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Global land-ocean linkage: direct inputs of water and associated nutrients to coastal zones via submarine groundwater discharge (SGD)

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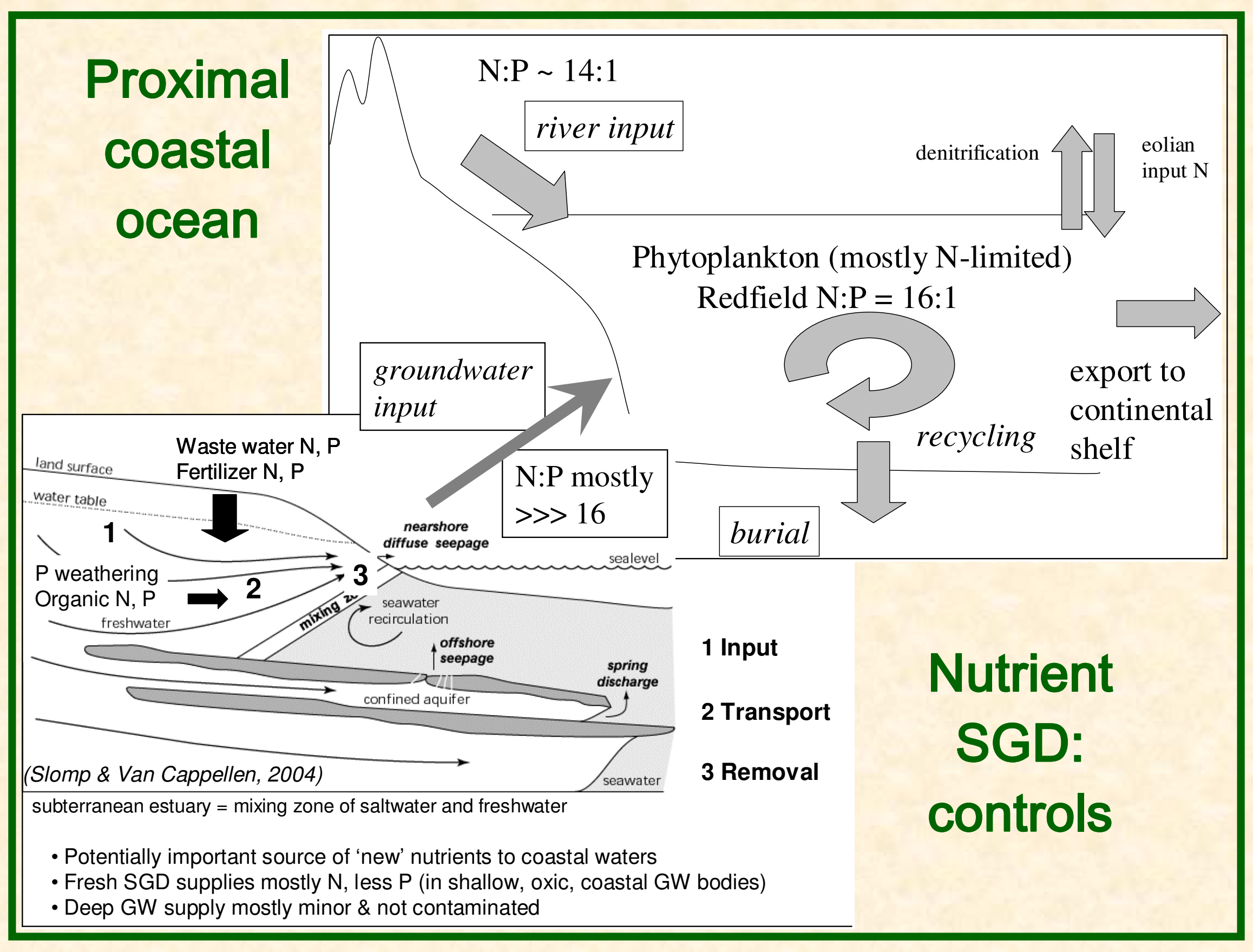
Introduction

