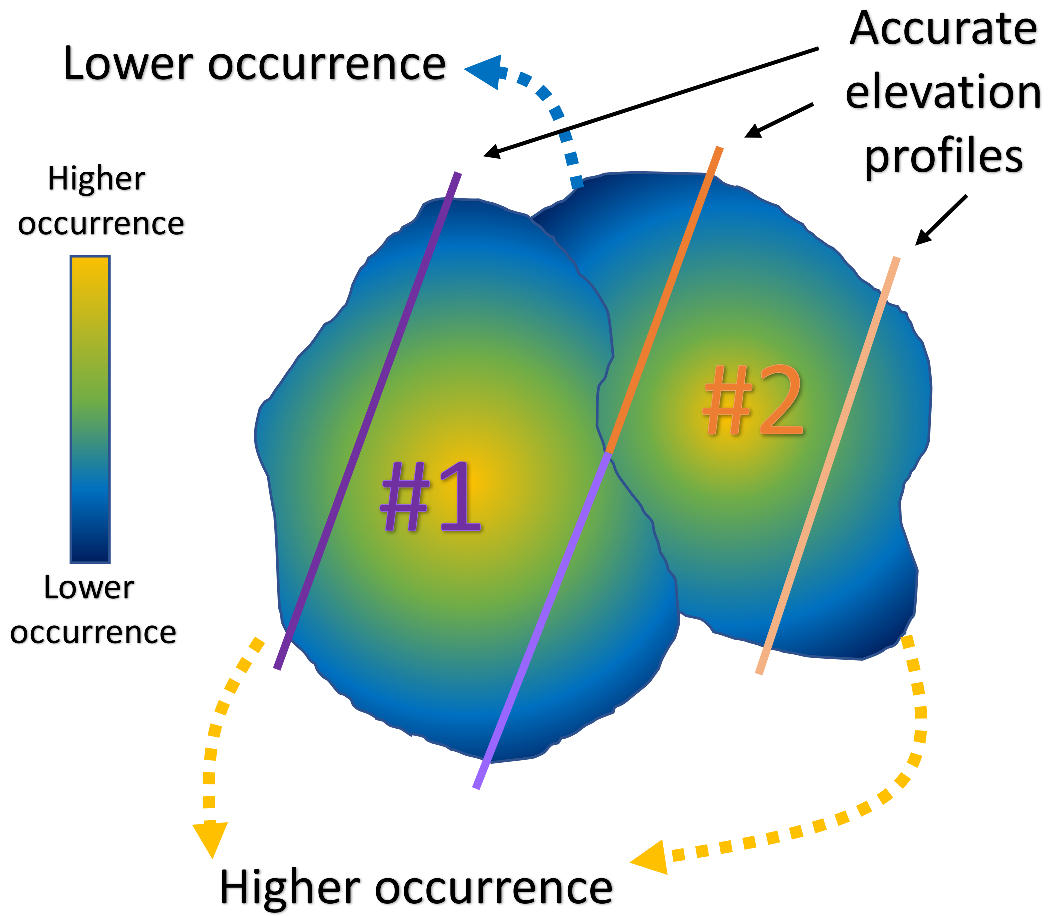
- Large desert lakes (e.g., Lake Eyre) consist of **multiple subbasins**, having **different water-occurrence – elevation relations**

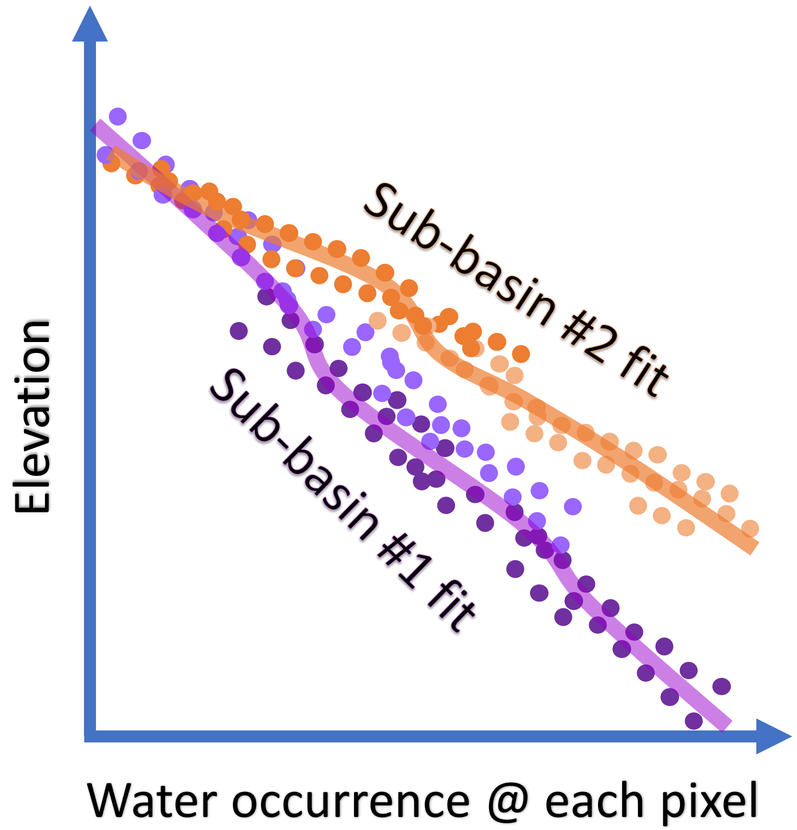




Adaptation to multiple subbasin lakes

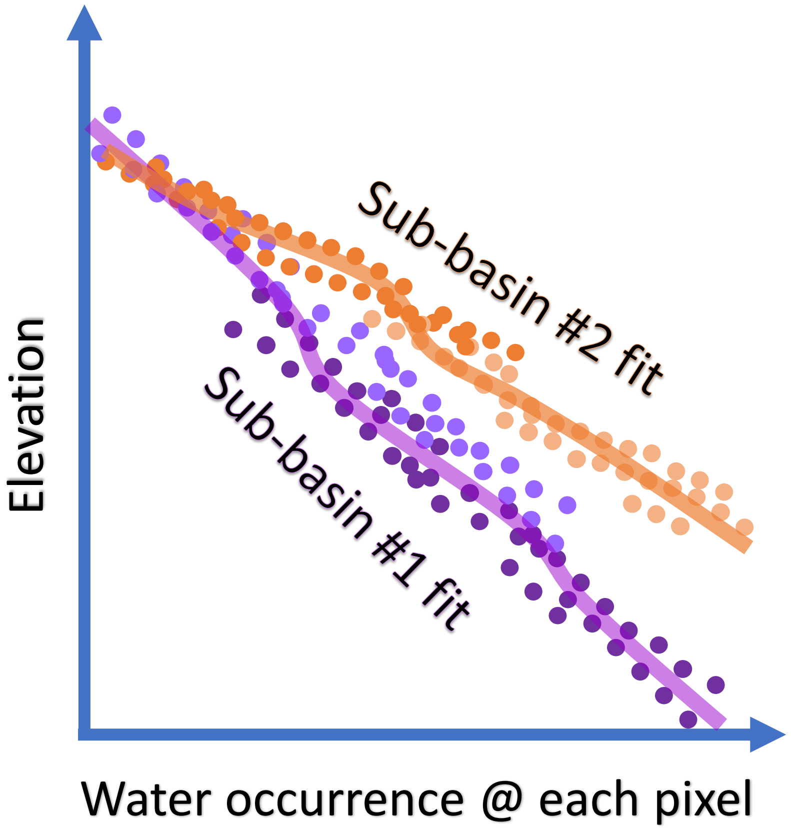
- We can separate these subbasins using their water frequency, thus creating "**pseudo subbasins**" and fit a relation to each of them

