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GEWEX INARCH

Department of Natural Resources and Environmental Science, University of Nevada, Reno

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Snowmelt-driven diel streamflow signal in the mountanious western US

Sebastián A. Krogh (UdeC; skrogh@udec.cl)

A. Harpold (UNR), J. Kirchner (ETH)

L. Scaff (UCSB), B. Gordon (UNR), G. Sterle (UNR)

October 19, 2021, INARCH 5th Workshop

EGU European Geosciences Union — Hydrology and Earth System Sciences

Diel streamflow cycles suggest more sensitive snowmelt-driven streamflow to climate change than land surface modeling

Sebastian A. Krogh[1,2,3], Lucia Scaff[4], Gary Sterle[2], James Kirchner[5,6], Beatrice Gordon[1], and Adrian Harpold[1,2]

[1]Department of Natural Resources and Environmental Science, University of Nevada, Reno, 89557, USA
[2]Global Water Center, University of Nevada, Reno, 89557, USA
[3]Departamento de Recursos Hídricos, Facultad de Ingeniería Agrícola, Universidad de Concepción, Chillán, 3812120, Chile
[4]Global Water Futures, Canada First Research Excellence Fund (CFREF), University of Saskatchewan, Saskatoon, SK S7N 3H5, Canada
[5]Department of Environmental Systems Science, ETH Zurich, CH-8092 Zurich, Switzerland
[6]Swiss Federal Research Institute WSL, CH-8903 Birmensdorf, Switzerland

In HESSD: https://hess.copernicus.org/preprints/hess-2021-437/

MOTIVATION

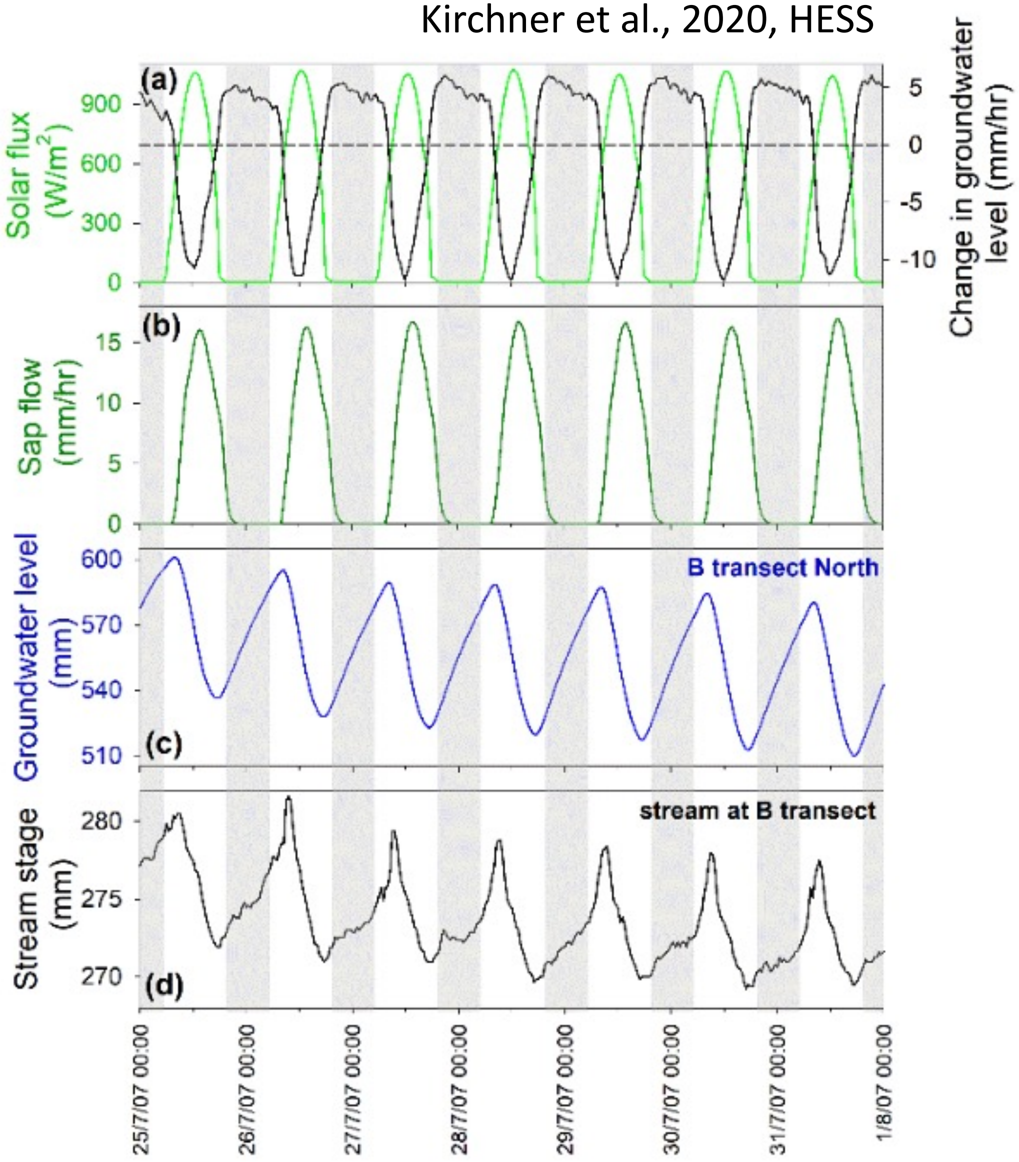
There is a **daily** physical relationship between **snowmelt/ET pulses**, and the groundwater and streamflow response following **solar radiation inputs**.

During summer months, daily solar fluxes cycles are tightly correlated with changes in sap flow (ET)

During this period, stream stages and riparian groundwater levels decline during the day and rebound at night

This cycles are typically reversed during the snowmelt period …

Kirchner et al., 2020, HESS



Example Sierra Nevada (Sagehen Creek)

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In contrast to point-scale observations (e.g., snow pillow), diel cycles integrate a watershed-scale response that include several physical processes:

- Snowmelt
- Snowpack storage-release
- Subsurface storage-release,
- ET/sublimation,
- Surface storage and routing, etc.

Can we use this integrated signal to better understand these environments?

