# Integrating human water management into land surface models

*Jan Polcher & Xudong Zhou*
*Laboratoire de Météorologie dynamique/IPSL, CNRS, Paris*
*Hohai University, Nanjing*

- State of the art and past experience with water management in land surface models (LSMs).
- The adduction network and dam.
- Some new ideas to simulate water management.
- Bringing the community together to accelerate progress.

# The need to add water management in LSMs

The reviews of Nazemi & Wheater points out two issues on previous efforts to include human management in Earth system models :

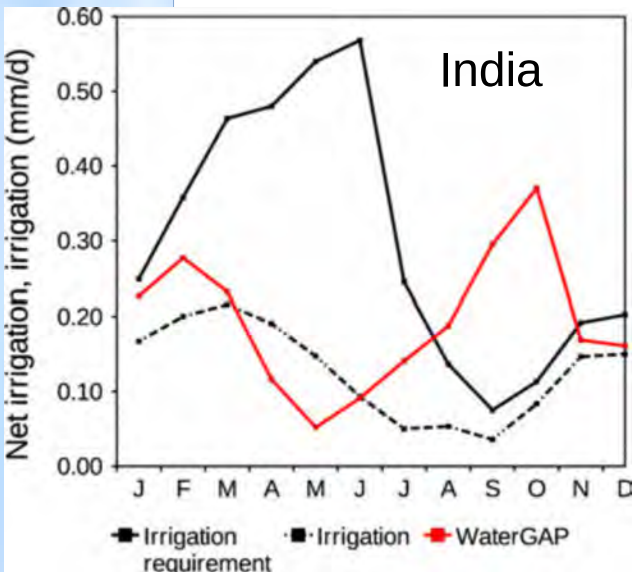
- Very few of the previous studies have conserved water.
- Models will need to balance demands and resources.

State of the art outside of the climate community :

- Agricultural demands can be predicted by Agro models and LSMs.
- Resources are simulated by GHM.
- The balance of both is an economical problem.
- Climate scale predictions require water conservation.

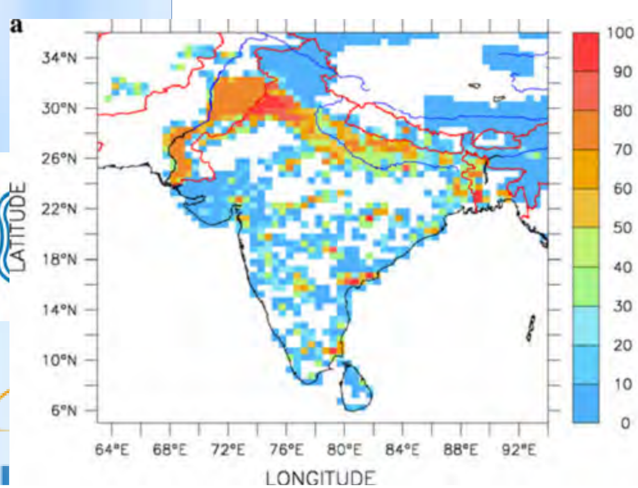
This is a truly multidisciplinary problem.

# Previous Studies with ORCHIDEE

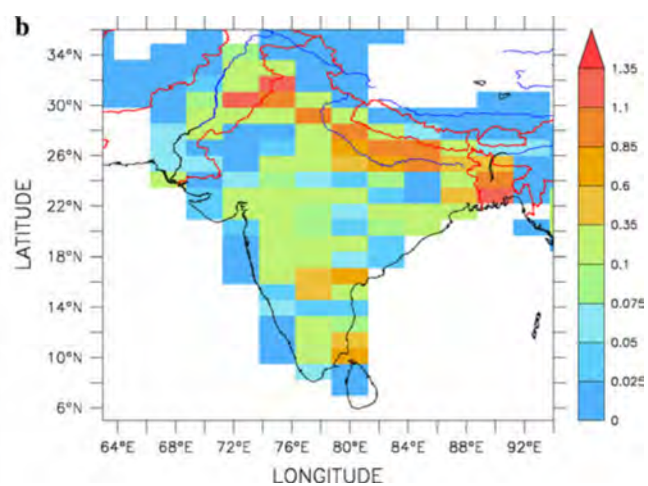



- The scheme implemented at IPSL conserves water.
- In ORCHIDEE irrigation demand is estimated with the ratio of actual to potential transpiration.
- It provides more realistic seasonal evolutions than the FAO formulation.

De Rosnay et al. 2003 & Guimberteau et al. 2012



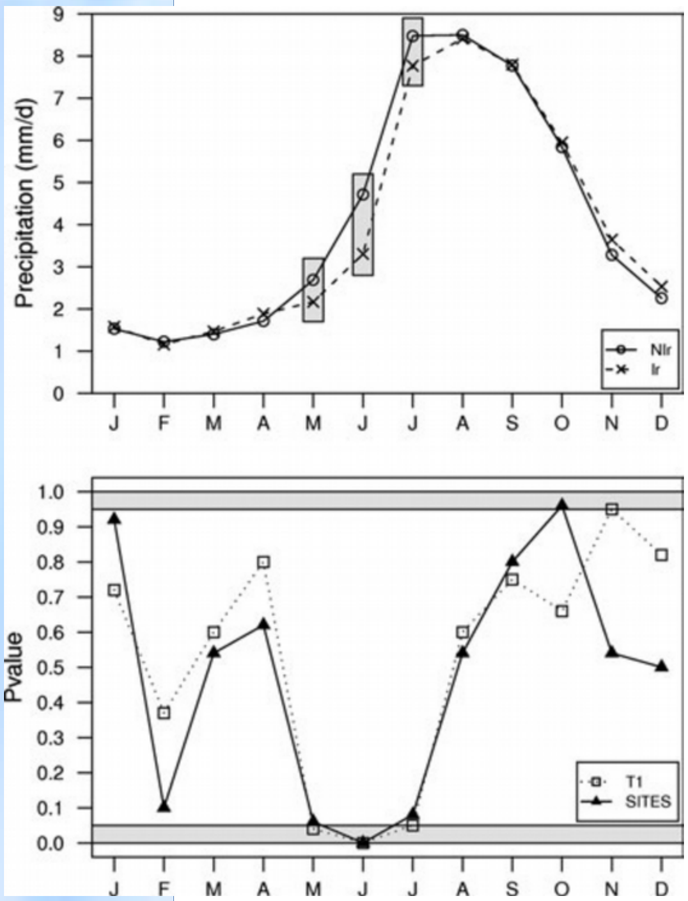

Areas equipped for irrigation (Siebert et al. 2005)




Mean annual irrigation predicted by the GCM.

