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TAKING THE PULSE OF OUR PLANET FROM SPACE

A Consistent Estimate of the Arctic Water Cycle

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Introduction

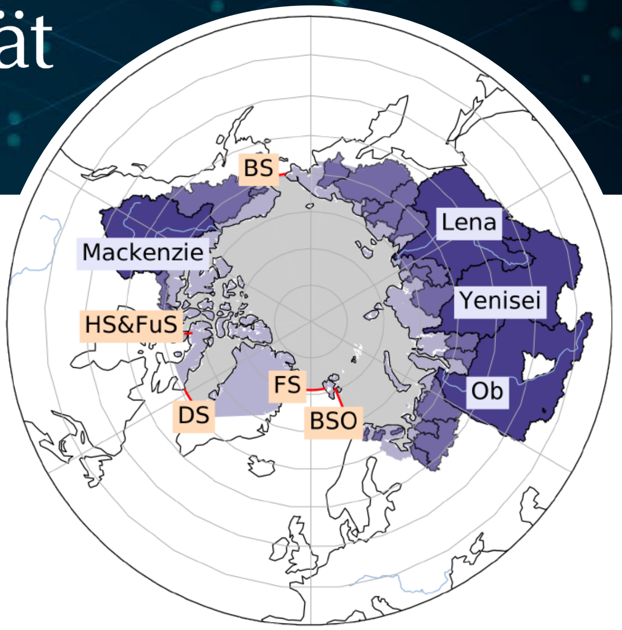
Analysis of the Arctic water budget, including its atmospheric, terrestrial and oceanic components

