Innovative techniques for remote sensing of hydrological-hydraulic variables

Candidate: *Molari Giada*
Cycle XXXIII

Supervisors:
Alessio Domeneghetti (main supervisor)
Attilio Castellarin (co-supervisor)

Introduction

Monate Lake case study

- Survey area
- Hydrological model (HyMOD)

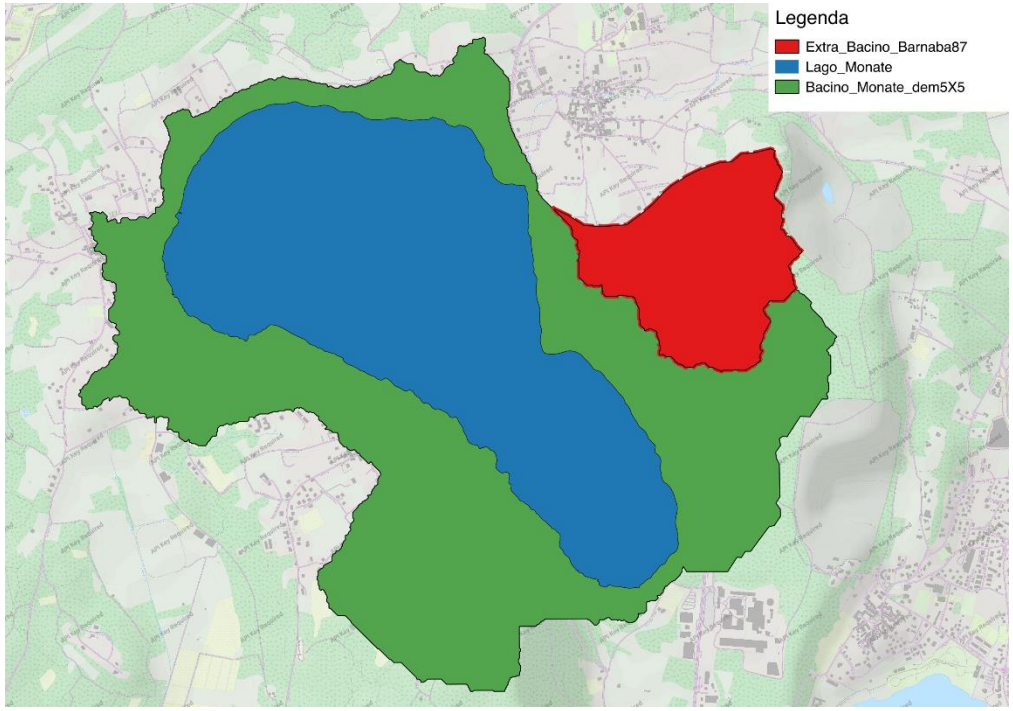
Remote sensing techniques for hydraulic applications

- Satellite altimeters
- River bathymetry estimation
    - RiBEST tool
    - 2D hydraulic modelling
    - Data Assimilation approach on SRTM-based bathymetry
- Global investigation of river geomorphologic relationship

Monate case study

Survey area

The Monate Lake is a prealpine lake of glacial origin in Varese (Italy). Its surface is 2.6 km^2 and the Acquanegra torrent is its only emissary.
The peculiarity of this survey area is that topographical watershed does not coincide with the phreatic one. An addition ground watershed (red line) exists, situated between Monate Lake and Cava Faraona.



Lake(2.6 km^2)

Surface Watershed (3.25 km^2)

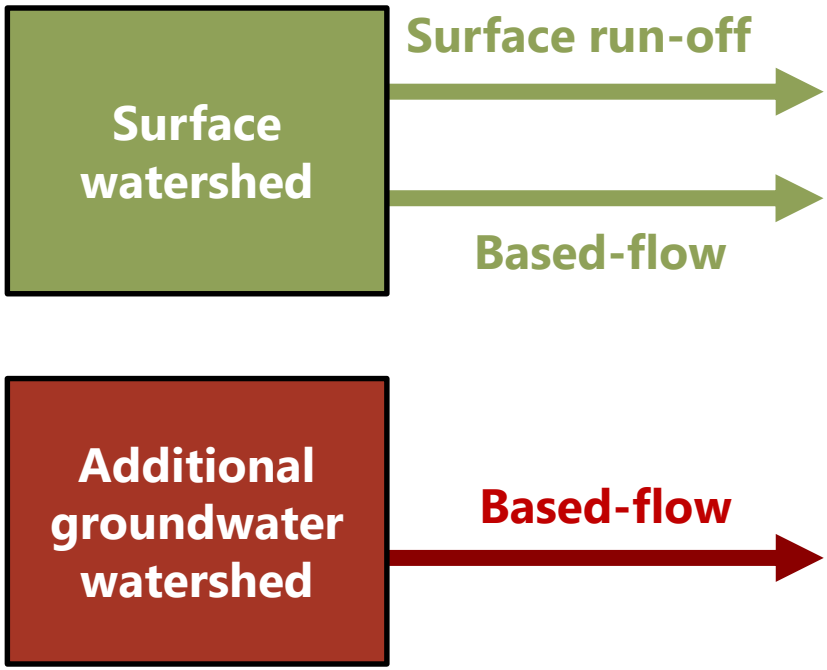
Additional Groundwater Watershed (0.58 km^2)

Monate case study

Hydrological model - HyMOD

HyMOD model is based on the theory of runoff yield under excess infiltration with typical conceptual hydrological components. The main characteristic is spatial variability of water storage capacity within the basin.

5 parameters: ***Cmax, α, β, Kquick, Kslow***



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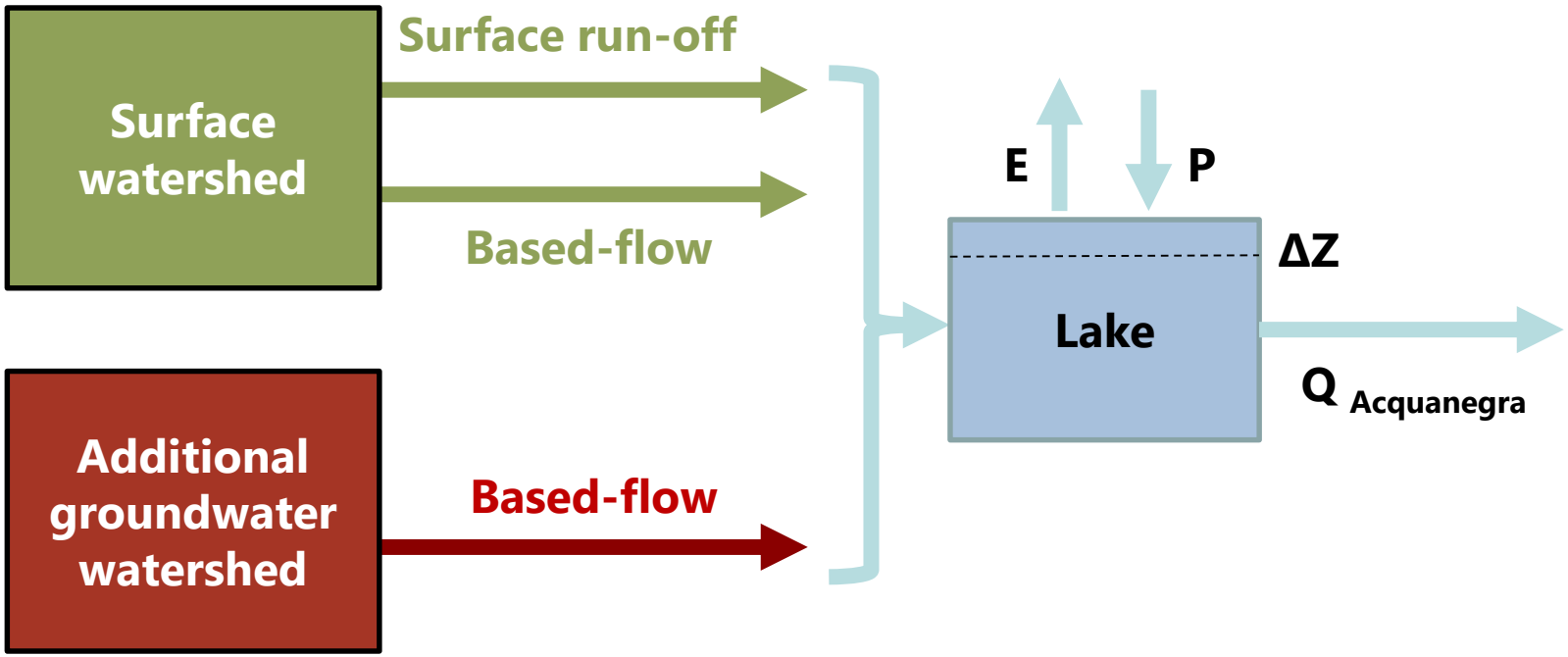
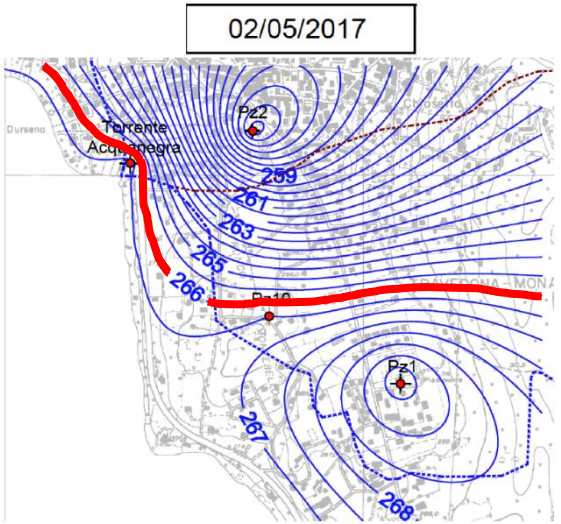


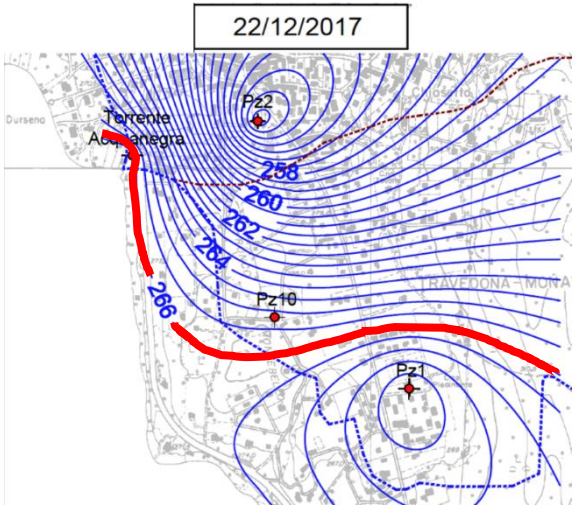
Monate case study

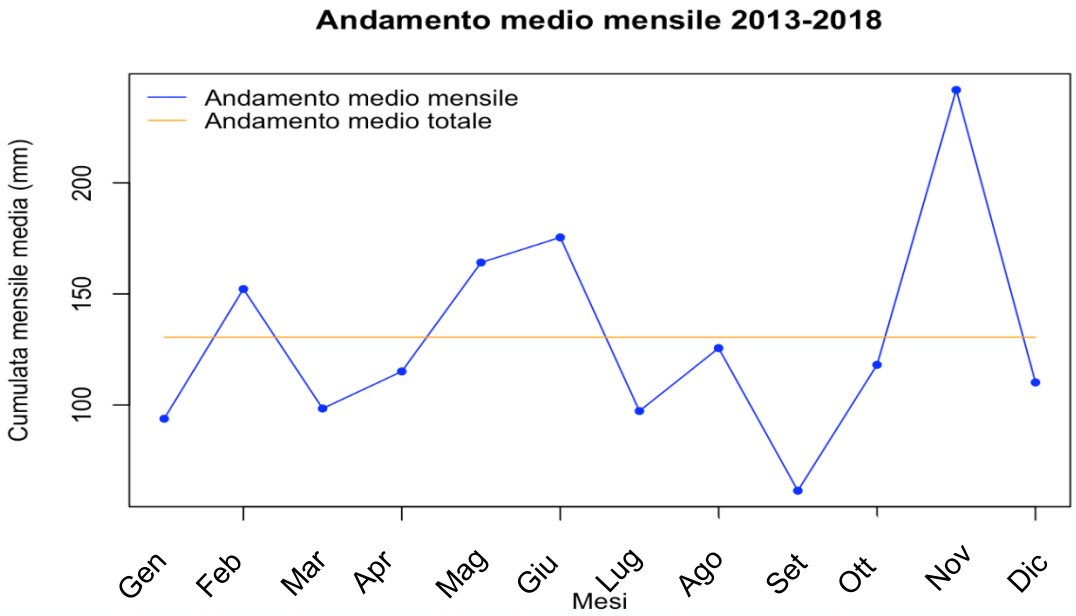
Groundwater watershed area variability

The displacement of the phreatic watershed highlights a seasonal variation of the edge of the groundwater watershed.

The area of the additional groundwater watershed is now considered as the sixth parameter of the HyMOD model.



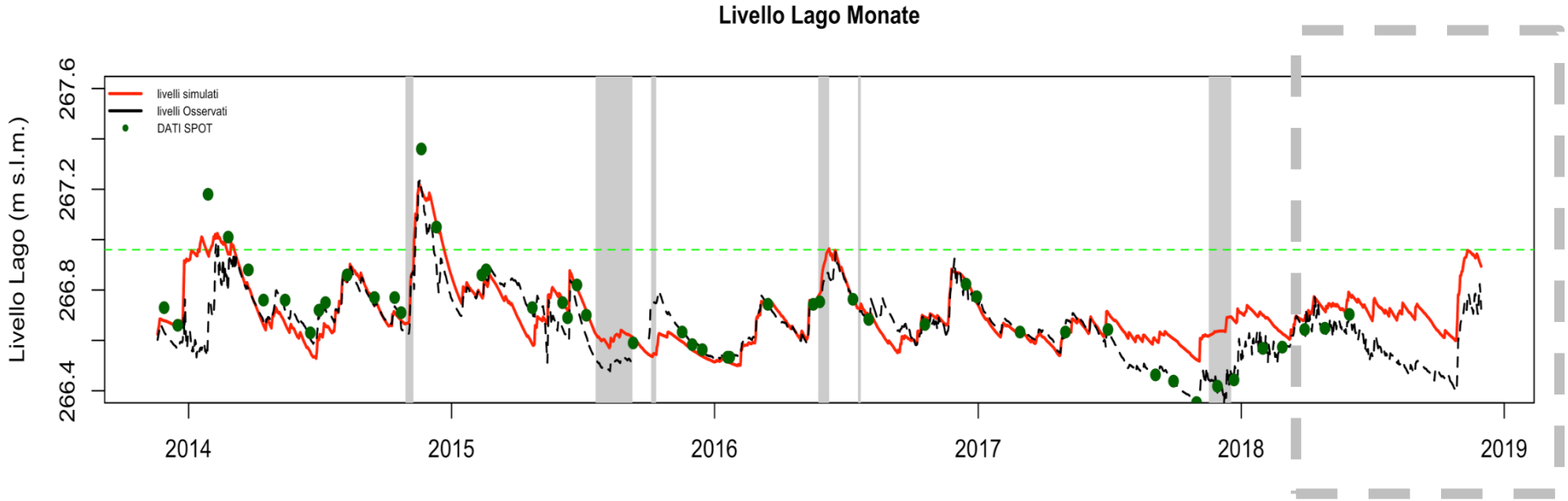


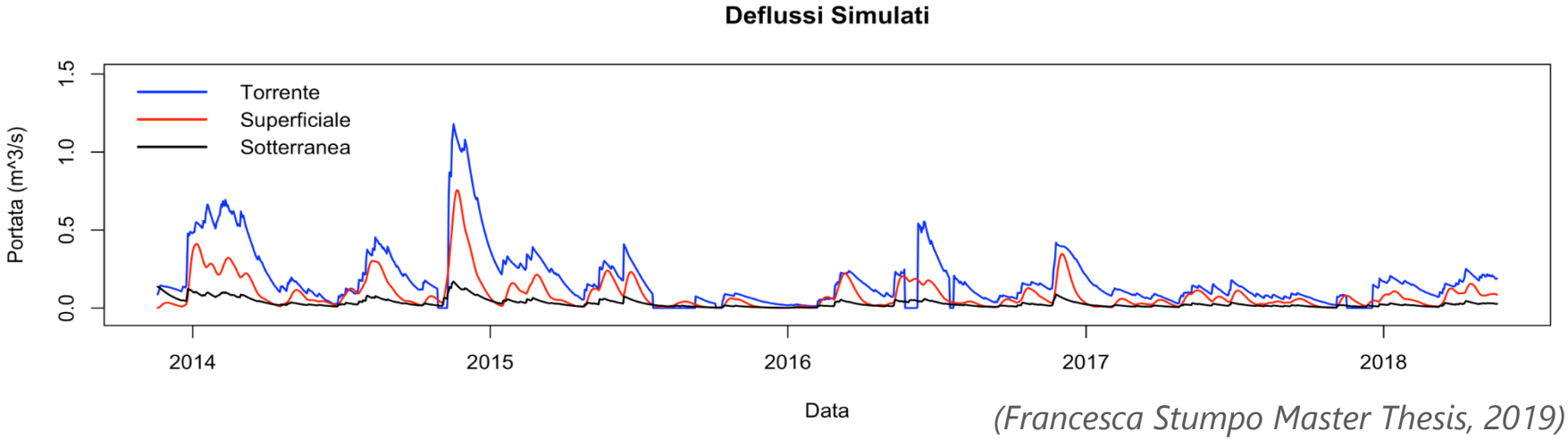


(Francesca Stumpo Master Thesis, 2019)

