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CHARACTERIZING TERRESTRIAL RUNOFF PATTERNS TO THE PACIFIC OCEAN FROM WESTERN U.S.

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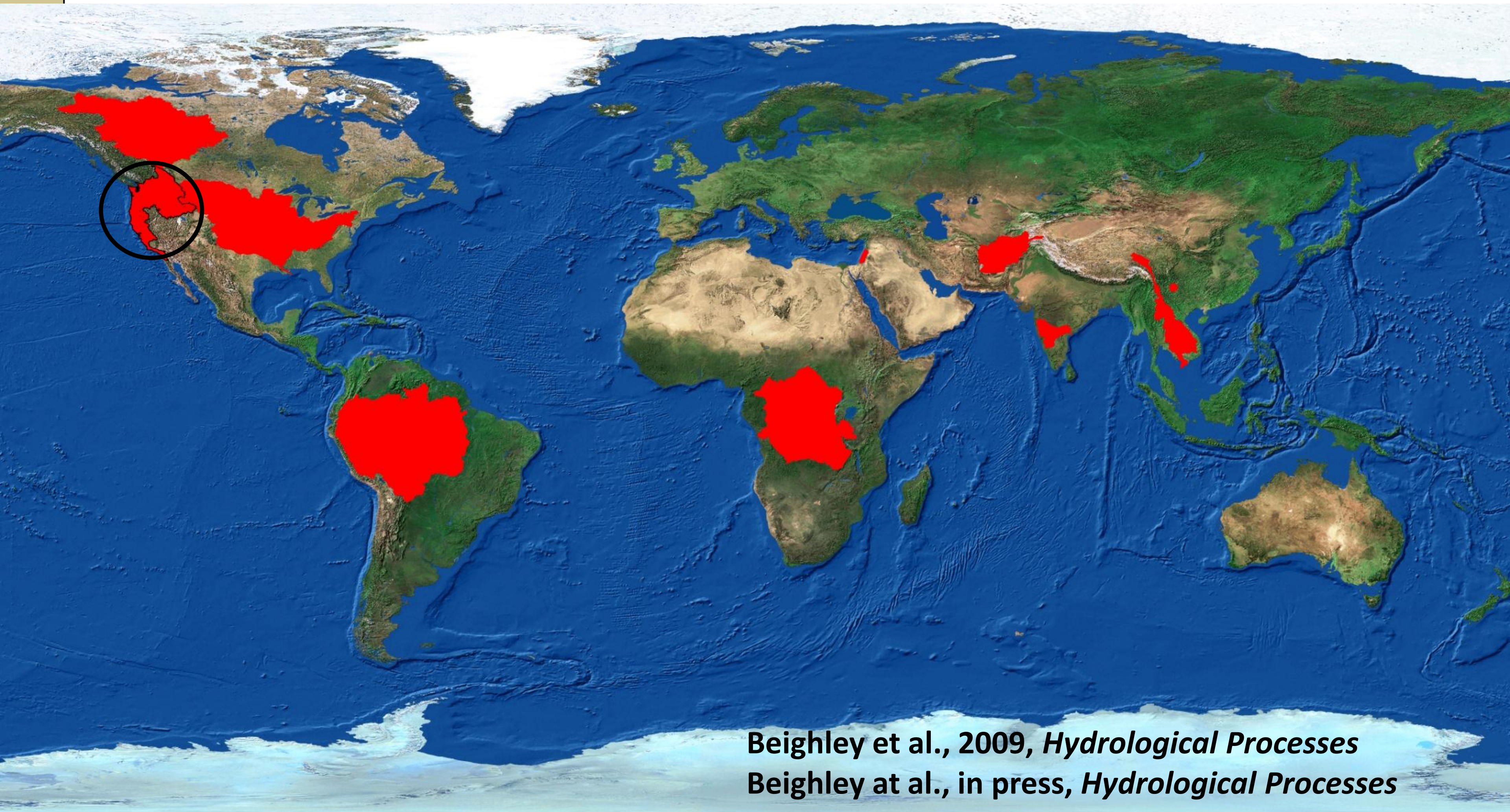
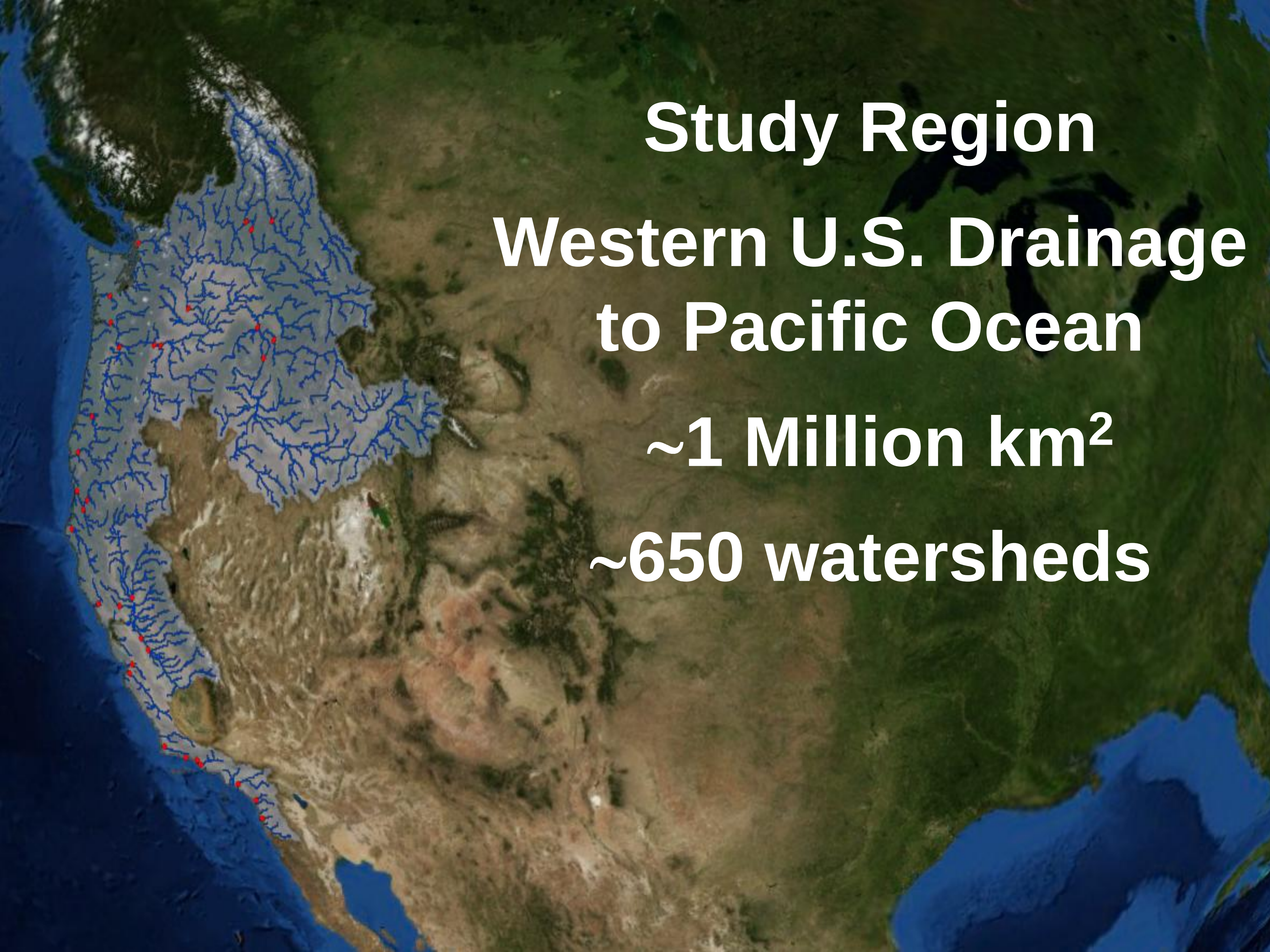
Spatial Hydrology Research Laboratory http://spatialhydro.sdsu.edu/

Hillslope River Routing Model - Applications

- Running on ~10% of global land surface
- Study watersheds ranging from 10 to 6,000,000 sq km
- HRR coupled with a simple WBM; CLM; **MOSAIC**; VIC



Beighley et al., 2009, *Hydrological Processes*
Beighley at al., in press, *Hydrological Processes*



Study Region

Western U.S. Drainage to Pacific Ocean

~1 Million km^2

~650 watersheds

Research Objectives/Methods

- Quantify spatial & temporal distribution of terrestrial runoff from western U.S. into Pacific Ocean
  - How does ENSO conditions impact terrestrial export of water?
- Use Hillslope River Routing (HRR) model to convey MOSAIC surface & subsurface runoff to ocean
- MOSAIC output from North American Land Data Assimilation System (NLDAS): Period 2000-2009
- Discuss potential model improvements from a future SWOT mission

Hillslope River Routing (HRR) Model

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- Multi-scale hydrologic-hydraulic model
- Vertical water/energy balance OR "Output from other models"
- Lateral surface and subsurface kinematic wave routing
- Diffusion wave channel and floodplain routing
- Reservoir routing based on "Stage-Storage" and Outflow relationships
- Irregular computational grid based on topographic boundaries defined by drainage network
- Model tracks ALL water stores and fluxes: soil water, surface runoff, subsurface runoff, channels-floodplains and lakes