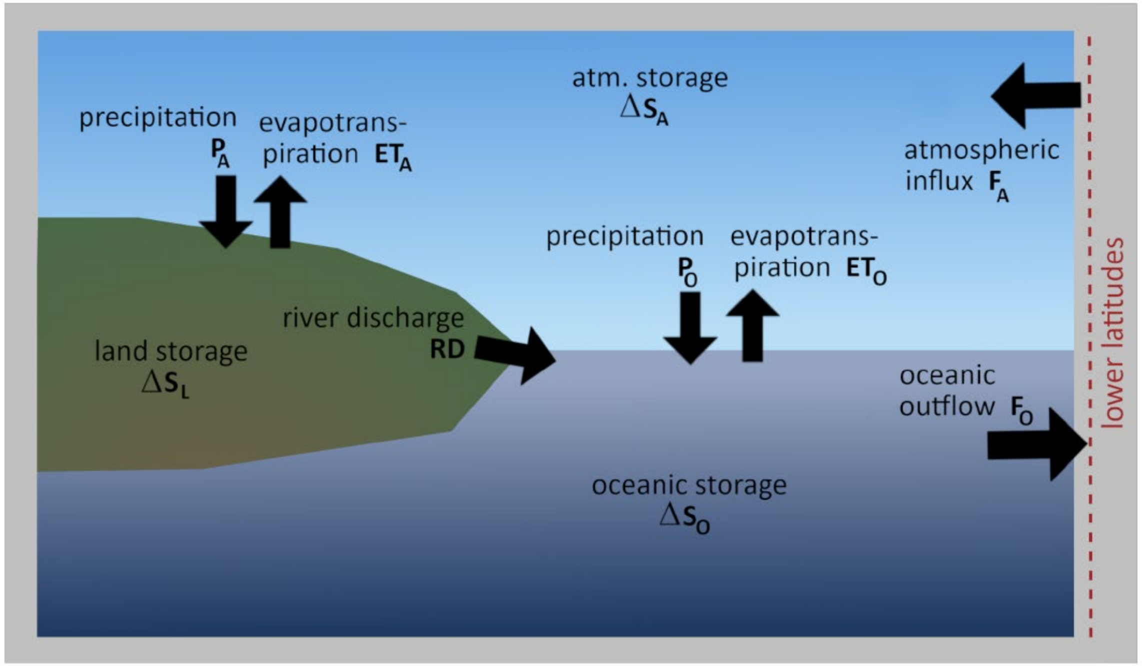
$$Atm.: \Delta S_A = ET_A - P_A - F_A$$

$$Land: \Delta S_L = P_L - ET_L - RD$$

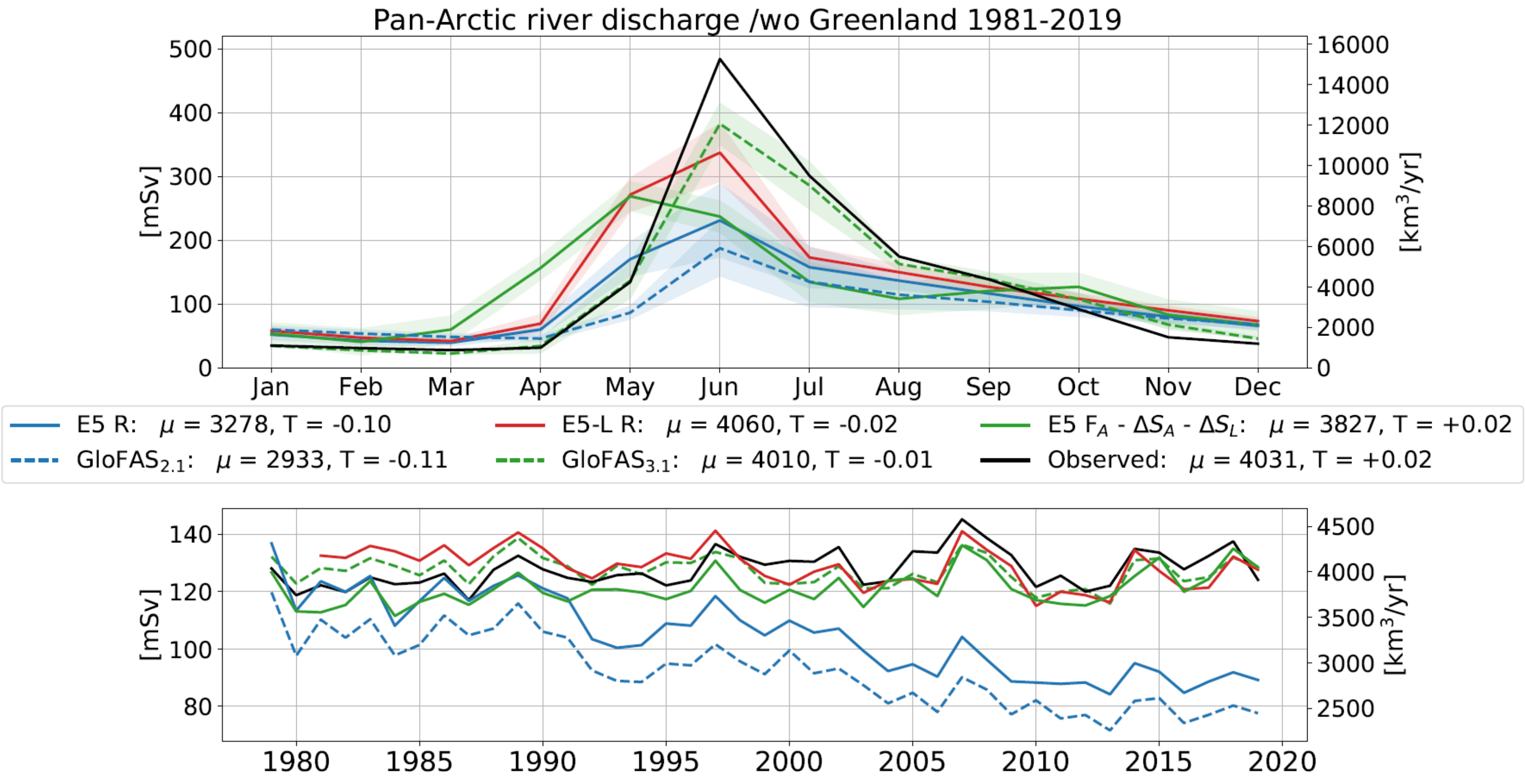
$$Ocean: \Delta S_O = P_O - ET_O + RD - F_O$$

Combination of largely Independent estimates of the various budget terms (in-situ observations, satellite observations (GRACE), reanalyses (e.g.: ERA5, ERA5-Land, GloFAS))





River Discharge



→Reanalyses tend to underestimate seasonal runoff peaks and are not able to reproduce observed trends