Under many climate and aquifer conditions, continental groundwater contributes freshwater and associated nutrients as baseflow to river flow, but also as submarine groundwater discharge (SGD) directly to the coastal zone (Church 1996). At the global scale, near-shore coastal water bodies are generally said to be nitrogen (N)-limited (Howarth and Marino 2006). Inputs from river water are mainly at or slightly below Redfield ratio (N/P~14) (Seitzinger et al. 2005). As phosphorus (P) is mostly efficiently retained in groundwater systems (Spiteri et al. 2008), continental groundwater directly discharging into the sea (SGD) mainly shows N/P ratios >> 16, especially in agricultural areas. Box modelling has shown that nutrient inputs via SGD have the potential to significantly affect coastal zone nutrient cycling at the global scale (Slomp and van Cappellen 2004) that can lead to increased eutrophication or hypoxia. Most studies on the nutrient flux to the coastal zone by SGD have focused on local to regional scales (mainly in the U.S. and Europe), concentrating on areas of high total SGD including recycled fluxes from the saltwater / freshwater mixing zone. While at local scales, the effects of this recycling in the 'subterranean estuary' are important to understand short-term changes in nutrient availability, at the global scale, quantification of the yet poorly constrained net fluxes of freshwater and nutrients discharged via this transport path to the oceans is crucial.

Main aim: we present the first steps towards spatially-explicit estimates of nutrient inputs to the coastal zone via freshwater SGD:
(1) using baseflow estimates from a global hydrological model, combined with
(2) assessments of nutrient concentrations in coastal groundwater bodies.

Proximal coastal ocean



(Slomp & Van Cappellen, 2004)

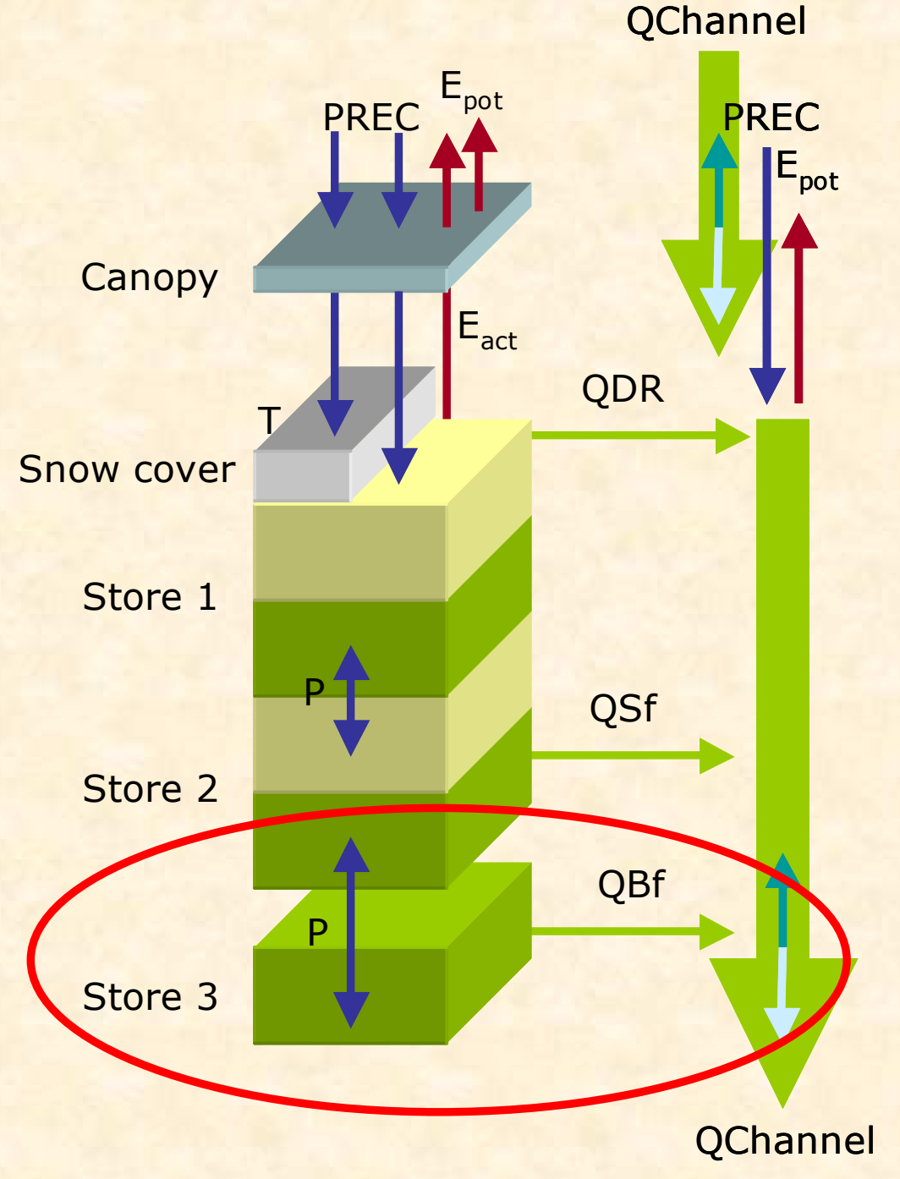
subterranean estuary = mixing zone of saltwater and freshwater