Vertical Water/Energy Balance Model

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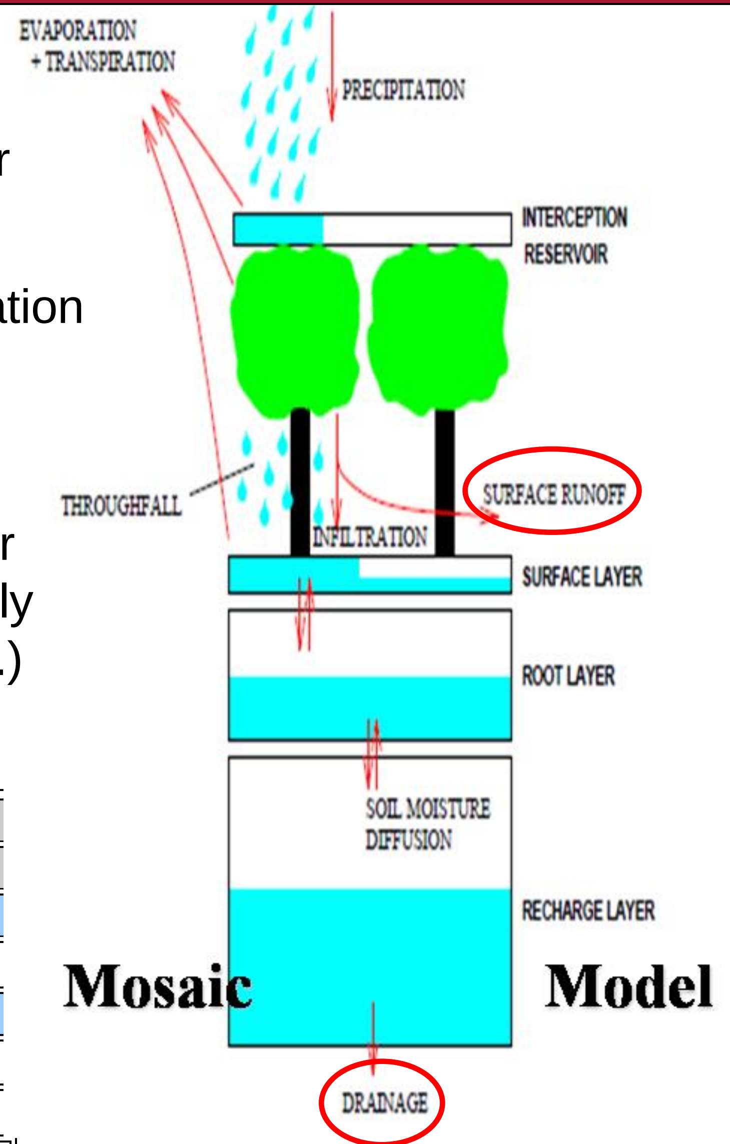
MOSAIC LSM (Koster & Suarez, 1994)

- Surface Runoff and Drainage passed to HRR for lateral surface and subsurface routing
- Output from North American Land Data Assimilation System (NLDAS) http://ldas.gsfc.nasa.gov/nldas/
- NLDAS-2, 0.125 degree, hourly output
- Precipitation Forcings: Climate Prediction Center (gauge data adjusted for elevation and temporally disaggregated w/ Doppler Radar Stage II precip.)

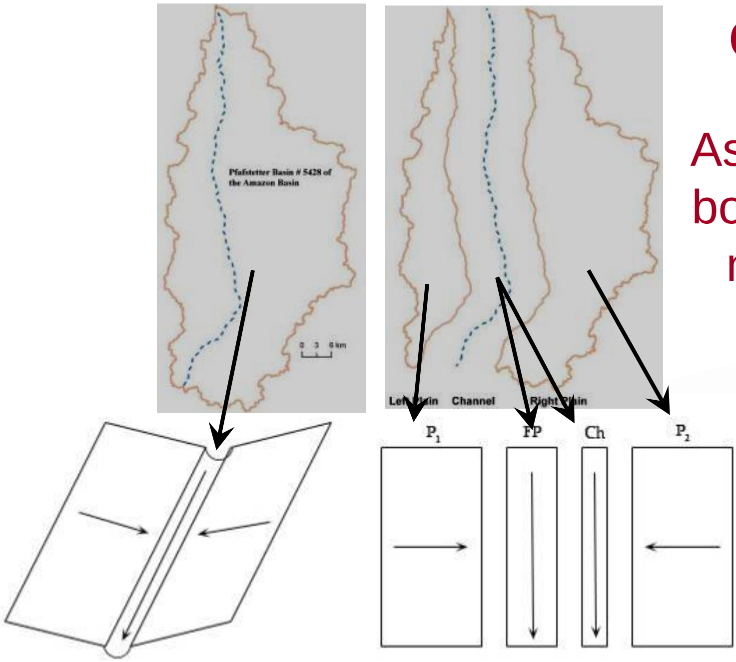
http://disc.sci.gsfc.nasa.gov/hydrology/data-holdings

Data Type (Short Name)	Description	FTP	GDS	Mirador	
				Navigation	Search
NLDAS-1, 0.125 degree, North America					
NLDAS_FOA0125_H.001	Hourly forcing	✓	✓	✓	✓
NLDAS-2, 0.125 degree, North America					
NLDAS_FORA0125_H.002	Hourly primary forcing	✓	✓	✓	✓
NLDAS_FORB0125_H.002	Hourly secondary forcing	✓	✓	✓	✓
NLDAS_MOS0125_H.002	Hourly Mosaic	✓	✓	✓	✓



Hillslope River Routing Framework – Need Hydraulic Characteristics

Channel Routing

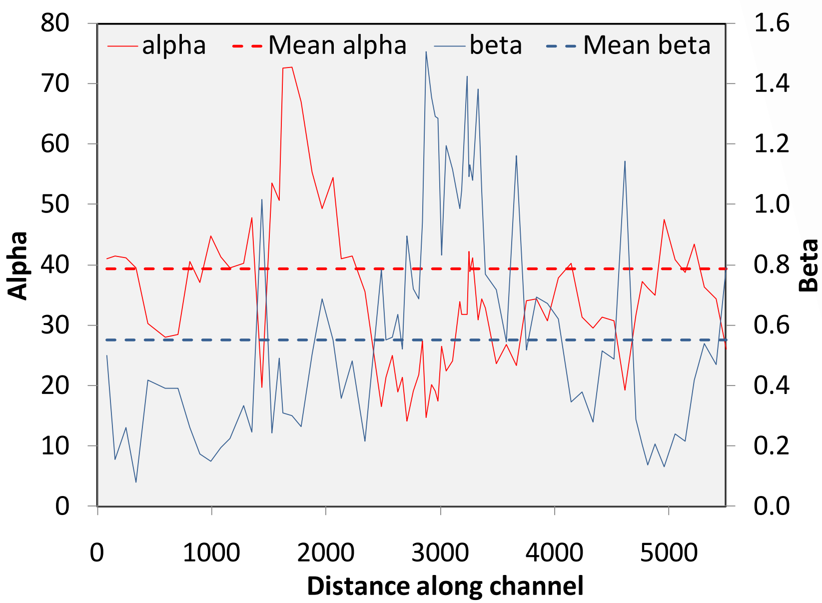


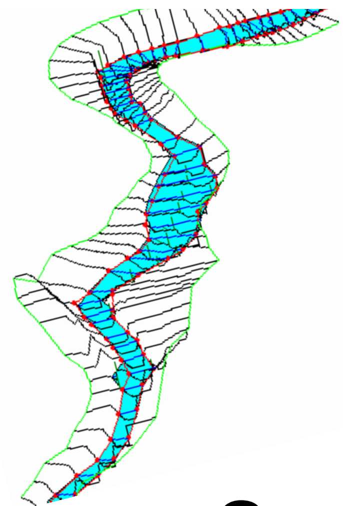
Assume open book for each model unit

$\underline{\boldsymbol{w}} = \alpha(\underline{\mathbf{h}}\text{-}c)^{\beta}$

depth = $\underline{\mathbf{h}}$-*c*

c = bed elev.

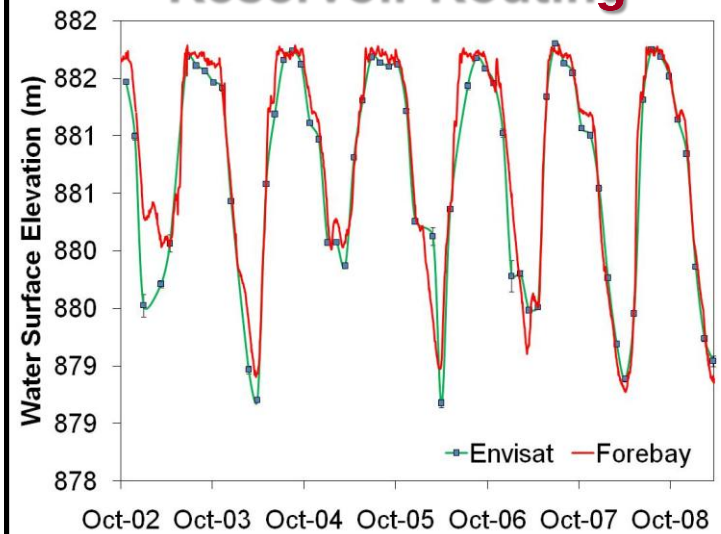




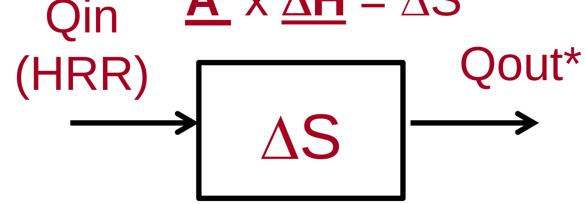
$\boldsymbol{\alpha} = \mathbf{?}$

$\boldsymbol{\beta} = \mathbf{?}$

Reservoir Routing



$\underline{\mathbf{A}}$ x $\underline{\mathbf{\Delta H}}$ = ΔS



Qout* = *f* (Qin, S, t)

***f* (Qin, S, t) = ?**

Iterative process:
work up- to down-stream,
assume function, model Qin,
compare to ΔS, repeat….

