Estimates of Flood Inundation and Evaporation in the Niger Inland Delta Region using JULES

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WATCH Water and Global Change

1. Abstract

Observed river gauging data indicate significant evaporative losses from the land and water surface in the Niger Inland delta. These losses indicate an important potential feedback between the land-surface and atmosphere. Moreover, the reduction of flow downstream of the wetland has clear implications for water management in the region and beyond.

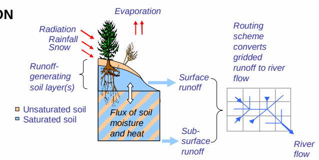
Here we have modelled the land-atmosphere coupling in the Niger Inland Delta by adding an overbank flow parameterization to the Joint UK Land-Environment Simulator (JULES) land-surface model (Blyth *et al.*, 2002). Our hydrological model comprises a probability-distributed model of soil moisture and runoff production (PDM; Moore, 2007) coupled with a discrete approximation to the 1D kinematic wave equation to route river water downslope (G2G; Bell *et al.*, 2007). The model was driven using data from the ALMIP experiment (Boone *et al.*, 2006).

The model simulates the broad features of the observed river flow pattern, including a downstream attenuation of the flood-wave through the wetland region. The model results illustrate significant evaporative losses from the inundated region leading to a ~10 percent reduction in river flow. The greatest relative decreases in river flow occur during spring and summer low flows. Moisture flux from the inundated region is greatly increased, accounting for up to 50 percent of the total land-atmosphere water flux during periods of maximum flooding. Moreover, a temperature anomaly of up to -8 K was observed in the inundated region

Further work is planned to use sub-grid-resolution topographic data to improve the representation of overbank flow in the model; to compare the extents of modelled and observed inundated areas using satellite microwave remote sensing; and to include wetland evaporation process in online climate simulations to investigate land-atmosphere feedbacks.

2. Model

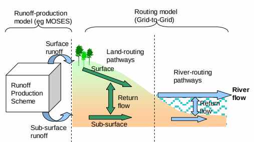
RUNOFF PRODUCTION



The Met Office Surface Exchange System (MOSES; Cox *et al.*, 1999) is the basis for the Joint UK Land Exchange Scheme (JULES; Blyth, 2002) and provides the facility to diagnose the hydrological state of the surface and soil given time-varying inputs of temperature, wind speed, humidity, shortwave and longwave radiation, and precipitation. Within JULES there are four horizontal soil layers, each with an associated temperature and soil moisture content. Water and heat are assumed to move in the vertical direction only. Estimates of surface and subsurface runoff are calculated as the amount of liquid water leaving a grid square on the land and below ground, respectively. The influence of stomatal resistance of vegetation is also modelled explicitly in order to estimate evapotranspiration from the canopy, and account is taken of the effect of spatially-varying soil properties and land cover. Estimates of grid-square runoff (surface and sub-surface) required by the Grid-to-Grid routing model are available as a byproduct of the surface runoff production scheme, which operates using the probability distributed principle (PDM; Moore, 2007). These gridded runoff values provide estimates of liquid water leaving a grid-square both on the land-surface and below ground, taking into account the effect of spatially-varying soil properties and land-cover.

FLOW ROUTING

The Grid-to-Grid routing model (G2G) is configured on a grid to use estimates of runoff provided by a runoff-production, or land-surface, scheme such as JULES (above). The G2G model (Bell *et al.*, 2007) is based on the discrete approximation to the 1-D kinematic wave equation with lateral inflow. It is assumed that a separate runoff-production model component partitions precipitation and evaporation fluxes into water stored in the soil and canopy, and water is generated as surface and sub-surface runoff.

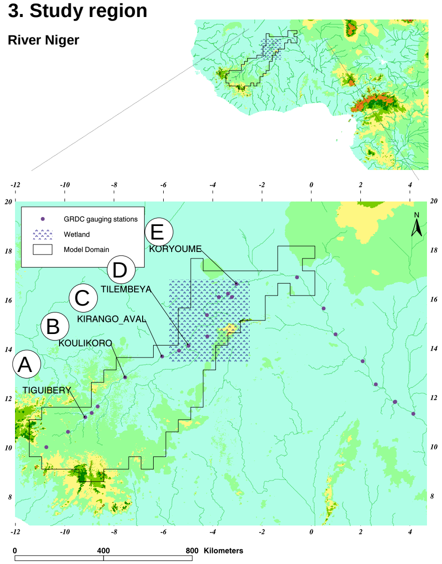


Kinematic routing is applied separately to sub-surface and surface runoff; the model also allows for different formulations over land and river pathways. A return flow term allows for flow transfers between the sub-surface and surface pathways representing surface/sub-surface flow interactions on hillslopes and in channels. Optimal flow routing parameters for the Niger River were identified.

