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SWOT Mission Capabilities for the Prediction of Flow-Duration Curves: A Global Scale Assessment

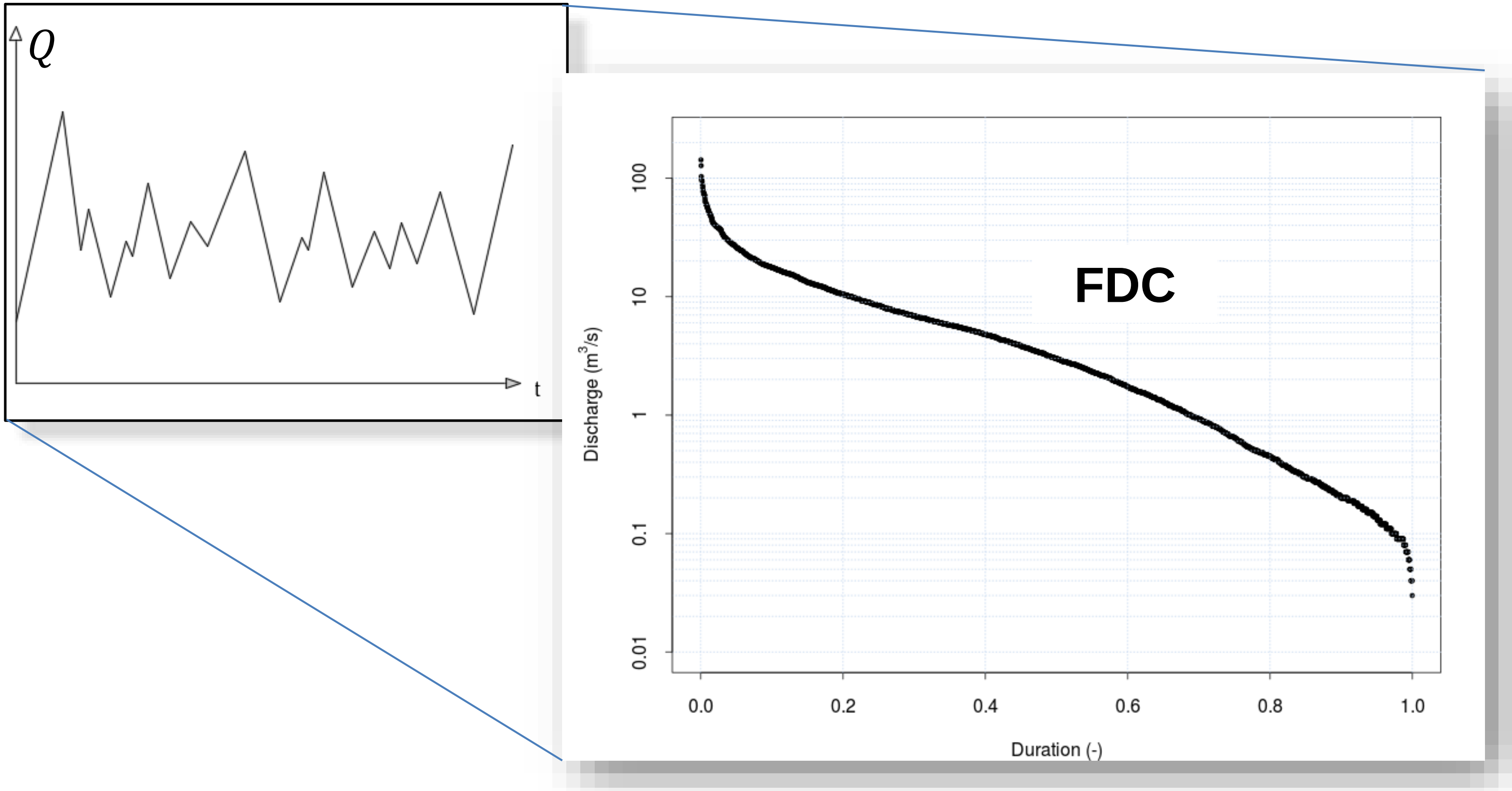
Alessio Domeneghetti, Alessio Pugliese, Attilio Castellarin and Armando Brath

DICAM – Dep. of Civil, Chemical, Environmental and Materials Engineering

Alma Mater Studiorum - University of Bologna, Italy

IL PRESENTE MATERIALE È RISERVATO AL PERSONALE DELL'UNIVERSITÀ E NON PUÒ ESSERE UTILIZZATO AI TERMINI DI LEGGE DA ALTRE PERSONE O PER FINI NON ISTITUZIONALI

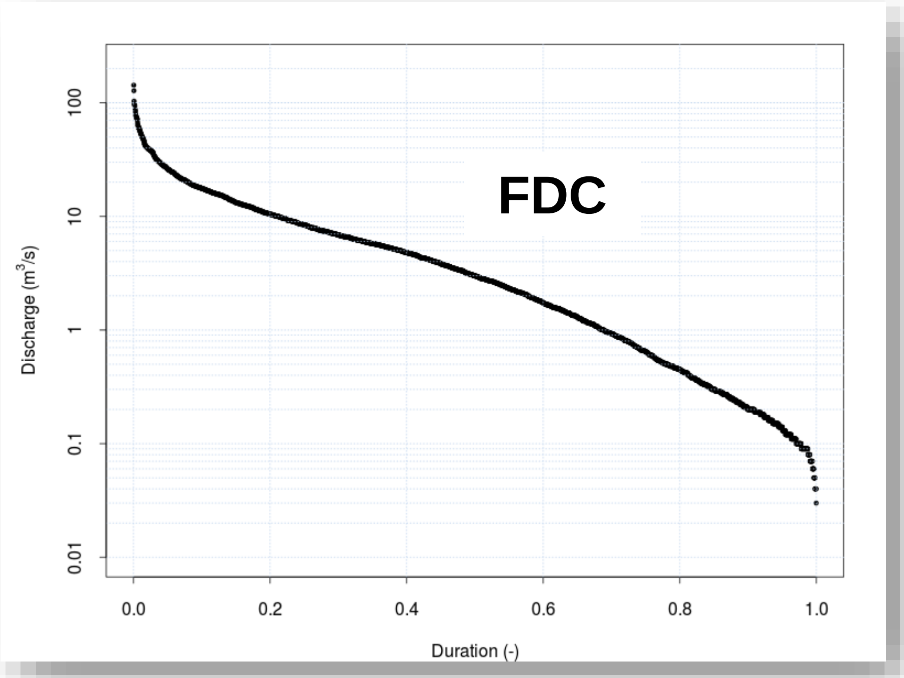
Flow Duration Curves (FDCs)



A Period of Record Flow-Duration Curve (POR FDC) represents the percent of time (duration) in which a given streamflow ***Q**** is equaled or exceed (***Q*** vs. %time ≥ ***Q****) over an historical period of time (Vogel and Fennessey, 1994).

Vogel, R. M. and Fennessey, N. M.: Flow-Duration Curves. I: New Interpretation and Confidence Intervals, J. Water Res. Pl.-ASCE, 120, 485–504, doi:10.1061/(ASCE)0733-9496(1994)120:4(485), 1994.

Flow Duration Curves (FDCs)

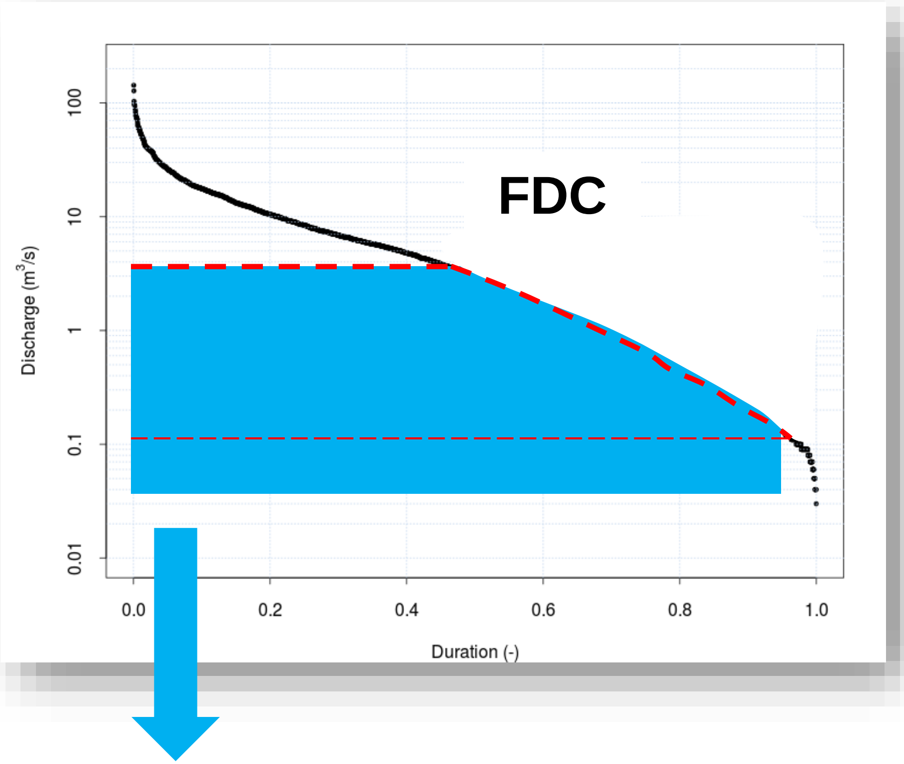


- Reservoir management and optimisation

(Ridracoli Dam, Emilia-Romagna, Italy)

- *Hydropower*
- *Irrigation*
- *Drinking water*
- *…others*

Flow Duration Curves (FDCs)



Totoal water volume exploited for hydro-power production

- Reservoir management and optimisation

(Ridracoli Dam, Emilia-Romagna, Italy)