- Potentially important source of 'new' nutrients to coastal waters
- Fresh SGD supplies mostly N, less P (in shallow, oxic, coastal GW bodies)
- Deep GW supply mostly minor & not contaminated

Nutrient SGD: controls

PC-Raster based Hydrological Model, tuned for base flow conditions

PCR-GlobWB (van Beek et al. in prep.)

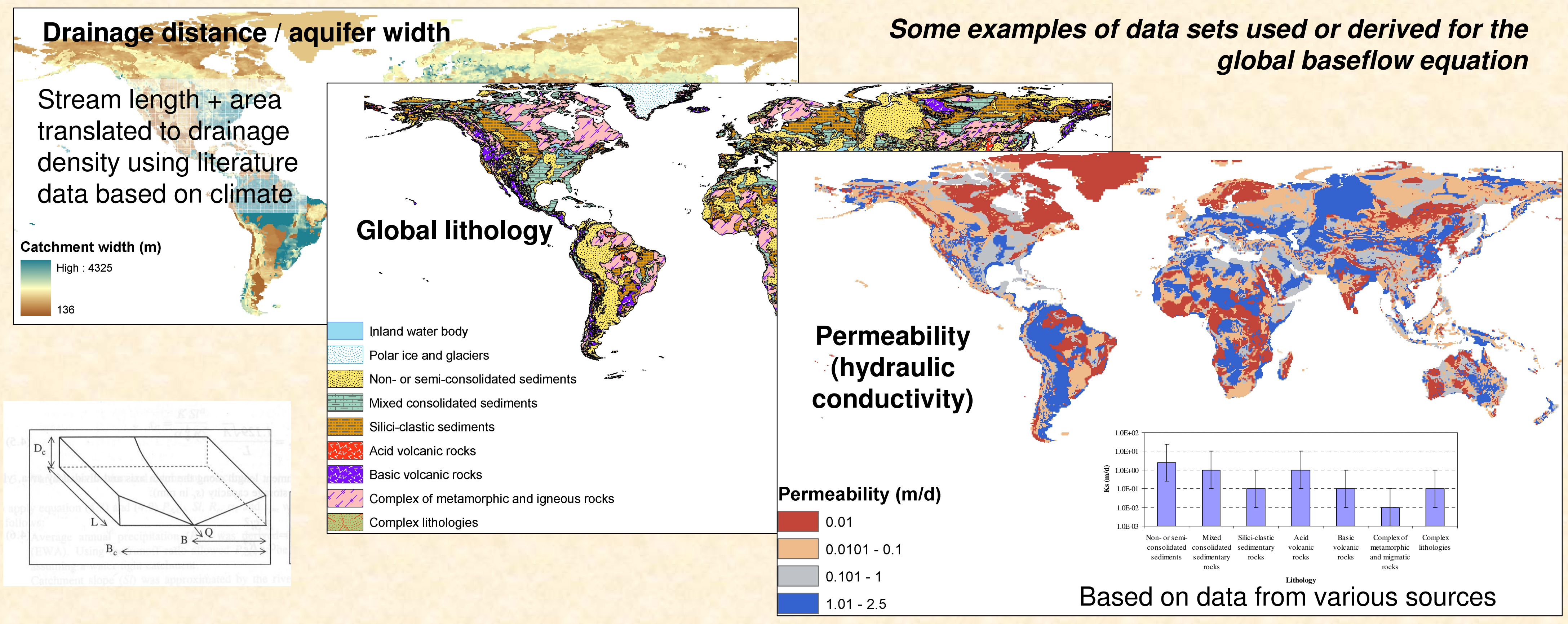


The conceptual model is partly based on the HBV model. Climate variables used are from the ERA40 data set. Groundwater flow is based on the work by Kraaijenhof-Van der Leur (1958), following the Boussinesq-Dupuit assumptions):

$$k_r = \frac{\pi^2 kD}{4 fB^2} \qquad (t^{-1})$$

where:
k – hydraulic conductivity (L t^{-1})
D – aquifer thickness (L, 50m assumed)
f – drainable porosity (obtained from global lithology data + some Holdridge climate data) (dimensionless, 0 – 0,5)
B – aquifer width (L)

