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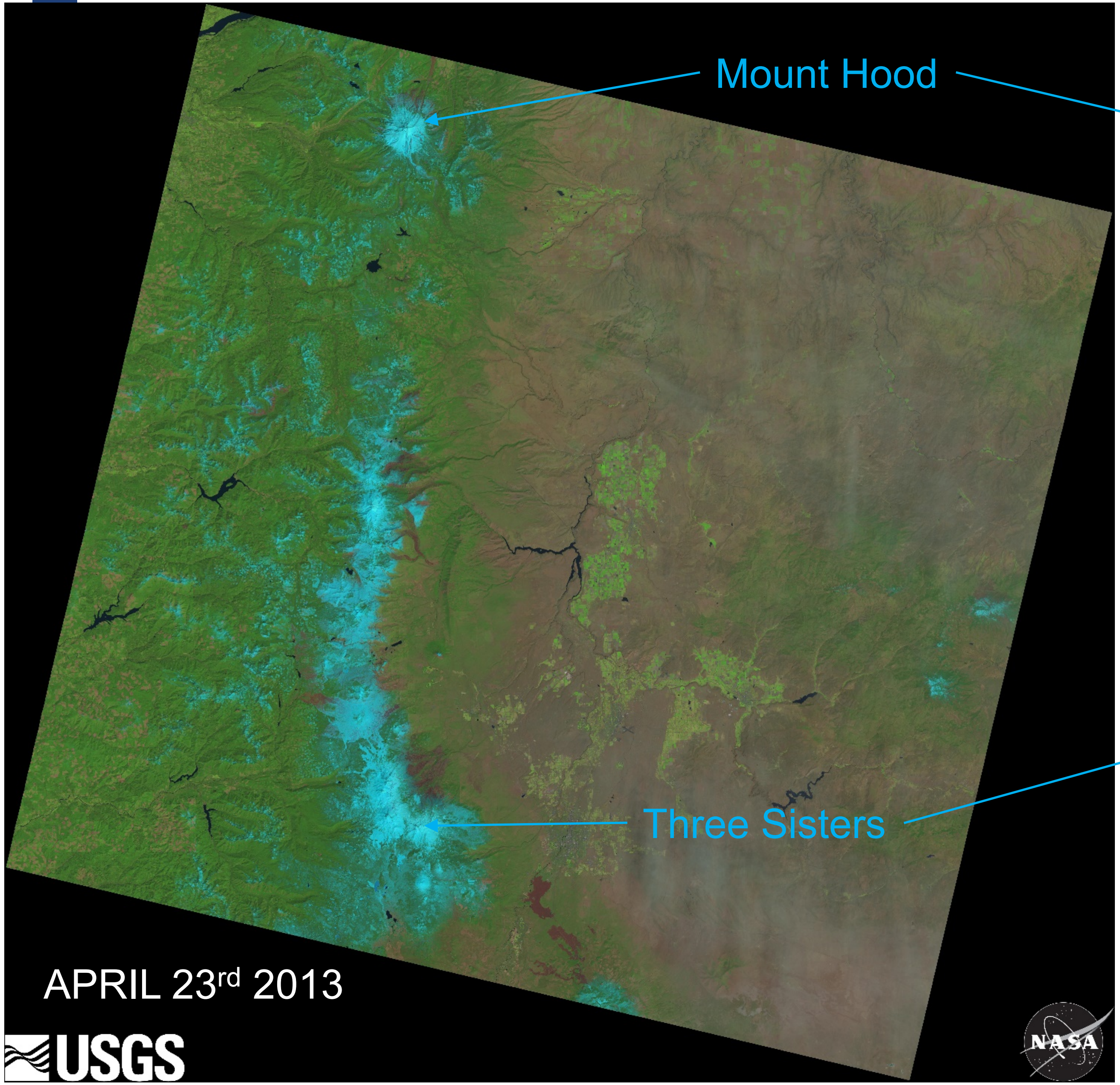
On the origin of low flow regimes in alpine systems

New insights from a year without snow in the Cascade Mountains of Oregon, USA

Clément Roques, Elizabeth Jachens, David Rupp, John Selker, Gordon Grant, Sarah Lewis, Cara Walter and Anne Nolin


Mount Hood
Three Sisters
APRIL 23rd 2013
USGS
NASA

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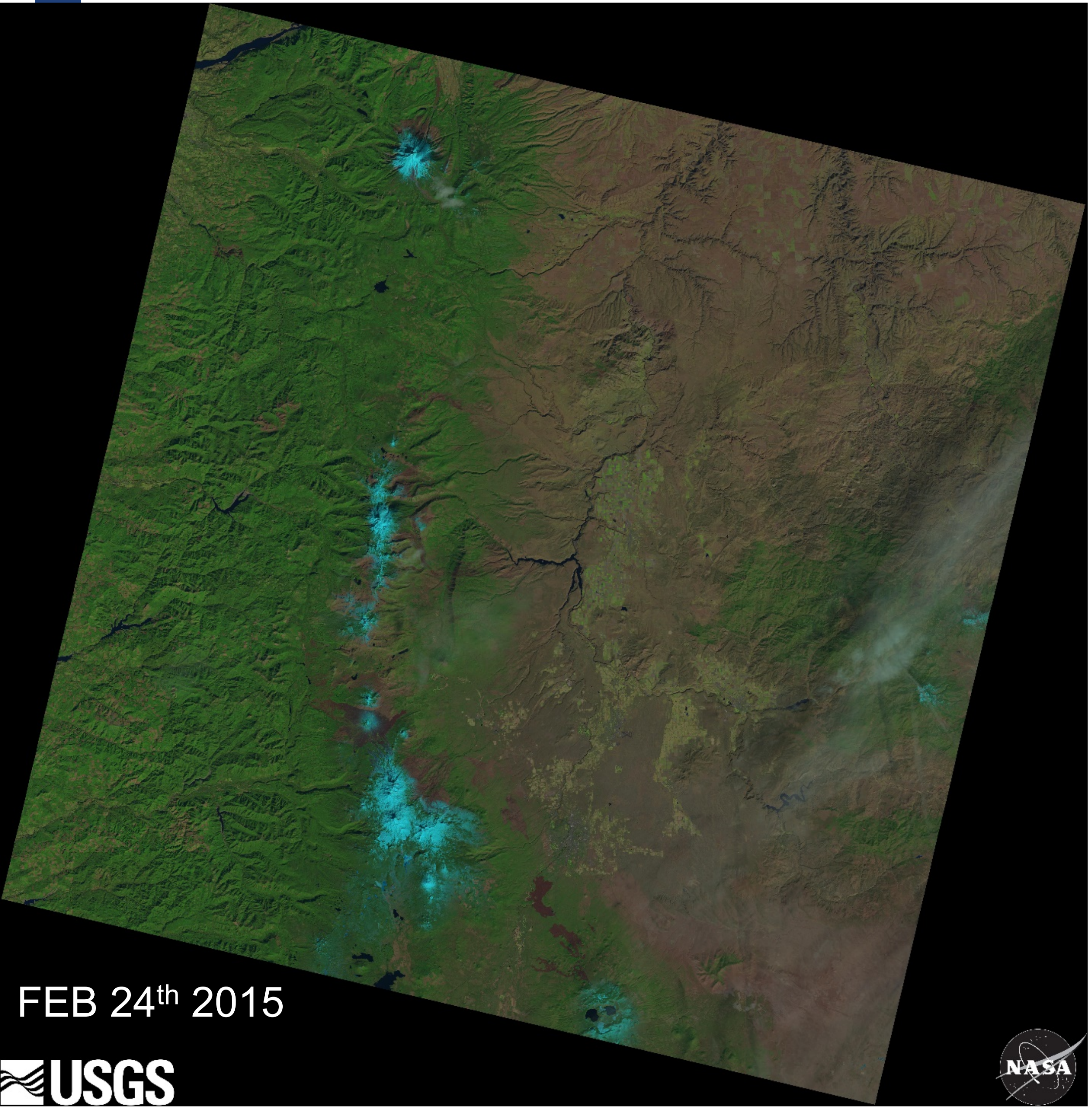
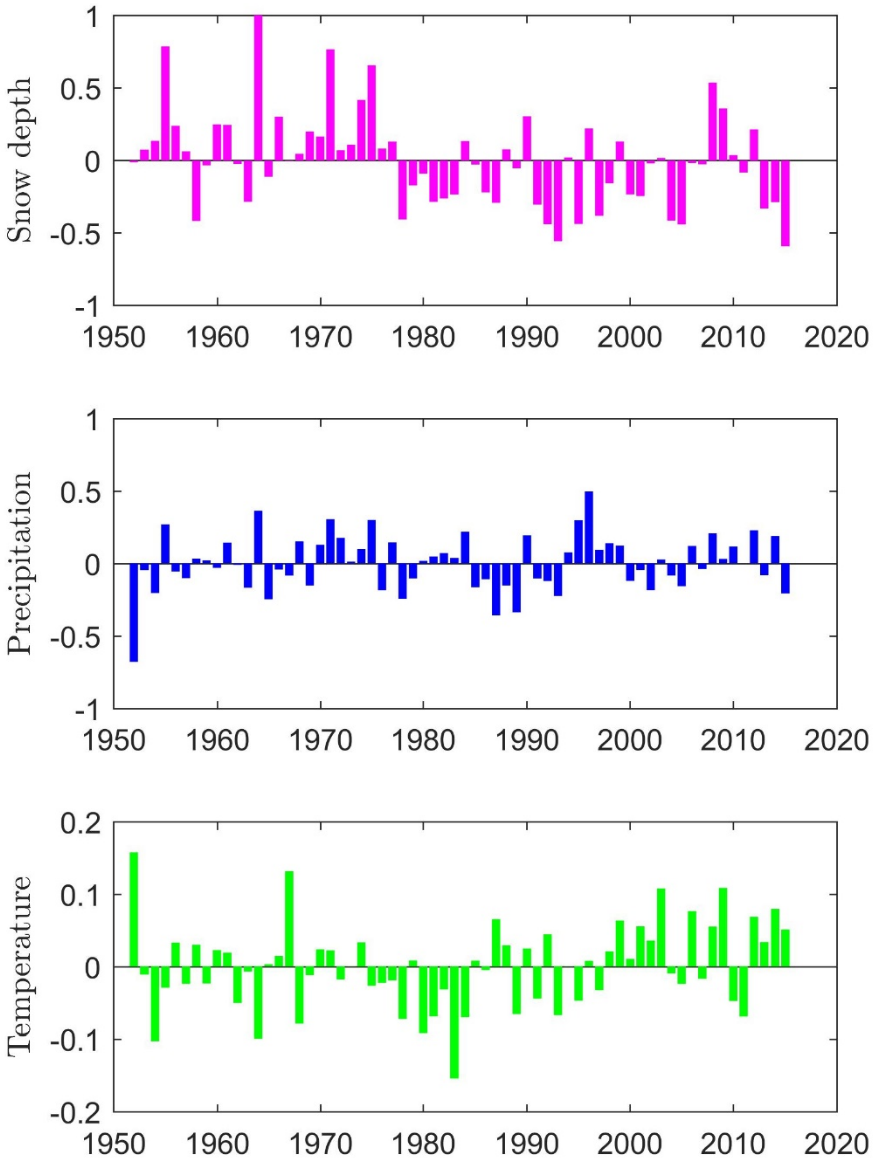
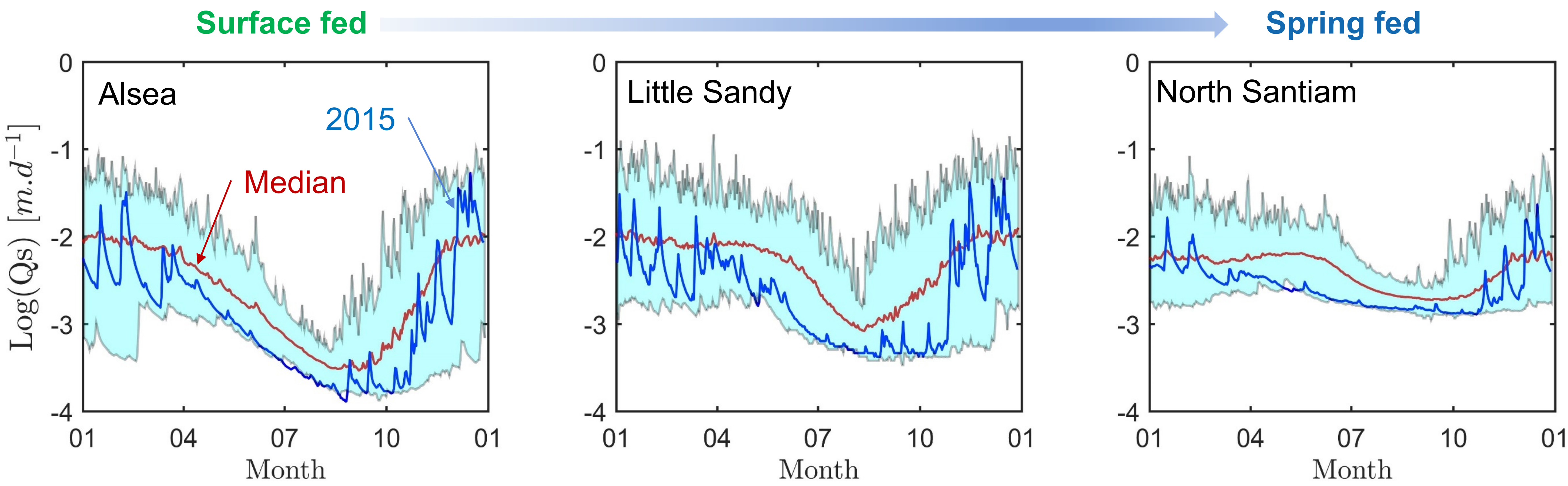
Climatic data, GHCN, Mount Hood