- *Hydropower*
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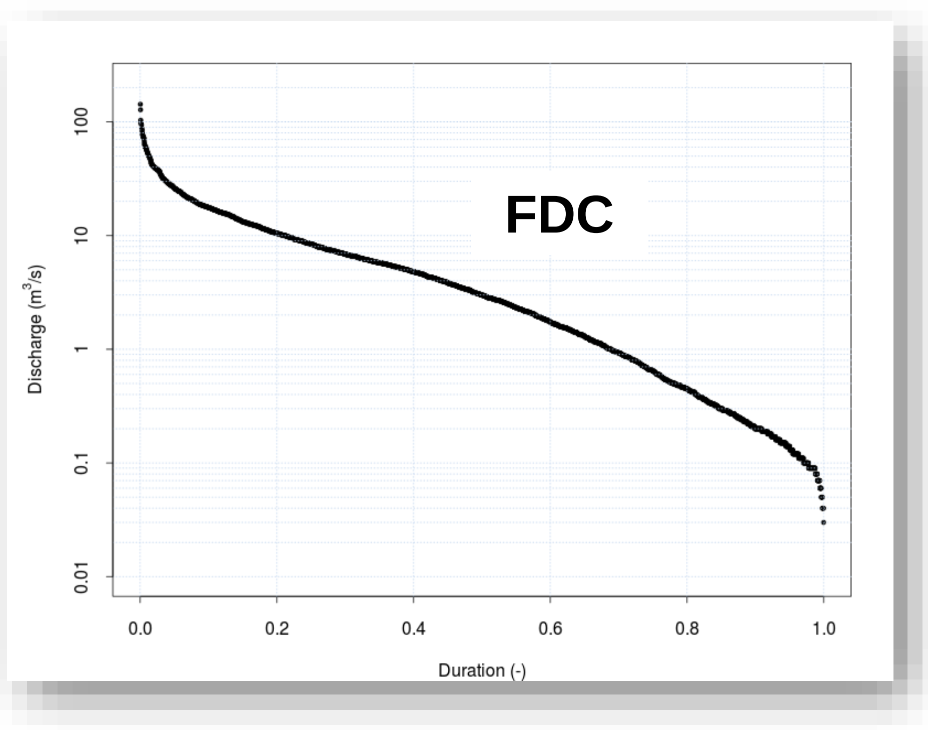
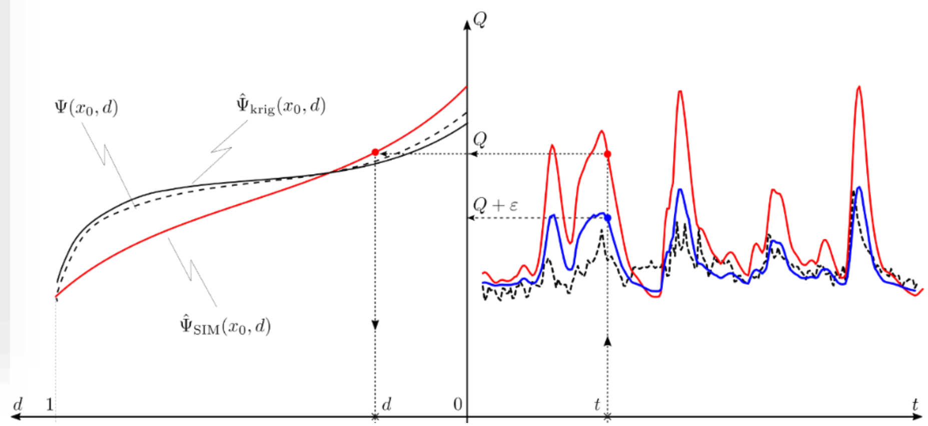
Flow Duration Curves (FDCs)



- Streamflow series reconstruction in ungauged locations

  (Smakhtin & Masse, HYP, 2000)
  (Farmer et al, HESS, 2018)
  (Pugliese et al., HESS, 2018)

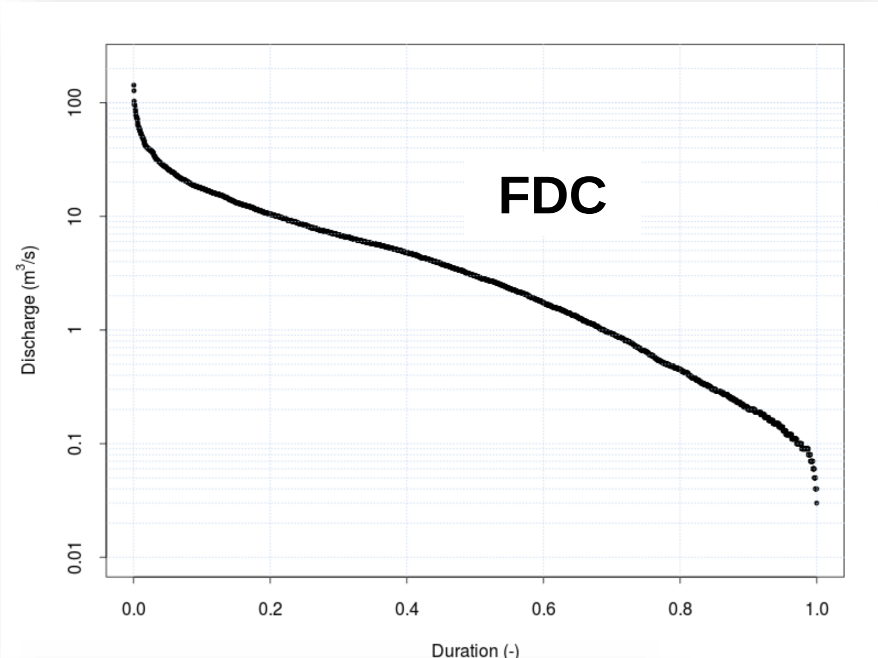


Pugliese, A., Persiano, S., Bagli, S., Mazzoli, P., Parajka, J., Arheimer, B., Capell, R., Montanari, A., Blöschl, G., Castellarin, A., 2018. A geostatistical data-assimilation technique for enhancing macro-scale rainfall–runoff simulations. Hydrol. Earth Syst. Sci. 22, 4633–4648. https://doi.org/10.5194/hess-22-4633-2018

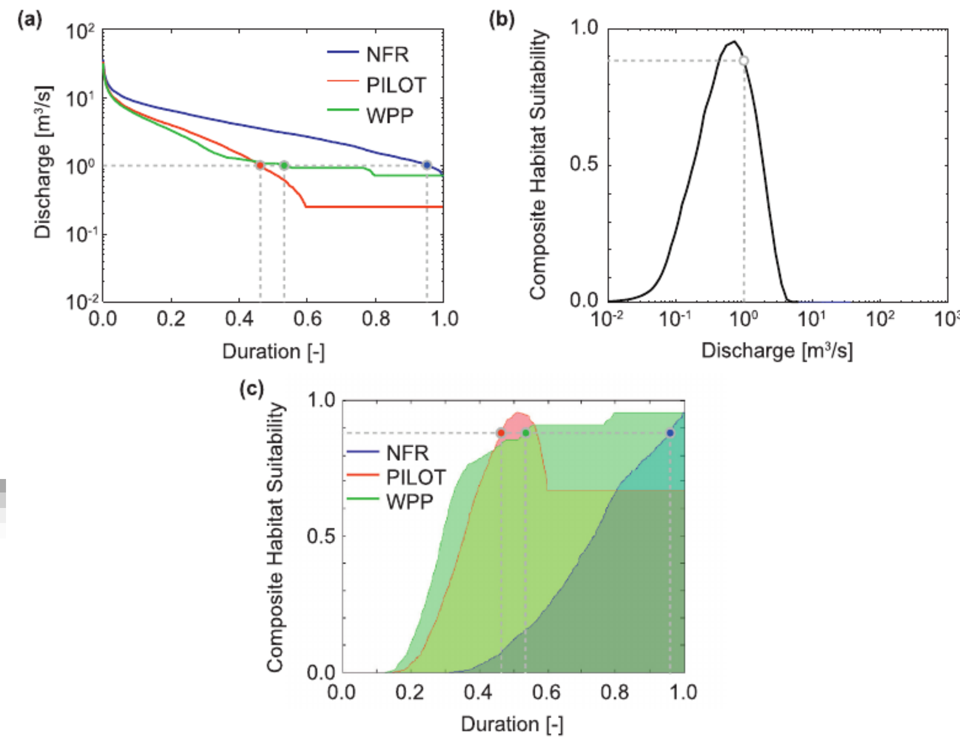
Farmer, W. H., Over, T. M., and Kiang, J. E.: Bias correction of simulated historical daily streamflow at ungauged locations by using independently estimated flow duration curves, Hydrol. Earth Syst. Sci., 22, 5741-5758, https://doi.org/10.5194/hess-22-5741-2018, 2018.

Smakhtin, V.Y., Masse, B., 2000. Continuous daily hydrograph simulation using duration curves of a precipitation index. Hydrol. Process. 14, 1083–1100

Flow Duration Curves (FDCs)



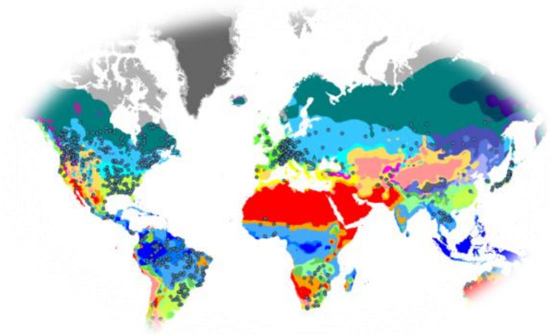
- Eco-Habitat Suitability
- Environmental flow requirements



(Ceola et al., AWR, 2018)

Ceola, S., Pugliese, A., Ventura, M., Galeati, G., Montanari, A., Castellarin, A., 2018, Hydropower production and fish habitat suitability: Assessing impact and effectiveness of ecological flows at regional scale, *Advances in Water Resources*, doi: 10.1016/j.advwatres.2018.04.002

Global scale prediction of FDCs



Research questions:

1. Are SWOT data capable to compensate the lack of streamflow records in remote areas/ungauged basins?
2. How well the SWOT mission can contribute to handle the request of FDCs from practitioners where streamflow measurements are missing?
3. Is SWOT lifetime suitable for FDC estimation?
4. How much climatic patterns might influence satellite-based FDCs?

The SWOT mission

NASA/CNES - CSA/UKSA

SWOT (Surface Water and Ocean Topography)

- **Data quality**

Main scientific goals:

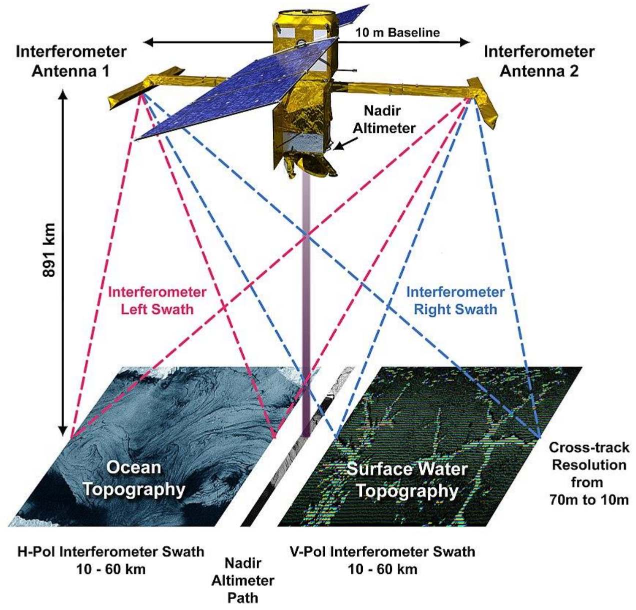
❖ 90% coverage of terrestrial surface water (oceans, rivers, lakes):

Hydrological data from radar images for rivers with $w \geq$ 100 m (hopefully 50 m)

1. water surface elevations;
2. surface profile slope;
3. water surface area;

River discharge estimation algorithms

Streamflow series *Q(t)*



Credit: Yeosang Yoon with images from NASA

The expected river discharge errors are(*):

$< 35\%$ RRMSE

(Durand et al. 2016, WRR)