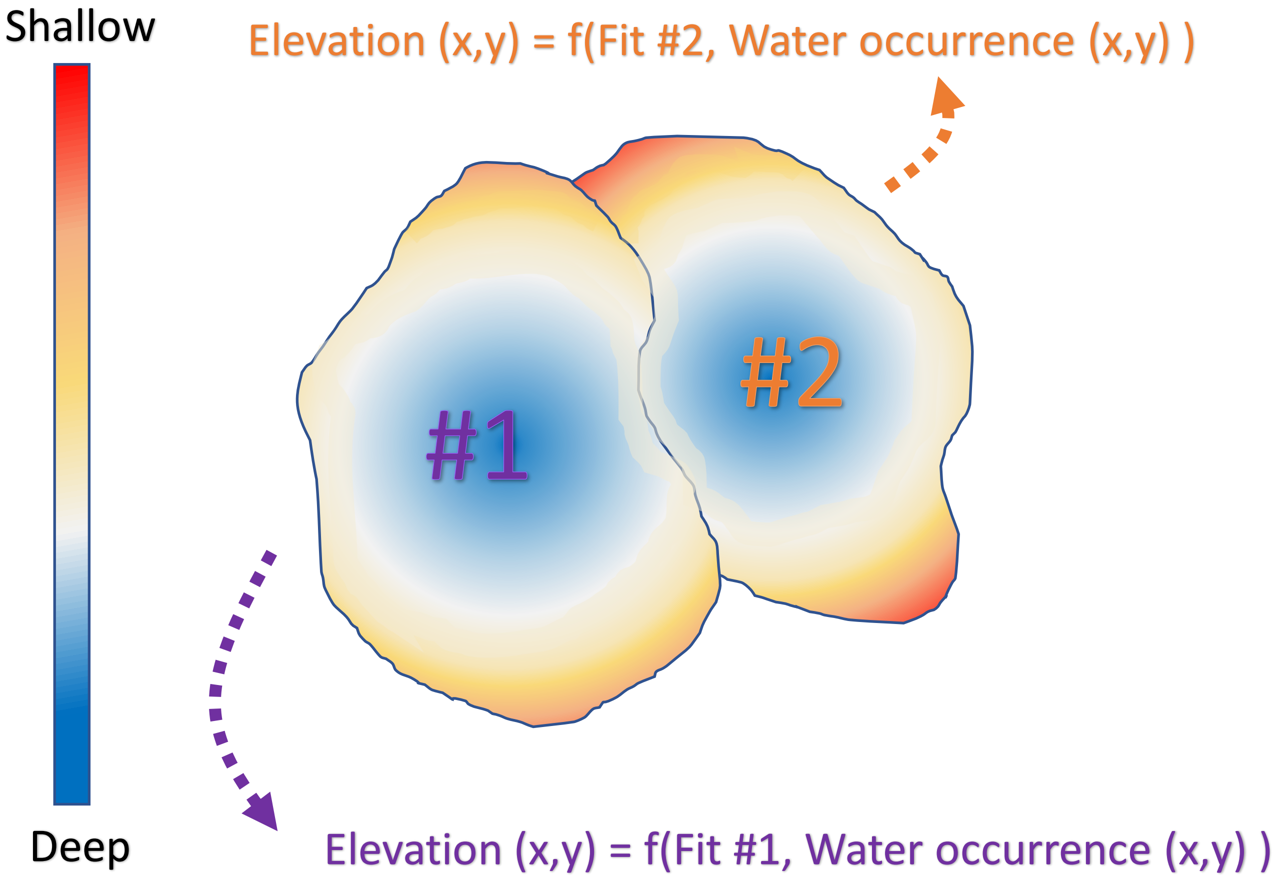




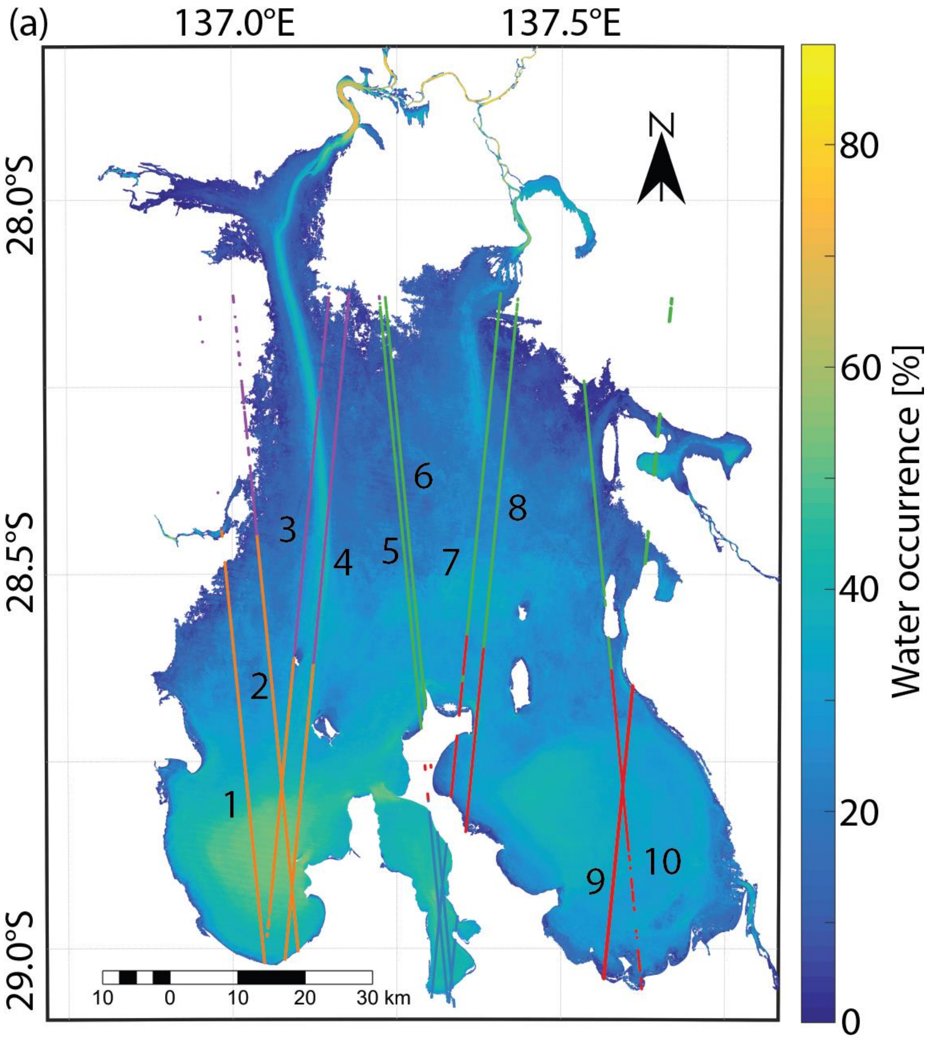
Adaptation to multiple subbasin lakes

- This allows us to **generate bathymetry** maps even **in large and complex lake systems!**



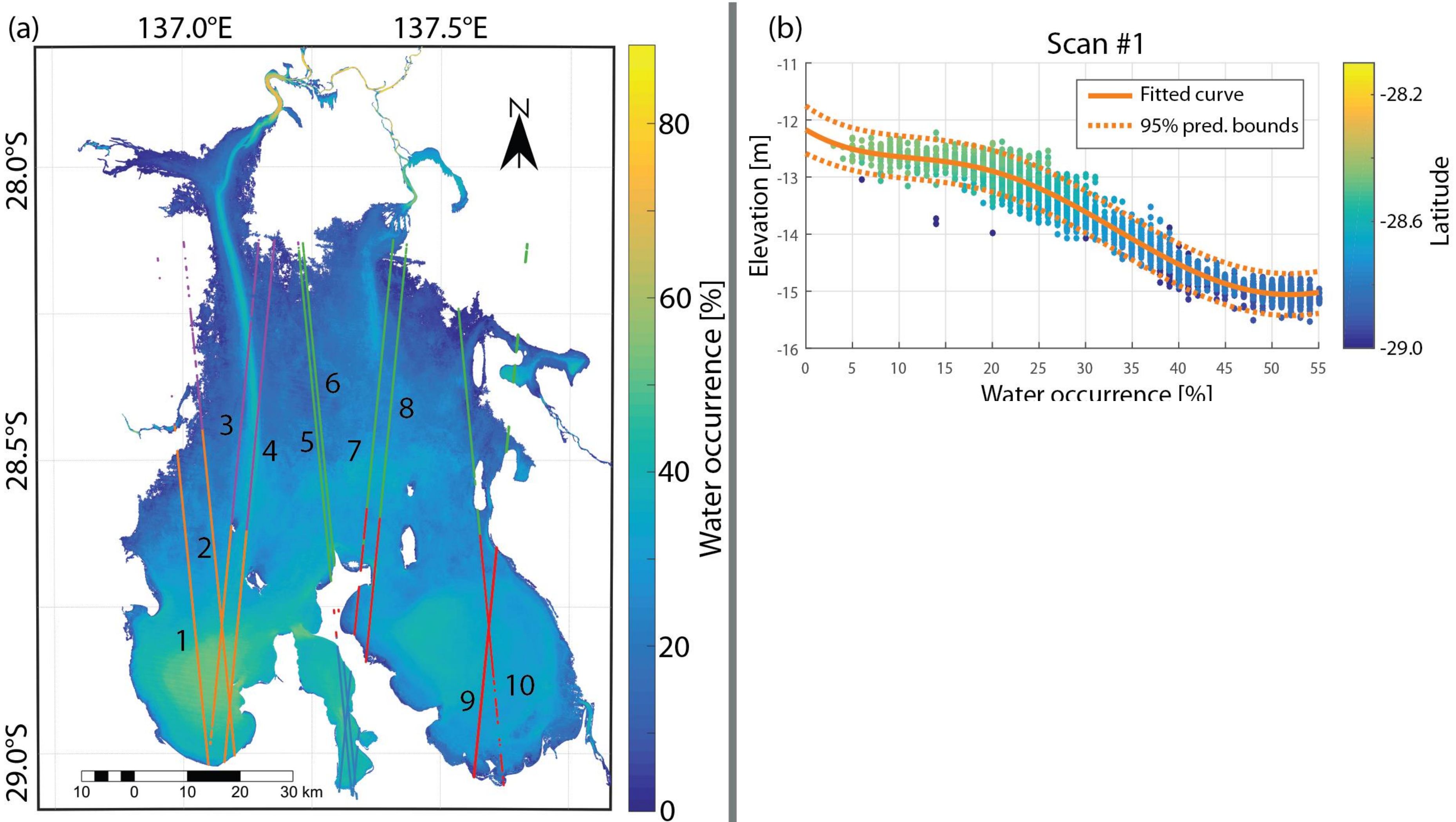


Example #1: Multiple subbasins lake - **Lake Eyre** (North)



- Ten **ICESat-2 profiles over Lake Eyre** North are presented on top of its **water occurrence map**
- With a surface area of >9,000 km^2, **Lake Eyre** is the **largest desert lake in the world**
- It also consists of a **few subbasins**, making it **difficult to survey** with other remote sensing methods

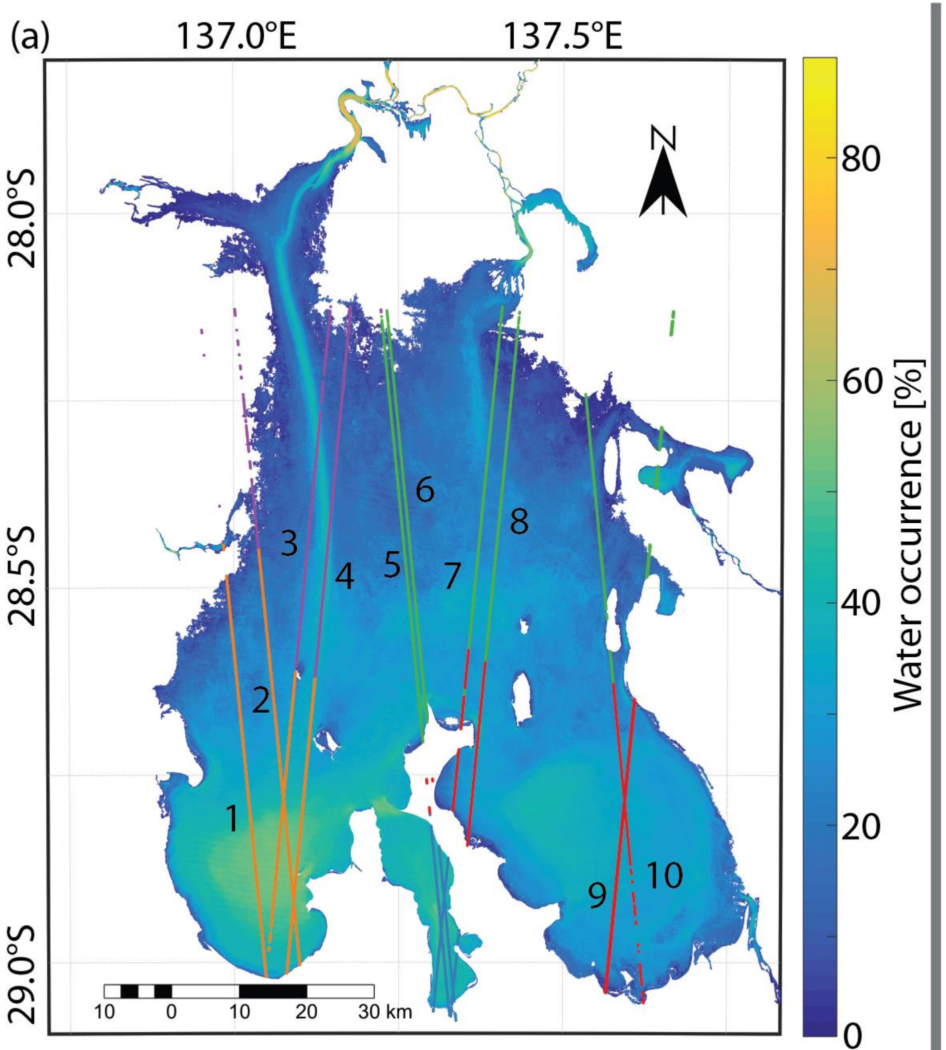
Example #1: Multiple subbasins lake - **Lake Eyre** (North)

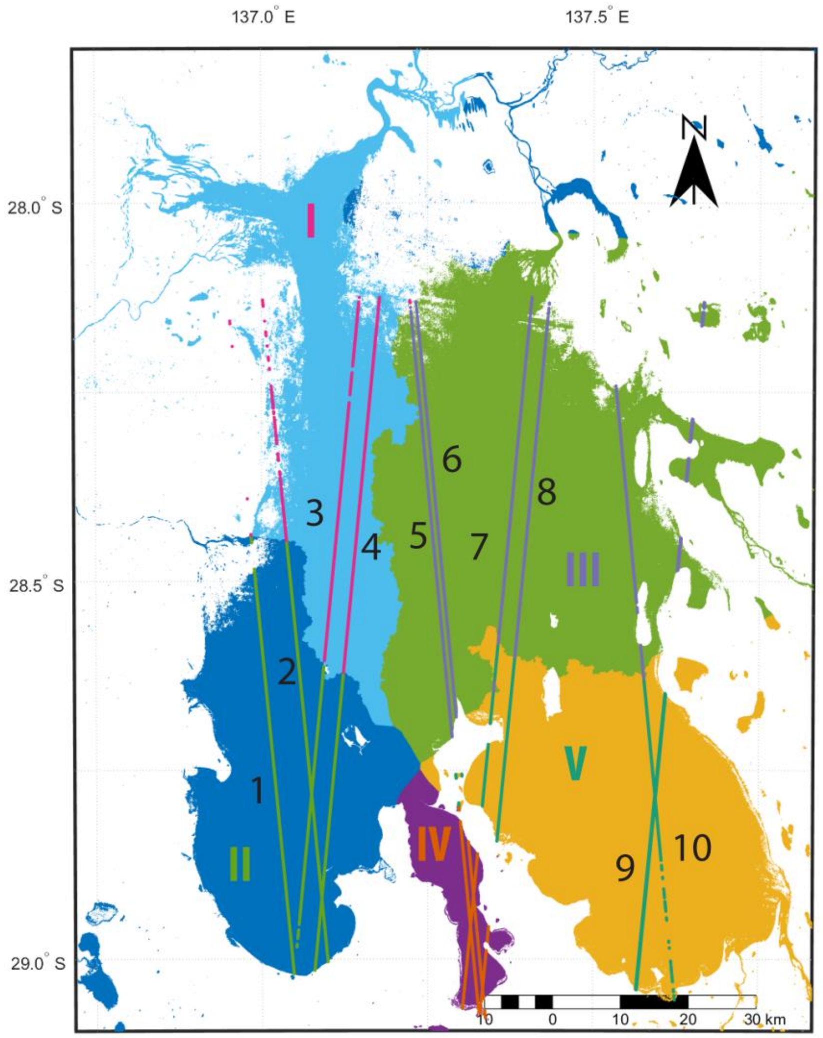


Using the first scan, **we obtain a relation between elevation and water occurrence**.