Monate case study

Hydrological model - HyMOD





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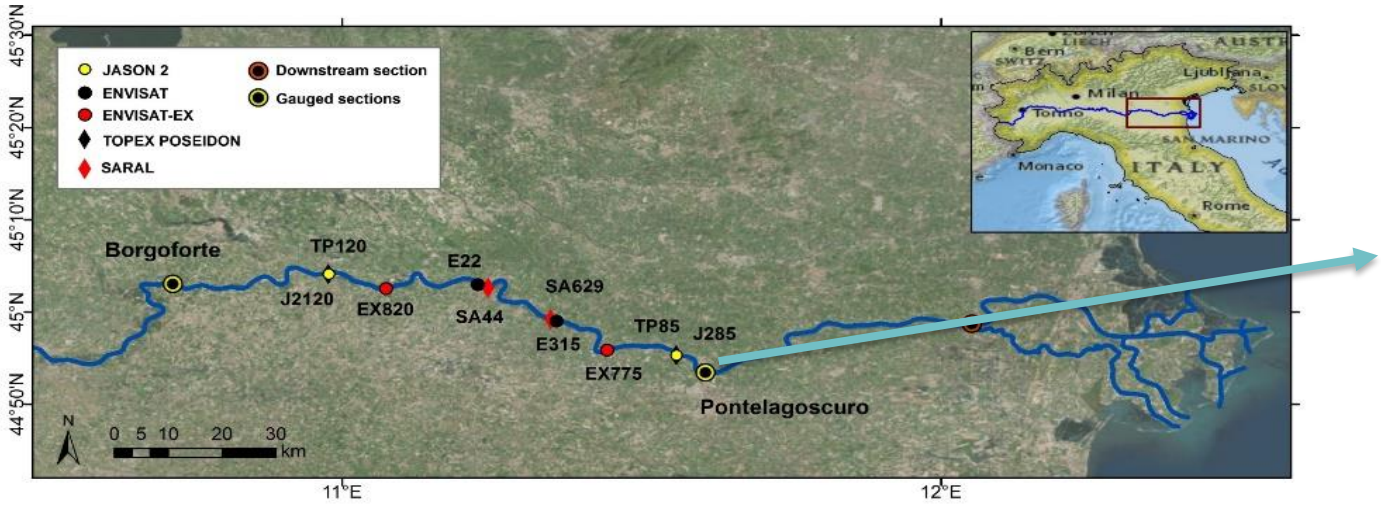
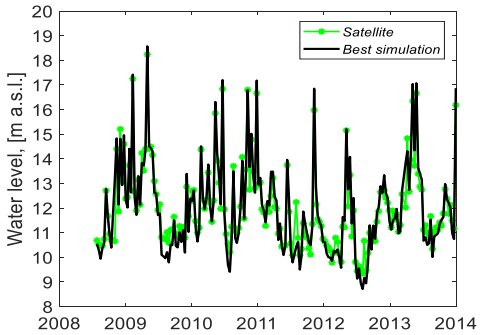
Satellite altimeters

Study aims





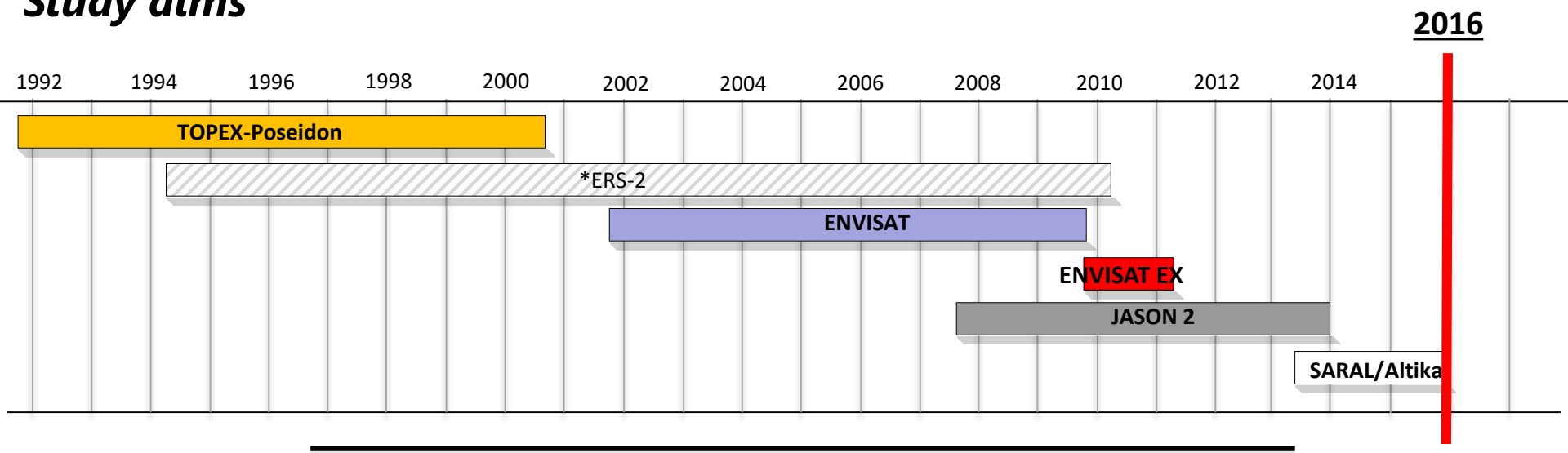
The goal of this study is to investigate the potential of satellite altimetry series for calibrating a quasi-2D model relative to the Po River (Italy). The remote sensed data are collected from different satellite missions (ENVISAT, ENVISAT extended SARAL/Altika, TOPEX/Poseidon, Jason-2 and Jason-3), relative to distinct periods of time between 1992 and 2019.

Aims:

- Comparison between data of **different satellite missions** (*Fig. 1*);
- Study of **satellite series length** effect on model hydraulic calibration *(Tab. 1)*;
- Evaluation of **data uncertainty** on model accuracy;
- Estimation of **multi-mission series benefits** *(Fig. 2)*.

Satellite altimeters

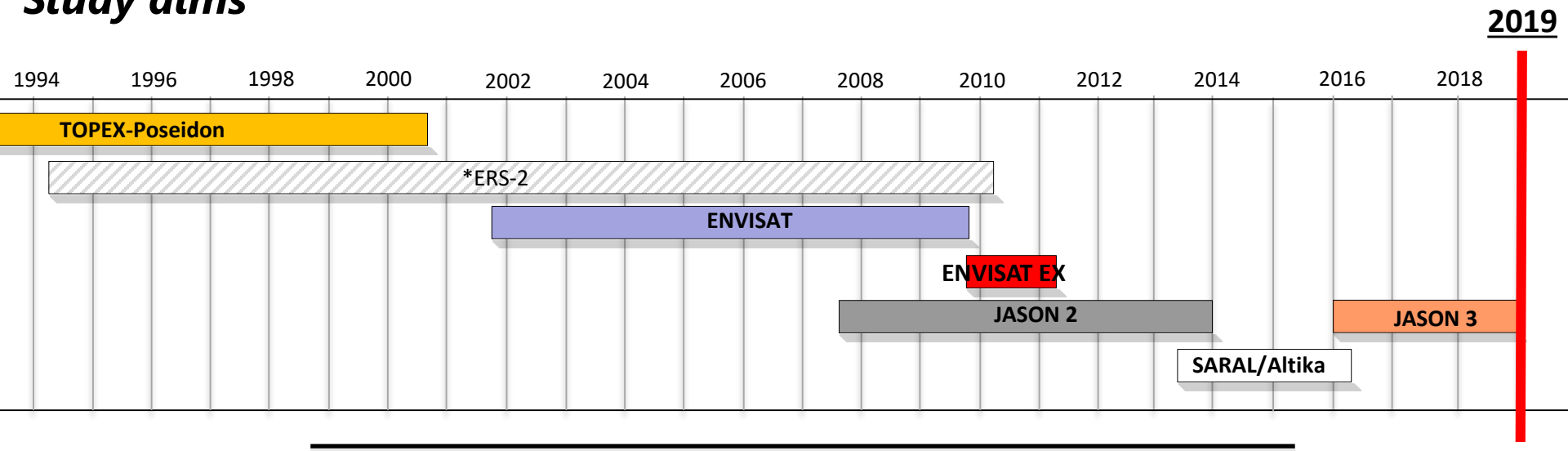
Study aims



Mission	Observation period	Temporal resolution [day]
TOPEX/Poseidon (TP)	1992–2002	10
ENVISAT (E)	2002–2010	35
ENVISAT XT (EX)	2010–2012	35
SARAL/AltiKa (SA)	2013–2016	35
JASON 2 (J2)	2008-2015	10

Satellite altimeters

Study aims



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JASON 2 (J2)	2008-2015	10
JASON 3 (J3)	2016-2019	35

Satellite altimeters

Academic presentations and further activities

Hydrological Processes

Ready for submission:

Satellite altimetry for hydraulic model calibration: single- vs. multi-mission series

*Alessio Domeneghetti [(1)], **Giada Molari**[(1)], Mohammad J. Tourian[(2)], Angelica Tarpanelli[(3)], Tommaso Moramarco[(3)], Nico Sneeuw[(2)], Armando Brath[(1)]*

[(1)] School of Civil Engineering, Department DICAM, University of Bologna, Bologna, Italy
[(2)] Institute of Geodesy, University of Stuttgart, Germany,
[(3)] Research Institute for Geo-Hydrological Protection, National Research Council, Perugia, Italy

irpi

University of Stuttgart
Germany

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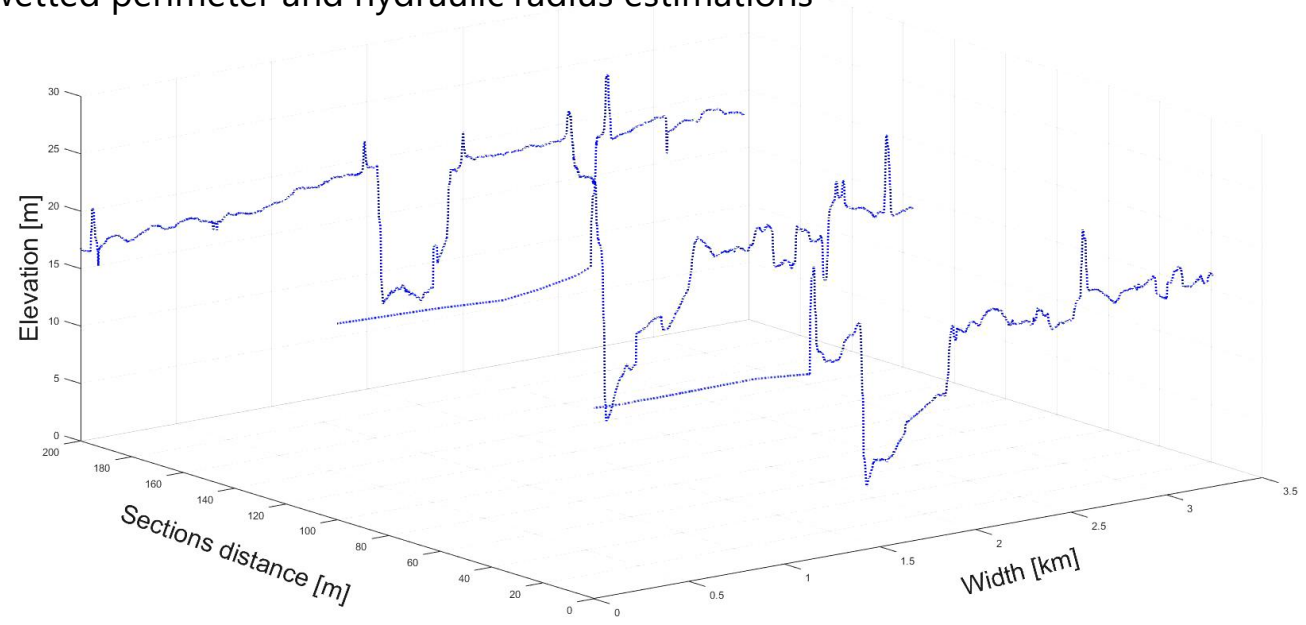
River bathymetry estimation

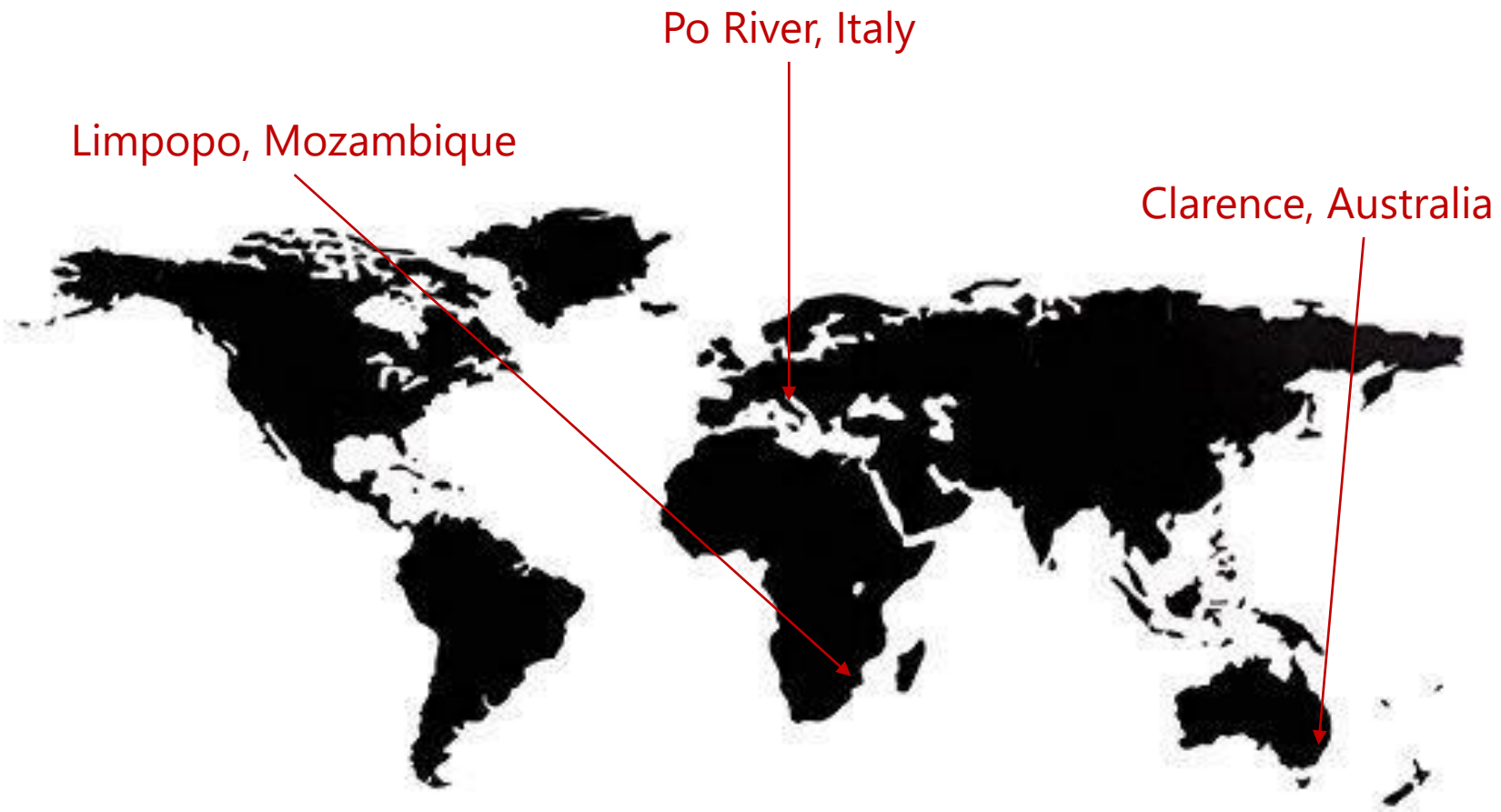
RiBEST (River Bathymetry Estimation From Satellite)