The coarse resolution of the GCM allows to assume that the irrigation demand will be satisfied locally with water from the stream reservoir or ground water.

# Impacts and limitations




- Irrigation in the GCM has shown some impact on the Indian Monsoon.
- It was demonstrated that small scale gradients at the surface (≈10km) have a larger impact on the atmosphere.
- Stronger impacts are expected at convection-permitting resolutions.

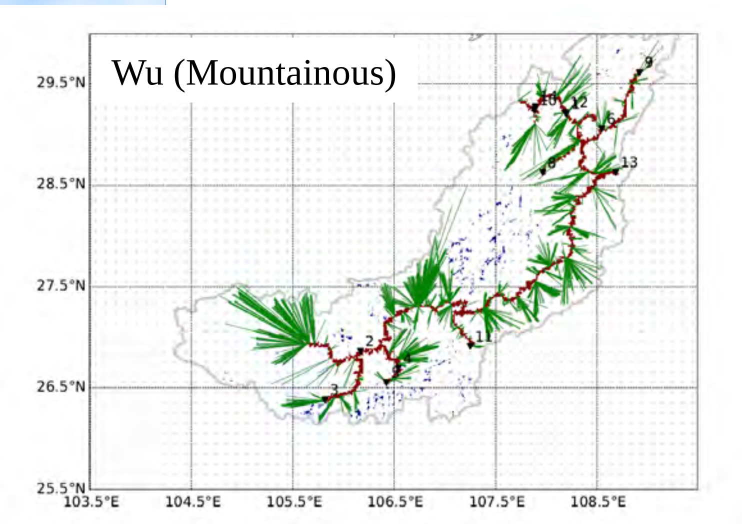
At C-P resolutions human infrastructures start to play an important rôle :

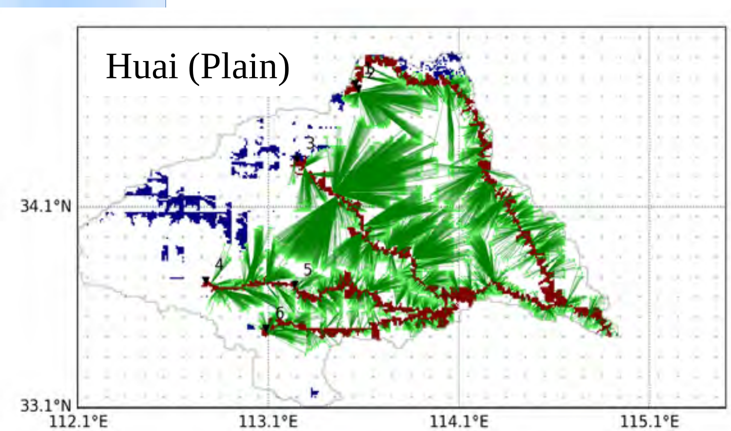
- Storage in reservoirs, i.e. local water is not sufficient
- Adduction networks transport water from the stream to the irrigation perimeter.

ORCHIDEE's scheme starts to fail below for grid sizes below 1/2°.

Guimberteau et al. 2012

# Deducing adduction networks




- Construction of channel networks is the result of economical optimization (with the least cost for transferring and lifting up the water)

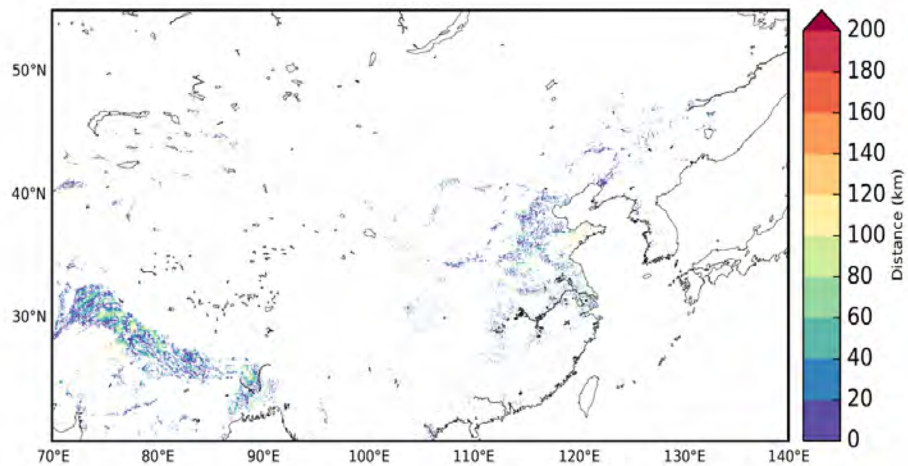
$$cost = (d + kH)/\log(U)$$

- The preferred channels are determined by geography (d=distance to river)
- A penalty factor is given for lifting up water (kH = function of height difference)
- River with larger upstream area is given higher priority (U = area of upstream area).