This is nice, but still **doesn't tell the whole story**…

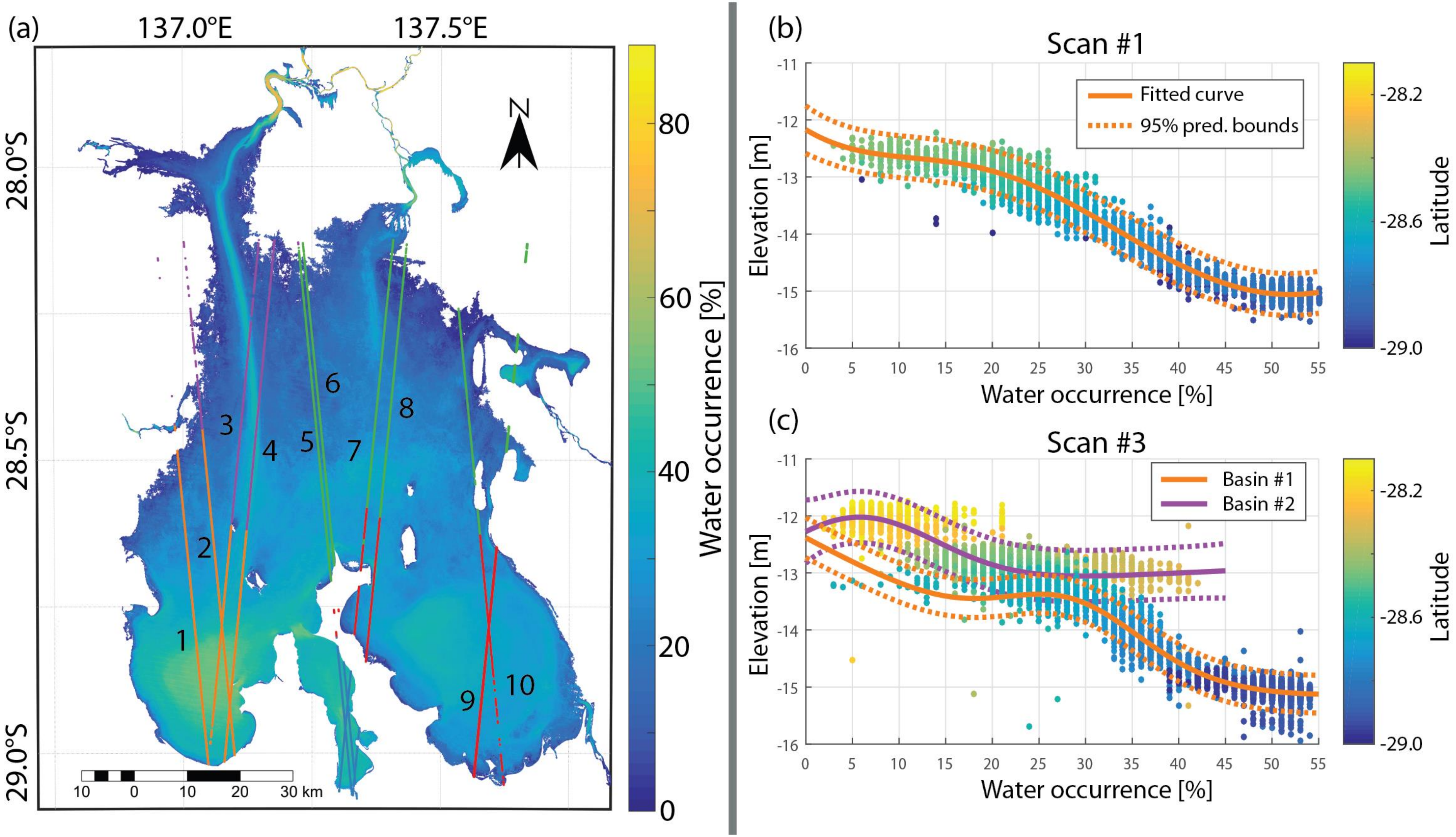
Example #1: Multiple subbasins lake - **Lake Eyre** (North)





To understand the **different water occurrence – elevation relations**, we first **divide the lake into pseudo subbasins** using the water occurrence map

Example #1: Multiple subbasins lake - **Lake Eyre** (North)

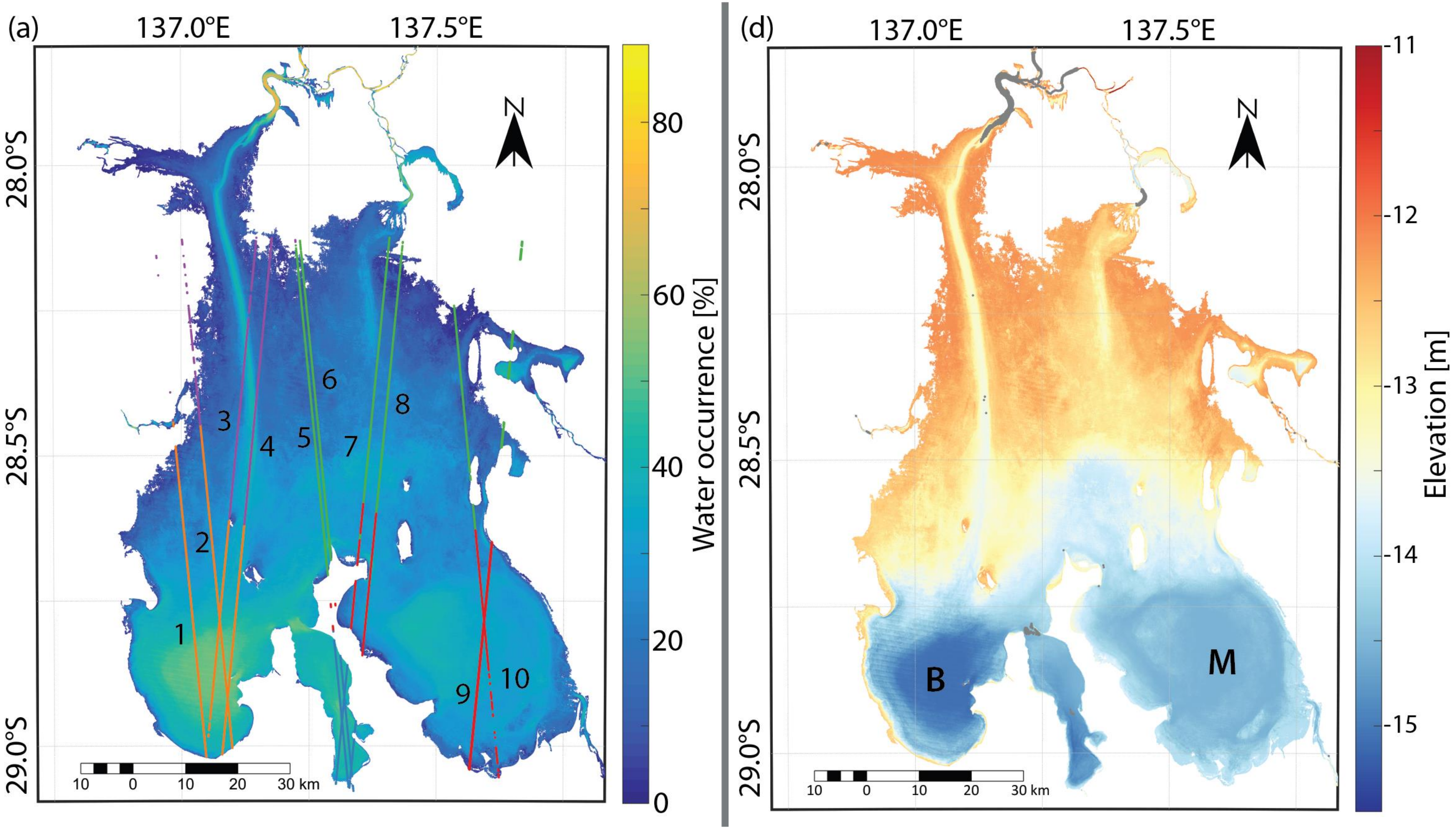


Using the third scan, we observe **a much-complicated relation**.

In fact, this relation seems **tied to the pseudo subbasins**.

If we now obtain a **different relation for each subbasin**, we can have much **more robust results**

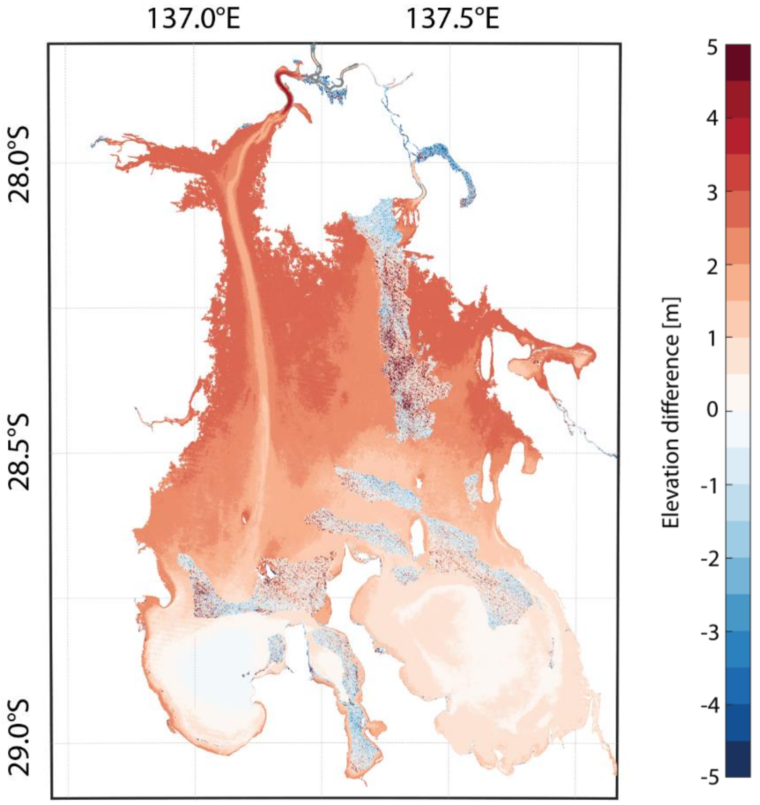
Example #1: Multiple subbasins lake - **Lake Eyre** (North)



Despite the subbasins, we can now **generate the bathymetry map** of the whole lake **using the different fits** obtained for each of the subbasins