Study Region w/ major rivers and stream gauges

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Model Characteristics

- 27,320 channels (**need cross-section & slope for each ch.**)

  Length {slope}

  – Mean: 5.7 km {4.1%}

  – Median: 3.2 km {3.2%}

  – Max: 314 km {36%}

- 54,640 hillslopes

  Length (area) {slope}

  – Mean:1.2 km (19 km^2) {18%}

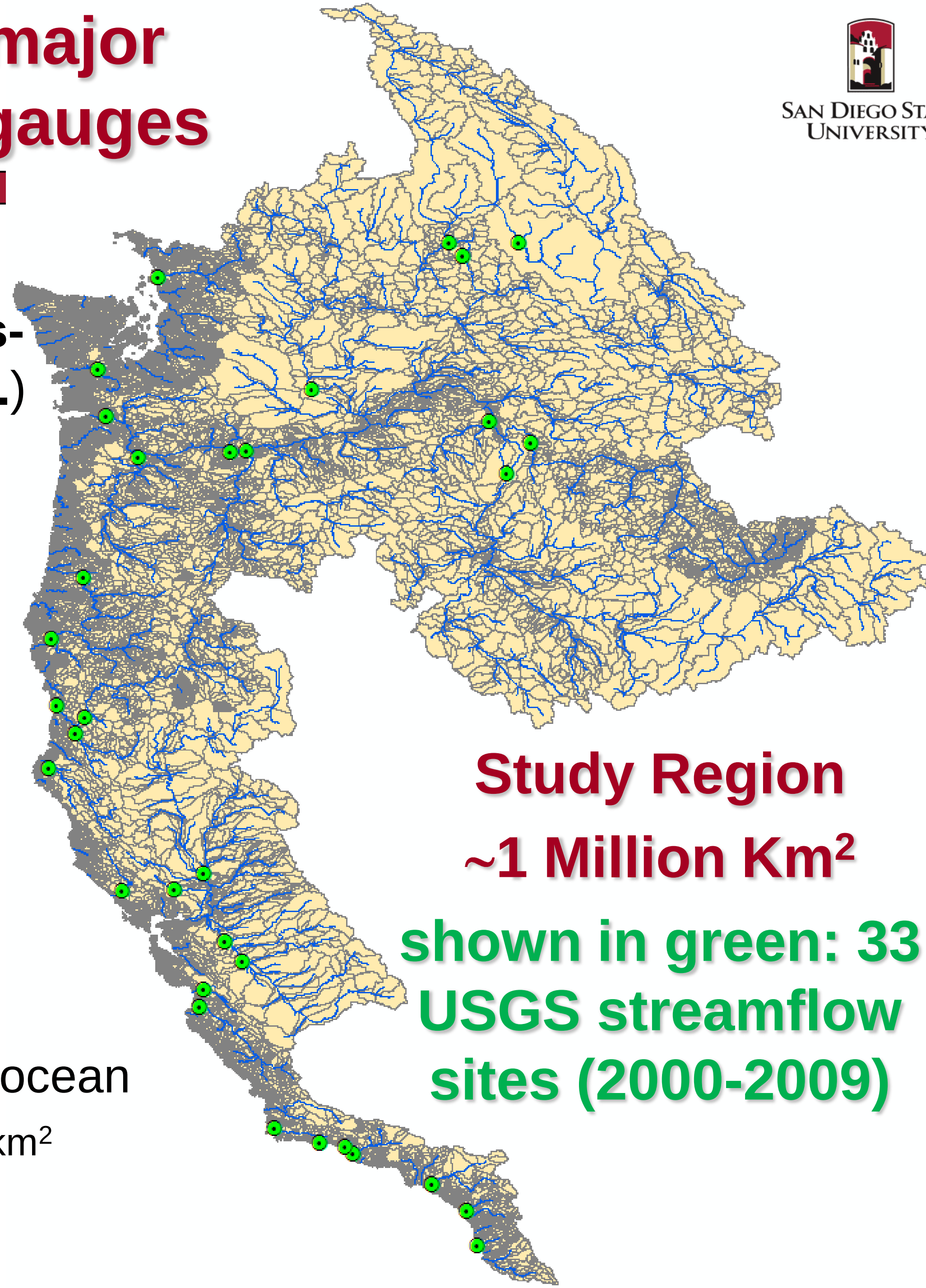
  – Median: 0.8 km (2.7 km^2) {16%}

  – Max: 31 km (9,700 km^2) {83%}

- 648 watersheds discharge to ocean

  – Watershed areas: 5 to 651,000 km^2

  – Median area = 25 km^2

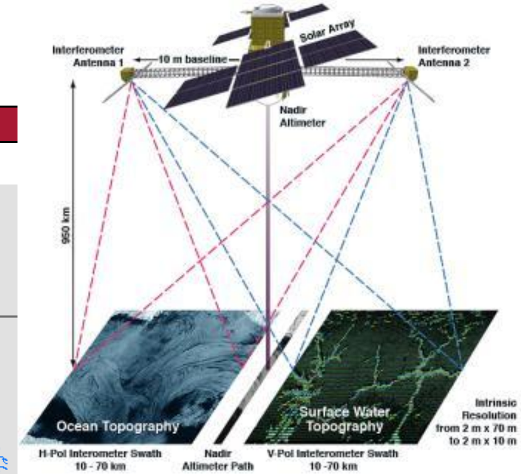


Study Region

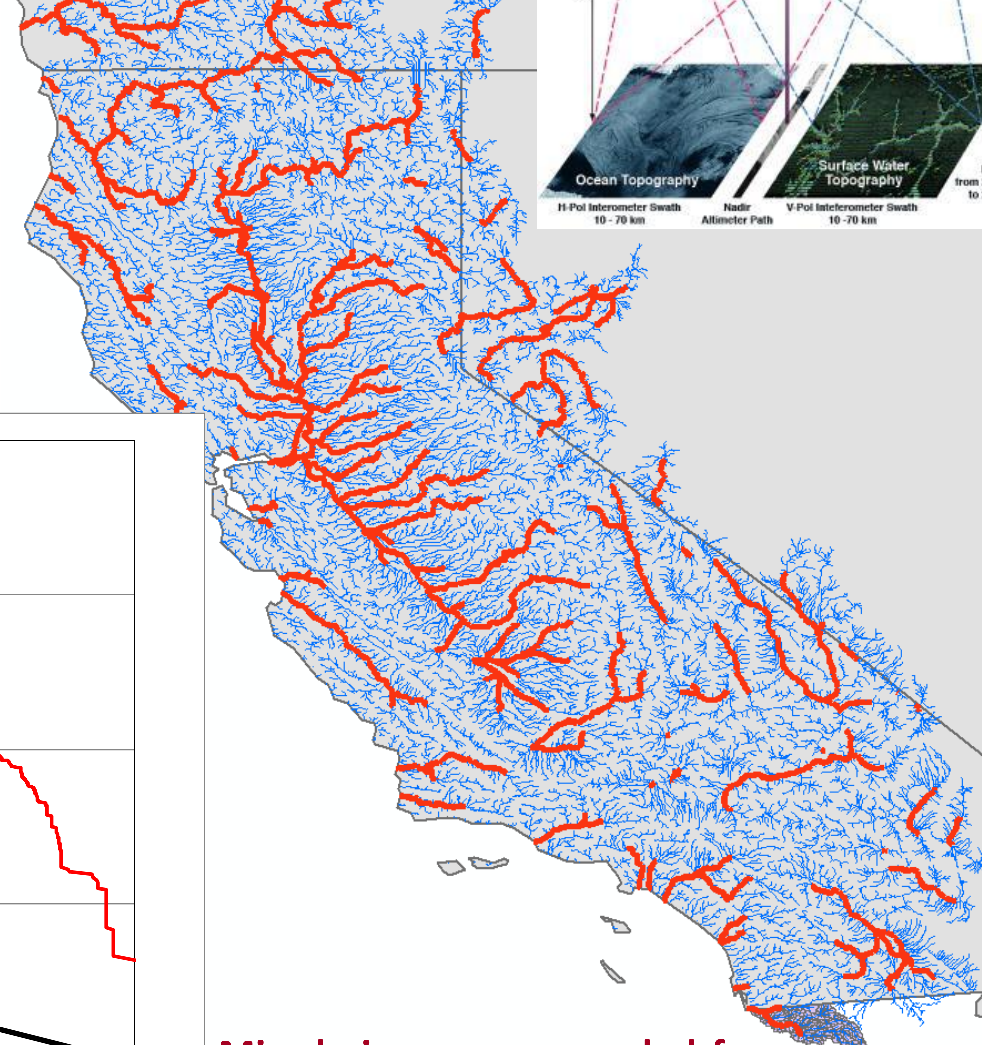
~1 Million Km^2

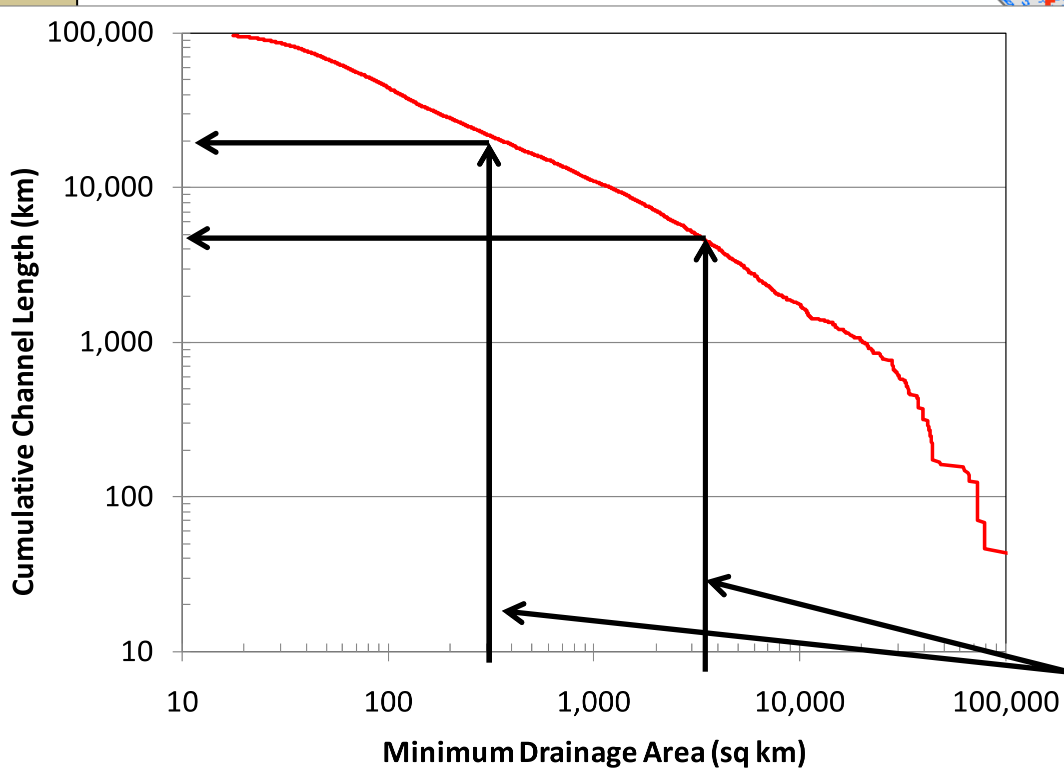
shown in green: 33 USGS streamflow sites (2000-2009)

SWOT Satellite and CA Rivers



- Assume drainage area needed for 50-100 m channel is about 300 to 3000 km^2
- SWOT will see between 5,000 & 20,000 km of channel
- All rivers draining >1,000 sq km shown in Red (about 10,000 km)





Min drainage area needed for a 50-100 m wide channel?