(*) non-braided rivers

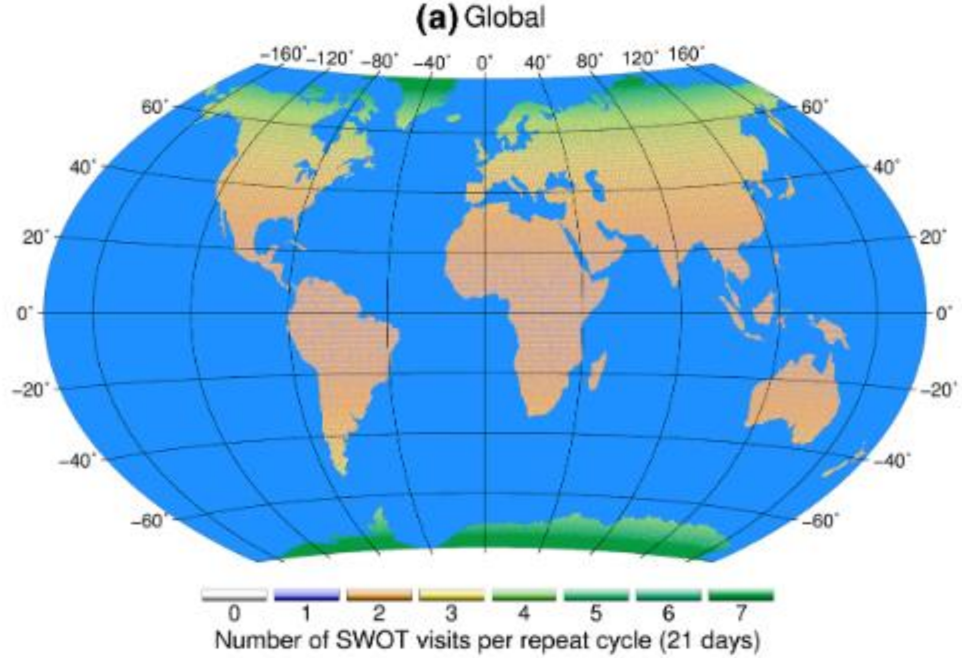
Durand, M., C. J. Gleason, P. A. Garambois, D. Bjerklie, L. C. Smith, H. Roux, E. Rodriguez, P. D. Bates, T. M. Pavelsky, J. Monnier, X. Chen, G. Di Baldassarre, J. M. Fiset, N. Flipo, R. P. d. M. Frasson, J. Fulton, N. Goutal, F. Hossain, E. Humphries, J. T. Minear, M. M. Mukolwe, J. C. Neal, S. Ricci, B. F. Sanders, G. Schumann, J. E. Schubert e L. Vilmin (2016). «An intercomparison of remote sensing river discharge estimation algorthms from measurements of river height, width, and slope». Water Resources Research, 52, pp. 4527–4549. doi:10.1002/2015WR018434

The SWOT mission

- **Data frequency**

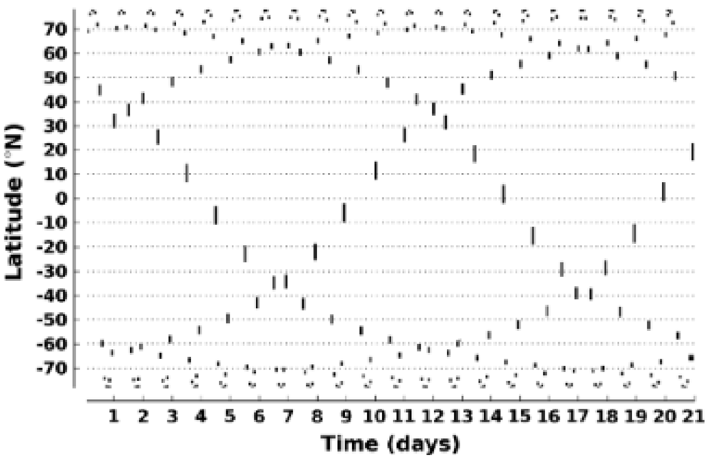
SWOT spatial coverage and revisit times per orbit repeat period (~21 days) depend on orbit characteristics, instrument swath width, nadir gap width and the latitude (Biancamaria et al., 2016).

Credit: Biancamaria et al., 2016



SWOT would observe most areas between 2 and 8 times over each 21-day period, depending on distance from the equator

Credit: Biancamaria et al., 2016

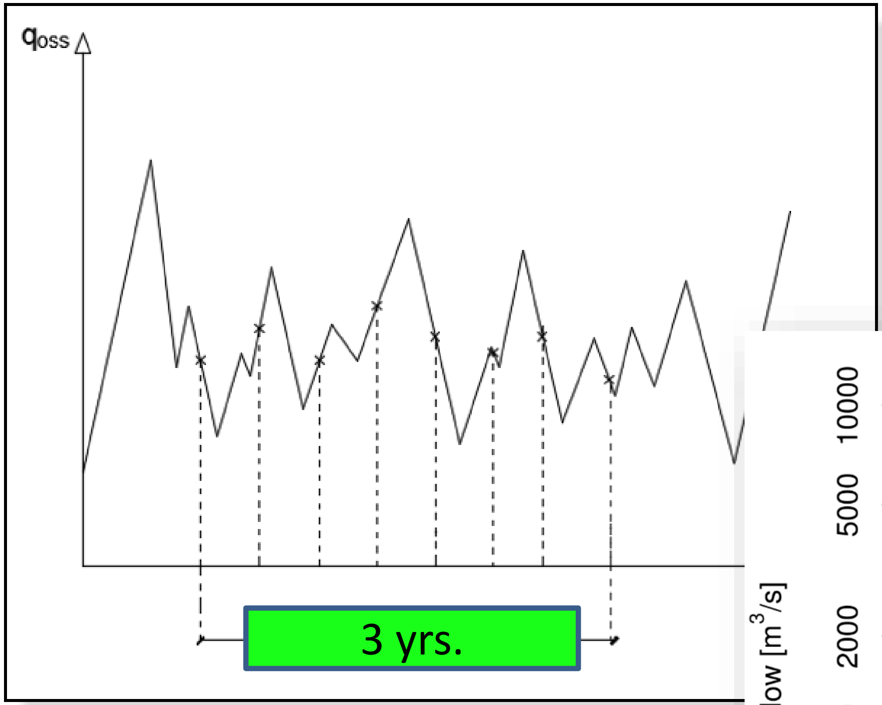


In the analysis we consider:

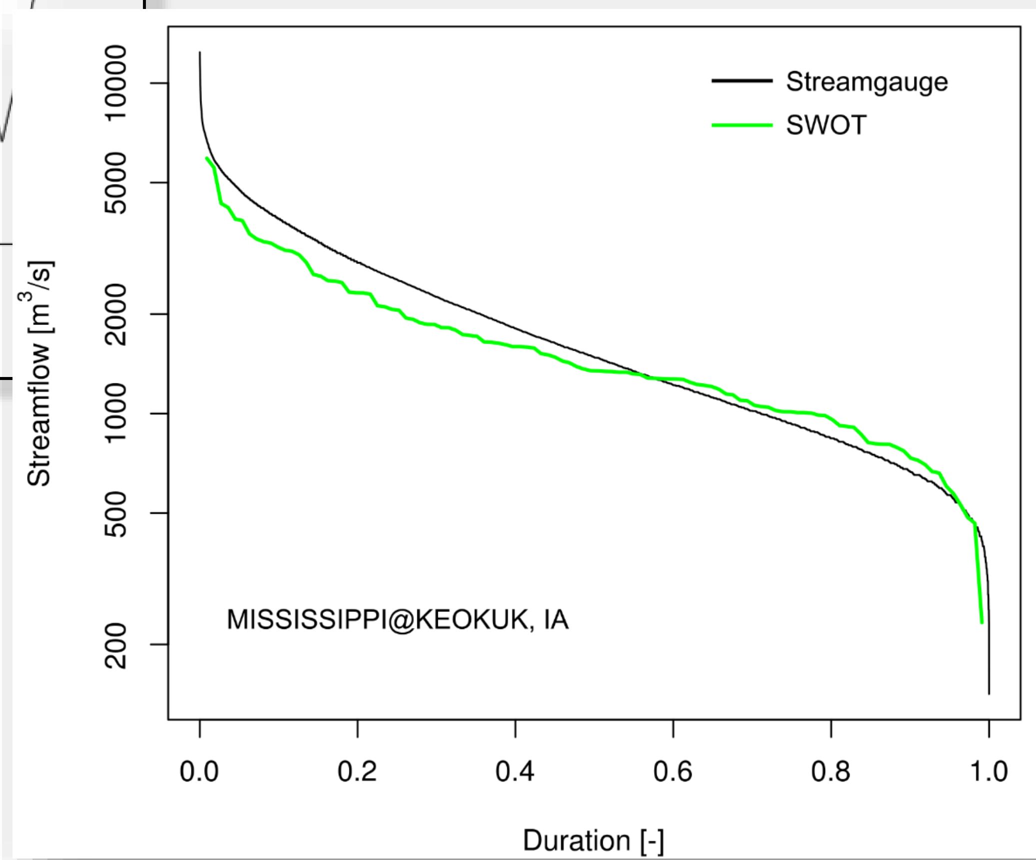
- 1 observations/10 days
- 3 yrs. time frame (mission lifetime)

Biancamaria, S., D. P. Lettenmaier e T. M. Pavelsky (2016). «The SWOT Mission and its Capabilities for Land hydrology». In: Surveys in Geophysics 37, pp. 307–337. doi: 10.1007/s10712-015-9346-y

SWOT FDCs estimates



How well 3 yrs. of SWOT observations will perform compared to streamgauge ones for predicting empirical FDCs?