Example #1: Lake Eyre - **Validation**

WOLP - SRTM

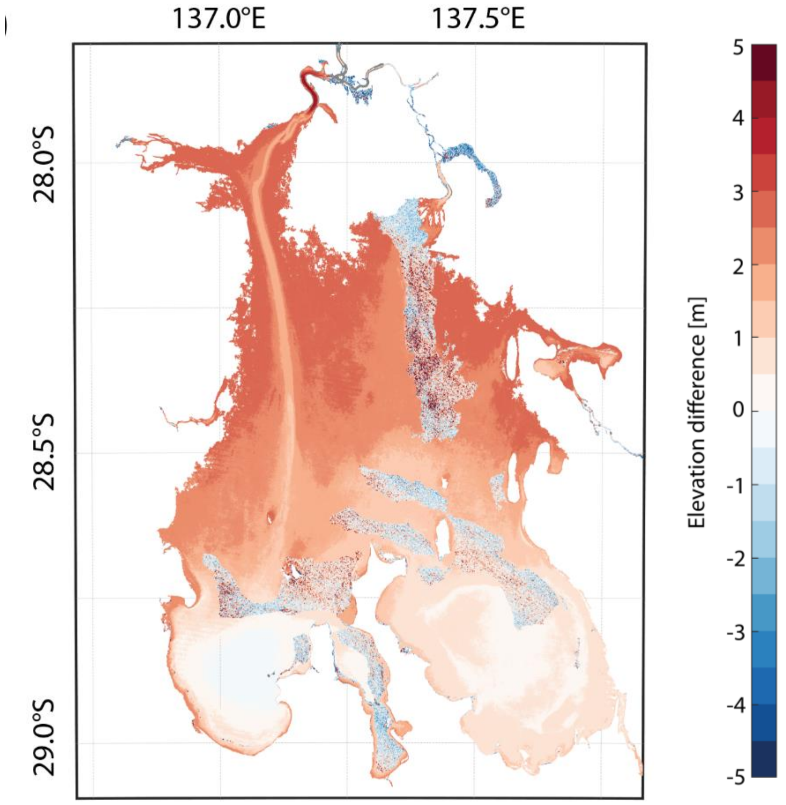


How do we know if **our results are good?**

First, let's **compare them to the SRTM** data

Example #1: Lake Eyre - **Validation**

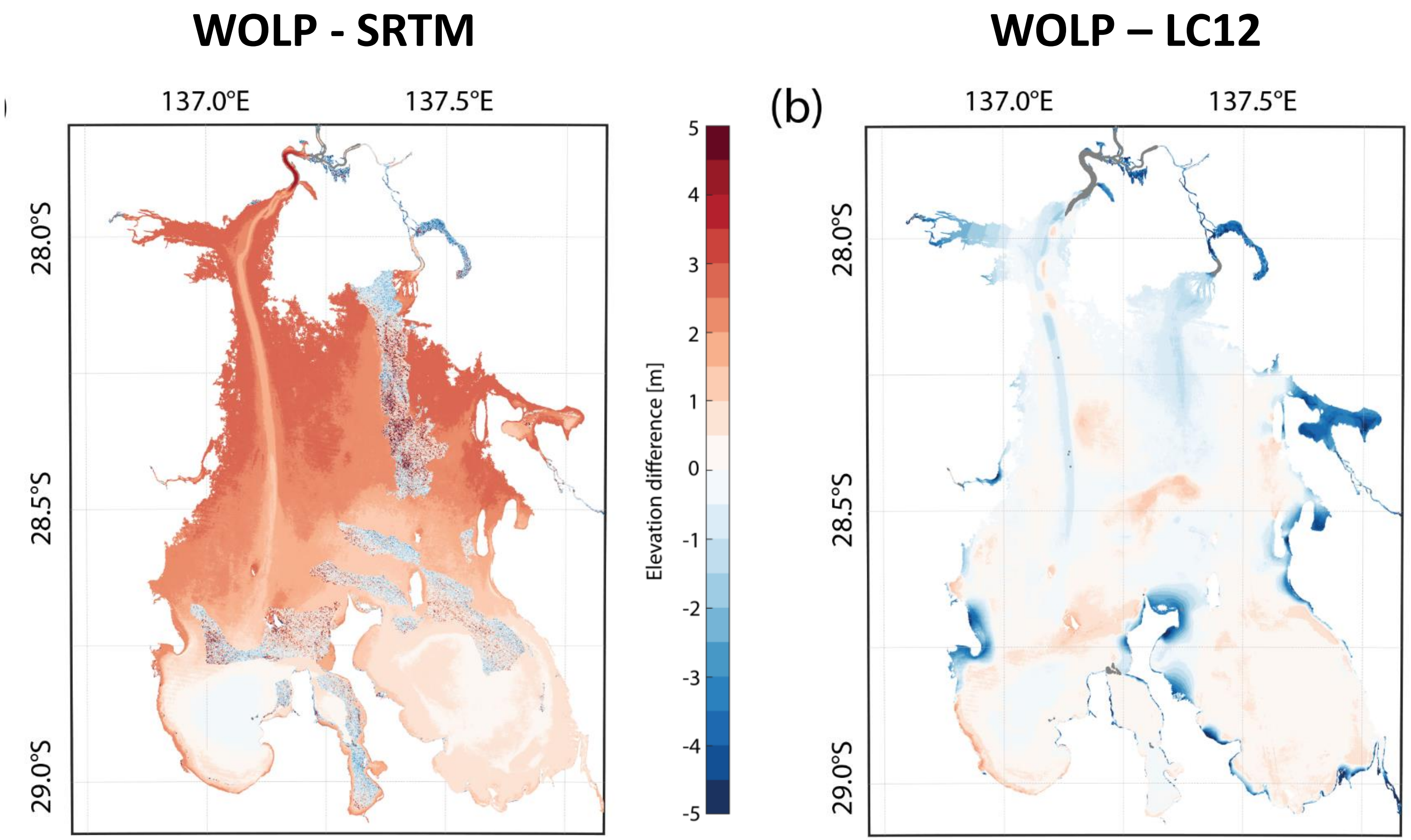
WOLP - SRTM



We see **noise** in some areas, and smooth differences in others.

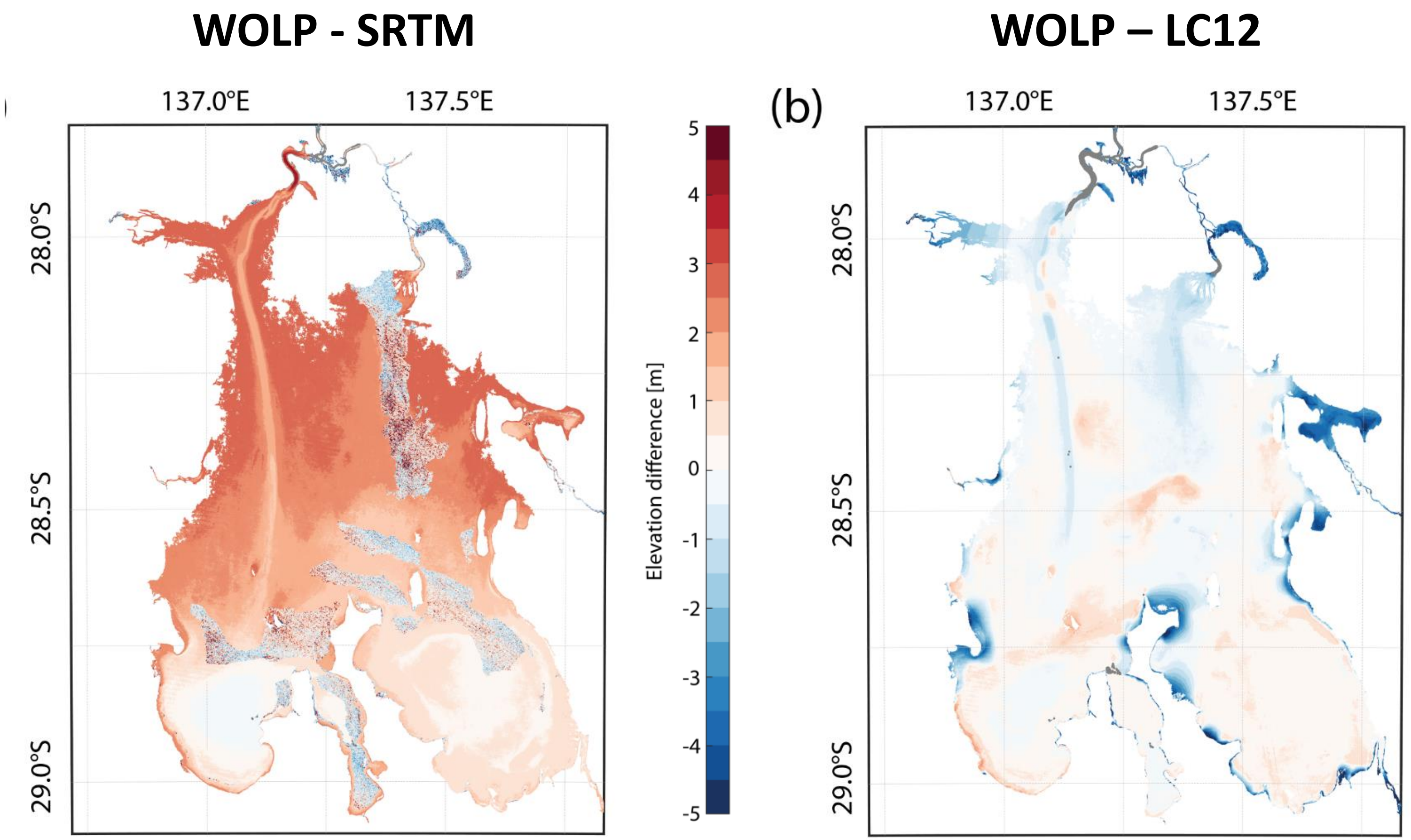
Still, how can we know **which map is better**?

Example #1: Lake Eyre - **Validation**



We can **compare the data to a better map** (LC12), based on interpolation of SRTM data, ICESat-1 data and a **bathymetric survey conducted in the 70's** (Leon & Cohen, 2012)

