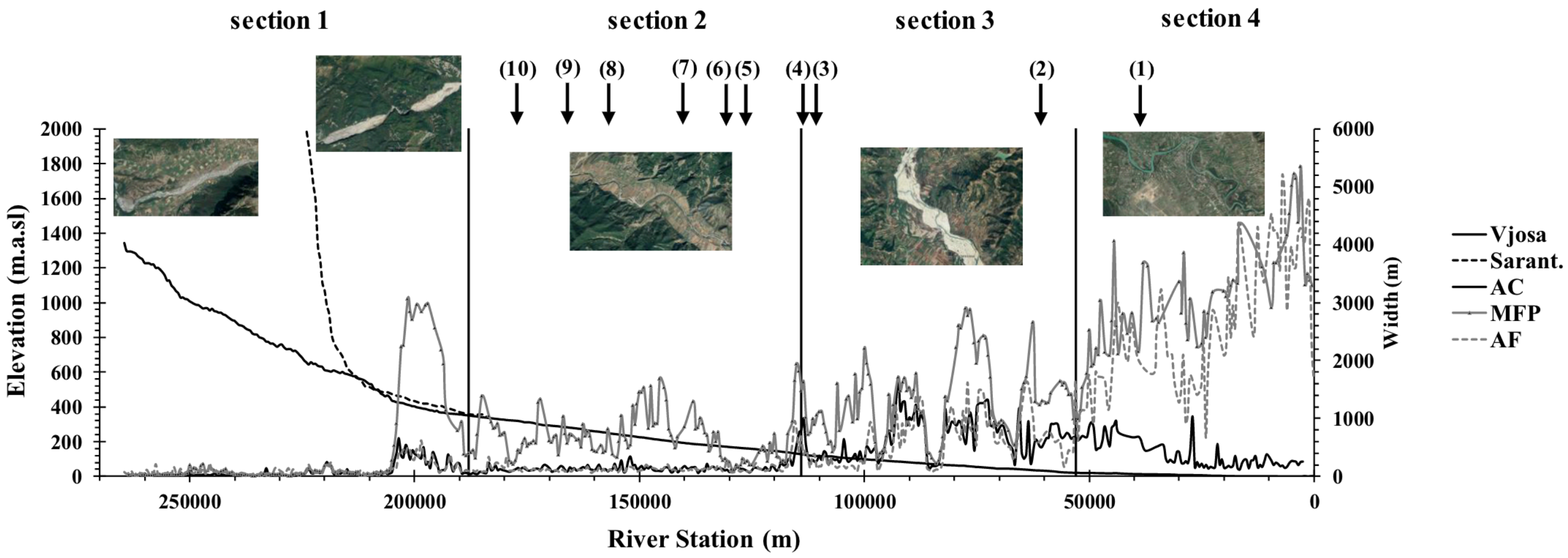
Sediment source and pathway identification using Sentinel-2 imagery and (kayak-based) lagrangian river profiles on the Vjosa river

Jessica Droujko, Srividya Hariharan Sudha, Gabriel Singer, and Peter Molnar

Introduction

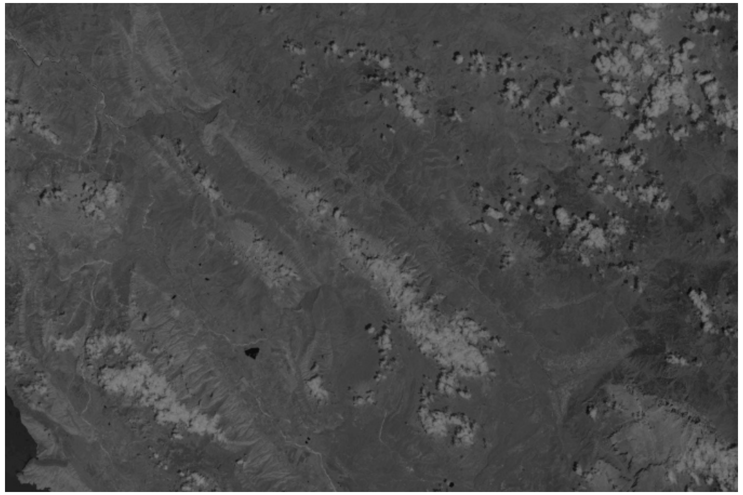
Aim to explore the potential of remote sensing to identify sources of sediment and their pathways



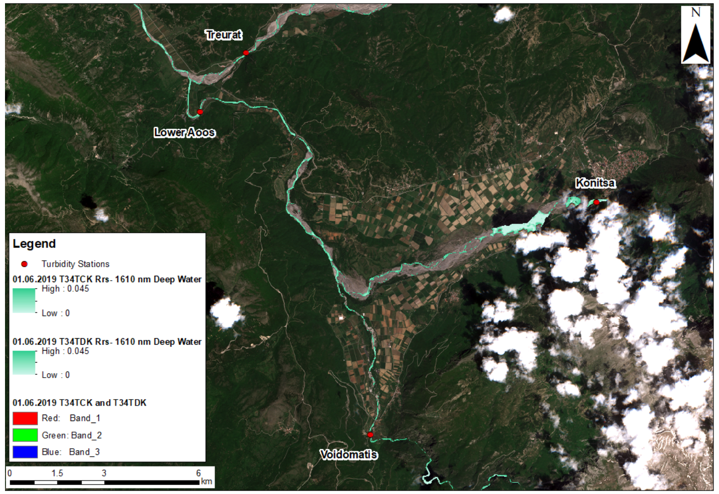
Longitudinal profile of the Vjosa river for the Active Channel (AC), Active Floodplain (AF), Morphological Floodplain (MF) and the main tributaries of the investigated catchment (Hauer et al. 2021)

ETH zürich

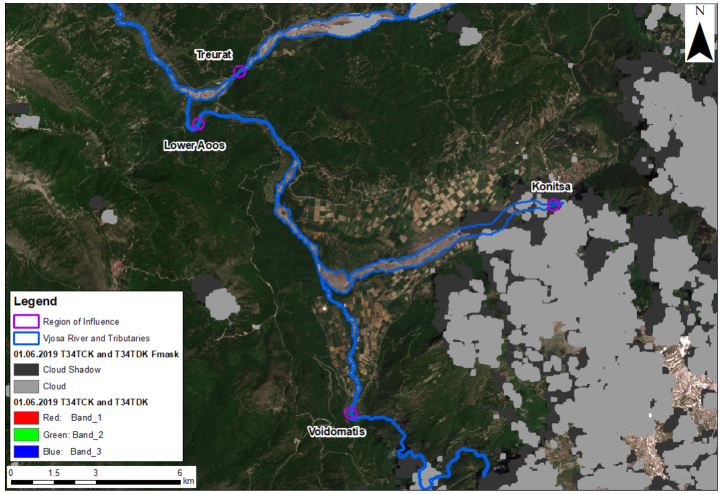
Satellite image processing



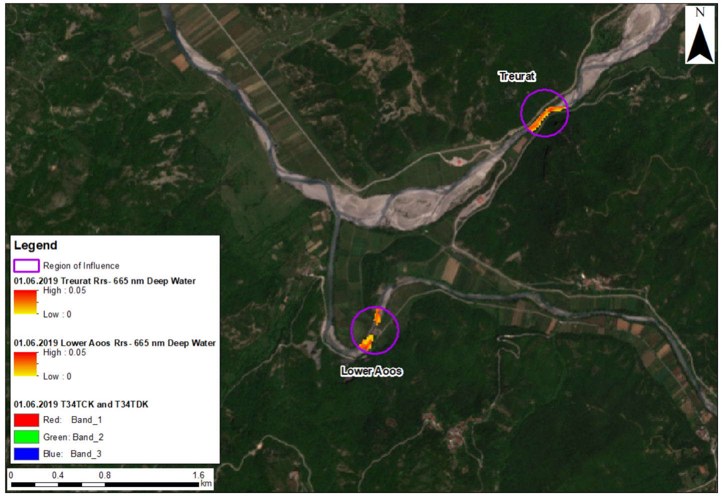
Atmospheric correction of Sentinel-2 Level-1C products using ACOLITE



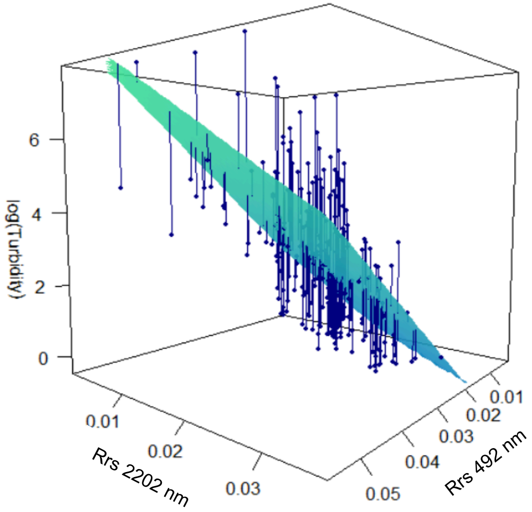
Deep water pixel extraction



Cloud and cloud-shadow mask



Regression built with pixels around in-situ sensor locations



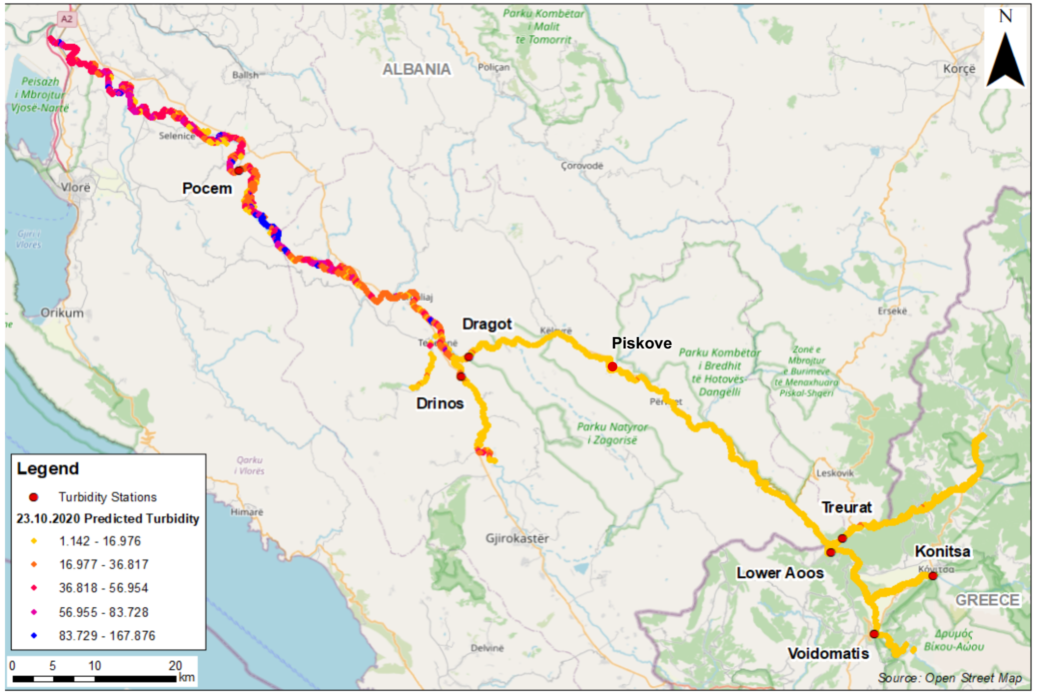
Regression using two bands:

- 492 nm
- 2202 nm

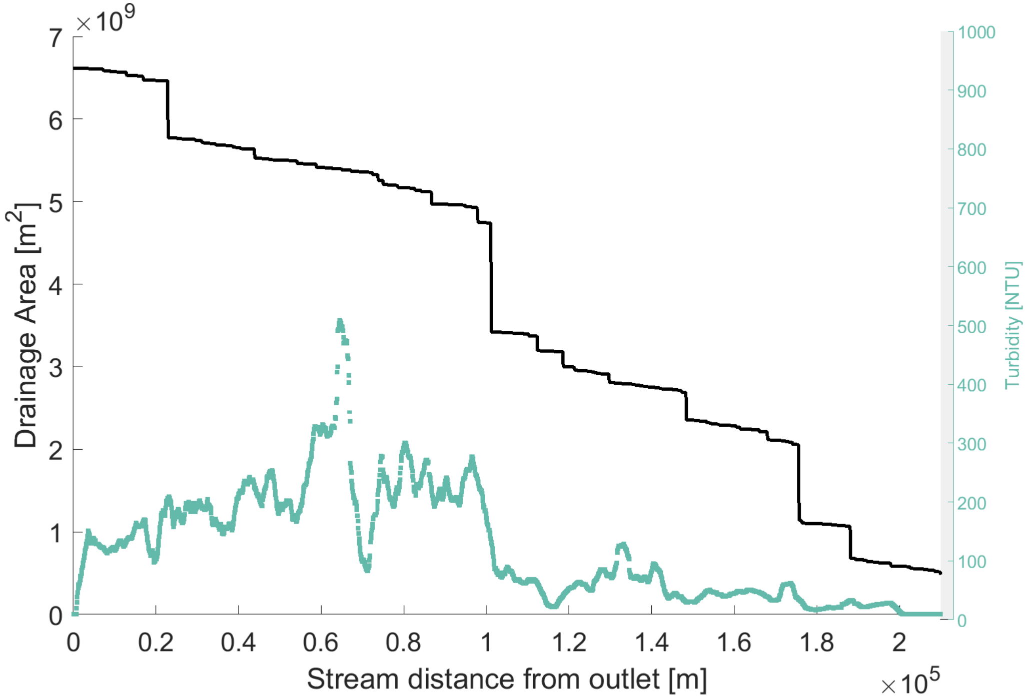
Sharing is encouraged

Turbidity maps for every satellite image over 2 years

Regression applied to entire catchment

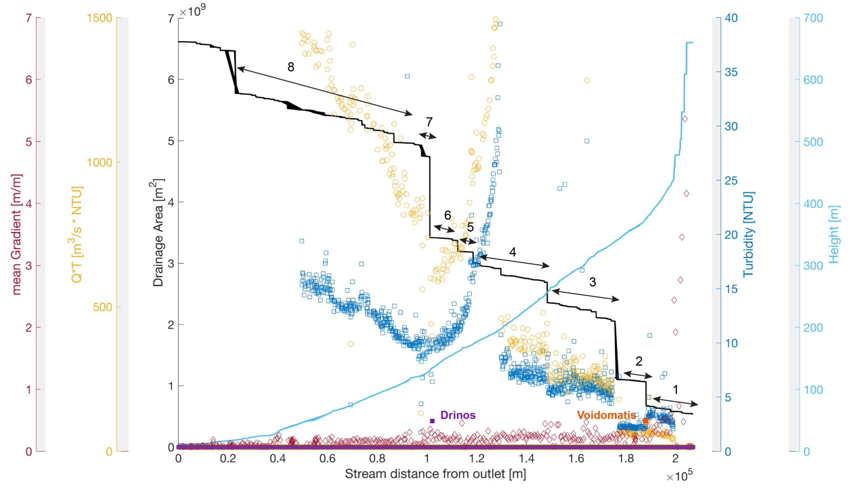


One year average of satellite images

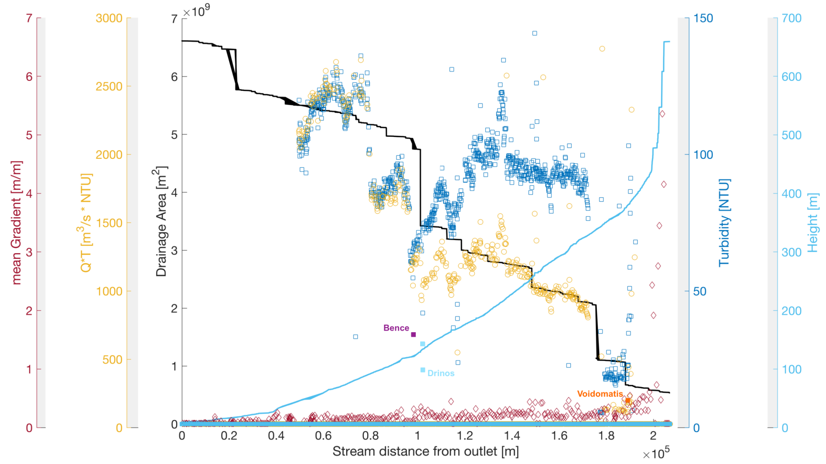


Concentration changes from satellites are seen in kayak measurements

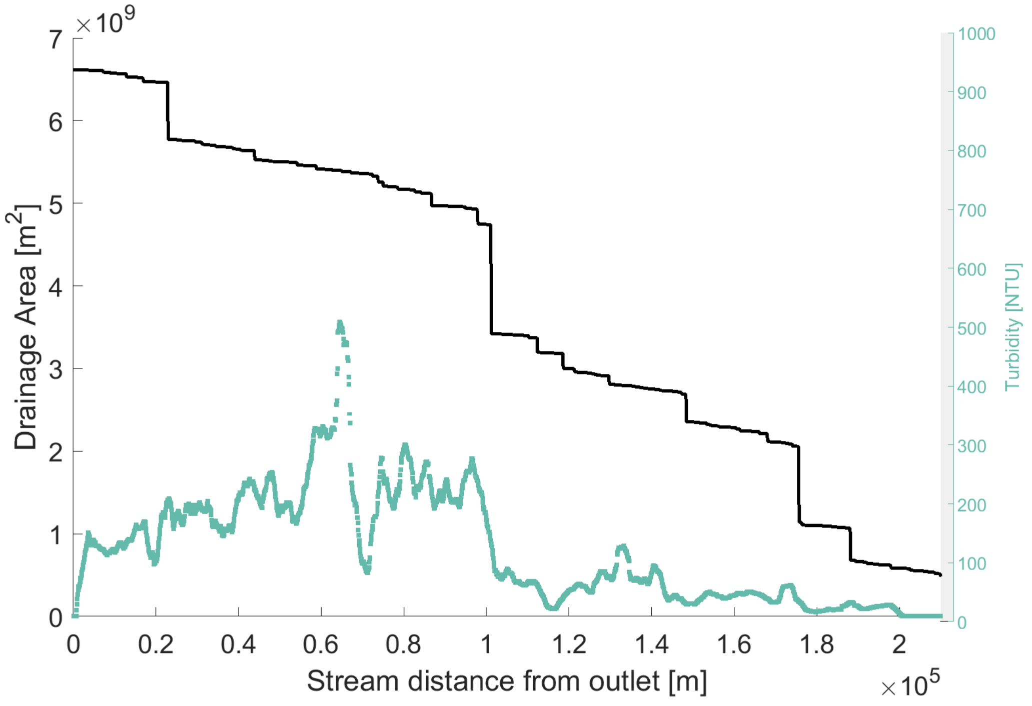
Kayak trip - Spring 2019



Kayak trip - Fall 2020

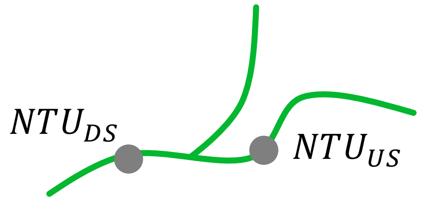


One year average of satellite images

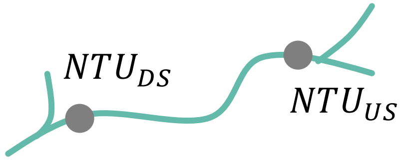


More info on seasonality in supplementary materials

Some changes in concentration of tributaries + reaches are significant



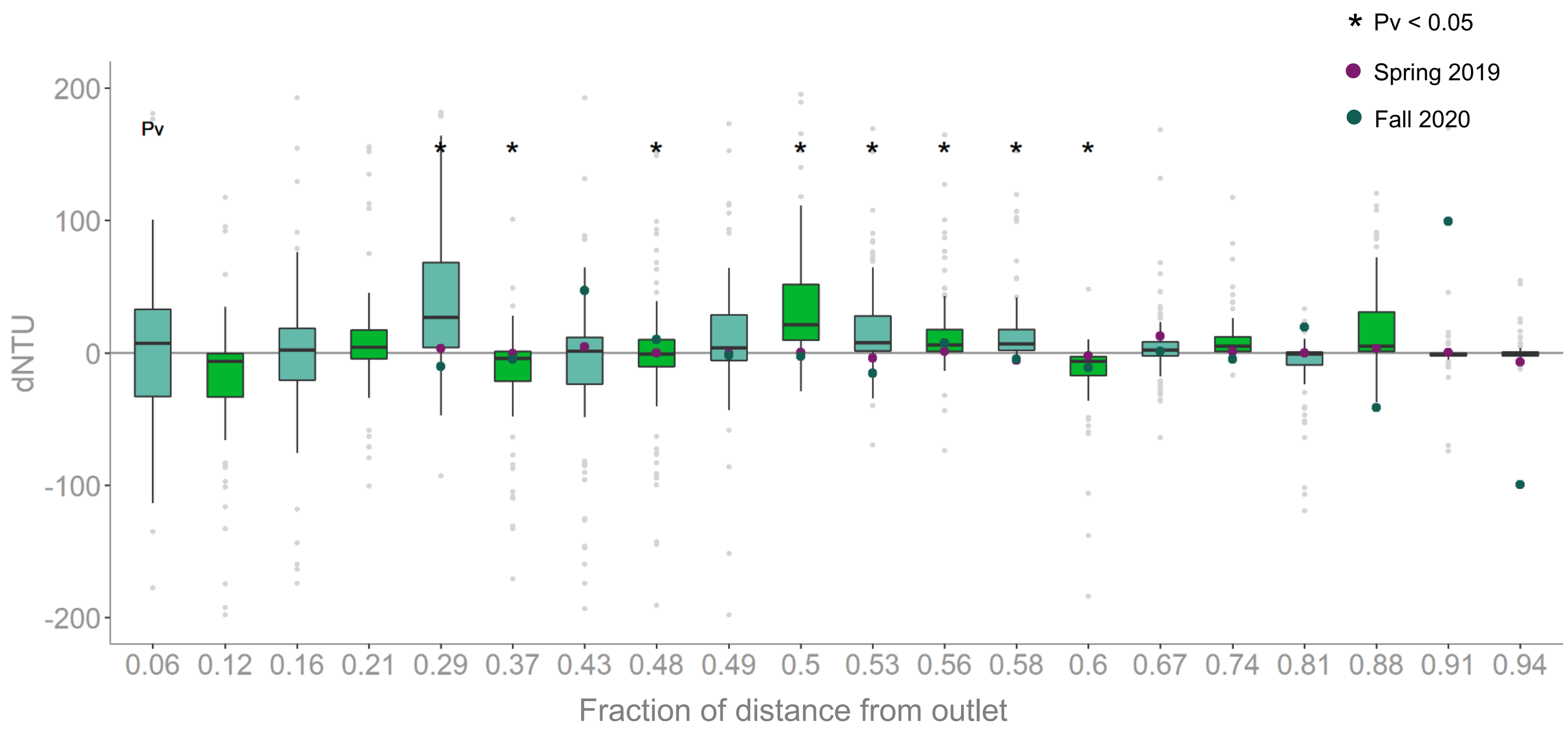
$$dNTU_{trib} = \mathrm{NTU_{US}} - \mathrm{NTU_{DS}}$$



$$dNTU_{rea} = \mathrm{NTU_{DS}} - \mathrm{NTU_{US}}$$

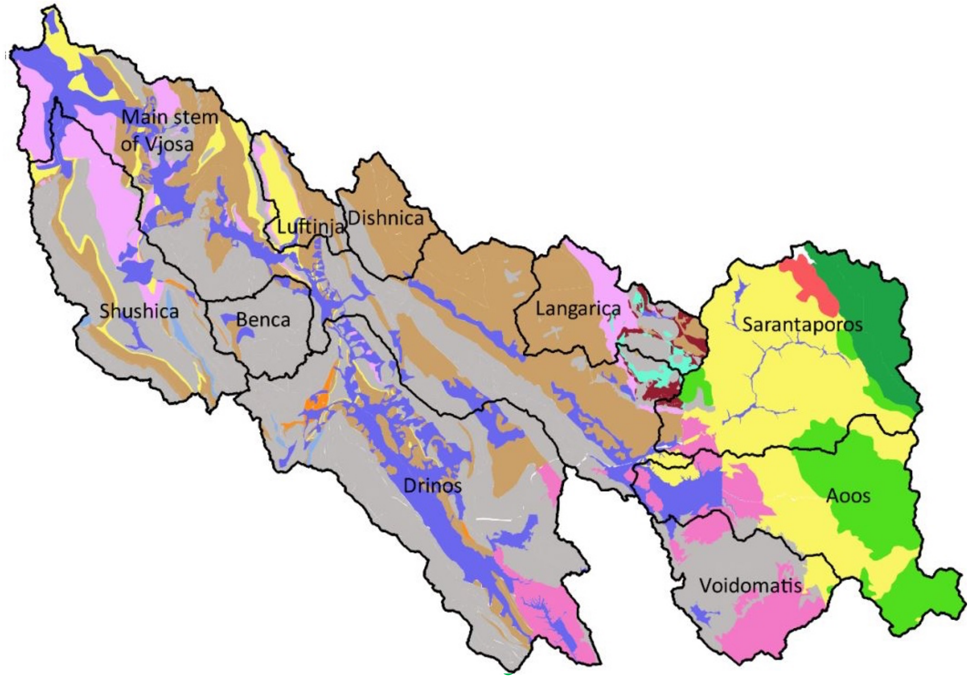
dNTU > 0 if more discharge brings disproportionally more sediment (source)

dNTU < 0 if more discharge brings less sediment, then there is deposition (or clear water input)

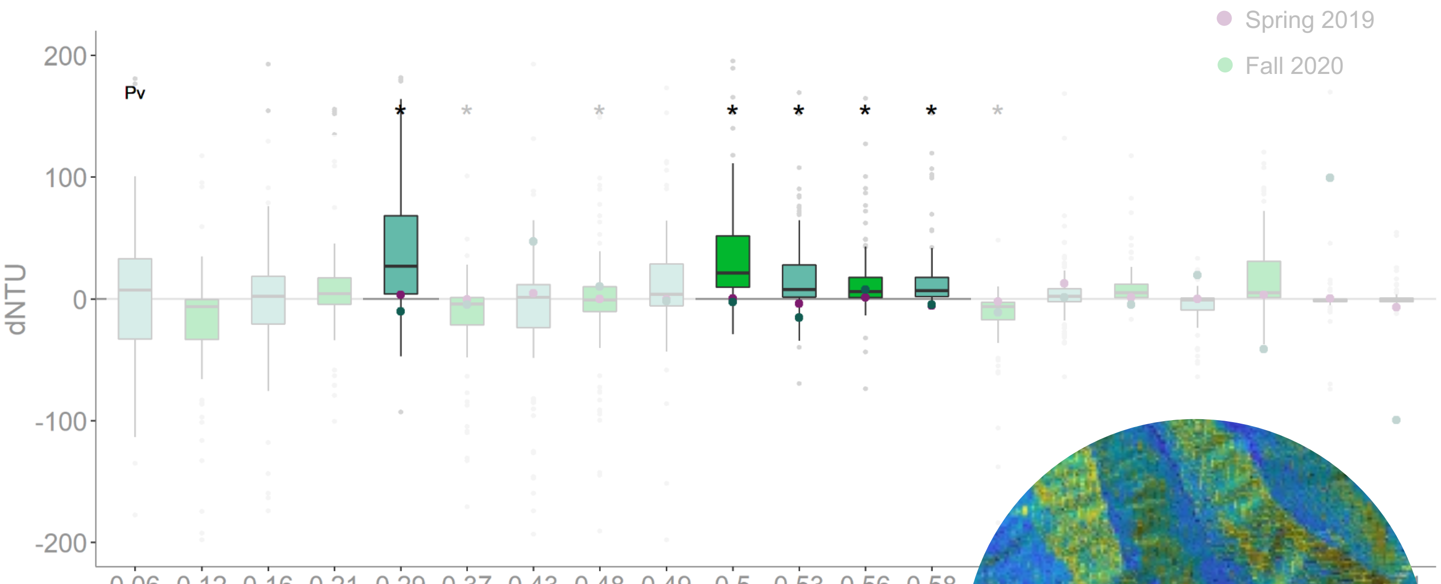


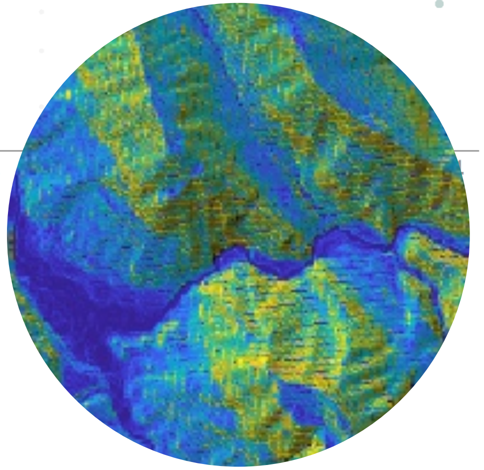
Some reaches and tributaries are significant sources