Development and testing of the RiBEST tool.
Based on a DEM and river centreline, RiBEST can automatically provide river geometry and hydraulic variables such as:

- River bathymetry
- Modified cross section geometry
- Flow area, wetted perimeter and hydraulic radius estimations

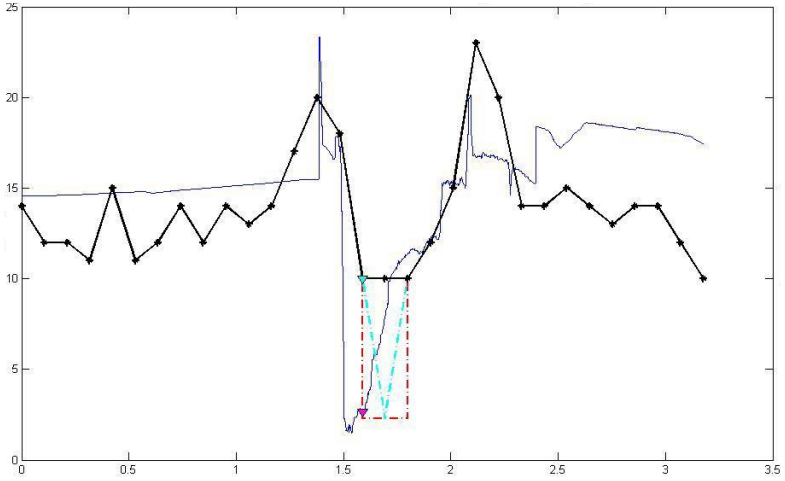


RiBEST tool

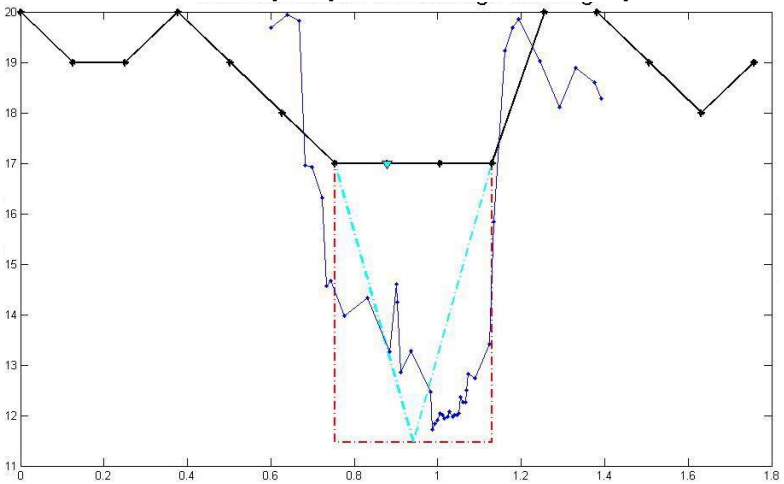


RiBEST tool

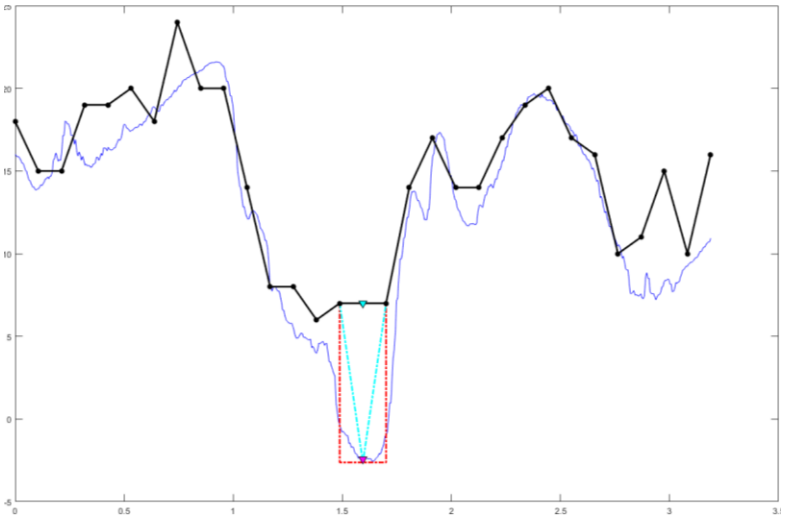
Po River, Italy



Limpopo, Mozambique



Clarence, Australia



SRTM 30

Observed topography

RiBEST modification 1

RiBEST modification 2

RiBEST tool

Further activities

Paper in preparation:

RiBEST – a tool for river bathymetry and hydraulic parameters estimation

Giada Molari[(1)], *Stefania Grimaldi* [(2)], *Paolo Paron* [(3)], *Alessio Domeneghetti* [(1)]

[(1)] *School of Civil Engineering, Department DICAM, University of Bologna, Bologna, Italy*
[(2)] *Monash University, Melbourne, Australia*
[(3)] *IHE Delft Institute for Water Education, Hydroinformatics Chair, Delft, The Netherlands*

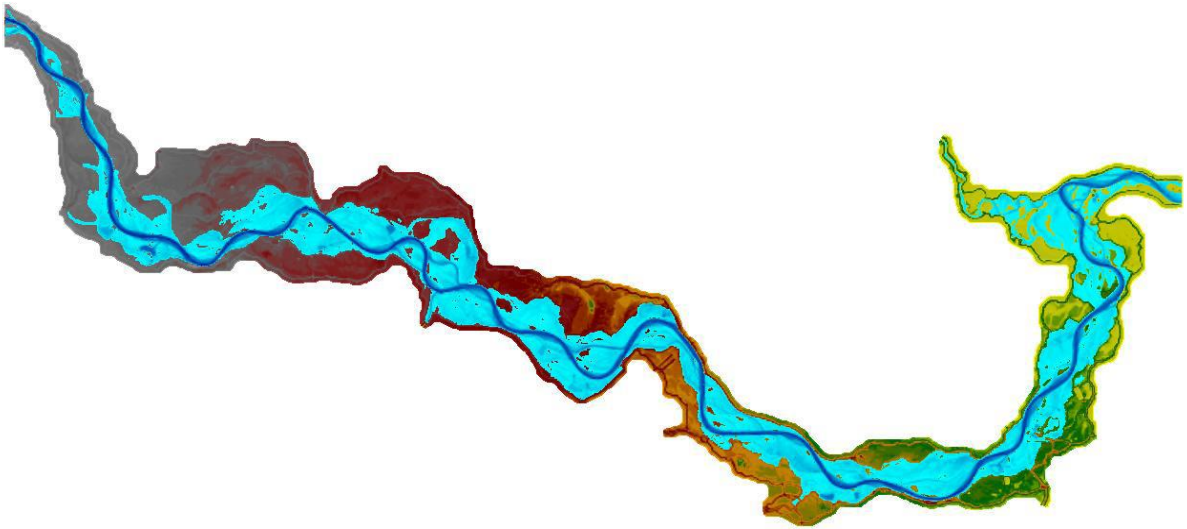
United Nations Educational, Scientific and Cultural Organization

IHE DELFT Institute for Water Education in partnership with UNESCO

MONASH University

2D modelling application

The RiBEST application for 2D modelling is still ongoing in collaboration with IHE Delft, Netherlands, in order to assess how much the bathymetric information influences the accuracy of **2D** hydraulic models.



Po River : Cremona - Borgoforte

2D modelling application

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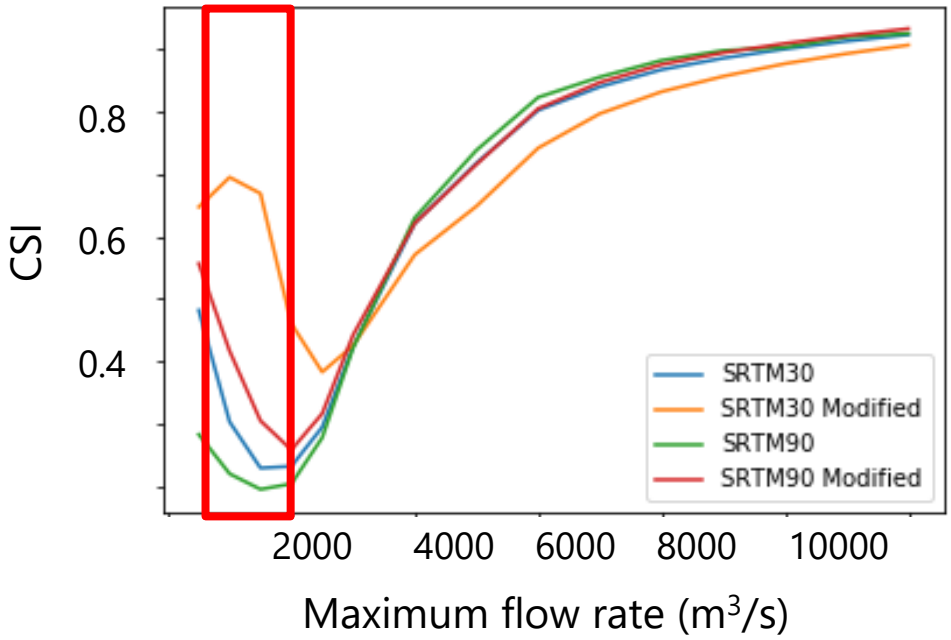
CSI (Critical Success Index) = hits / (hits + false alarms + misses)

Its range is 0 to 1, with a value of 1 indicating a perfect forecast



2D modelling application

Ready for submission:

Impact of micro topography and bathymetry modification on inundation modelling with different magnitudes based on SRTM data

*Hamounda Tarek[(1)], Maurizio Mazzoleni[(1)], **Giada Molari**[(3)], Kun Yan[(2)], Ioana Popescu[(1)], Alessio Domeneghetti[(3)]*

[(1)] IHE Delft Institute for Water Education, Hydroinformatics Chair, Delft, The Netherlands
[(2)] Deltares, Delft, The Netherlands
[(3)] School of Civil Engineering, Department DICAM, University of Bologna, Bologna, Italy

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Data assimilation

DA methods combine **observations** with **model output** with the objective of improving the latter. The object is to predict the state of a system, or its future, in the best possible way.

Basic idea of DA

Series of **observations**

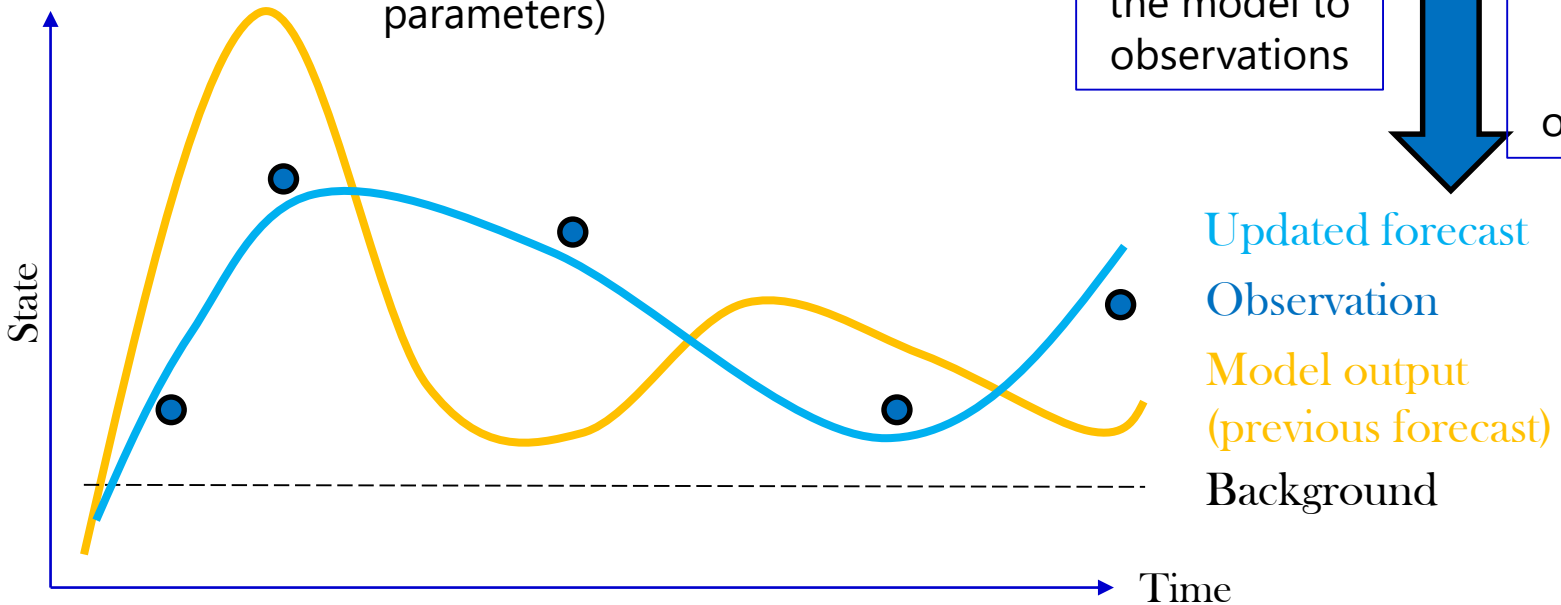
Background (prior information)

Updated forecast closer at observations

Predicted state (model output) with errors

Fitting process of the model to observations

INVERSE PROBLEM : from effects (model output) to causes (model parameters)



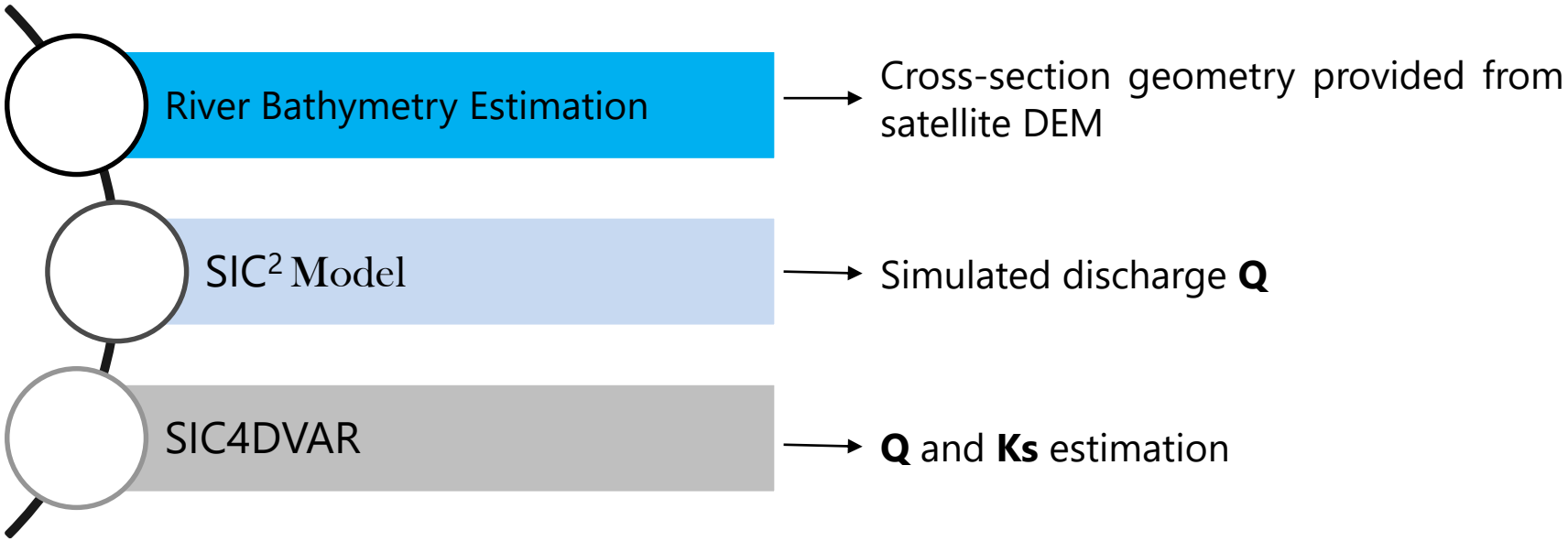
Data assimilation

Fitting process of the model to observations

The comparison between model output and observations is performed by some form of **optimization**.