→Best agreement with observations using GloFAS 3.1

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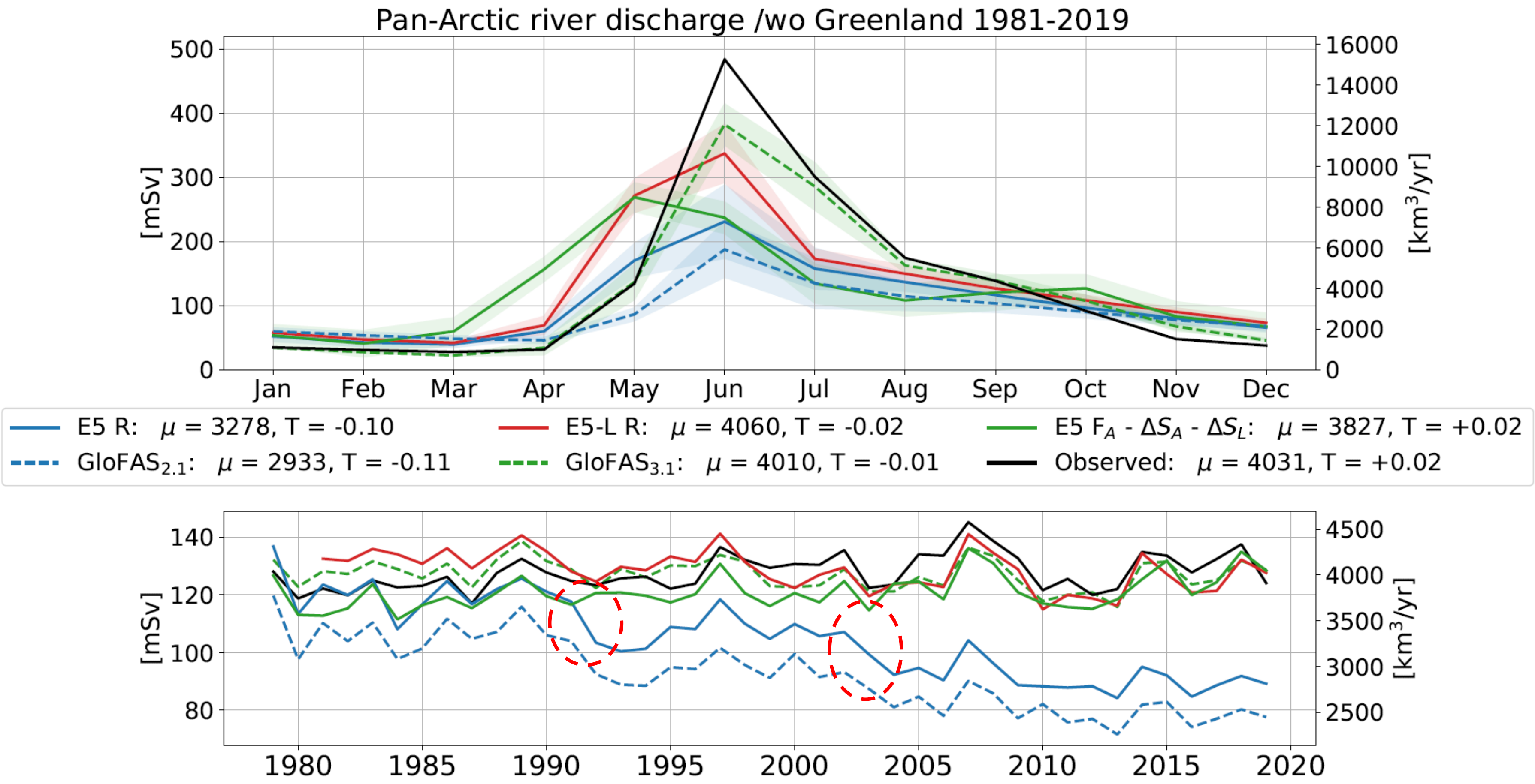