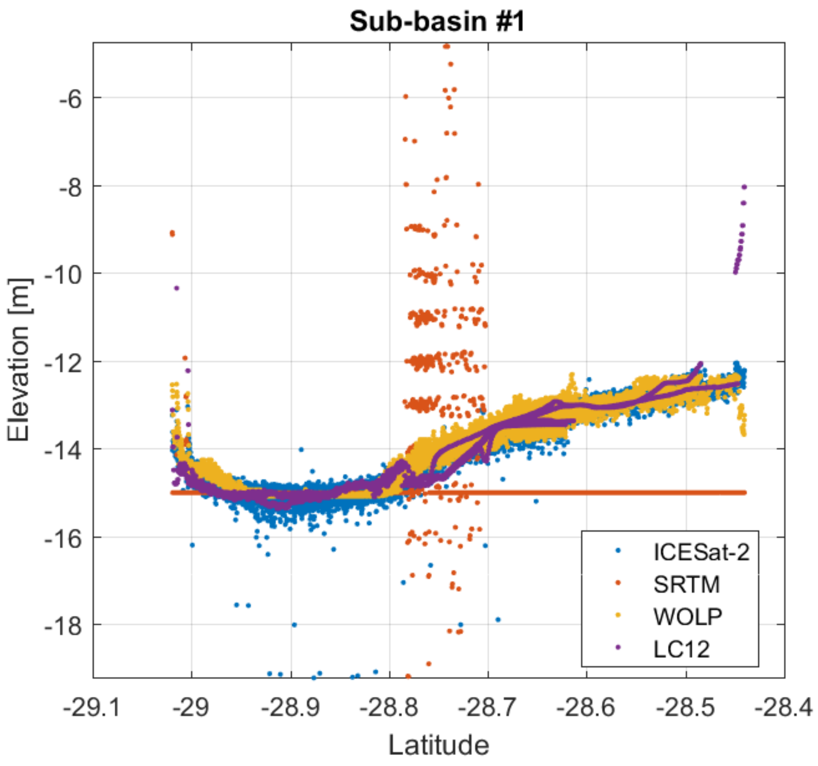
Example #1: Lake Eyre - **Validation**



The root mean square difference (RMSD) of the **SRTM map vs. LC12 is 1.77 m**

The RMSD of our map **(WOLP) vs. LC12 is 0.52 m**. <u>Much better!</u>

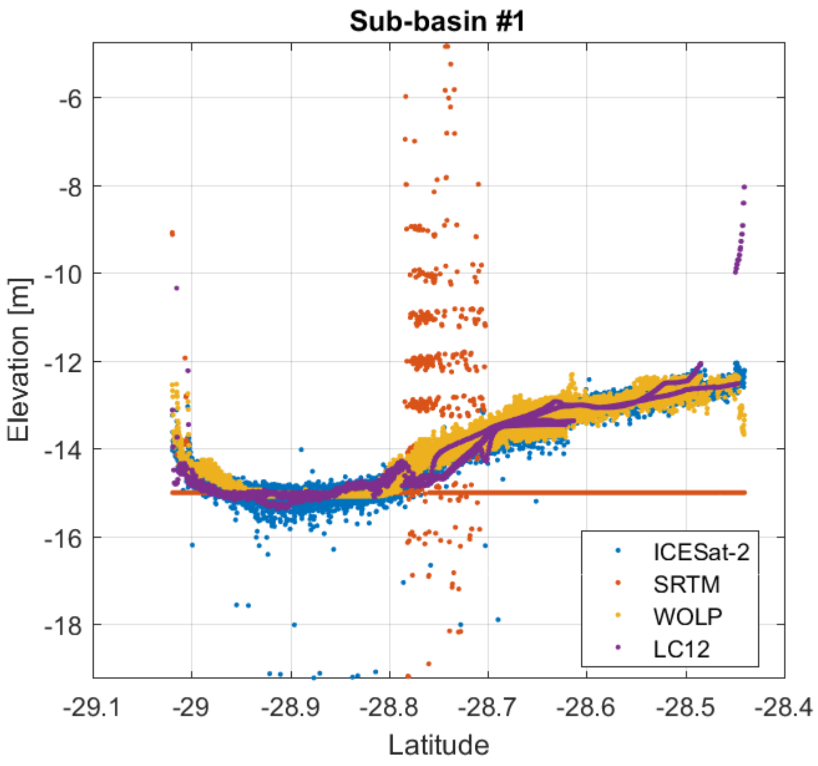
Example #1: Lake Eyre - **Validation**

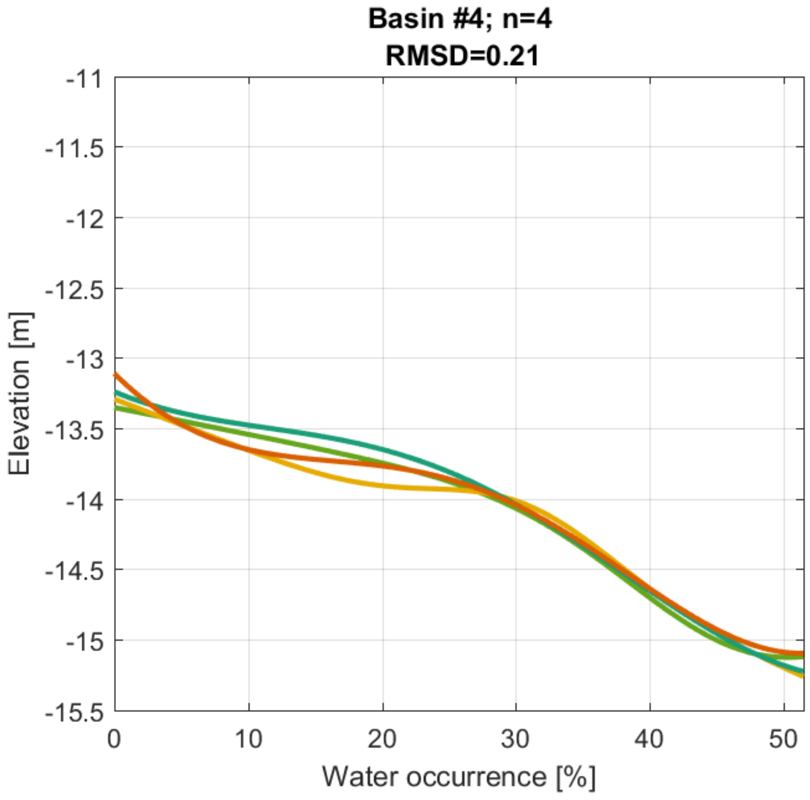


We can also look at the ICESat-2 cross sections:

- WOLP bathymetry clearly follows the ICESat-2 data, which is similar to the LC12 map
- SRTM data have constant elevations regions and other really noisy regions

Example #1: Lake Eyre - **Validation**

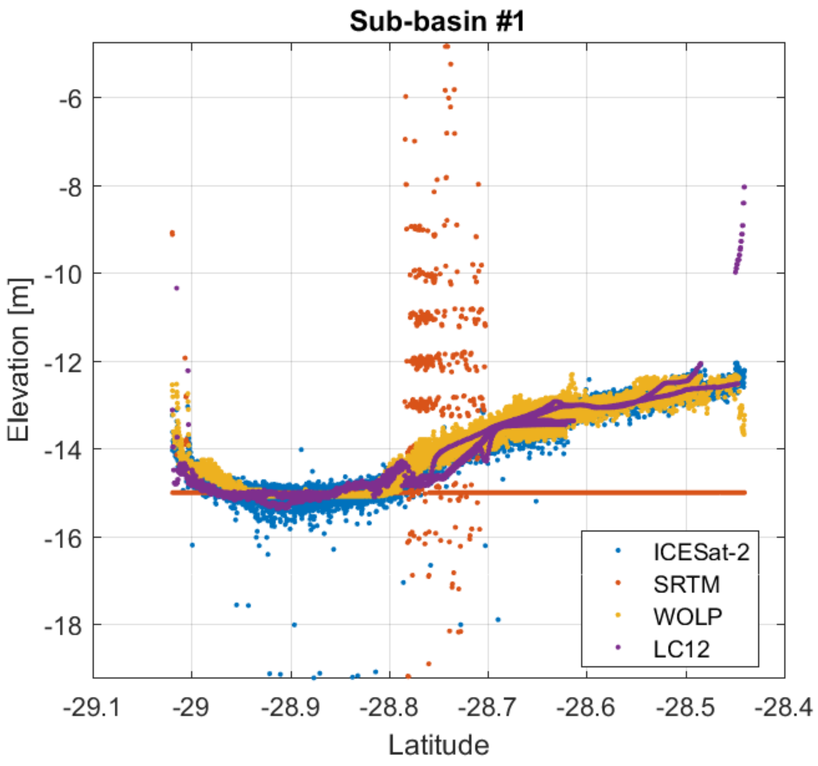


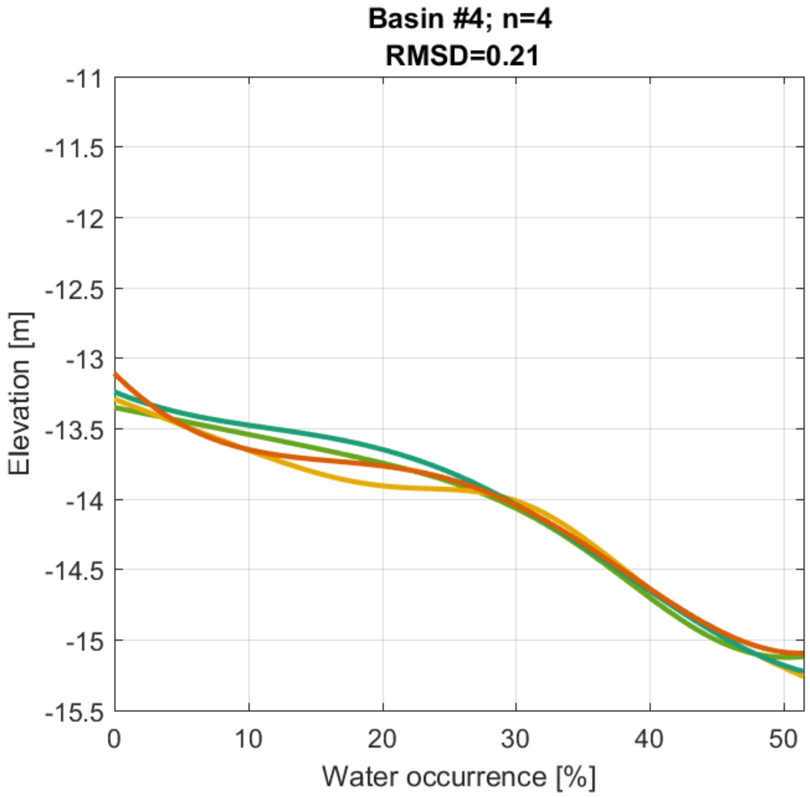


We can extend this validation, using a **cross validation**:

- We take all ICESat-2 profiles for each subbasin
- Putting aside one profile at a time, we check what is the **RMSD** of the results obtained **using all other scans, validated over the unused profile**

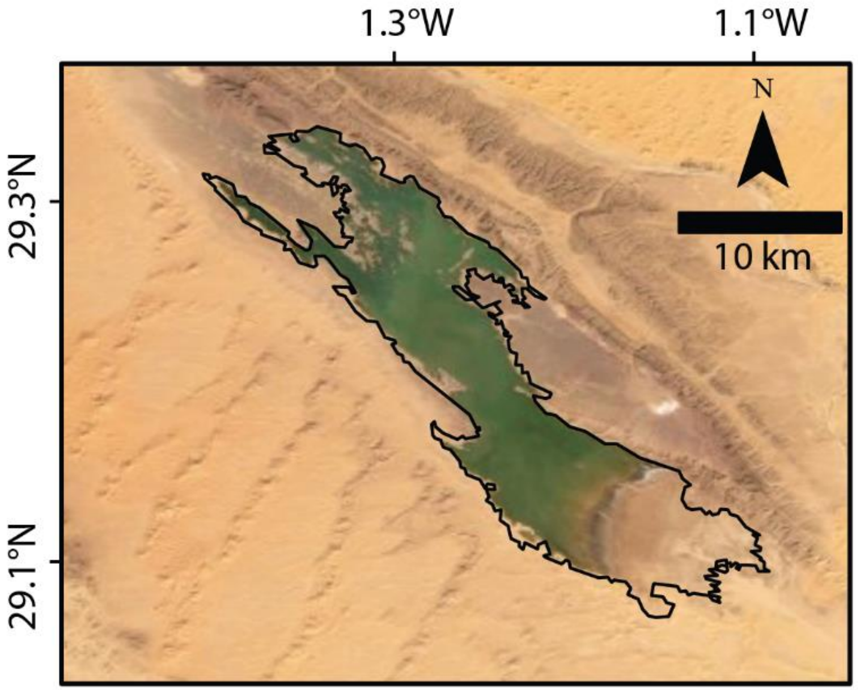
Example #1: Lake Eyre - **Validation**





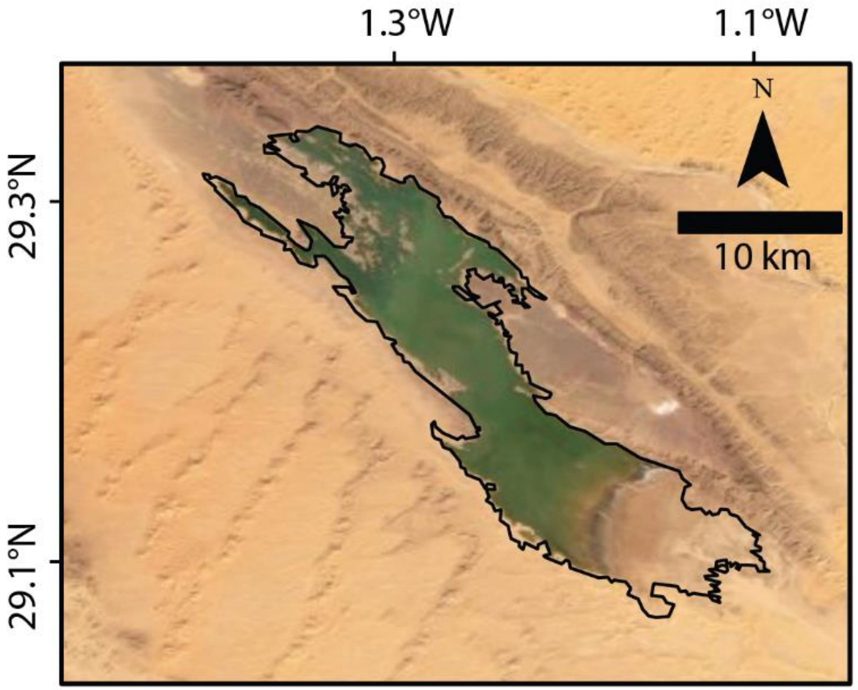
The **cross-validation RMSD is even lower** than when compared to the LC12 map, suggesting **these results could be even better** than the ones obtained using an interpolation of SRTM and bathymetric surveying

