Anthropogenic effects on the land surface water cycle at continental scales

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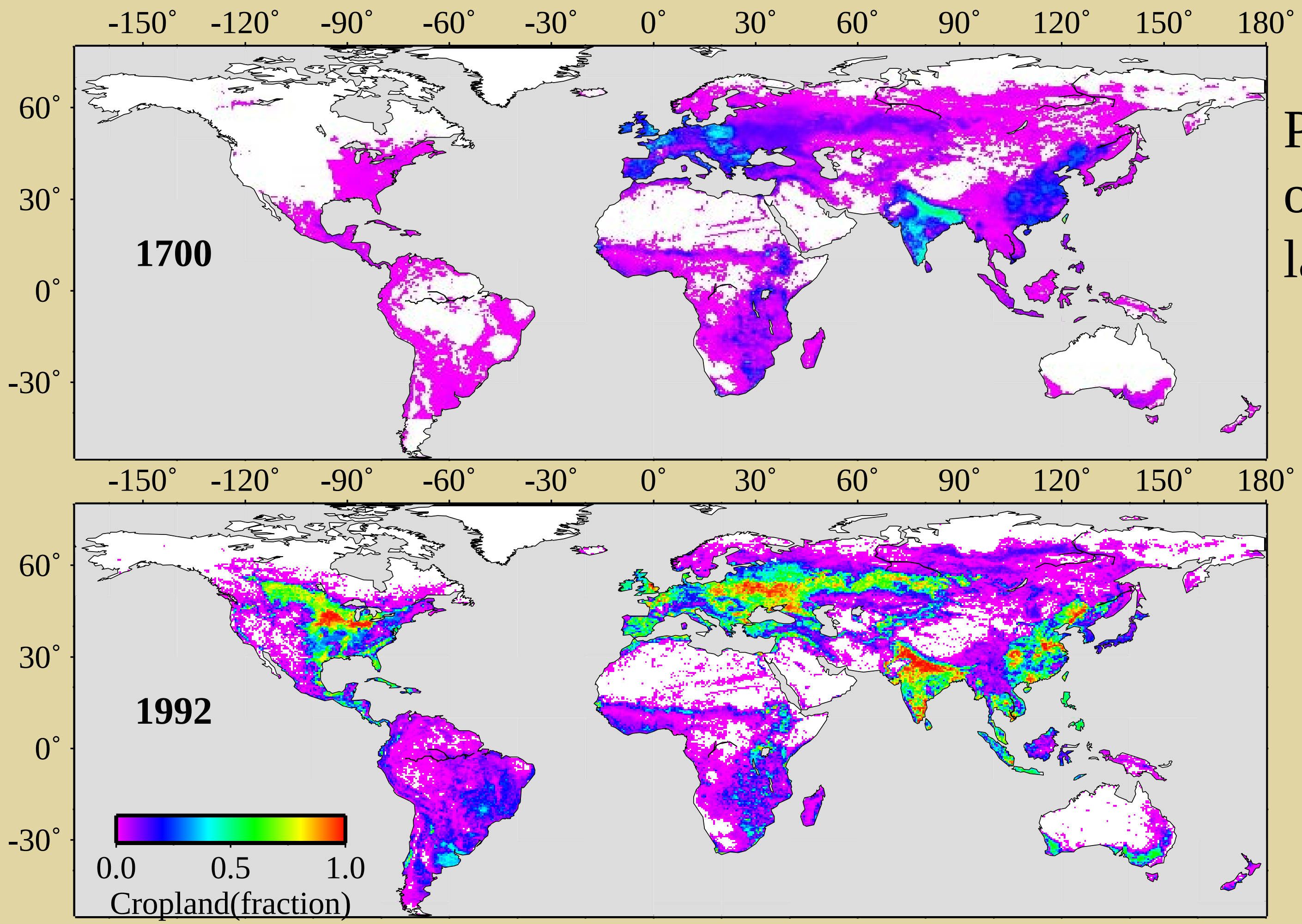
Basic premise

- Humans have greatly affected the land surface water cycle through
  - Land cover change
  - Water management
  - Climate change
- While climate change has received the most attention, other change agents may well be more significant

Background: Cropland expansion



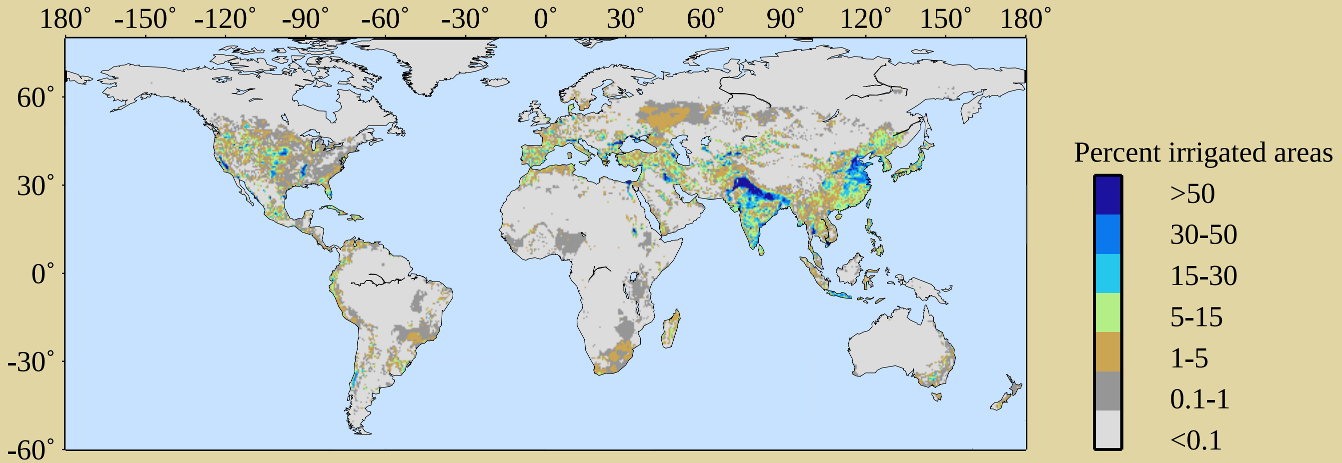
Percentage of global land area:

3

14

Ramankutty and Foley, *Global Biogeochem. Cycles*, 1999

Background: Irrigated areas



Siebert et al., 2005, Global map of irrigated areas version 3, Institute of Physical Geography, University of Frankfurt, Germany / Food and Agriculture Organization of the United Nations, Rome, Italy

- Irrigated areas, globally:
  - $2.8 \cdot 10^6$ km^2
  - 2% of global land area
- Location of irrigated areas:
  - Asia: 68%
  - America: 16%
  - China, India, USA: 47%