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Using these relationships to diagnose whether snowmelt has occurred (or rather, whether its signal has made it to the gauge)

In the mountanious western US, there is a strong diurnal component in streamflow (Lundquist and Cayan, 2002)

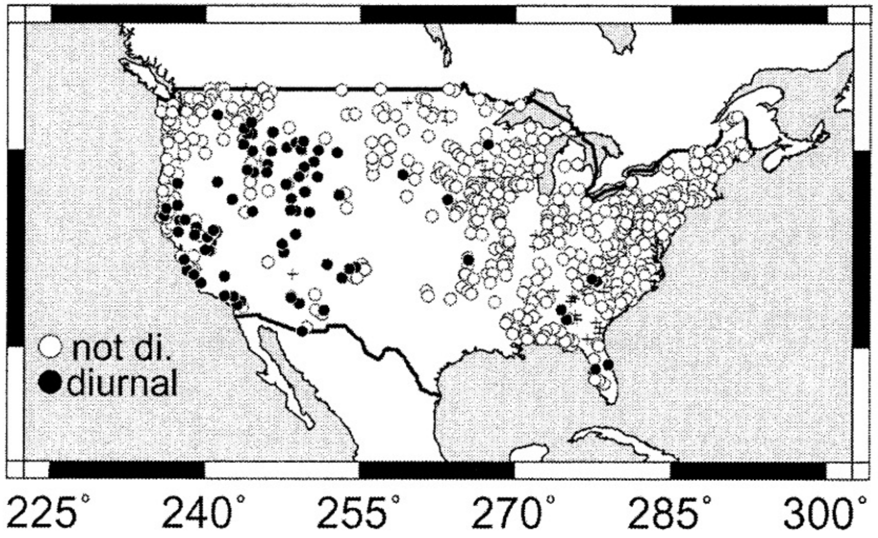
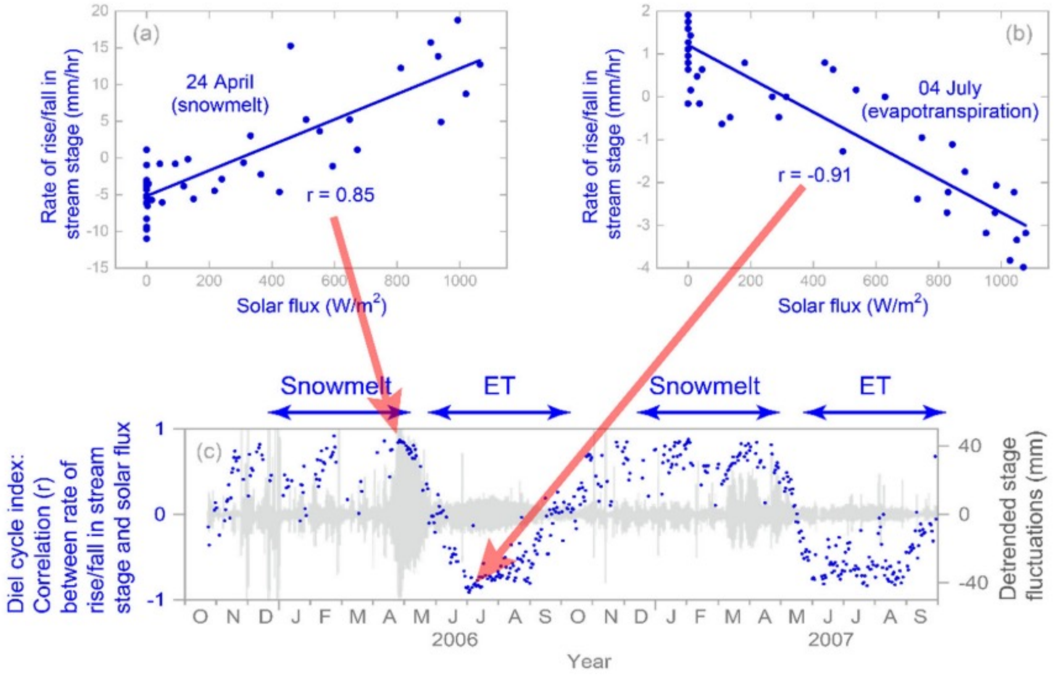


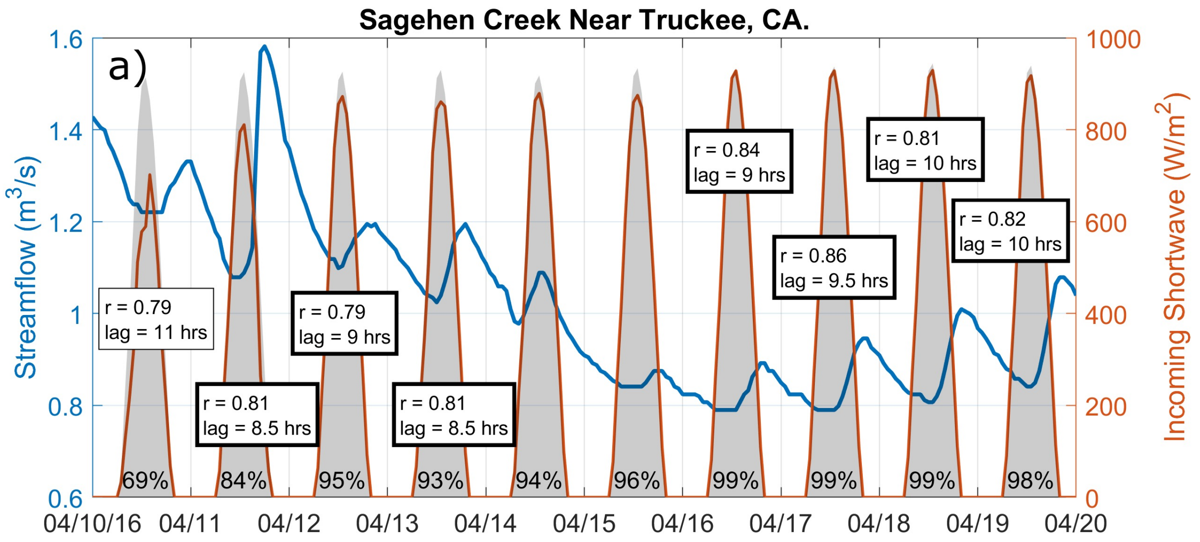
FIG. 1. June 2000 stations with clear diurnal cycles.

Kirchner et al (2020): The "diel cycle index"



This type of analyses can be used to characterize the occurrence of snowmelt but not necessarily the magnitude or rate of snowmelt.