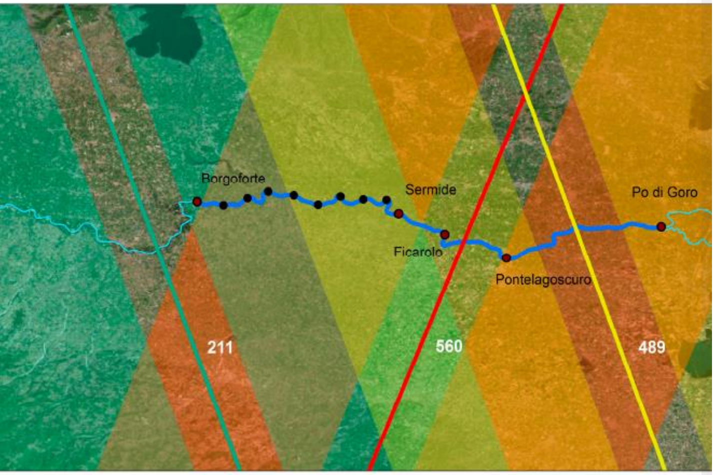


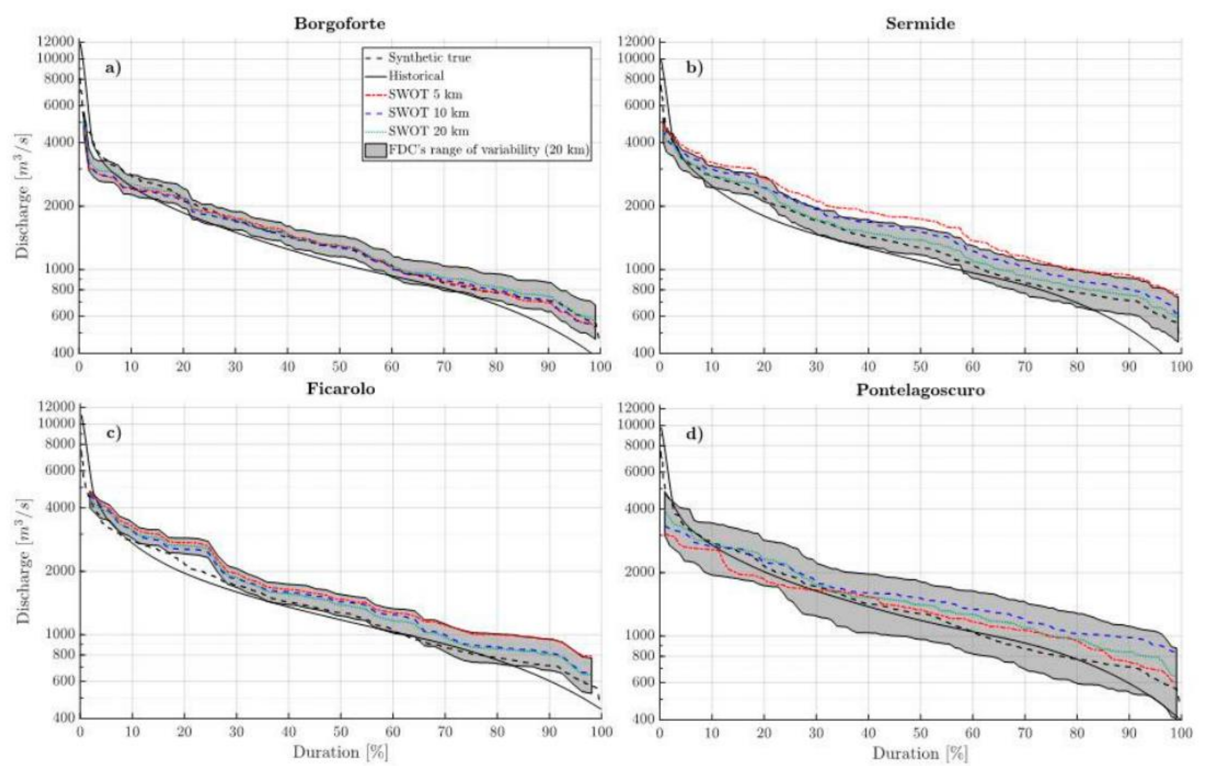
In order to assess SWOT capabilities multiple realizations of the curve during the period of record of a given streamgauge are needed to understand what can be "seen" from the satellite.

Pioneer study at local scale on the Po river, Italy

- considers the mission lifetime (3 yrs)
- 3 satellite orbits (i.e., 211, 489, 560) in the Po River, Italy
- Higher errors are obtained at the FDC tails, where very low or high flows have lower likelihood of being observed

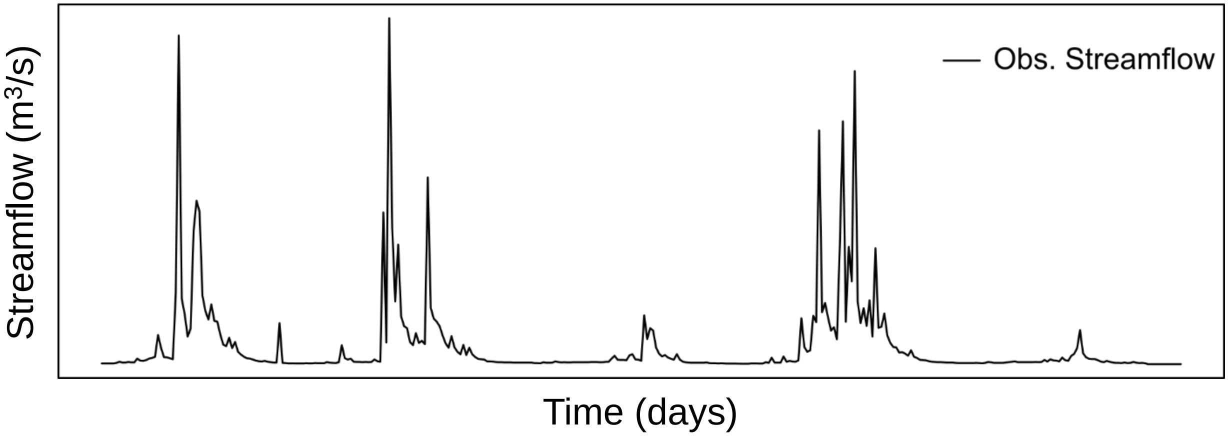
(Domeneghetti et al., RS, 2018)





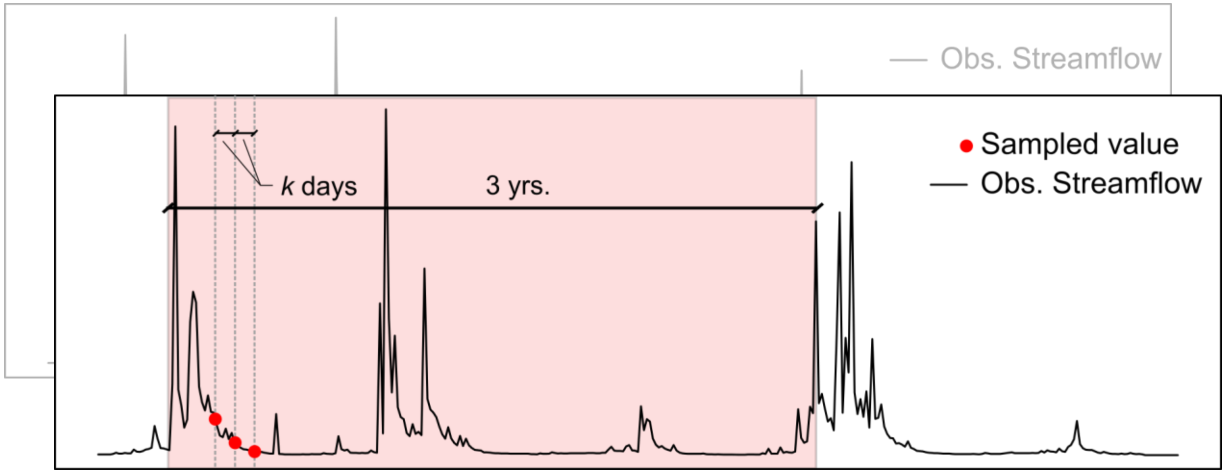
Domeneghetti, A., Tarpanelli, A., Grimaldi, L., Brath, A., Schumann, G., 2018: Flow Duration Curve from Satellite: Potential of a Lifetime SWOT Mission, Remote Sensing, 10(7), 1107, doi:10.3390/rs10071107.

Methodology: mimicking SWOT FDCs



Methodology: mimicking SWOT FDCs

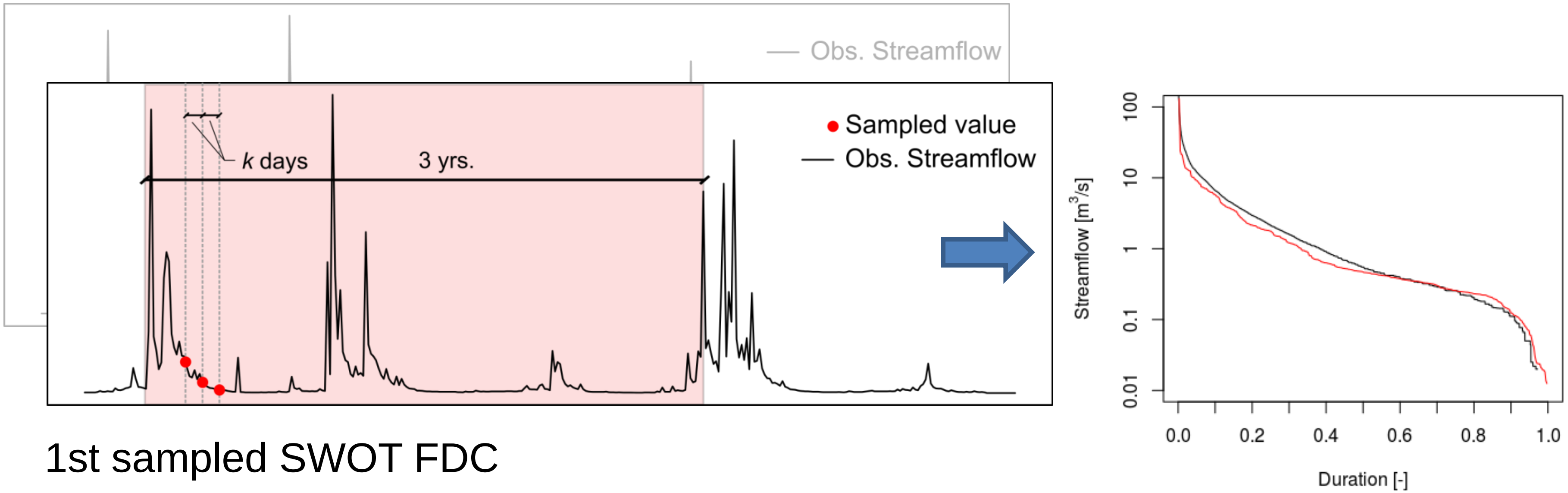
1) Time sampling, k variable sampling rate (in days)



1st sampled SWOT FDC

Methodology: mimicking SWOT FDCs

1) Time sampling, k variable sampling rate (in days)