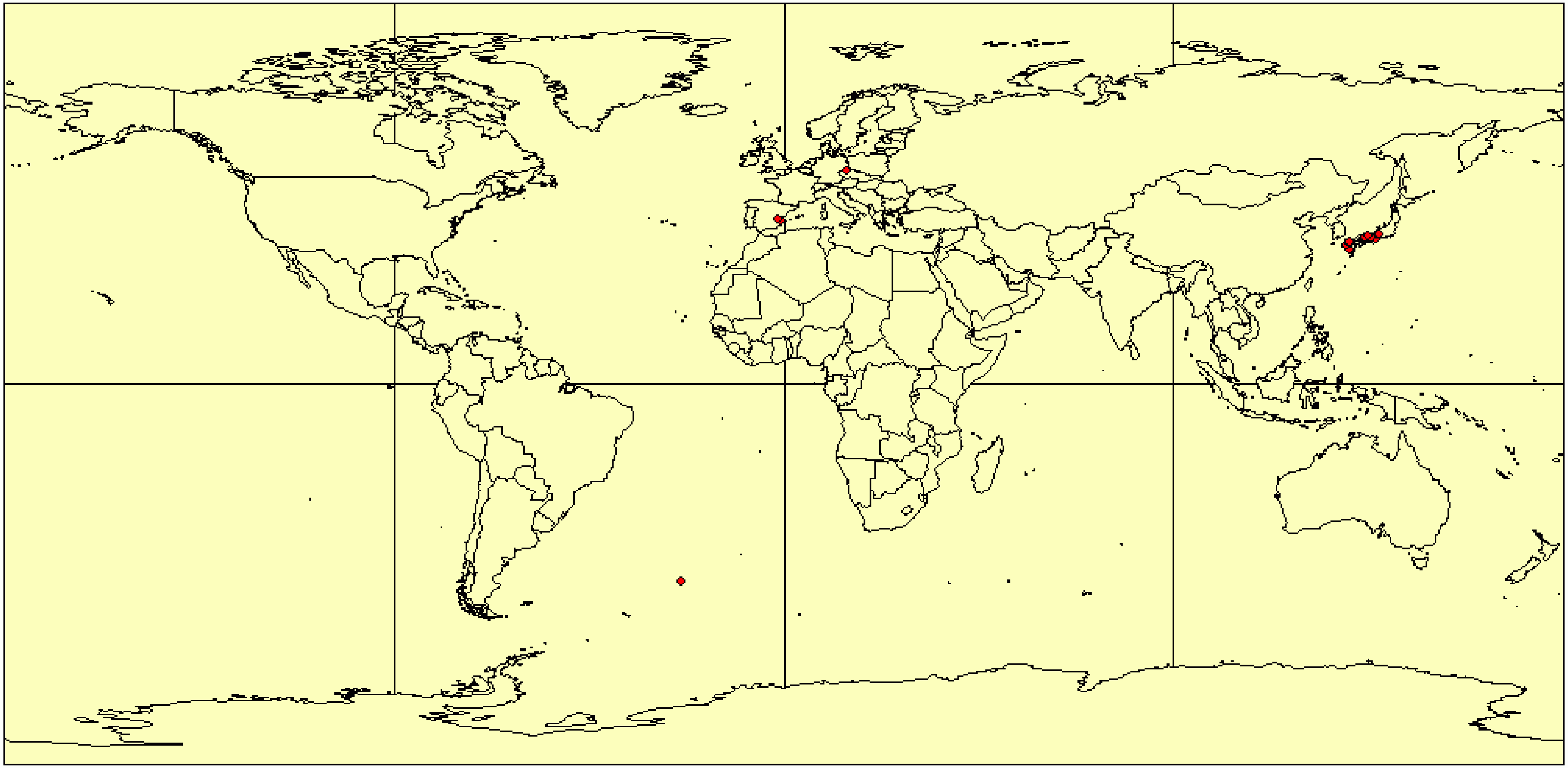
- Irrigation: 60-70 % of global water withdrawals *(Shiklomanov, 1997)*

Global Reservoir Database

Location (lat./lon.), Storage capacity, Area of water surface, Purpose of dam, Year of construction, …

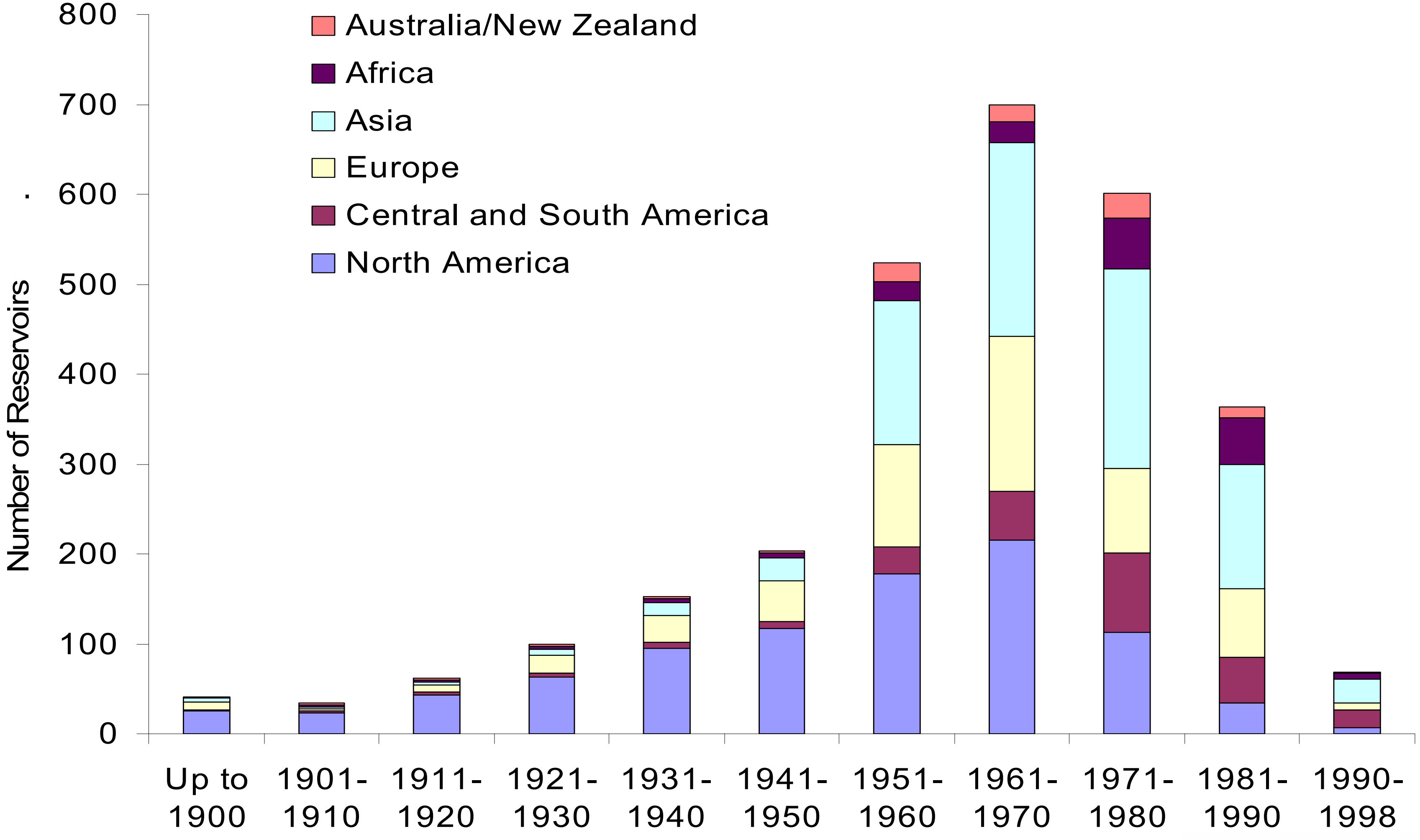
～1750年

13,382dams,



Visual courtesy of Kuni Takeuchi

Reservoir construction has slowed.