Some examples of data sets used or derived for the global baseflow equation

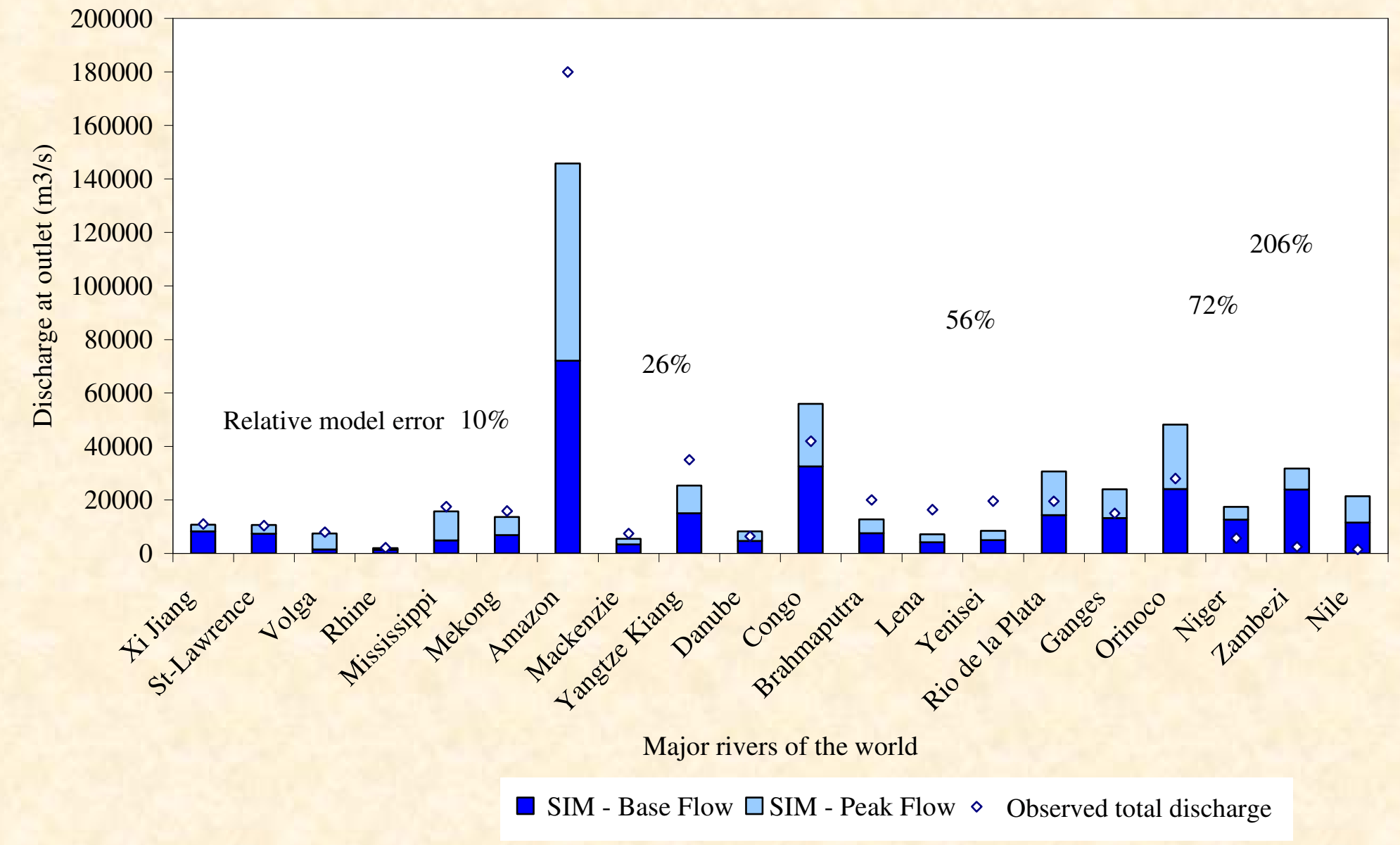


Based on data from various sources

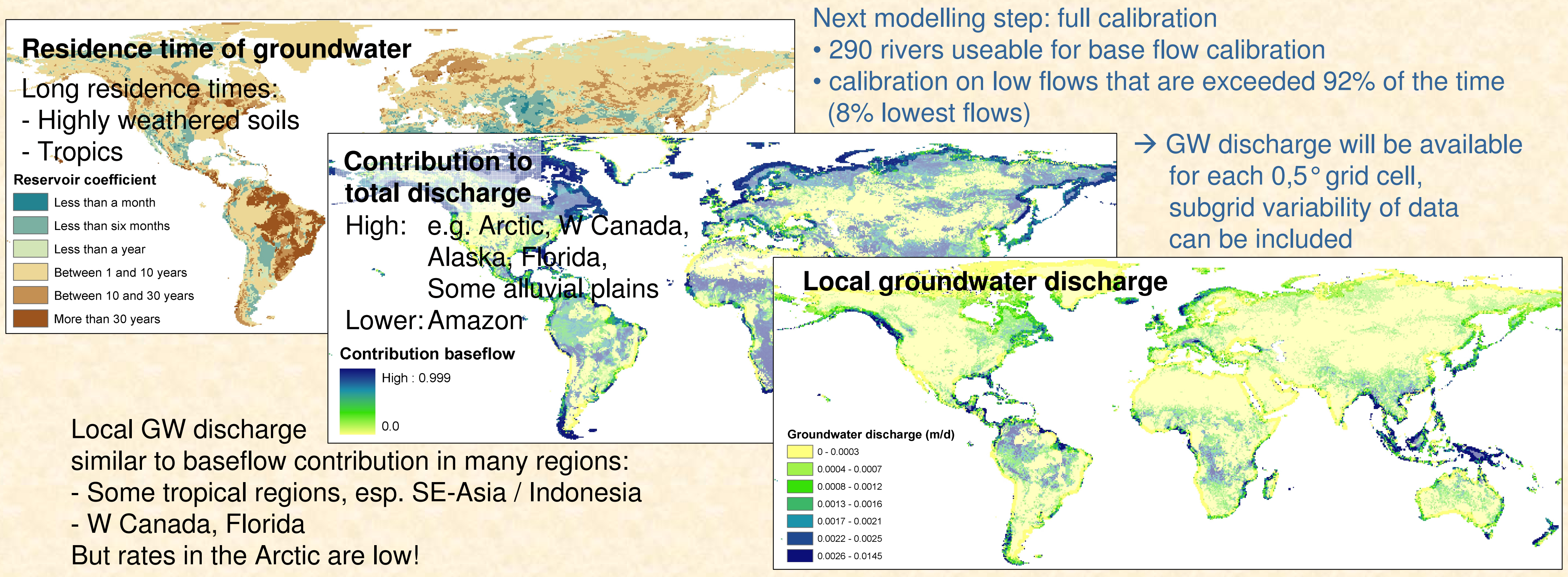
Annual values derived from monthly model calculations

Model results

Mean annual total discharge: model vs. observations



NB:
- Model not fully calibrated yet, energy balance + lakes not yet considered
- Good model performance for most temperate and tropical regions
- Weaker performance for Arctic + semi-arid regions