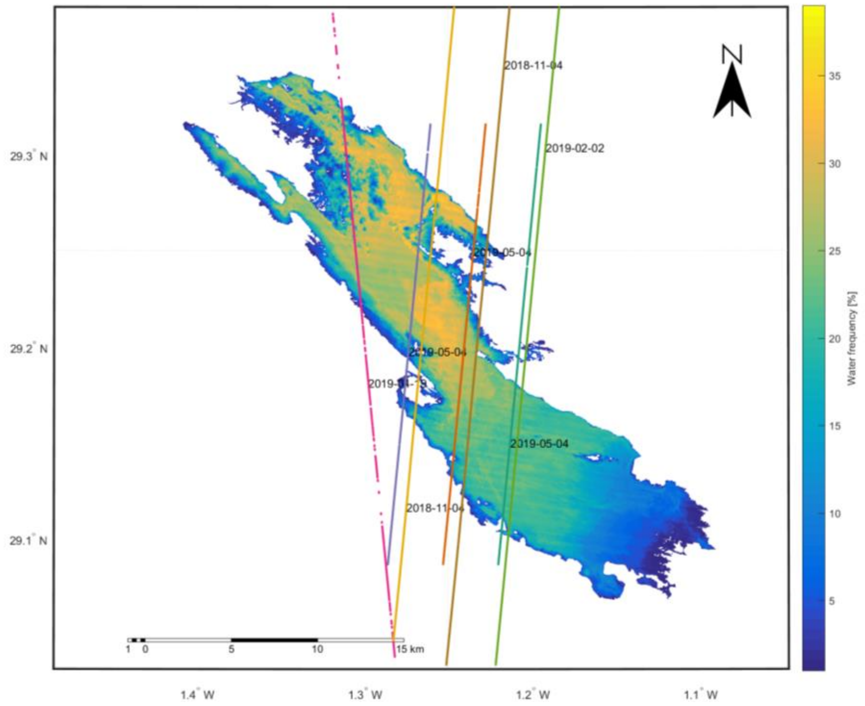
Example #2: Non-surveyed lake - **Sabkhat El-Mellah**



- Satisfied with the results from Lake Eyre we can now generate bathymetry to other desert lakes
- **Sabkhat El-Mellah** is a shallow desert lake in the Sahara which has **no bathymetry map**

Example #2: Non-surveyed lake - **Sabkhat El-Mellah**

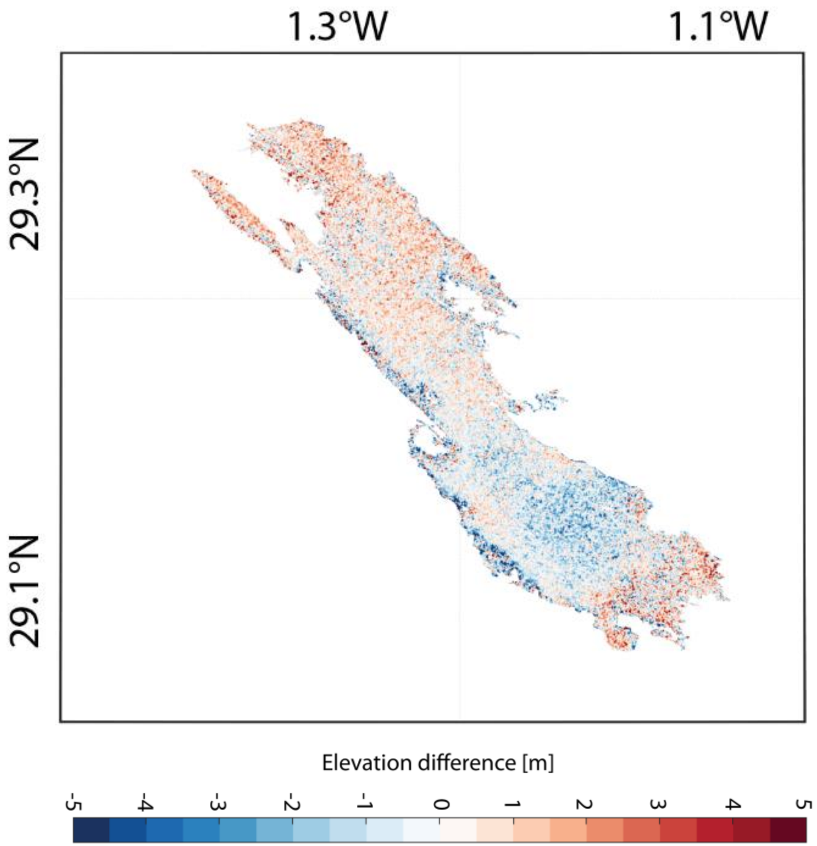


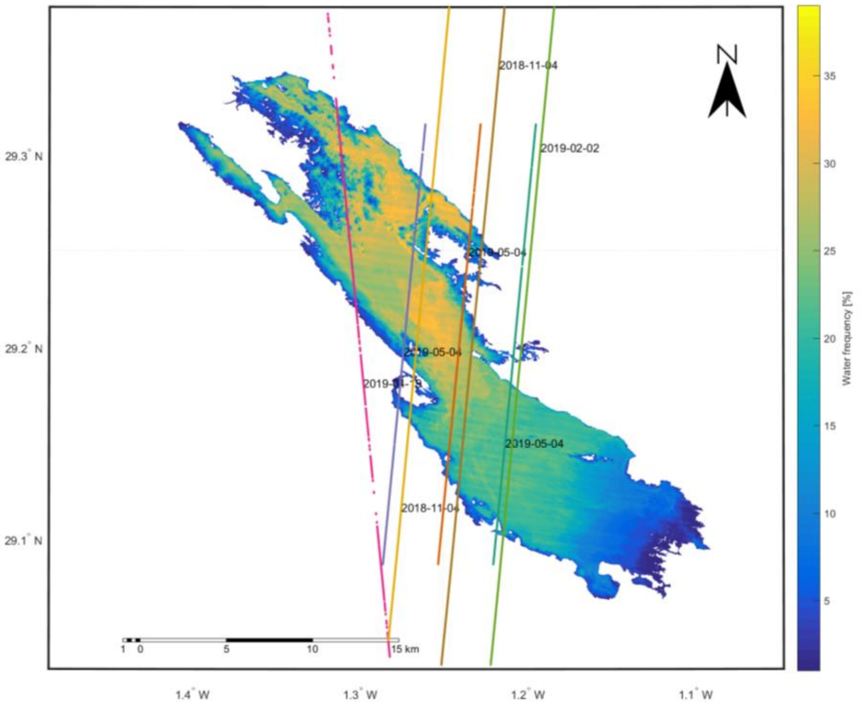


- We use the same methodology to **relate water occurrence and elevation**

Example #2: Non-surveyed lake - **Sabkhat El-Mellah**

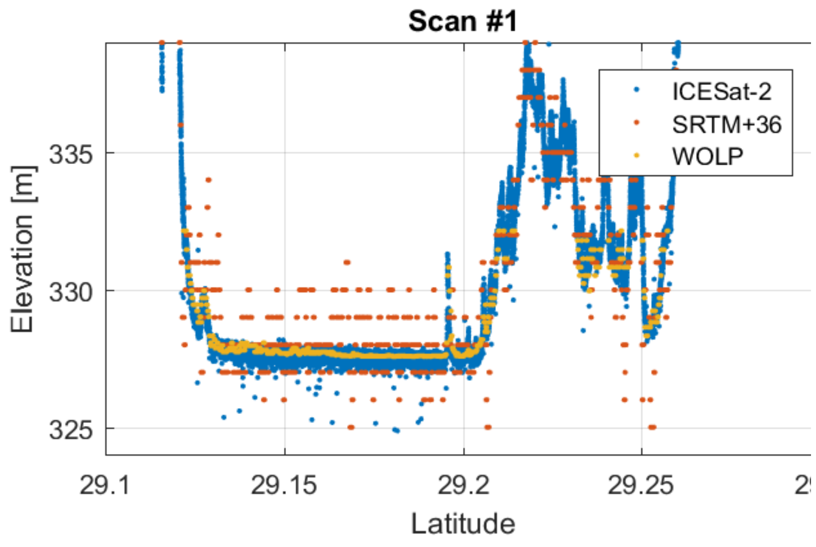
WOLP - SRTM

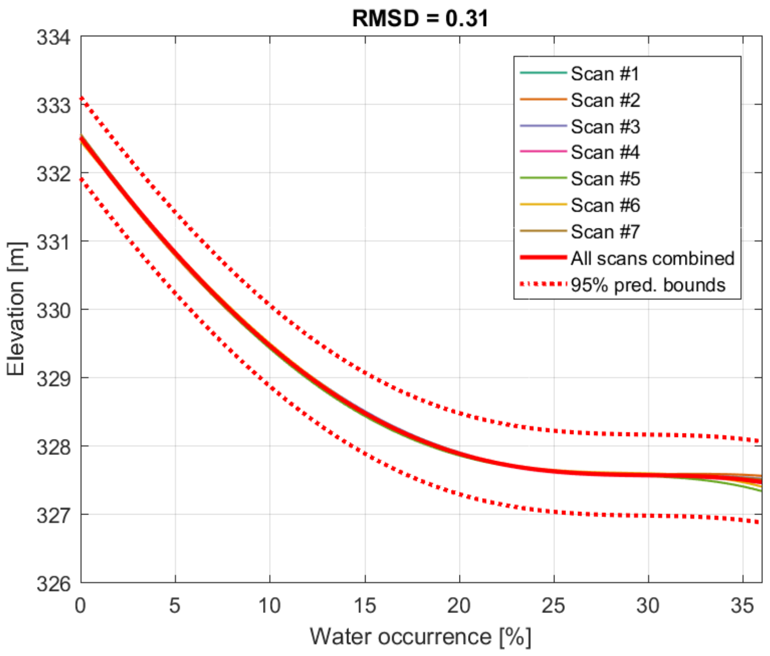




- Again we find the same **noisy** pattern of the **SRTM data**

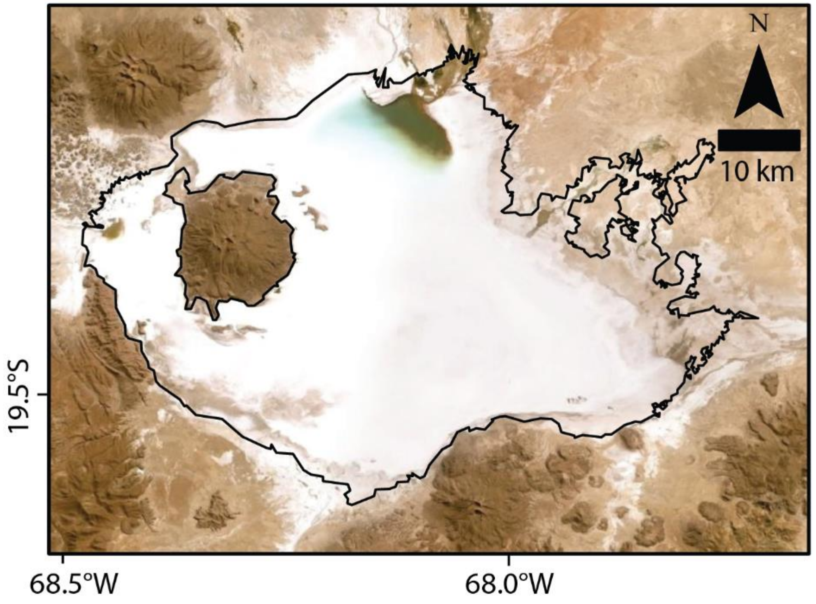
Example #2: Non-surveyed lake - **Sabkhat El-Mellah**