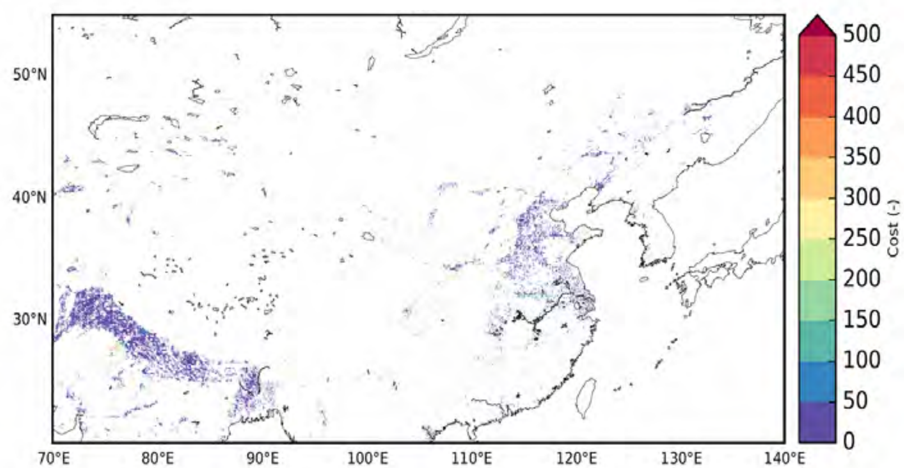
Precise demand locations and demand-supply paths allow to define the interactions between river water to the land surface process.

# Regional adduction networks

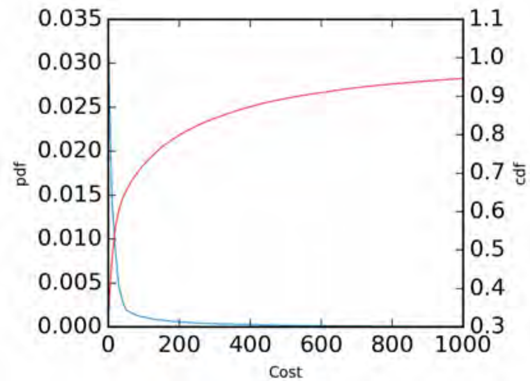
Length of channels



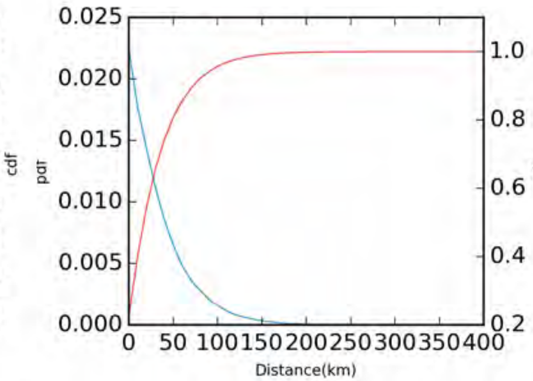

Cost function




Cost function




Length of channels




Histograms of the optimal cost function and distance and for East Asia

| | Region | Mean | Std | Median |
|---|---|---|---|---|
| **Distance (km)** | *East Asia* | 36.4 | 34.7 | 26.6 |
| | *Wu* | 24.5 | 16.9 | 22.7 |
| | *Huai* | 15.0 | 11.3 | 11.7 |
| **Cost** | *East Asia* | 200.6 | 506.5 | 22.5 |
| | *Wu* | 829.5 | 666.1 | 656.9 |
| | *Huai* | 58.0 | 143.5 | 8.0 |

- Only catchments  larger than 10000km$^2$ are considered as abstraction points
- The 1km map is extrapolated from FAO 10km map

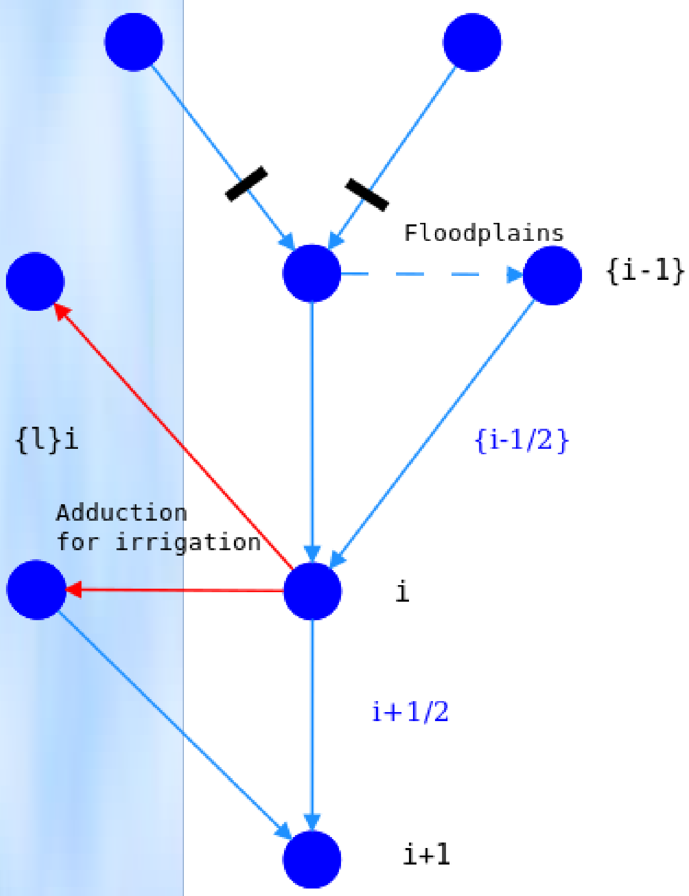
# Dam regulation in Global Hydrological Models

- Simulation based algorithms (Hanasaki et al.)
  - Annual release is function of the storage and mean inflows
  - Monthly distribution is controlled by withdrawals
  - This scheme does not take into account the climate of the current year.
- Optimization based algorithm (Haddeland et al.)
  - A costly search for optimal release
  - Difficult to use in a prognostic mode
  - Can it be converted into a learning algorithm as the years of the simulation progress ?