MOSAIC – HRR Re-Mapping

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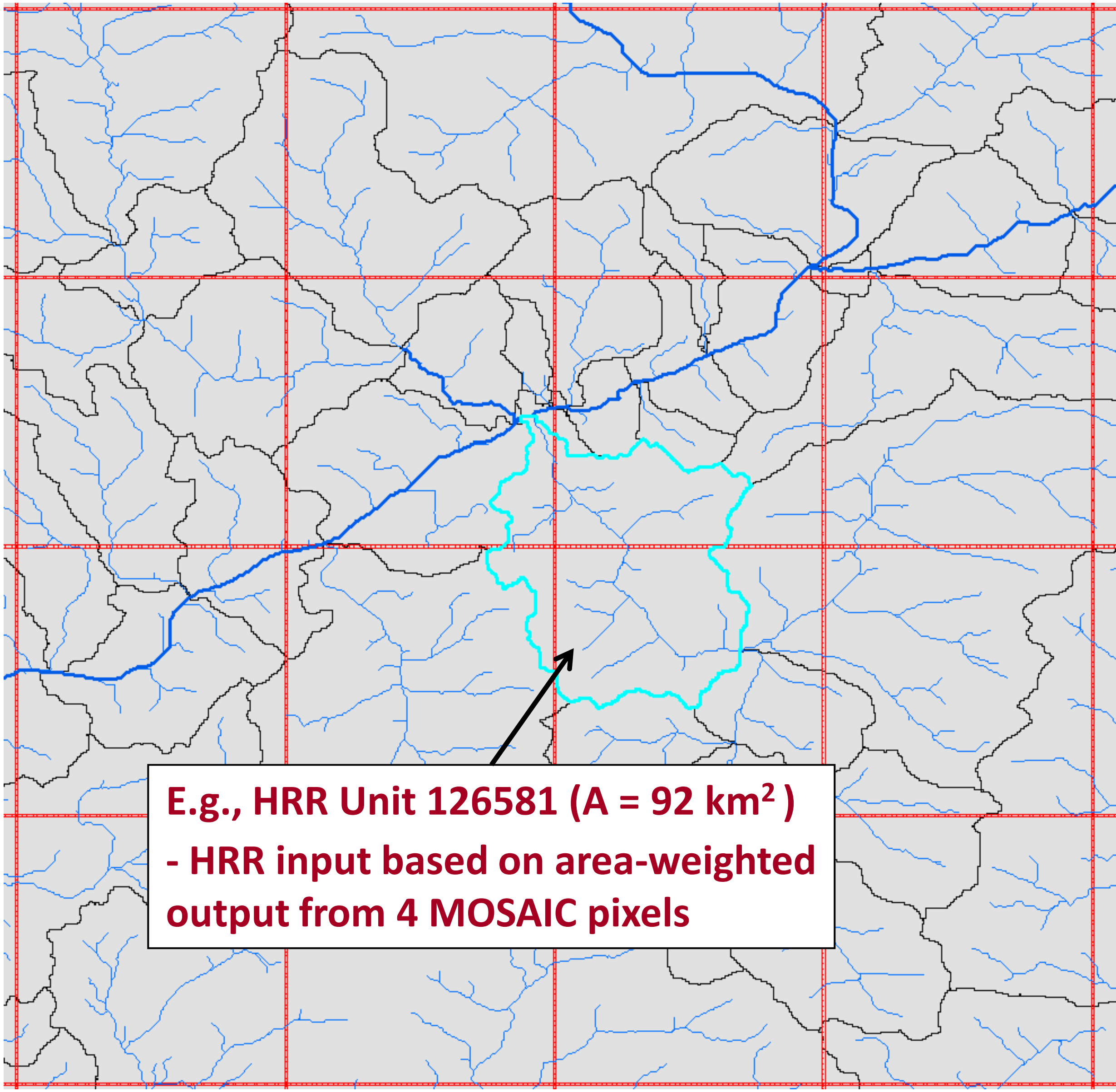
MOSAIC Model

- 0.125 deg (~180 km^2) pixels shown in RED
- Hourly files for North America (GRIB format)

HRR Model

- Irregular boundaries shown in black
- Areas 1 to 1000 km^2
- Area-weighting used to re-map MOSAIC surface and subsurface runoff (ssrunsfc & bgrunsfc) to HRR for routing



Study Region w/ SRTM water bodies and NID Res. locations

SRTM Water Bodies

- Total water surface area =12,200 km^2

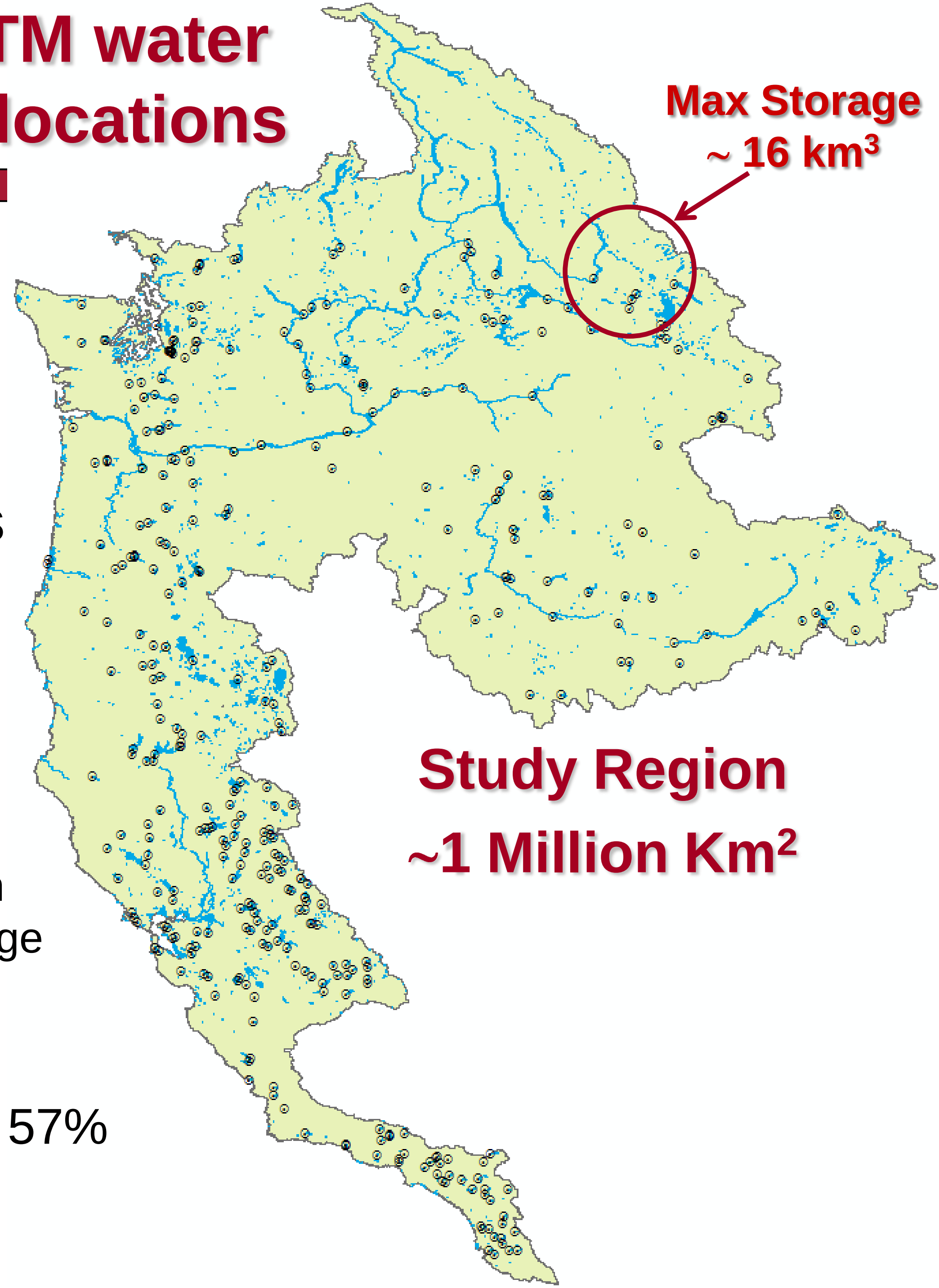
National Inventory of Dams

- 374 dams/reservoirs
- Surface Area = 7,400 km^2
  - 60% of SRTM surface area
- Storage = 120 km^3
  - 117 mm over entire study region
  - 1 to 2% of global reservoir storage