ETH zürich



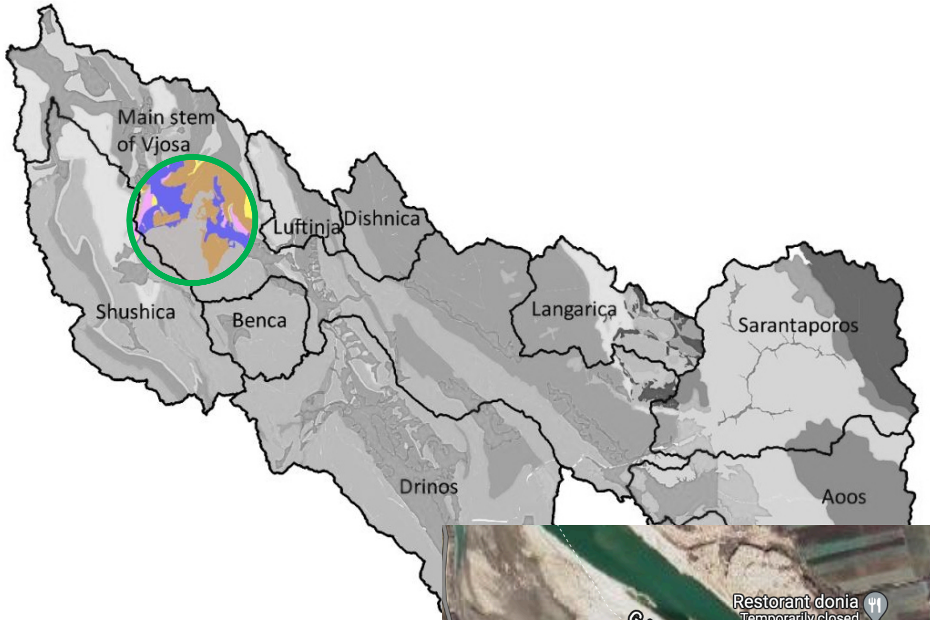
Geological map of Vjosa river



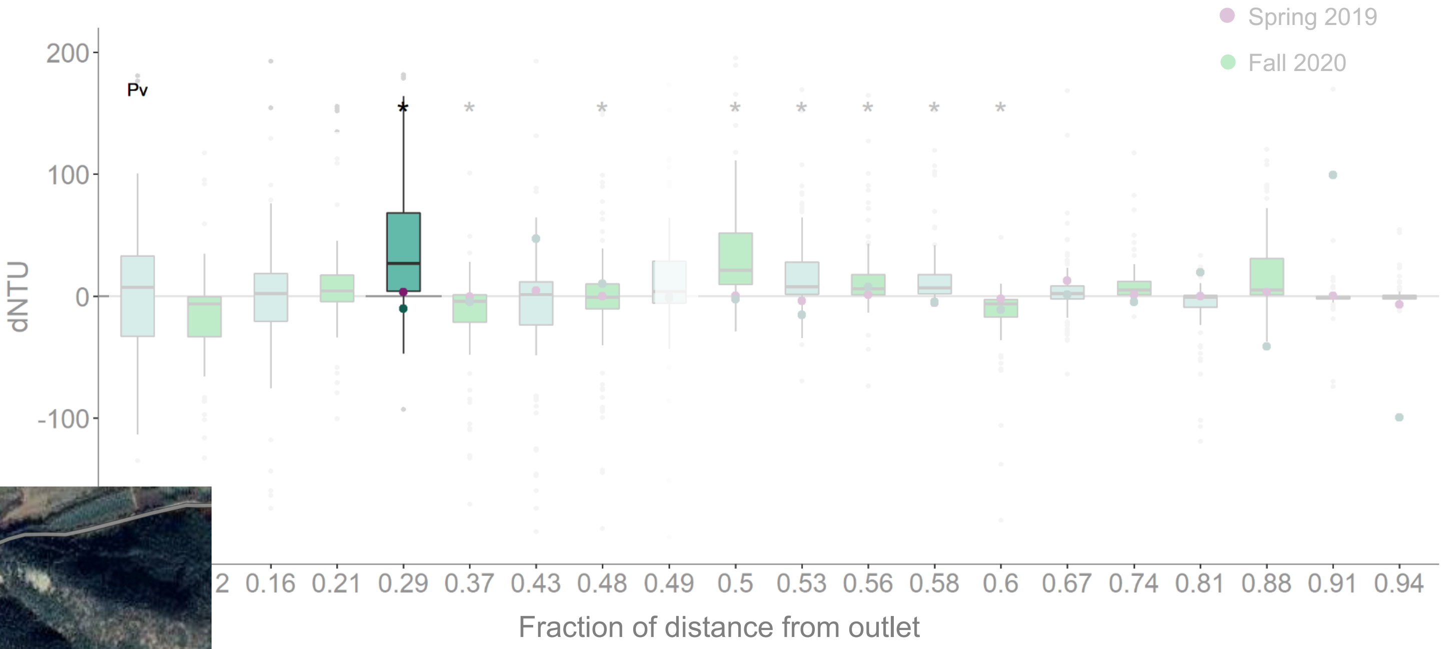


Sharing is encouraged

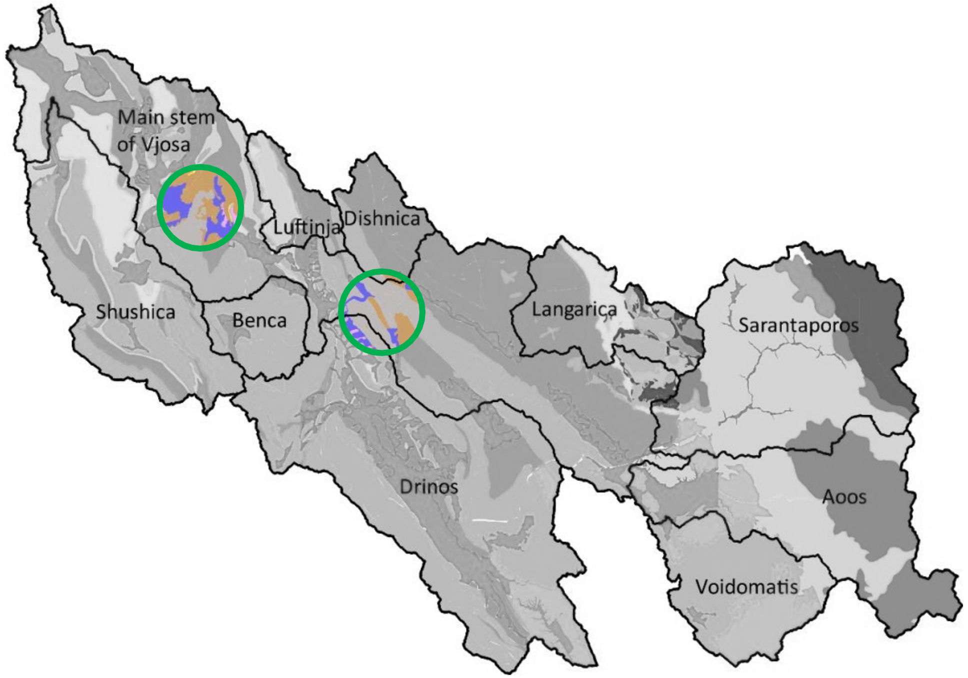
Some reaches and tributaries are significant sources



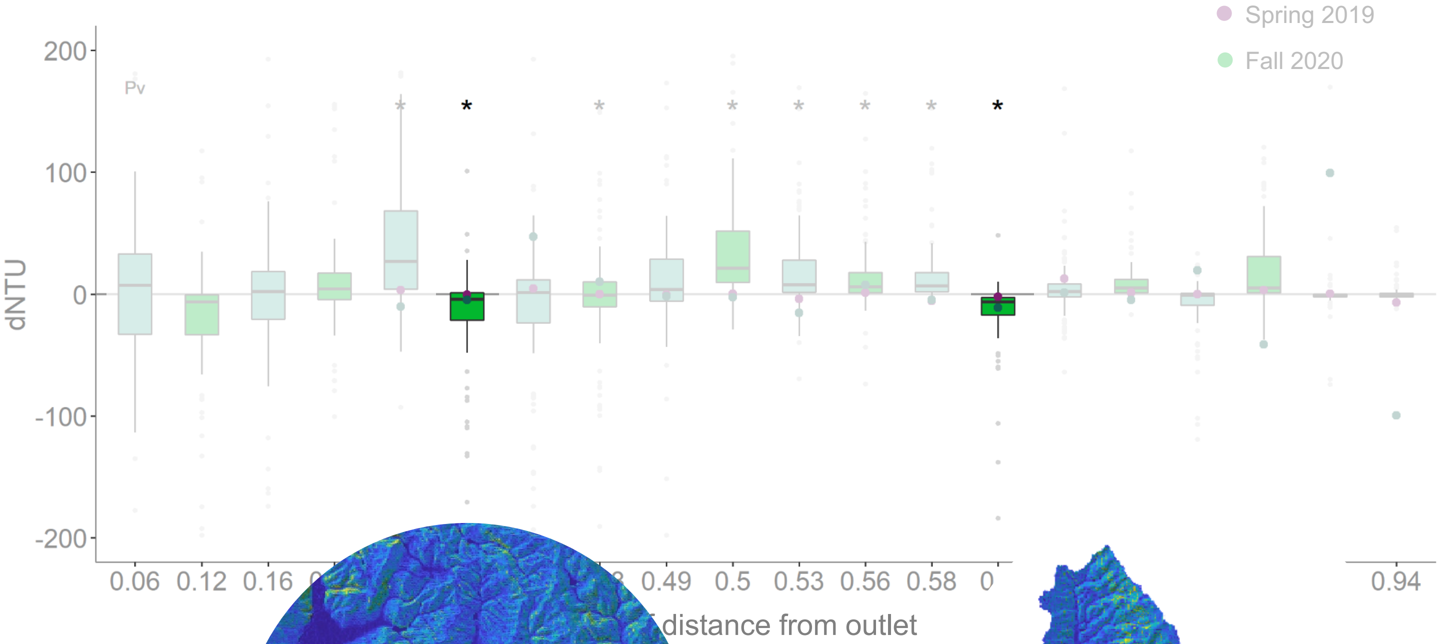
Geological map of Vjosa rive

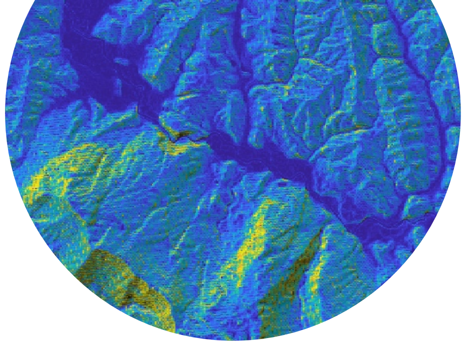


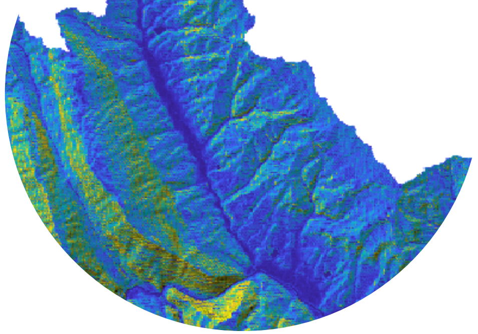
Significant sinks at limestone constrictions