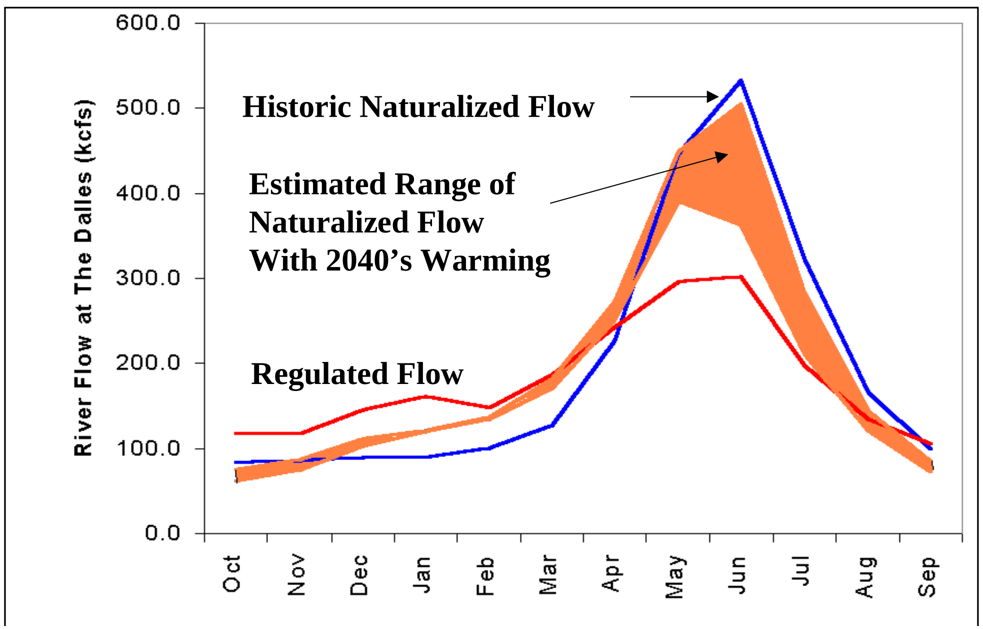


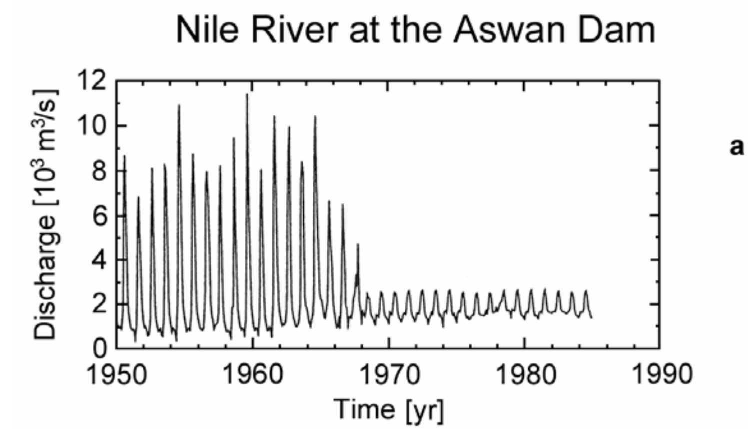
Pacific Institute

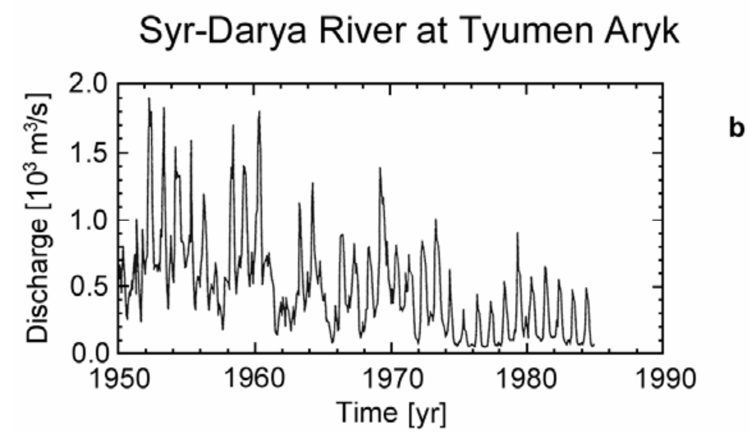
Global Water System Project
IGBP – IHDP – WCRP - Diversitas

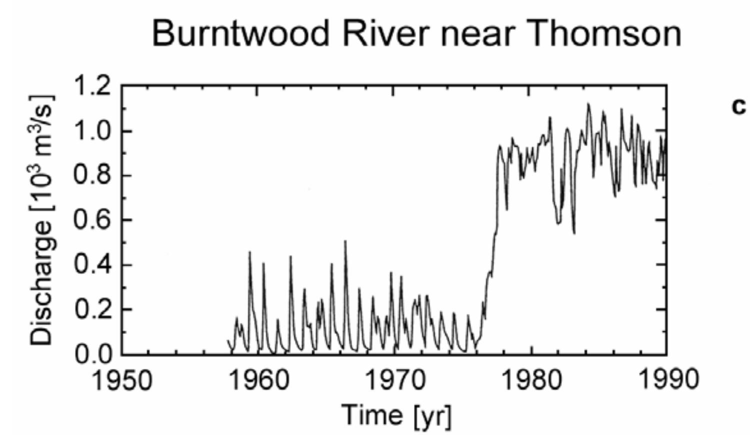
Human modification of hydrological systems

Columbia River at the Dalles, OR









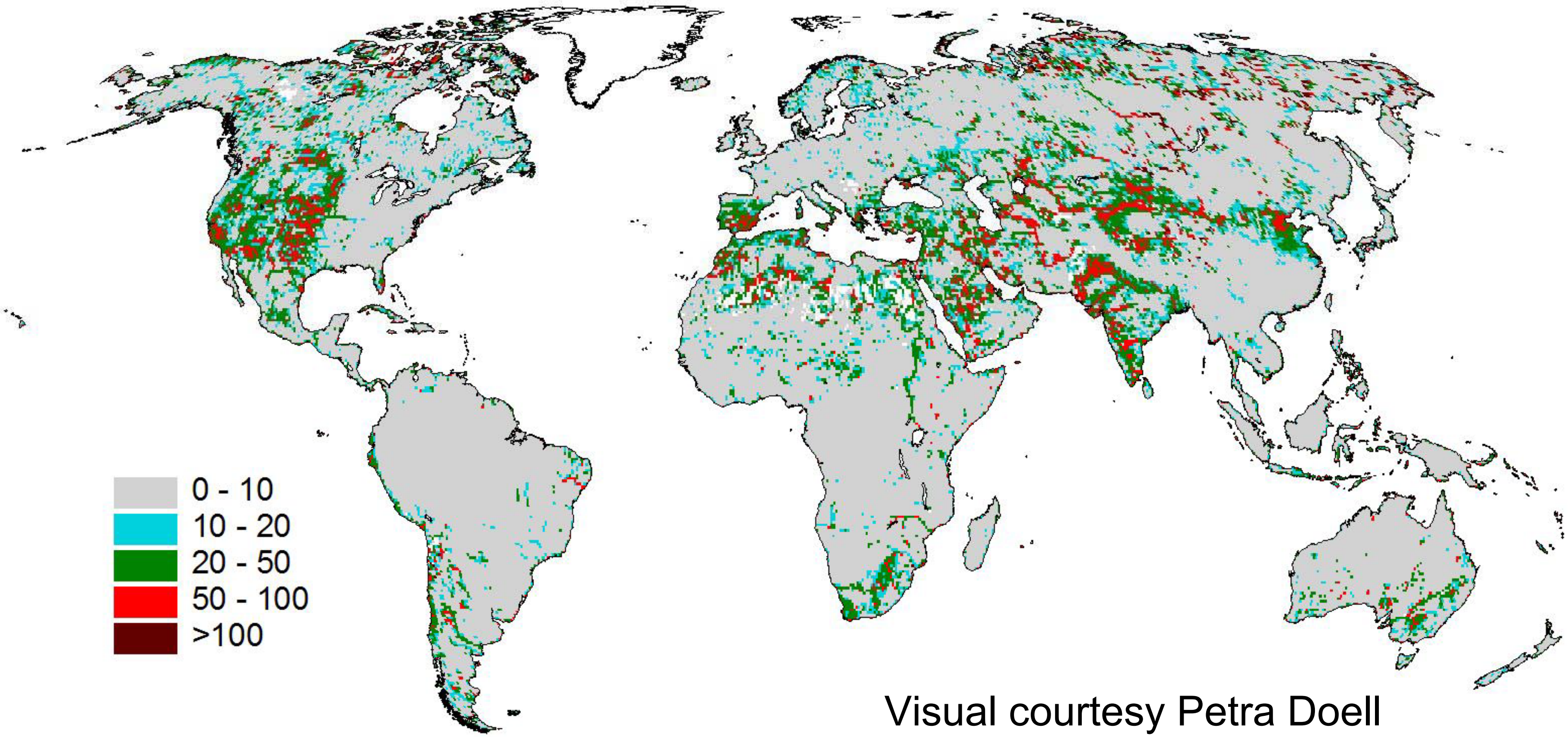
Alteration of river flow regimes due to withdrawals and reservoirs

JOHANN WOLFGANG GOETHE UNIVERSITÄT FRANKFURT AM MAIN

WaterGAP analysis based on “Range of Variability” approach of Richter et al. (1997)

Change in seasonal regime

Average absolute difference between 1961-1990 **mean monthly river discharge** under natural and anthropogenically altered conditions, in %



Visual courtesy Petra Doell

So does it make sense to model the continental water cycle without including anthropogenic influences?

- From the standpoint of global climate modeling (which has been the focus of much of the activity in land surface modeling, maybe (there's lots of ocean out there, global signal probably modest)
- From the standpoint of the land surface (where people live), probably not
- While there have been many studies of vegetation effects (on climate and the water cycle, land surface models are only beginning to be able to represent the effects of water management
- And are the observations (globally or continentally) up to the task?

Is the interest in global effects of water system manipulation by humans purely a management concern?