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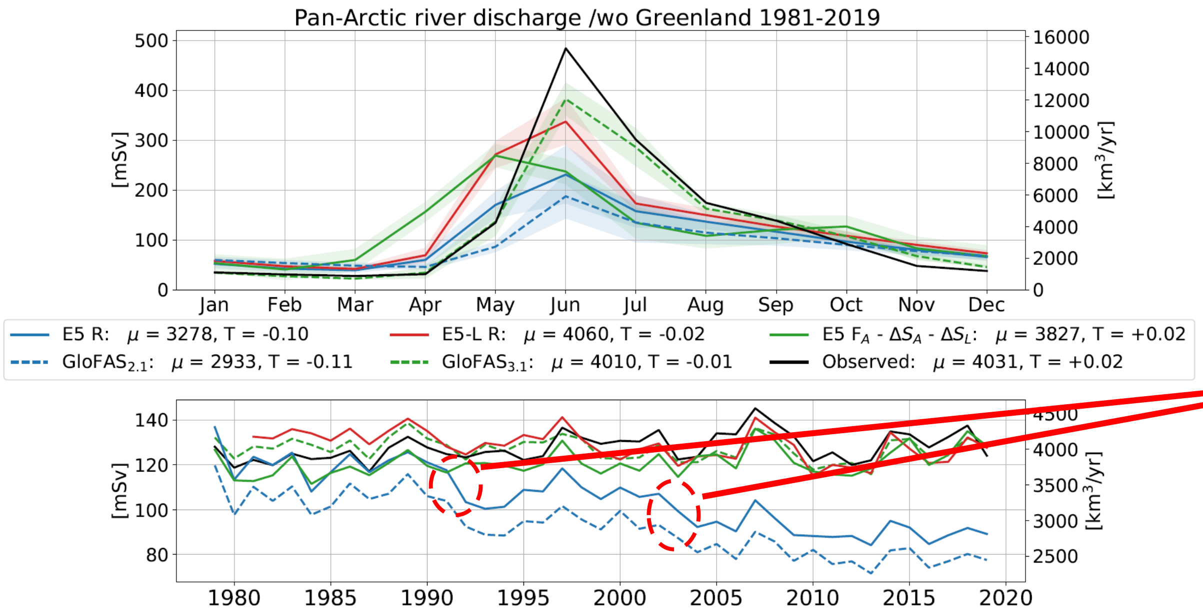
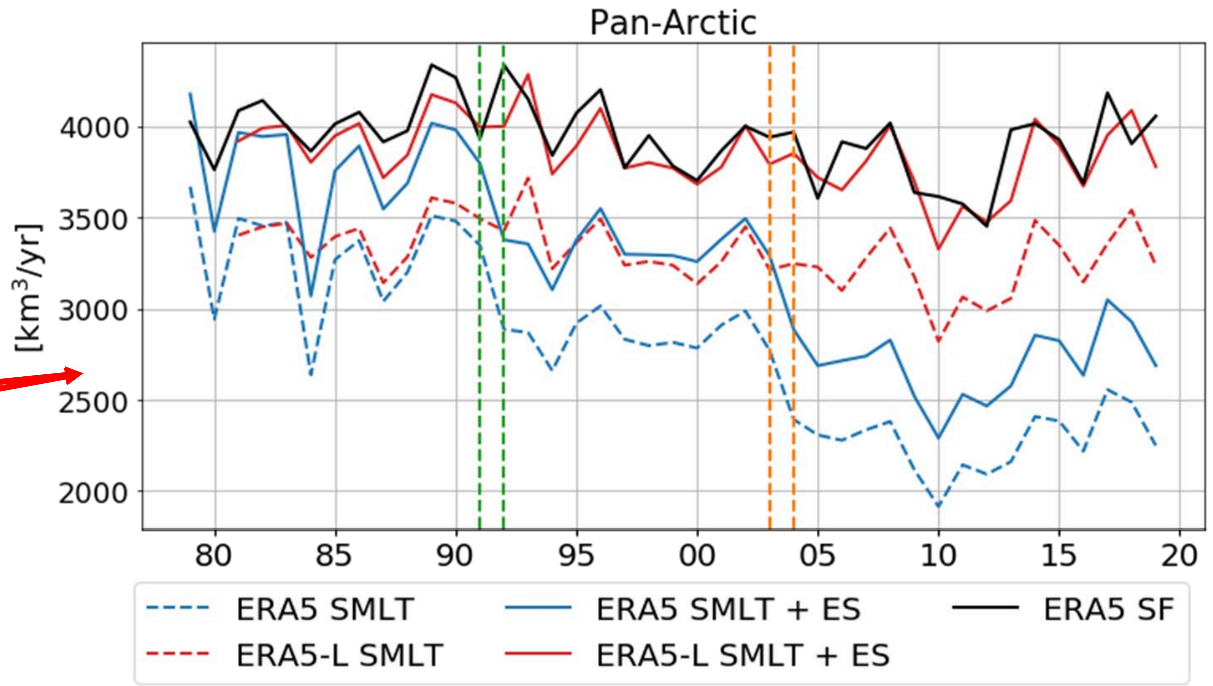
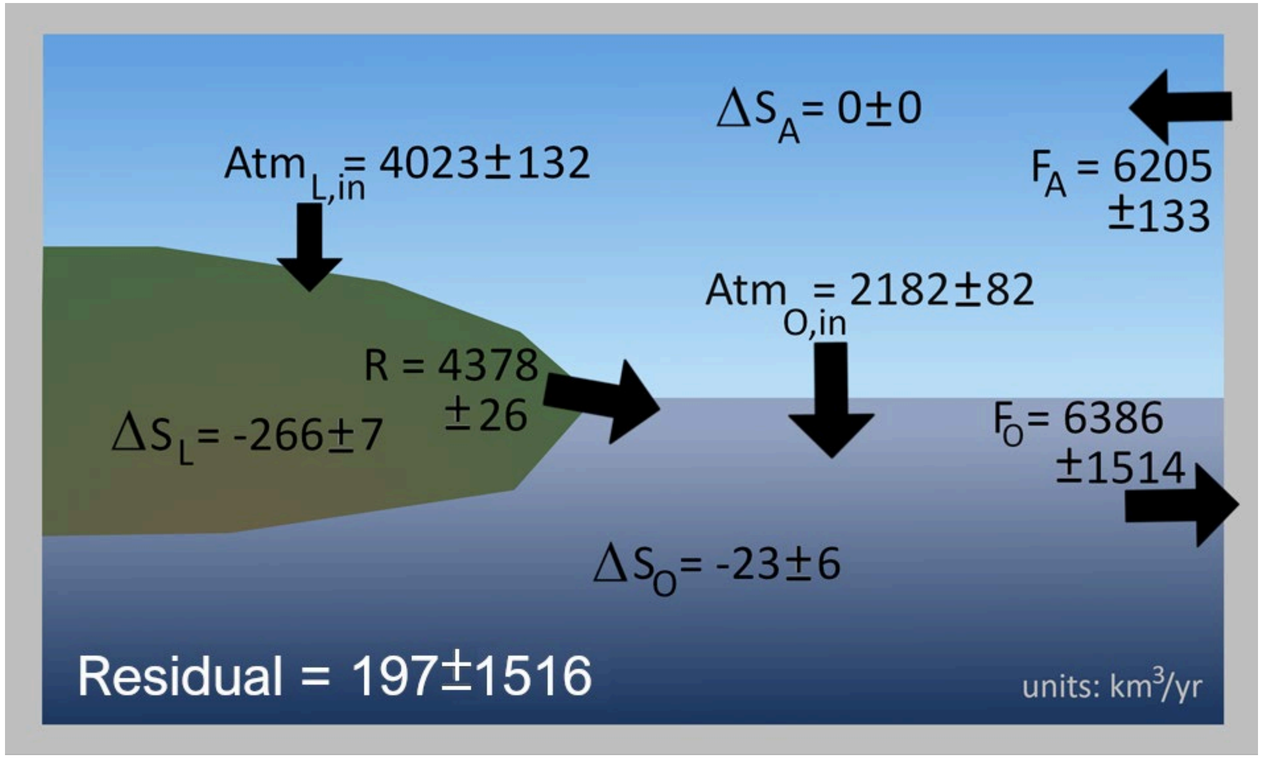