Diel streamflow analysis



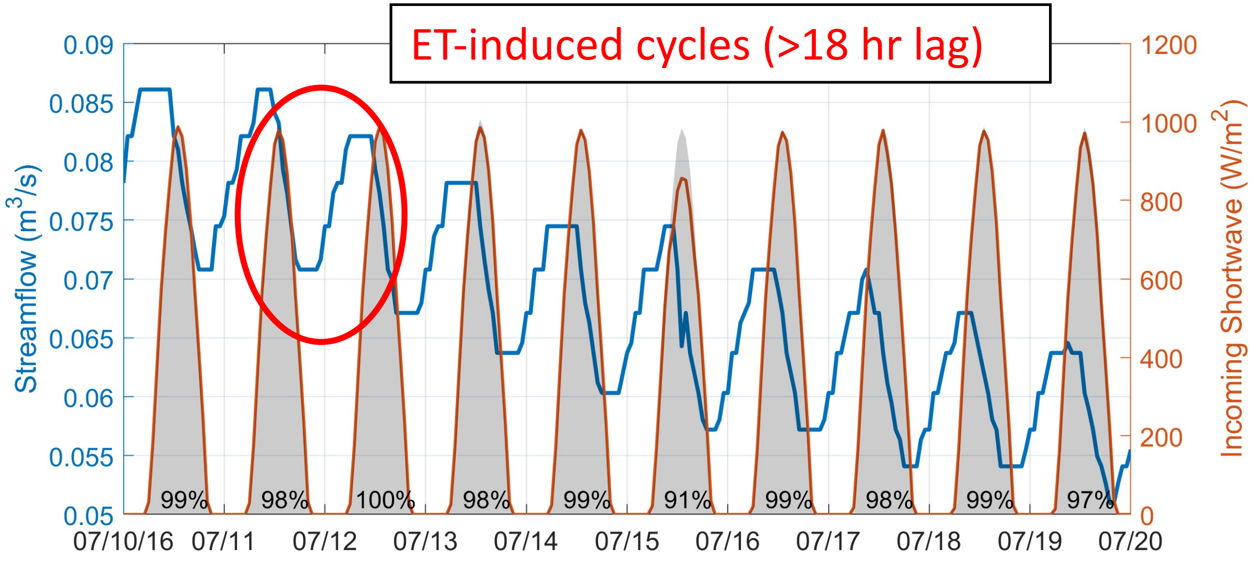
We analyze **lagged-correlations** of hourly solar radiation and streamflow.

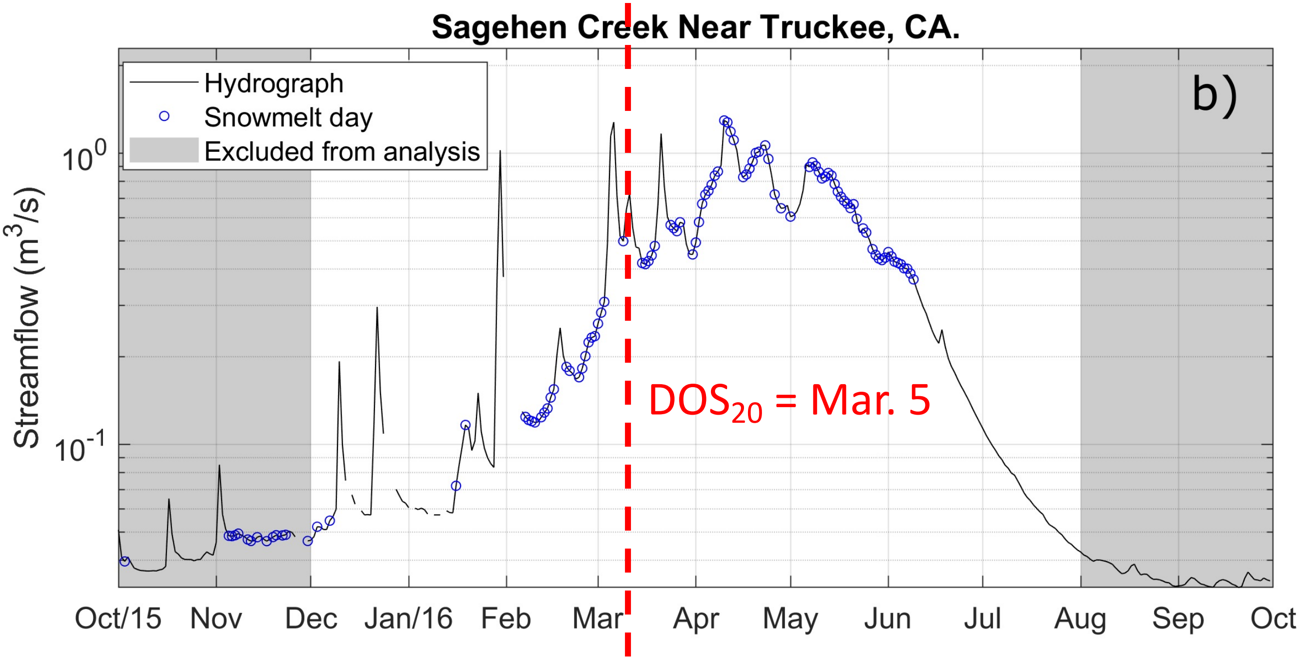
Filters (lag-window, period of analysis) and **correlation cutoffs** to avoid ET effects and noise.

We classify days as **snowmelt-driven vs non-snowmelt-driven streamflow**. Binary index.

Previous' day ET signal may appear providing a "false" snowmelt signal.

Other potential issues include ROS events.





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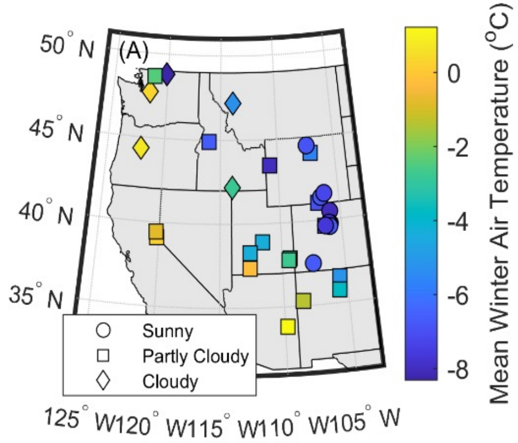
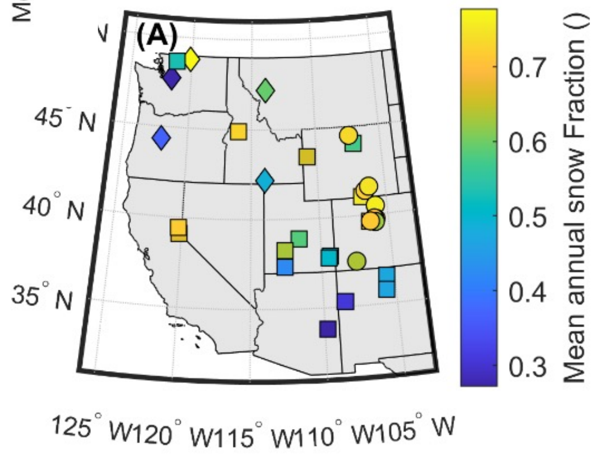
We apply this method to every day on records between **December 1st and August 1st**, for 31 watersheds in western US (small and high).