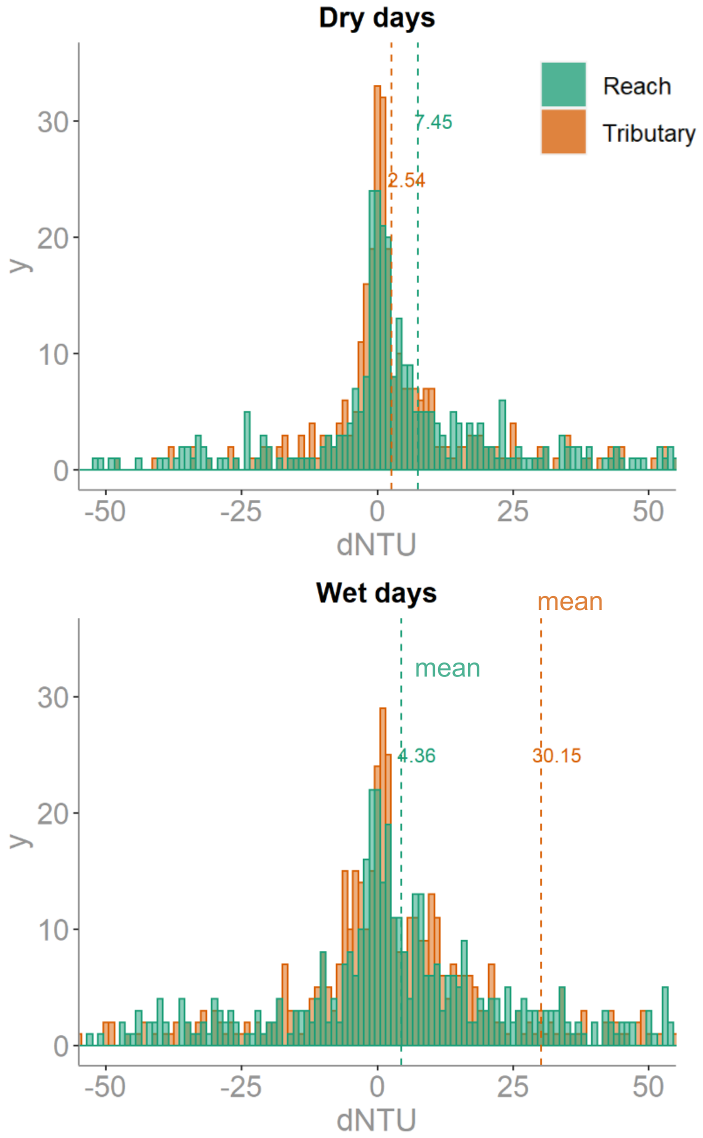
Geological map of Vjosa river







Within-reach variability in NTU is almost as broad as the variability due to tributaries



On average the system is transporting same concentration downstream

High within-reach variability, probably from morphologically natural river system

See supplementary materials

- Satellite imagery can be used to identify sinks and sources
- systematic downstream variability in mean SSC connected to tributary and within-reach inputs
- temporal variability at a location connected to rainfall and flow history and sediment sources (see supplementary materials)

ETH zürich

Questions?

Find all of the results and extended methods here:

SCAN ME

Sharing is encouraged

This presentation participates in OSPP

EGU

Outstanding Student & PhD candidate Presentation contest

erc

European Research Council

ERC-STG FLUFLUX

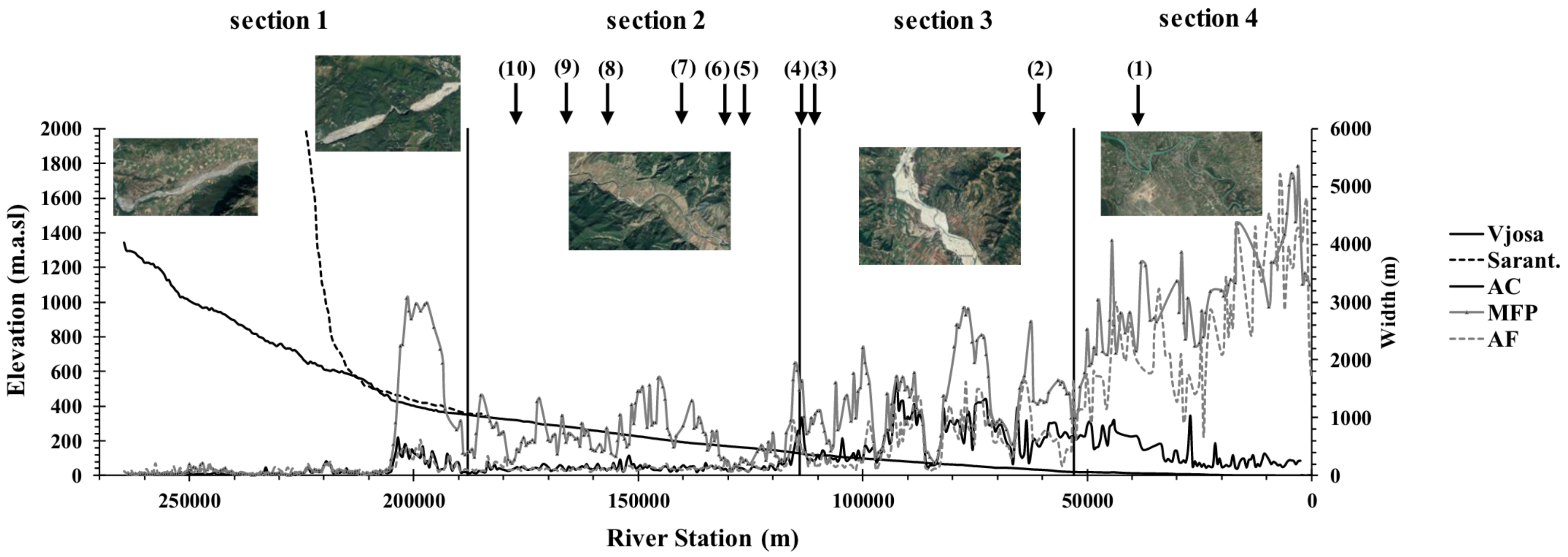
ETH zürich

Backup slides

Sharing is encouraged

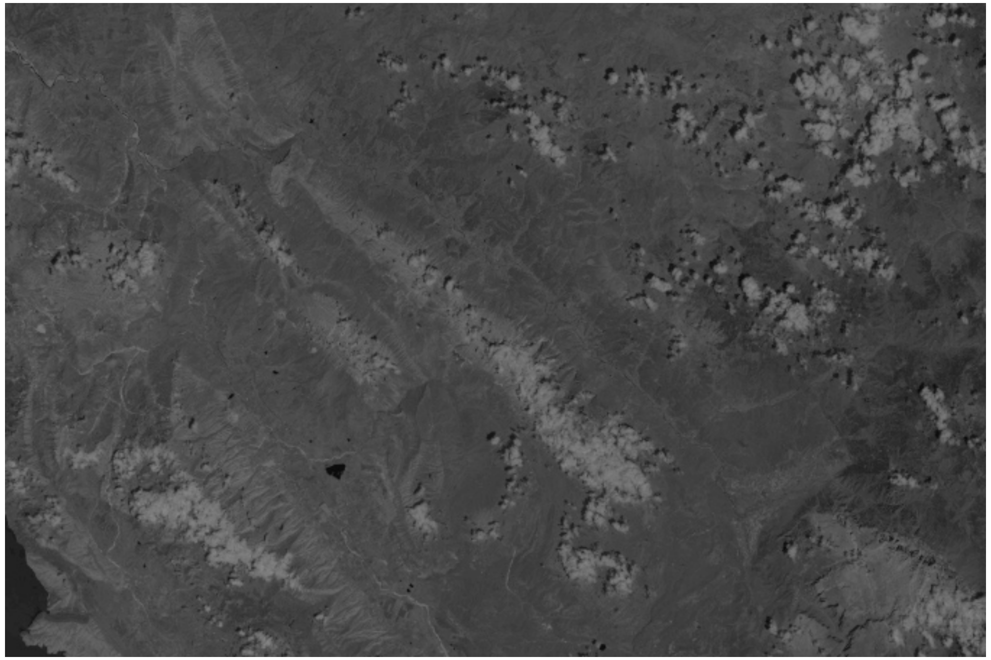
Introduction

- The Vjosa river, which is situated in Albania and Greece, is a geologically diverse river with morphological variability that is not seen anymore in other European rivers at this scale
  - The active channel and floodplain width varies from 100s to several 1000 meters, which is a prerequisite for good aquatic habitat quality and floodplain biodiversity
- Most sedimentological studies on the Vjosa to date focus on bedload, but we know that suspended load, can often be greater in total sediment flux than bedload
- Therefore, it is imperative to measure SSC and we have attempted to do so and identify sources of sediment and their pathways, using remote sensing and in-situ kayak observations



Longitudinal profile of the Vjosa river for the Active Channel (AC), Active Floodplain (AF), Morphological Floodplain (MF) and the main tributaries of the investigated catchment (Hauer et al. 2021)

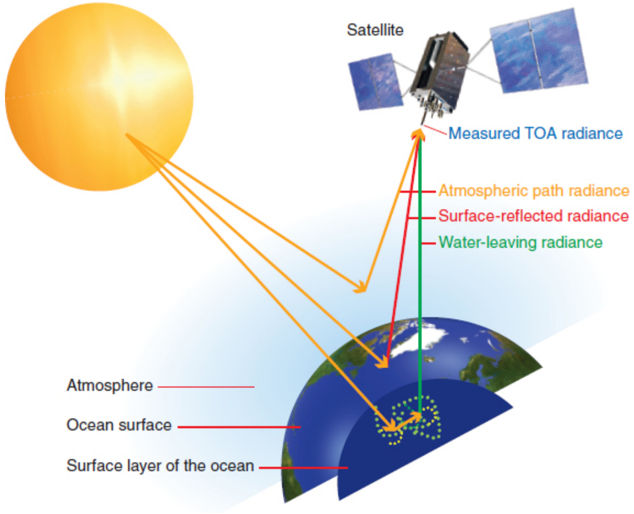
Methodology

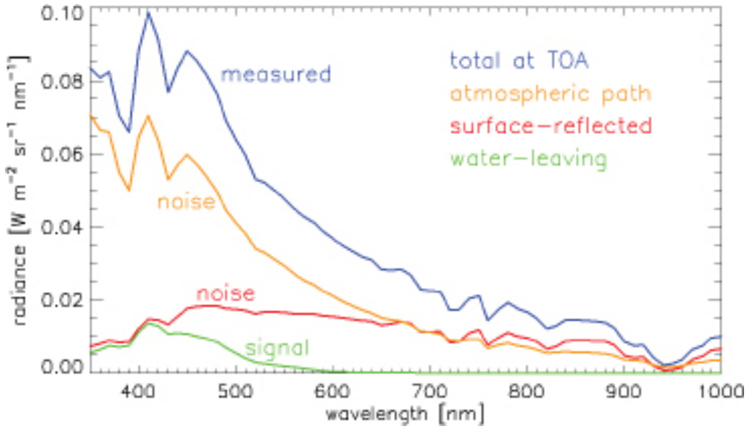


Atmospheric correction of Sentinel-2 Level-1C products using ACOLITE

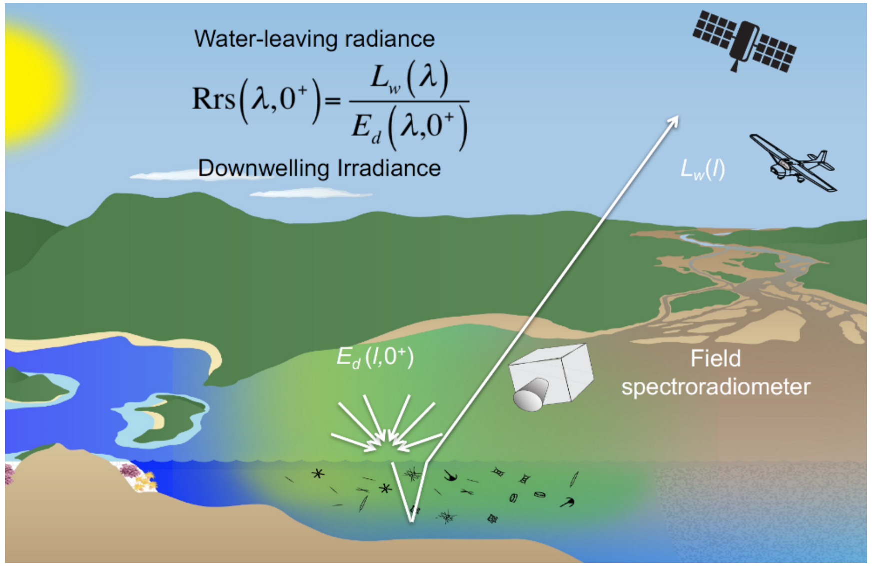
- We used TOA products from Sentinel-2 and atmospherically corrected these images using ACOLITE

- This processor converts Top-of-Atmosphere (for Sentinel-2 this is "Level-1C") radiance into water-leaving radiance, and then into remote sensing reflectance (Rrs)



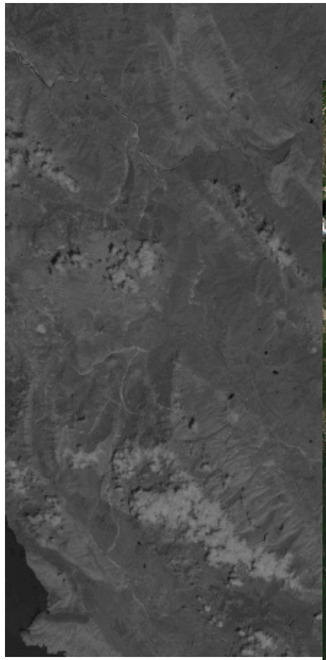


Source: National Research Council. Assessing the Requirements for Sustained Ocean Color Research and Operations. 2011.

