Representing Human Water Management in Earth System Models

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In recent changes in the global water cycle, can we distinguish between climate change ("non-intentional") and human management ("intentional")?

* Can we detect the human signals within the variability of the continental water cycle?
* Building Earth system models which include water management.
A changing continental water cycle

- The water cycle changes at global scale because of a modified greenhouse effect.

- On continents, the water cycle is further modified by water and land use.

- In some regions both pressures on the water cycle interact.

- These changes occur in a system with a large inter-annual variability and where many quantities are difficult to observe.
Detection and attribution of changes

Detection of precipitation changes is notoriously difficult because of the high temporal and spatial variability.

Detection in slower land surface variables is more promising, but they are affected by both climate change and human management.

A simpler question could be: is the impact of human management detectable within climate variability?

This requires that:

- We quantify with sufficient precision climate induced variability of the water cycle.
- We can estimate the man made change to the natural state.
Matching models and observations

\[
\frac{dW}{dt} = P - E - x \cdot (R + D)
\]

\[Q = f(R, D)\]

The assimilation of discharge allows us to deduce where inconsistencies exist with the estimated “natural” moisture convergence (P-E).

The procedure can be used to identify where missing processes or modelling & forcing errors cause large deviations from the “real” system.

F. Wang, et al. 2018
Are land surface models missing processes?

- Three atmospheric forcing are used to drive the LSM
- 27 discharge stations are assimilated
- Precipitation is assumed to be correct to place the moisture convergence error on evaporation.
Are there feedbacks between water management and climate?

- These and many other studies have shown that over continents the water usage is “visible” within climate variability and trends.
- Attribution of the relative amplitude of both components has eluded us so far because climate change and water management are not independent.

Are there possible feedbacks?

- Land use changes
- Irrigation (two way interaction)
- Water storage (two way interaction)

Only Earth system models (climate + hydrology) allow to extract the role of possible feedbacks.
Which tools do we need to advance our understanding?

- Field campaigns to target detailed processes of the interaction between climate and water management:
  - Hydrological studies
  - Atmospheric sciences

- Models which combine our atmospheric and hydrological understanding:
  - Probably regional Earth system models for their resolution.
  - Complete representation of water management.
  - Needs to be combined with other existing processes already in Earth system models: ocean, chemistry, carbon cycle, ...
Dam regulation in Global Hydrological Models

★ Simulation based algorithms (Hanasaki et al.)
- Annual release is function of the storage and mean inflows at start of season.
- Monthly distribution is controlled by average 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 ODDYCCCEIA (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.
Estimating demands

- Irrigation demand is estimated in ORCHIDEE by comparing potential and actual transpiration.
- This is not suitable for some crop types like rice. ORCHIDEE-Crop refines these estimates.
- These demand estimates are difficult to evaluate as the objective quantification will differ from the one expressed by farmers or established by society.
Deducing adduction networks

- Construction of channel networks is the result of economical optimization (with the least cost for transferring and lifting up the water)
  
  \[ cost = \frac{d + kH}{\log U} \]

- The preferred channels are determined by geography (\(d=\text{distance to river}\))

- A penalty factor is given for lifting up water (\(kH = \text{function of height difference}\))

- River with larger upstream area is given higher priority (\(U = \text{area of upstream area}\)).

Precise demand locations and demand-supply paths allow to define the interactions between rivers and the land surface process.
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.
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 upstream (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.
Application to the Yellow River

- The Yellow river feeds some of the largest irrigated areas in China.
- Steps undertaken to implement the model:
  - Locate irrigated areas within the 1km routing network
  - Estimate the adduction network
  - Place the dams on the river graph
  - ORCHIDEE is run. It will predict the water available and the agricultural demands which need to be balance at the dams. It also simulates the natural flow.
Impact of irrigation and regulation

- The abstraction for irrigation reduces the flow in the river.
- But during some seasons the demand can not be satisfied.
- Adding regulation modifies the annual cycle of discharge especially after dams.
- The regulation allows to better satisfy irrigation demands => further reducing discharge.
Impact on the annual cycle

- The annual cycle of the river flow is strongly changed by irrigation and regulation.
- The along-river plots allow to show where the key processes occur.
- Irrigation has strong seasonal variations.
- Dams play only at certain points and ensures water is available where and when irrigation needs it.
Conclusion

We have demonstrated that human water management can be represented with a supply/demand approach in a LSM.

Results need still to be better understood.

It needs to be demonstrated that such a model also works globally.

It is a challenge for our community to disentangle the different causes of the changing water resources. We owe it to our society to concentrate on this issue.