Large hydrological gradients!



Then, we develop a snowmelt timing metric that aims to capture **the timing of the beginning of the snowmelt season**.

We call it **DOS_{20}** (Date of Snowmelt). And is calculated as the **20^{th} percentile of the snowmelt days**.

(We also tested other percentiles and definitions … see HESSD SI)

Research Questions

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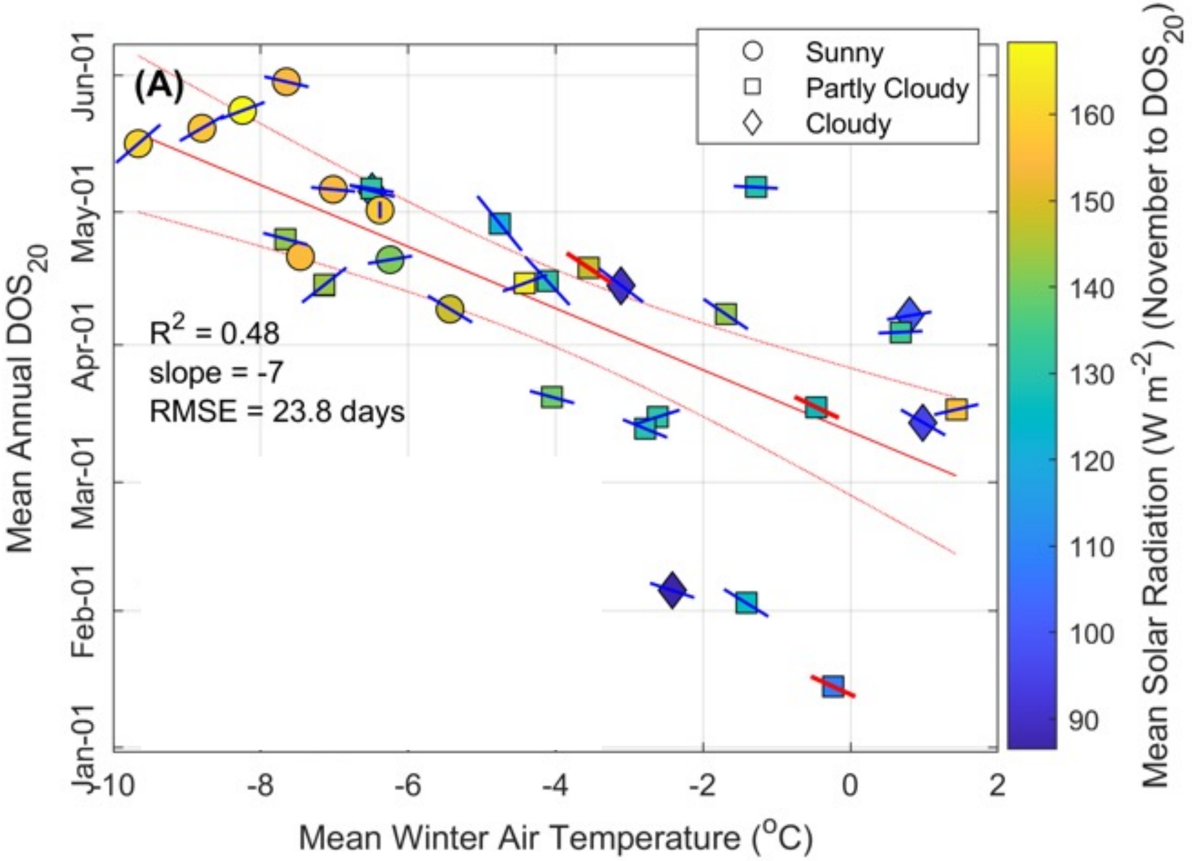
1. Does the diel streamflow analysis show evidence of **earlier and more intermittent snowmelt in warmer watersheds and years** (as shown by point-scale observations and models)
2. Can we use the **timing of snowmelt** to predict the **timing of streamflow volume** and make predictions under climate change?
3. How do these projections compare **against commonly-used land surface models**?

Mean annual values for DOS_{20} show a cross-site relationship with mean winter air temperature (T_{NDJF}) (more disperse at warmer watersheds)



Interannual variability at each watershed **show a less consistent picture** (variable number of years with data across sites; [4-31] yrs).

Most watersheds with **negative slopes**, but only a few of them are statistically significant (red overlapping lines).

We correlate the **DOS_{20} with the date of 25% and 50% of the annual streamflow volume (DOQ_{25} and DOQ_{50}),** suggesting that DOS_{20} can predict the timing of streamflow volume.

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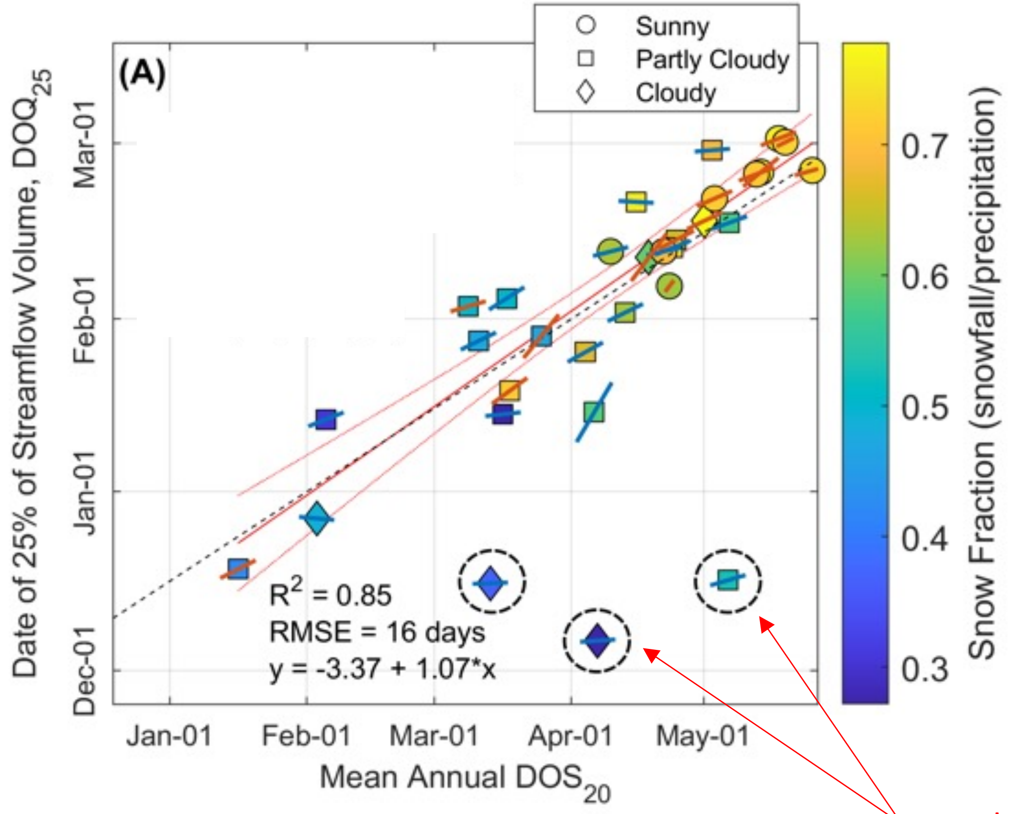