The Experiment of 2015 “Snow Drought” in the Oregon Cascades

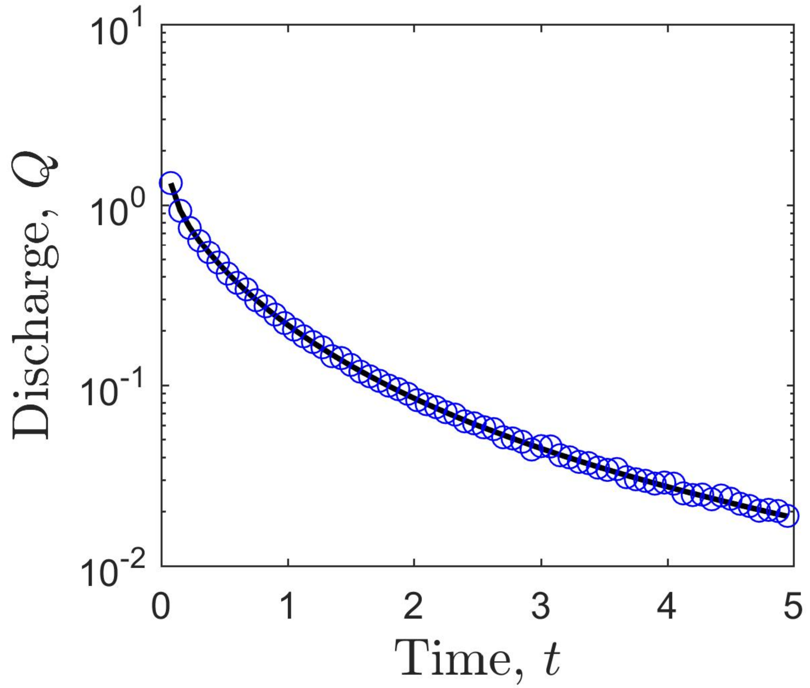
How low will it go?
Landscape *vs* drought flow regimes?

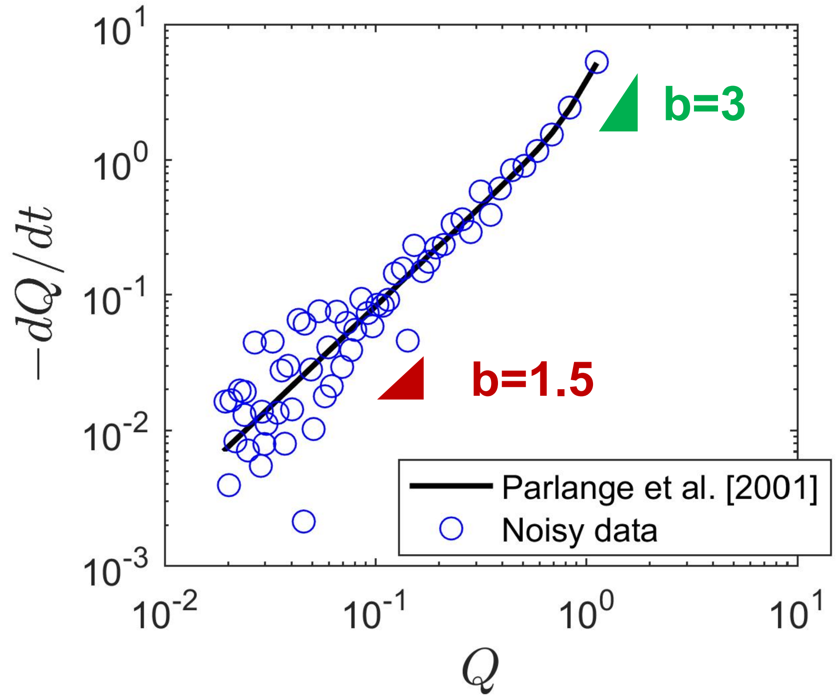


What do we know about drought flow?

- Recession analysis: which method for baseflow parameter estimation?
- Theory / Boussinesq flow?
- Timescale of a basin? What about the Brutsaert’s 45 days timescale?
- Competing factors:
  - landscape heterogeneity;
  - climate;
  - 3D flow;
  - geology;
  - …

Recession analysis: theory and challenges

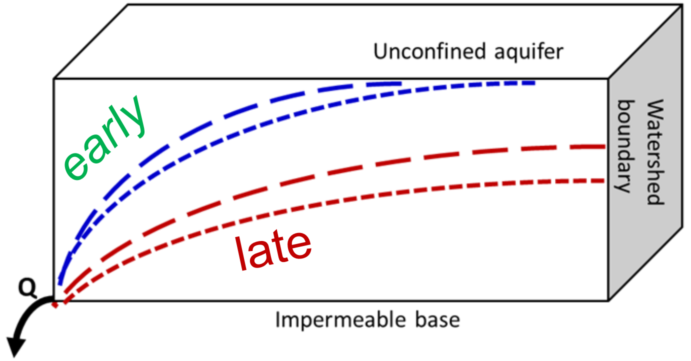




$$-\frac{dQ}{dt} = aQ^b$$

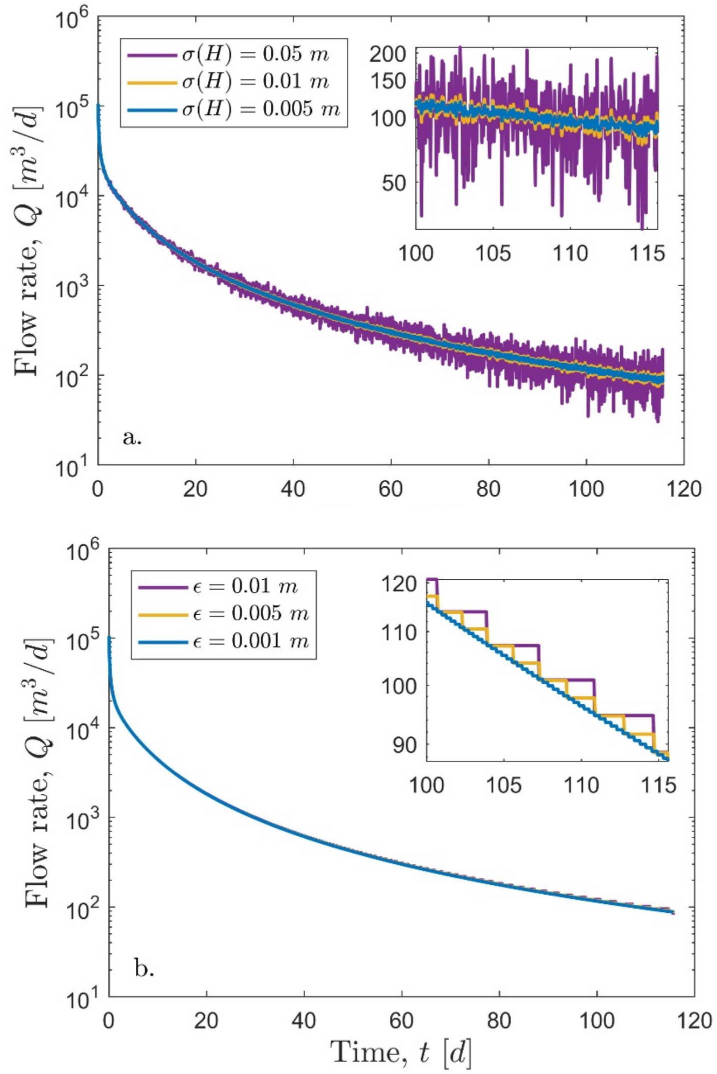
Early time: $a = \frac{1.133}{K\varphi D^3 L^2}$ and $b = 3$;

