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How well can we estimate the water and energy budgets across northern Eurasia?

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Introduction

A major goal of the Northern Eurasia Earth Science Partnership Initiative (NEESPI) project is quantifying the seasonal mean cycle and interannual variability of the water and energy cycles across northern Eurasia. Significant uncertainties exist in such a quantification, in large part due to the sparseness of the in situ observational network. The network's limitations can be bridged through the use of hydrological models, global reanalysis products, and remote sensing. Questions remain, however, about the accuracy of these products and their consistency. Using multiple data sources, we have estimated the components of the terrestrial water budget across the NEESPI domain and evaluate their consistency through consideration of the physical constraints on the budgets..

Methods

The mass conservation equations for the atmosphere and land surface:

$$\frac{\partial w}{\partial t} = -\nabla\cdot qv - P + E$$

$$\frac{\partial s}{\partial t} = P - E - R$$

w = precipitable water
s = soil moisture
$\nabla\cdot qv$ = moisture divergence
P = precipitation
E = evaporation
R = runoff

Through the manipulation of these equations, we can infer different components of the water budgets to arrive at multiple estimates of a component. For example, over long time scales, the storage terms become negligible, leaving:

$$R = -\nabla\cdot qv = P - E$$

To satisfy conservation of energy, the following equation holds:

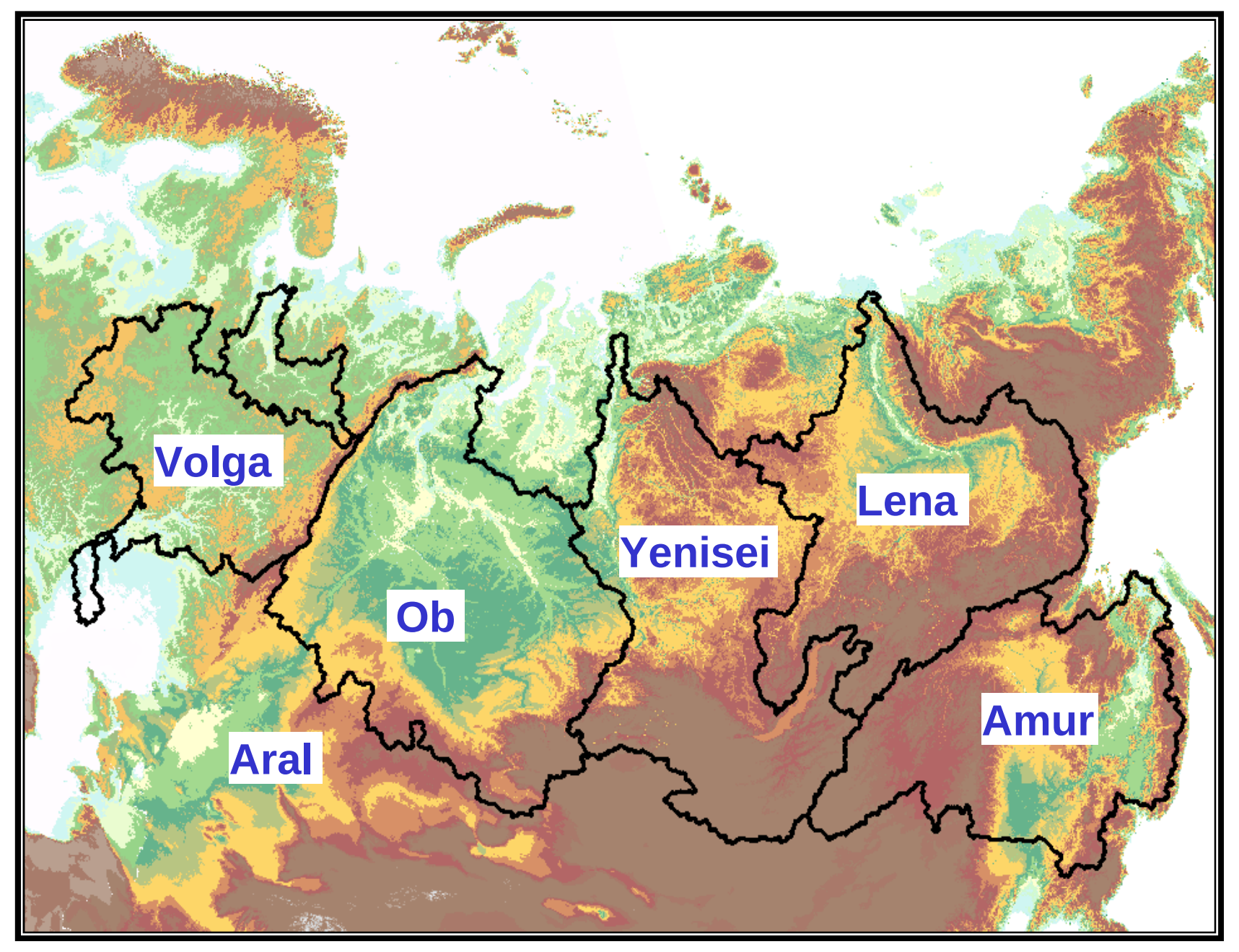
$$R_{net} = \lambda E + H + G$$

R_{net} = net radiation
H = sensible heat flux
G = ground heat flux

Data

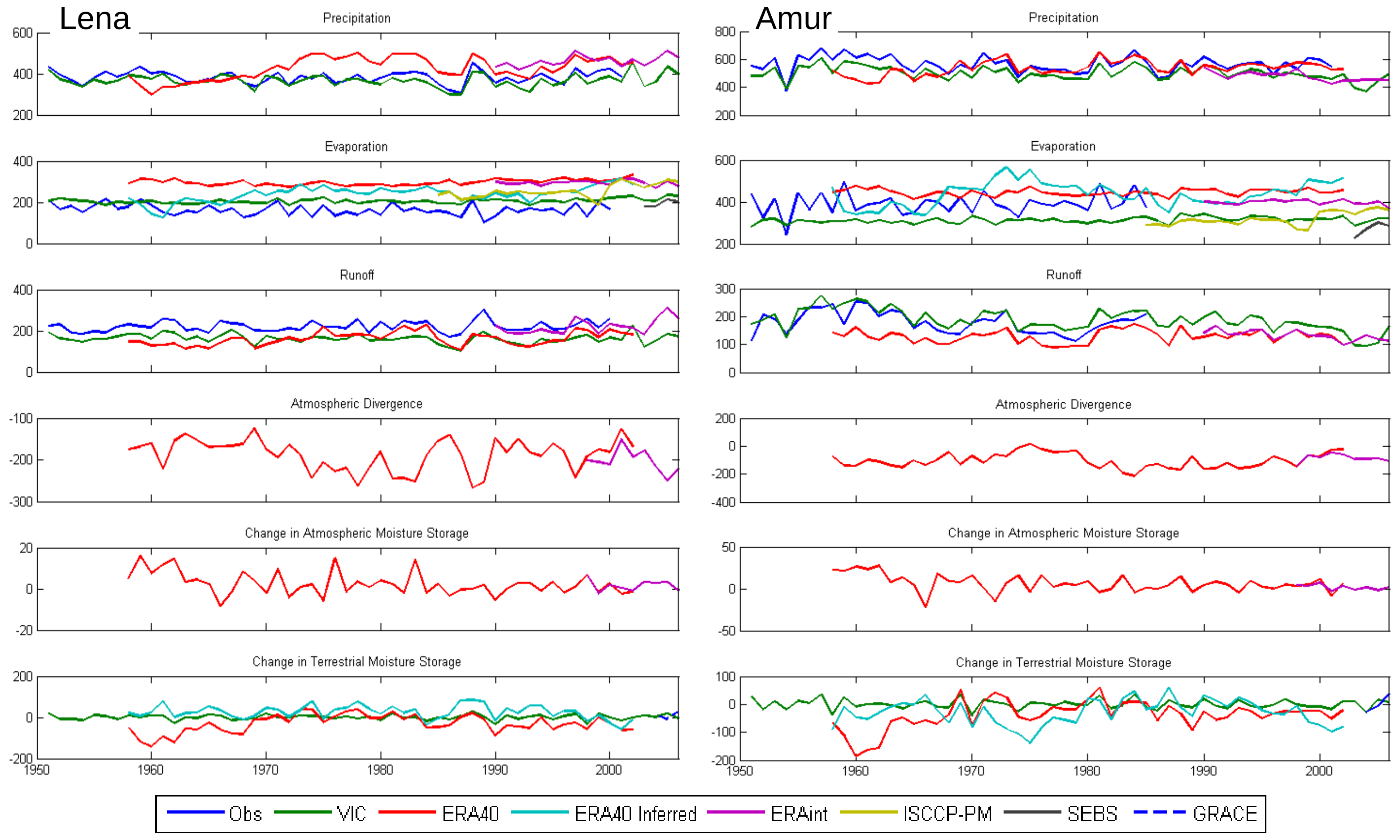
Variable	Dataset	Start Year	End Year
Precipitation	Gauge observations	1891	2001
	ERA40	1957	2002
	ERA interim	1989	2006
	PGF (Sheffield *et al*, 2006)	1948	2006
Evaporation	Obs P - Obs Q	1930	2001
	VIC	1950	2006
	ISCCP/Penman Monteith-based	1984	2006
	SEBS	2002	2006
	ERA40	1957	2002
	ERA40 (inferred from budget)	1957	2002
	ERA interim	1989	2006
	ERA interim (inferred)	1989	2006
Discharge	Gauge observations	1930	2006
	VIC	1950	2006
	ERA40	1957	2002