# Attempting to balance demands and resources in a LSM

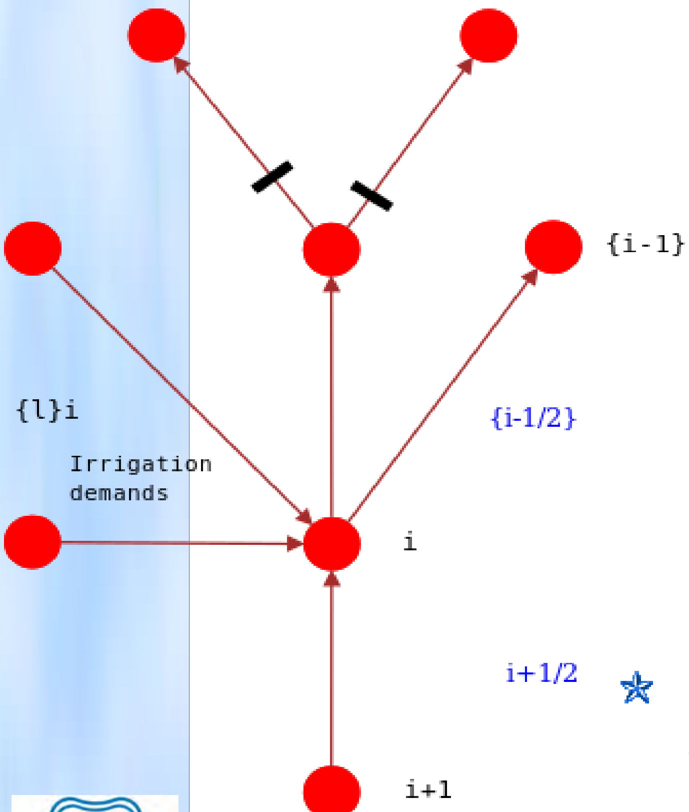
- The balance is achieved in an economic world but where also regulations preserve ecological balance which is supported by water.
- The balance is performed mostly at the level of dams where regulation occurs.
- The proposed model is inspired by the hydro-economical model ODDYCCEIA (Neverre et al. 2016)
- The aim is to obtain a framework which is compatible with the constraints of climate modelling :
  - Water conservations in the model.
  - Demands and resources evolve with climate.

# Modelling water value classes in ORCHIDEE




- The routing scheme predicts 4 value classes with the following priority:
  - *Ecological flow*
  - *Domestic water*
  - *Agricultural needs*
  - *Energy production*
- For analysis purposes the model continues to predict a natural flow.
- Runoff and drainage generate ecological flow in the graph.
- Regulation points (dams) can transfer water to other classes.
- Water bodies (regulated or not) revert all classes to ecological flow.
- Floodplains are not yet implemented.

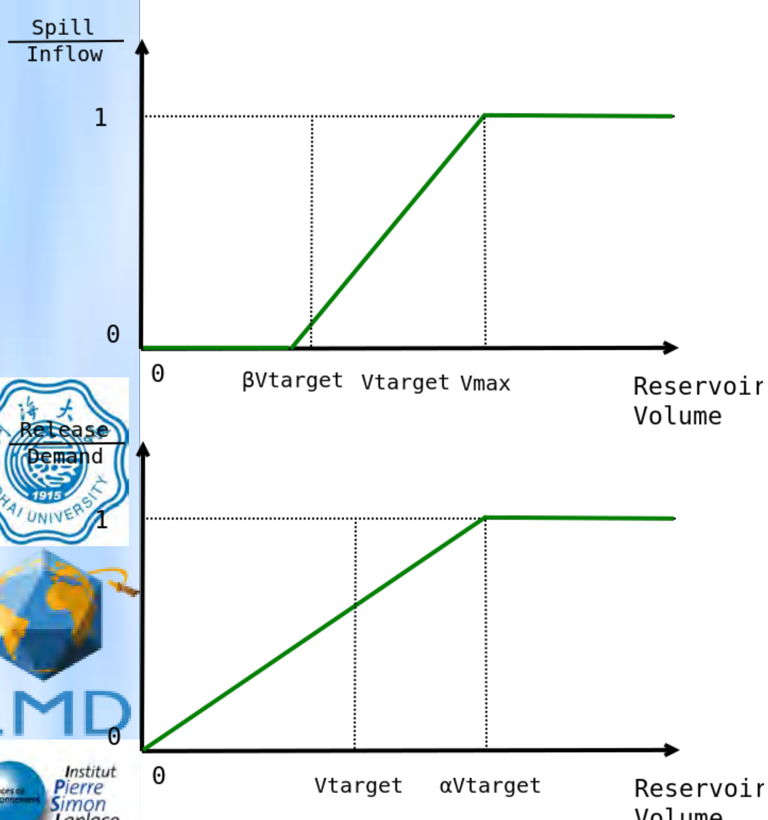
# Modelling water demands




- For each of the water classes a demand function is formulated at each grid point :
  - Ecological flow : total water in river cannot fall below the 90% quantile.
  - Domestic demand : To be implemented
  - Irrigation : based on the difference between potential and actual transpiration of crops.
  - Energy : to be implemented.
- Grid-box demands are transferred to the vertices following the adduction network.
- All unsatisfied demands are propagated up-stream (Daily time step).
- Dams respond with their management rules to unsatisfied demands integrated over downstream vertices and resources.