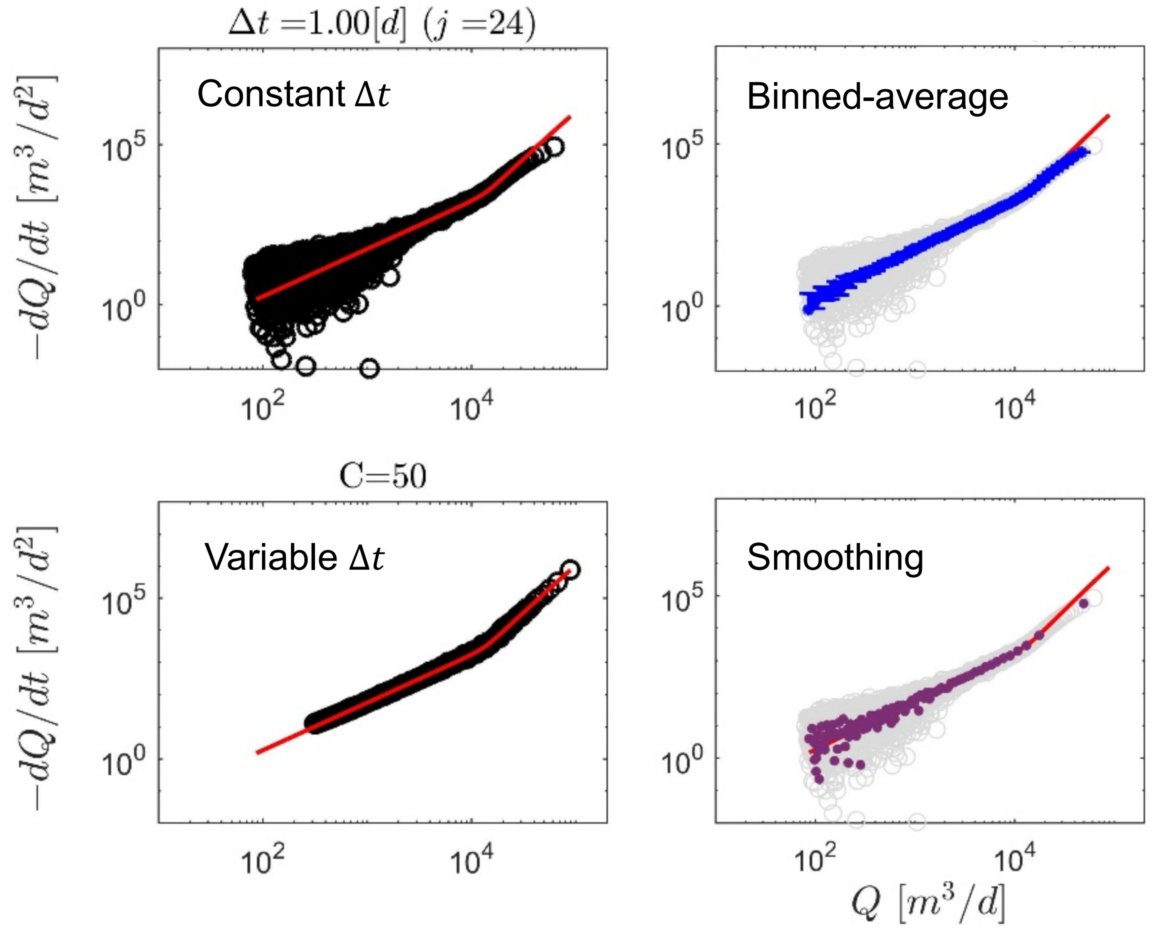
Late time: $a = \frac{4.804 K^{1/2} L}{\varphi A^{3/2}}$ and $b = 1.5$;



[Boussinesq, 1904]
[Polubarinova-Kochina,1962]
[Brutsaert and Niebert, 1997]
[Parlange et al. 2001]
[Rupp and Selker, 2006]
[Kirchner, 2009]
[Berghuijs et al., 2016]

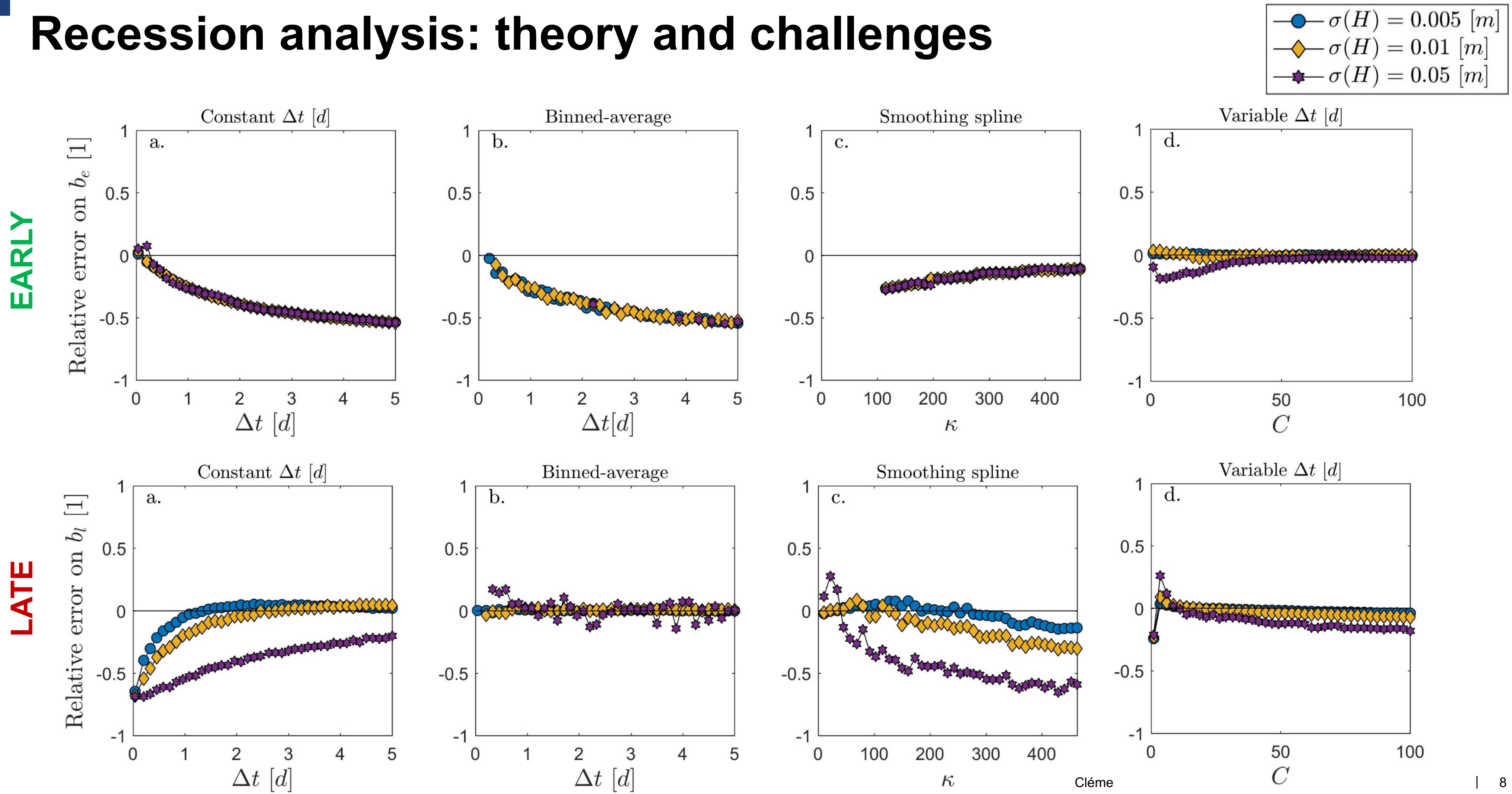
Recession analysis: theory and challenges



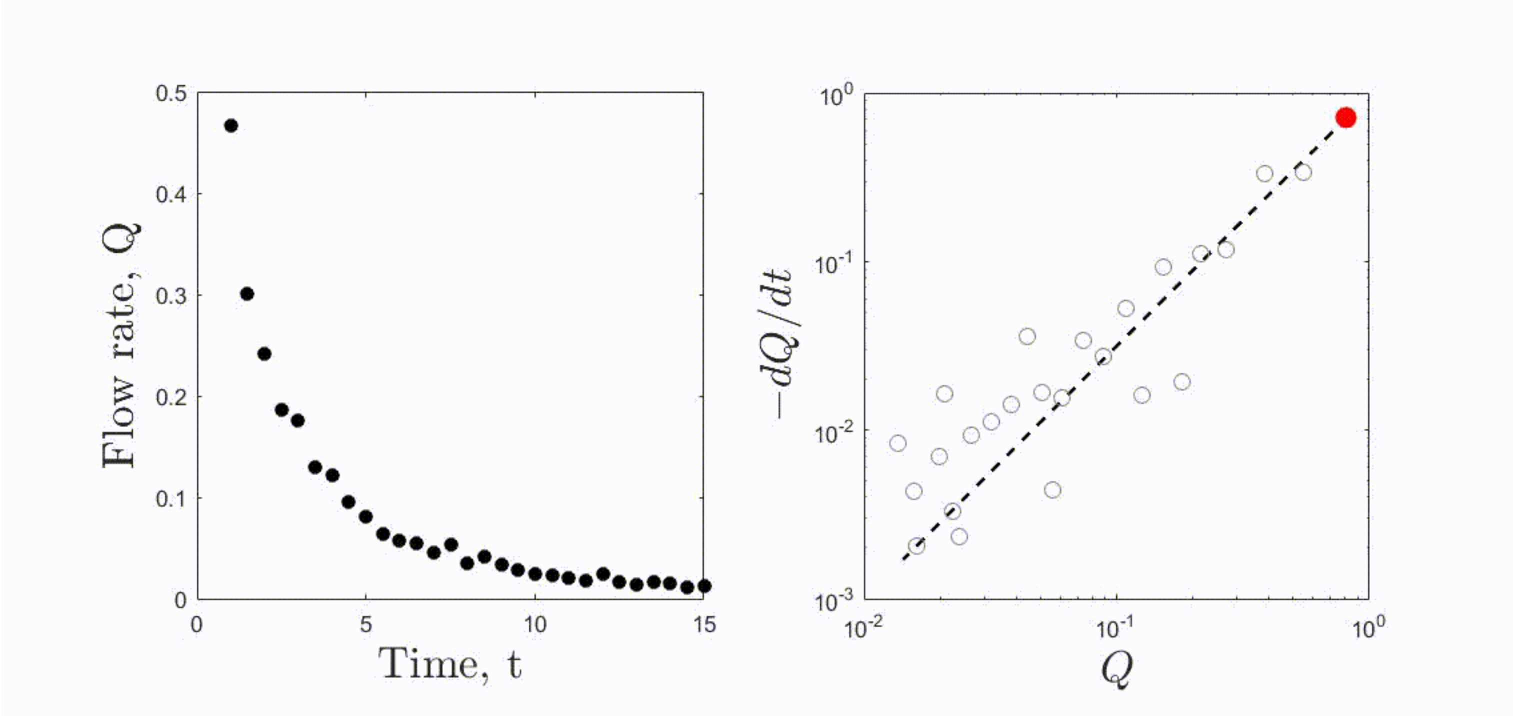


Roques et al., AWR, 2017

Recession analysis: theory and challenges



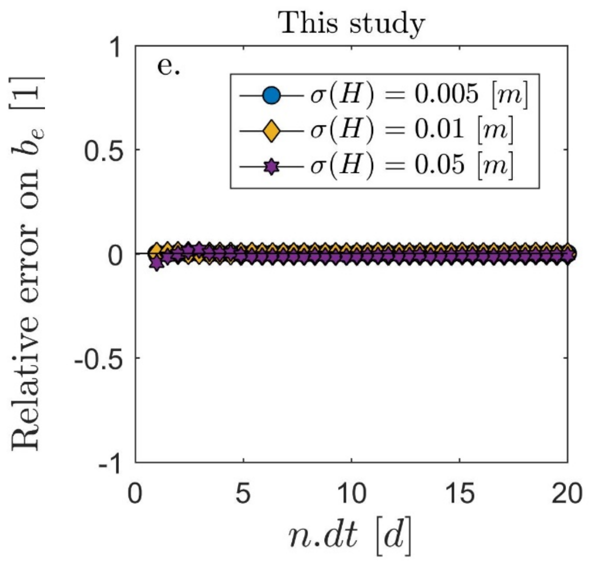
New improvements for recession analysis



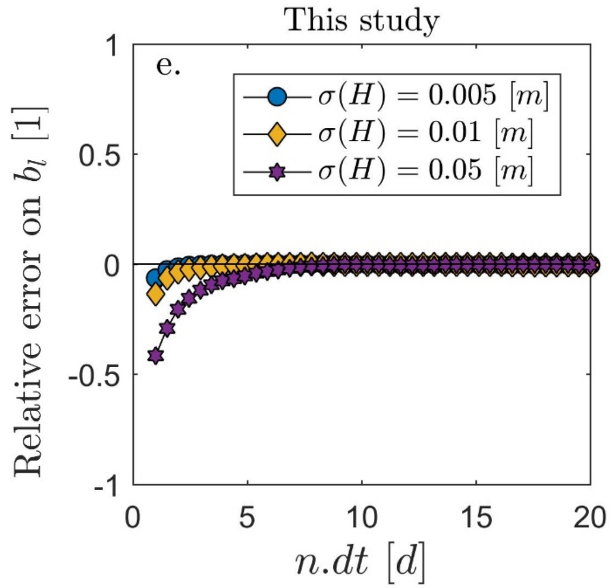
$$-\frac{dQ}{dt} = \frac{Q_i - Q_{i+m}}{t_{i+m} - t_i} = f(\bar{Q}) \qquad \boldsymbol{m(t) = 1 + \left\lfloor n\, e^{\left(-\frac{1}{\gamma t}\right)} \right\rfloor}$$

Derivative estimated using the local slope coefficient of a least-squares linear regression function over $[t_i, t_{i+m}]$;
Direct linear fitting and residual coefficient (R2) from the local linear fit as weight vector.