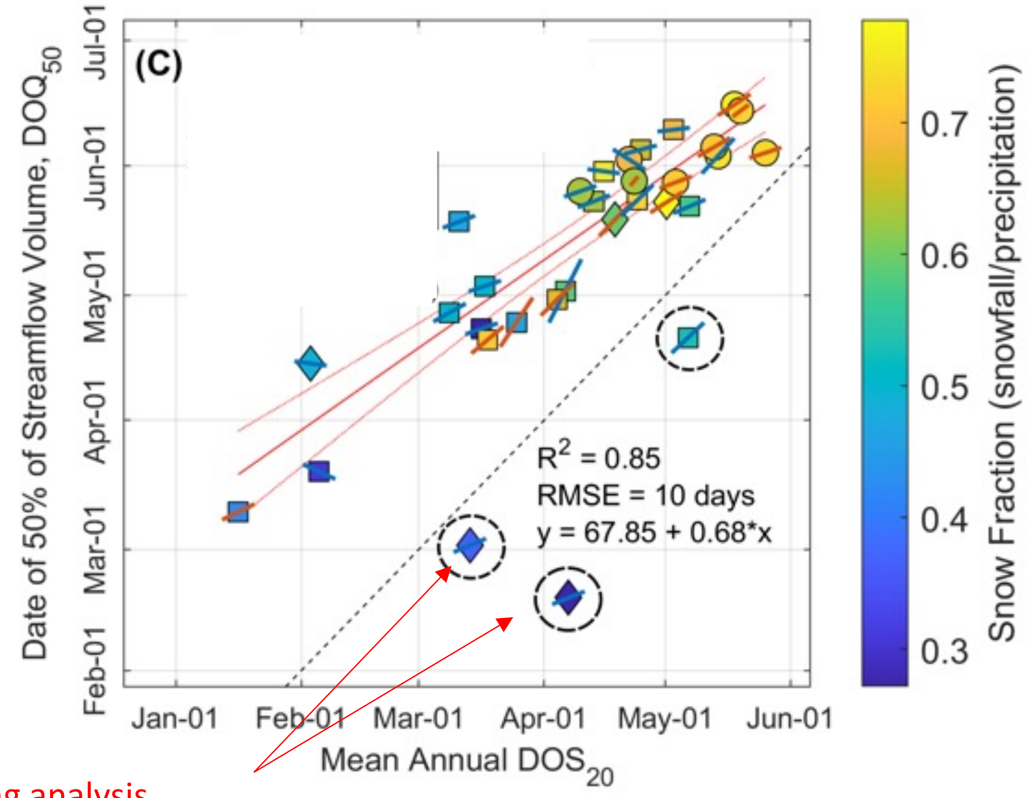

Excluded from the following analysis.
Presumably more rainfall-dominated (low snow fraction), located in the Pacific Northwest

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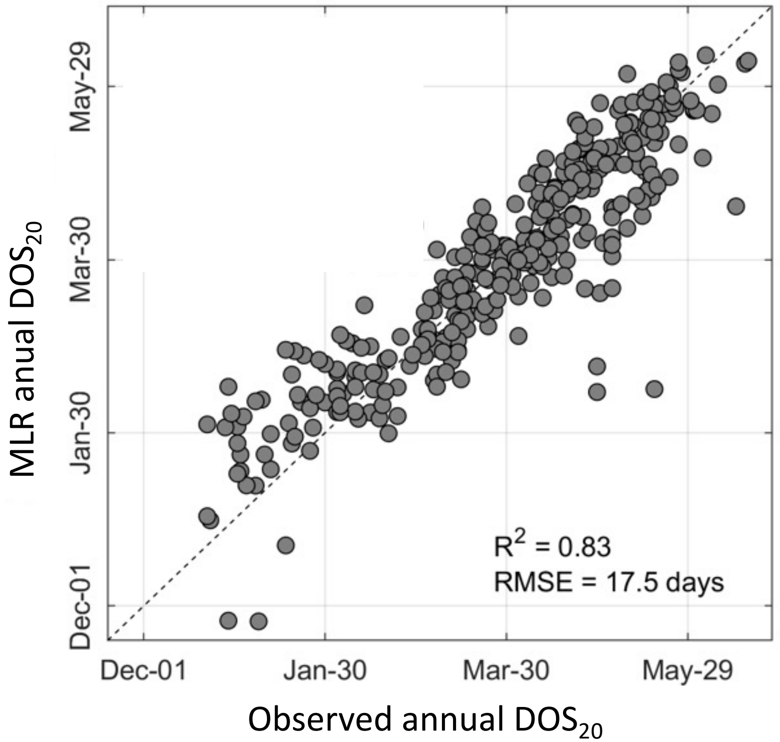
Stepwise multiples linear regression (MLR) to predict DOS_{20} as a function of climate (x_i): air temperature, RH, solar radiation and precipitation.