Variable	Dataset	Start Year	End Year
Convergence	ERA40	1957	2002
	ERA interim	1989	2006
$\partial w/\partial t$	ERA40	1957	2002
	ERA interim	1989	2006
$\partial s/\partial t$	GRACE CSR RL04	2002	2006
	VIC	1950	2006
	ERA40 – Terrestrial budget residual	1957	2002
	ERA40 - Atmosphere/ Terrestrial residual	1957	2002
	ERA interim	1989	2006
Radiative Fluxes	PGF (DSW & DLW)	1948	2006
	ERA40	1957	2002
	ERA interim	1989	2006
	ISCCP	1984	2006
	SRB	1984	2006

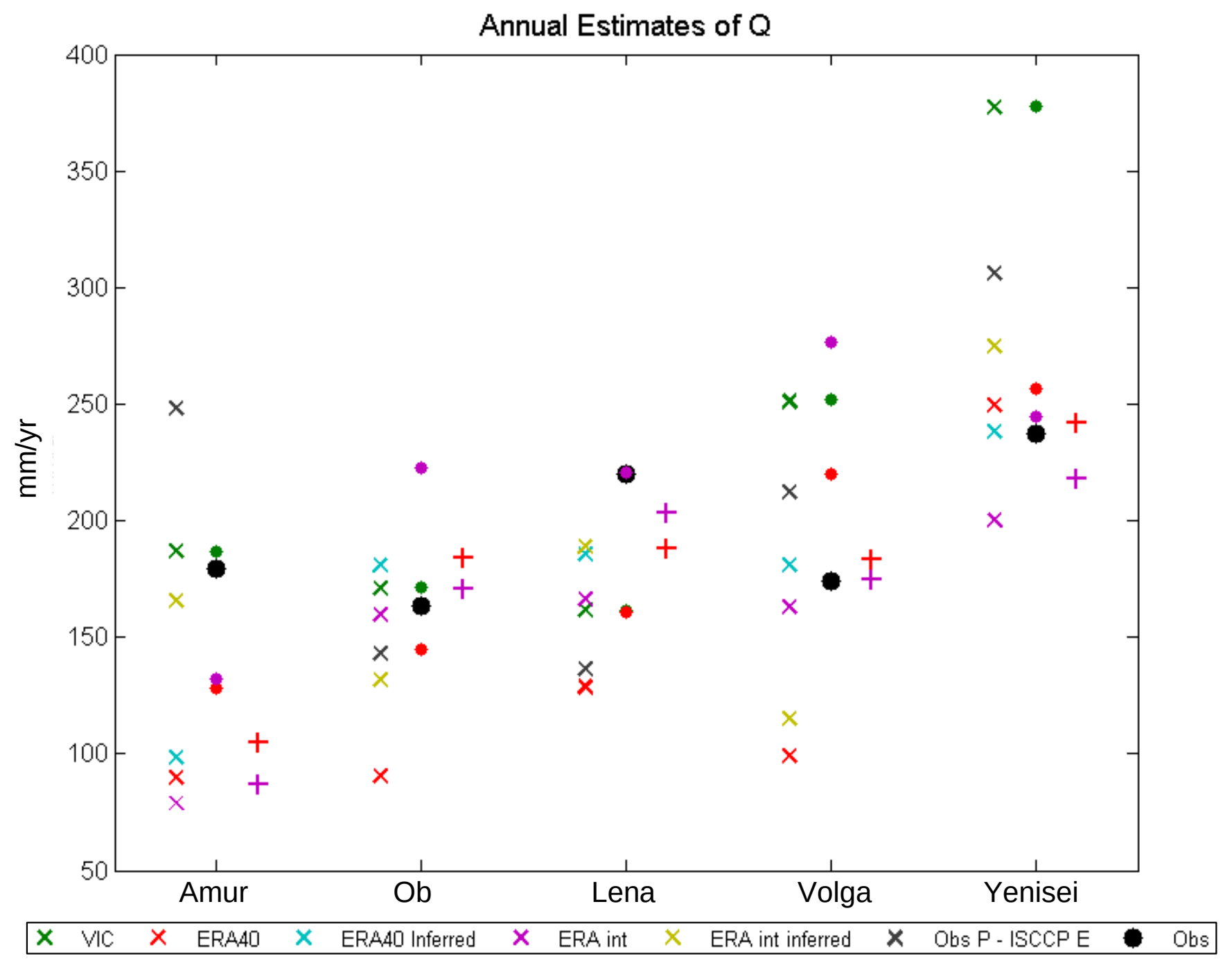


- Region of study shown to the left with river basins overlain on an elevation map.
- Unless otherwise noted, analyses are calculated for 1950-2006. Many datasets do not fully cover this period, and this was handled by using data whenever available for the above period.
- Water balance analyses are done by river basin.
- Radiative flux evaluations were taken as an average across the whole domain (defined as north of 40N, east of 30E).

Annual Components of Water Budget



Inferring Discharge from Other Variables



On long time scales, the storage terms should equal zero, leaving

$$R = -\nabla\cdot qv = P - E$$

In the figure to the left, the estimates of discharge from P-E, moisture convergence, and modelled discharge vary widely.

Circles represent estimates from runoff fields, x's from P-E, and +'s from atmospheric convergence. The large black dots are gauge measurements of discharge.

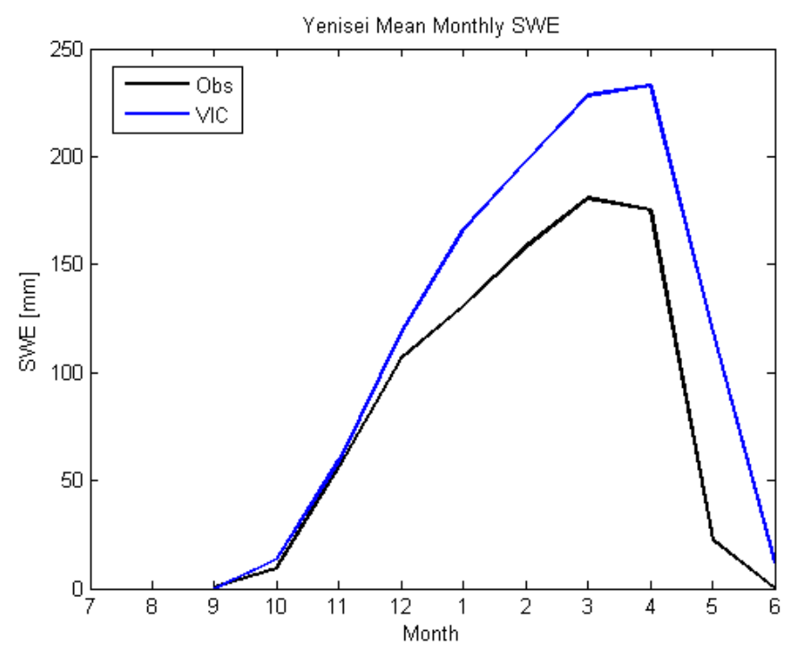
On monthly time scales, we can rearrange the terms of the water balance, such that:

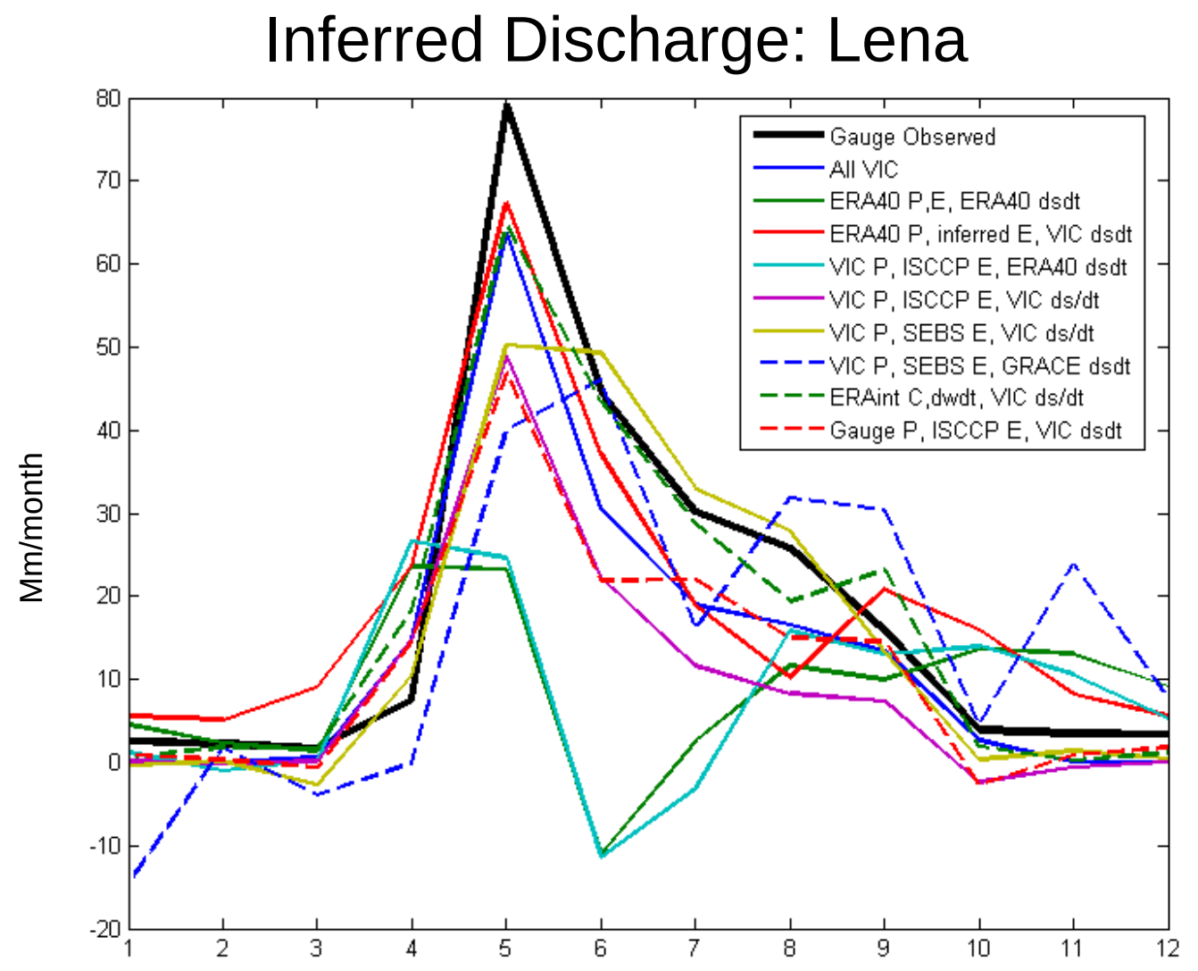
$$R = P - E - \frac{ds}{dt}$$

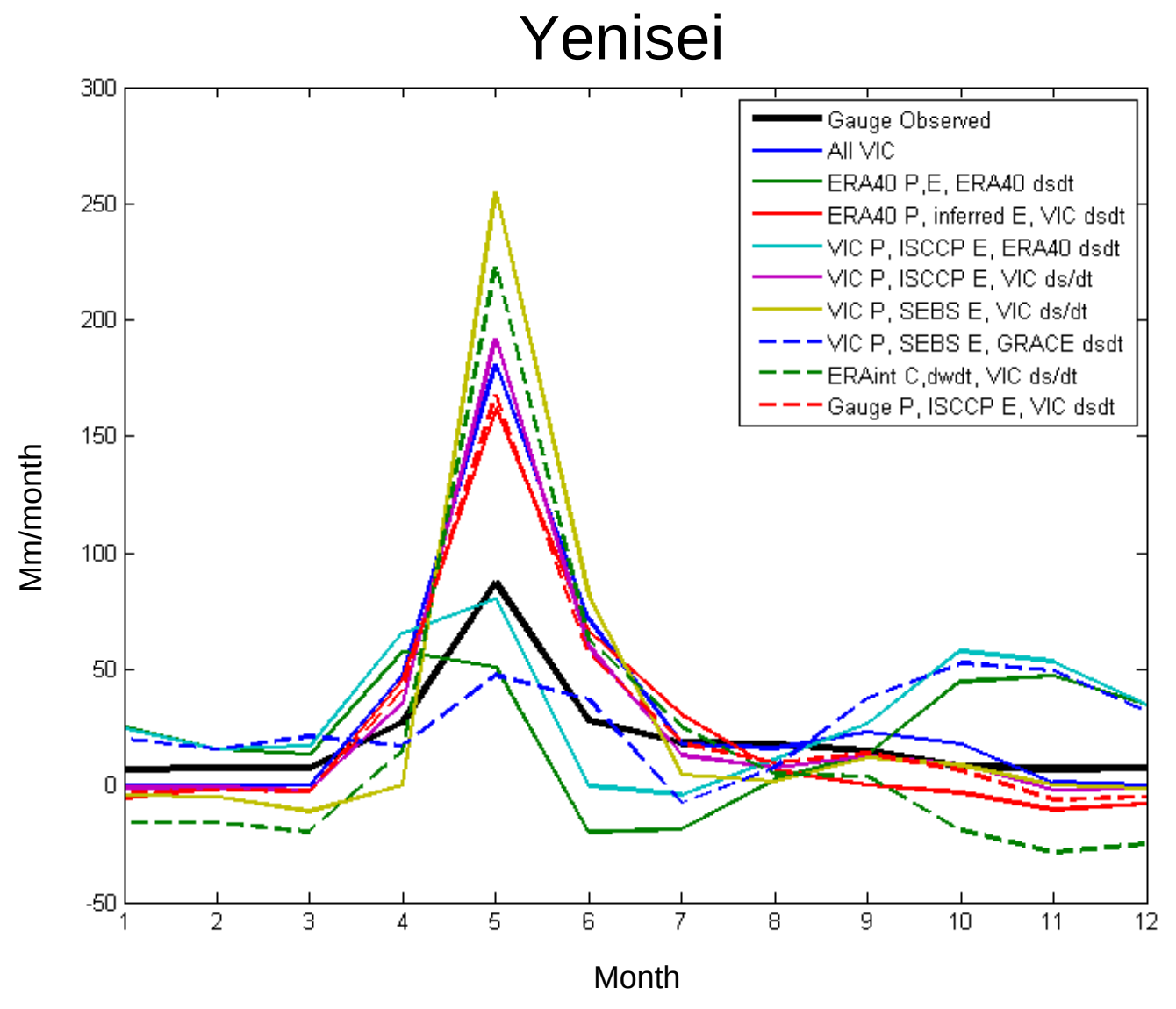
The figure to the right shows great variability in estimates of monthly discharge. The observed discharge is shifted by approximately 30 days to account for lag time in streamflow. The storage term for the ERA40 is calculated as

$$\frac{ds}{dt} = -\nabla\cdot qv - \frac{\partial w}{\partial t} - R$$

The peak of the Yenisei discharge is overestimated because the VIC modelled snowpack is too large, causing the change in storage term to be too large.