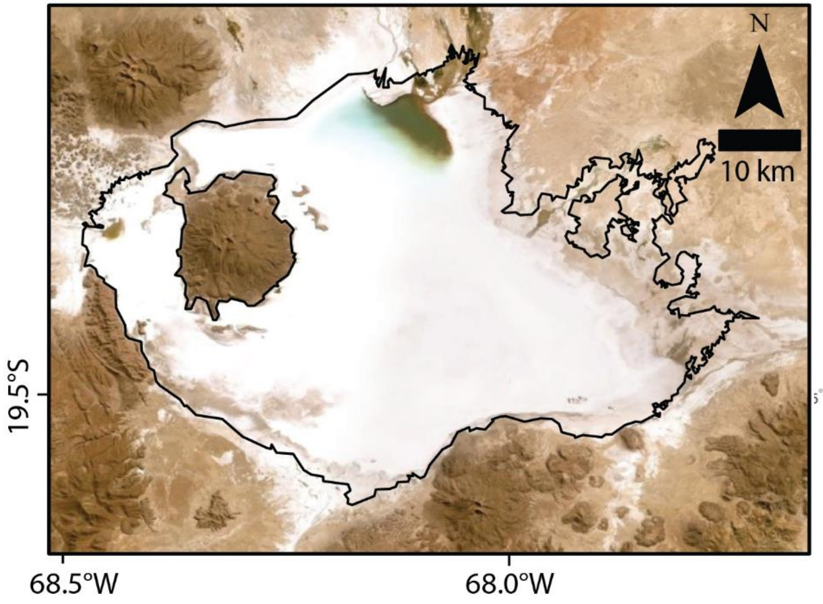
- WOLP profiles are much more similar to the ICESat-2 data
- Cross validation of **SRTM** data vs. ICESat-2 **RMSD is 2.04 m**
- **WOLP RMSD is only 0.31 m**

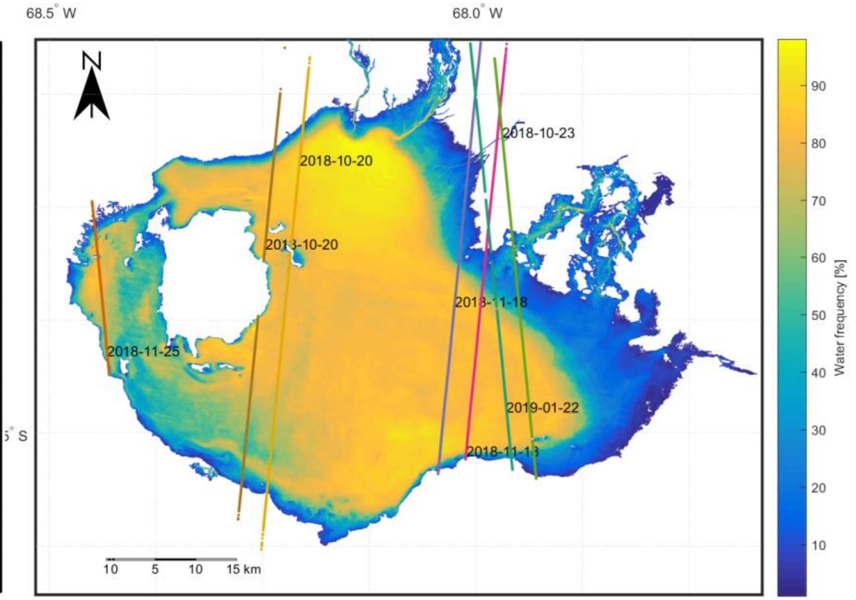
Example #3: Inundated lake – **Lago Coipasa**



- Most **desert lakes are being filled** occasionally
- If the **SRTM** scan occurred **during such a filling**, the **data is problematic**
- **Lago Coipasa**, in the high Bolivian Altiplano **was inundated** during the SRTM scan

Example #3: Inundated lake – **Lago Coipasa**

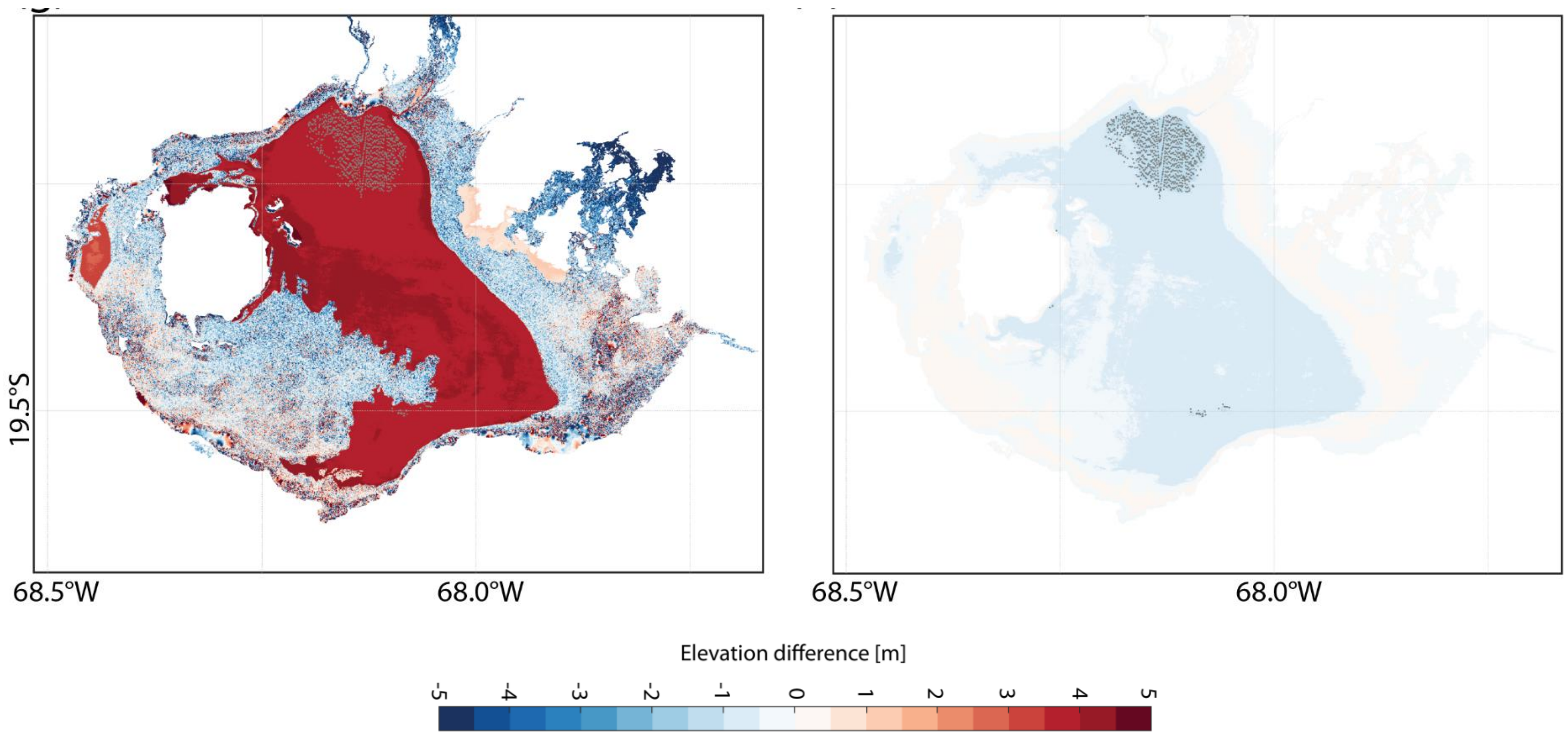




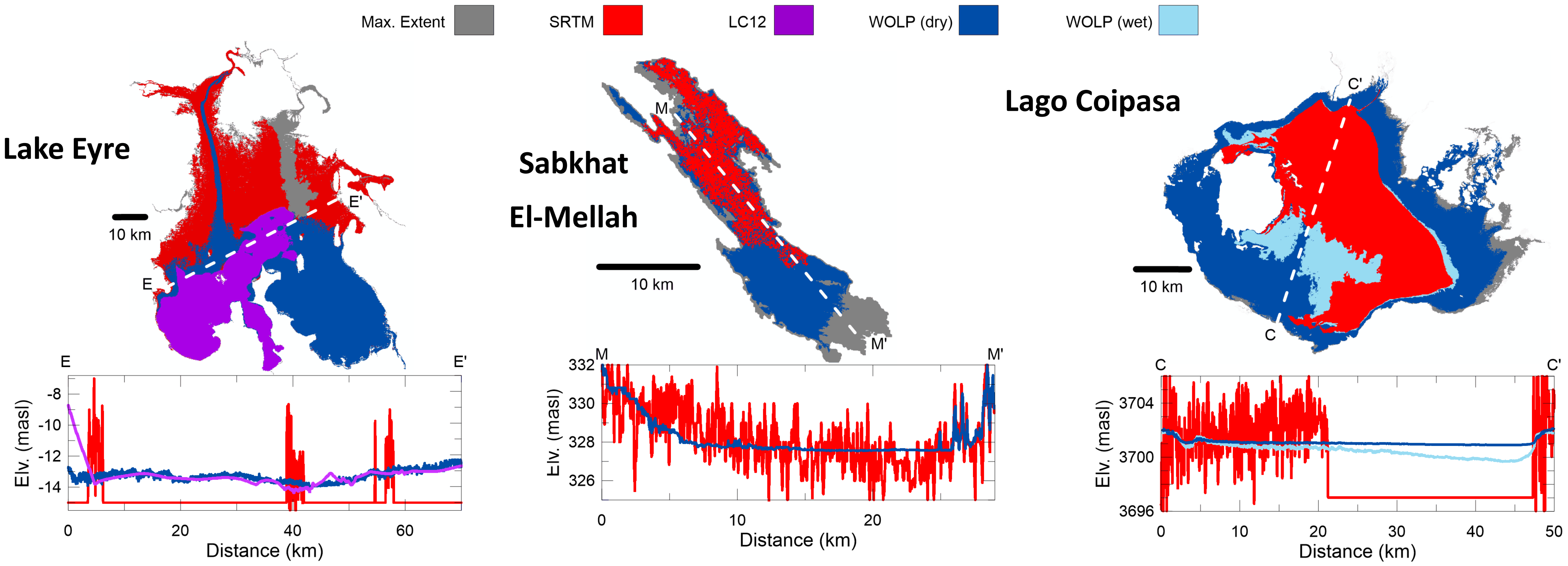
- It was actually filled again, in between ICESat-2 scans
- For that reason we prepared **two different bathymetric maps**:
  - One consisting all **pre-flood** ICESat-2 scans ("dry")
  - The other consists of **post-flood** scans, manually extracting water surface elevation data ("wet")

