Comprehensive Final Report

1. Header

Project Title: Improving the land-surface components of Climate Forecast System Reanalysis (CFSR)
PI and institution: Bart Nijssen, University of Washington
Report Year: Final report
Grant #: NA13OAR4310107

2. Main goals of the project, as outlined in the funded proposal

This is a joint project between the NOAA National Centers for Environmental Prediction (NCEP) Environmental Modeling Center (EMC), NOAA's Climate Prediction Center (CPC), Princeton University, and the University of Washington. The overall intent of the project is to utilize past land data assimilation system activities (notably NLDAS and GLDAS) to improve upcoming reanalyses. Specific objectives are to improve (1) land characterization data sets (e.g. vegetation type and soil texture class, and the characterization of urban areas, etc.), (2) atmospheric forcing data sets (e.g. precipitation, downward solar and longwave radiation), (3) assimilation of near-real time land states (e.g. surface skin temperature, albedo, soil moisture, snow extent, vegetation greenness and density), (4) land-model spin-up procedures, and (5) downscaling techniques for forcing data and land states. The University of Washington has a modest advisory role in the project.

As defined in the proposal, the University of Washington is to provide guidance and support … *on the implementation of the river routing model into CFSR as well as calibration and validation of the model at a global scale. This work will directly build on current efforts by the UW to implement the same routing model as an option in CESM as part of their collaborative DOE proposal: "Improving Decadal Prediction of Arctic Climate Variability and Change Using a Regional Arctic System Model (RASM)". CFSR routing results will be compared with offline global simulations from the VIC land model, which uses the same routing model, but different land surface forcings. In addition, snow and soil moisture data fields from the UW's multi-model surface water monitor will be used to evaluate terrestrial water cycle changes in the CFSR simulations.*

3. Results and accomplishments

The UW had an advisory role in the project and activities at the UW have focused on the development of the pre-existing Lohmann routing model [*Lohman et al. 1996*] as a stand-alone application (RVIC) and on inclusion of the same routing algorithm into a coupled regional climate model (Regional Arctic System Model – RASM) and VIC.

The RVIC streamflow routing model is an expanded version of the routing model originally introduced by *Lohmann et al.* [*1996*]. RVIC is a semi-distributed, source-to-sink, routing model that solves a linearized version of the Saint-Venant equations. The model develops impulse response functions (IRFs) to define the time evolution of flow between pairs of source and sink points. Following the development of the IRFs, a simple convolution is performed combining the IRF for each source-to-sink pair and the runoff flux from each source point (Fig 1. bottom). RVIC has been configured to run as a stand-alone routing model (e.g. as a post processor of semi-distributed hydrologic models) or coupled within earth system models.

RVIC can be used in two modes (Figure 1): In the first mode, it creates the IRFs between pairs of sink and source points. In the second mode, it uses these IRFs to route runoff generated at multiple locations (source points) to the relevant sink points, to create time series of streamflow at all sink points.

When routing is performed in RASM or directly in VIC, RVIC is only used as a pre-processor to create the IRFs, which are then used as input to the routing algorithms in RASM or VIC. Because the IRFs are time-invariant, the actual routing code is a simple convolution, which is easy to implement and fast. Because this convolution is a linear process, IRFs can be developed at a high spatial resolution and then remapped to coarser resolutions. Figure 2 demonstrates this upscaling process for an actual implementation for the Mackenzie River basin in the Canadian Arctic. The upscaled IRFs are coarser (spatially) and create some dispersion and lag of the runoff signal, but retain most of the character of their high-resolution version [*Hamman et al. 2017*].