EARLY

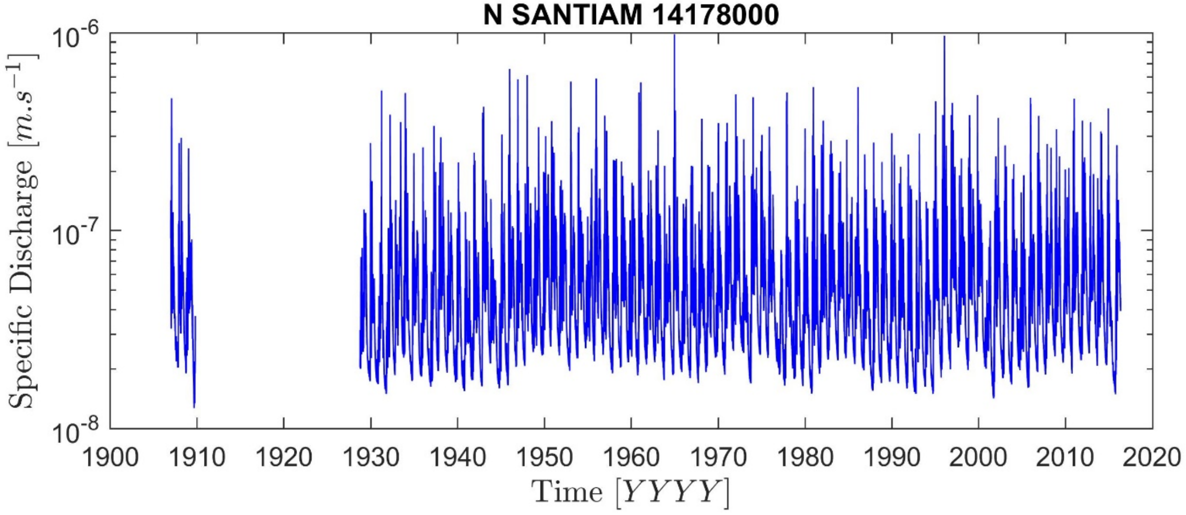


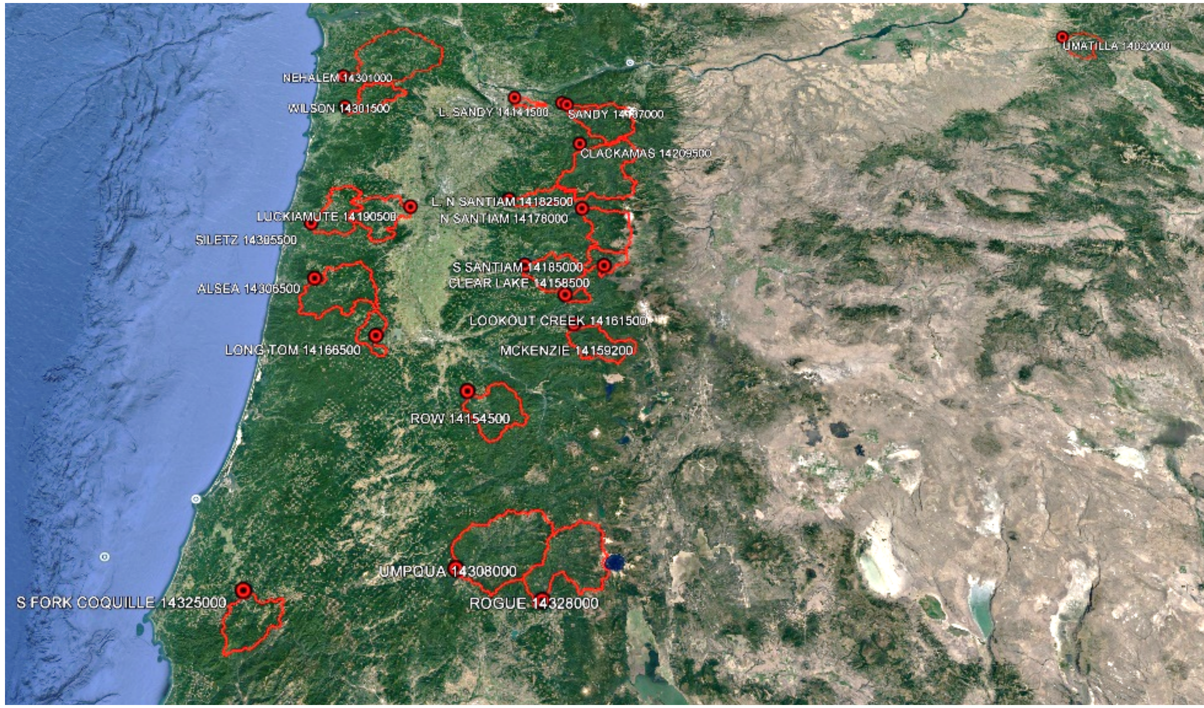
LATE



Roques et al., AWR, 2017

On the recession analysis of historical discharge data in Oregon Cascades (21 USGS stations)





Routine for selecting recessions:

- Minimum ΔQ threshold to define peak flow
- Beginning of the recession 3 days after peak flow
- Minimum of 30 days

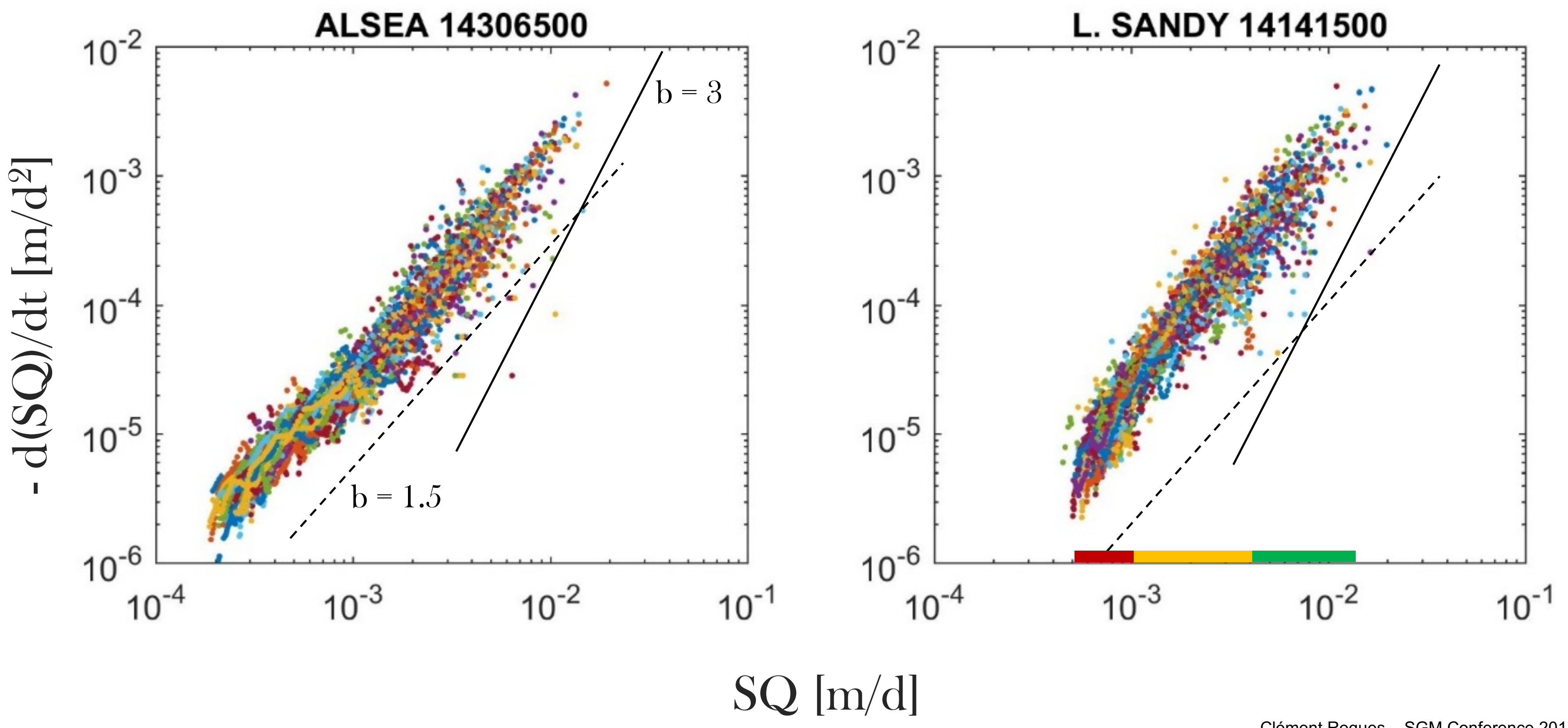
Recession analysis

Defining early-late times:

Early: $Q_{95}>Q_r>Q_{75}$

Middle: $Q_{60}>Q_r>Q_{40}$

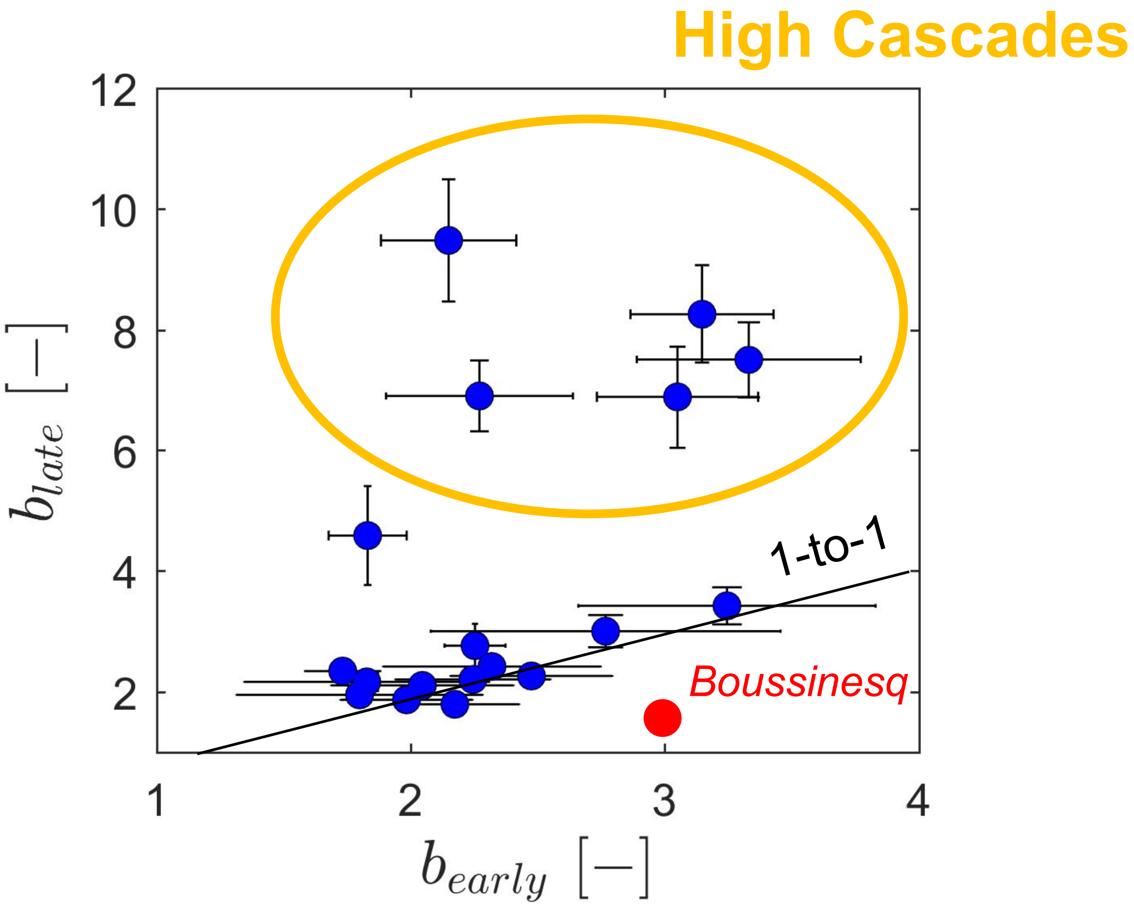
Late: $Q_{25}>Q_r>Q_{05}$



b early, mid, and late-recession:

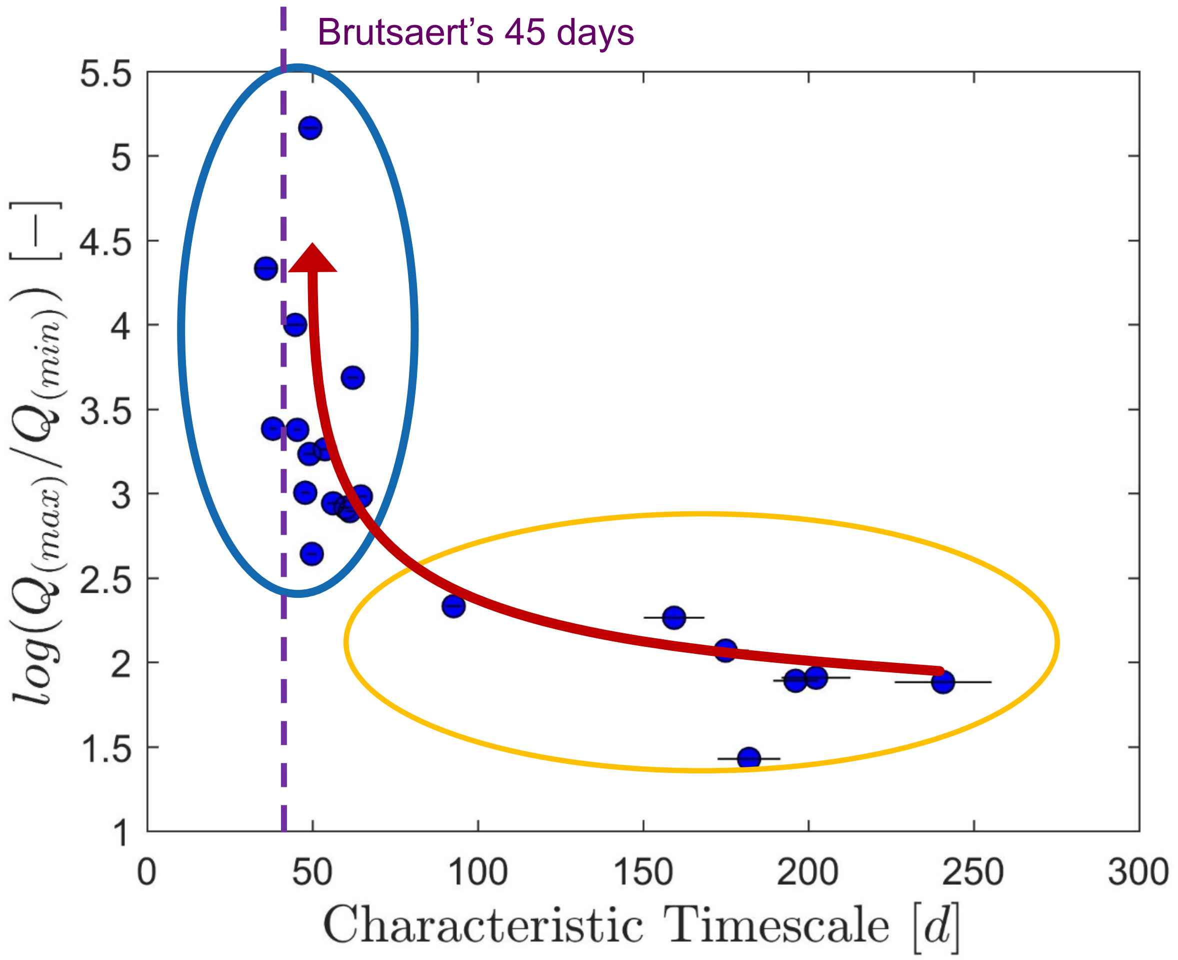
- High values of b in late flow
  not correlated with watershed area and drainage density

- Boussinesq doesn’t capture key features

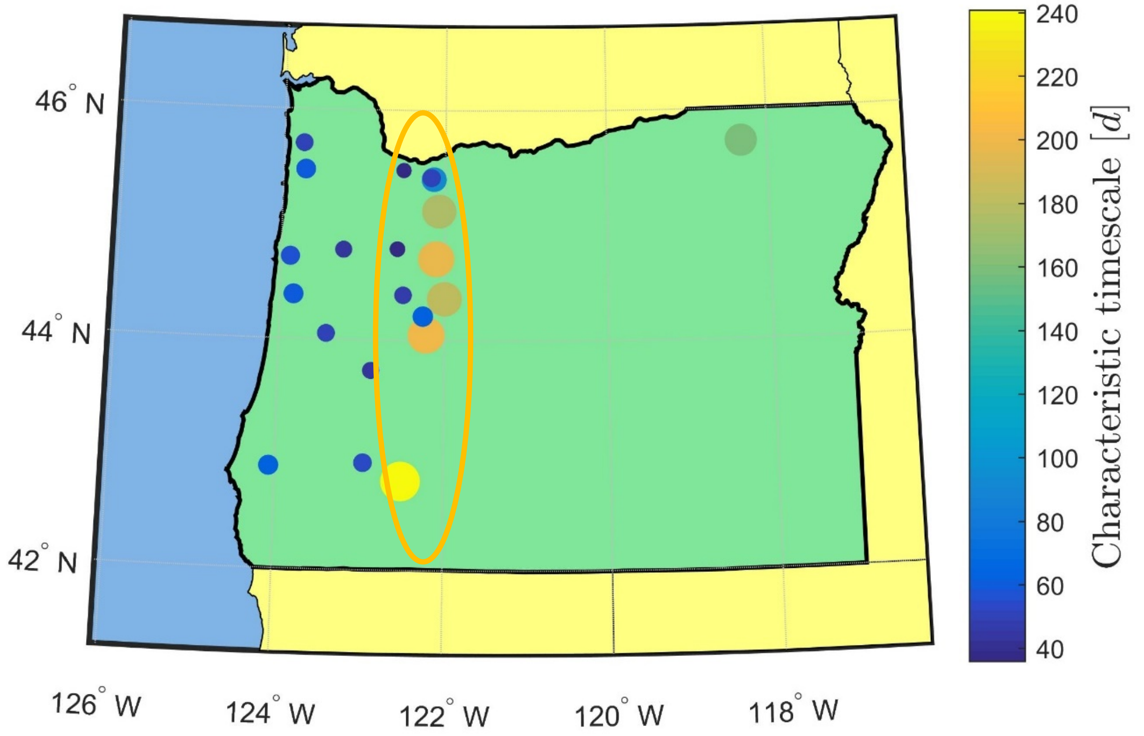


Watershed maturation

Old watersheds settle to 45 days



⇔ *storage half-life of a basin*



Areas with developed channel networks feel aquifer boundaries, low storage capacity - quickly drain local hillslopes

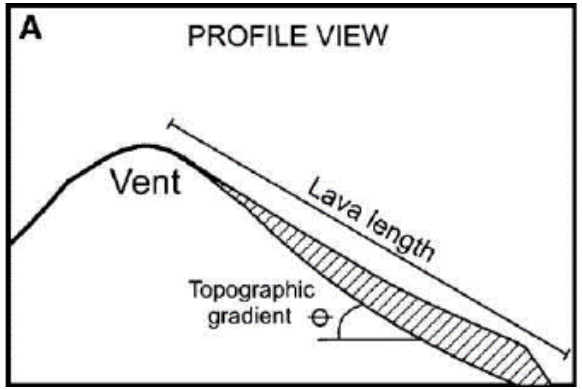
Un-dissected landscape doesn't feel aquifer boundaries – large storage capacity

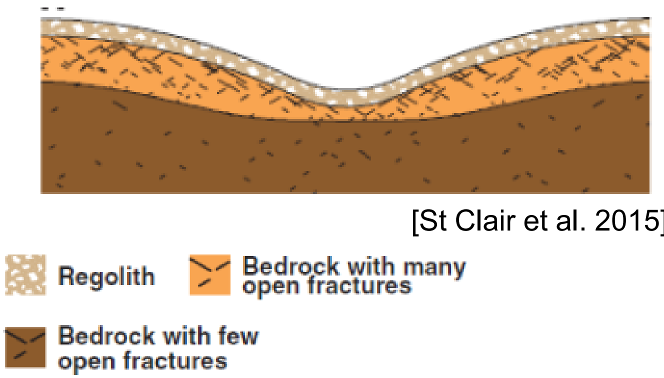
[Roques et al., in preparation]

Factors influencing baseflow recession

Geology/Geomorphology

Effect of vertical compartmentalization

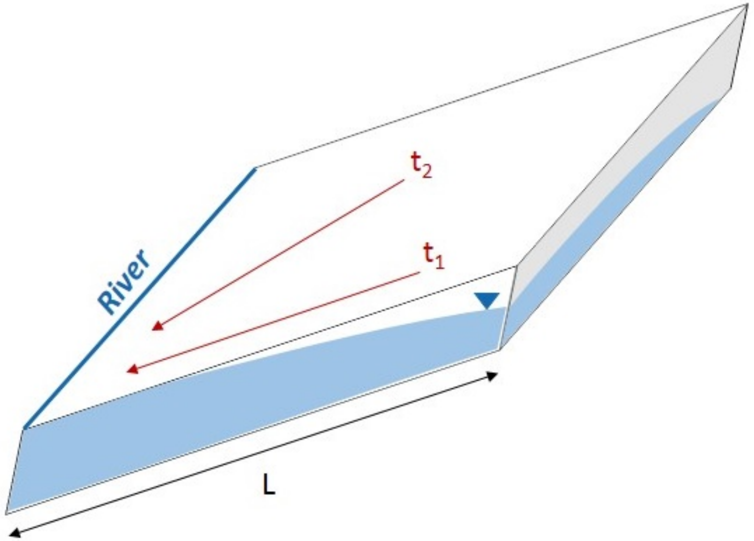


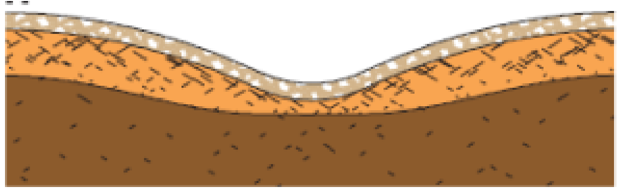


[St Clair et al. 2015]