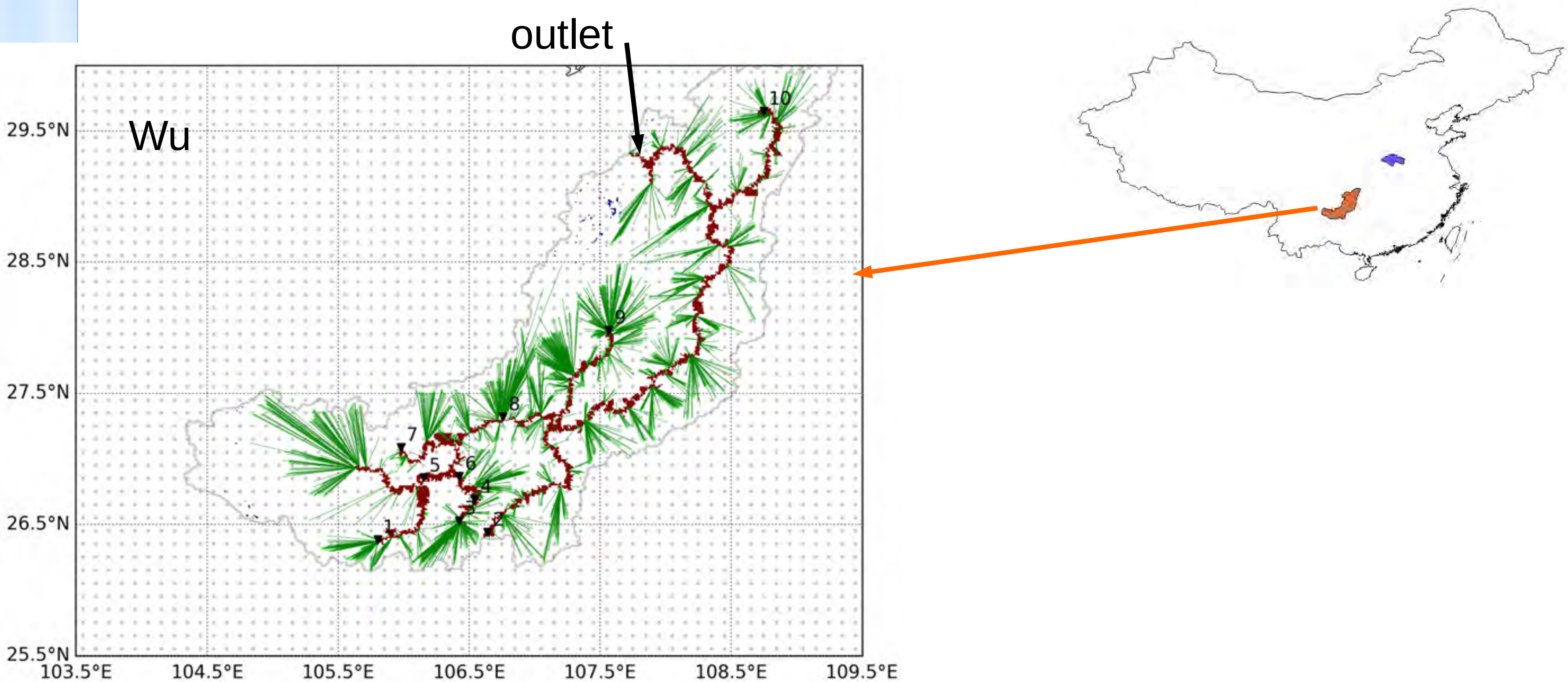
# Demand satisfaction and regulation

- Unsatisfied demands are generated as follows :
  - In each vertex the demand can be fulfilled by the water available in the corresponding class.
  - If there is no demand for ecological flow then water from this class can be used.
- Dams respond to inflow and unsatisfied demands :




- During the filling period hedging is performed to maintain space for floods.
- Else the dams satisfies the demands with a hedging parameter to preserve resources.
- Any demand which can not be satisfied will propagate up-stream to other dams.
- Releases responding to irrigation demand are amplified to compensate for river storage.