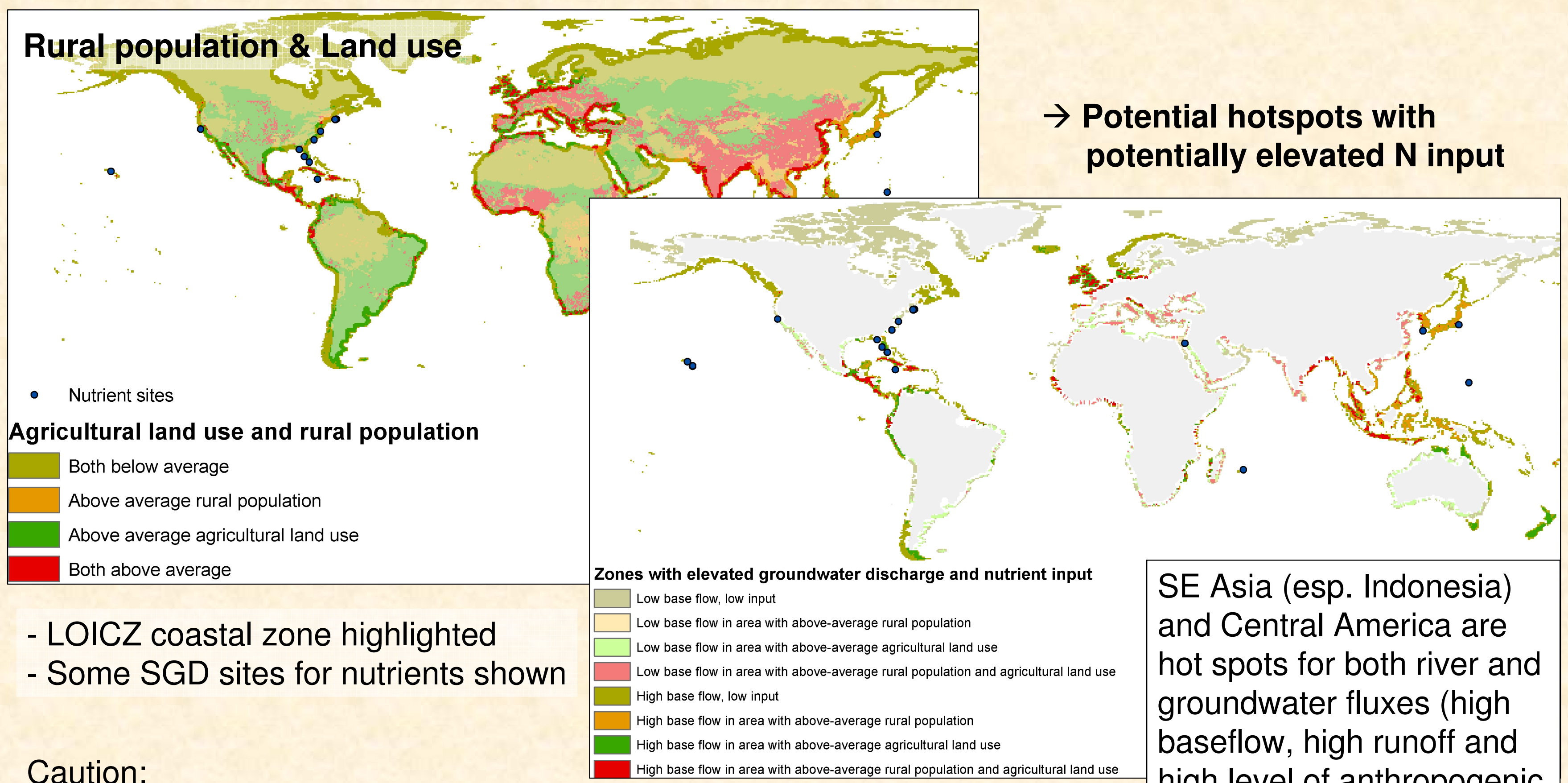
Next modelling step: full calibration
- 290 rivers useable for base flow calibration
- calibration on low flows that are exceeded 92% of the time (8% lowest flows)

→ GW discharge will be available for each 0,5° grid cell, subgrid variability of data can be included

Local GW discharge similar to baseflow contribution in many regions:
- Some tropical regions, esp. SE-Asia / Indonesia
- W Canada, Florida

But rates in the Arctic are low!