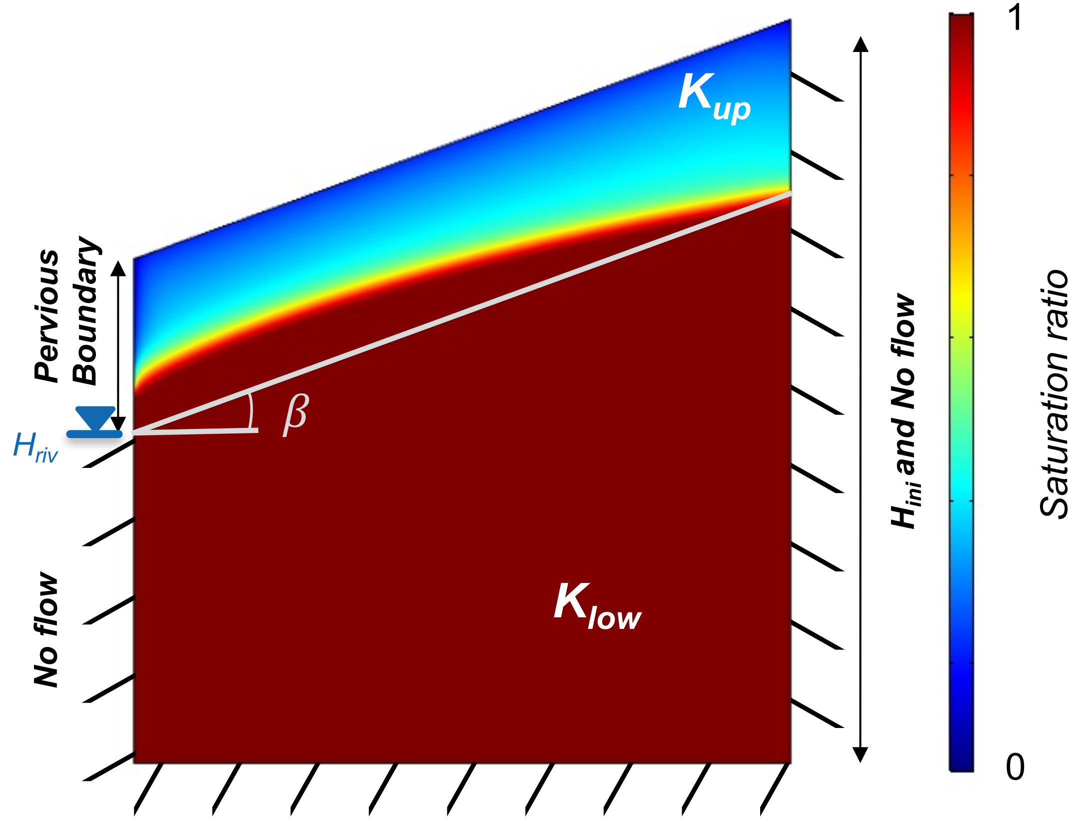
Hydrology

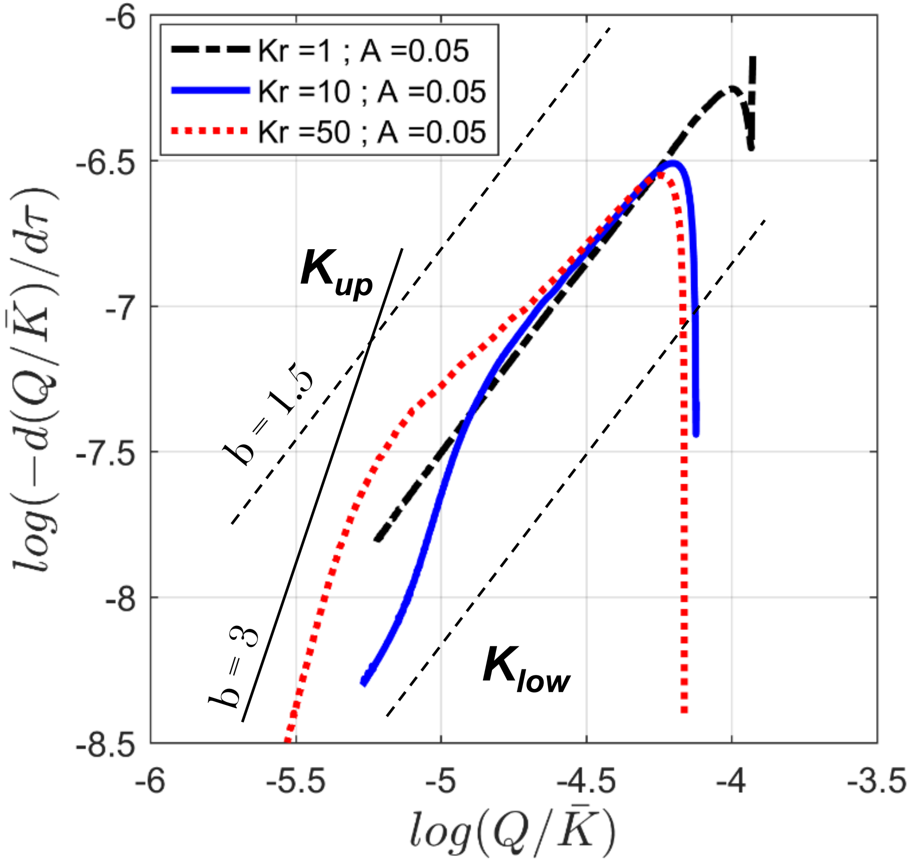
Effect of flow rotation





Effect of vertical compartmentalization on baseflow recession

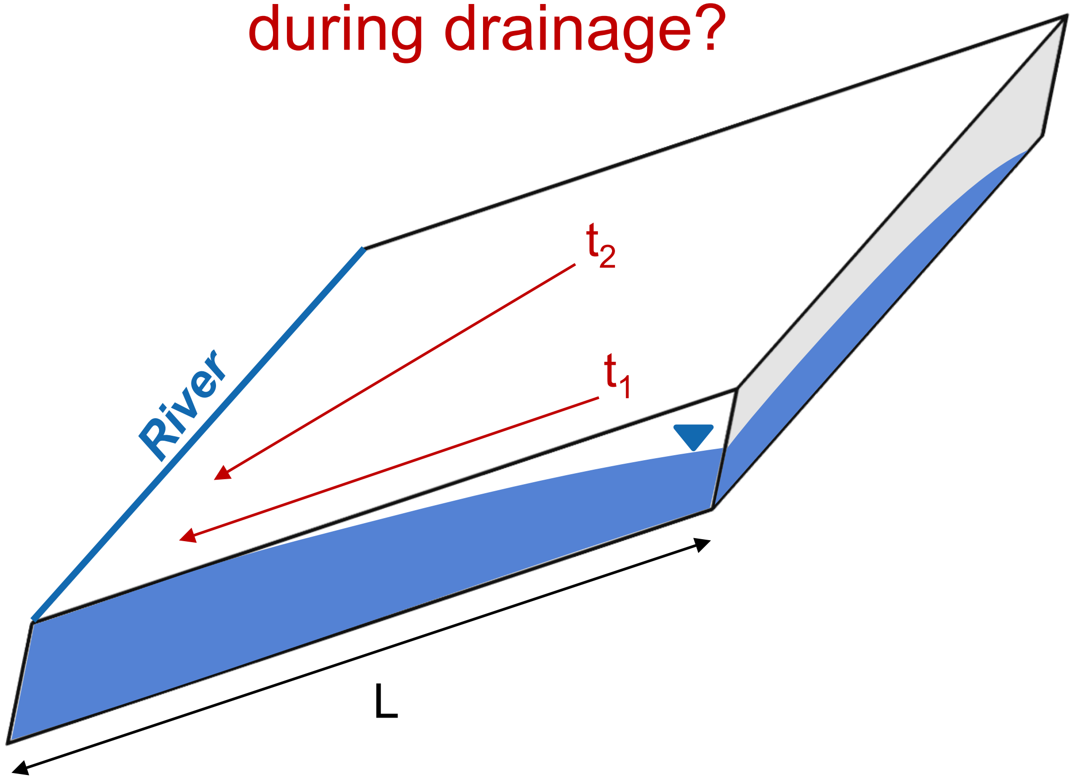


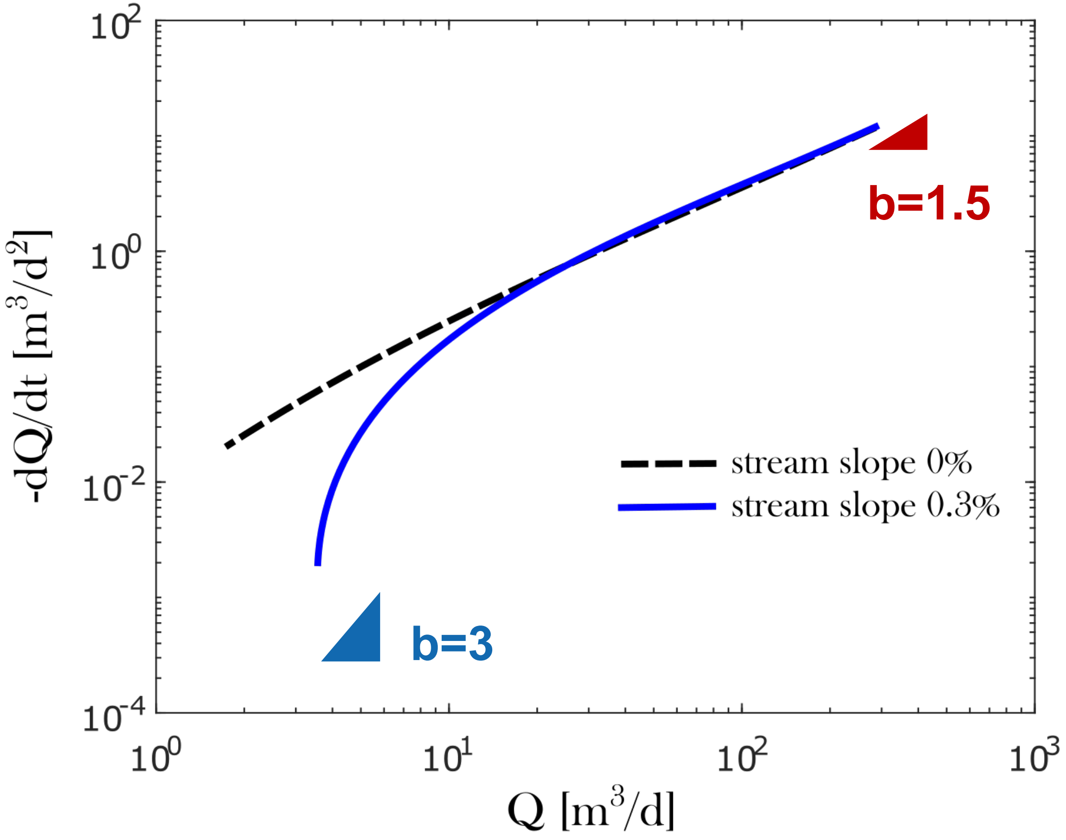


$$K_{low}(x,z) = K_{up}\exp(A(z_{(x)} - Z_s))\ ;\ K_{up}/K_{low,(z=river)} = K_r$$