→River discharge discontinuities caused by snow assimilation system

→2004 discontinuity traced back to introduction of IMS (Interactive Multisensor Snow and Ice Mapping System)

Variational optimization - annual



Annual budget before optimization

Combination of reliable river discharge estimates with oceanic + atmospheric fluxes and storage changes

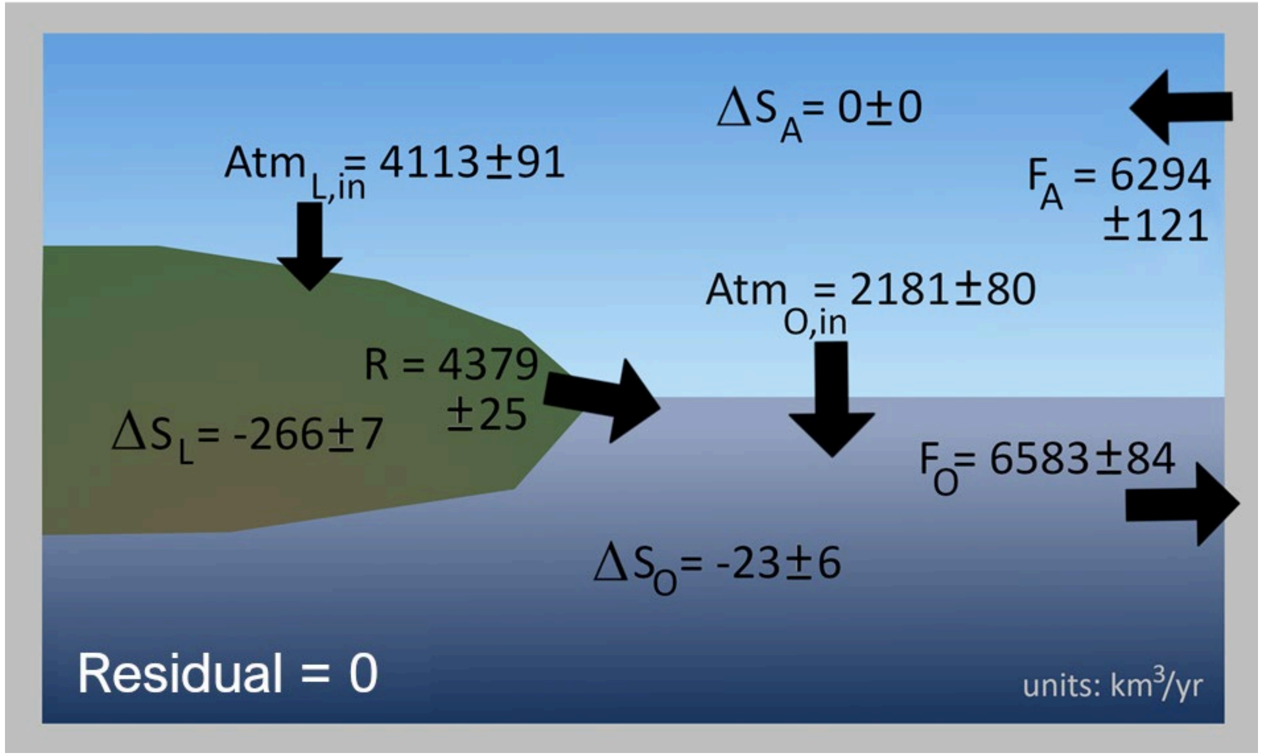
→ small annual imbalance of ~3%

Enforcing budget closure:

$$F_k = F'_k + \frac{{\sigma'}_k^2}{\sum_i {\sigma'}_i^2} \sum_i F'_i$$

→ One reliable estimate of every volume budget term

Variational optimization - annual



Annual budget after optimization

Combination of reliable river discharge estimates with oceanic + atmospheric fluxes and storage changes

→ small annual imbalance of ~3%

Enforcing budget closure:

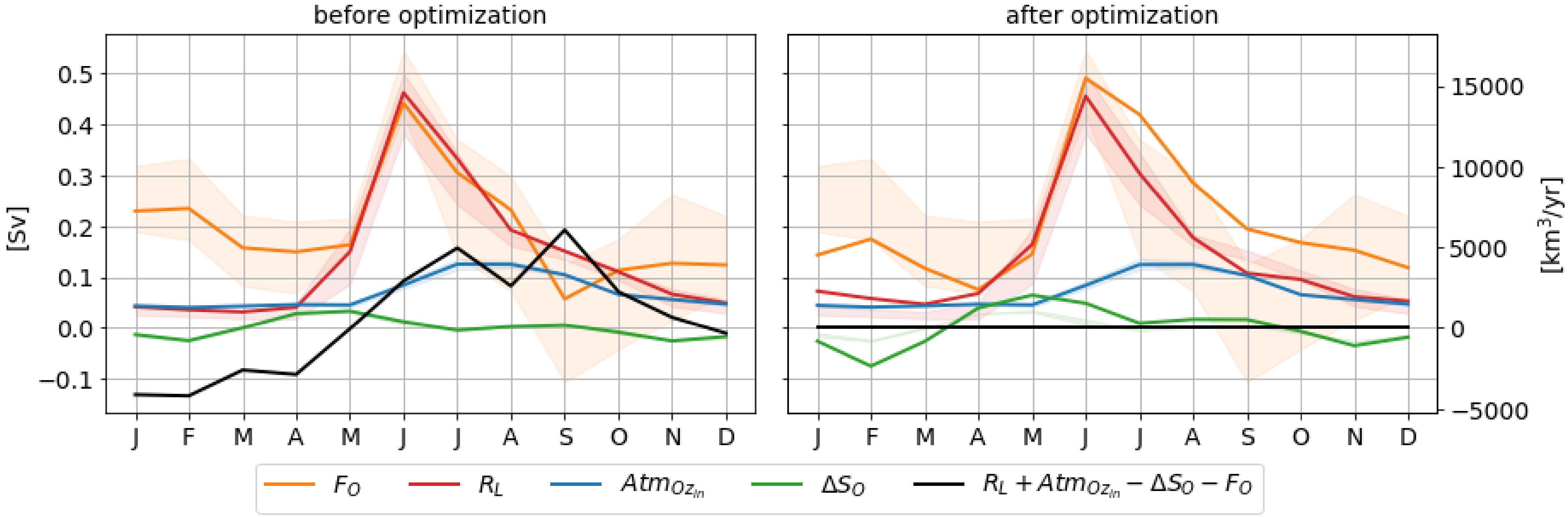
$$F_k = F'_k + \frac{\sigma'^2_k}{\sum_i \sigma'^2_i} \sum_i F'_i$$