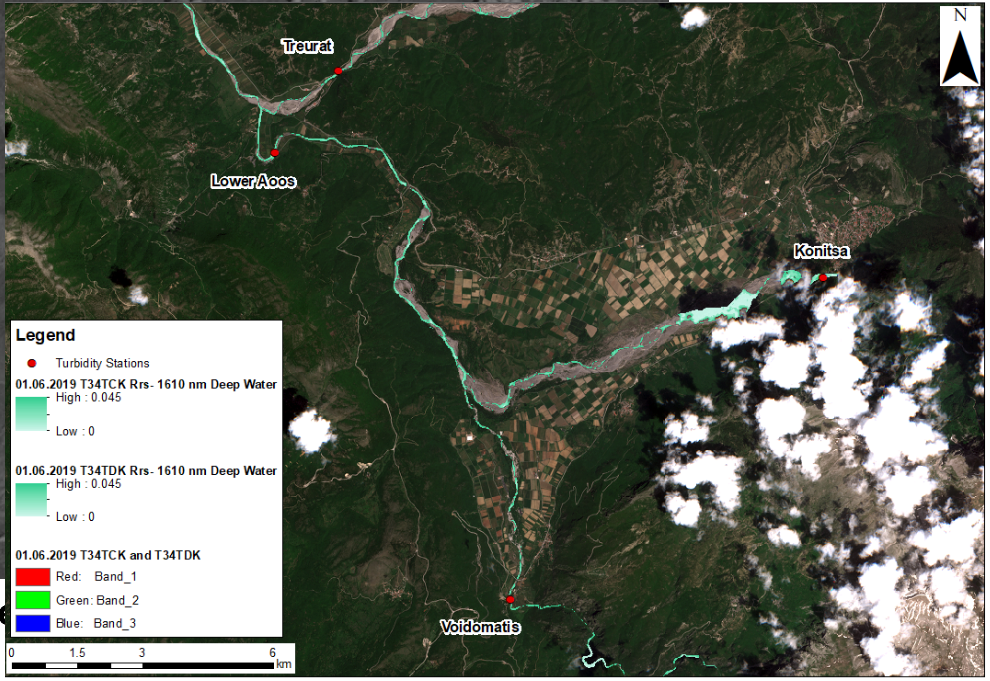


Source: Fundamentals of Aquatic Remote Sensing. Applied Remote Sensing Training. Palacios. Link: https://appliedsciences.nasa.gov/sites/default/files/fundamentals-aquatic-web.pdf

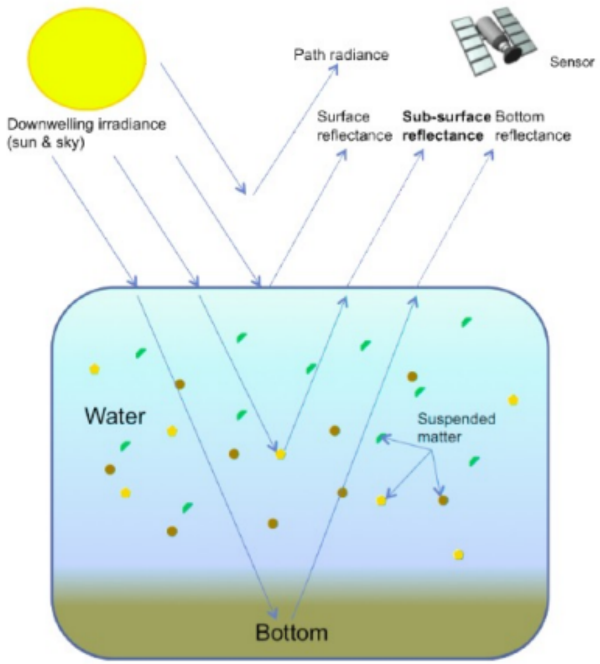
Methodology



Atmospheric corre[...]
using ACOLITE



Deep water pixel extraction

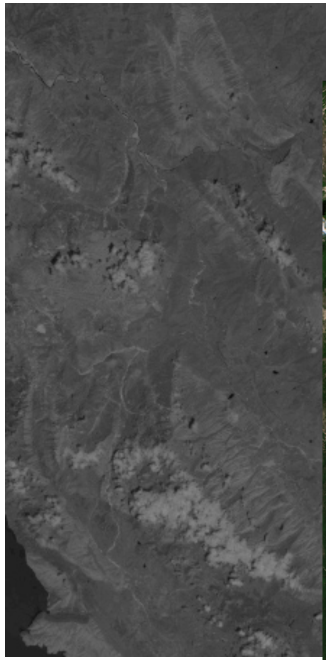


Source: Remote Sensing of Lake Tahoe's Near Shore Environment. Lake Tahoe Science Program. US Forest Service. S. Watanabe

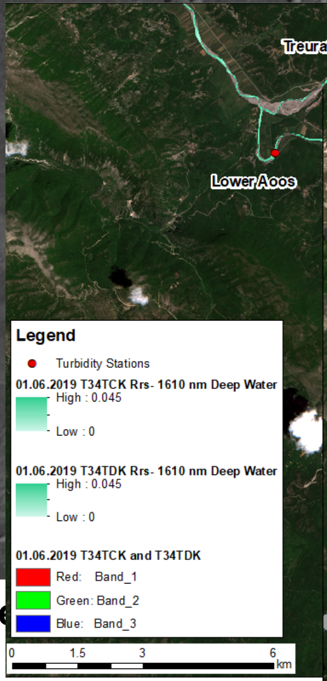
- Our remote sensing signal can also contain bottom reflectance (noise)
- Deep water has less bottom reflectance than shallow water
- We used Rrs of SWIR band (1610 nm) as an indicator to extract deep water pixels (since this wavelength is absorbed in deeper waters)
- We used a cutoff value to select only deep water pixels
- The cutoff value (0.045 sr^{-1}) was chosen through trial-and-error

ETH zürich

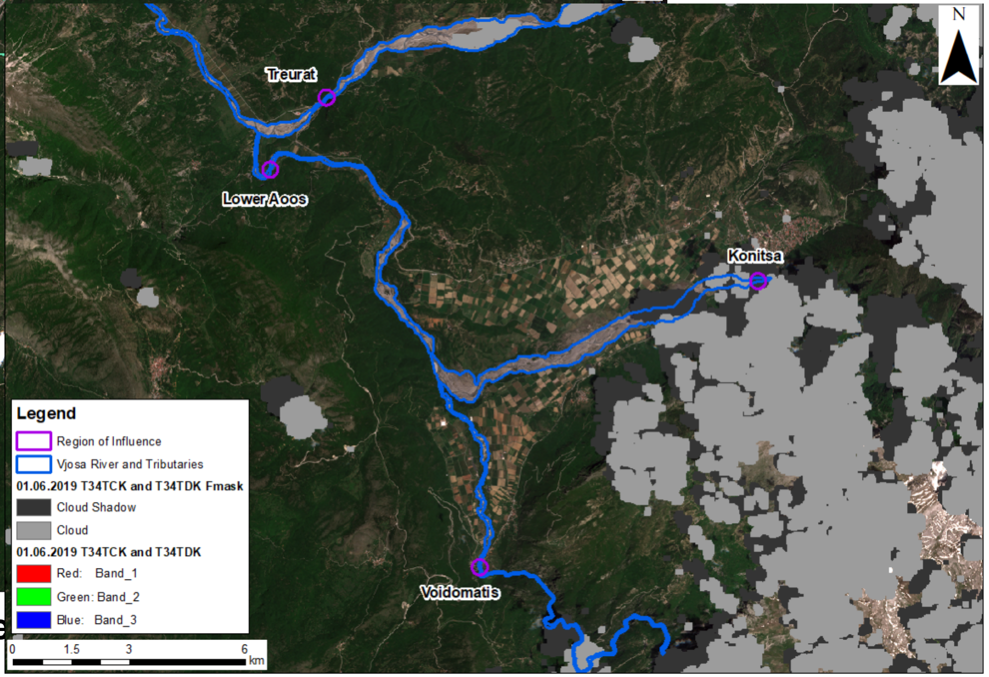
Methodology



Atmospheric corre
using ACOLITE



Deep water pixel e

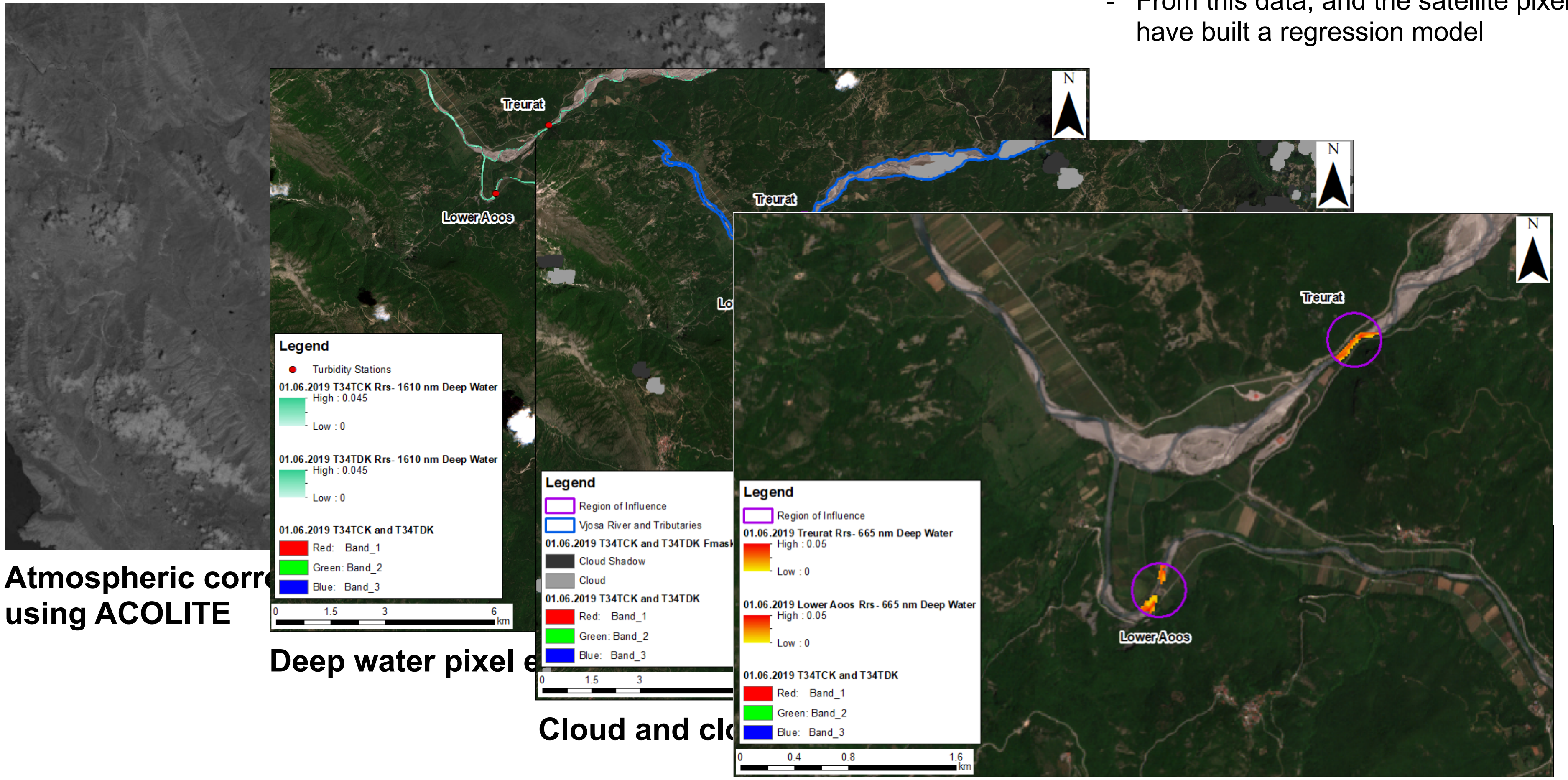


Cloud and cloud-shadow mask

- Fmask (Function of mask) is used for automated clouds, cloud shadows masking

Methodology

- We collected 2 years of in-situ data from 8 stationary turbidity sensors
- From this data, and the satellite pixels around the stationary loggers, we have built a regression model

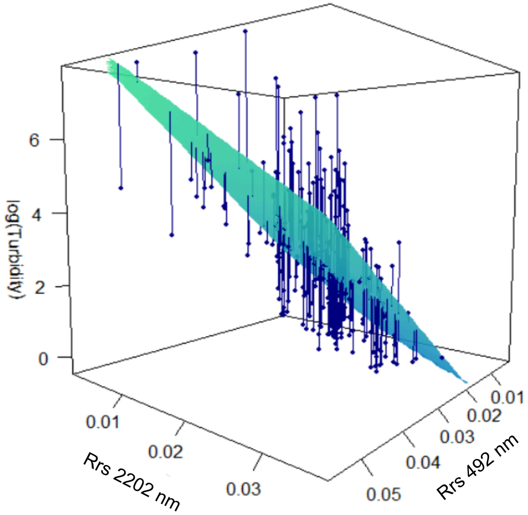


Atmospheric corre using ACOLITE

Deep water pixel e

Cloud and cl

Regression build with pixels around in-situ sensor locations

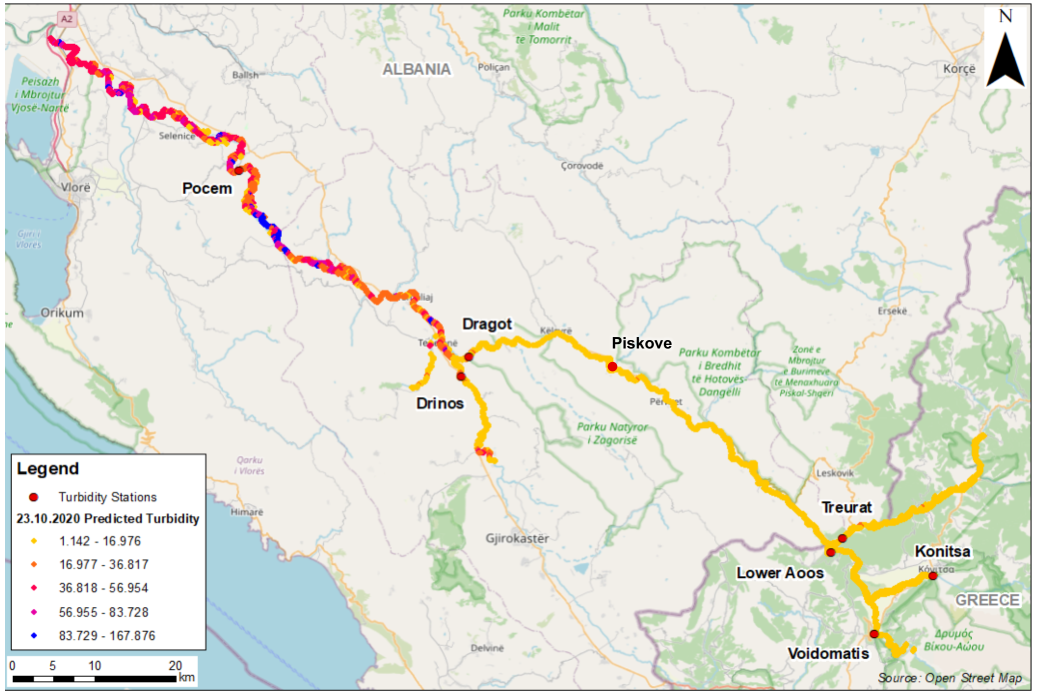


Regression using two bands:

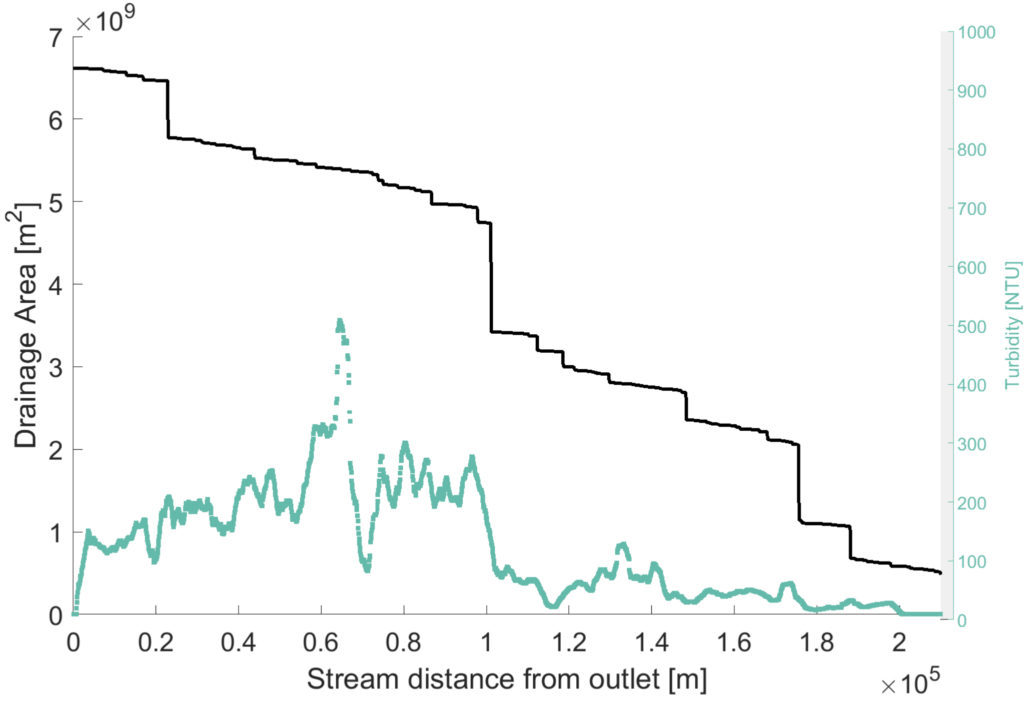
- **492 nm**
- **2202 nm**

Turbidity maps for every satellite image over 2 years

Regression applied to entire catchment



One year average of satellite images

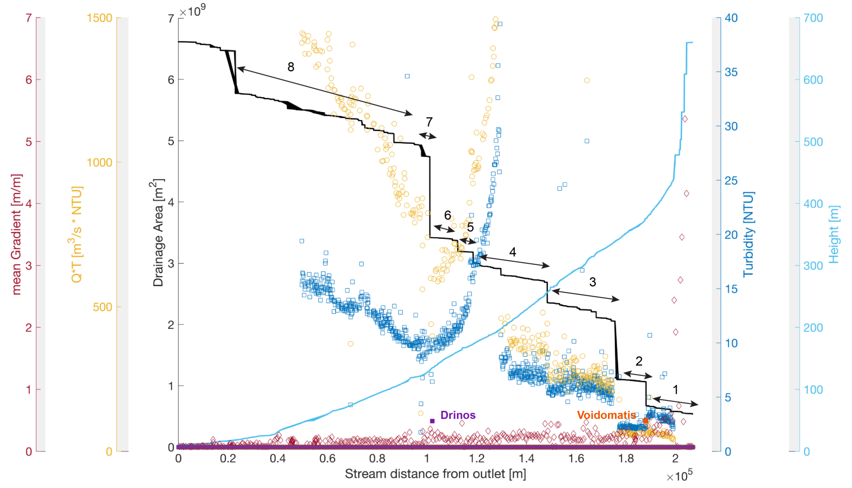


- Applying this regression, we obtain turbidity maps for every satellite image over a two year period (LEFT)
- Compiling all of the turbidity maps over one year, we obtain an average (RIGHT)
  - This is the average turbidity plotted along the stream distance from the headwaters to the outlet
- What's interesting in this data is that we find:
  - variability in SSC connected to tributary inputs (for example the tributary at 1E5m in RIGHT figure) and within-reach inputs (for example the dip and peak at 7E4m in the reach where there are no tributary inputs)

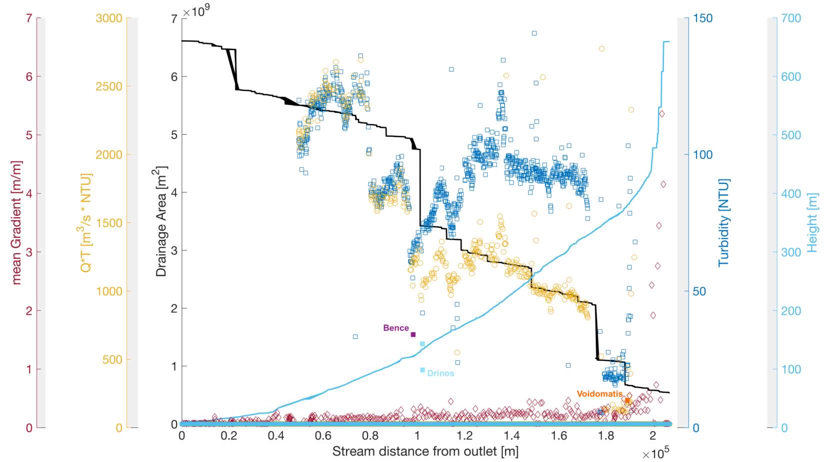
Sharing is encouraged

Concentration changes from satellites are seen in kayak measurements

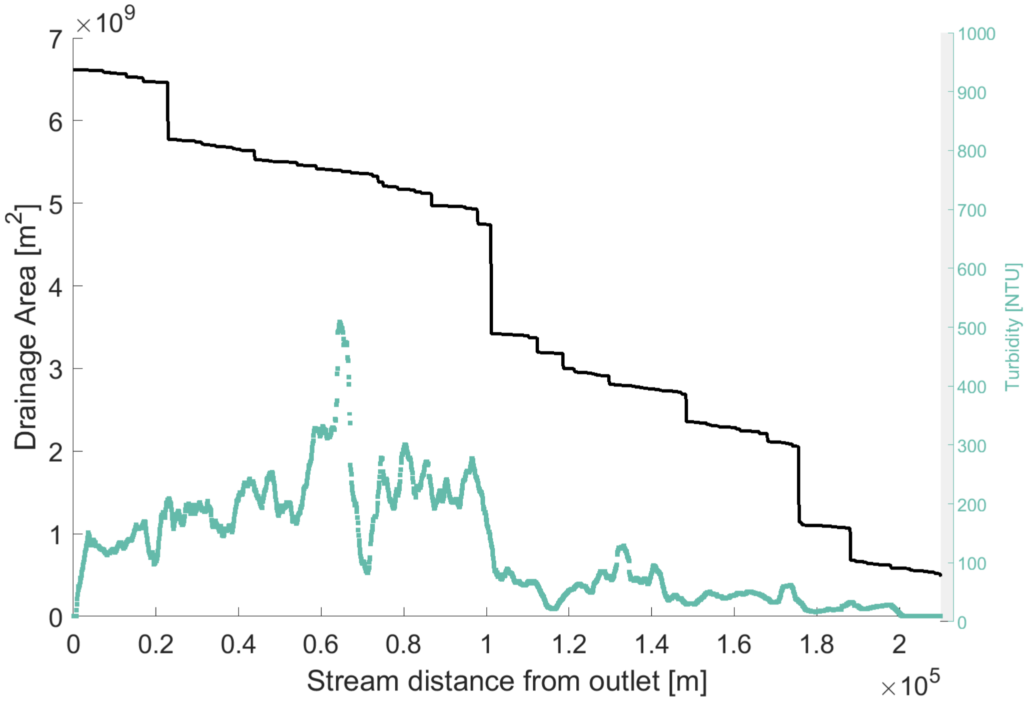
Kayak trip - Spring 2019



Kayak trip - Fall 2020



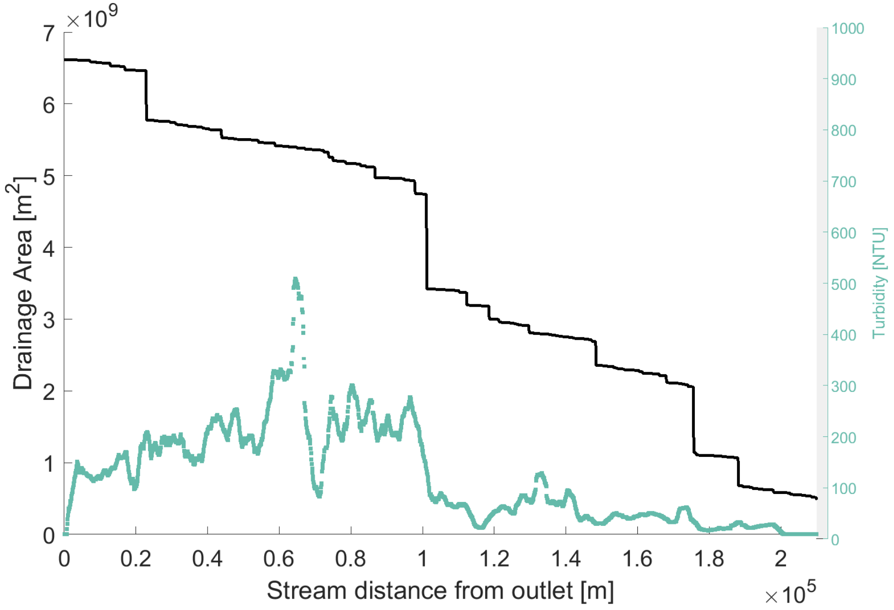
One year average of satellite images



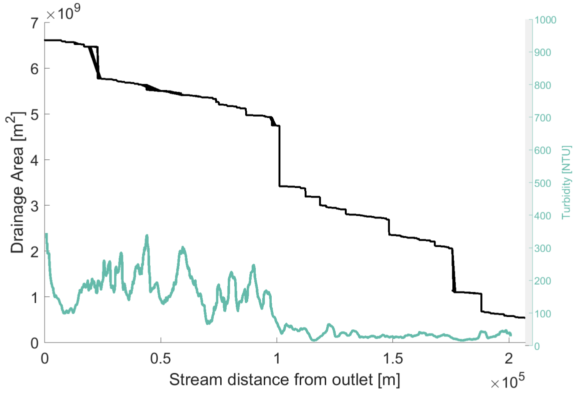
- Here we have these longitudinal profiles again but measured from a kayak, once in Spring 2019 and Fall 2020 (LEFT)
- In all three of these figures, we see this tributary input and within-reach variability
  - Namely the piskove peak and dip peak in braided section

Large variability between Winter 2019 and Summer 2020 concentration signal from satellite images

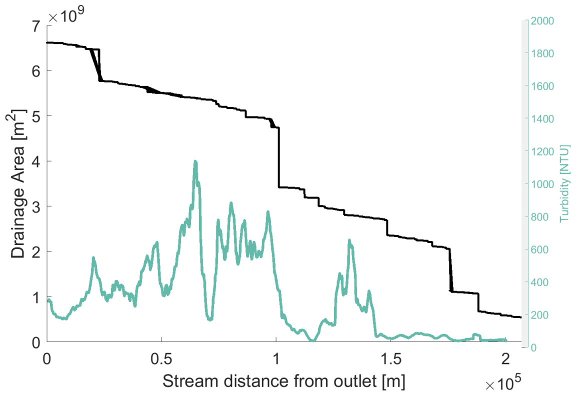
One year average of satellite images



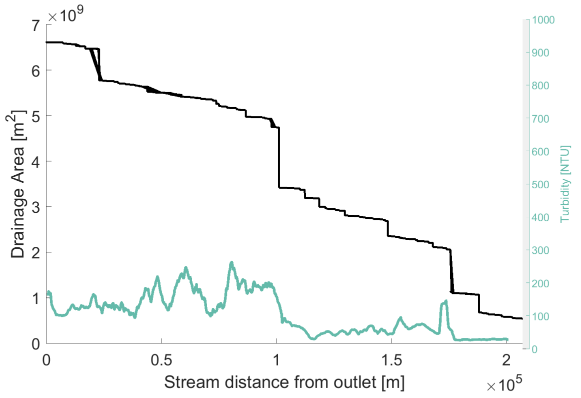
Fall 2019



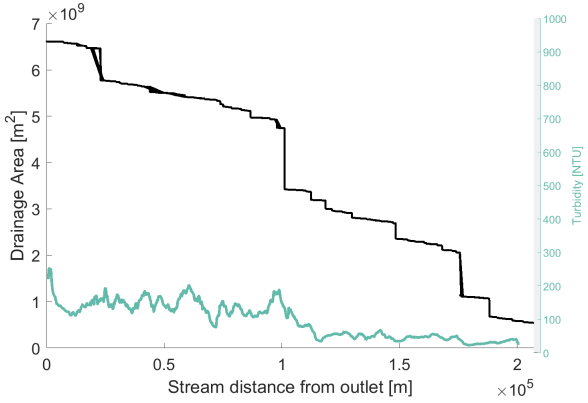
Winter 2019



Spring 2020



Summer 2020



What are the sources of variability?