$$\emptyset_{low}(x,z) = \emptyset_{up}\exp\left(A/n\,(z_{(x)} - Z_s)\right)$$

Effect of flow rotation on baseflow recession





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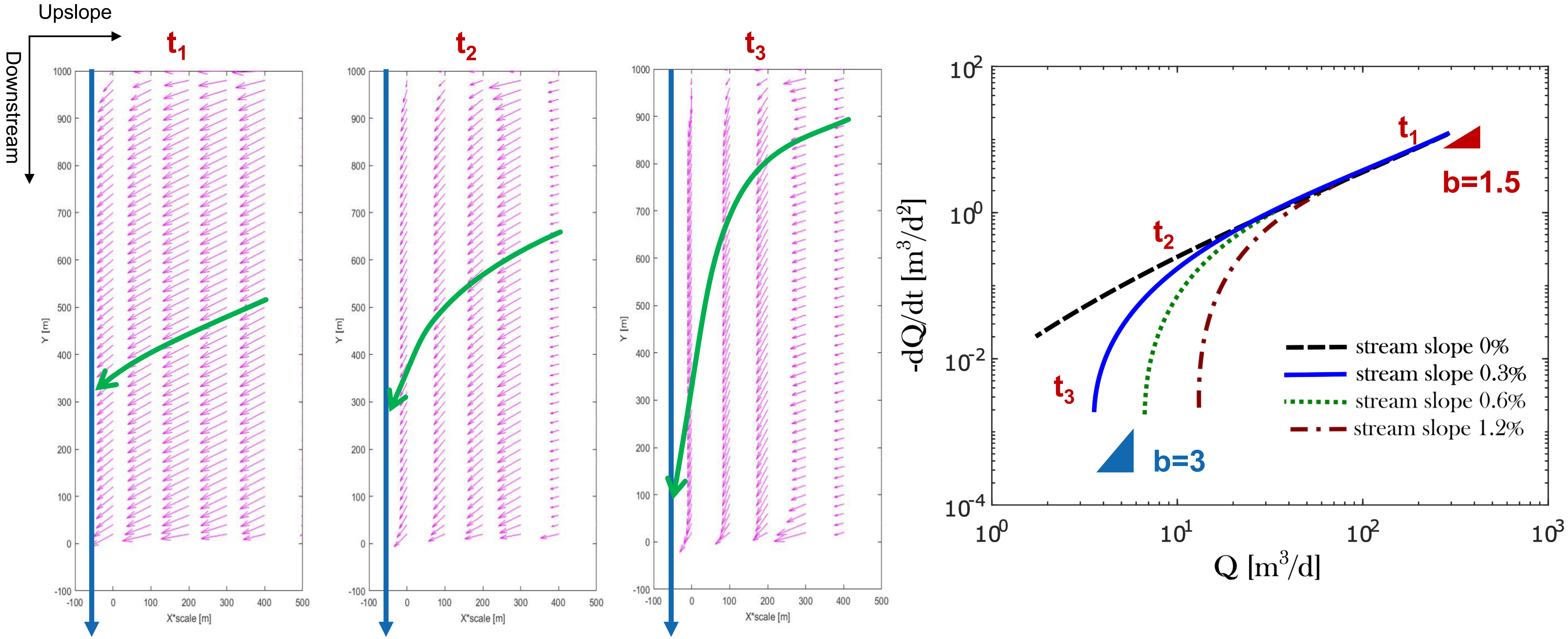
Effect of flow rotation on baseflow recession

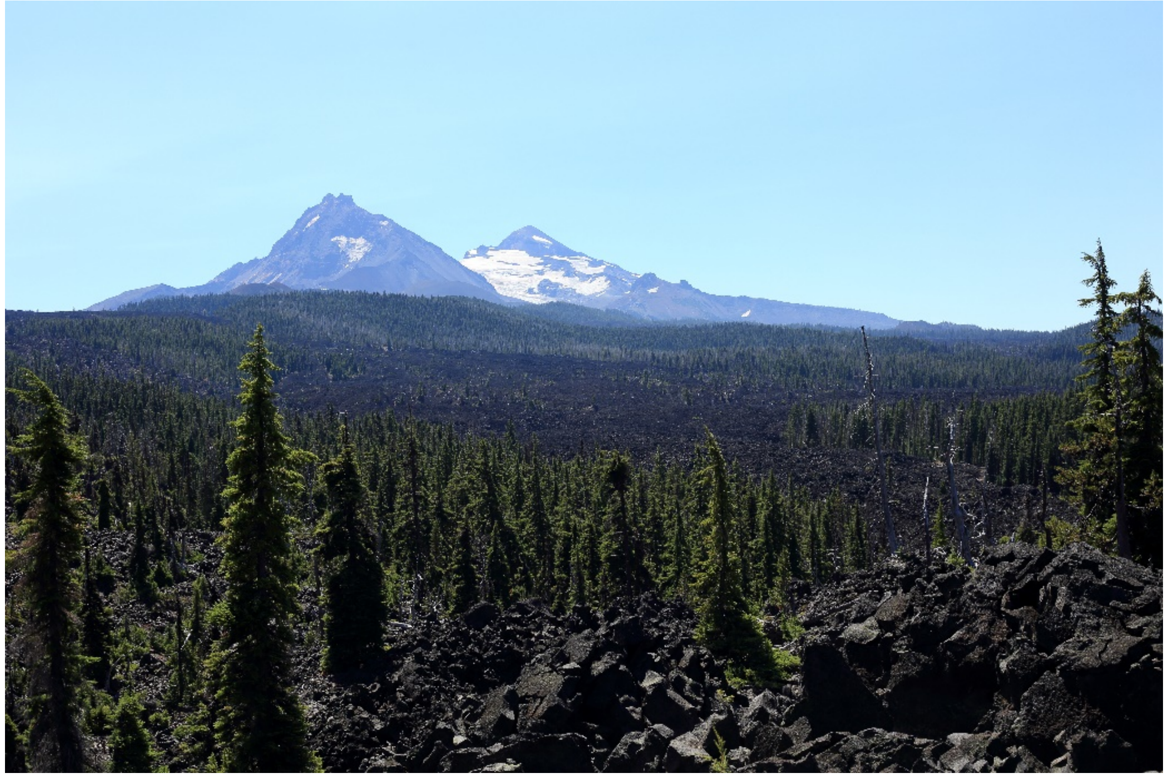


PhD thesis: Elisabeth Jachens, Oregon State University

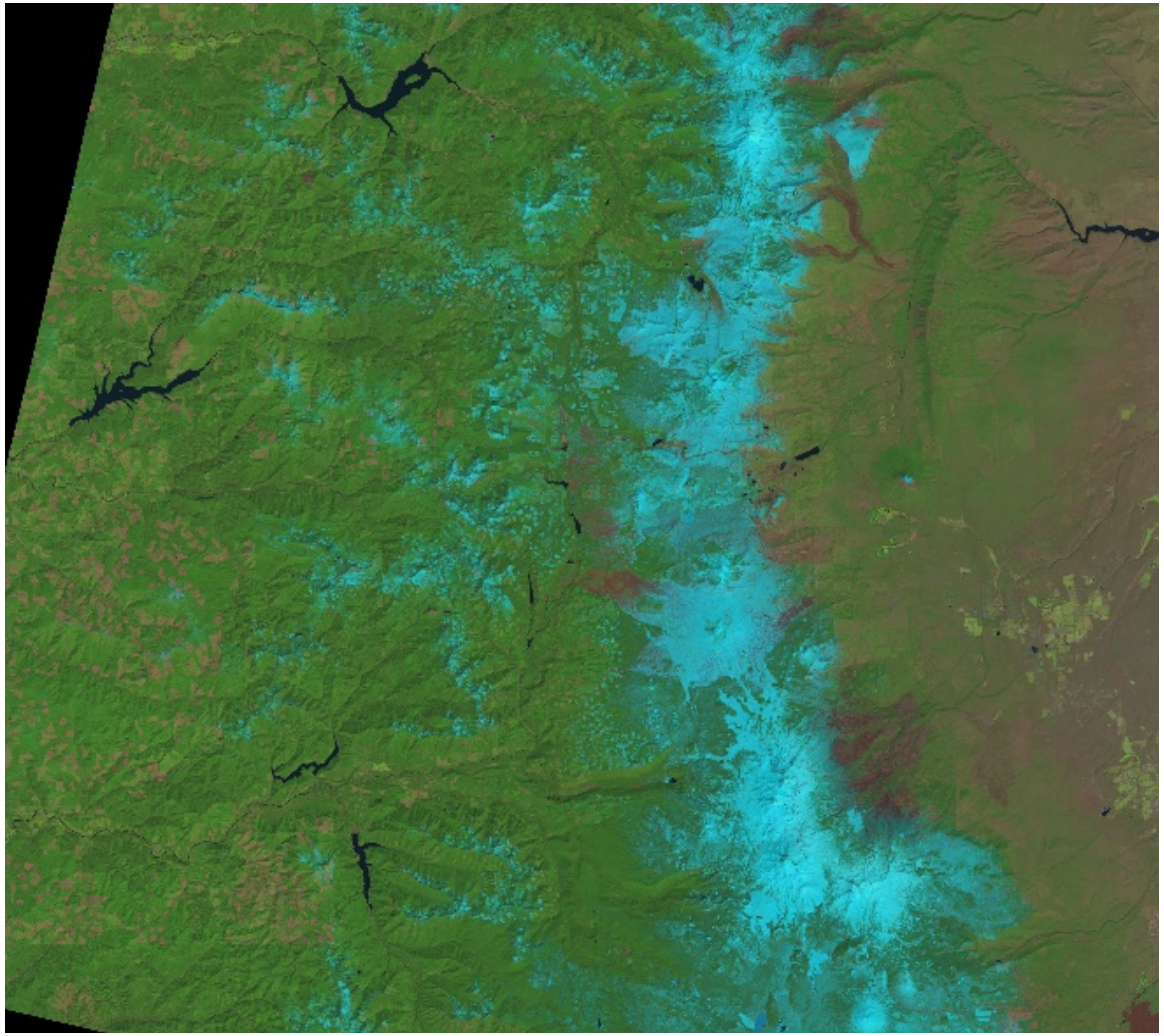
Conclusions

- **Recession analysis:** careful diagnostic at baseflow!
- **Watersheds "mutate"** from high to low timescale. Storage capacity decreases by weathering, erosion, network development, organic matter…

Is this a generalizable characteristic of "immature" landscapes?



- **Implication for droughts =>**
  - Watersheds are strongly sensitive to drought if 45 days timescale holds.
  - Young High Cascades much less sensitive.
  - Do we know? The bending curve may need further analysis.