I argue no – there are important unresolved science questions relating to the effects of the managed system on regional climate, for instance, constituent transport, and processes in the coastal and near-coastal zone – among others

Some preliminary results from an extension to the VIC construct to represent reservoirs and irrigation withdrawals

for details:

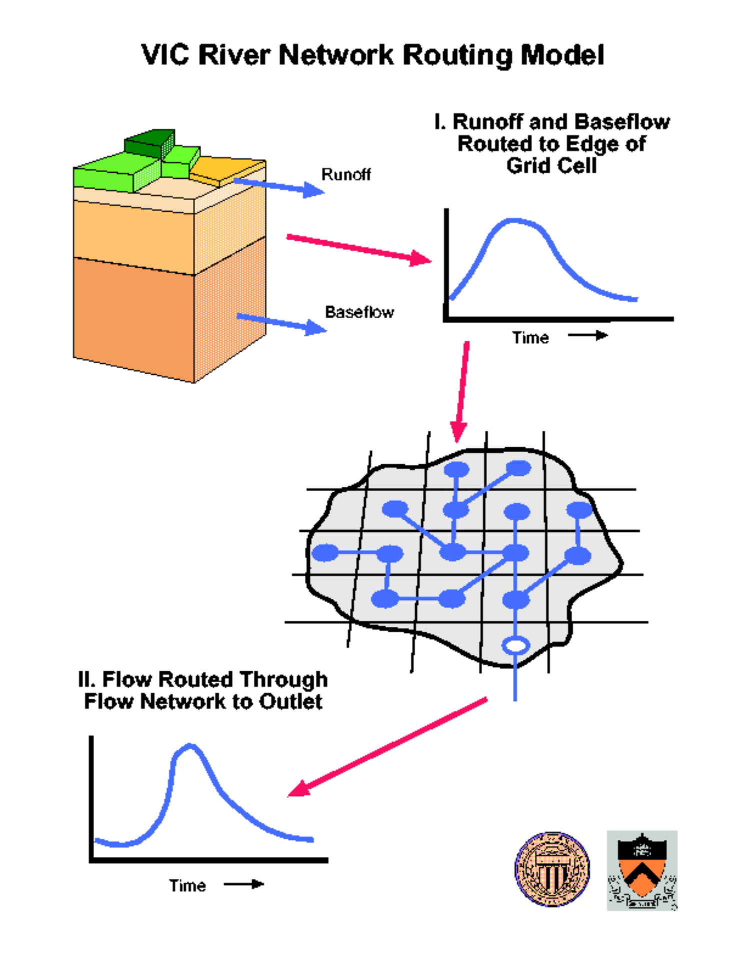
Haddeland et al, GRL, 2006 (reservoir model)

Haddeland et al, JOH, 2006 (irrigation model and evaluation for Colorado and Mekong Rivers)

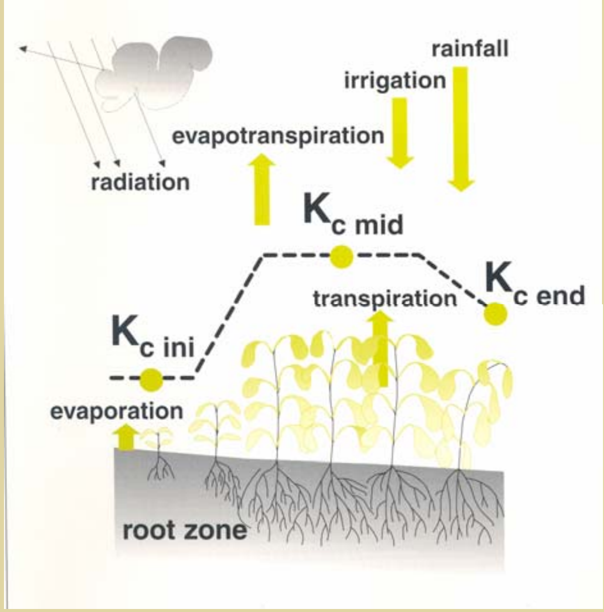
Haddeland et al, HESS-D, 2007 (vegetation change effects on hydrology of N America and Eurasia, 1700-1992)

Approach

- Macroscale hydrologic model
  - VIC
- Model development
  - Irrigation scheme: VIC. Surface water withdrawals only
  - Reservoir module: Routing model
- Model runs:
  - With and without irrigation and reservoirs
  - Historical vegetation