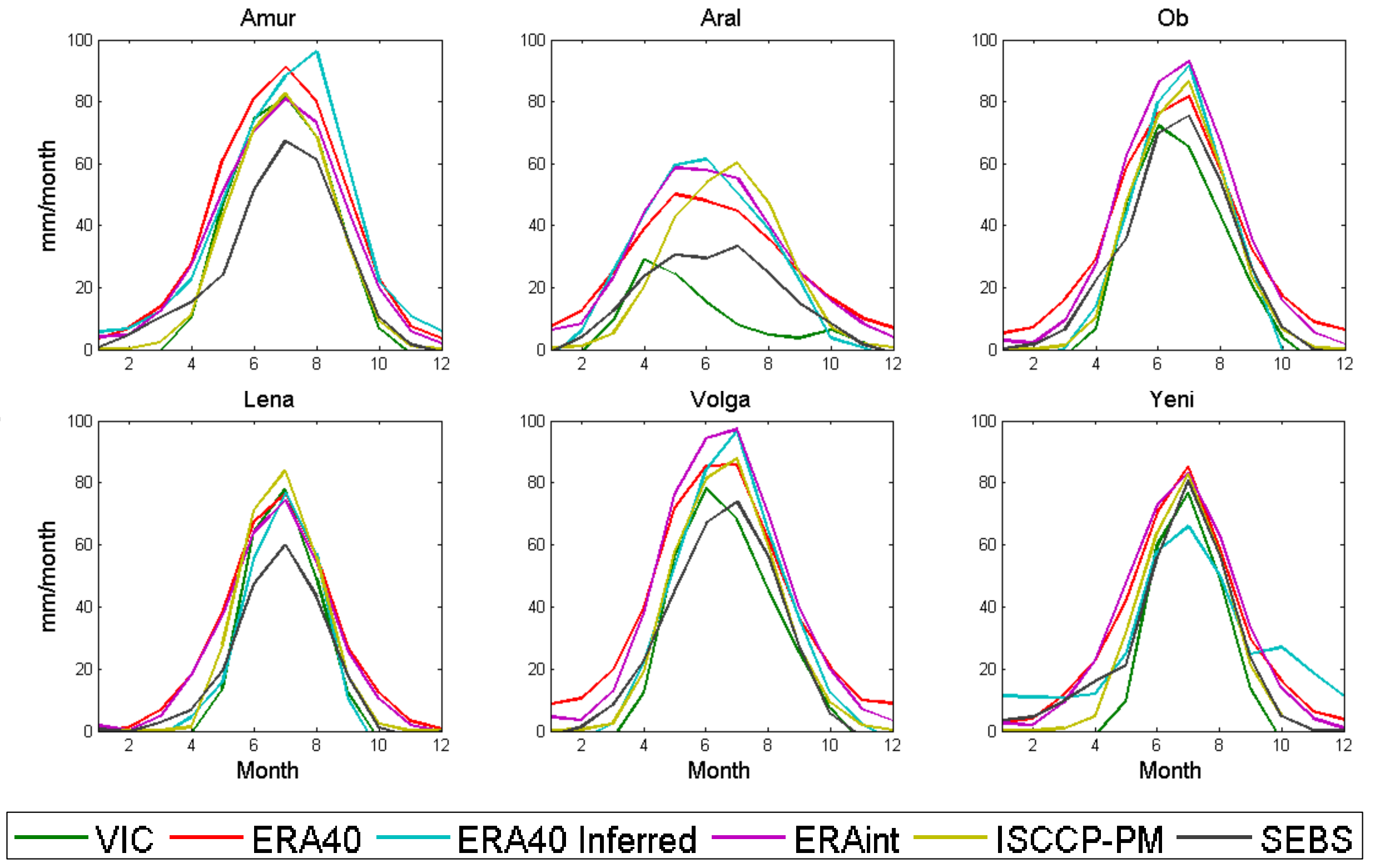




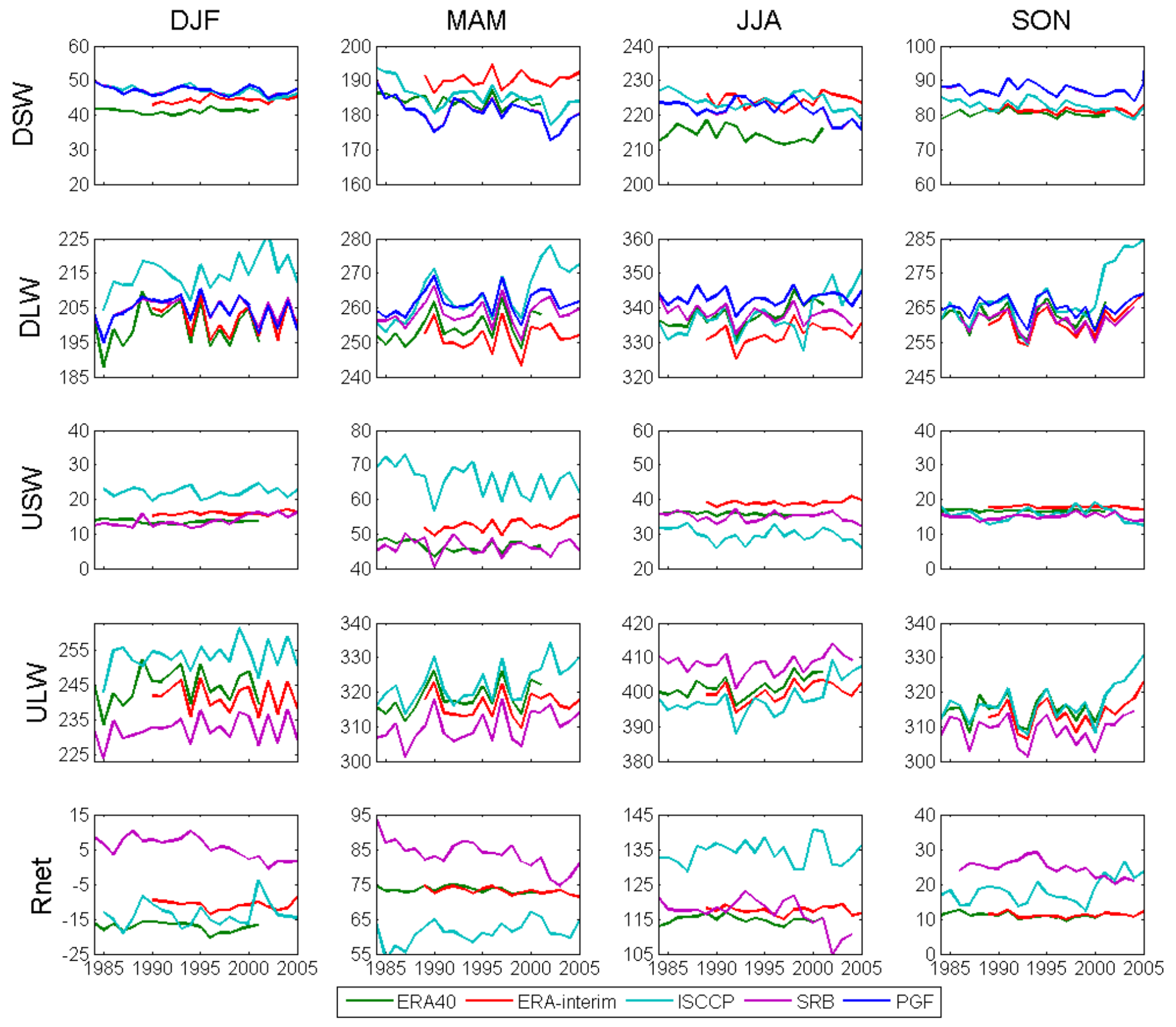
Seasonal Cycle of Evapotranspiration

Evapotranspiration remains the most difficult variable to directly measure. With models and remote sensing, it is possible to estimate ET across the domain.

To the right, estimates of the mean seasonal cycle of ET (1989-2006) show large spread across most months. ERA40 Inferred is the residual of ERA40 precipitable water, ERA40 moisture convergence, and gauge precipitation.



Estimates of Radiative Fluxes



- Seasonal radiative fluxes averaged across region
- Biases exist in the radiative components, but interannual variability is similar between products
- Differences in winter & spring USW can be partially attributable to the snow albedo
- For ULW, differences of 2-4 K in skin temperature can lead to differences of 10-15 W/m^2, which could account for the spread in estimates.

Conclusions

- Large uncertainty exists in estimates of the annual and monthly components of the water and energy budgets. This variability is pronounced when inferring annual and monthly discharge from precipitation, evapotranspiration, and storage changes.
- Inferring monthly discharge from different estimates of P, E, and storage changes can highlight what variables contribute the largest uncertainty. Because of the importance of snow storage in the hydrological cycle of this region, differences in estimates of snowpack accumulation and melt can greatly impact estimates of inferred discharge. Observed snow water equivalent estimates should be used to confine the storage term.
- Uncertainty in the radiative fluxes leads to spread in the estimates of net radiation, which may then affect estimates of sensible and latent heat fluxes. As shown above, considerable spread exists in estimates of evapotranspiration, and one reason for this is varying estimates of available energy at the land surface.

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