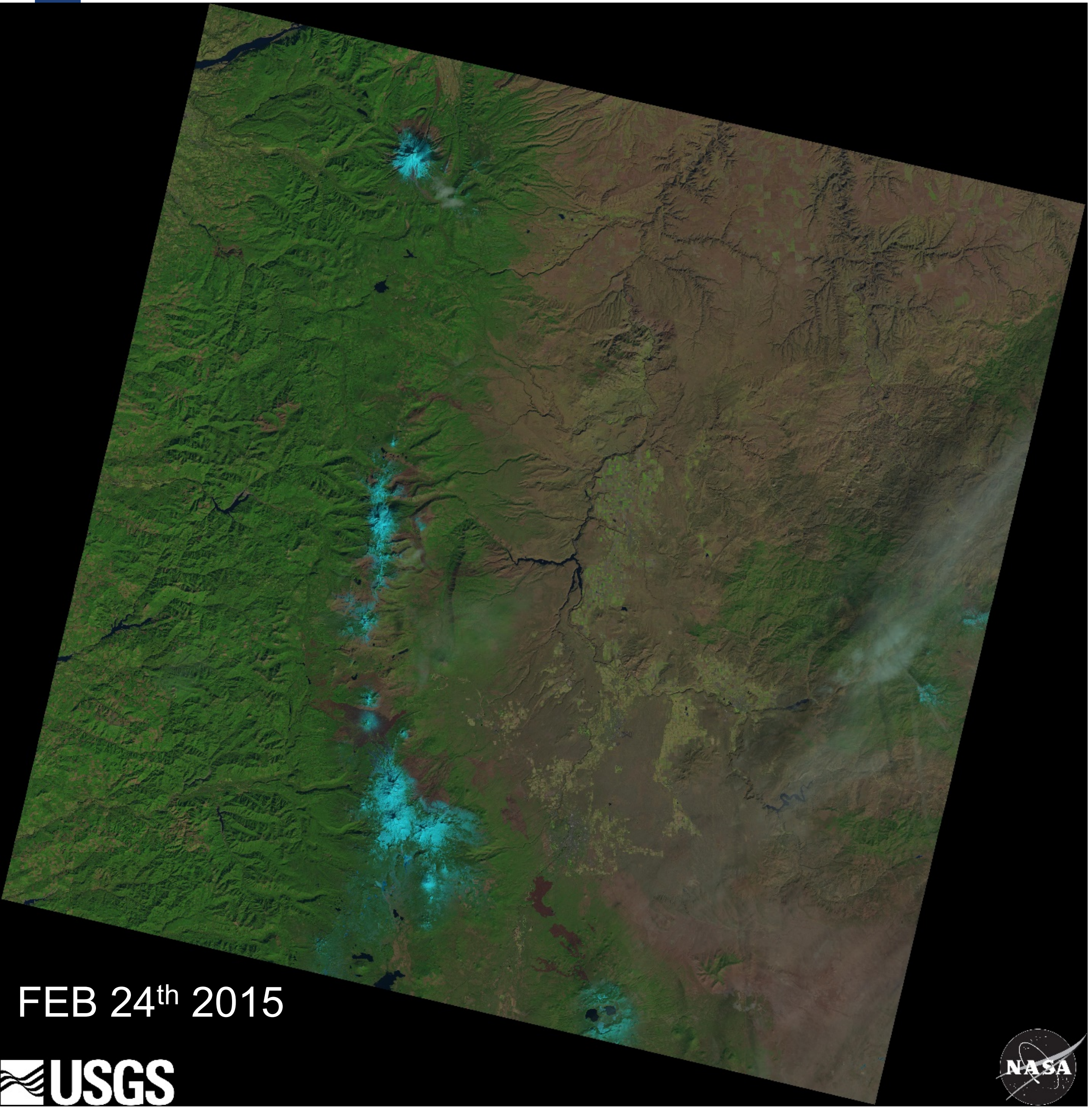


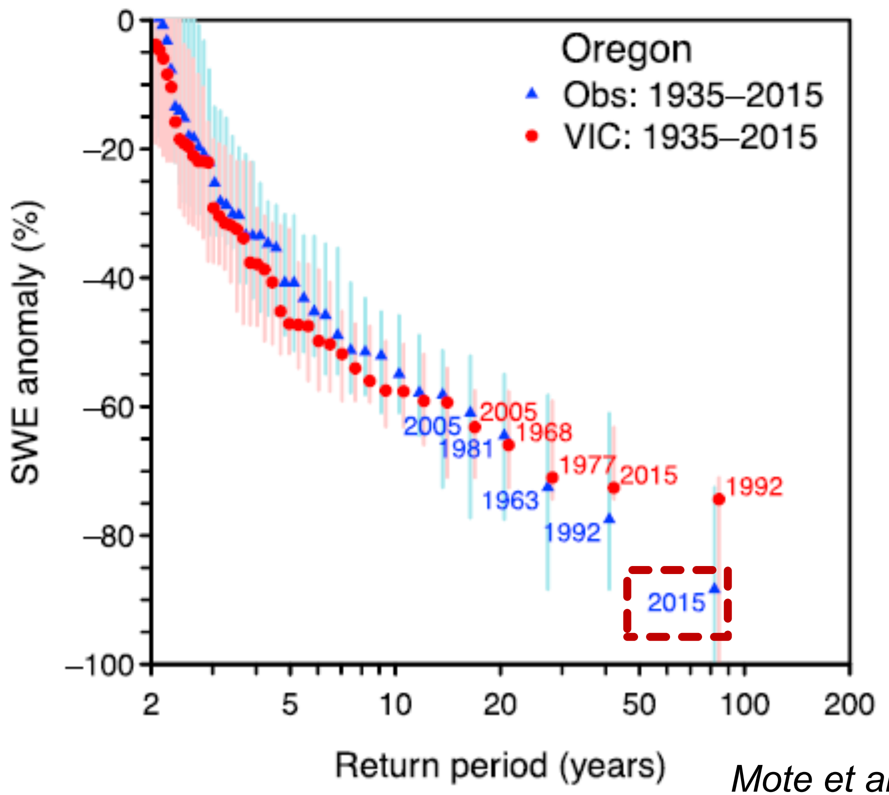
High Cascades

Precipitation infiltrates into extensive young lava flows and emerges later at large springs.

Western Cascades

Precipitation and snowmelt run off hillslopes rapidly to stream channels through shallow sub-surface pathways.

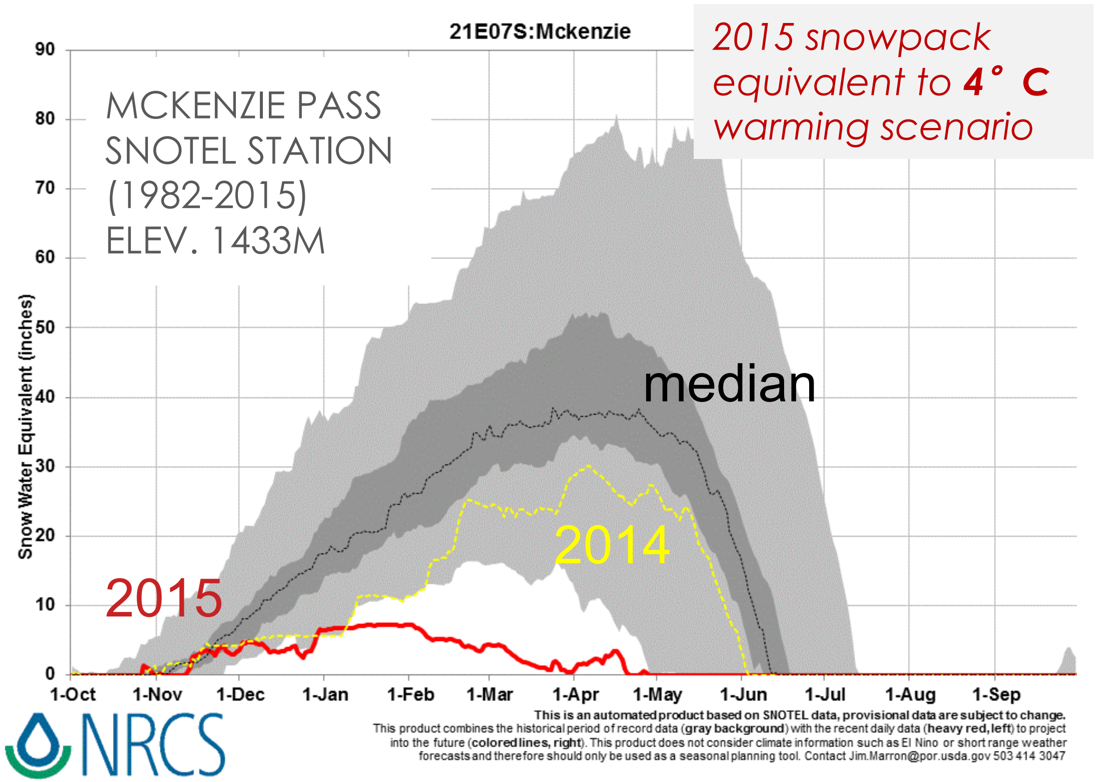


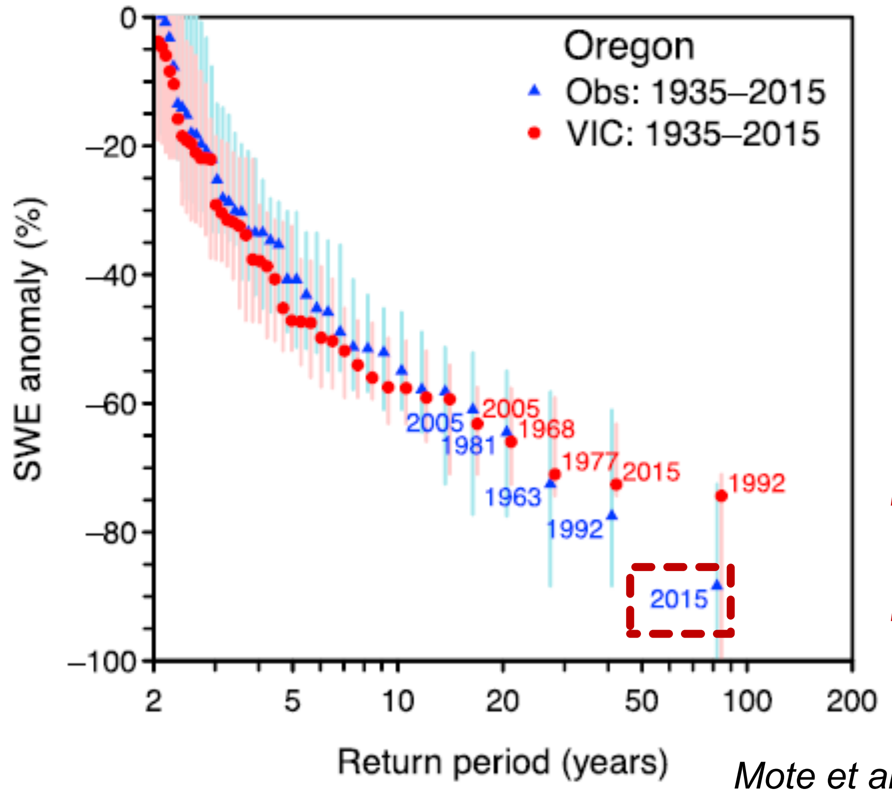


Mote et al., GRL, 2016

How sensitive are streamflow to such recharge anomaly?

The Experiment of 2015 “Snow Drought” in the Oregon Cascades





Is 2015 the new normal?

Mote et al., GRL, 2016

How sensitive are streamflow to such recharge anomaly?