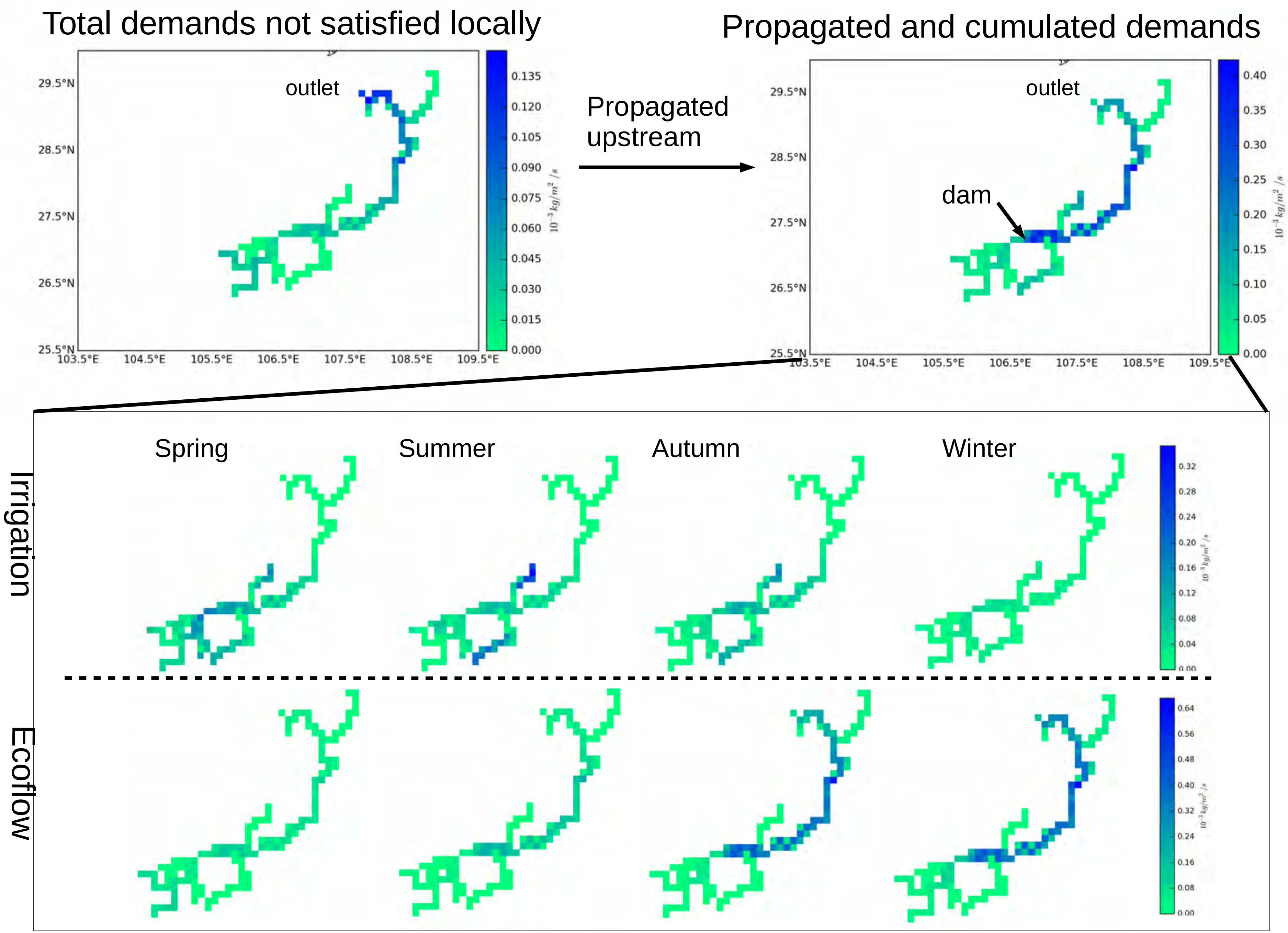
# Test case: Wu River Basin



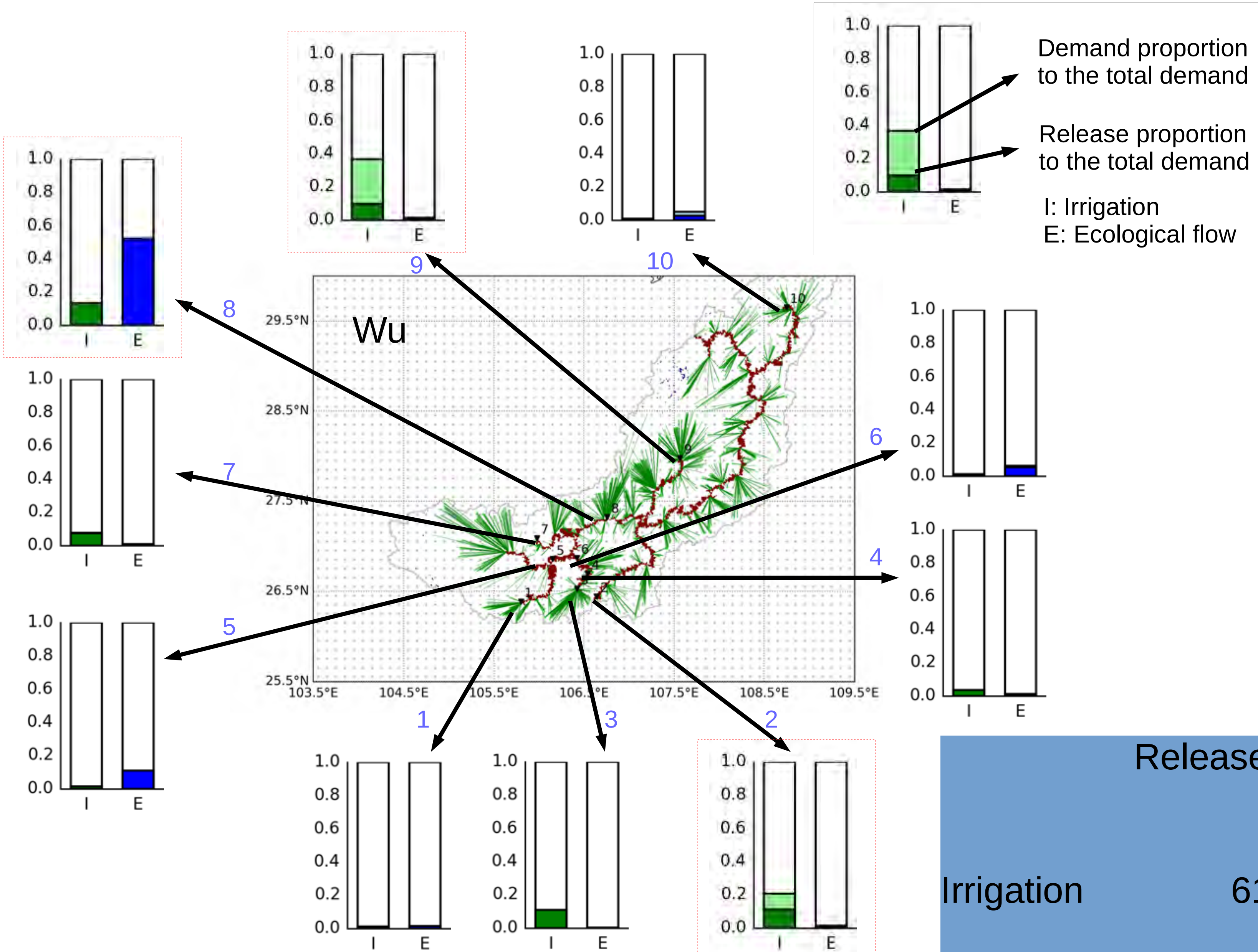

| | Wu River Basin |
|---|---|
| Climatic type | Humid |
| Rainy season | April-June |
| Drainage area (km²) | ~83140 |
| Irrigation area ratio | ~9.7% |
| Irrigation extraction ratio | ~4.86% |
| Number of dams | 10 |

- The runoff/drainage and irrigation demand are simulated by ORCHIDEE with 0.1° forcing.
- **Ecological flow demand:** total water in rivers cannot fall below the 90% quantile of the 7-days consecutive values (7Q90).