10 largest = 36% of storage

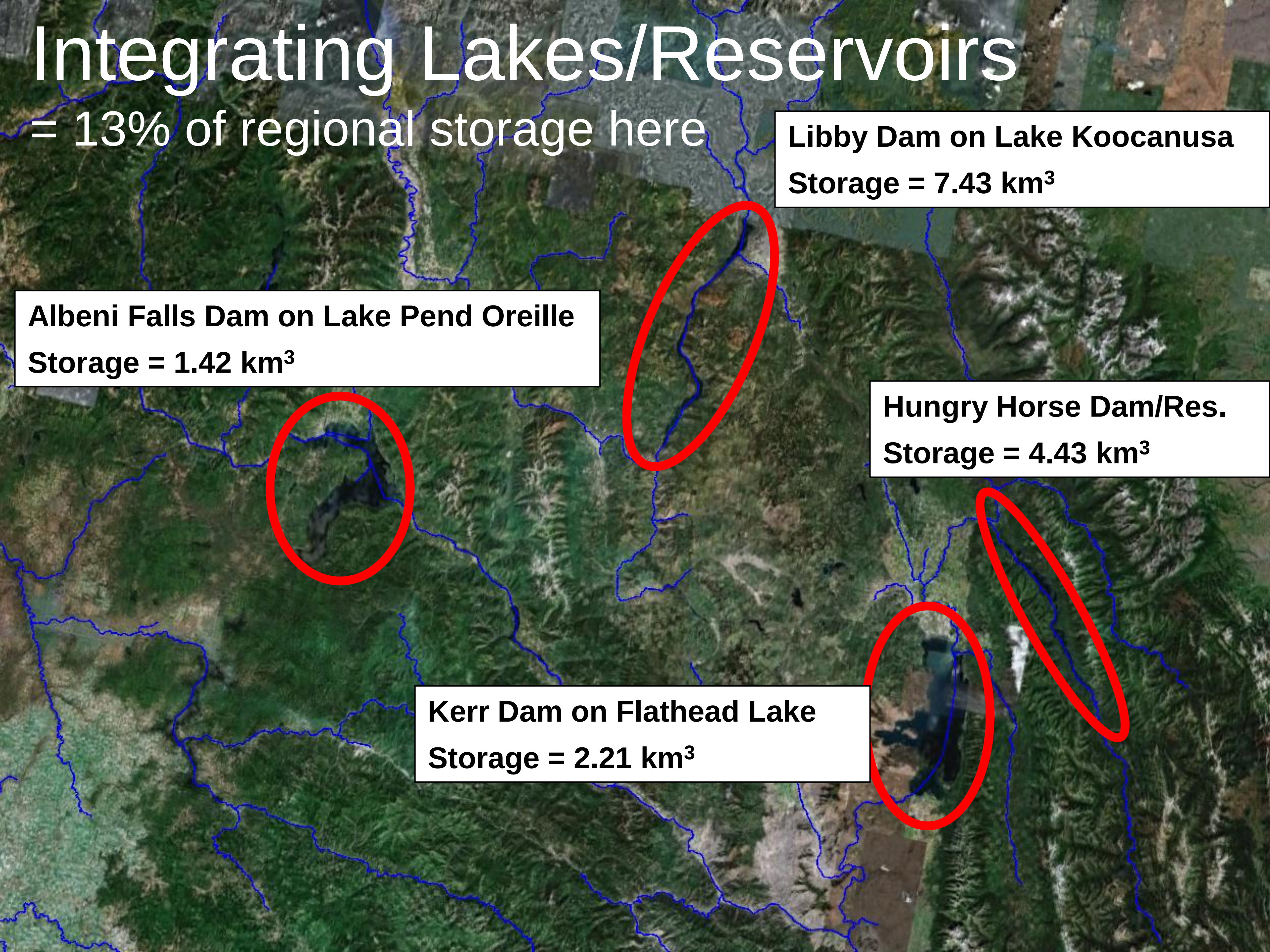
25 largest (S ≥ 0.22 km^3 ea.) = 57%

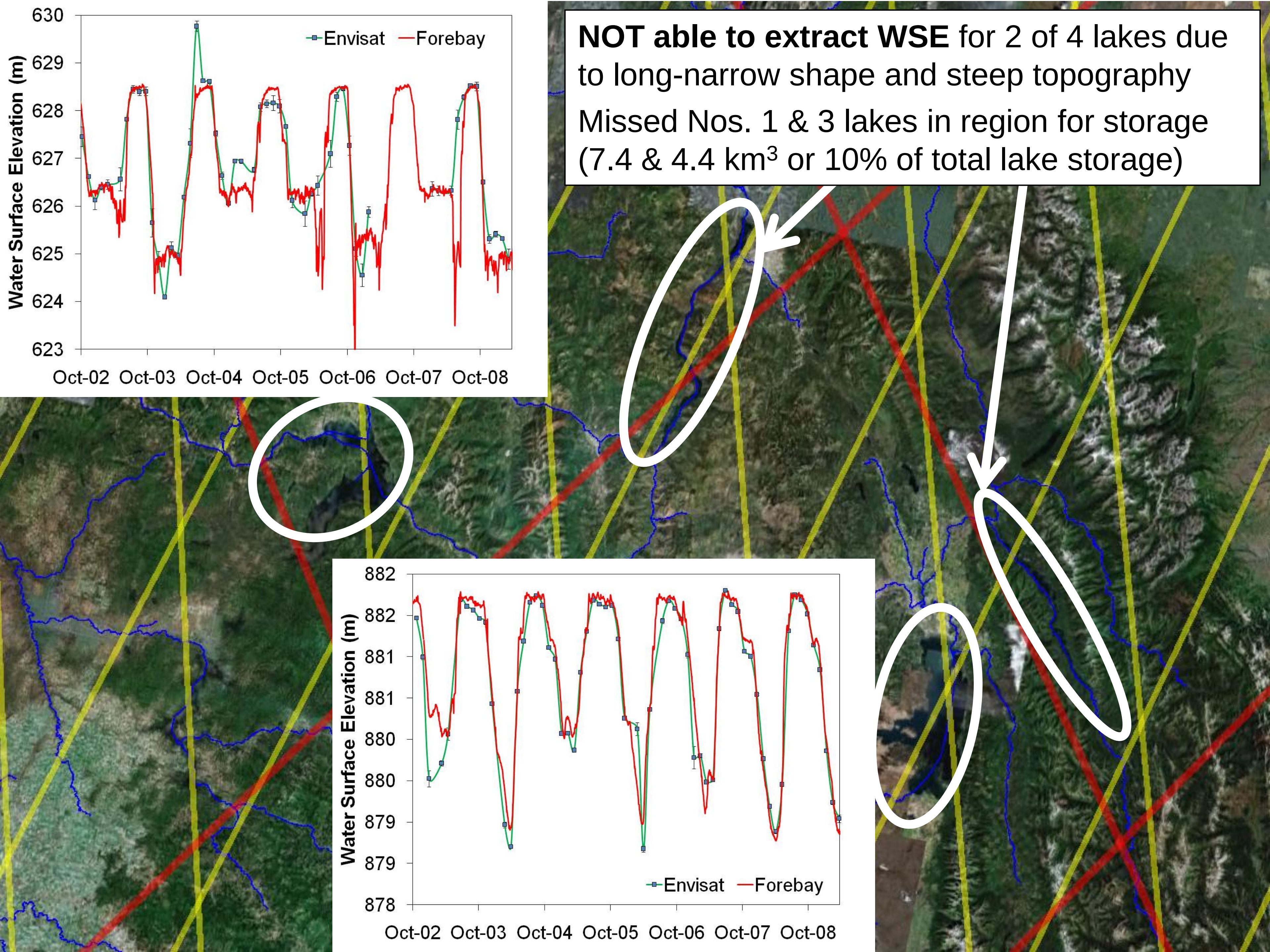
100 largest = 86%



Integrating Lakes/Reservoirs

= 13% of regional storage here



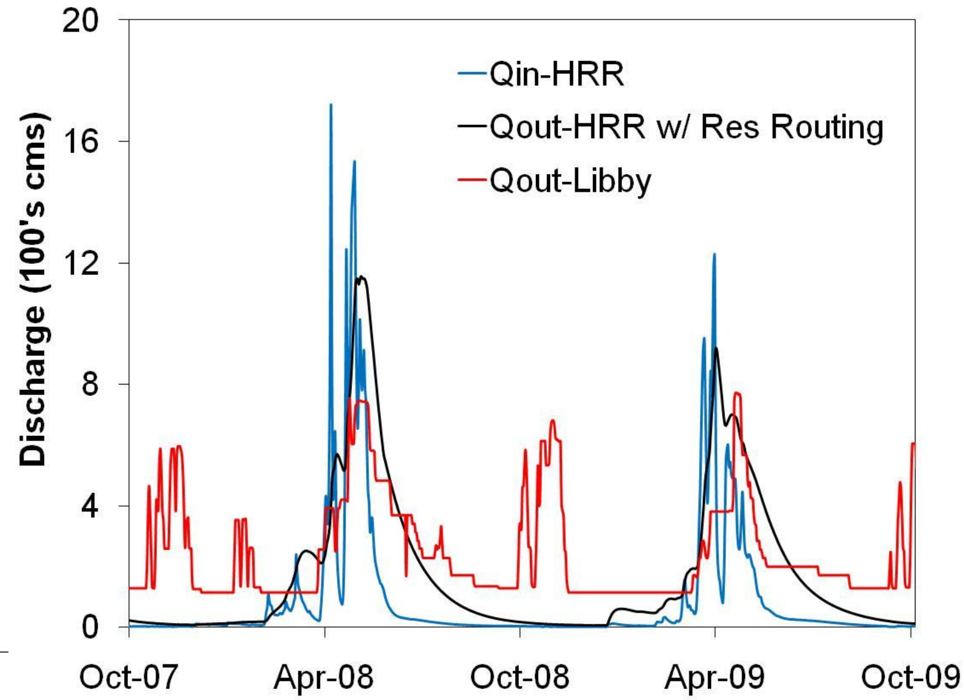


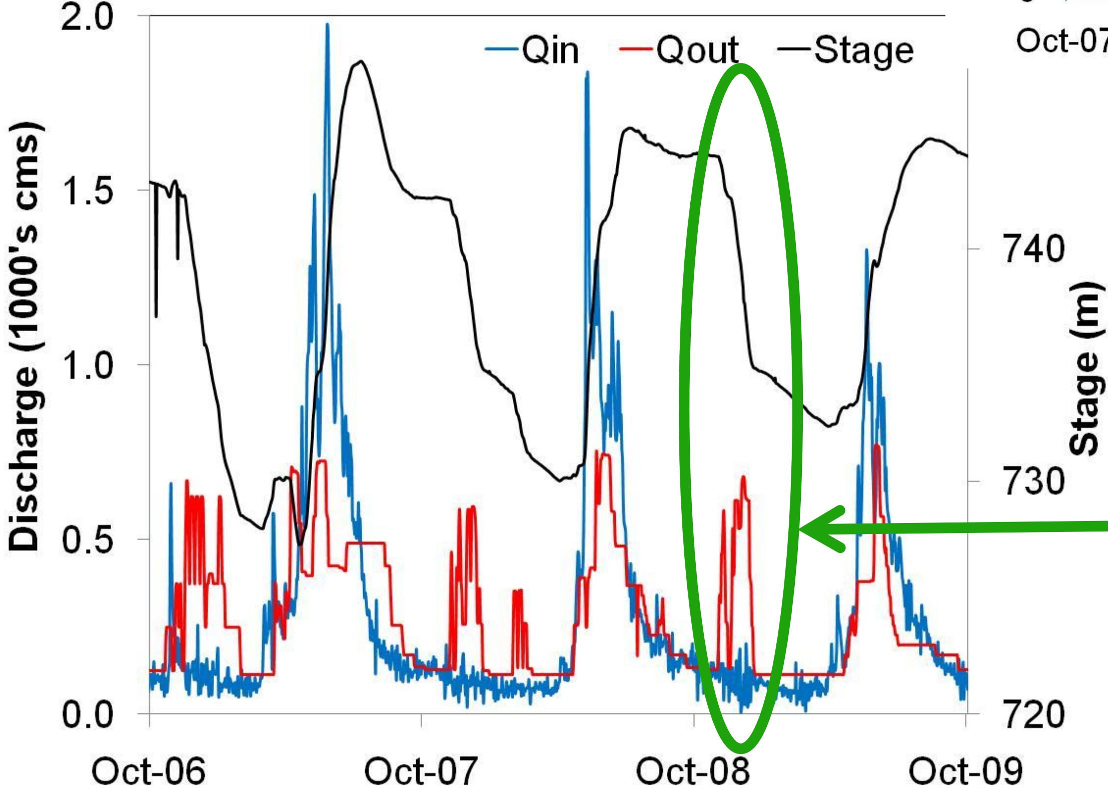
NOT able to extract WSE for 2 of 4 lakes due to long-narrow shape and steep topography
Missed Nos. 1 & 3 lakes in region for storage (7.4 & 4.4 km^3 or 10% of total lake storage)
Water Surface Elevation (m)
630
629
628
627
626
625
624
623
Envisat
Forebay
Oct-02
Oct-03
Oct-04
Oct-05
Oct-06
Oct-07
Oct-08
Water Surface Elevation (m)
882
882
881
881
880
880
879
879
878
Envisat
Forebay
Oct-02
Oct-03
Oct-04
Oct-05
Oct-06
Oct-07
Oct-08

Preliminary Results – Lakes/Reservoirs