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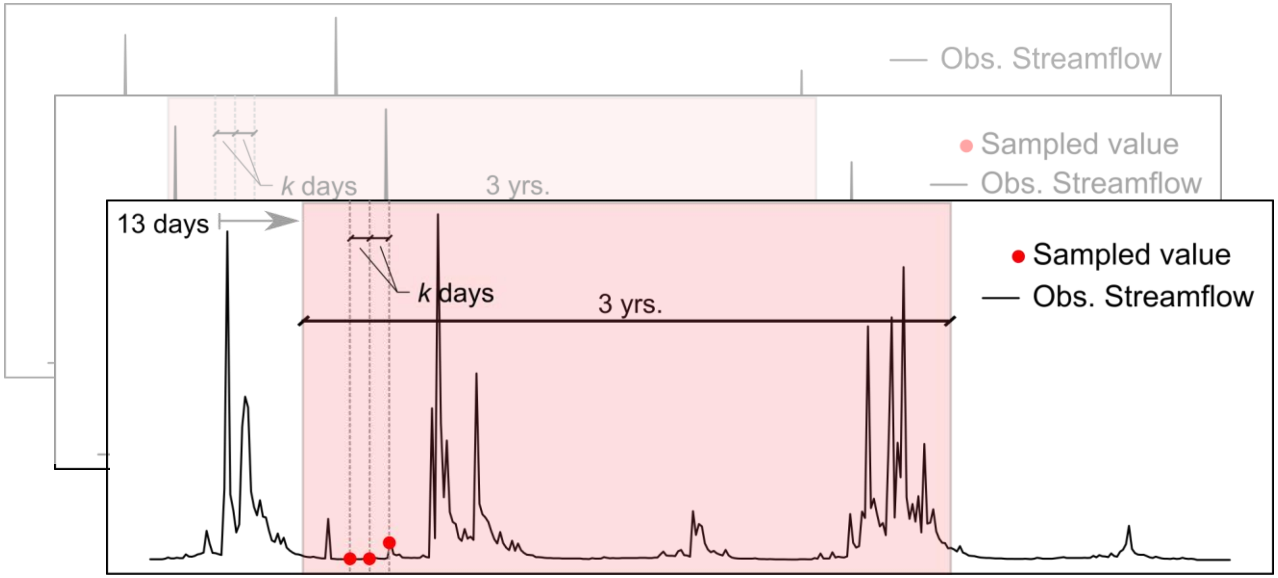
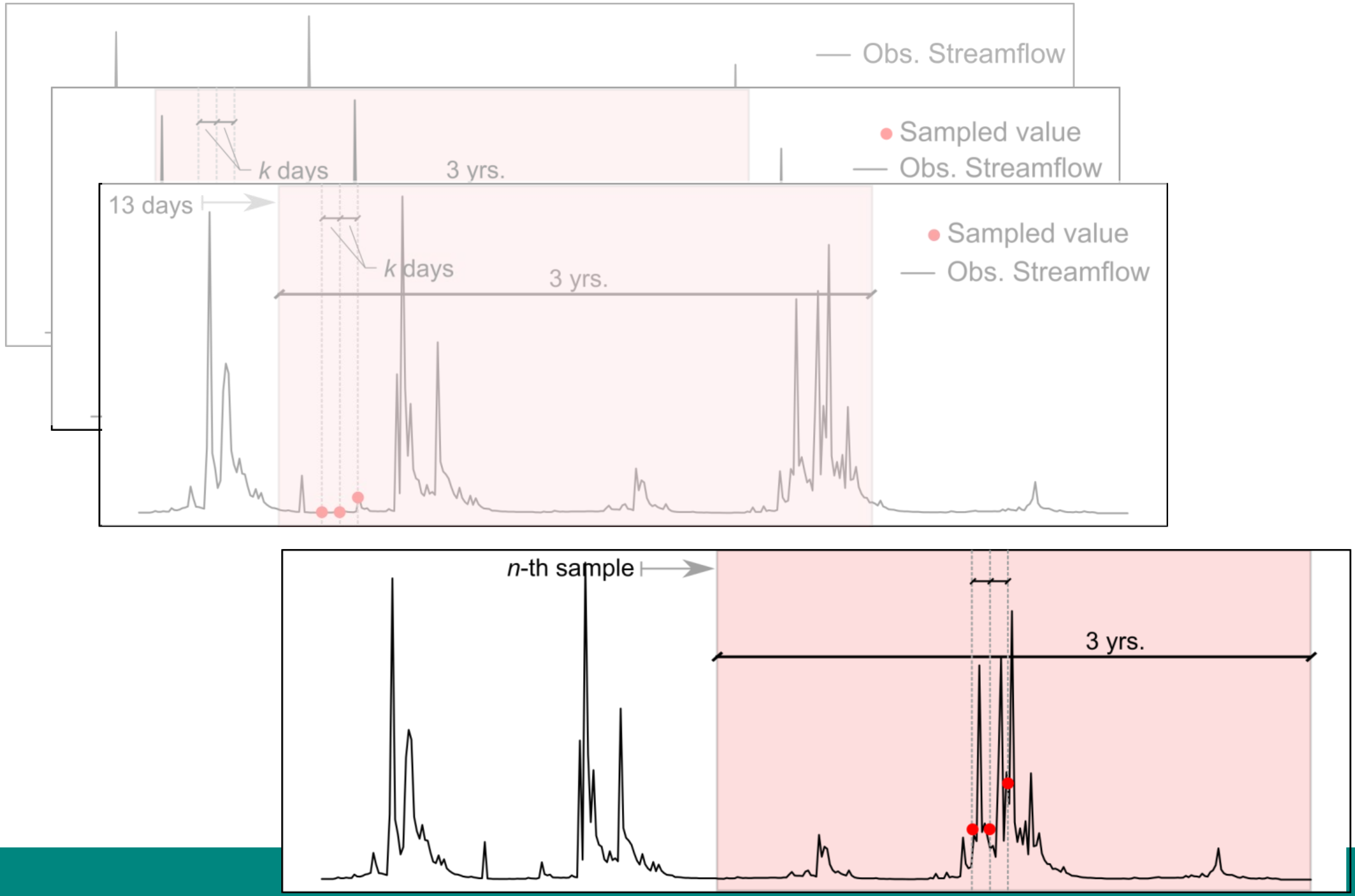


2nd sampled SWOT FDC

...

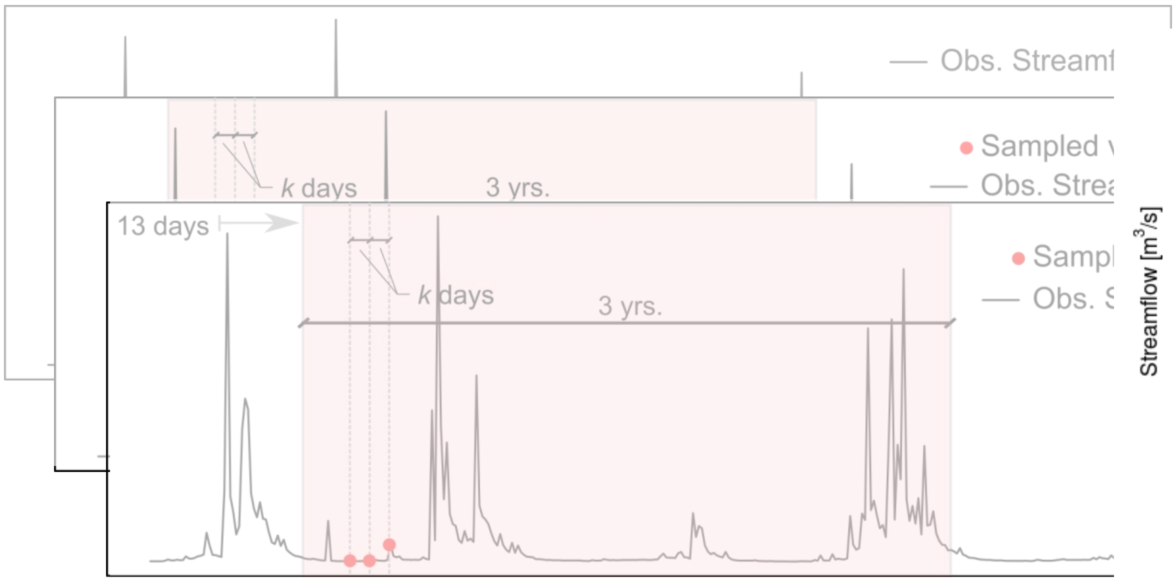
Methodology: mimicking SWOT FDCs

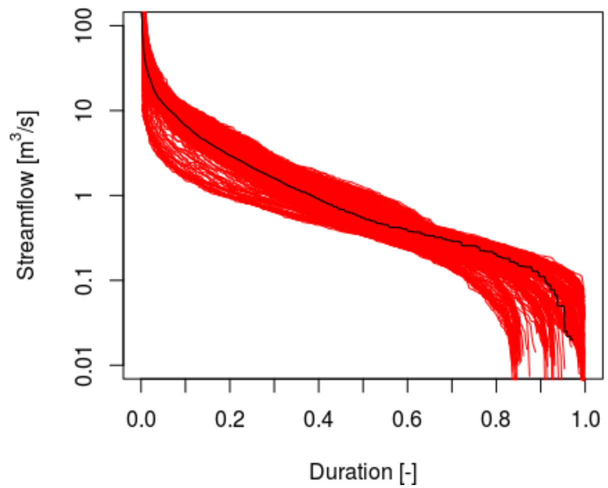
1) Time sampling, k variable sampling rate (in days)

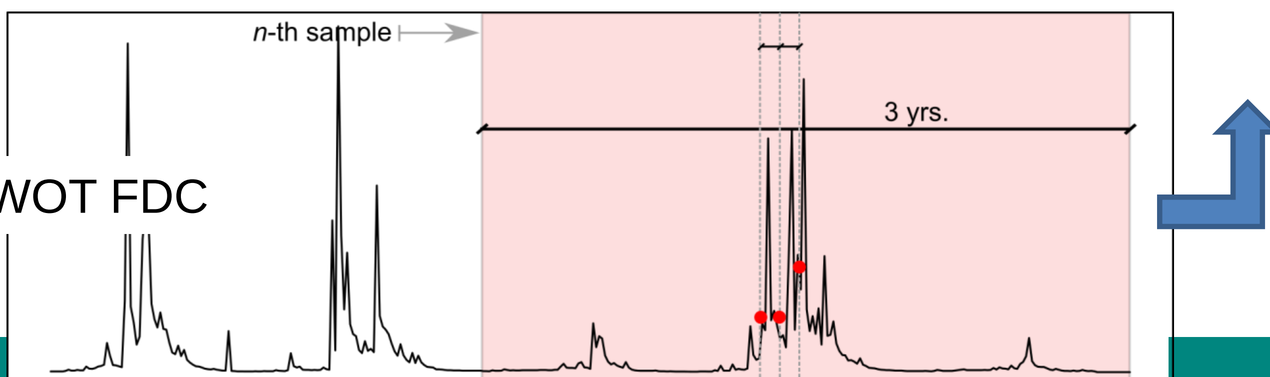


Methodology: mimicking SWOT FDCs

1) Time sampling, k variable sampling rate (in days)







*n*th sampled SWOT FDC

Methodology: mimicking SWOT FDCs

1) Time sampling, k variable sampling rate (in days)

4 different sampling rates -> different «scenarios»

$k = 3, 5, 7, 10$ (days)