→ One reliable estimate of every volume budget term

Var. optimization - seasonal

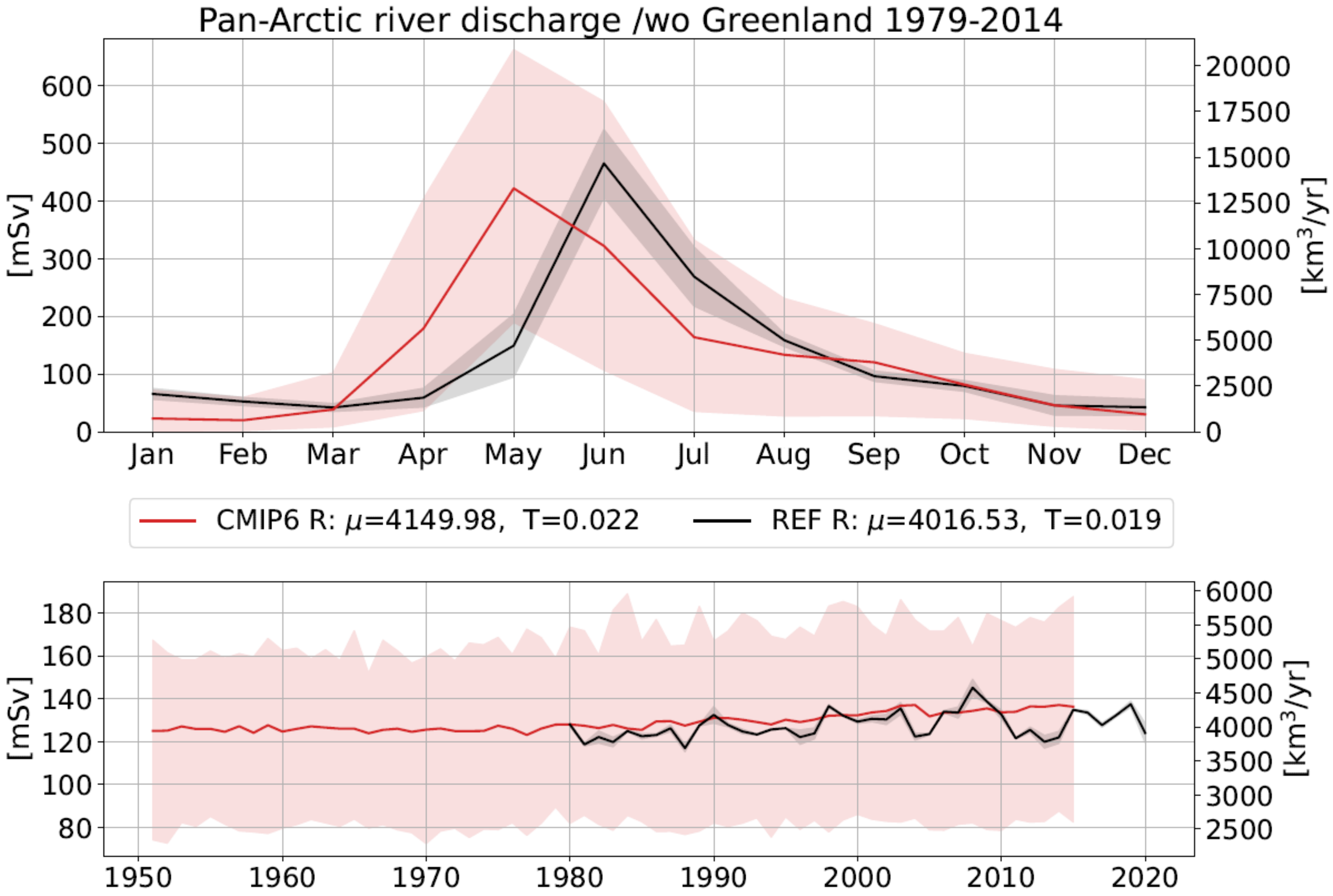
Step 1: Distribute budget residual across the individual terms $F_k = F'_k + \frac{{\sigma'}_k^2}{\sum_i {\sigma'}_i^2} \sum_i F'_i$

Step 2: Ensure that annual mean = annually optim. fluxes $FO_k = F_k + \frac{12{\sigma'}_k^2}{\sum_i {\sigma'}_i^2} \left(F_m - \frac{1}{12} \sum_i F'_i\right)$



CMIP6 - Runoff

- Models disagree in discharge peak timing (64% in May, 36% in June), probably due to different river routing schemes
- Good reproduction of multiannual means and trends



CMIP6 - P,E,ΔS

Atmospheric water input:

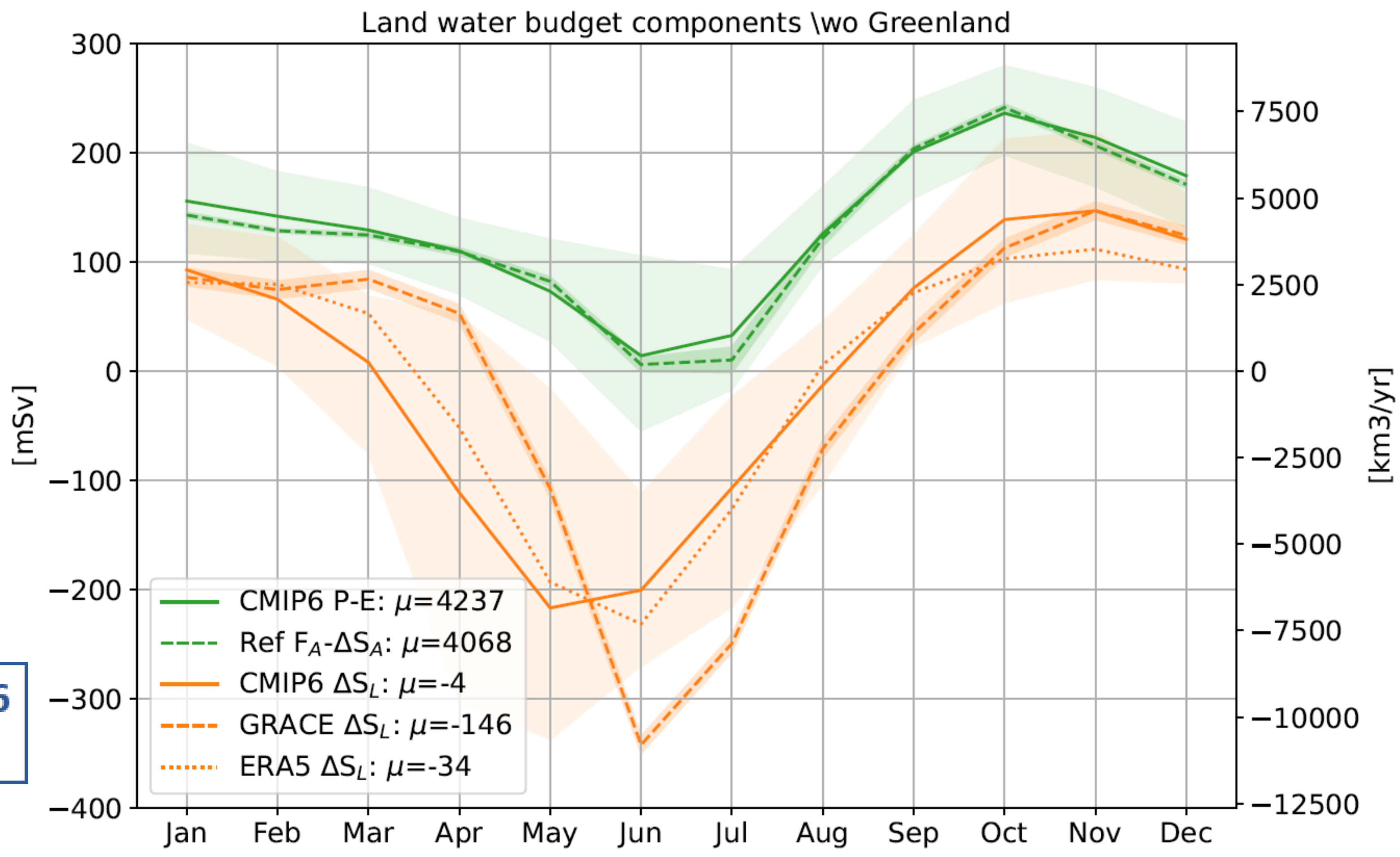
- Good agreement in seasonal cycles, moderate in annual means

Land storage change:

- 1 month offset between CMIP6 and obs. based reference
- Large difference in annual mean tendency

CMIP6

Ref



Summary

- Reanalyses (ERA5, ERA5-Land, GloFAS 2.1) underestimate the seasonal runoff peak and are not able to reproduce observed trends
- Distinct improvements using GloFAS 3.1
- Closure of water budget obtained using satellite observations, in-situ observations and reanalyses and a variational optimization scheme

→ **Up-to-date observation-based estimates of Arctic water budget components on annual and seasonal scales, including uncertainty estimates**

Winkelbauer, S., Mayer, M., Seitner, V., Zsoter, E., Zuo, H., and Haimberger, L.: Diagnostic evaluation of river discharge into the Arctic Ocean and its impact on oceanic volume transports, Hydrol. Earth Syst. Sci., 26, 279–304, https://doi.org/10.5194/hess-26-279-2022, 2022.

CMIP6

- Seasonal offset in river discharge peak and land water storage change peak
- Good agreement with observed increase in river discharge (1979-2014)
- Underestimation of land water storage change

CMIP6 Outlook

- Calculate accurate oceanic volume and heat fluxes

- Evaluation of the Arctic energy budget using observationally constrained data

Mayer, M., Tietsche, S., Haimberger, L., Tsubouchi, T., Mayer, J., & Zuo, H. (2019). An Improved Estimate of the Coupled Arctic Energy Budget, Journal of Climate, 32(22), 7915-7934, https://doi.org/10.1175/JCLI-D-19-0233.1.

- Include model weighting (performance and independence)

Brunner, L. et al. (2020): A weighting scheme to constrain global temperature change from CMIP6 accounting for model independence and performance Earth Syst. Dynam. Diss. DOI: 10.5194/esd-2020-23