Among DA methods, variational DA has been the preferable approach in operational geophysical applications, for which the problem is formulated as an optimal control one. In particular **4DVAR** is adapted for nonlinear systems where heterogeneous variables are estimated simultaneously.

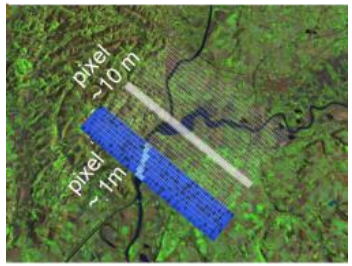
Object: Discharge estimation using 4DVAR approach and river bathymetry SRTM – based for the Po River (Italy)

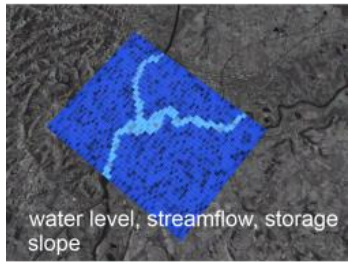


Data assimilation

SWOT

- First satellite mission dedicated to hydrology, river hydraulics and mesoscale oceanography
- Date of launch: September 2021
- **21** - day repeat
- Ka-band Radar Interferometer (KaRIn)
  - Cross-track resolution: 60 to 10 meters



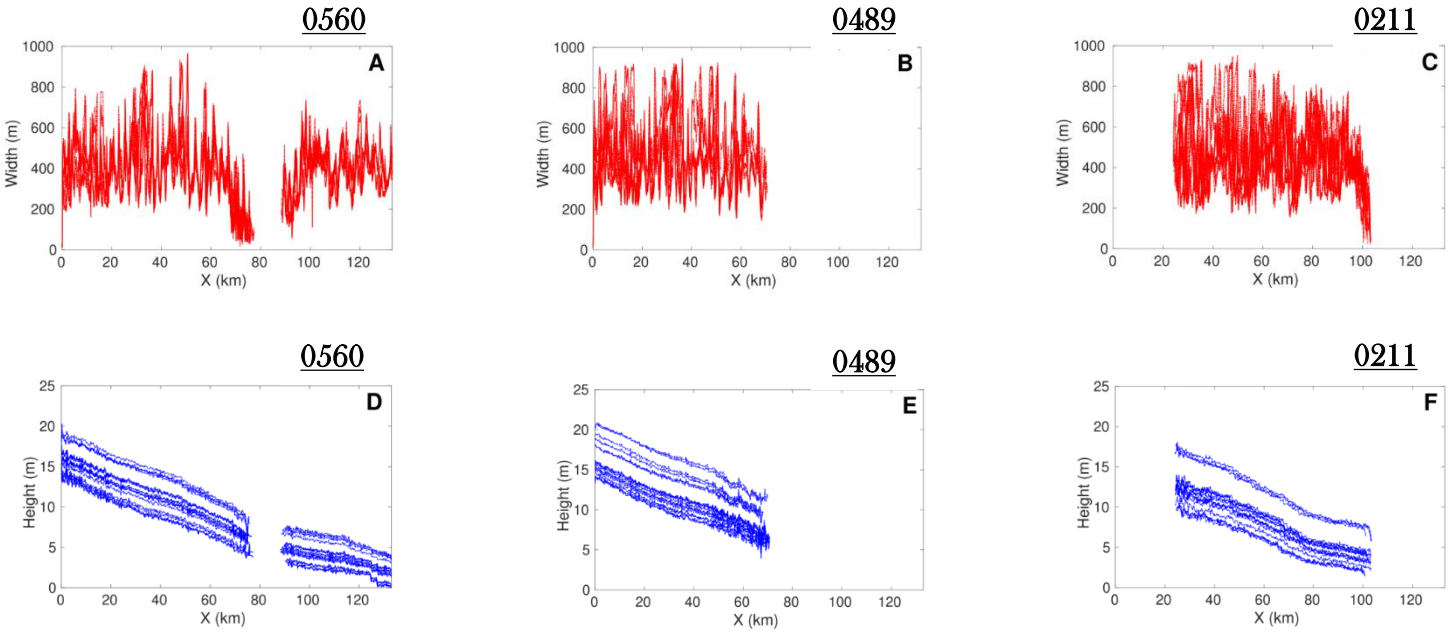


NASA CSA ASC cnes UK SPACE AGENCY

Data assimilation

- Reach : 133 km
- Nodes observations:
  - every 200 m
  - $\sigma \sim 2{,}5\ m$
- Irregular sampling
- May 2008 – April 2009

The SWOT Hydrology Simulator – Po River

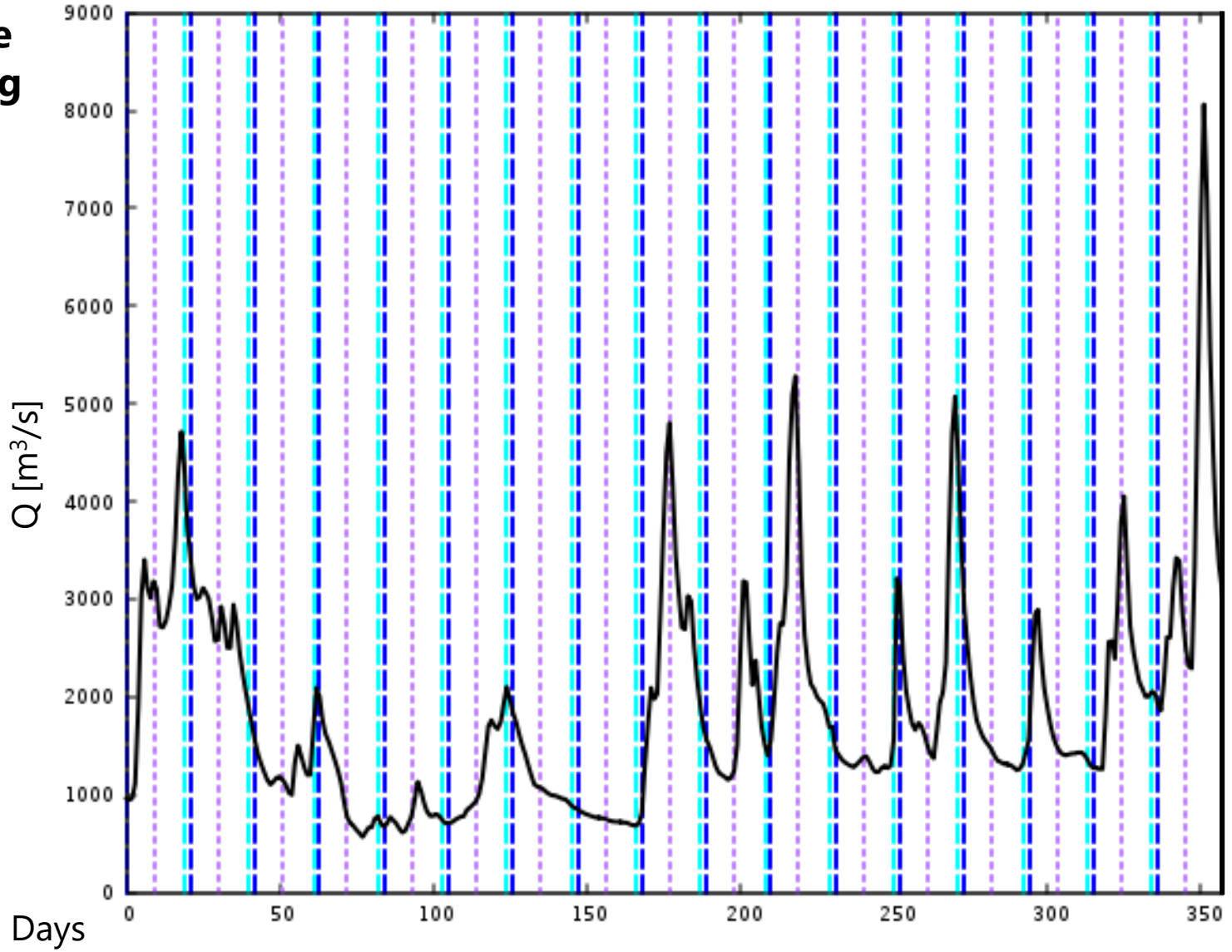


(Oubanas et al. WRR 2018)

Data assimilation

River Discharge Estimation using SIC4VAR

- Reference
- Background
- Estimate



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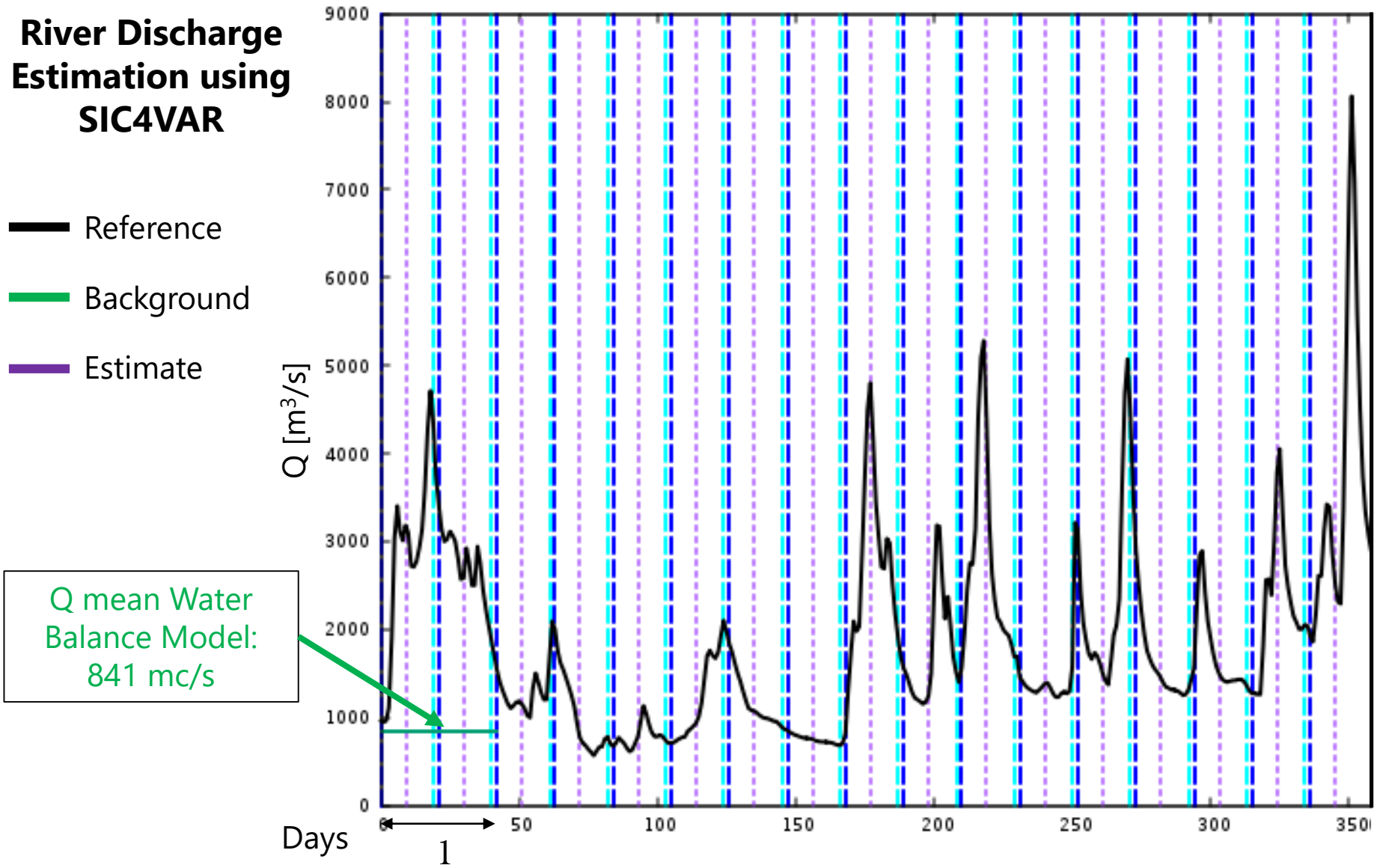

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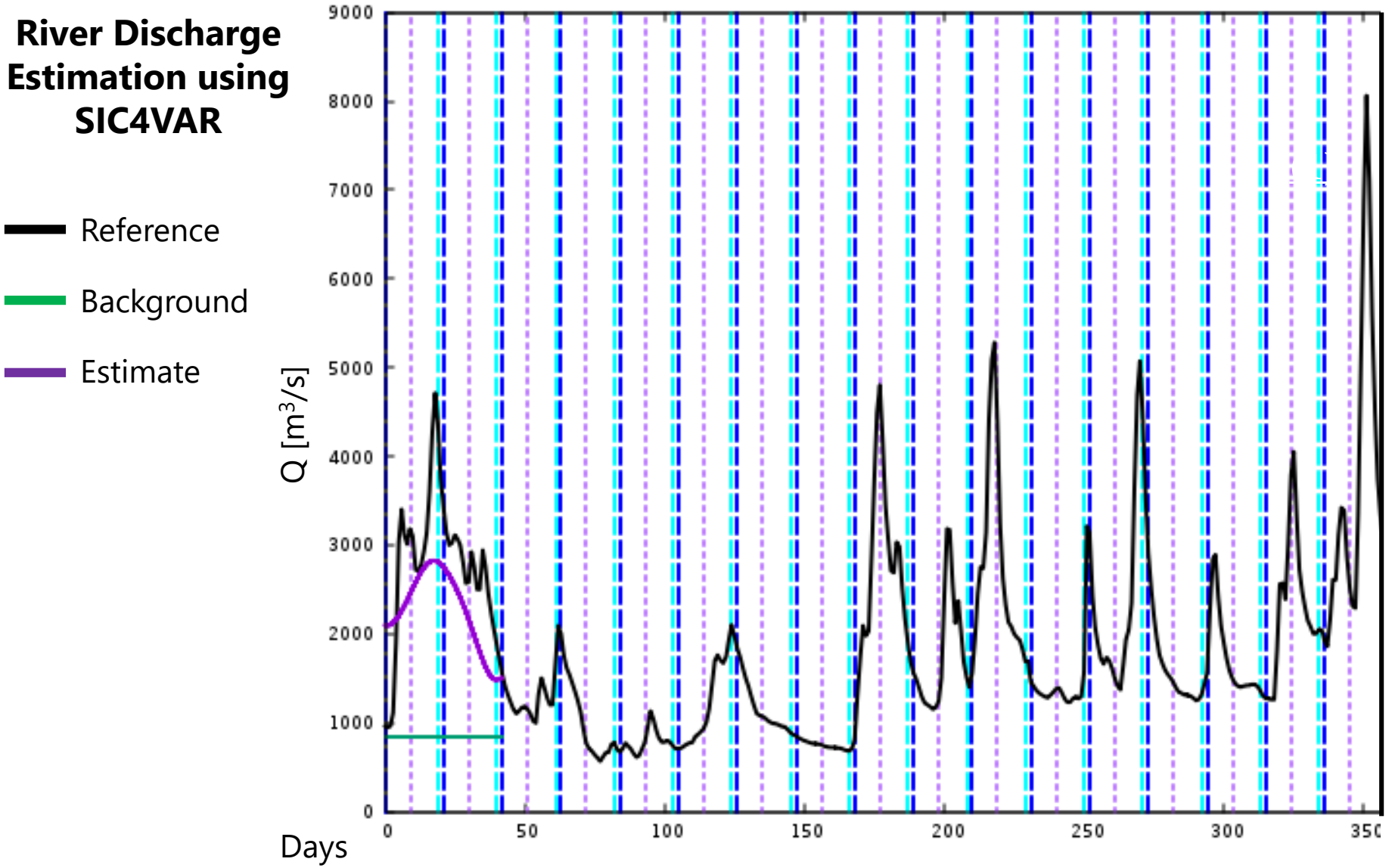