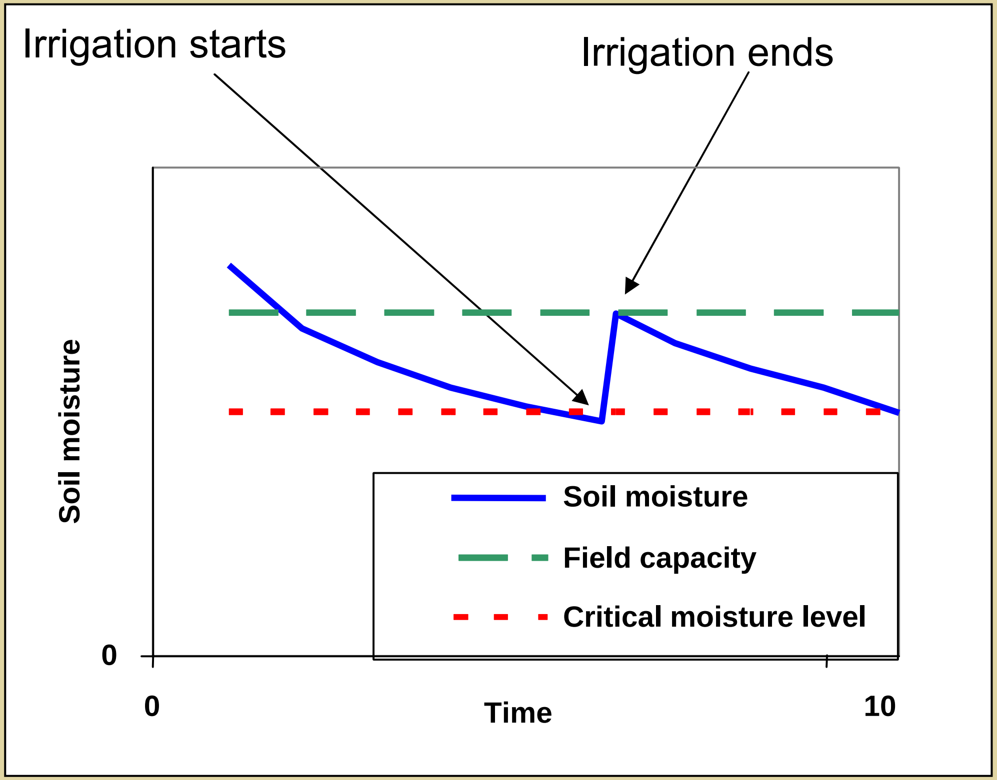


Model development: Irrigation scheme

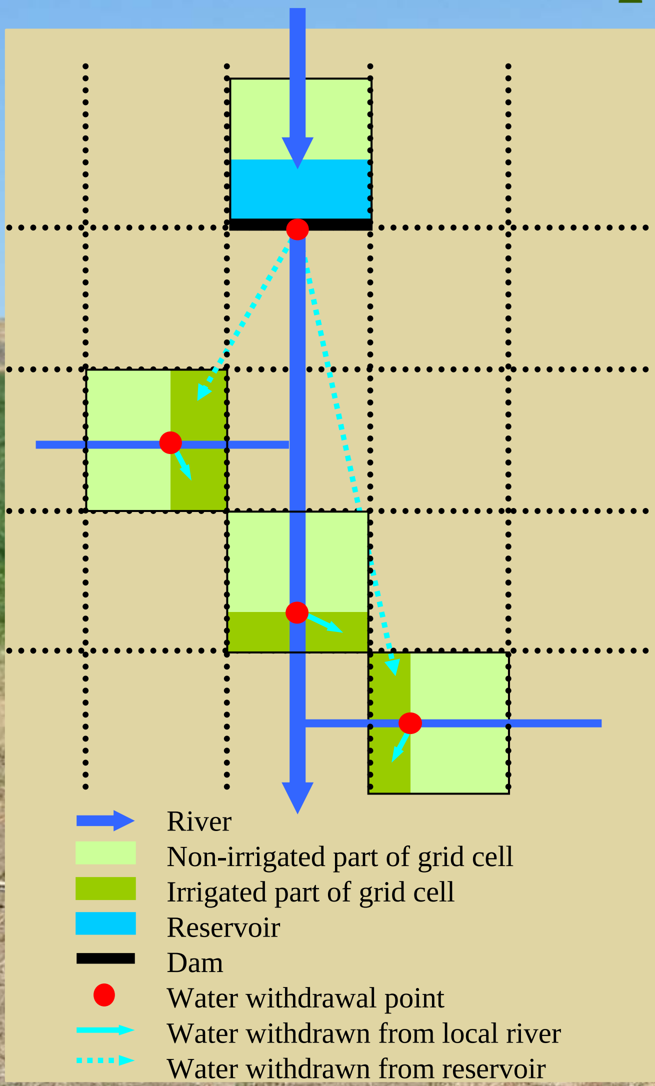


$$ET = K_c * ET_o$$

ET_o: Reference crop evapotranspiration



Model development: Reservoir model



1st priority: Irrigation water demand

2nd priority: Flood control

3rd priority: Hydropower production

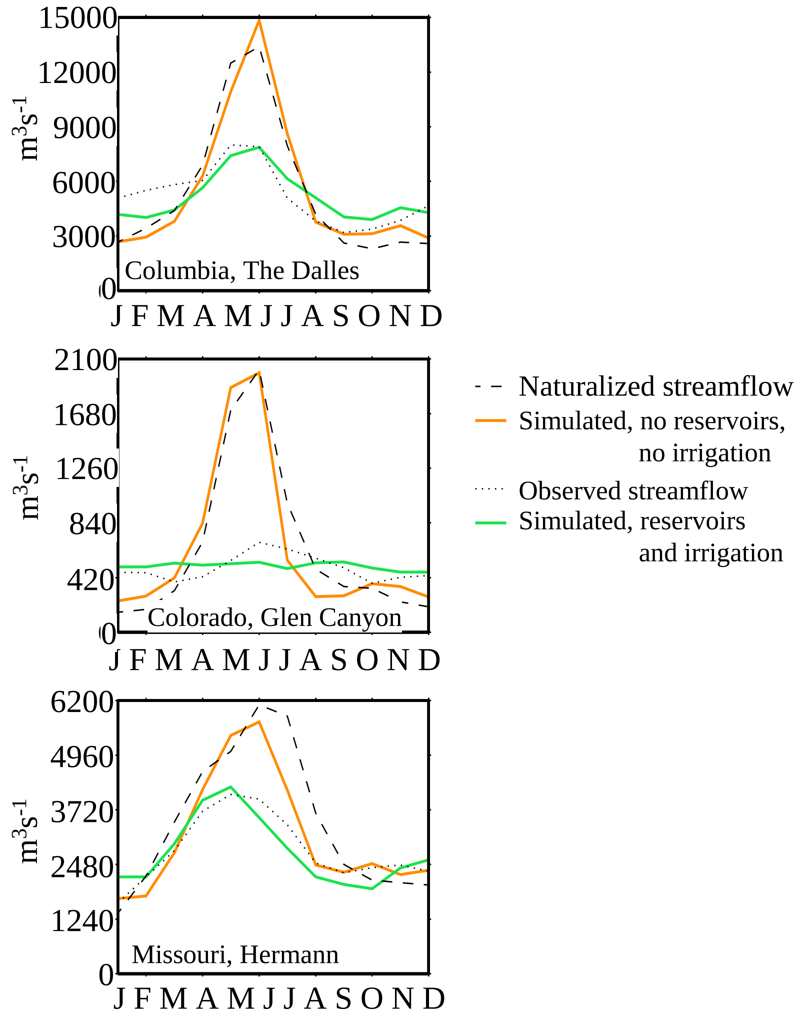
If no flood, no hydropower:

Make streamflow as constant as possible

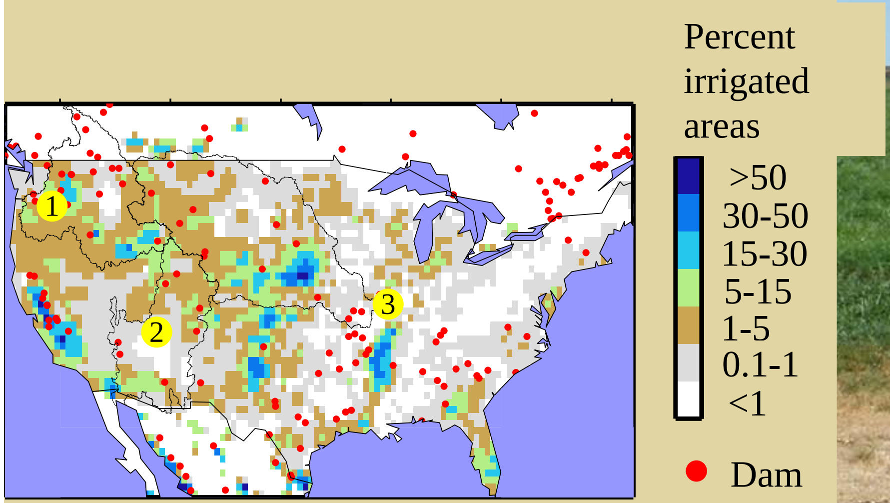
$$Q_{\min_i} = 7Q10$$

$$Q_{\max_i} = \min\left[\begin{array}{l} \left(S_{i-1} + Q_{in_i}\right), \\ \left(S_{i-1} - S_{end} + \sum_{day=i}^{365} Q_{in\,day} - \sum_{day=i+1}^{365} Q_{\min} - \sum_{day=i}^{365} E_{res\,day} \right) \end{array} \right]$$