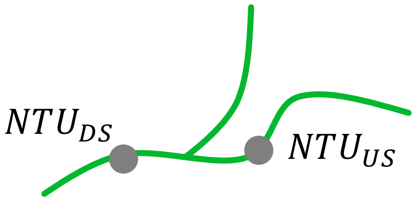
- We see from these plots that there is a seasonal signal, where in winter the mean SSCs were much higher than in the other seasons, especially the dry summer
- But there also seem to be recurring patterns
  - like the jump at the large tributary input
  - and the dip peak in the braided section

Some changes in concentration of tributaries + reaches are significant

dNTU > 0 if more discharge brings disproportionally more sediment (source)

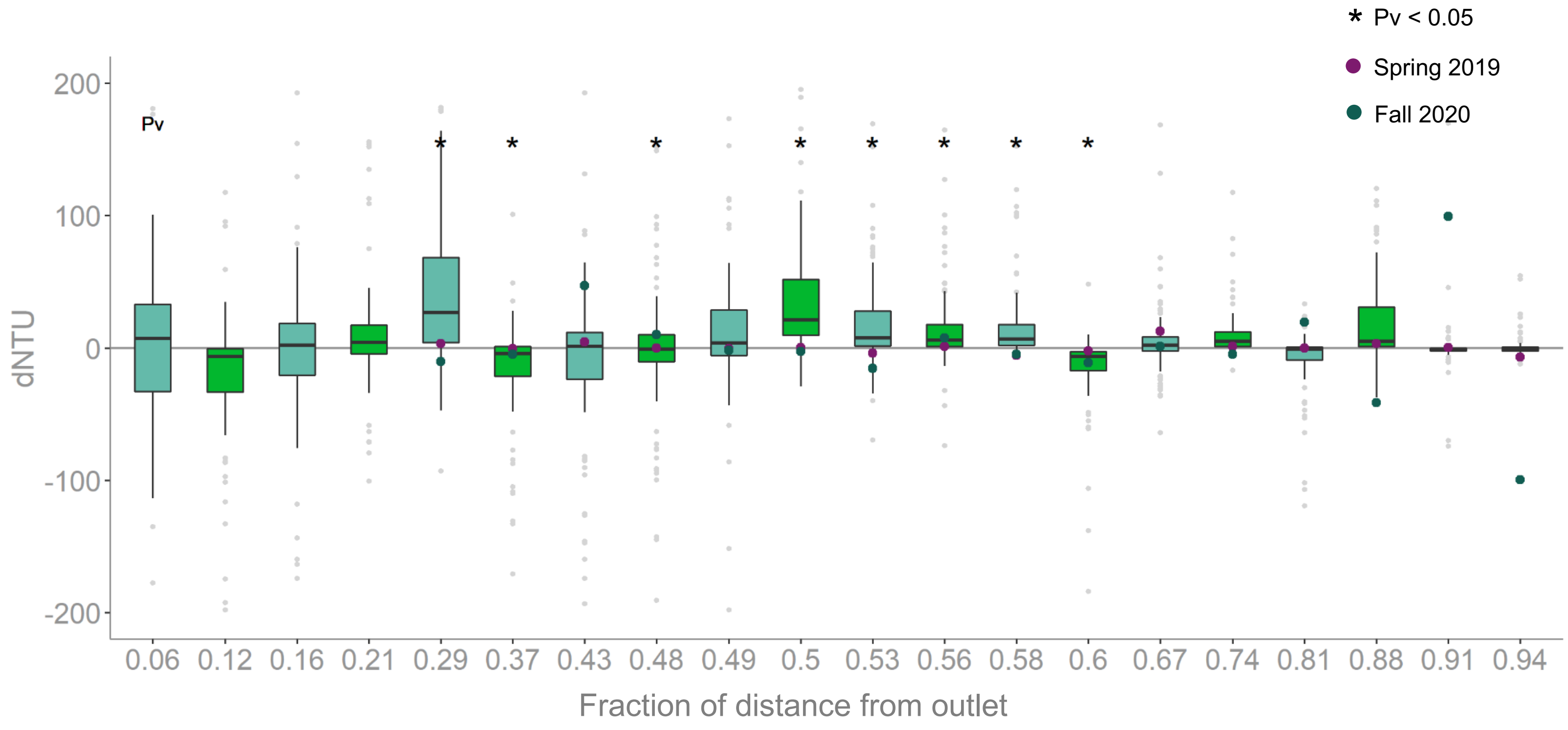
dNTU < 0 if more discharge brings less sediment, then there is deposition (or clear water input)

- From the remote sensing derived SSCs, we computed the difference in SSCs due to tributaries and reaches
- These differences are shown in the boxplots and contain all the images and the two kayak measurements (the dots)
- if more discharge brings disproportionally more sediment, then the dNTU>0 and there is a sediment source
- if more discharge brings less sediment, then dNTU<0 and there is deposition (or clear water input)
- You see from the stars that some sources and sinks have small p-values and therefore significantly differ from zero
- Also, most of the kayak points fall within the "whiskers" of the boxplots
  - We see this everywhere except for upstream
  - One possible reason is that the river is too narrow to extract proper reflectance data, also the river is clearer upstream so the measurements may fail

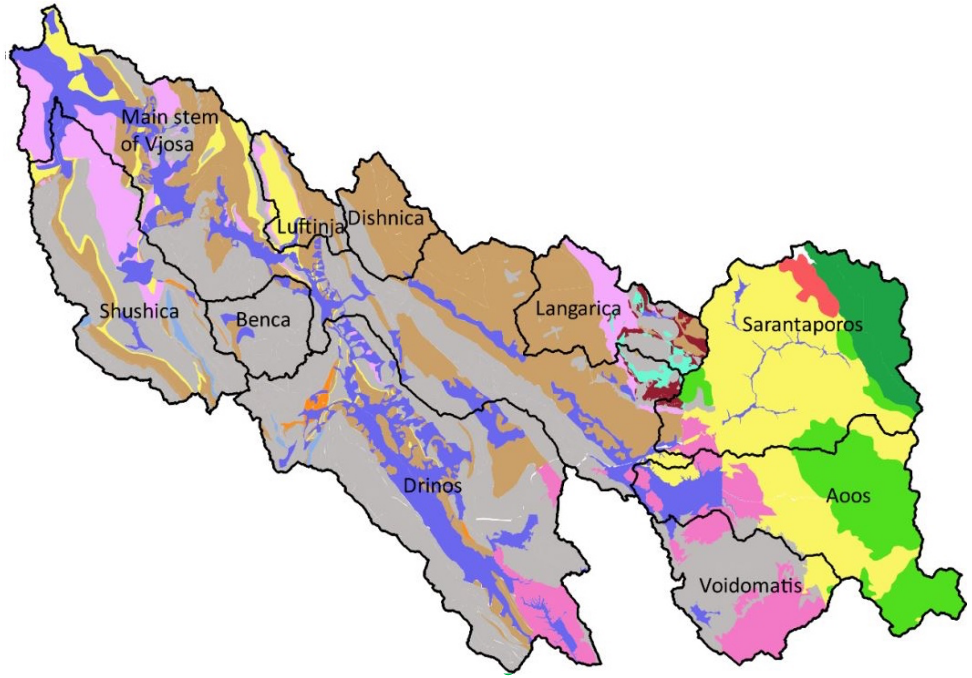


$$dNTU_{trib} = \mathrm{NTU_{US}} - \mathrm{NTU_{DS}}$$

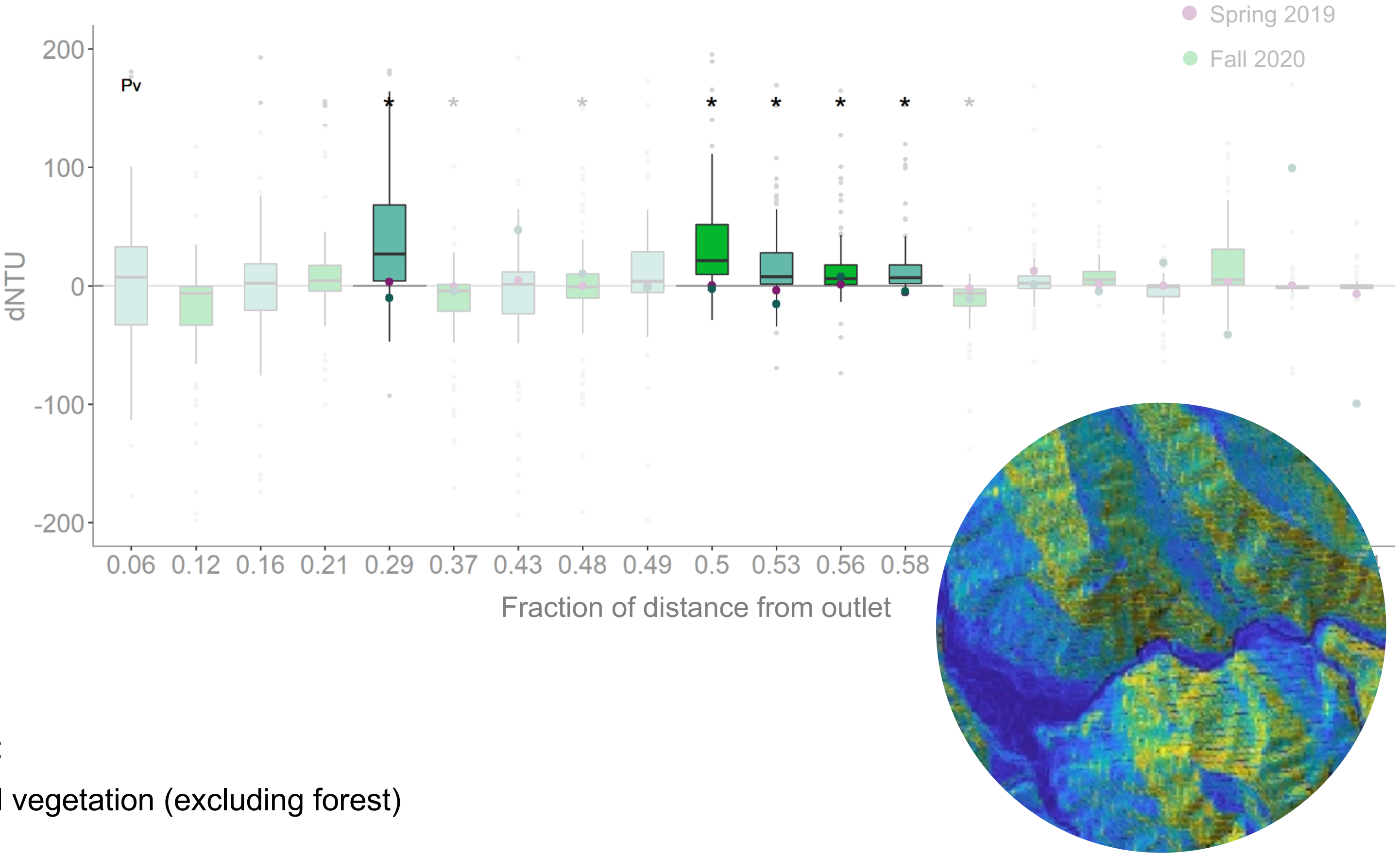
$$dNTU_{rea} = \mathrm{NTU_{DS}} - \mathrm{NTU_{US}}$$