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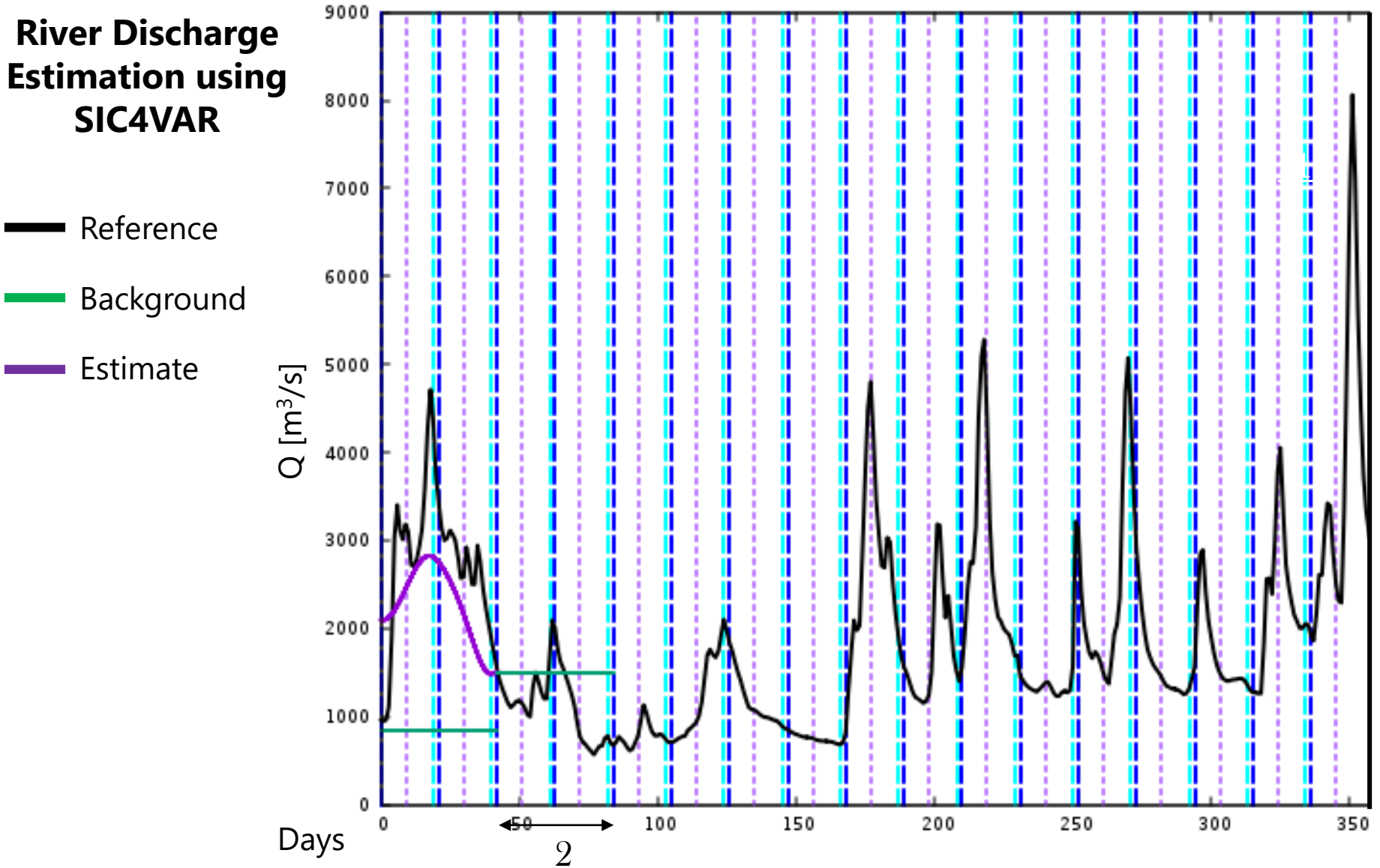

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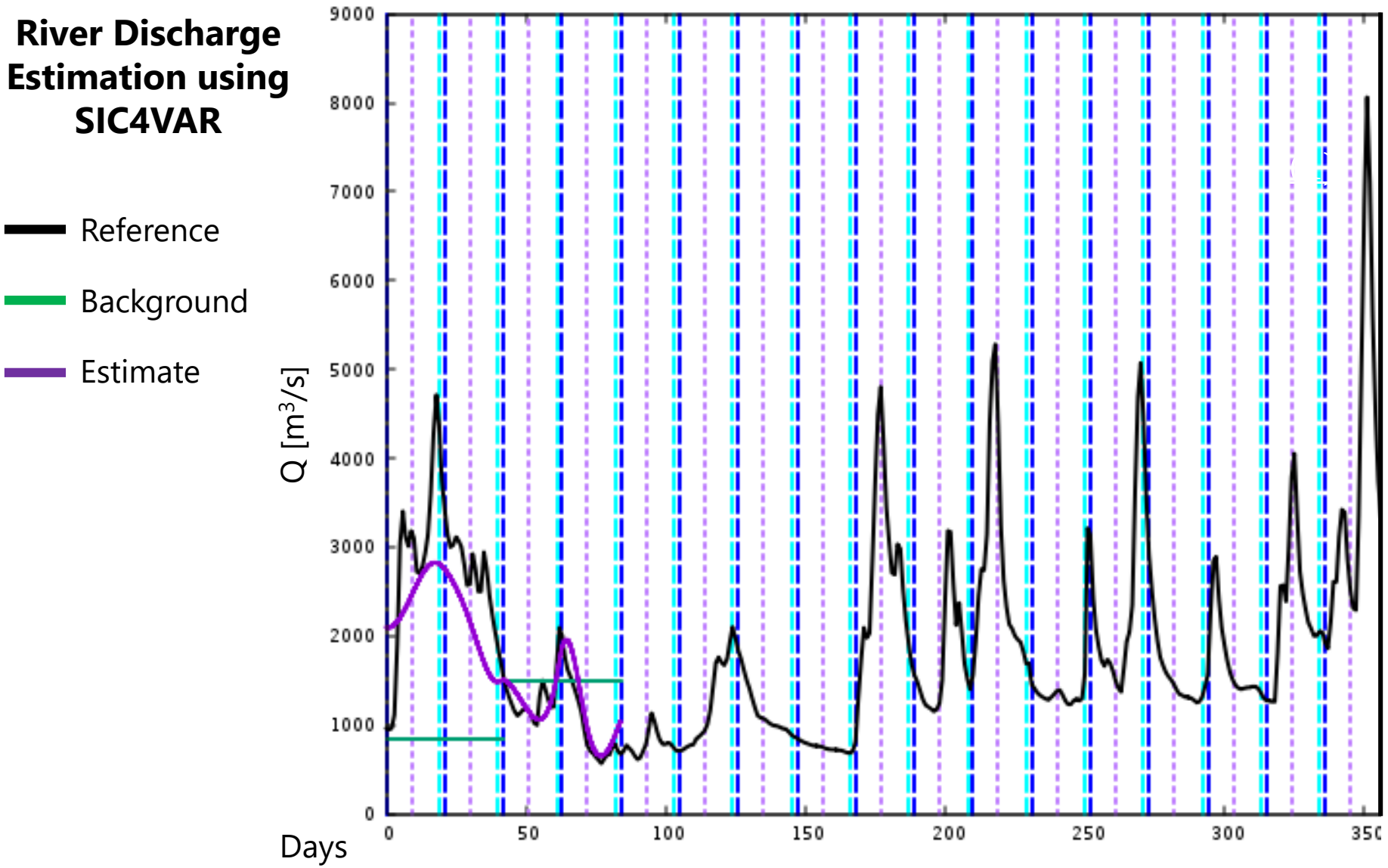

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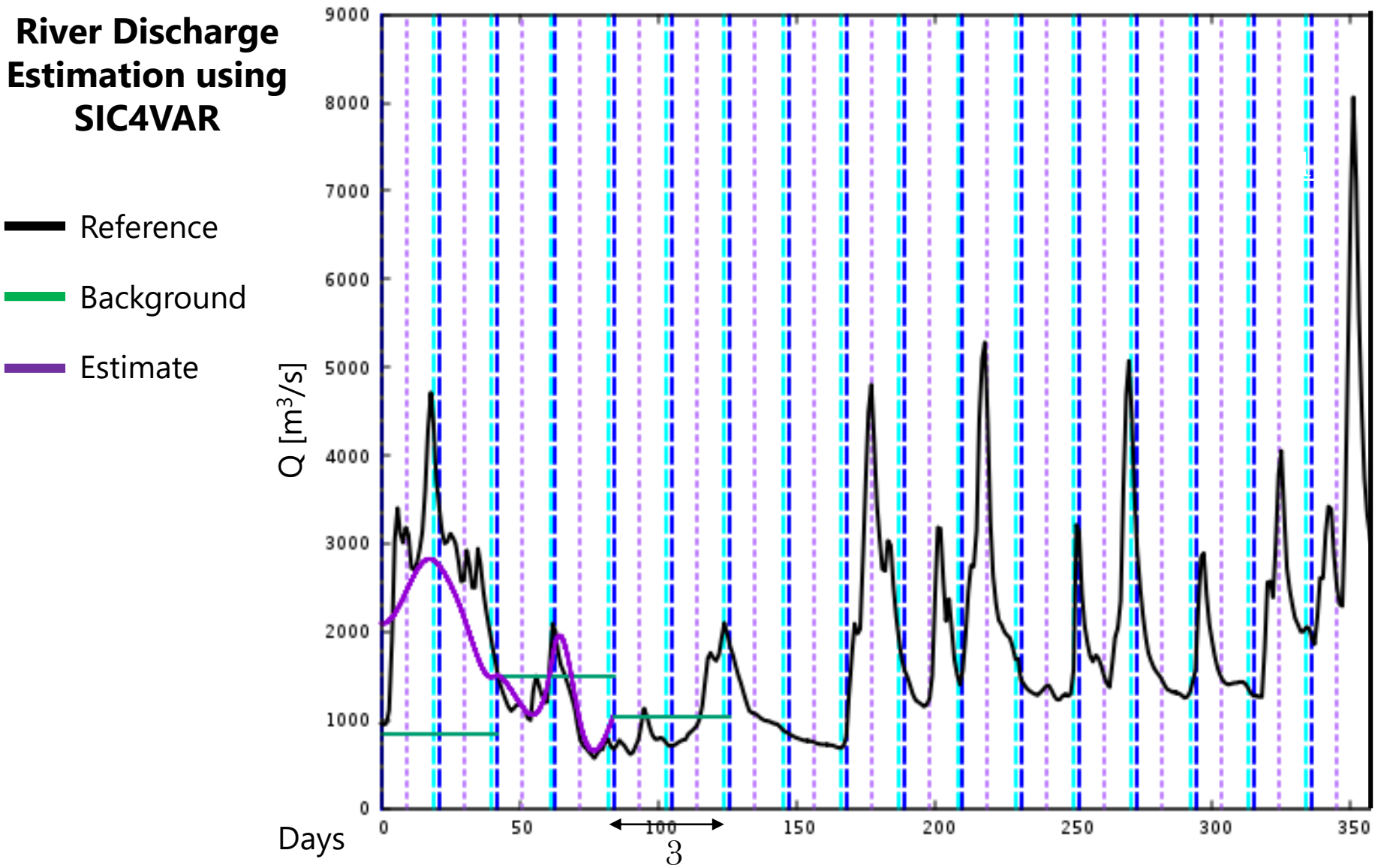

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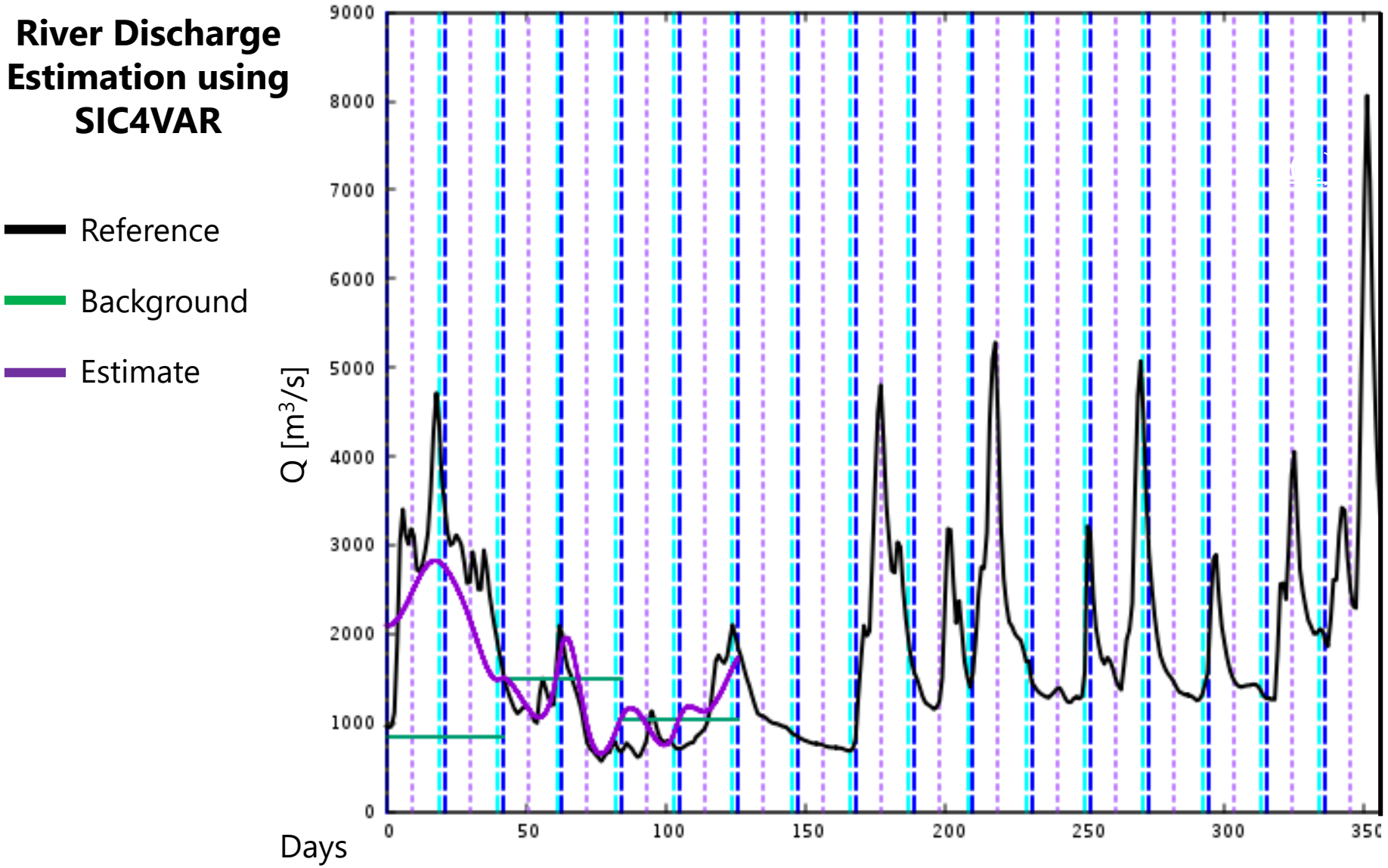