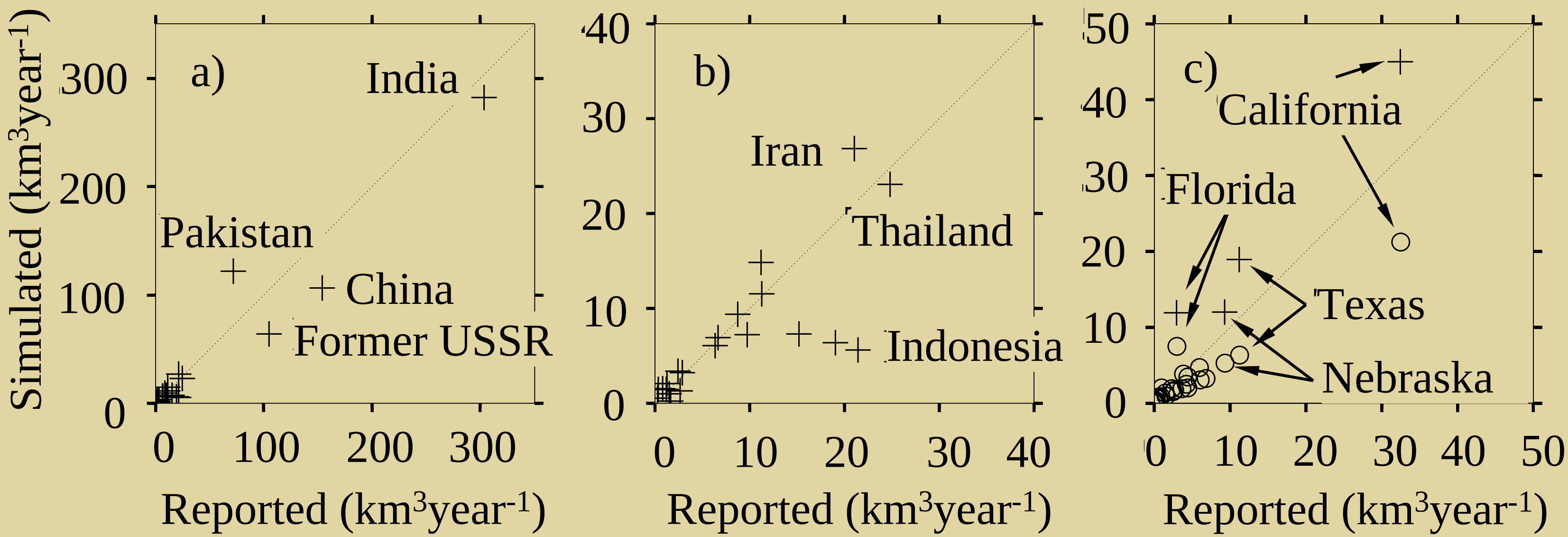
Model development: Evaluation



Model evaluation:
1) Columbia, 2) Colorado, and 3) Missouri River basins

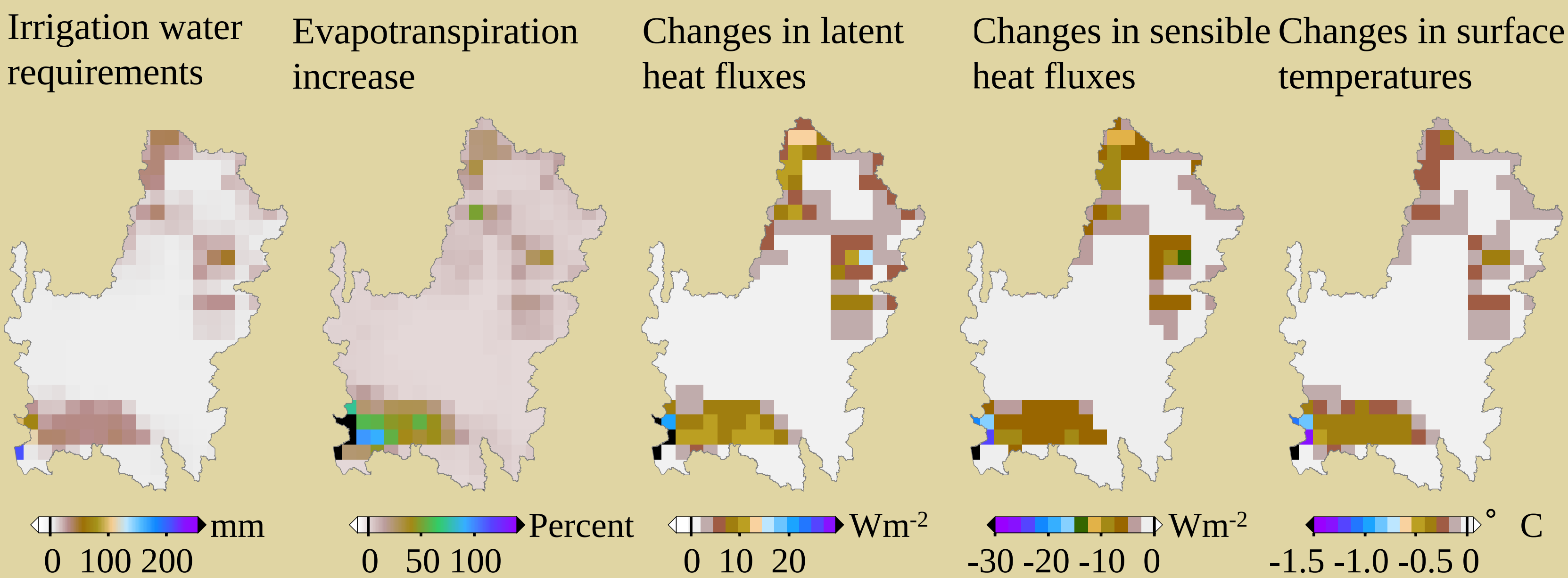


Model development: Evaluation



a) Mean annual simulated and reported irrigation water requirements for countries in Asia. b) The lower values shown in b). c) Mean annual simulated irrigation water requirements (+) and simulated irrigation water use (o) compared to reported irrigation water use in the USA.

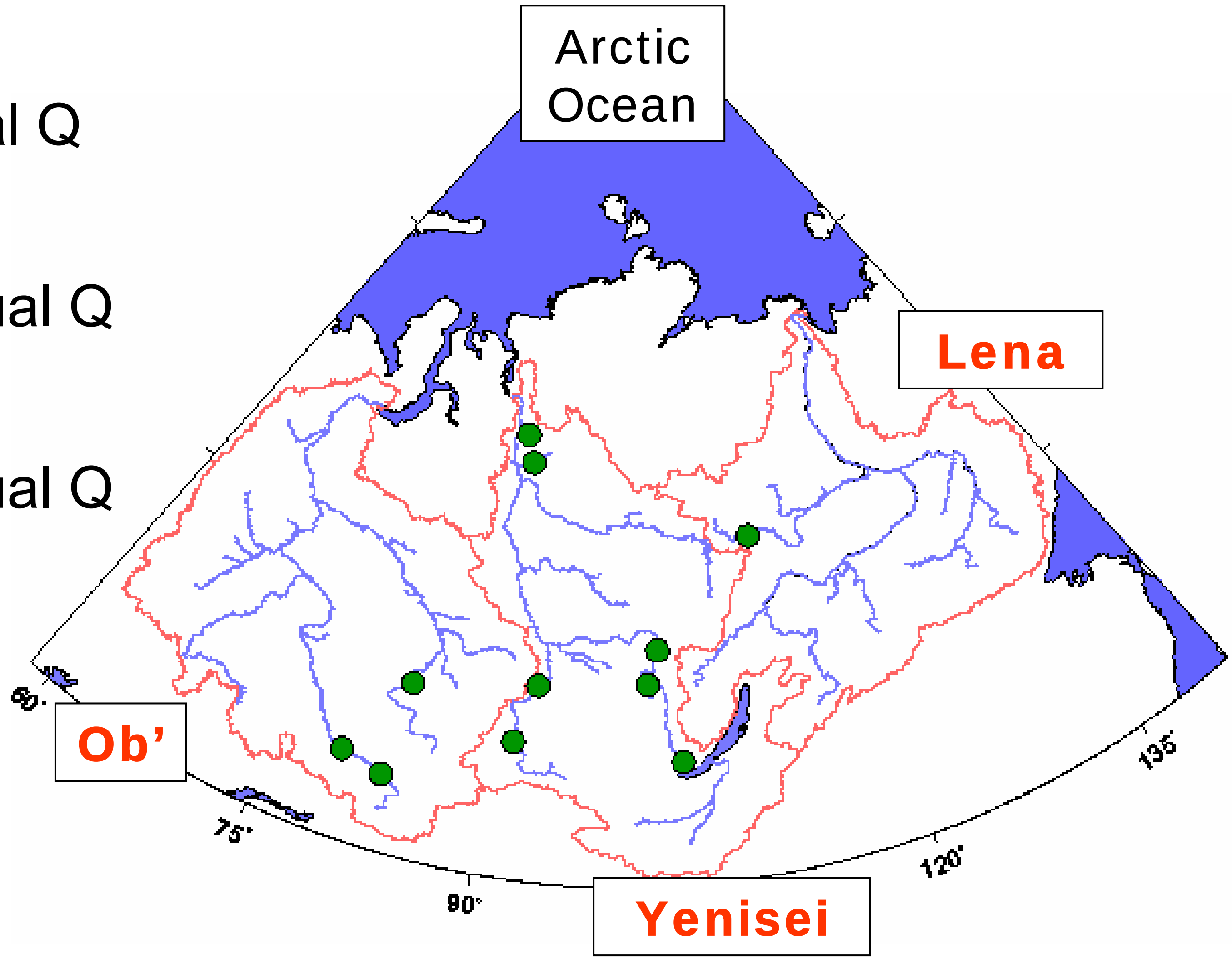
Colorado River basin



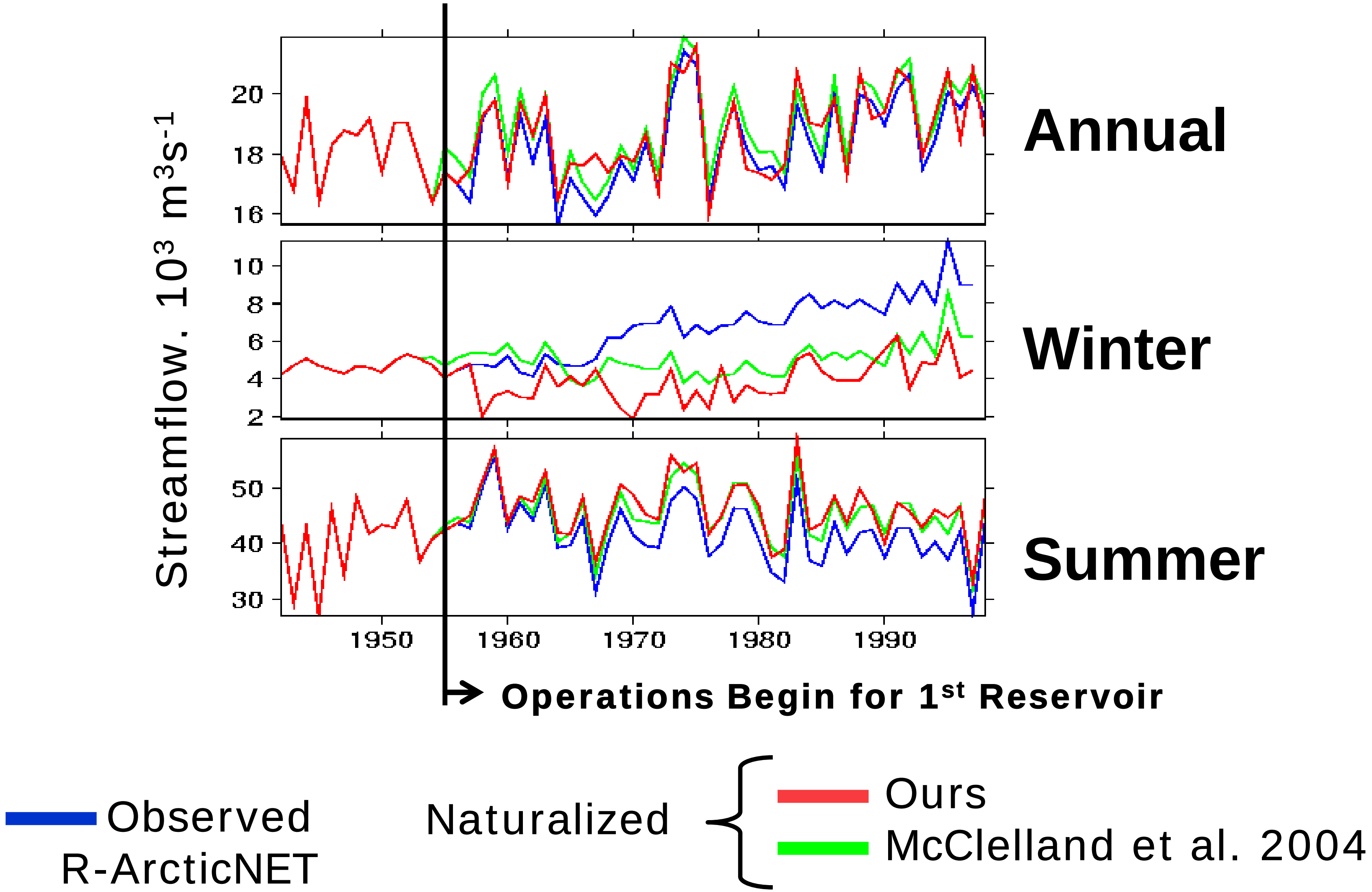
- Figure: Results for three peak irrigation months (jun, jul, aug), averaged over the 20-year simulation period.
- Max changes in one cell during the summer: Evapotranspiration increases from 24 to 231 mm, latent heat decreases by 63 W m^{-2}, and daily averaged surface temperature decreases 2.1 ° C
- Mean annual “natural” runoff and evapotranspiration: 42.3 and 335 mm
- Mean annual “irrigated” runoff and evapotranspiration: 26.5 and 350 mm