Combine with land-use and population data



→ Potential hotspots with potentially elevated N input

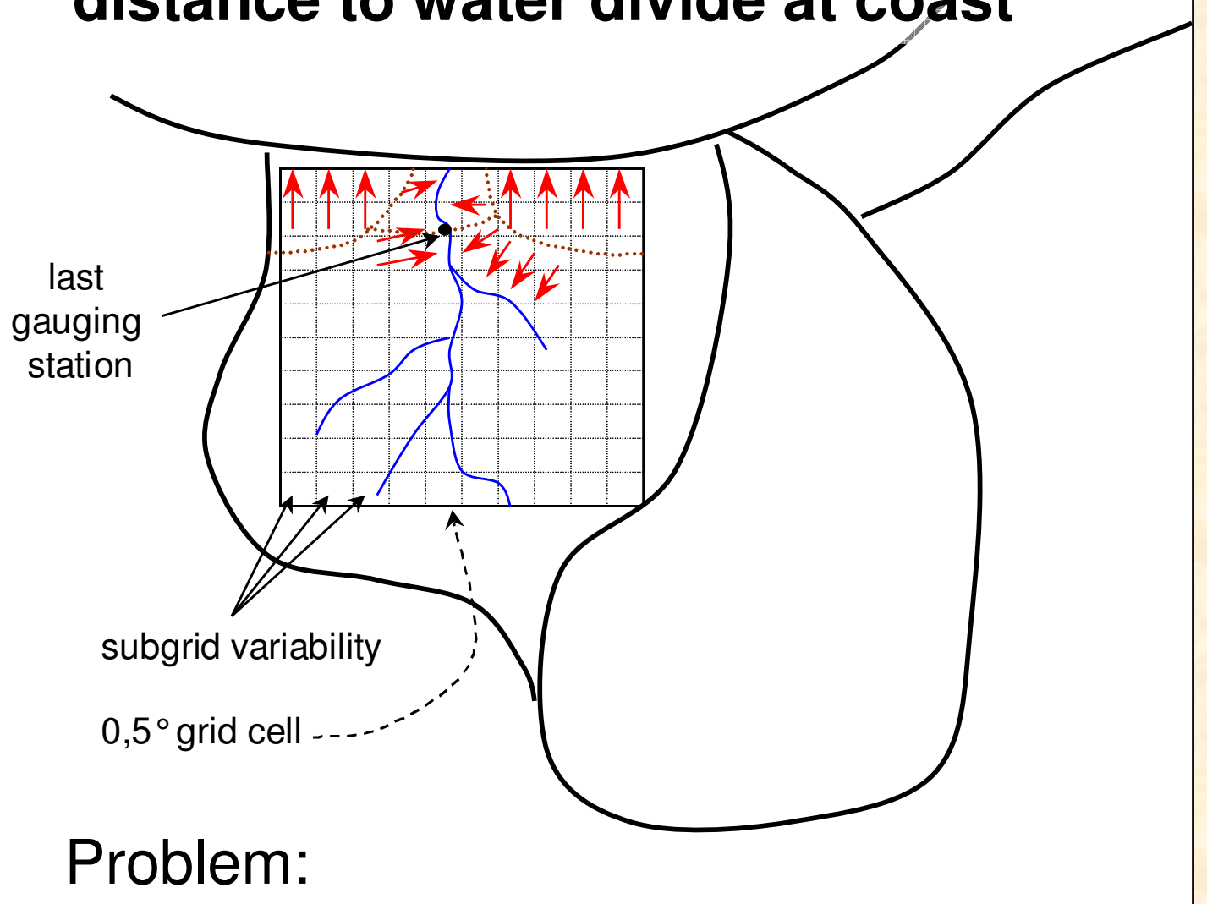
- LOICZ coastal zone highlighted
- Some SGD sites for nutrients shown

SE Asia (esp. Indonesia) and Central America are hot spots for both river and groundwater fluxes (high baseflow, high runoff and high level of anthropogenic activity) – exact locations and time scales may be different

Caution:
- Very local phenomena not detected
- Total GW flow in coastal cells, not SGD
- GW abstraction and saltwater intrusion not yet considered
- Effect of residence time in GW on nutrient concentrations not yet considered