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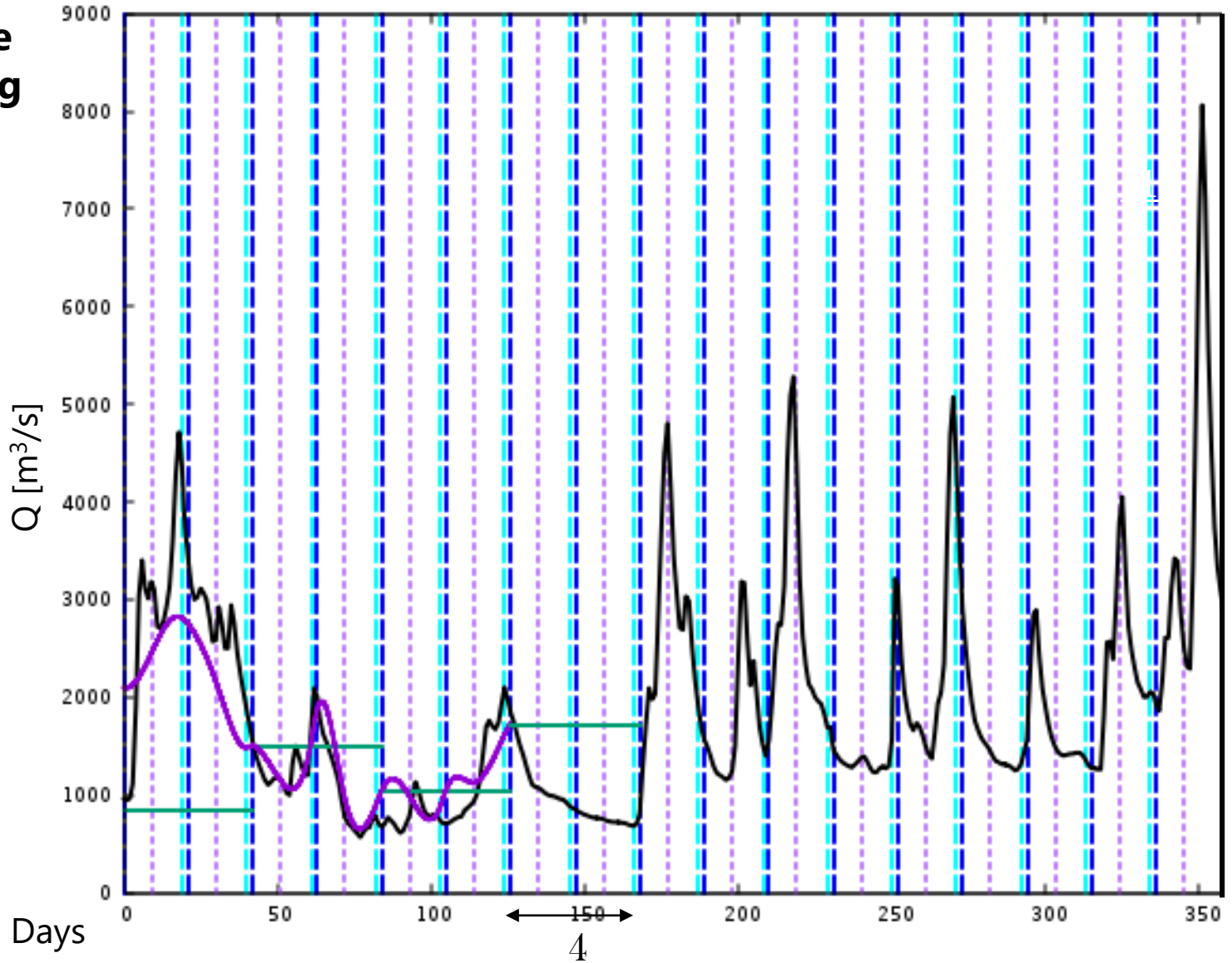

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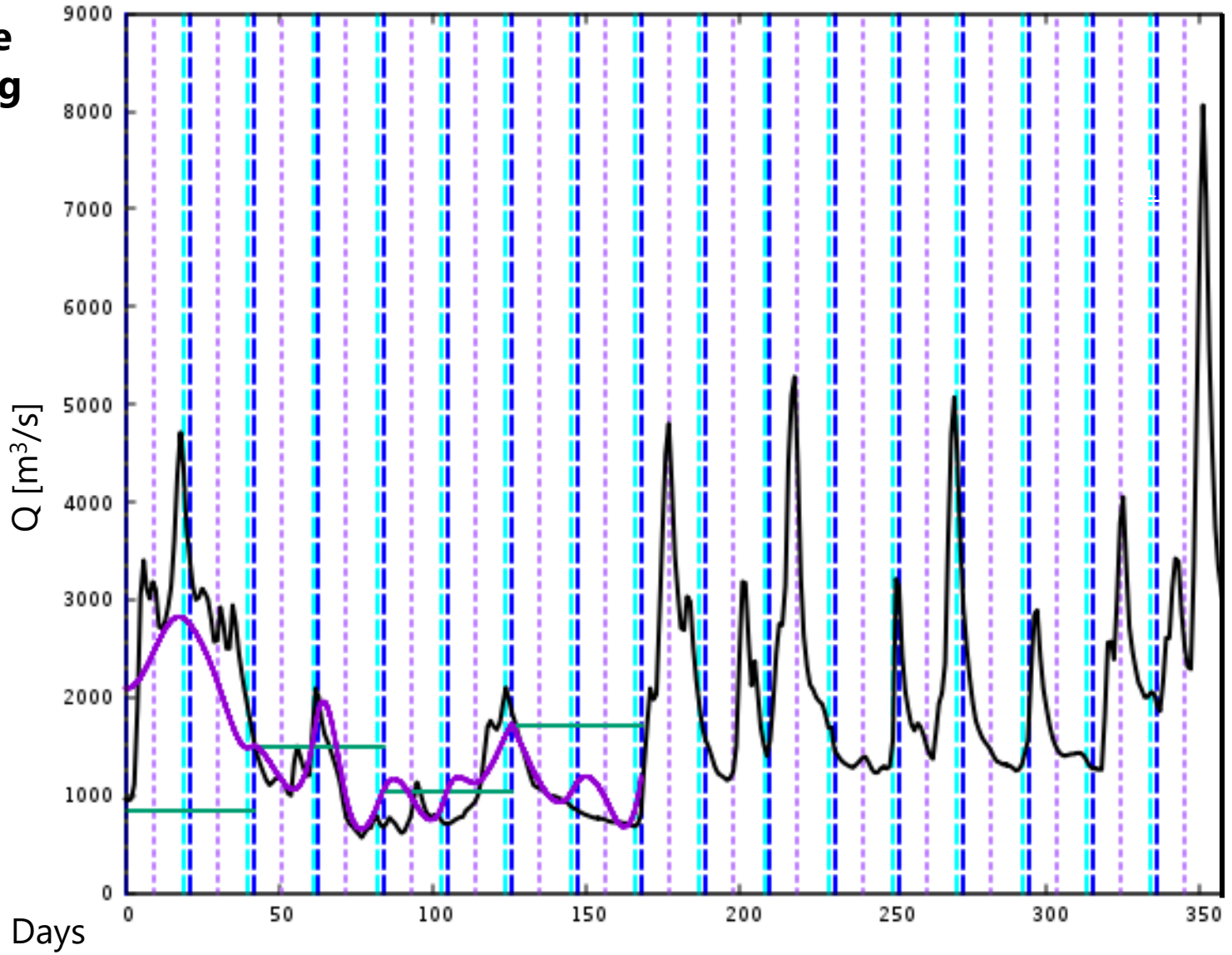

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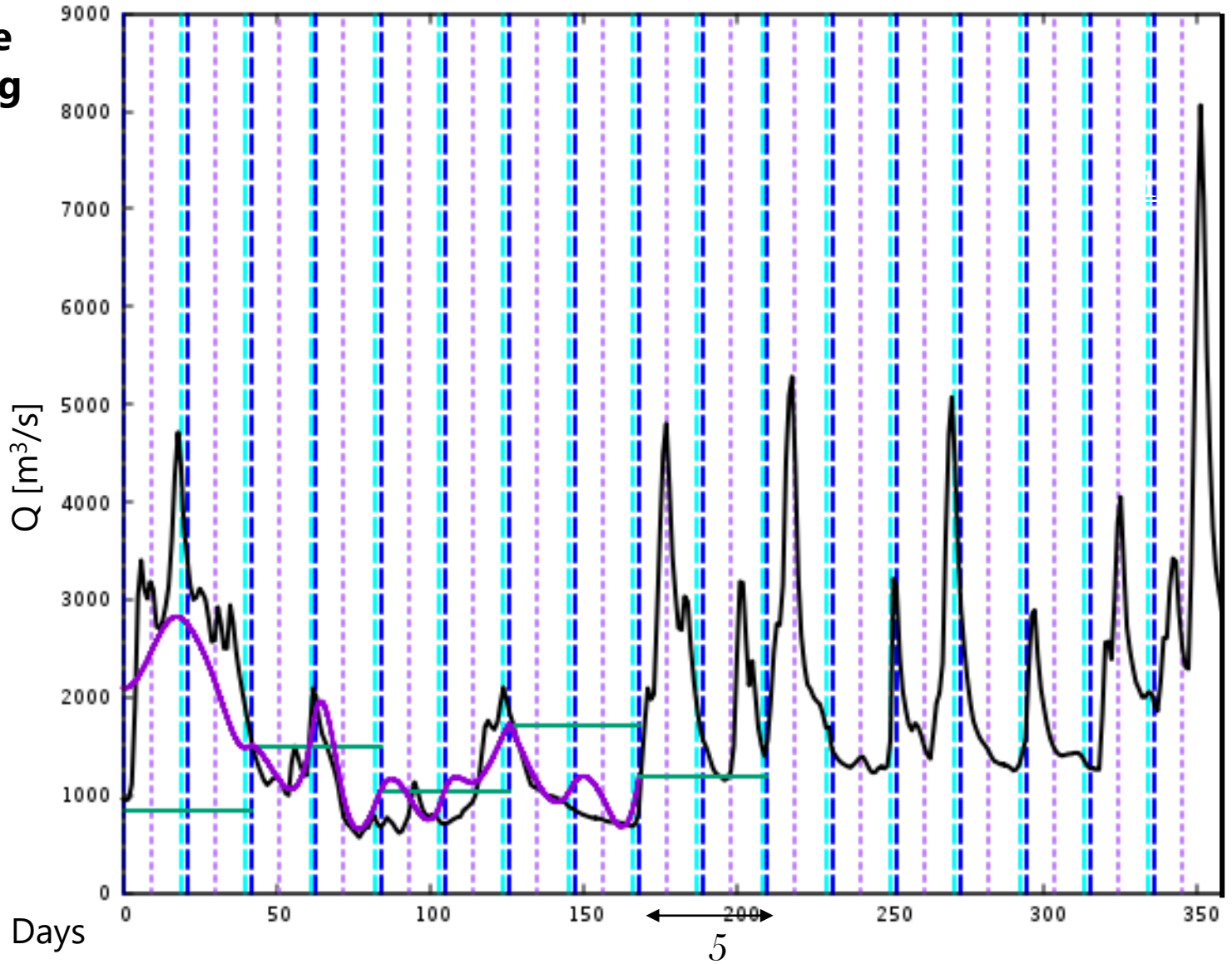

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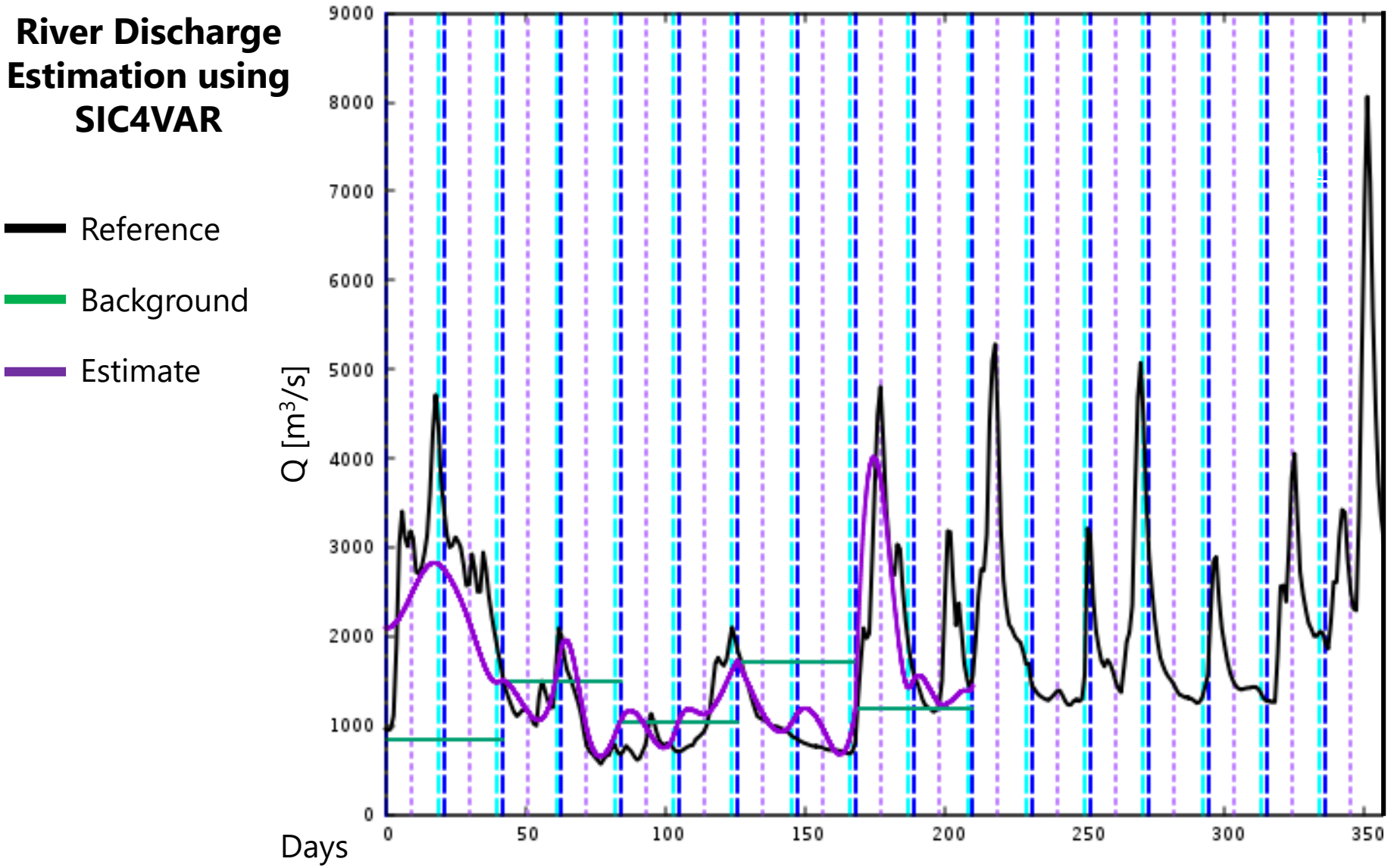

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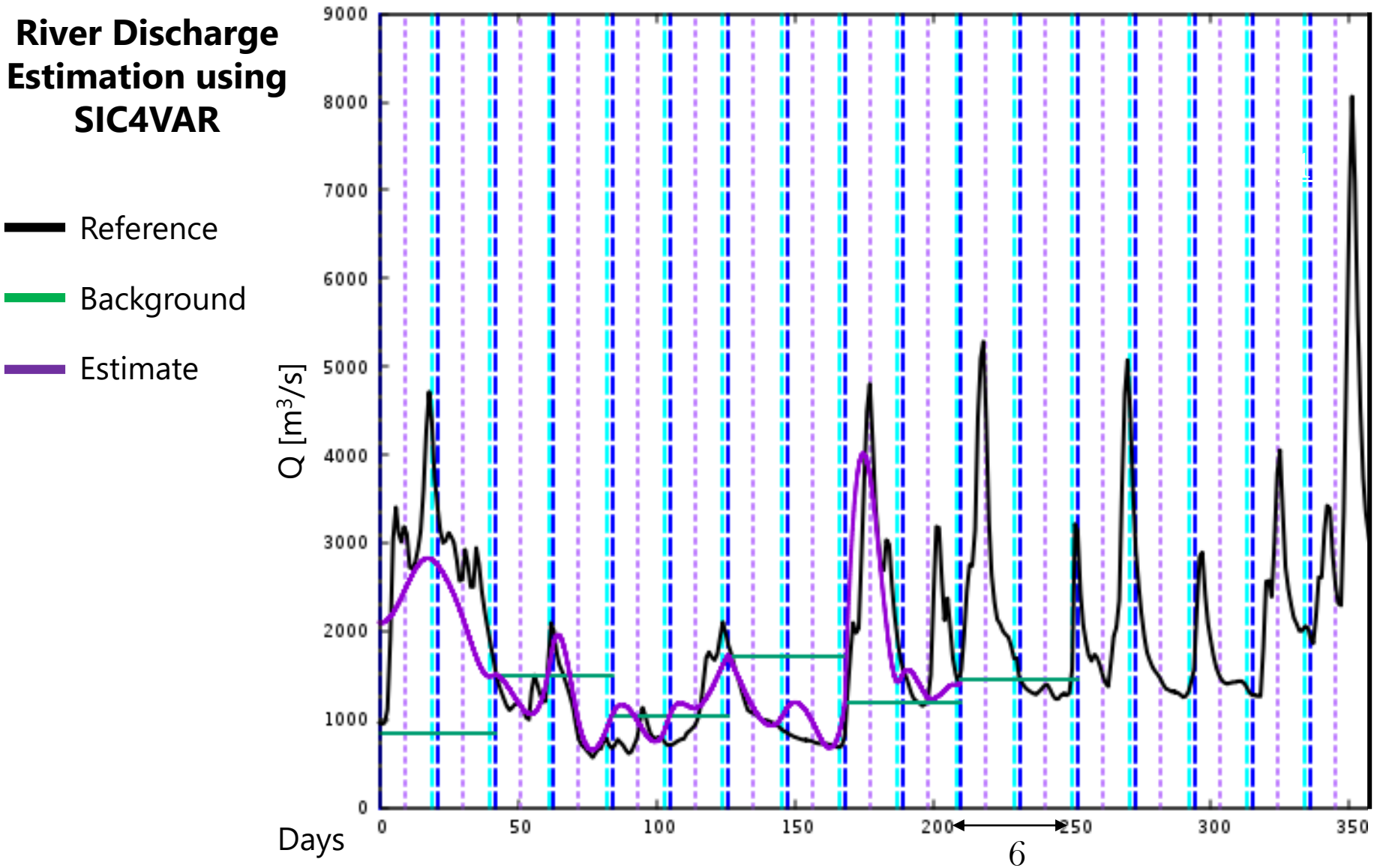