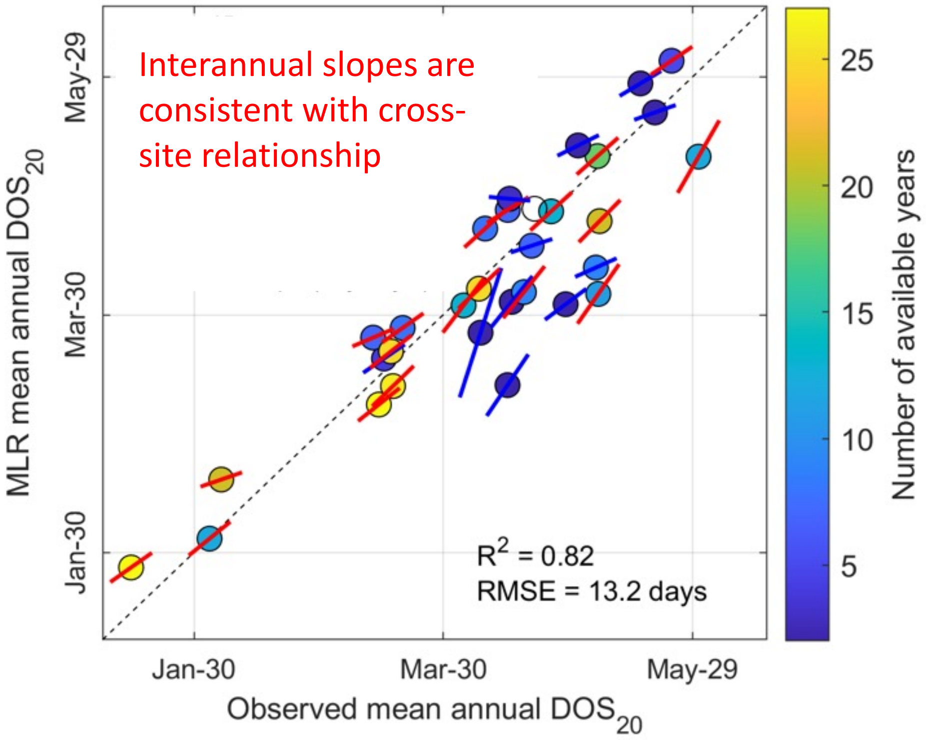
$$DOS_{20} = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \beta_4 x_4 + \beta_5 x_1 x_2 + \beta_6 x_1 x_3 + \beta_7 x_1 x_4 + \beta_8 x_2 x_3 + \beta_9 x_2 x_4 + \beta_{10} x_3 x_4$$

β_i: Regression coefficients
x_i: Climate data

Calibrated to site-year values (>300)



Tested for mean annual values (#31)



We call this a **Space-for-Time (STS) relationship**, which we use under a climate change scenario to predict changes in DOS_{20}.

Climate change as simulated by the Weather Research and Forecasting model (WRF, 4-km) under a pseudo-global warming by the end of the century (Li et al., 2017) at each watershed.

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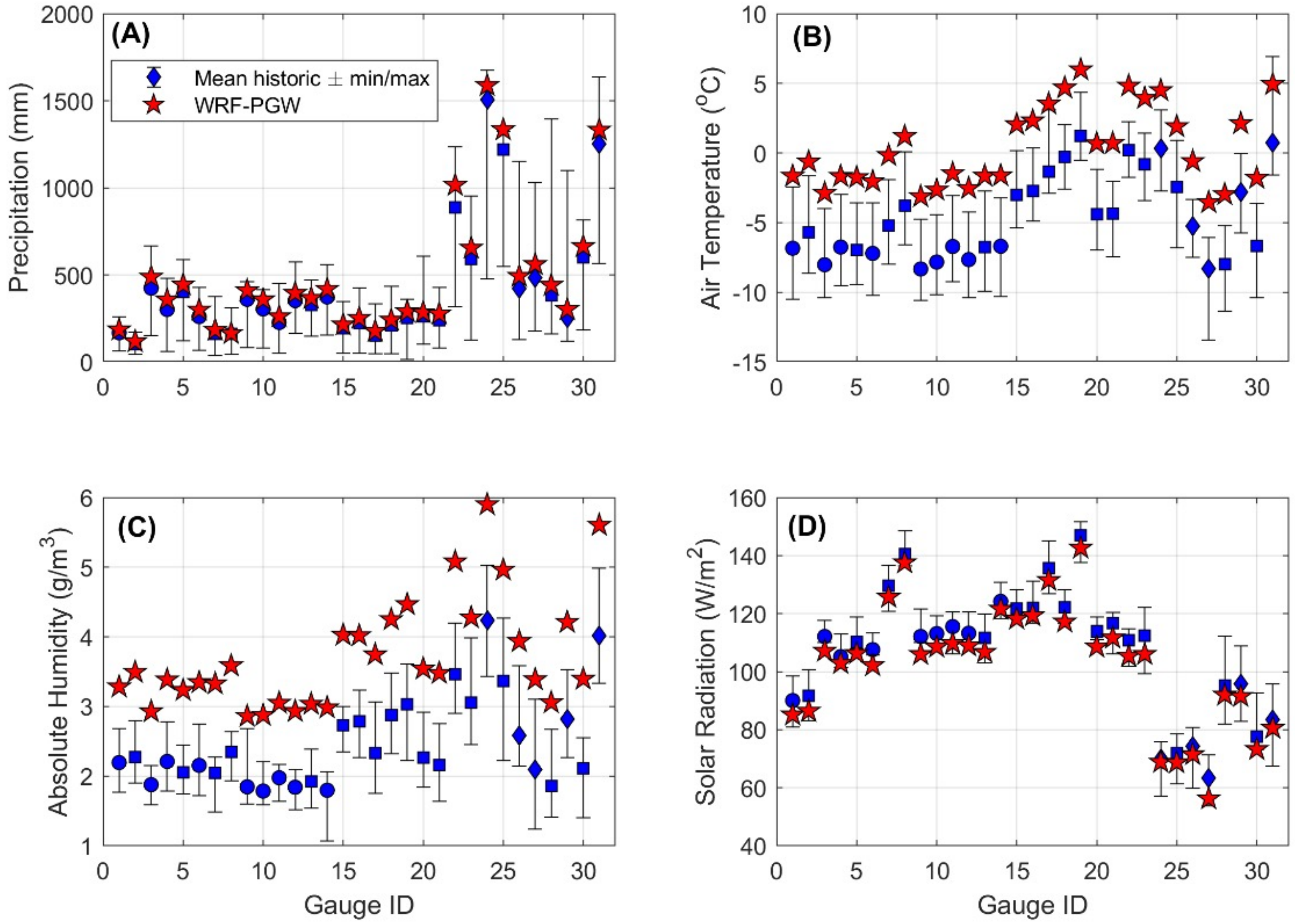
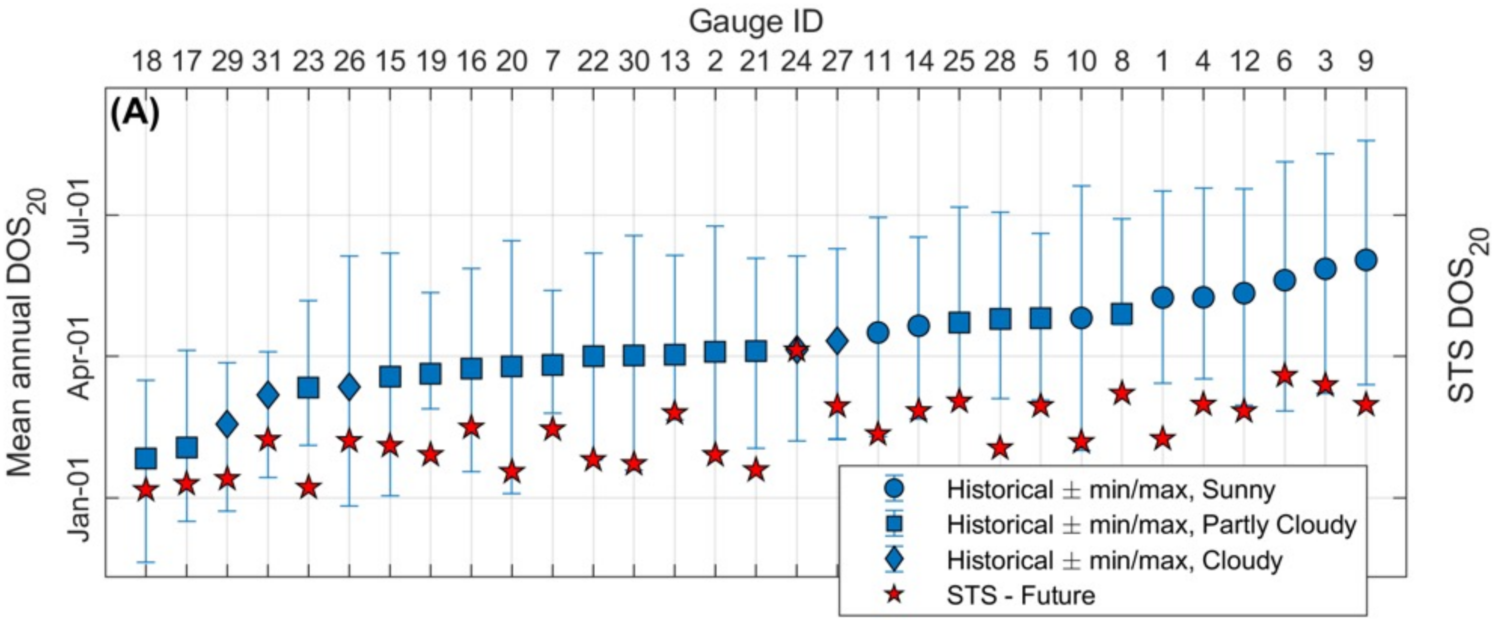