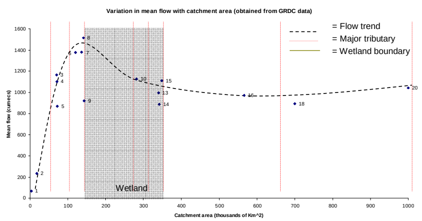
Flow paths were calculated from the HYDRO1K digital elevation model using the method of Olivera *et al.*, 2002. At present, the extent of inundated water surface is calculated using a simple power-law which relates flood discharge to channel width ($w = 4Q^{0.5}$; Leopold and Maddock, 1953). This model captures the tendency for the area of open water to increase with flood discharge but does not explicitly account for the large increase in inundated area when the river exceeds its bankfull discharge. Consequently, we expect our results to provide a lower bound on the potential impact of wetland inundation on the rate of evaporation from the water surface to the atmosphere.

3. Study region

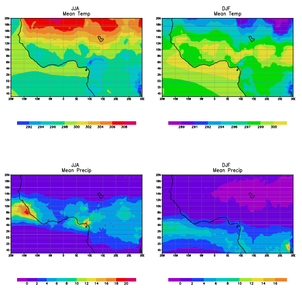
River Niger



The Niger river rises in the Guinea Highlands and flows NE for km when it reaches the Inland Delta in Mali. The wetland region extends over 32,000 km^2. At approximately 17 degrees N, the Niger river alters its course to run towards the SE, reaching the Niger Delta after some 1,600 km and ultimately discharging into the Gulf of Guinea.

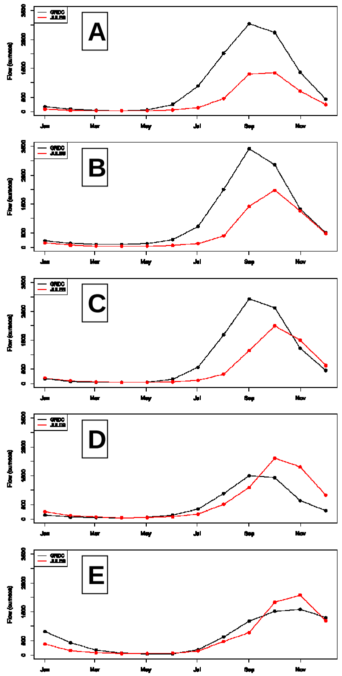


Observed flows:
Gauged river flow data were obtained from the Global Runoff Data Centre (GRDC) for ~20 stations spanning the Niger River. Mean flow increases with catchment area in the upper course of the Niger River, but as the wetland region (shaded) is reached, mean flow declines steadily to an approximately-constant value. The local influence of tributary inputs is shown by dashed lines



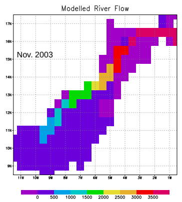
Driving data
We have driven the model using meteorological data from the ALMIP experiment, which is provided every three hours between 2001 and 2006. The following variables were used: surface pressure, surface temperature, humidity, vector wind velocity, long wave and short wave radiation, and liquid and solid precipitation.

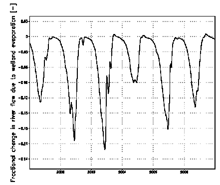
4. Results



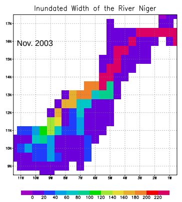
Comparison of modelled and observed flows
Figures A–E show observed and modelled monthly mean flows. Observed flows were calculated as means between 1975 and 1995. Modelled flows were calculated between 2001–2006. It is clear that, since the observed and modelled periods do not overlap (owing to limited data availability), the analysis presented here concerns whether the seasonal flow patterns match; the relative magnitudes of modelled and observed flows cannot be compared owing to the different periods over which they have been calculated.