# Demand and propagated demand

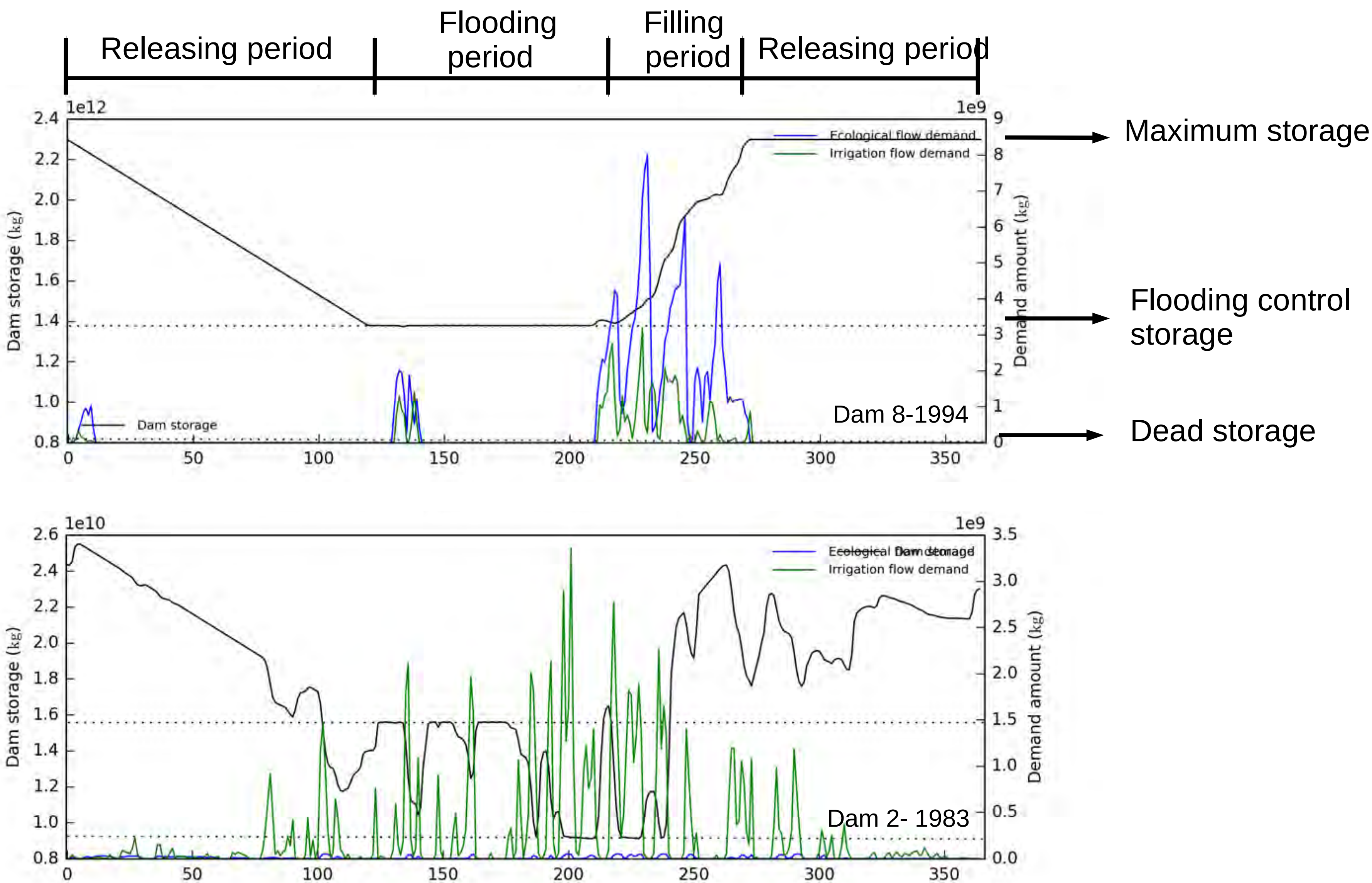


# Demand and release at dams location



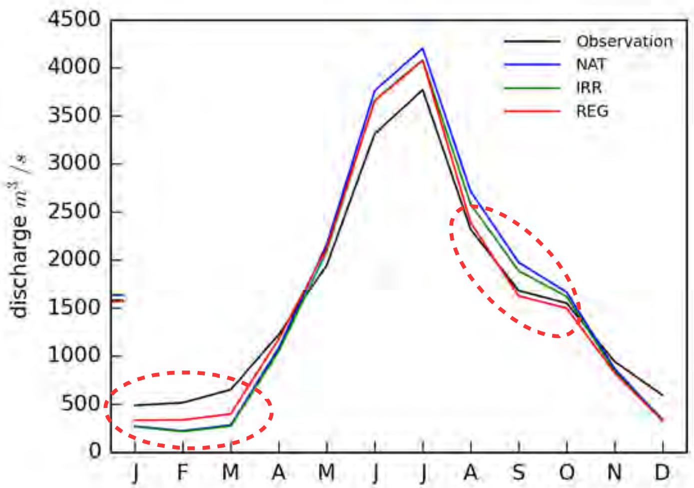

| | Release / demand |
|---|---|
| Irrigation | 61.6% |
| Eco flow | 94.4% |

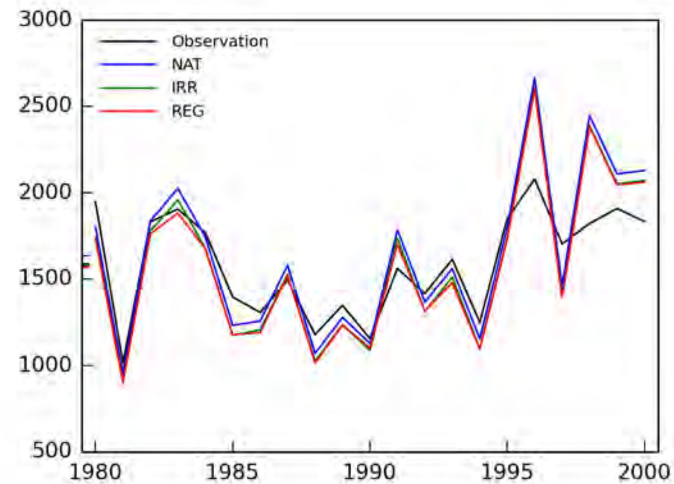
# Dam regulation based on the demands



# Impact of dam regulation on discharge

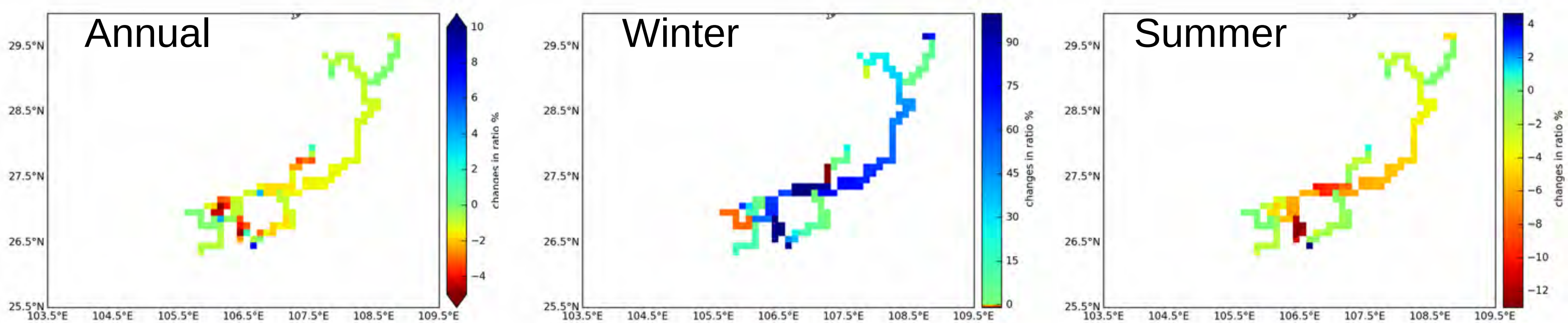
- Discharge at the outlet




*Dam regulation has little impact on annual mean of the discharge, but it changes the annual cycle.*

- Discharge changes in space (REG vs. IRR, in percentage)




*Discharge changes are opposite in summer and winter, and the mainstream is experiencing higher impacts.*

*In this simulation irrigation demands are unrealistically low.*

# Which knowledge and expertise need to be brought together ?

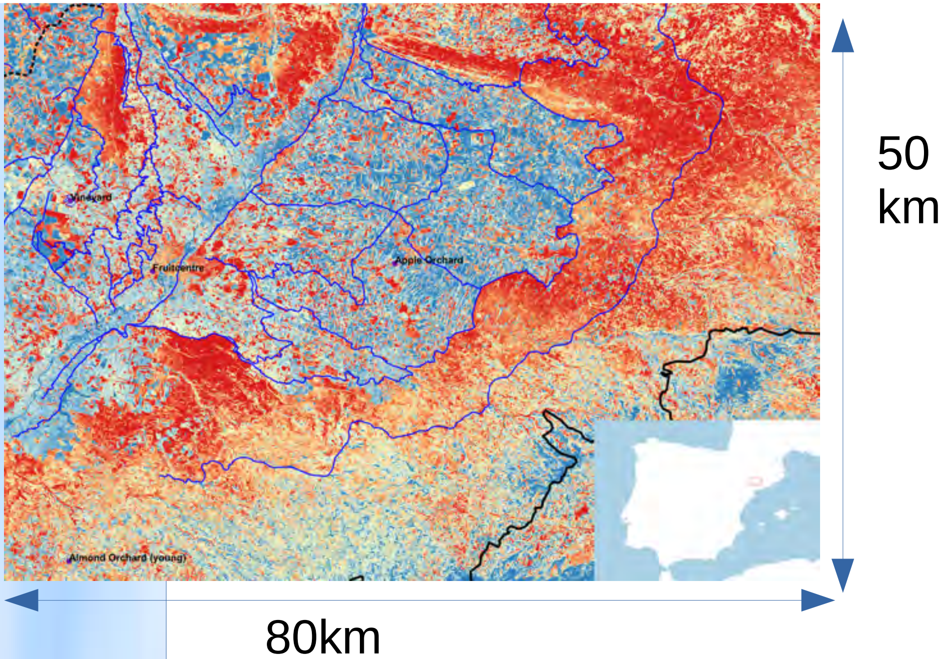
Building models able to combine climate change and water management to predict environmental consequence will require knowledge and data from different disciplines to be brought together :

- Agronomists for the demand side.
- Hydrologists for the water management infrastructures.
- Economists for the operation of infrastructures and distribution of resources.

A convergence will be attempted with a field campaign of HyMex !

# HyMex/LIAISE field campaign

Sentinel2 IR image, ESA & sen2ET project.




- The field campaign is planned for 2020
- It will pool resources from UK, France and Spain to observe the surface and atmosphere.
- Will involve ground and airborne observations.
- Will bring together agronomists, hydrologists and climatologists.

**Objectives** :

- The dry-down of the surface and its impact of the surface heterogeneities.
- The impact of irrigation on the PBL and precipitating systems.
- Validate and improve coupled models over irrigated areas.

# Conclusions

- There are simple methods to introduce irrigation. But they brake water conservations.
- It is time to think **out of the box** to bring these processes into land surface models while keeping them compatible with climate model constraints.
- Trans-disciplinary collaborations are needed to advance.
- A field campaign is planned to advance these issues.
- Within the Grand Challenge "Water for the food baskets of the world" we would like to encourage the community to advance together on this topic.
- Please come to the town hall meeting on Friday : 14:30-17:30.