Methodology: mimicking SWOT FDCs

2) SWOT measurement error

$$Q_{SWOT} = Q_{gauge}\,(1+\varepsilon)$$

SWOT estimates

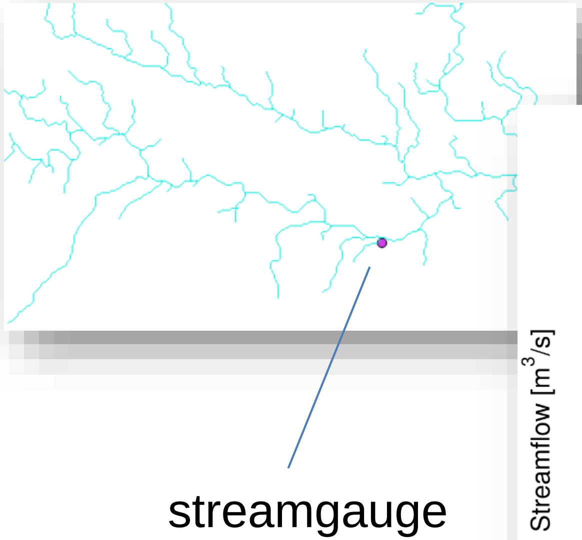
«TRUE» discharge from streamgauge

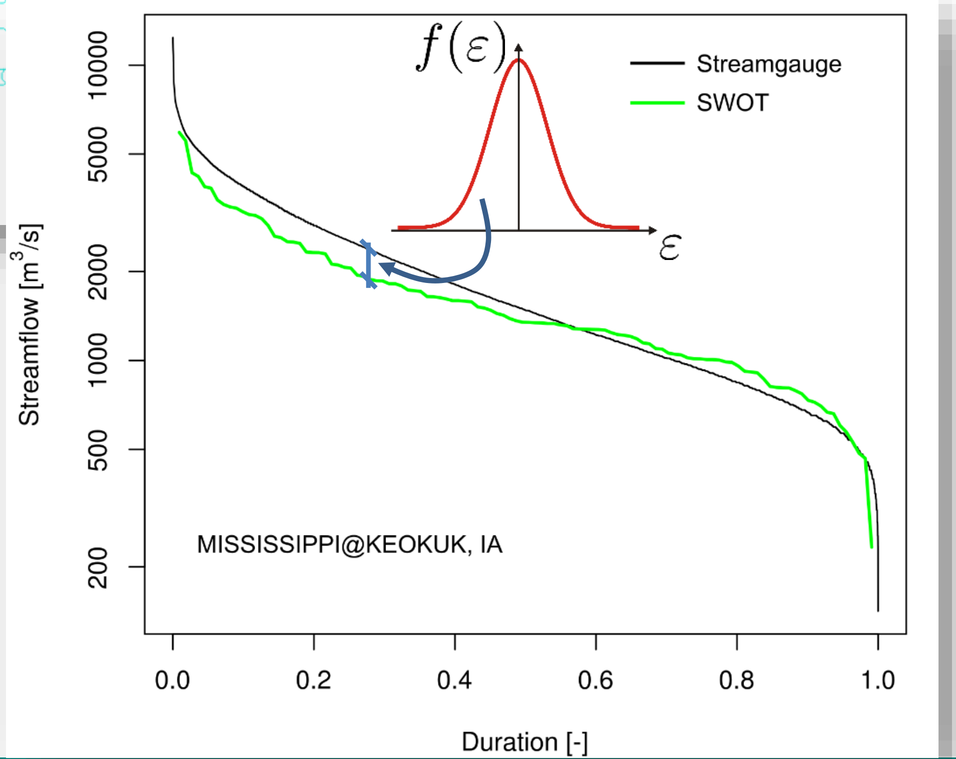
Random Error N(μ=0, σ= 30%)

Methodology: mimicking SWOT FDCs

2) SWOT measurement error

$$Q_{SWOT} = Q_{gauge}\,(1+\varepsilon)$$



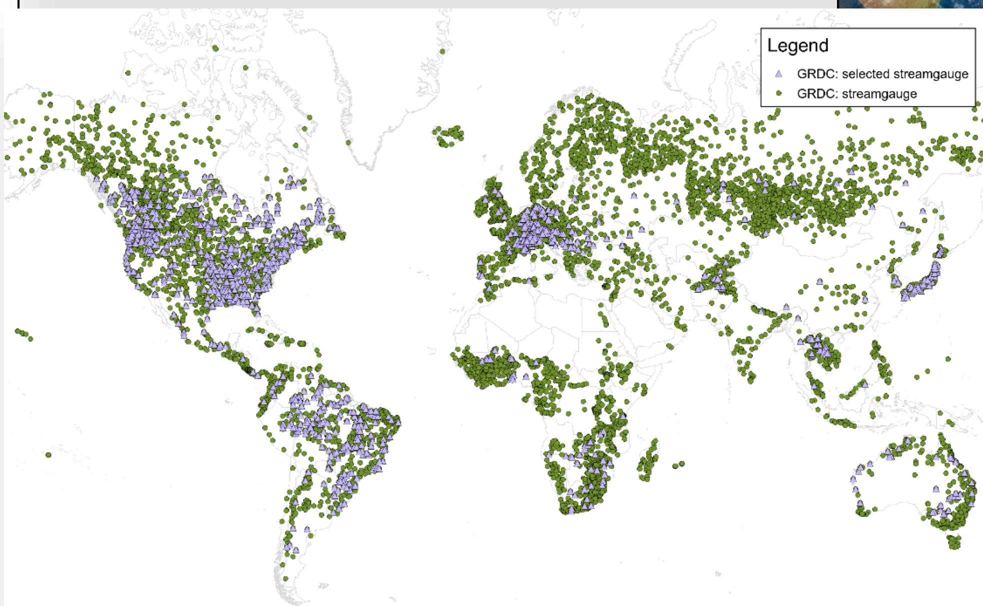


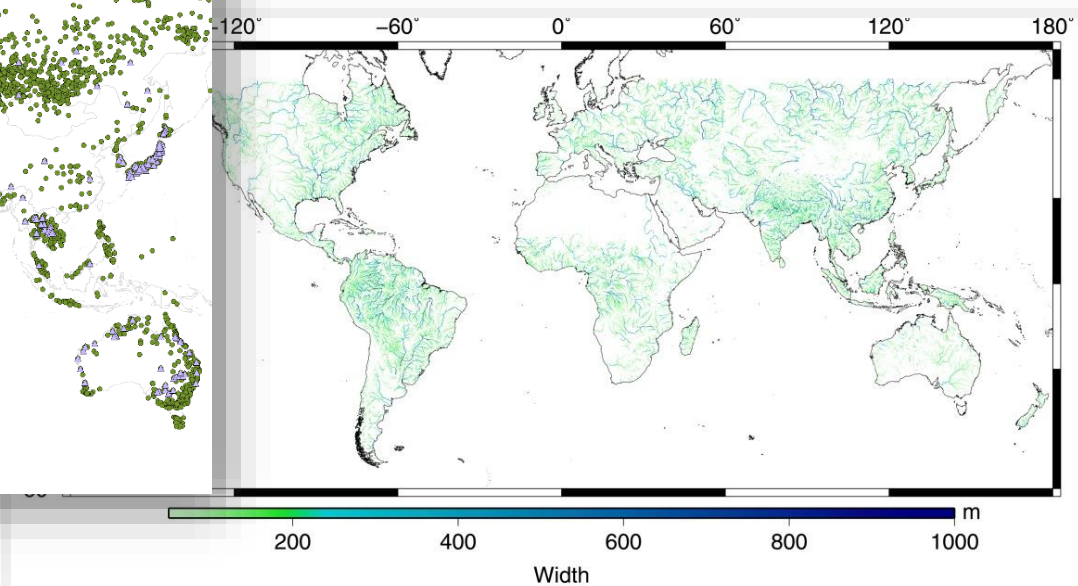
Data

HYDROLOGICAL DATA

Global Runoff Data Center (GRDC)
http://www.bafg.de/GRDC/EN/Home/homepage_node.html

A simple global river bankfull width and depth database
(Andreadis et al., 2013, WRR)





Andreadis, K.M., Schumann, G.P., Pavelsky, T.M., 2013. A simple global river bankfull width and depth database. Water Resour. Res. 49 (10), 7164–7168. http://dx.doi.org/10.1002/wrcr.20440.

Data

HYDROLOGICAL DATA

Global Runoff Data Center (GRDC)
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A simple global river bankfull width and depth database
(Andreadis et al., 2013, WRR)

- Filter 1: river width $\geq$ 100 m
- Filter 2: minimum streamflow series length = 10 yrs.
- Filter 3: up to 3 consecutive days gap is interpolated linearly

=

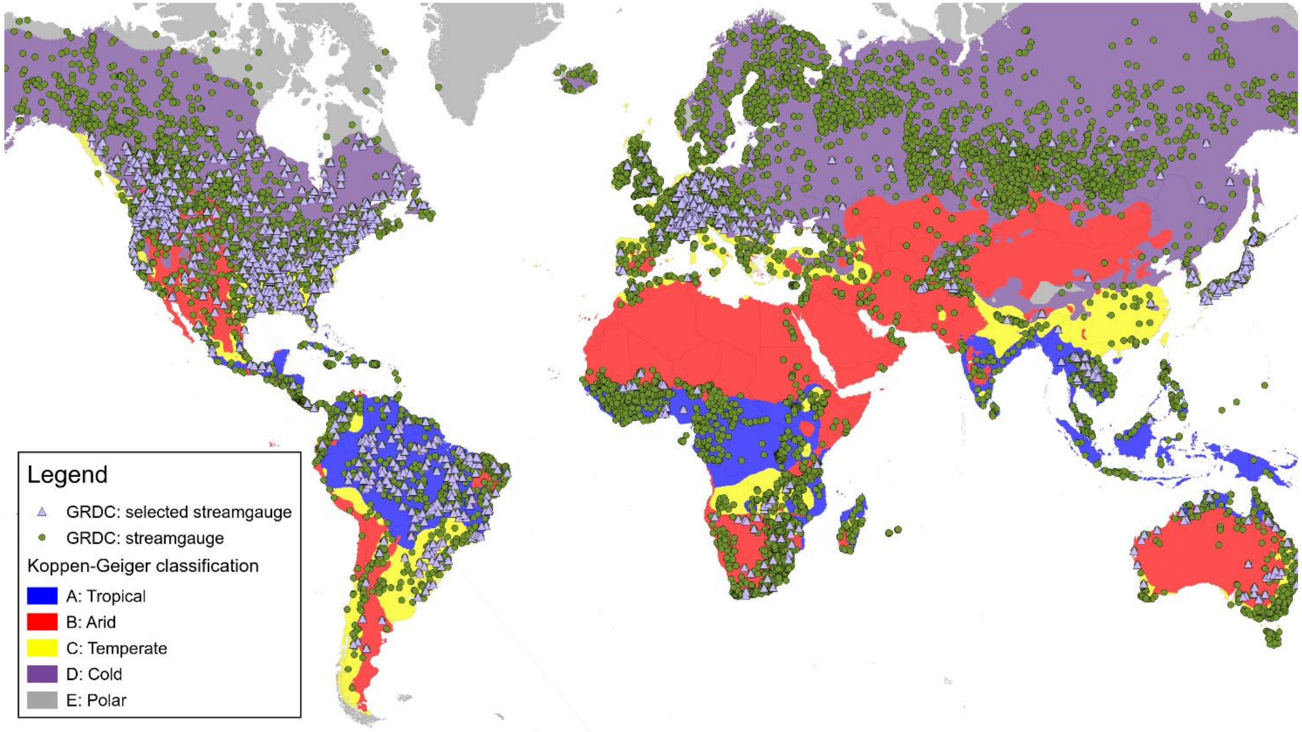
1200 streamgauges

Andreadis, K.M., Schumann, G.P., Pavelsky, T.M., 2013. A simple global river bankfull width and depth database. Water Resour. Res. 49 (10), 7164–7168. http://dx.doi.org/10.1002/wrcr.20440.