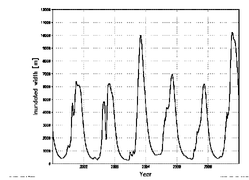
The model captures the broad features of the monthly hydrograph: a peak in flow between July and November which occurs steadily later in the year as one moves downstream. As the flow peak is translated downstream, it becomes attenuated. This attenuation is particularly pronounced within and downstream of the wetland region. The model significantly underestimates river flow in the upper course of the river, although in the lower reaches, flow magnitude is well-simulated. It is unclear whether this underestimate results from a deficiency in the model, a deficiency in the data or a difference in the time-periods over which the averages have been calculated.



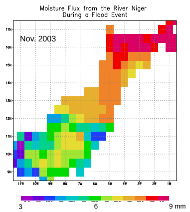


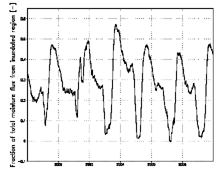
Modelled river flow
The fractional change in river flow that results from inclusion of the wetland evaporation scheme in JULES is ~10 percent, up to 18 percent at times. Evaporation is of greatest relative importance during spring and summer low flows when potential evaporation is highest; during floods the absolute value of moisture flux is highest but the resulting loss from the river channel forms a negligible proportion of the total flow.



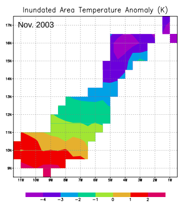


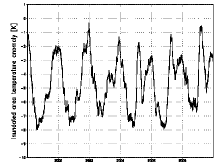
Inundated width
Inundated width is shown; it scales with river flow according to the relation defined in box 2.





Moisture flux
The highest moisture fluxes are from the inundated region. During periods of maximum flooding, evaporation from the inundated region accounts for up to 50 percent of the total land-atmosphere water flux





Temperature anomaly
A significant reduction in temperature of the open water tile in JULES was observed. The reduction in temperature is directly linked to the evaporative moisture flux and is up to -8 K at periods of highest discharge.

6. Conclusions

Observed river gauging data indicate significant evaporative losses from the land and water surface in the Niger Inland delta. Here we have modelled the land-atmosphere coupling by adding an overbank flow parametrization to the JULES land-surface model. The model simulates the broad features of the observed river flow pattern, including a downstream attenuation of the flood-wave through the wetland region.

Model results illustrate:

•Significant evaporative losses from the inundated region leading to a ~10 percent reduction in river flow

•Greatest relative decrease in river flow during spring and summer low flows

•High moisture flux from the inundated region accounting for up to 50 percent of the total land-atmosphere water flux during periods of maximum flooding

•A temperature anomaly of up to -8 K in the inundated region

Further work will include

•Use of sub-grid resolution topographic data to improve the representation of overbank flow in the model;

•Comparison of modelled and observed inundated area using satellite microwave remote sensing;

•Inclusion of the wetland evaporation process in online climate simulations to investigate land-atmosphere feedbacks.

7. References and acknowledgements

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Bell, V.A., Kay, A.L., Jones, R.G. and Moore, R.J., 2007. Development of a high resolution grid-based river flow model for use with regional climate model output. *Hydrology and Earth System Sciences*, 11(1): 532-549.

Blyth, E. M., 2002. Modelling soil moisture for a grassland and woodland site in south-east England. *Hydrology and Earth Systems Science*, **6**(1):39–47.

Cox, P. M., Betts, R. A., Bunton, C. B., Essery, R. L. H., Rowntree, P. R., and Smith, J., 1999. The impact of new land surface physics on the GCM simulation of climate and climate sensitivity. *Climate Dynamics*, **15**: 183–203.

Leopold, L. B. and Maddoc, T., 1953. The hydraulic geometry of stream channels and some physiographic implications. *USGS Prof. Paper* **252**.

Moore, R. J., 2007. The PDM Rainfall-Runoff Model. *Hydrology and Earth System Sciences*, 11(1): 483-499.

Olivera, F., Lear M. S., Famiglietta, J. S. and Asante, K., 2002. Extracting low-resolution river networks from high-resolution digital elevation models. *Water Resources Research*, **38**(11), 1-8.