Releases not related to Inflow

- Regulated releases in Oct-Dec
- Scheduled releases similar in magnitude to event outflows



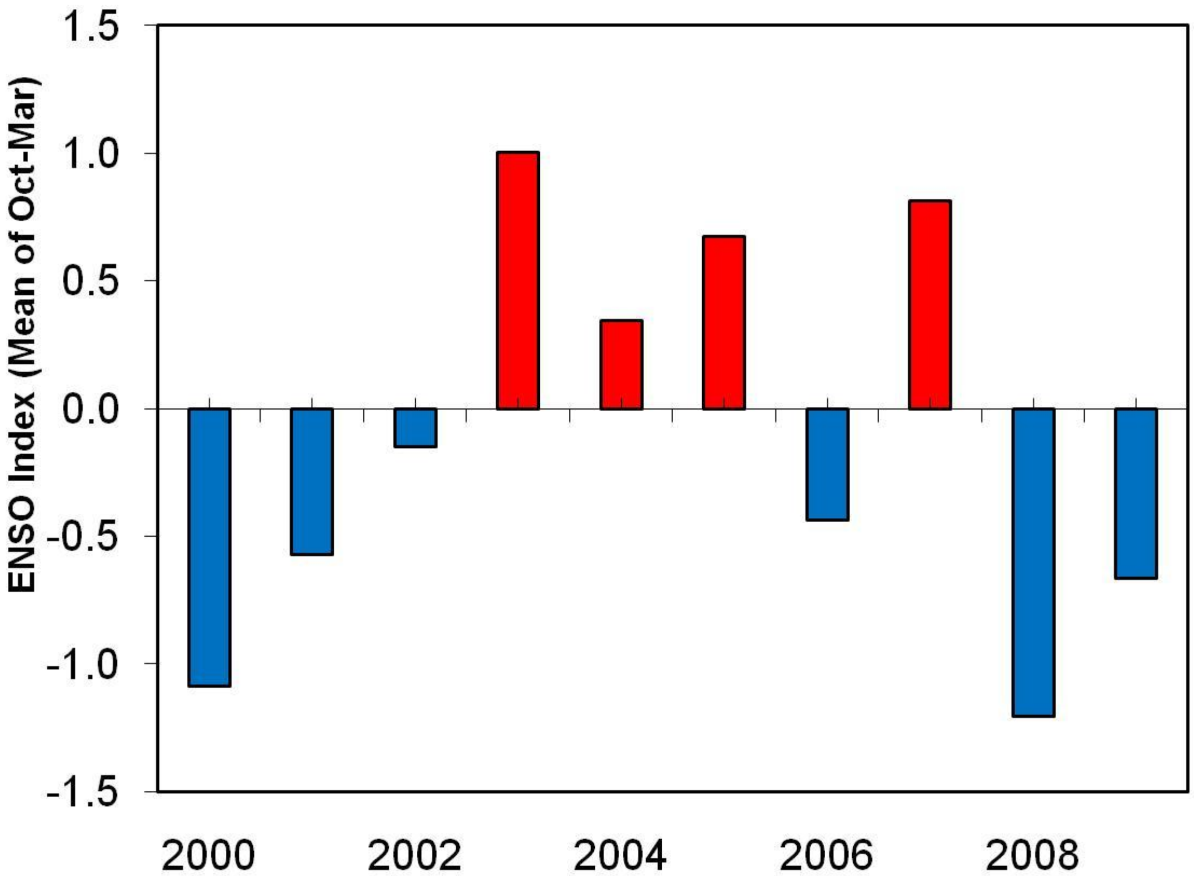


Exploring other methods to estimate releases based on:

- time of year
- storage targets
- drawdown before seasonal runoff

ENSO conditions based on Multivariate ENSO Index (MEI)

- "+" Index, conditions favor El Nino; "-" Index, favor La Nina
- Using mean Oct-Mar index to define ENSO conditions
- Results grouped into: All yrs; (+) yrs {red} ; (-) yrs {blue}
- http://www.esrl.noaa.gov/psd/people/klaus.wolter/MEI/mei.html



"Preliminary" Results (w/o all Res.) - Discharge

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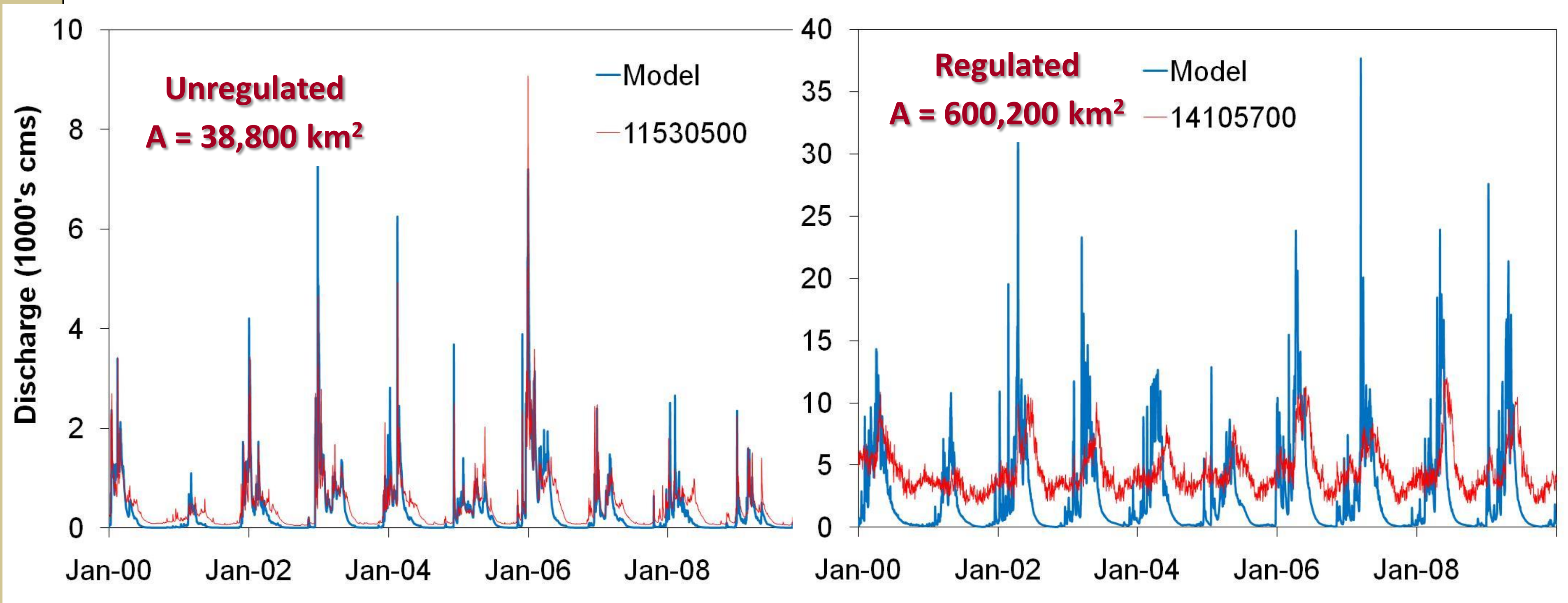
For 33 gauges, mean runoff & median peak discharge errors:

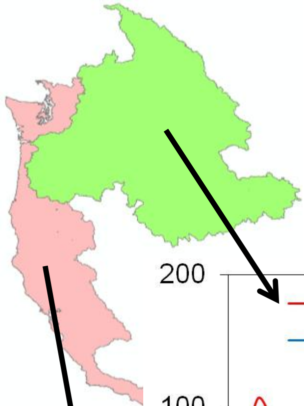
Q → -9, -15, 4% (ALL, - ENSO, + ENSO Yrs) Qp → 5, 32, 2%

Unregulated rivers, results are reasonable

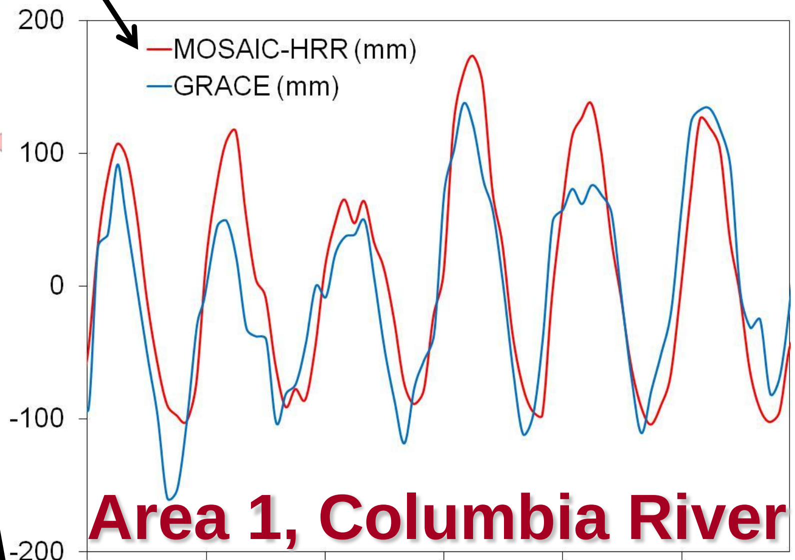
Regulated rivers, results are generally poor in terms of timing

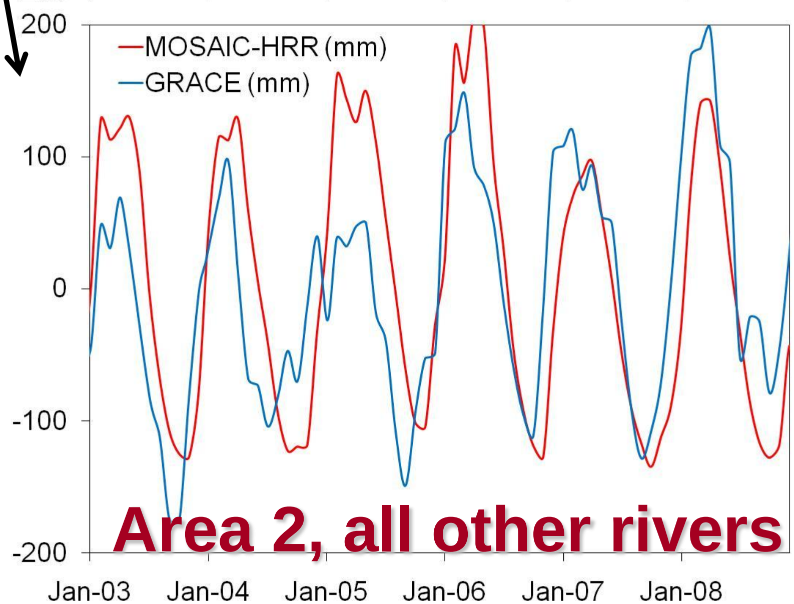


Preliminary Results – Total Water Storage



GRACE solution based on 2° Lat. by 3° Long. radius non-gaussian smoothing w/ ocean-land leakage cor. (Guo et al., 2010)





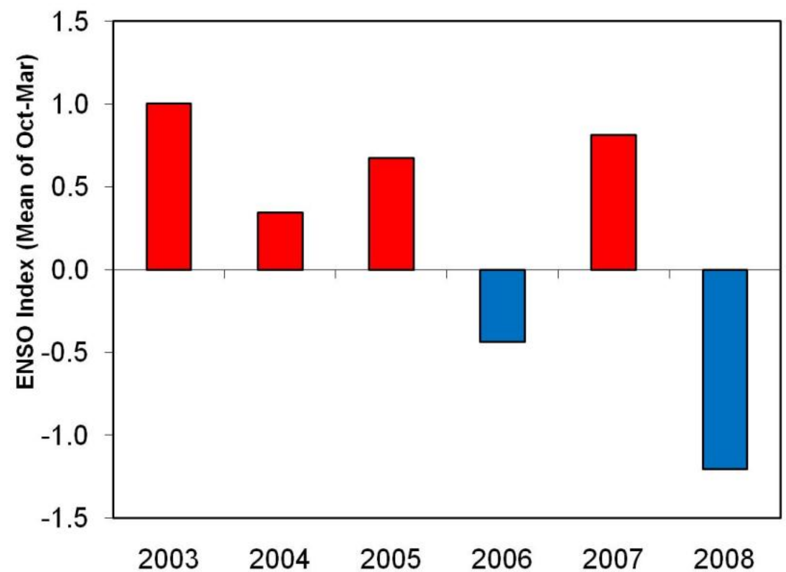
Distribution of Storages:

Area	SM	SWE	HRR	VEG
1	94.6	4.2	1.1	0.1
2	97.3	1.7	0.9	0.1

HRR fraction ranges from 0.5 to 2%

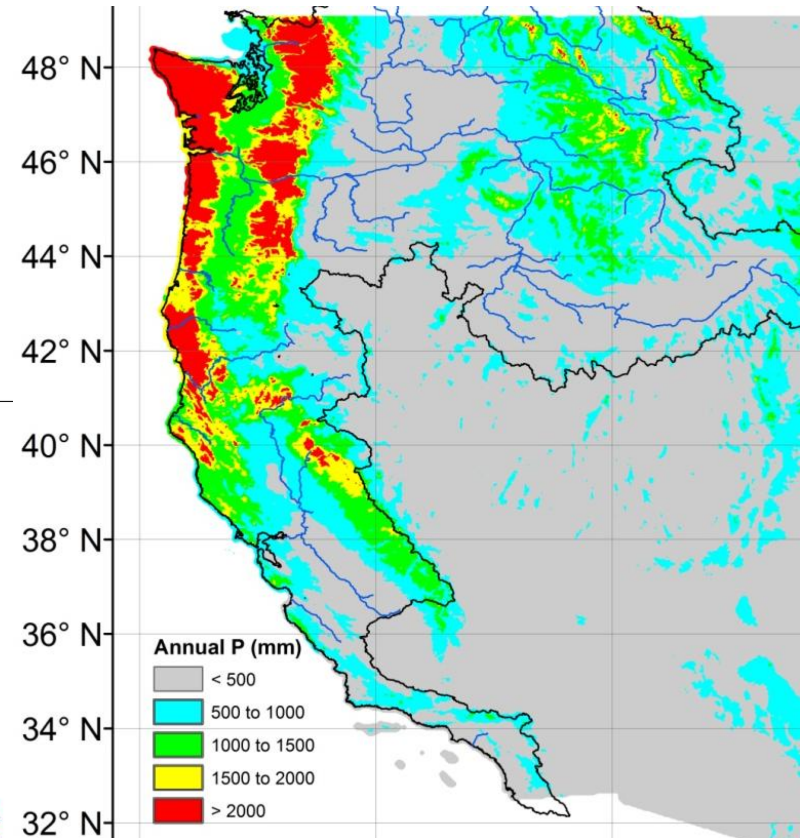
TWS correlated to ENSO

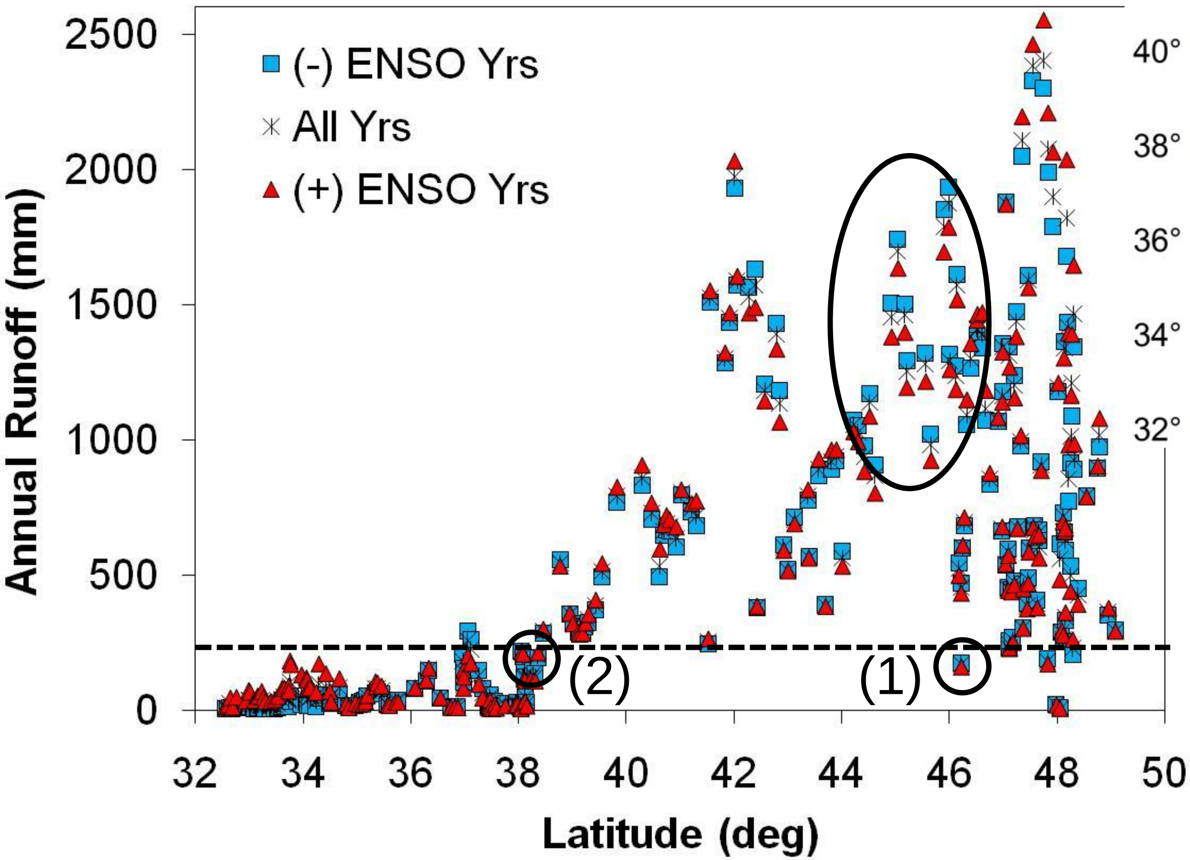
- Max storage peaks in (-) ENSO years



Preliminary Results – Annual Runoff

- Two rivers yield 52% of total runoff
  - (1) Columbia = 170 mm; 45% Q; 65% area
  - (2) Sacramento + San Joaquin rivers = 215 mm; or 7% Q; 13% area
- ENSO effects, ~(Q↑ in + yrs)
- Q variability ↑ as Lat. ↑ due to N-S precipitation bands (H, M, H, L)

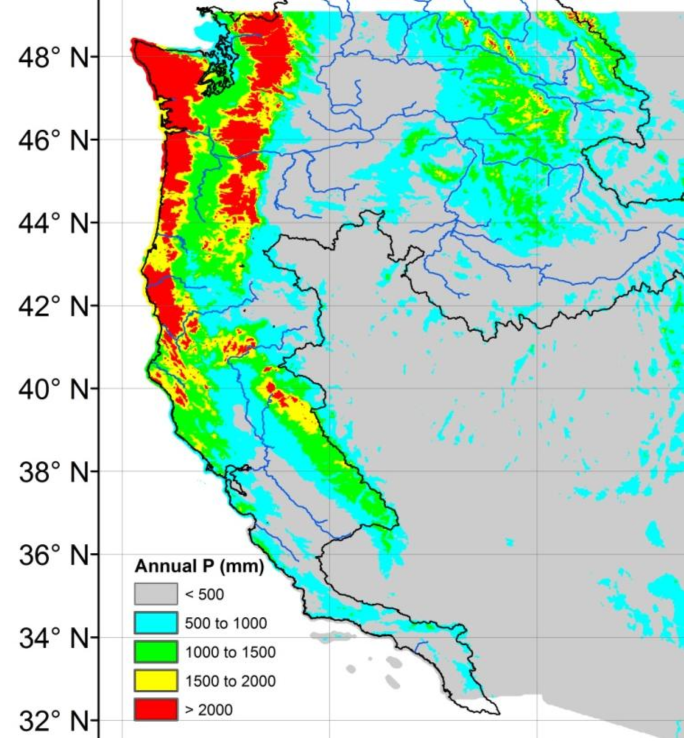


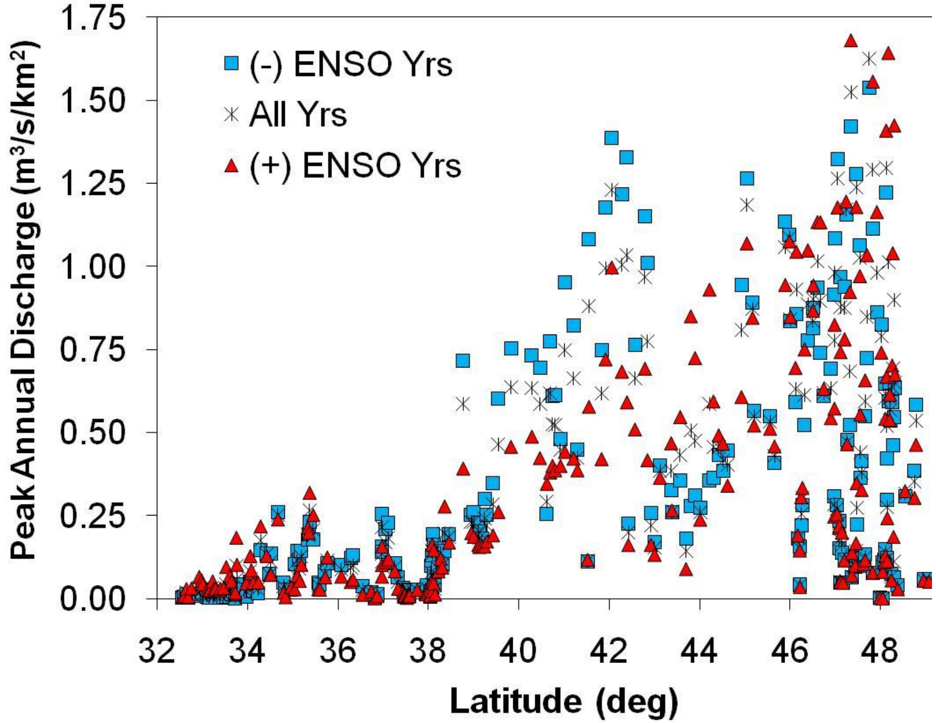


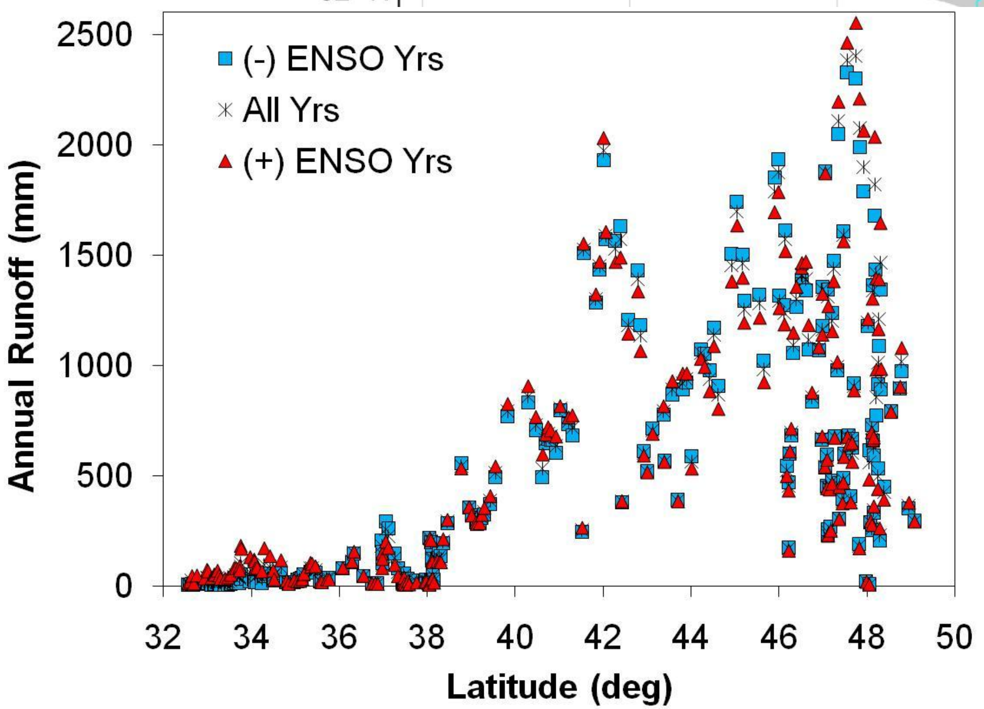
Annual runoff averaged over region = 235-240 mm

Preliminary Results - Peak Discharges

- Effects of ENSO on annual Qp are different (magnitude & direction) relative to annual Q, especially 40° to 45°
- Qp variability ↑ as Latitude ↑ due to N-S precipitation bands (H, M, H, L)
- Results are preliminary; still working on large reservoir routing & channel char.







Summary/Future Work

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- MOSAIC-HRR provides estimates of hourly Q to Ocean
  - Annual Q's somewhat less than gauge data (WBM?)
  - Qp errors vary but producing events at right time (right patterns)
  - Need to work on regulated rivers (add more reservoirs; release rules)
- ENSO conditions impact terrestrial export differently along coast in terms of magnitude & direction for both annual Q and Qp (<u>however, only 10 yrs of preliminary results</u>)
- For simulating (1) future hydrologic conditions (climate and/or land cover changes), or (2) sediment generation/transport, need repeat sampling of water surfaces to learn/train model
  - Lakes: build rules/functions for modeling lake/reservoir storage-release characteristics (e.g., currently, missing10-50 key lakes…)
  - Rivers: build database for channel width-stage-slope relationships (e.g., currently, 26,000 channels are rough guesses …)