Data

GLOBAL CLIMATE CLASSIFICATION

(Peel et al., 2007)



Köppen-Geiger classification

No. of GRDC stations:

Tropical	A	169
Arid	B	74
Temperate	C	225
Cold	D	368
Polar	E	7

M. C. Peel, B. L. Finlayson and T. A. McMahon (2007). «Updated world map of the Köppen-Geiger climate classification». In: Hydrol. Earth Syst. Sci., 11, pp. 1633–1644. url: http://www.hydrol-earth-syst-sci.net/11/1633/2007/

Results

For each site $j = 1, \ldots, 1200$

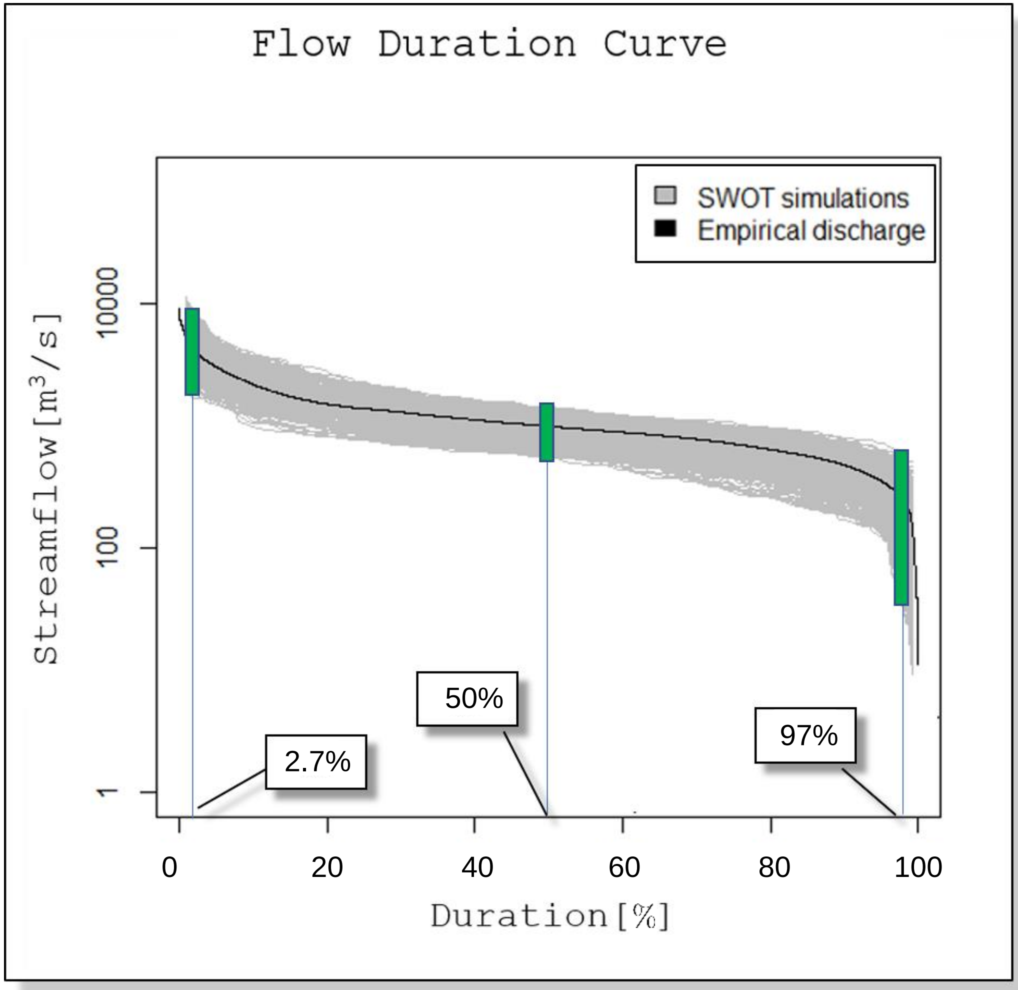
$$NSE = 1 - \frac{\sum_{i=1}^{n}\left(Q_{SWOT,i} - Q_{emp,i}\right)^2}{\sum_{i=1}^{n}\left(Q_{emp,i} - \mu_{emp}\right)^2}$$