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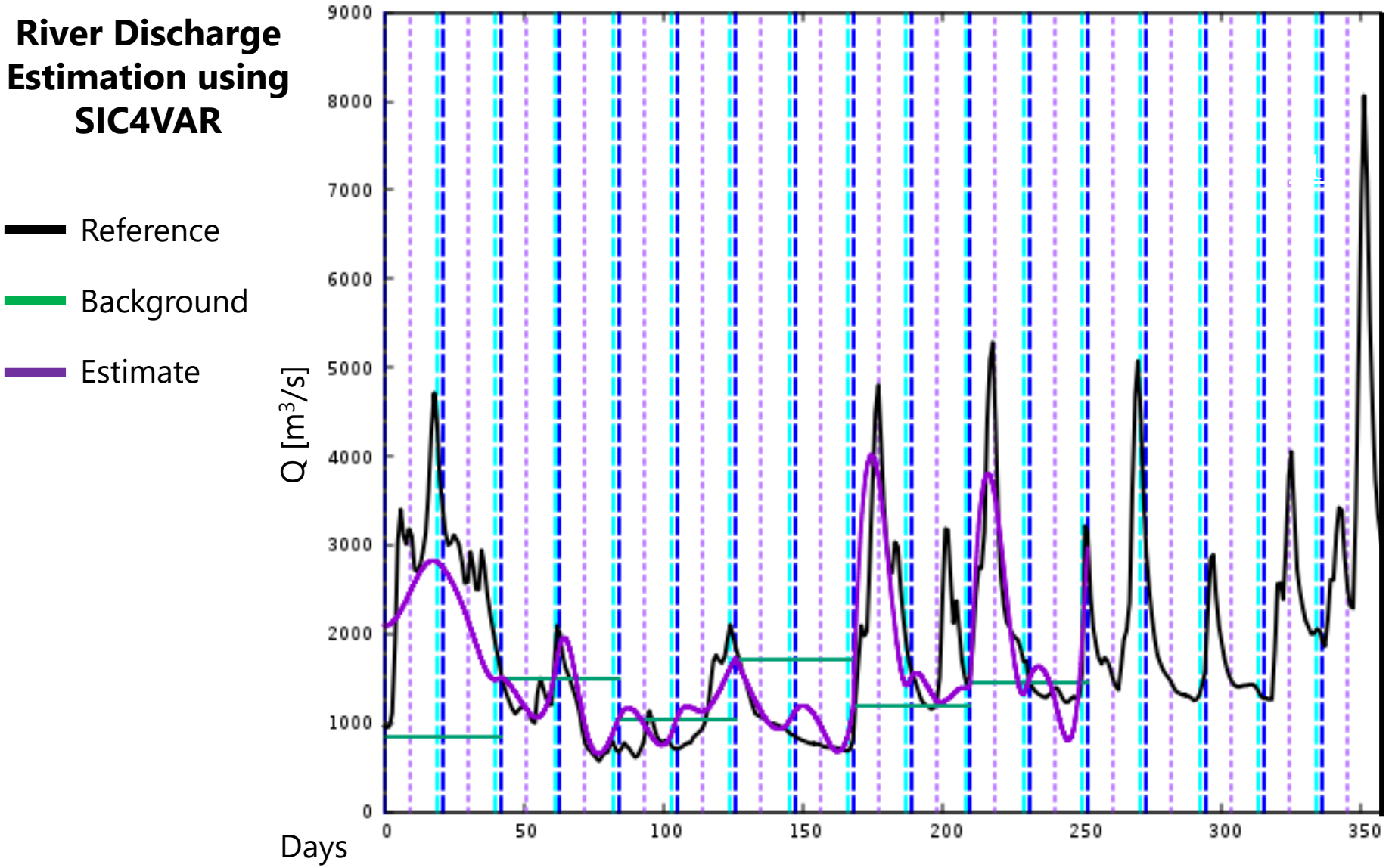

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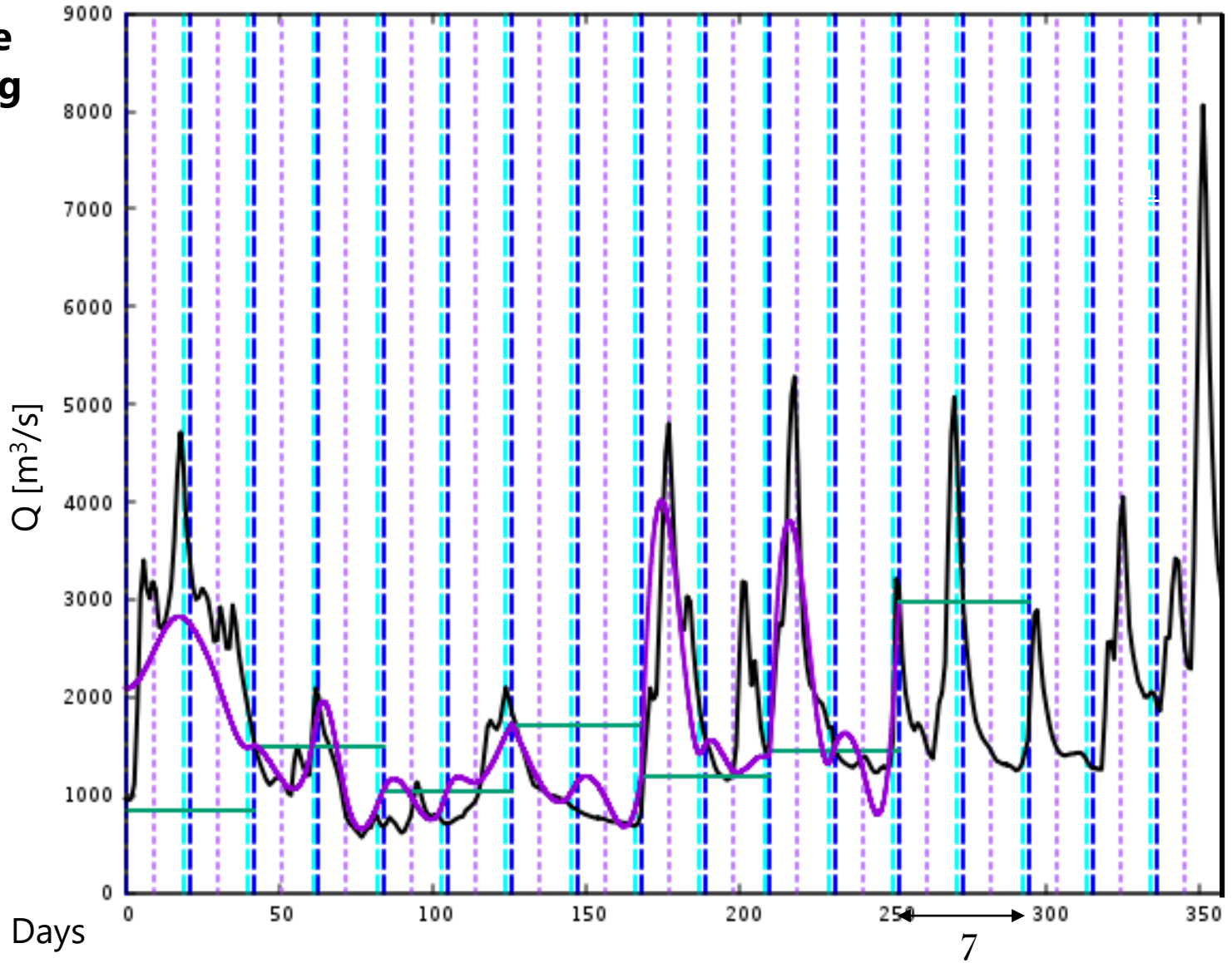

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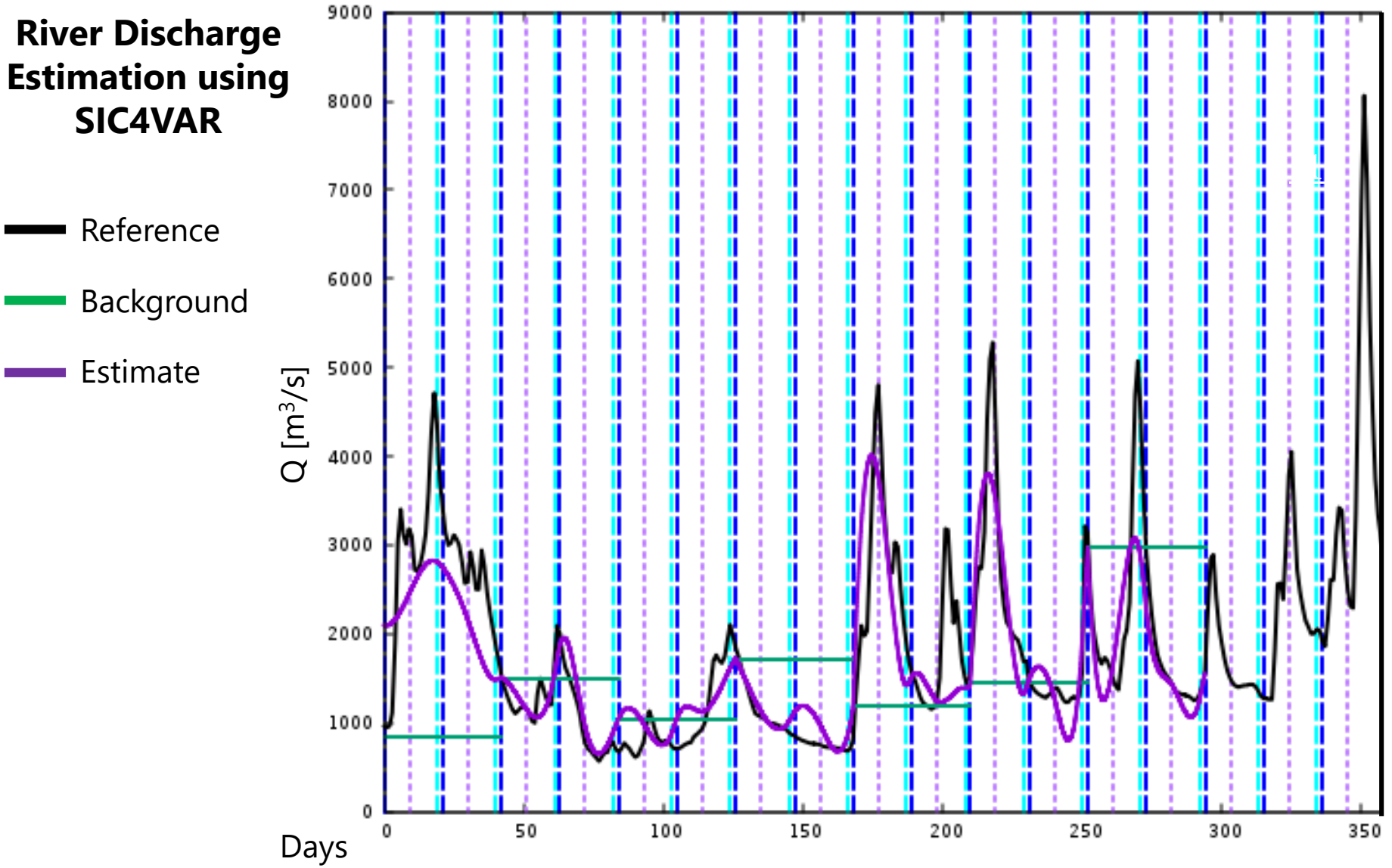

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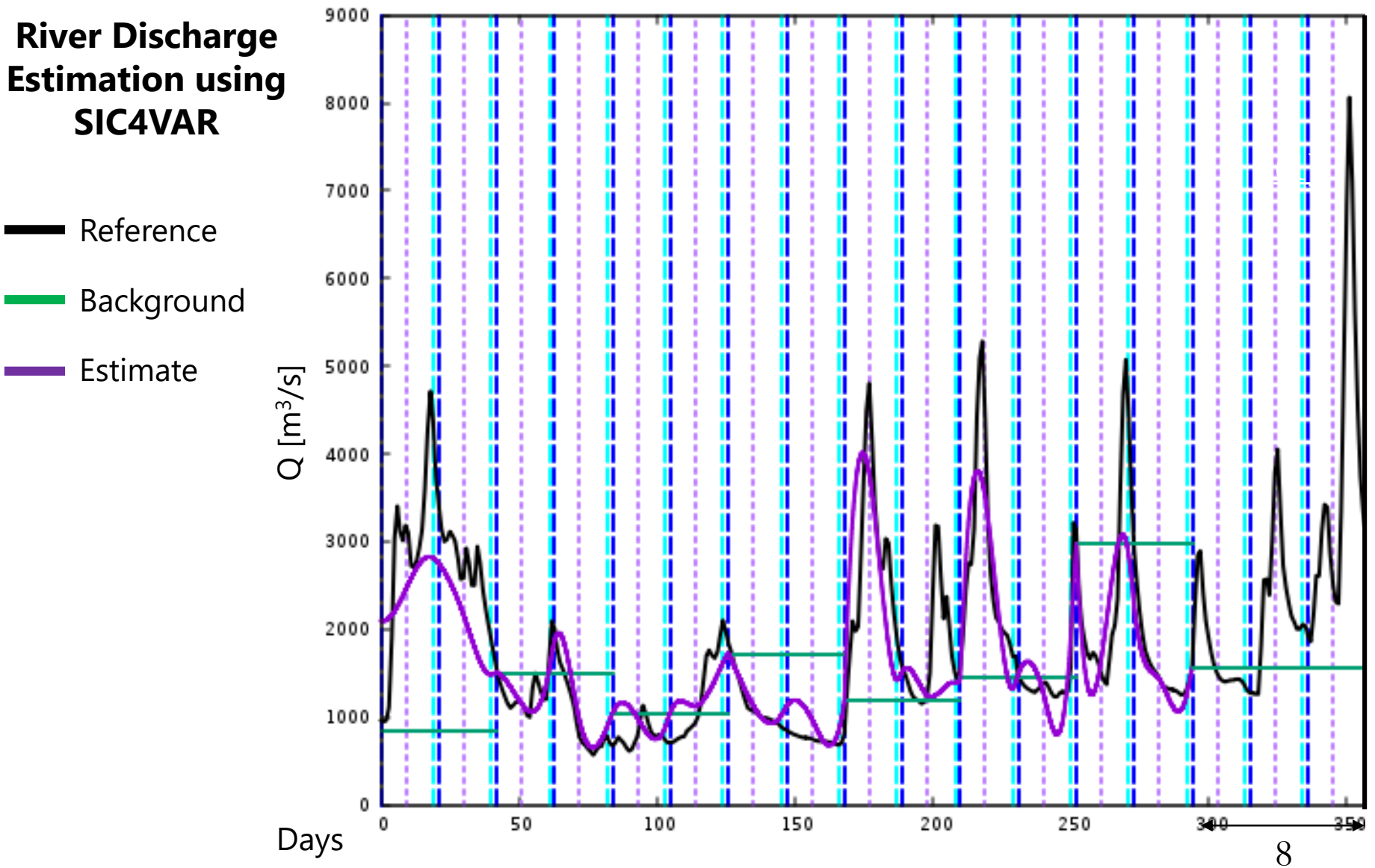

