

Simulating Airflow over Small Water Surfaces with WRF-OpenFOAM Coupled Model in the Upper East Region of Ghana

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Motivation

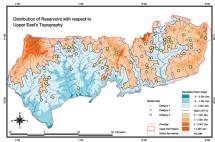
A coupled approach used in this research involves the use of a Numerical Weather Prediction (NWP) model and Computational Fluid Dynamics (CFD) to study the airflow over small inland lakes to investigate the spatial distribution of surface fluxes over heterogeneous surfaces in (semi-)arid regions. In most current mesoscale and global atmospheric models, the influence of small inland water bodies in the surface parametrization is neglected because the dimensions of these water surfaces mostly is smaller than the grid sizes used in these atmospheric models. As the meteorological measurements around the small lakes are rarely available in the region of study (Upper East region of Ghana, Africa), the WRF simulated results (where the horizontal dimension is several kilometers) are utilized to provide the initial and boundary structures, which can affected the heat fluxes over the (small) water surfaces significantly. for the CFD model.

Description of Study Site

The Upper East Region of Ghana (UER) has more than 160 small and shallow reservoirs which have different surface areas ranging from 1 to 100 hectares. These small reservoirs have the advantage of being operationally efficient with their flexibility, closeness to the point of use, and requires relatively few parties for management. Binaba dam, a small and shallow reservoir located in this region (10o 53'20" N, 00o 26' 20" W) was studied to determine the rate of heat fluxes in small lakes in this region.



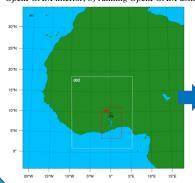


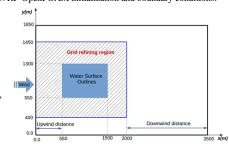


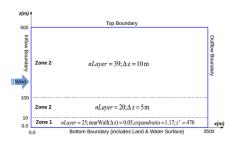
Distribution of small reservoirs in the Upper East Region of Ghana

Methodology

To estimate heat fluxes from small water surfaces, we are creating a modular assembly of coupled models where each model captures the most important physics of interest at sufficient fidelity and at minimum computational cost. WRF is used to provide the initial and boundary conditions for the OpenFOAM model to numerically calculate the unsteady state of airflow. Using OpenFOAM (with modified turbulence model including atmospheric stability condition) for a smaller domain (CFD) includes the small water surface allows for the use of smaller grid sizes for investigating the effects of stability conditions, limited fetch of the water surface, sharp changes in roughness, temperature and wetness on the heat fluxes from (small) water surfaces. Main steps are: 1) running WRF with defined configurations; 2) interpolating spatially and temporarily WRF-results to OpenFOAM boundary locations and initial field to OpenFOAM interior; 3) running OpenFOAM using WRF-OpenFOAM initialization and boundary conditions.



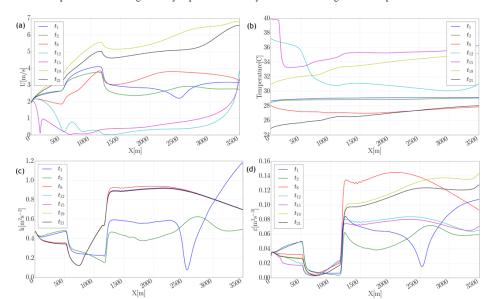




(left) WRF computational domain (5S-35N, 20W-20E) is defined in such a way that covers a large part of West Africa and the Gulf of Guinea. The domain should be large enough (3,800 × 3,500 km) to capture synoptic scale processes. Regarding the recommendation on defining the WRF domain, we try to avoid placing the domain boundaries over regions of complex orography; (middle) the plan view of computational domain, water surface outlines and grid refining region in OpenPoAM; (right) defined different noses in height (z-direction) to generate vertical computational grids. The properties of generated mesh in each zone are presented. In WRF- OpenFOAM coupled model, the netCDF files (Format conversion i-j-k blockMesh) in WRF should be converted to spatial transformation x-y-z blockMesh applicable in OF.

Results

The results suggest that the coupled WRF-OpenFOAM model is an important tool for studying the interactions between the Small Water Surfaces and Atmospheric Boundary Layer (SWS-ABL). Using the output of the WRF model as the initial and boundary conditions in OpenFOAM can be significantly improve the accuracy of simulations using similar computational resources.



The simulated flow parameters at height 2 m above the bottom surface in streamwise (x-direction) includes land and water surface. The water surface extends from x=550 to x=1200 m. The results are plotted for seven different times: t₁ = 01:00 (unstable), t₂ = 02:00 (unstable), t₃ = 08:00 (unstable), t₄ = 08:00 (unstable), t₅ = 08:00 (unstable), t₆ = 08:00 (unstable), t₇ = 12:00 (stable), t₁₁ = 12:00 (stable), t₁₂ = 19:00 (unstable) and t₃₂ = 24:00 hr (unstable): (a) velocity; (b) temperature; (c) turbulent kinematic energy; and (d) dissipation rate of the turbulent kinetic energy.

Summary

Using realistic atmospheric forcing for SWS-ABL simulations requires innovative solutions (perturbations) to spin up turbulence in stable and weakly unstable atmospheric conditions. To this aim, we can combine advantages of both Mesoscale (WRF) and Microscale (OpenFOAM) models:

- To use advanced physical models, considering high resolution roughness lengths (for momentum, temperature and water vapor), using very fine meshes in location of sharp changes in surface characteristics;
- Provide more realistic inlet profiles;
- WRF provides accurate representation of the fields away from the ground. In upper region of the OpenFOAM domain, we use the results of the WRF simulation:
- Optimizing the computational resources requirements;
- Thermo-stratification in ABL can be included in the coupled model;
- Investigate the interaction of large numbers of small water surfaces on airflow in ABL in the study region:
- The results of the WRF-OpenFOAM coupled model should be compared against field measurements for improving efficiency;
- Automatic coupling WRF and OpenFOAM (translating WRF results to readable data in OpenFOAM) for general usages (as future work).