Major Arctic Reservoirs (Capacity>1 km^3)

- Lena:
  - 7% Annual Q
- Yenisei:
  - 71% Annual Q
- Ob':
  - 16% Annual Q



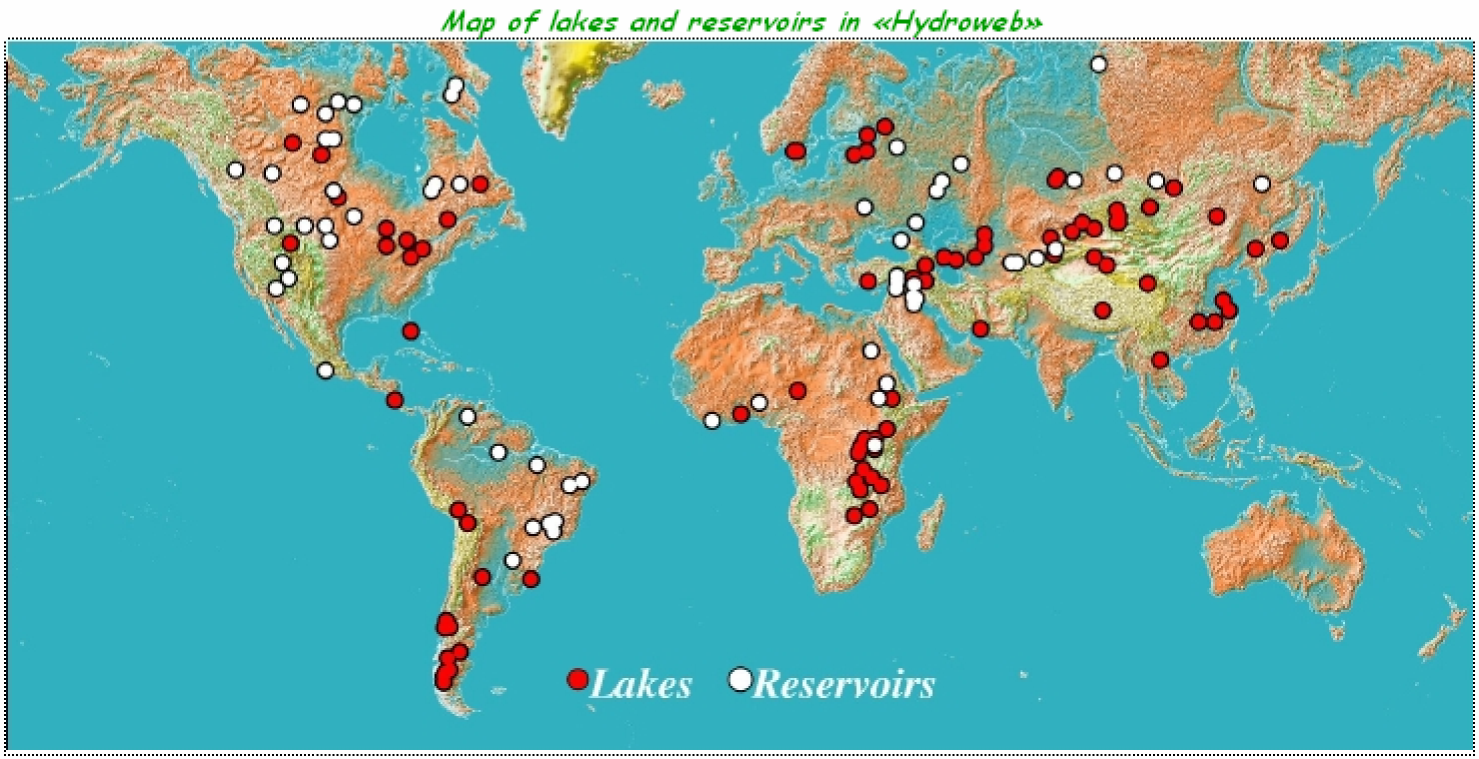
Streamflow Data (example: Yenisei)



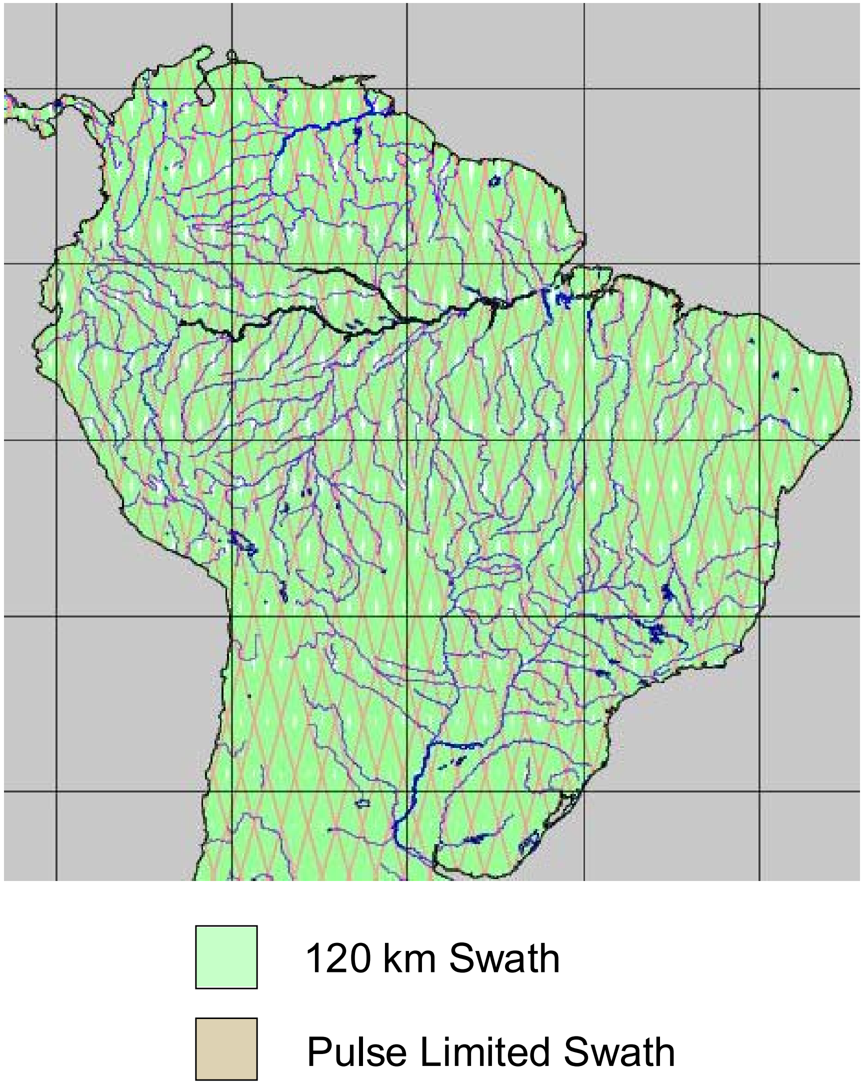
The role of observations

- What do we know about the dynamics of surface water storage globally (in lakes, wetlands, river channels, and man-made reservoirs)?
- Clearly, the answer is “very little” – as compared with global river discharge data (deficient that they are due to lags in reporting and archiving, e.g., at GRDC, and decline in station networks), the global network for surface storage is essentially nil – presenting major scientific, and practical issues (e.g., for management