Climate projections by the end of the 21st century:

- Warmer: + 4 - 5.2 °C
- More humid (+1 – 1.7 g/m^3) and wetter (+ 2 – 20%)
- Slightly less solar radiation ([-1 -7] W/m^2)

Simulations have been previously validated for the snowpack (NoahMP) and meteorological components.



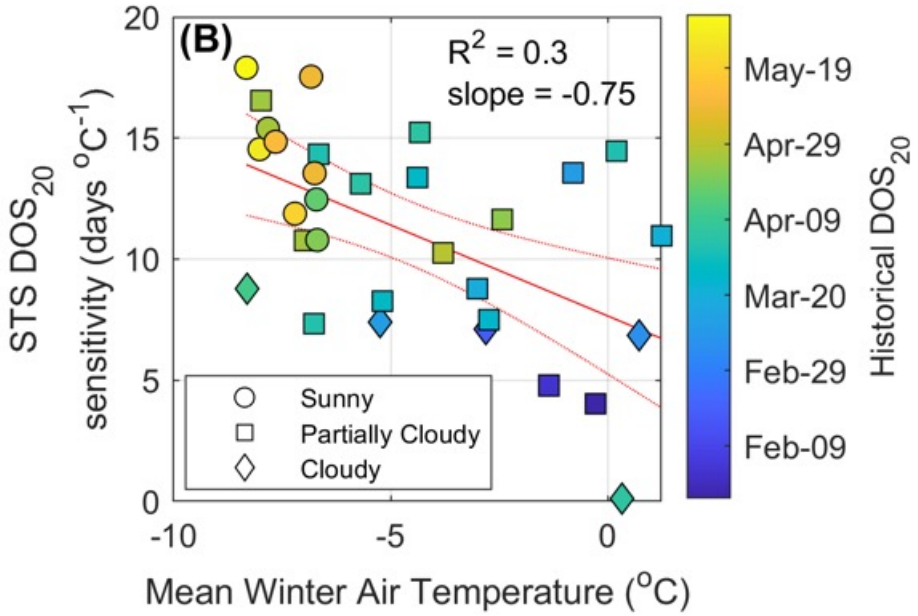
Large changes in early snowmelt timing (DOS_{20}) are projected. **Up to 2 months earlier.**

Some annual changes are within the observed range.

(Site#24: little changes. Almost no change in humidity and solar radiation)

On average, 1°C of warming produces 11 ± 4 of earlier DOS_{20}.

Colder watersheds (T_{NDJF} < -8°C) are more sensitive (~70%) to climate change than warmer watersheds (T_{NDJF} > 0°C).



What about changes to early (25%) streamflow volume timing (DOQ_{25})?

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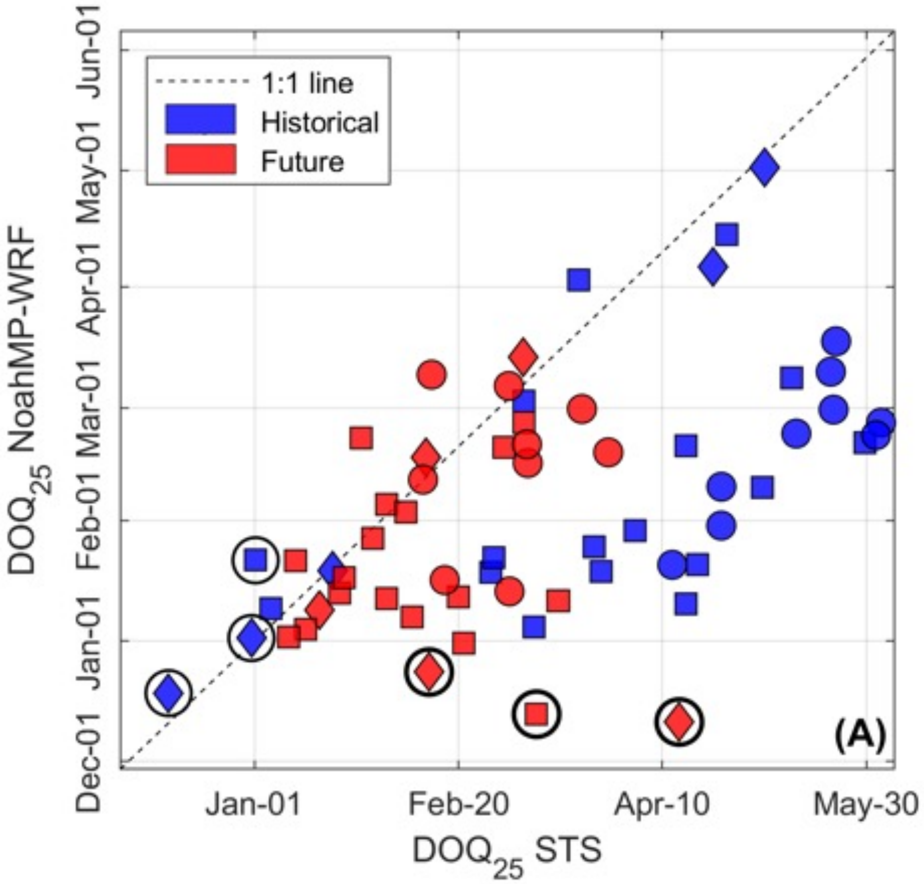
DOQ_{25} as simulated by WRF (with NoahMP)



DOQ_{25} as simulated using the Space-for-Time (STS) approach with the linear regression between DOS_{20} and DOS_{25}.