$$MRE = \frac{1}{n}\sum_{i}^{n}\frac{Q_{SWOT,i} - Q_{emp}}{Q_{emp}}$$

$d_{2.7\%} = Q_{10}$ High flows

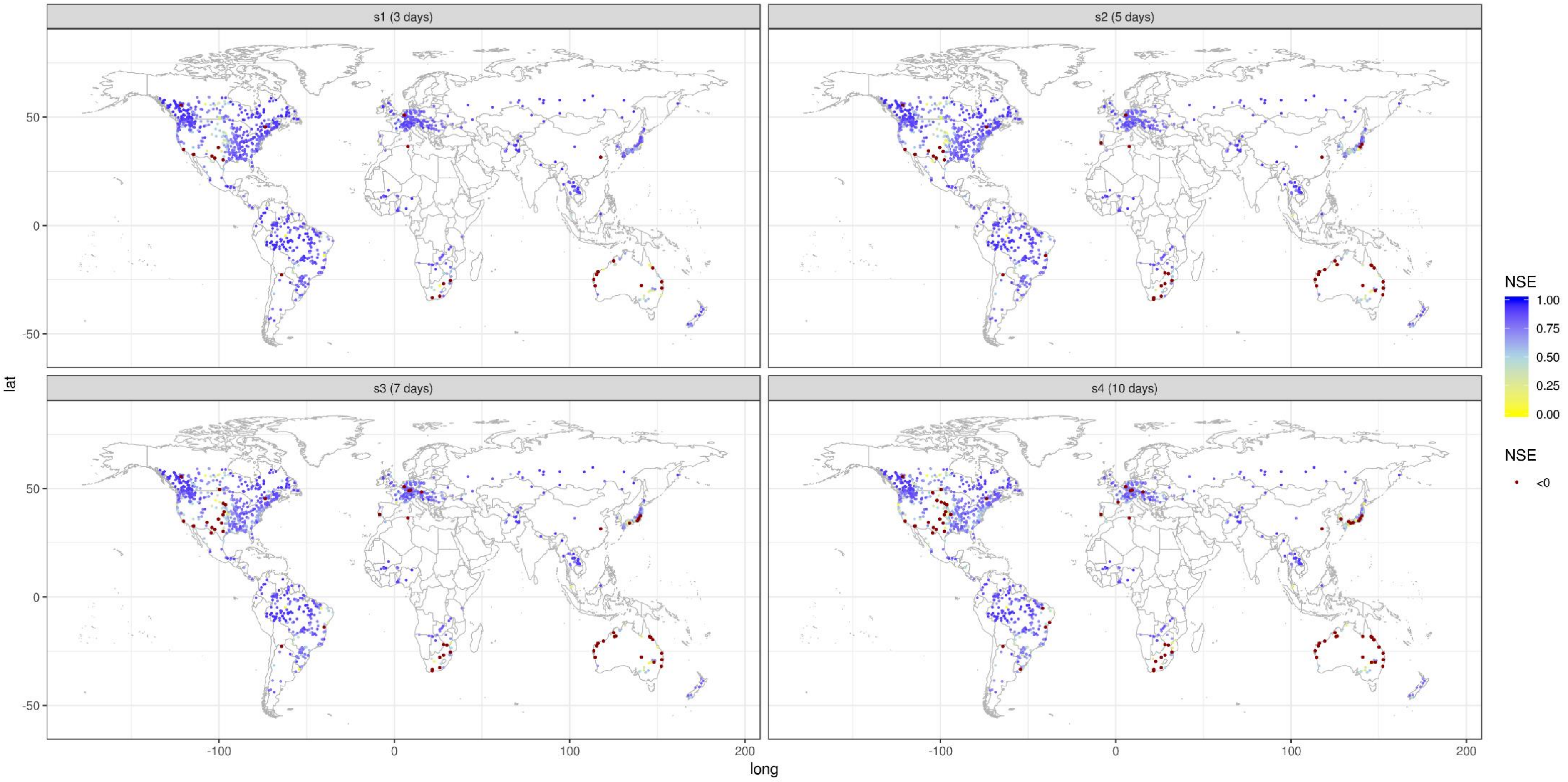
$d_{50\%} = Q_{median}$ Median flows

$d_{97\%} = Q_{355}$ Low flows

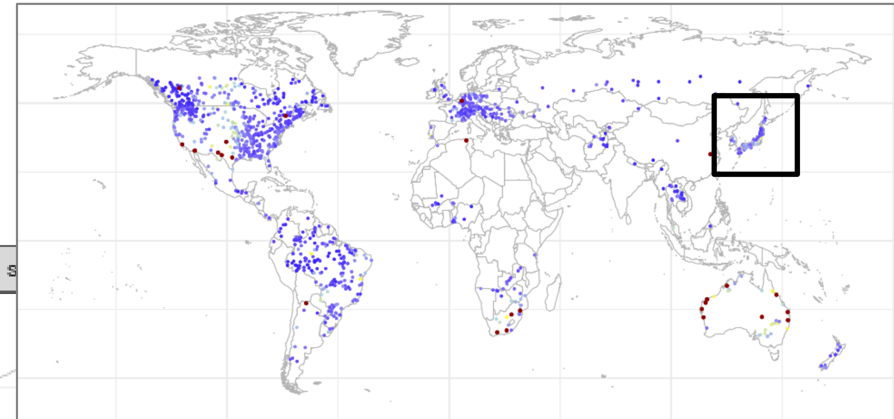


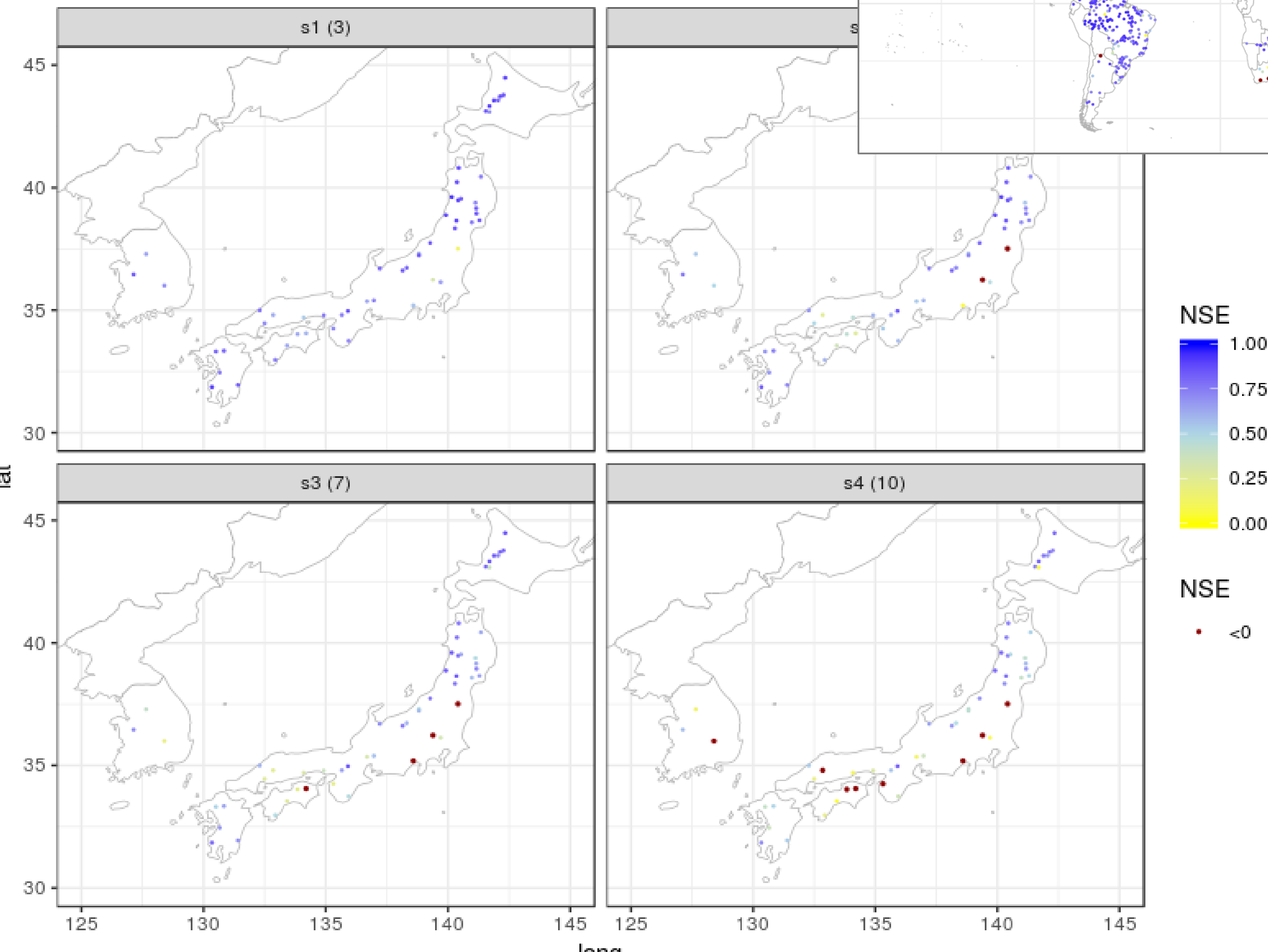
Results

NSE – Global overview

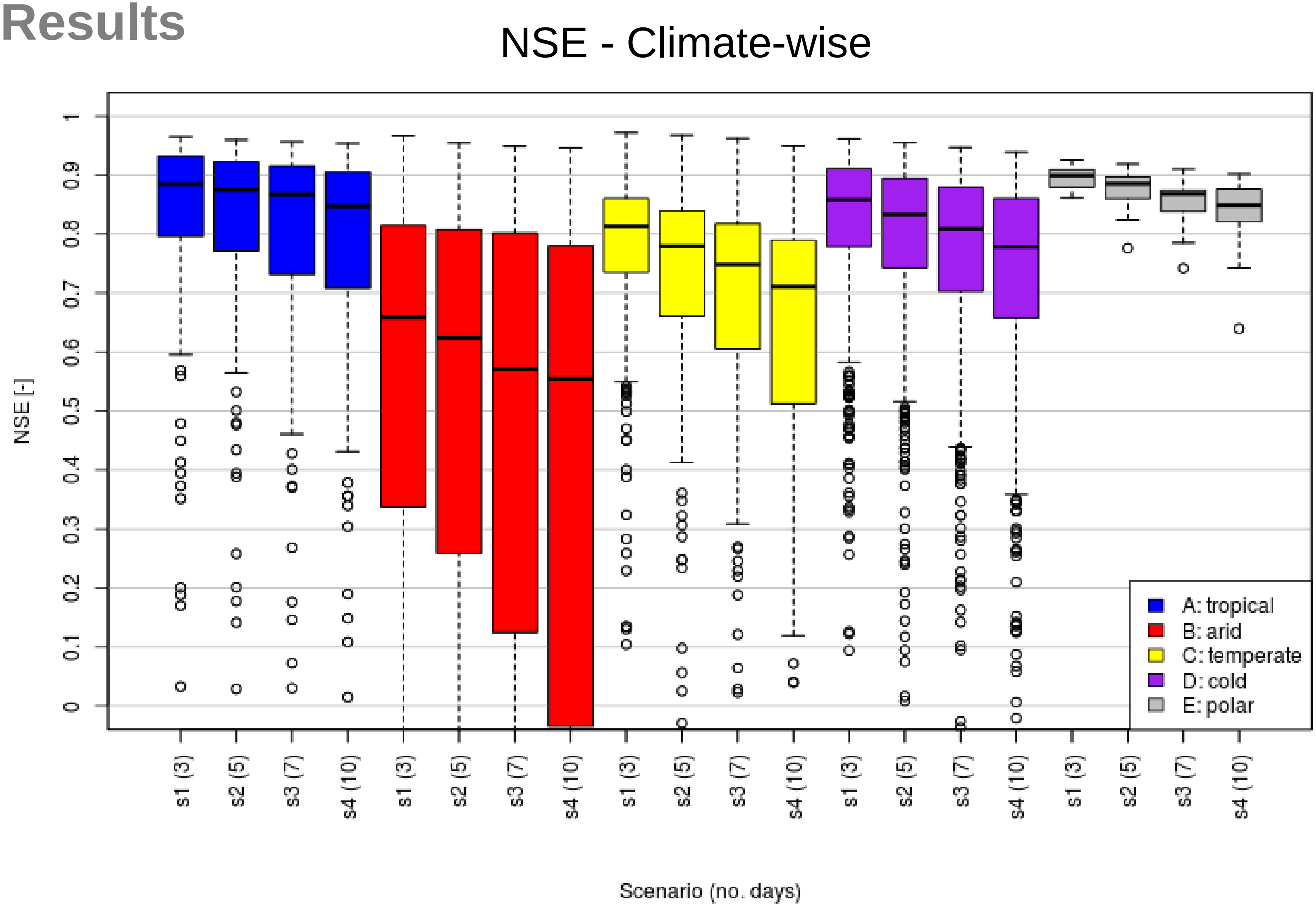


Results




s1 (3)
s3 (7)
s4 (10)
45
40
35
30
125
130
135
140
145
NSE
1.00
0.75
0.50
0.25
0.00
NSE
<0

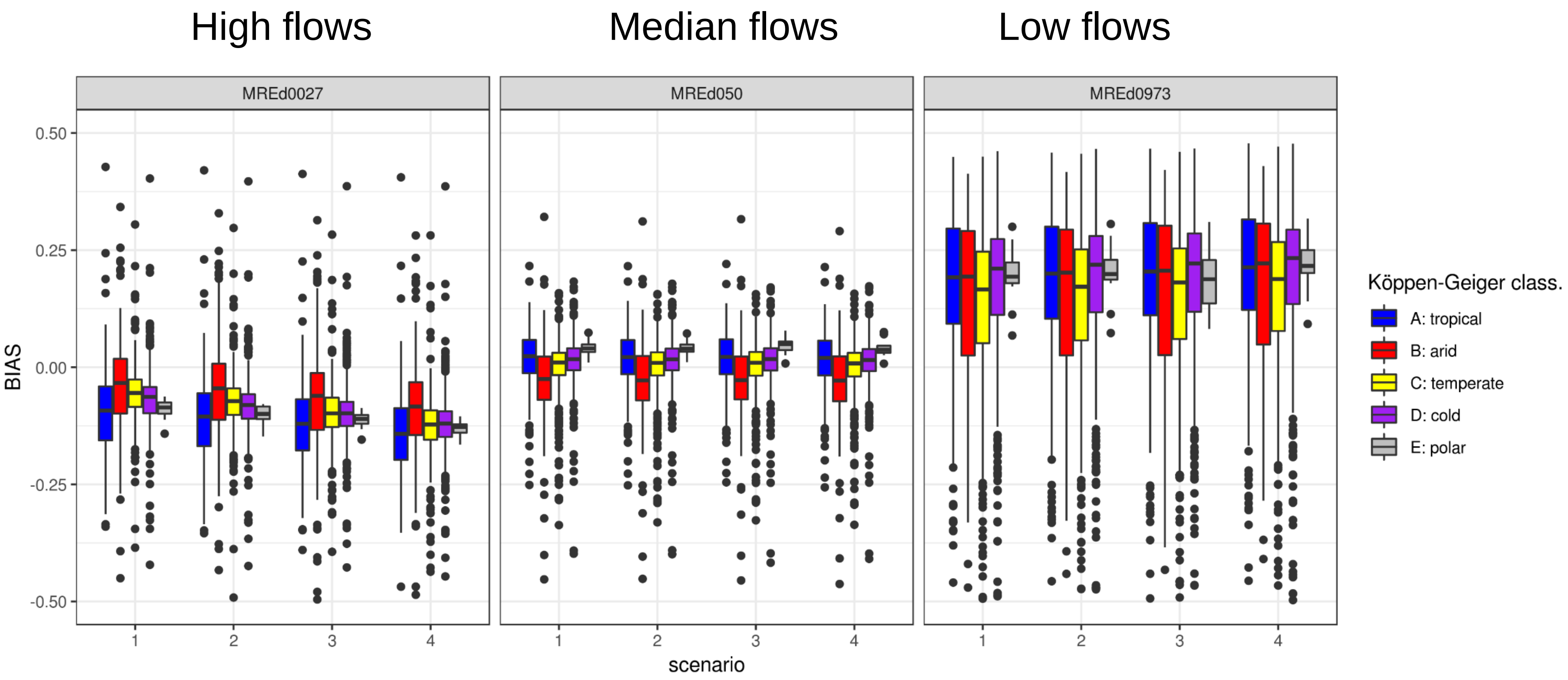
Results



Es: *s1 (3)* indicates scenario 1, with one SWOT observation every 3 days within the satellite revisit period (21 days)

Results

MRE - Duration-wise



Results

- Progressive detriment of SWOT capabilities to produce reliable FDCs as the time interval k increases (from s1 to s4). Trends depend on climatic conditions.
- Arid climate presents the highest relative errors. Tropical climate present best results.
- Duration-wise, we observe a general tendency of SWOT-based FDCs to underestimate high flows and overestimate low flows, in all macro-climatic conditions and sampling rates.
- Median flows tend to be the best “observable”, regardless the climate.
- As expected, temperate and cold climates have the lowest errors for median streamflow regimes – narrower curves in the median range of durations

Final remarks

1. SWOT-derived FDCs can be used as an alternative to gauge-derived FDCs to compensate the lack of streamflow records in ungauged basins, though different accuracy have been found in different climatic conditions;

2. Indeed, FDCs could be used “as is” in temperate and cold regions, whereas in arid and tropical areas higher uncertainty must be taken into account, especially in the low flow regimes;

3. LIMITS: this preliminary study do not include (yet) a specific random error generator for different duration ranges, but future work will.

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Alessio Domeneghetti

DICAM – Department of Civil, Chemical, Environmental and Materials Engineering

alessio.domeneghetti@unibo.it

www.dicam.unibo.it