Some reaches and tributaries are significant sources

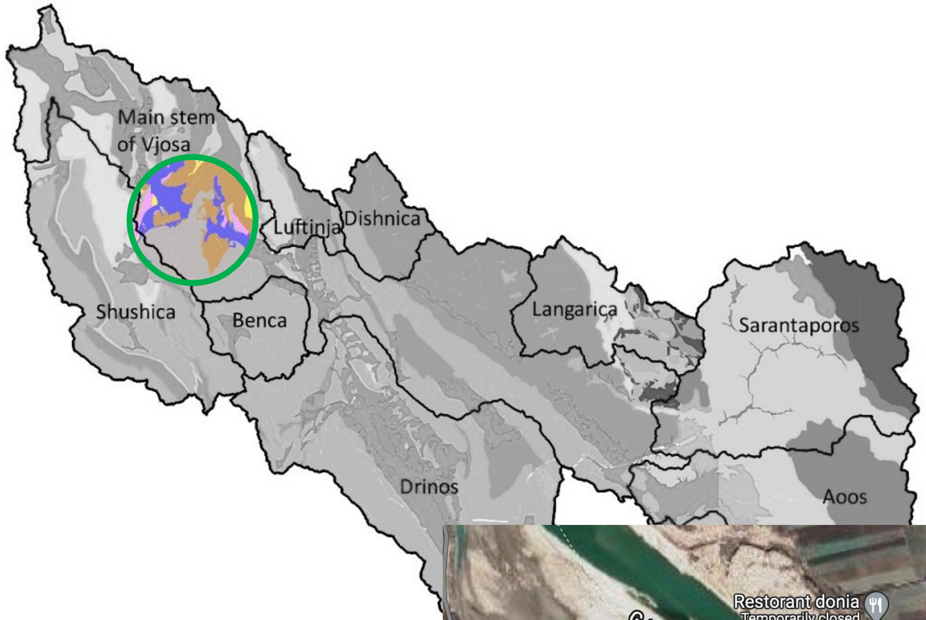


Geological map of Vjosa river

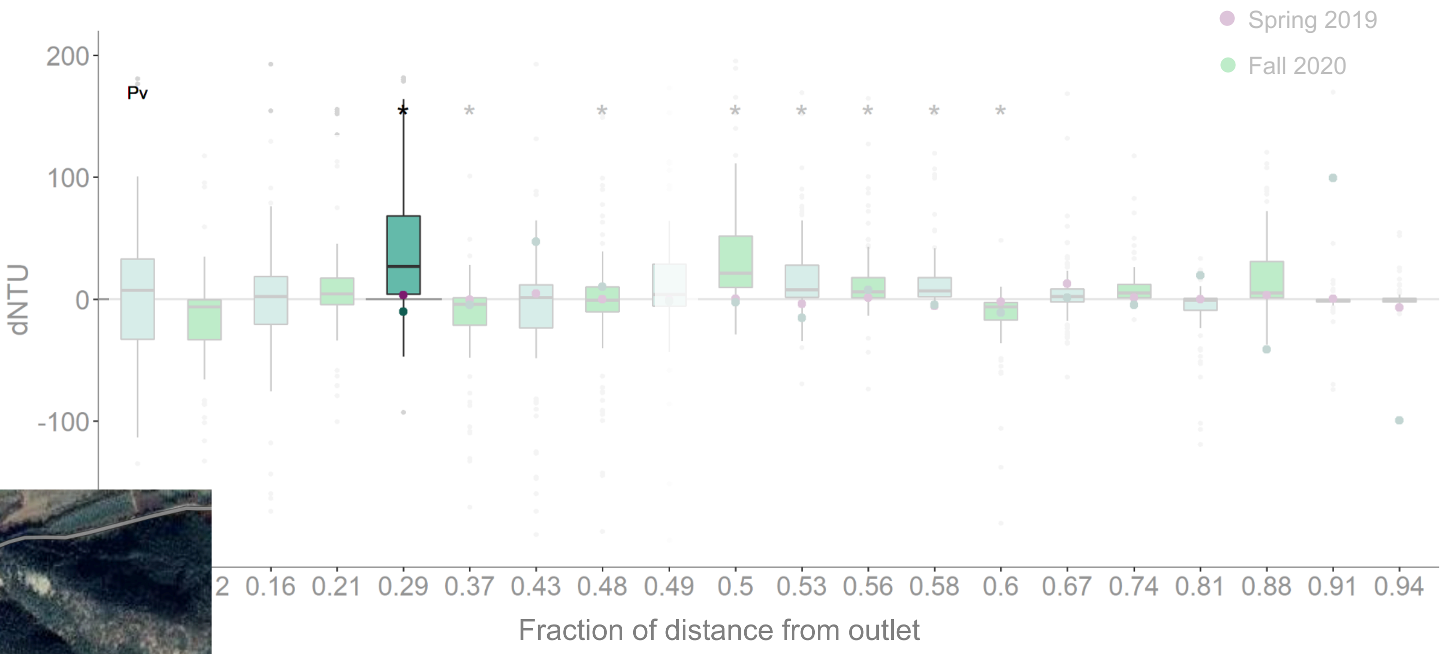


- Most of these river reaches or tributaries are full of:
  - flysch, clastic sediments, agriculture, natural vegetation (excluding forest)
  - And they have large braided sections
- However, two of these sections are quite constrained in a canyon full of springs but the turbidity increases as we move downstream
  - one possible reason could be that water is entering the groundwater table leaving a higher concentration in the main stem

Some reaches and tributaries are significant sources

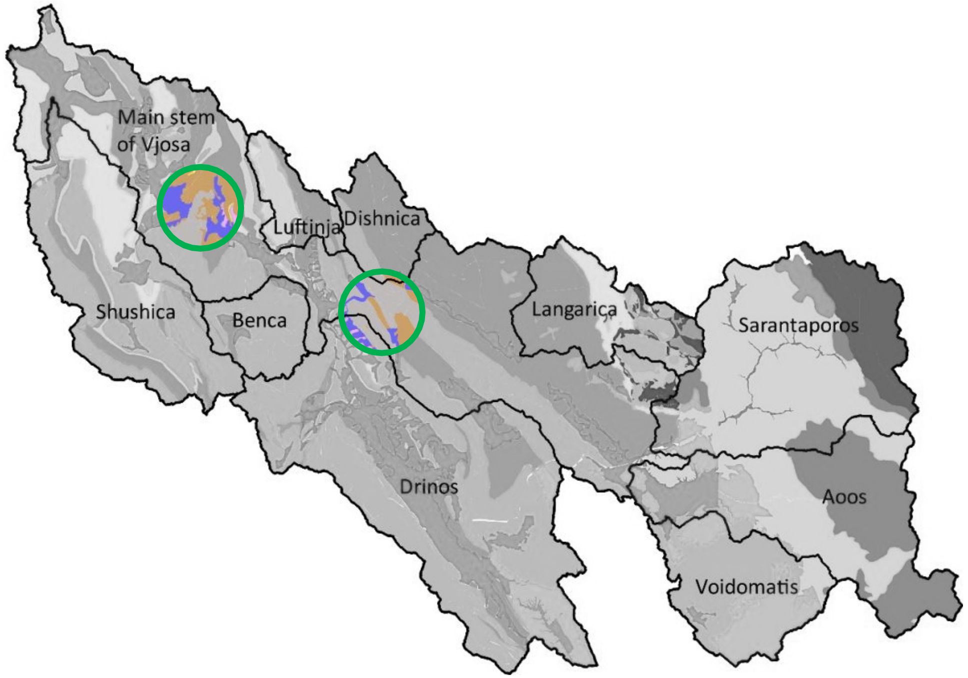


Geological map of Vjosa rive

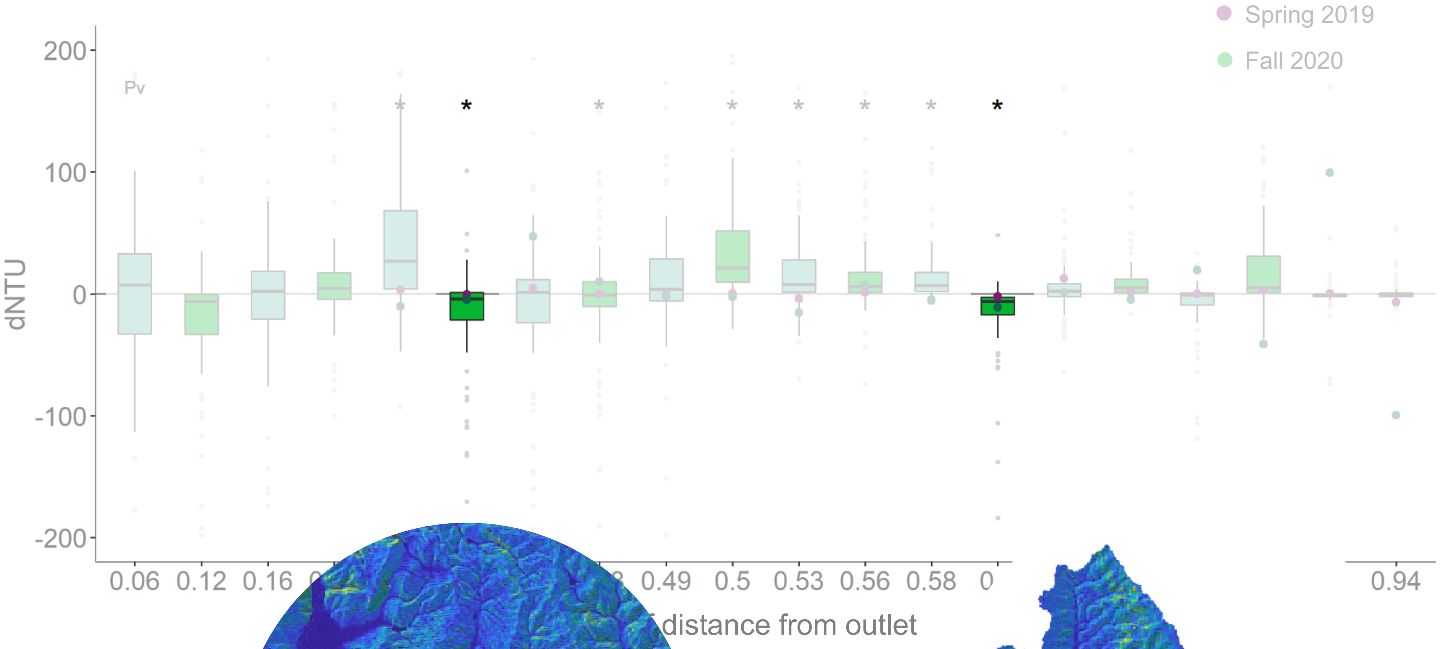


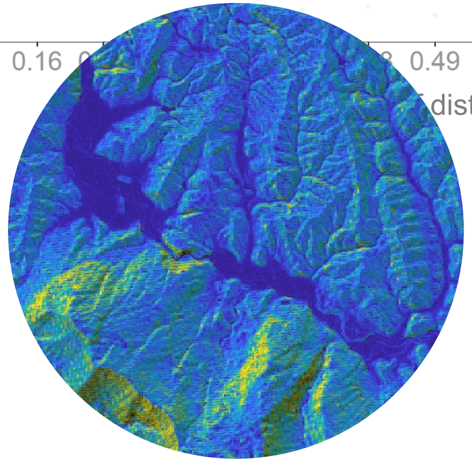
- The most downstream significant reach has the largest median and variability
  - This could be due to the bank construction activities that may have led to easier mobilization of sediment in this reach

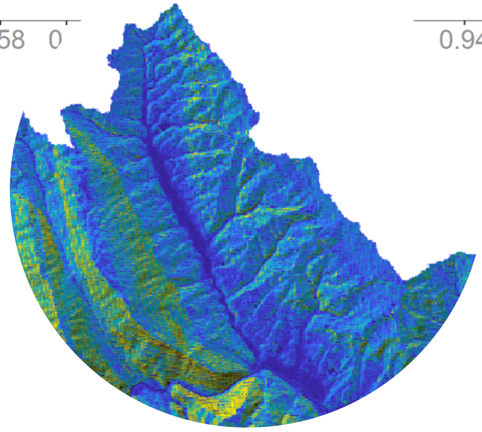
Significant sinks at limestone constrictions



Geological map of Vjosa river



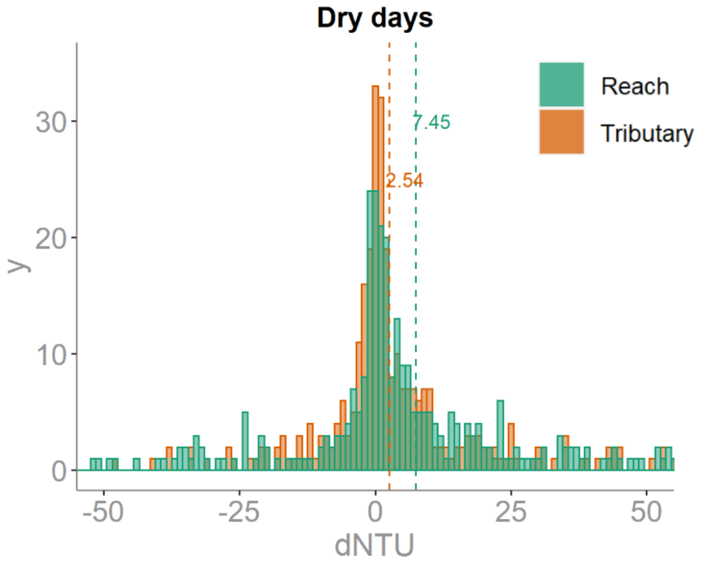


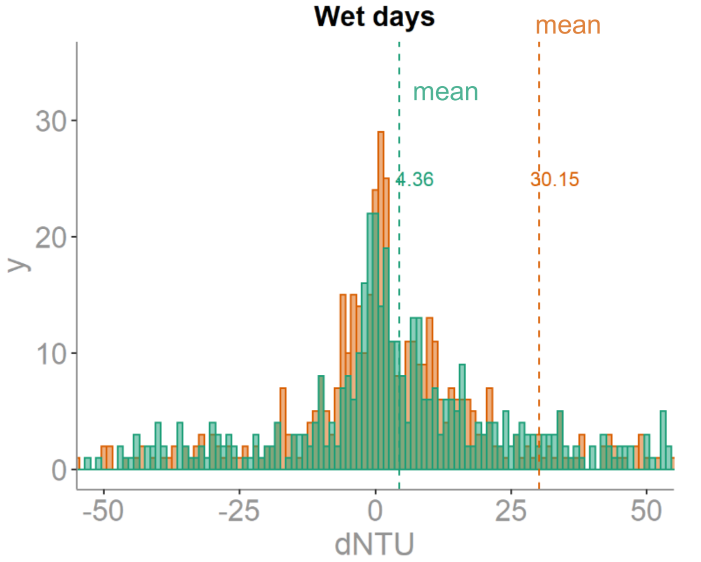


Looking at the significant sinks, we still find agriculture, flysh, clastic sediments, **but also limestone constriction** which act as sinks, and settle sediment while lettting clear water continue through the system

Within-reach variability in NTU is almost as broad as the variability due to tributaries

ETH zürich





- Here we have separated out the dry days, where there is no rain in the catchment for 6 days, and the wet days, which are all other days
- Both and increase and decrease in NTU over reaches and at tributaries
  - Sourcing sediment (increase conc.)
  - Adding clearer water + sediment deposition (decrease conc.)
- On dry days, distributions are around dNTU = 0
  - Therefore, on average the system is transporting the same concentration downstream
- **Within-reach variability in NTU is almost as broad as the variability due to tributaries**
  - Probably due to a morphologically natural river system; where there's ample opportunity for sediment exchange in the braided section
- During the wet days, both the green and orange histograms flatten
  - Tributaries become strong point sediment sources and bring high sediment concentrations into the main stream, values around dNTU are shifted to mean dNTU=30 (tributary rain-runoff effect)
  - The within-reach variability remains the same as on dry days (7-5), equally an increase in reaches acting more like sinks and sources