Example #3: Inundated lake – **Lago Coipasa**

“Dry” WOLP - SRTM **“Dry” WOLP – “Wet” WOLP**

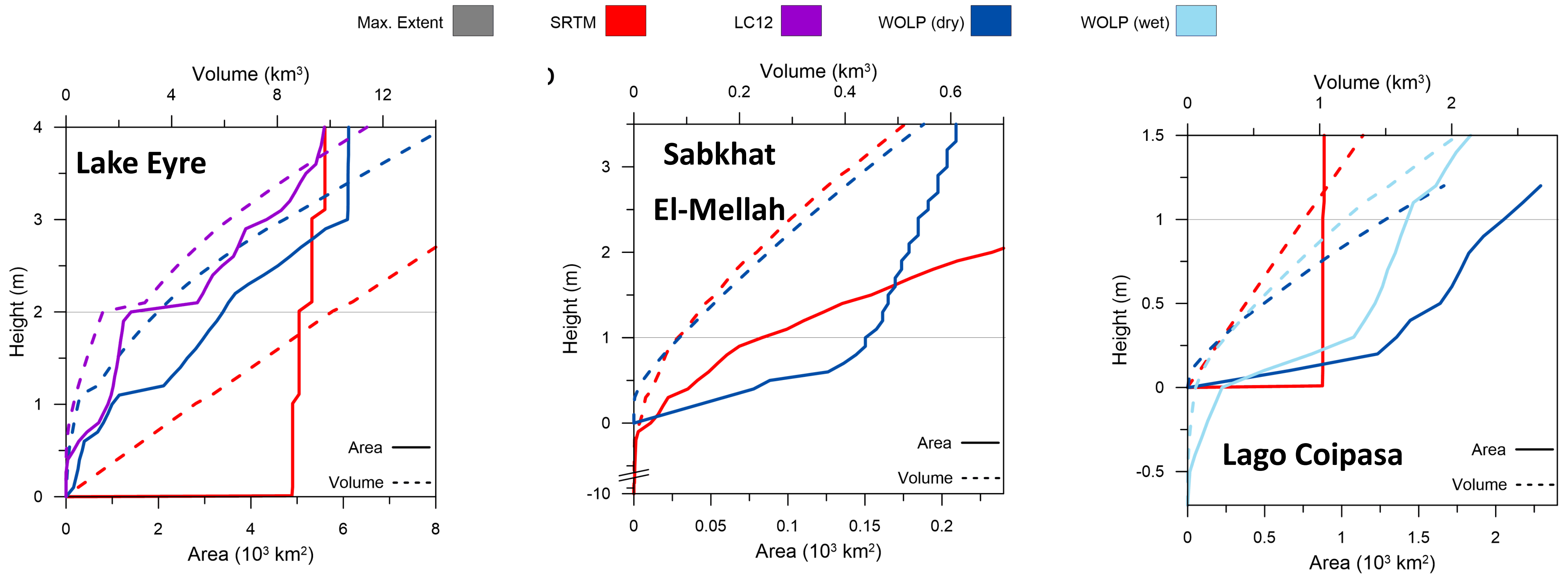


- **SRTM** data are much **noisier** than any of the derived (WOLP) bathymetries
- **SRTM RMSD** is **2.84 m**
- **“Dry” WOLP RMSD** is **0.28 m**
- **“Wet” WOLP RMSD** is **0.47 m**



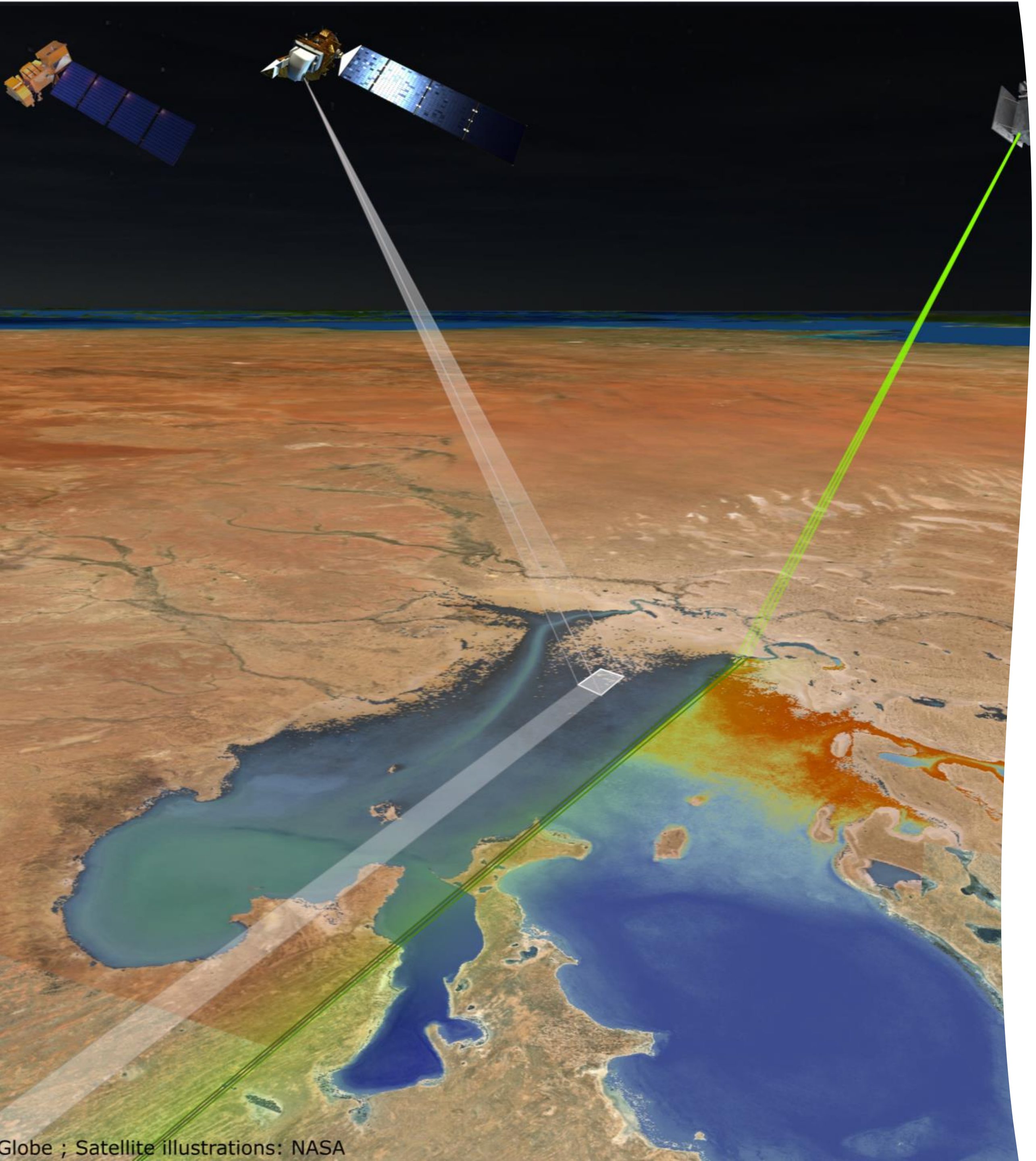
Discussion

- Cross sections show our data (**WOLP**) **is much** smoother and **more realistic than SRTM** data over the examined lakes



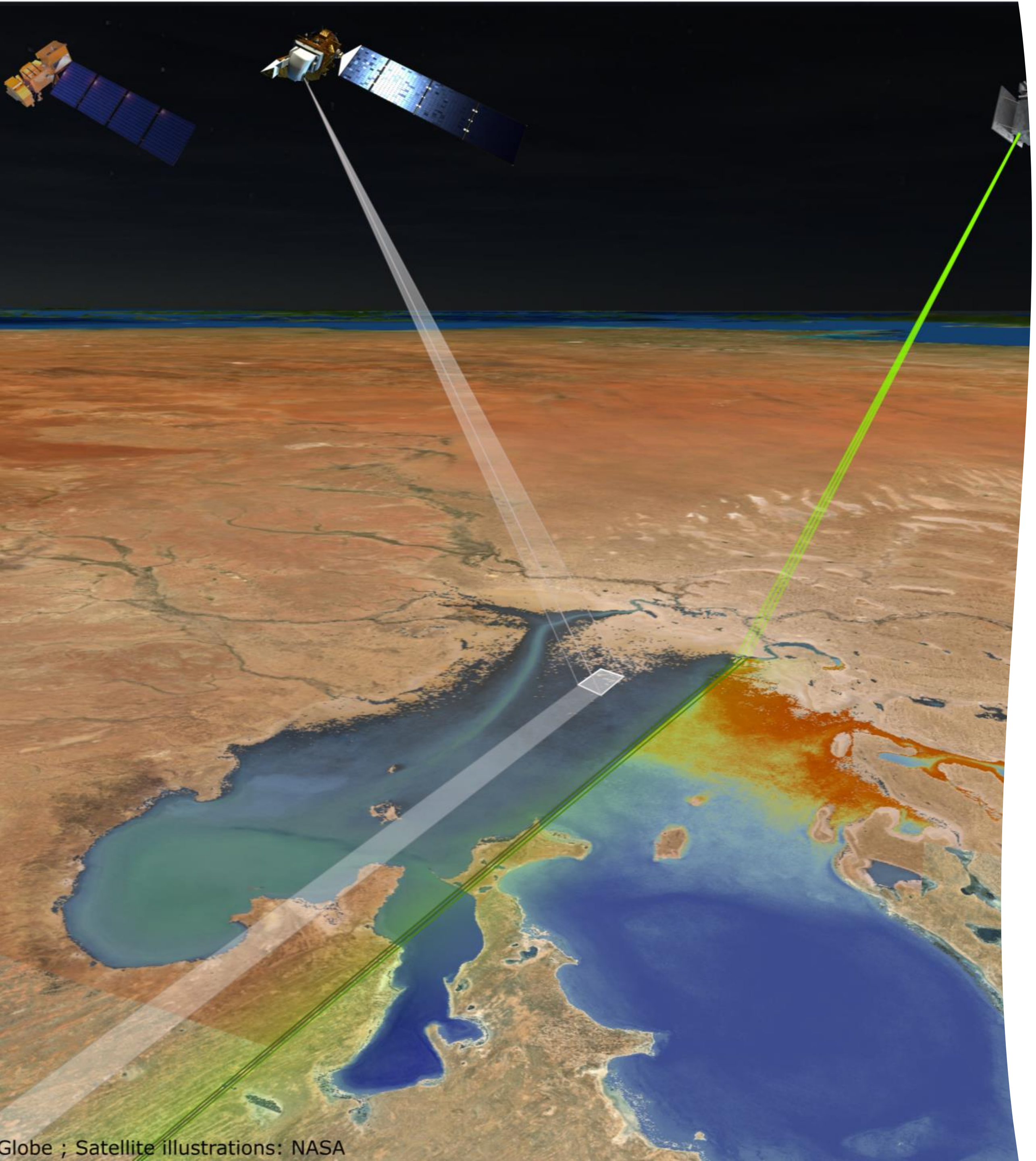
Discussion

- This makes any water budget calculation better
- As an example notice the hypsometric curves above



Conclusions

- Using a **new methodology** we derived the bathymetry of three desert lakes
- The methodology uses accurate **ICESat-2 elevation** altimetry data **integrated with water occurrence** data from the Landsat program
- The methodology can **be applied for complex lake systems** consisting of subbasins
- It can also be used for **inundated lakes**
- Results have **low error (~0.3 m) compared to SRTM data (~2.5 m)**



Further details

- Read our **paper**:
  - Armon, M., Dente, E., Shmilovitz, Y., Mushkin, A., Cohen, T. J., Morin, E., & Enzel, Y. (2020). Determining bathymetry of shallow and ephemeral desert lakes using satellite imagery and altimetry. *Geophysical Research Letters*, 47, e2020GL087367. https://doi.org/10.1029/2020GL087367
- Or contact by **email**
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Alternatives to SRTM / ASTER

- Integration of remote sensing with a **spatial interpolation of in-situ measurements** (Feng et al., 2011; Leon & Cohen, 2012)
- Combination of **optical imaging** and **radar** (Sun & Ma, 2019) or **laser altimetry** (Arsen et al., 2013; Li et al., 2019; Ma et al., 2019)

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