Historical period: NoahMP-WRF underestimates the timing of DOQ_{25}, producing earlier streamflow, particularly at colder sites.

Future period: NoahMP-WRF projects consistently earlier DOQ_{25} than the Space-for-Time (STS) approach.

Proyected changes according to each method:

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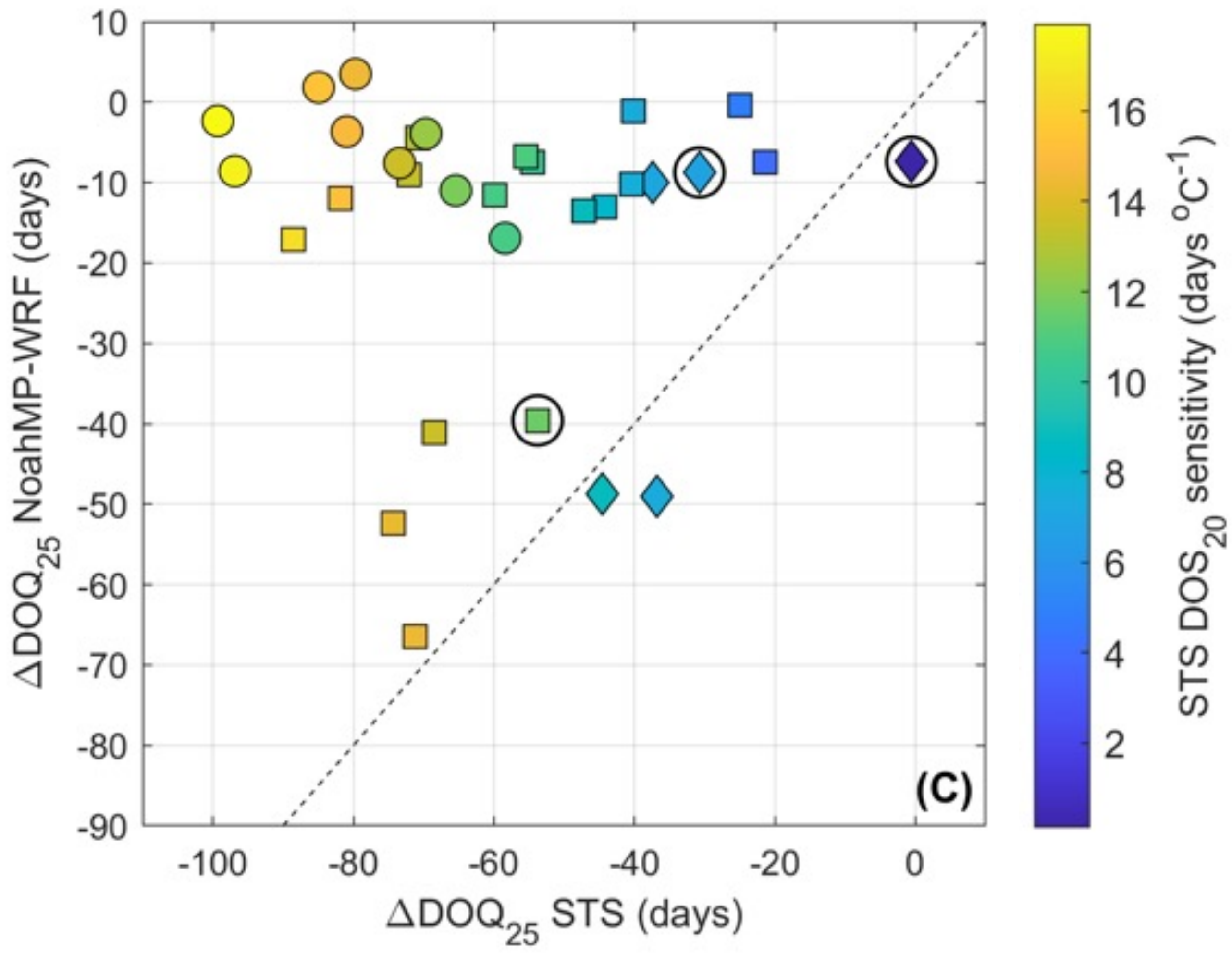

Large differences between methods reveal challenges in predicting changes to streamflow volume timing under climate change.

On average, empirically-driven (STS) mean annual changes are 4 times more sensitive than those from the land-surface model.

Little difference in sensitivity is projected by NoahMP-WRF across sites with a mean change of about 15 days.

Which one should we trust the most?

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Space-for-Time (based on the diel analysis)

Pro's:

- Does not require assumptions embedded in physically-based models.
- Well constrained by observed data representing large hydrological gradients across time and space.

Con's:

- It assumes that those variables not included (e.g., soil and vegetation characteristics) vary with climate.
- Cannot represent the physical processes controlling streamflow generations.

Land-Surface Model (based on NoahMP-WRF)

Pro's:

- Tracks the covariance between meteorology to estimate precipitation phase (critical driver).
- Represents hourly radiative, turbulent exchanges, and cold content required to predict snowmelt.

Con's:

- There are many assumptions behind processes representation (e.g., subsurface and snowpack storage and flow, vegetation, etc.).
- Spatial resolution becomes an issue for steep headwater catchments (computationally expensive!).

CONCLUSIONS

- By no means the STS method based on the diel streamflow analysis is a replacement for land-Surface simulations.
- However, it is a relatively “cheap” method that only requires hourly solar radiation and streamflow, and thus, potentially transferable.
- Limitations! -> ROS, large watersheds and storage, cross section shape …
- Can be use complementary as an independent tool to benchmark and test hydrological models beyond typical daily streamflow and SWE observations.
- Need to reduce uncertainties in streamflow projections for water managements applications …