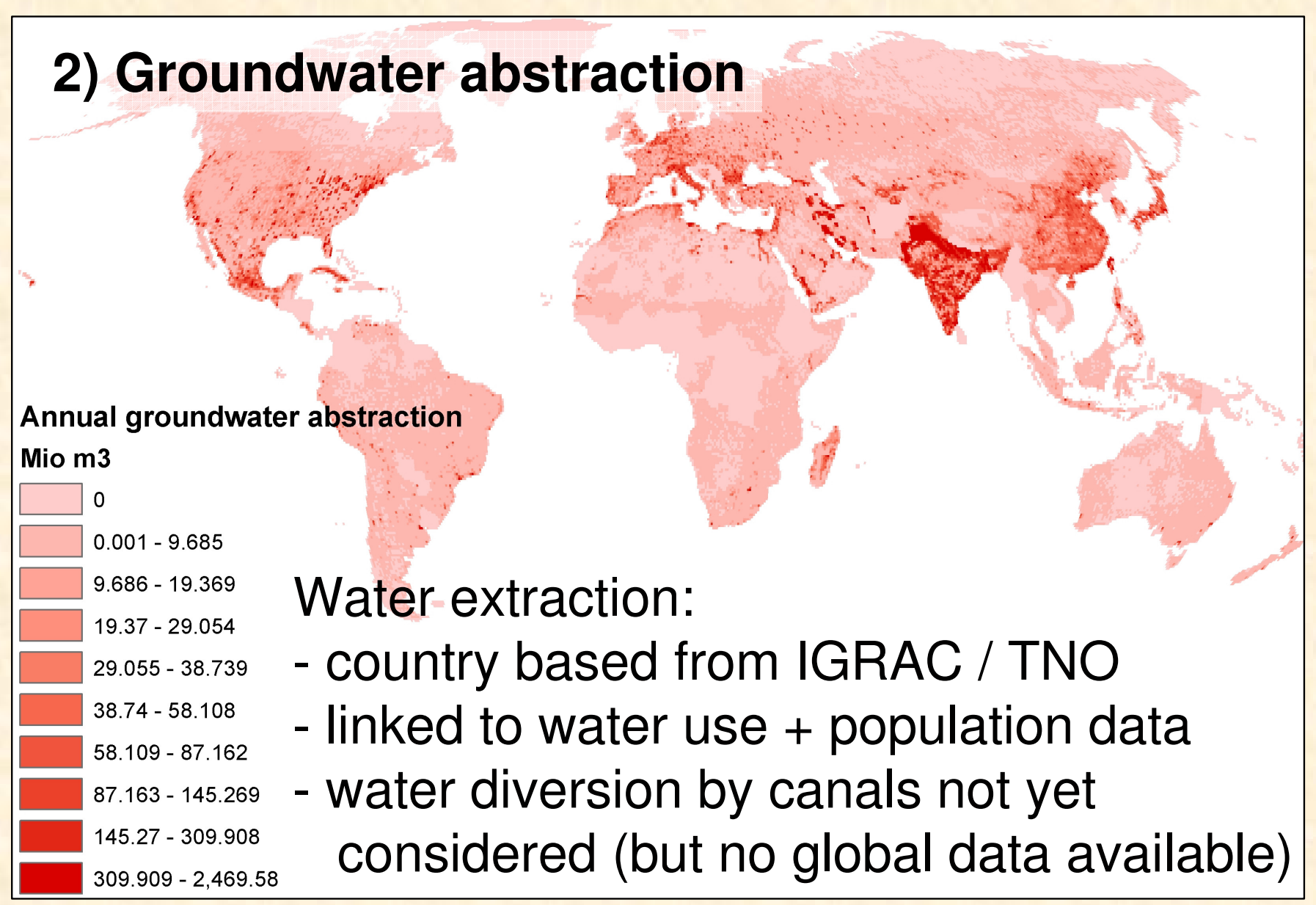
Next steps, including GW nutrient data

1) Coastal ribbon definition for SGD: distance to water divide at coast



Problem:
what is a stream?
→ every catchment that has a cumulated upstream area > xx km²
→ testing possible

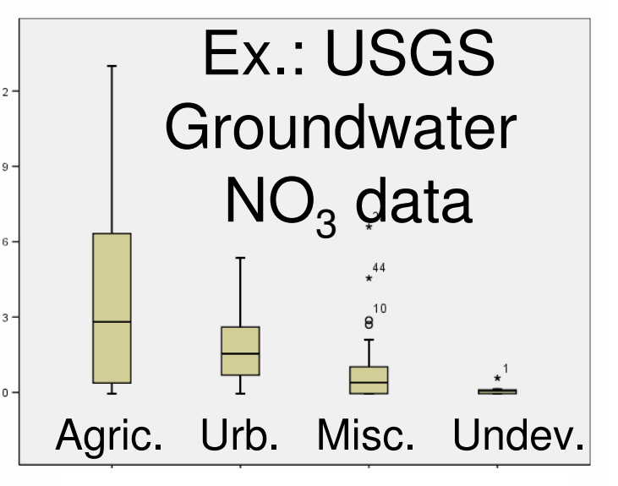
2) Groundwater abstraction



Water extraction:
- country based from IGRAC / TNO
- linked to water use + population data
- water diversion by canals not yet considered (but no global data available)

3) Groundwater quality data

- IGRAC / TNO: country-wide data
- USGS, EEA: large DB available
- for other places: link to income (GDP) and data from selected studies on some coastal GW sites



Conclusions

- Various direct pathways of coastal groundwater and associated nutrients to the coastal ocean; flows are highly variable, both spatially and temporally, and depend on redox conditions in the subsurface
- As source of 'new' nutrients, especially nitrogen (less P), freshwater SGD is potentially important for coastal nutrient cycling at global scale (strong response to human impact)
- First steps have been taken towards obtaining spatially explicit estimates of SGD at global scale and identifying potential hot spots
- Next steps should now include
  - Definition of coastal ribbon where baseflow = actual SGD
  - Groundwater abstraction and saltwater intrusion sites
  - Groundwater quality data

References

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