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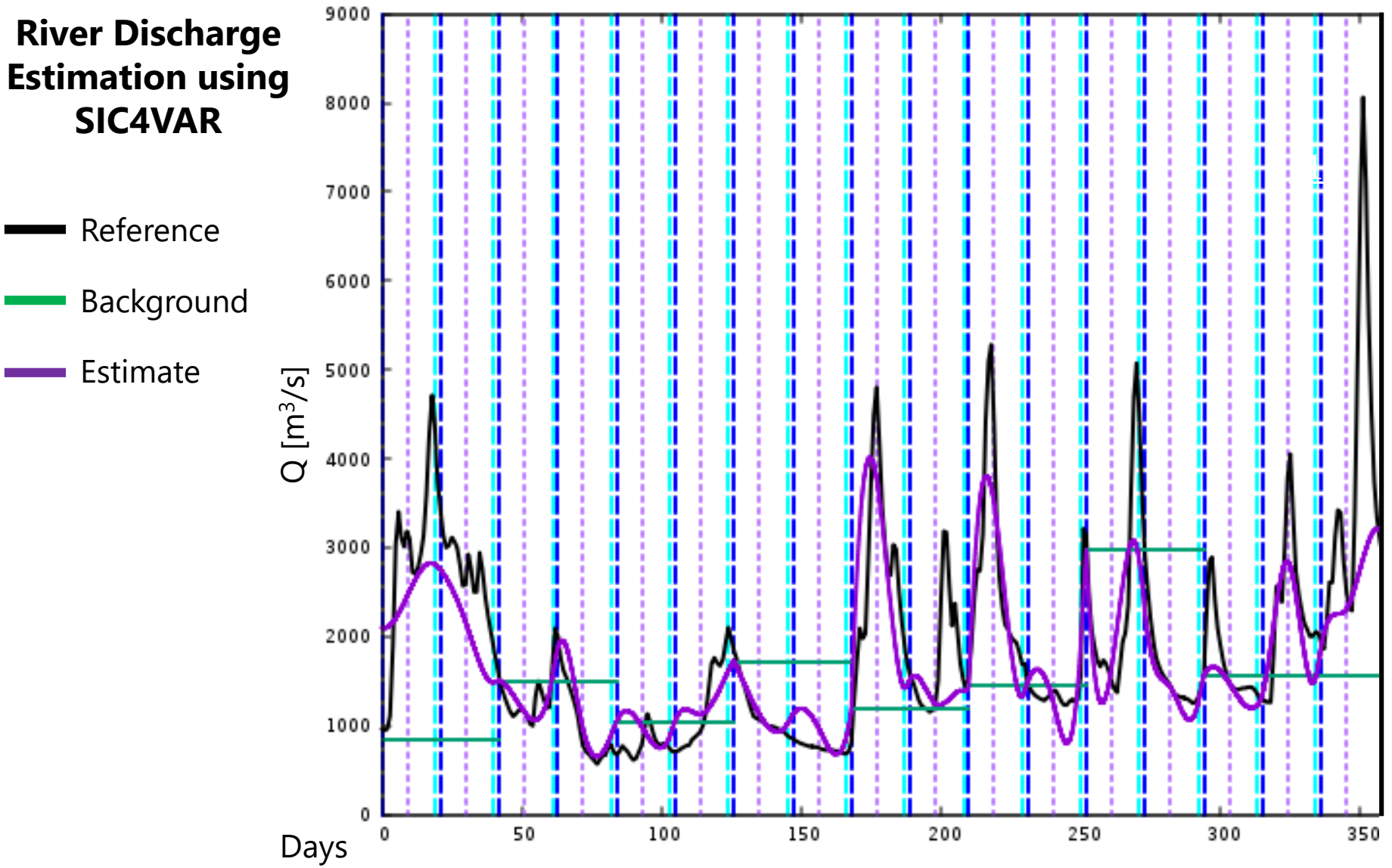

Data assimilation

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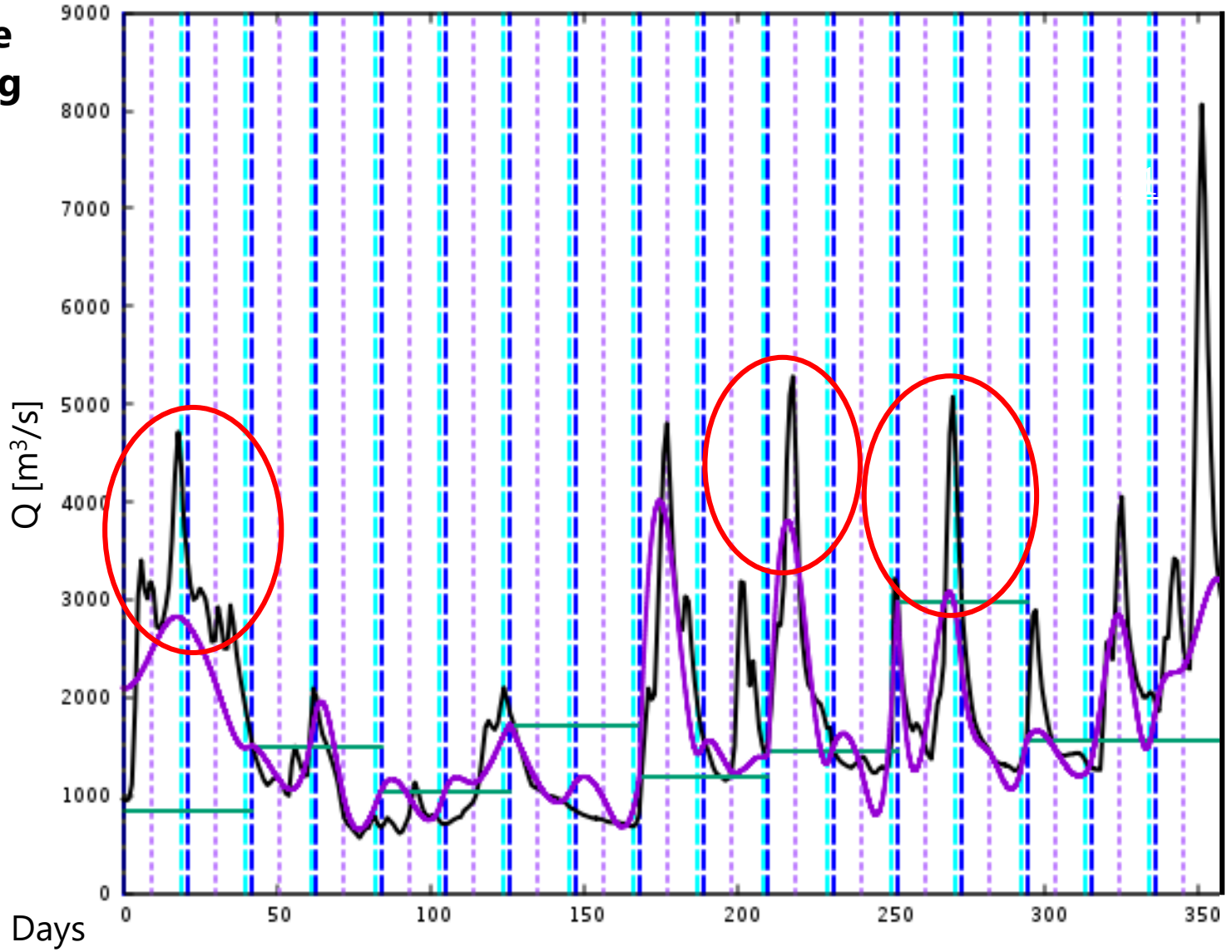
- Background
- Estimate



Introduction

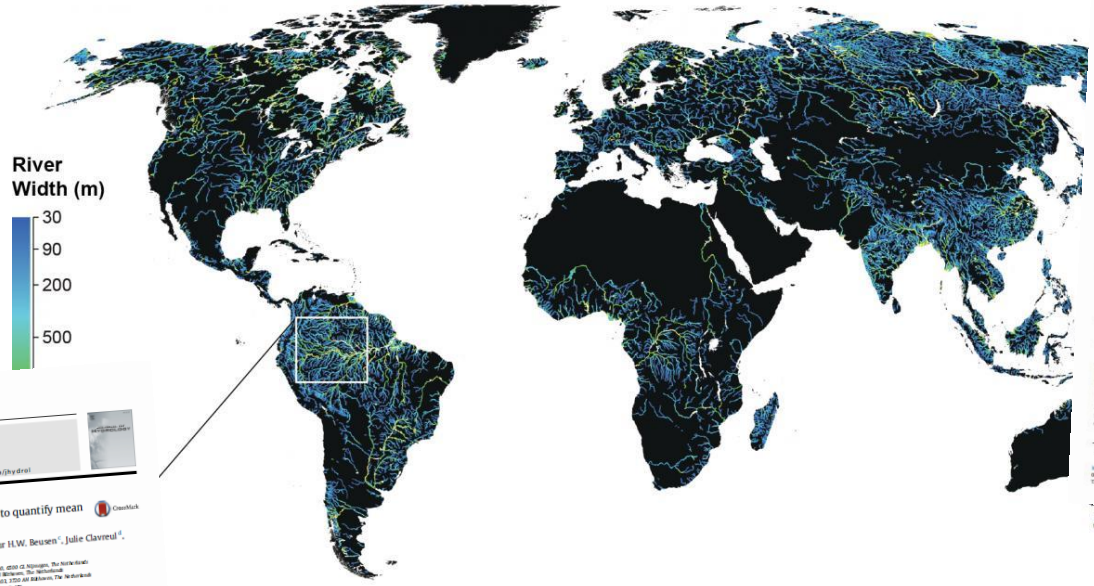
Monate Lake case study

- Survey area
- Hydrological model (HyMOD)

Remote sensing techniques for hydraulic applications

- Satellite altimeters
- River bathymetry estimation
    - RiBEST tool
    - 2D hydraulic modelling
    - Data Assimilation approach on SRTM-based bathymetry
- Global investigation of river geomorphologic relationship

River geomorphologic relationship



Journal of Hydrology

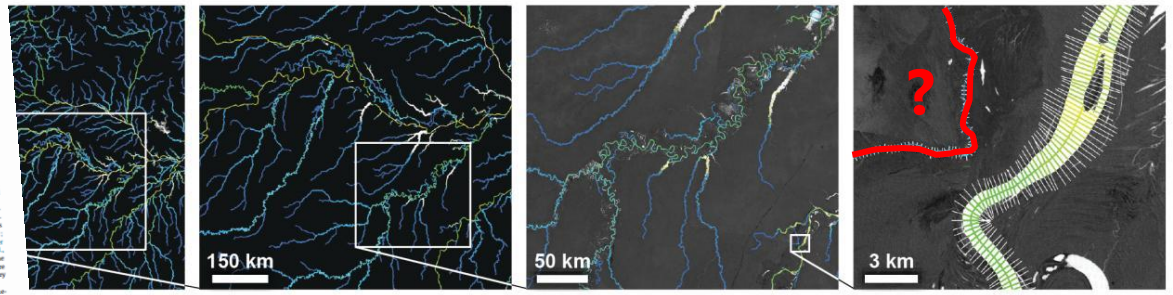
Efficient incorporation of channel cross-section geometry uncertainty into regional and global scale flood inundation models

(Neal et al, 2014)

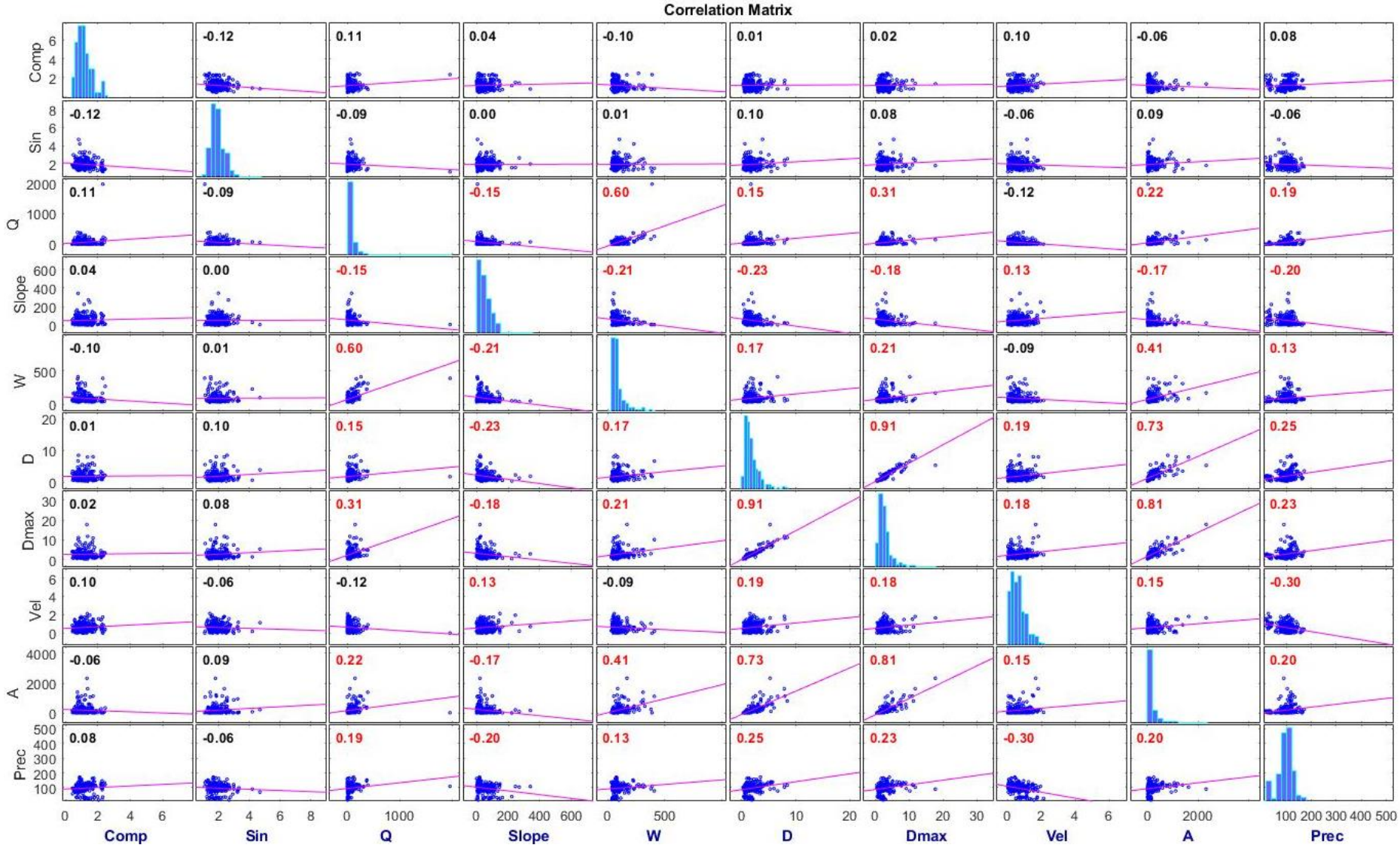
Journal of Hydrology

Developing and testing a global-scale regression model to quantify mean annual streamflow

(Barbarossa et al, 2016)



River geomorphologic relationship



Courses and seminars attended

Period abroad: 14/01-18/04 2019, IRSTEA (Montpellier)
Advisor: Hind Oubanas

Courses taken from a master program

- *Introducing to algorithms and programming* – Proff. Simone Martini, Maurizio Gabrielli, 09/12.2019, UniBo, 6 ECTS
- *Calcolo Numerico* – Prof. Silvia Bonettini, 02/06.2019, UniMore, 9 ECTS
- *Fondamenti di Machine Learning* – Prof. Luca Zanni, 09/12.2019, UniMore, 6 ECTS
- *Ottimizzazione Numerica A* – Proff. Luca Zanni, Silvia Bonettini, 09/12.2019, UniMore, 6 ECTS

Other courses, seminars and workshops

- Seminar: *Catastrophe Modelling* – Laurent Marescot (RMS Zurich), Maurizio Savina (RMS Zurich), Cecilia Bittoni, 21.06.2019, UniBo, 3 hours.

National and international conferences:

- Conference: *European Geosciences Union (EGU) General Assembly 2019*, 07/12.04.2019, Vienna (Austria), 5 days.
- Conference: *Giornate dell'Idrologia 2019*, 16/18.09.2019, Bologna, 3 days.
- Conference: *Living the Planet Symposium,* 14/16.07.2019, Milan, 3 days.

Evaluation of PhD activity

Thanks for your attention

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