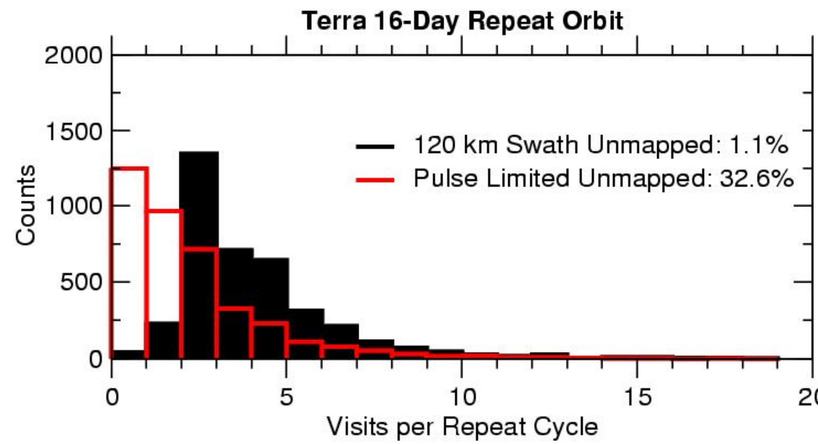
Location of global lakes and reservoirs for which stage data are currently available from Topex-Poseidon, Jason, and other altimeters



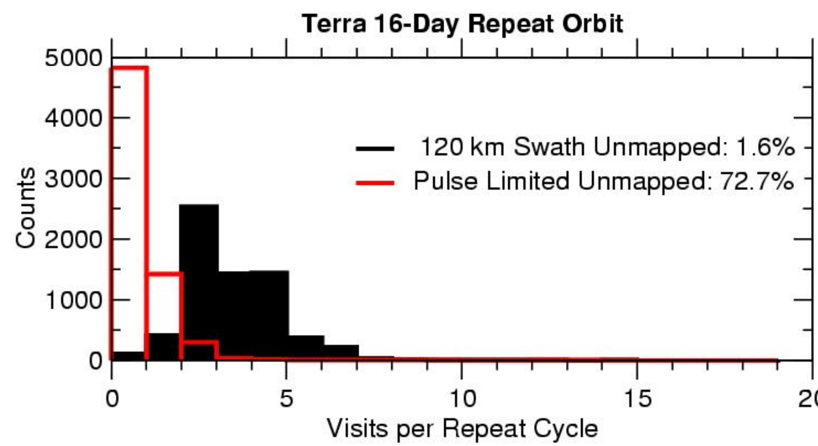
Source: CNES (www.legos.obs-mip.fr/soa/hydrologie/hydroweb/)



Global River Coverage Histogram

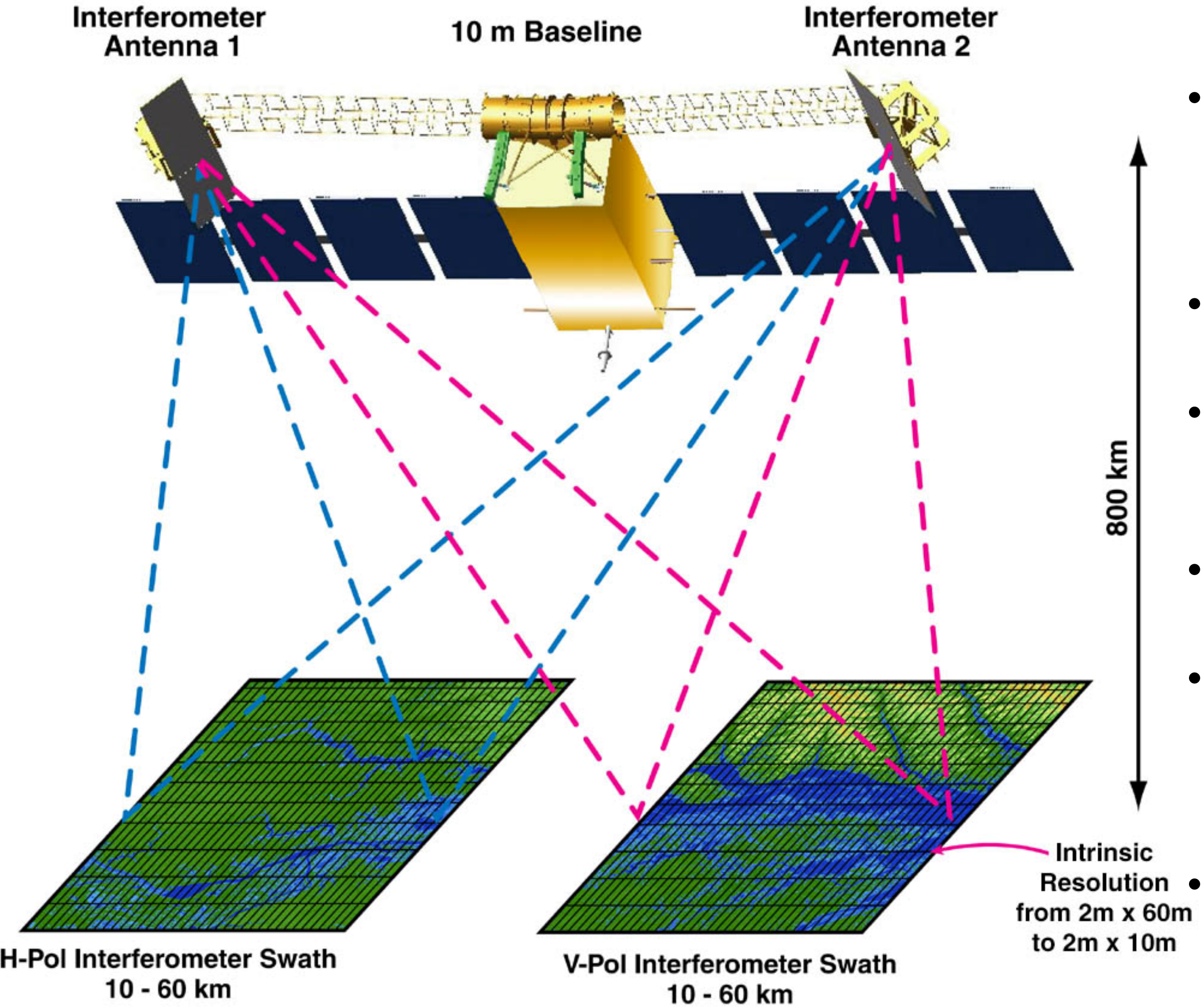


Global Lake Coverage Histogram



Visual courtesy Ernesto Rodriguez, JPL

KaRIN: Ka-Band Radar Intererometer



- Ka-band SAR interferometric system with 2 swaths, 50 km each
- WSOA and SRTM heritage
- Produces heights and co-registered all-weather imagery
- 200 MHz bandwidth (0.75 cm range resolution)
- Use near-nadir returns for SAR altimeter/angle of arrival mode (e.g. Cryosat SIRAL mode) to fill swath
- No data compression onboard: data downlinked to NOAA Ka-band ground stations

These water elevation measurements are entirely new, especially on a global basis, and thus represent an incredible step forward in oceanography and hydrology.

Conclusions

- Global change will be the defining challenge faced by hydrologists in the 21st Century – prediction of the effects of land cover, climate, and water management on the land surface hydrological cycle
- Modeling approaches that address these challenges, especially at large scales where site-specific data are not available, are in their infancy
- The motivation for addressing these problems are both scientific and societal (ref. Taikan's Venn diagram)
- The challenges posed by these problems cross process understanding (and the scale problems that have variously plagued and motivated hydrologists for decades),