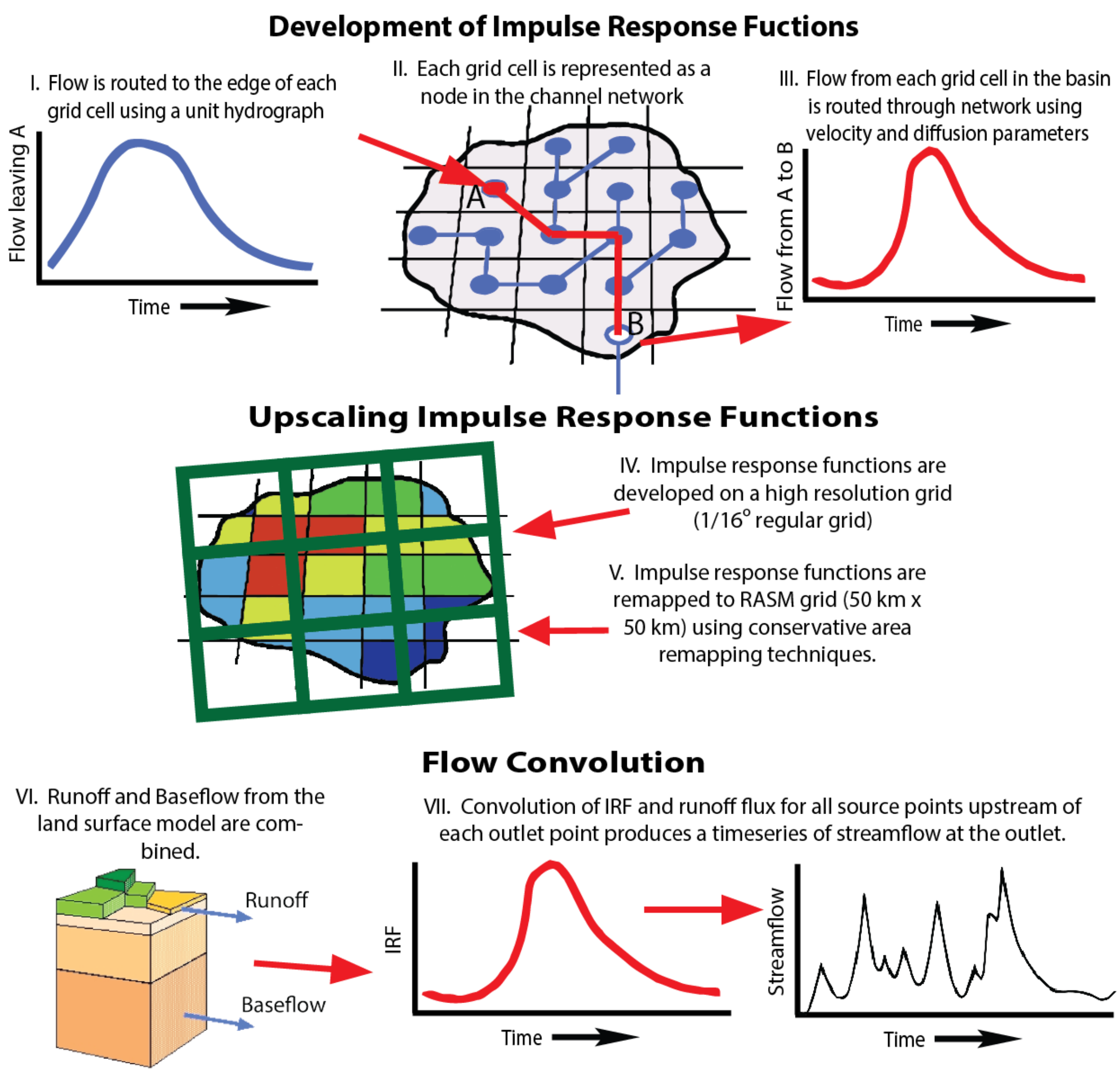

Figure 1 Schematic of the RVIC streamflow routing model. The three major steps of the RVIC model are shown as 1) Development of the impulse response functions (IRFs; top row), 2) Upscaling the IRFs (middle row), and 3) flow convolution using runoff fluxes from the land surface model.

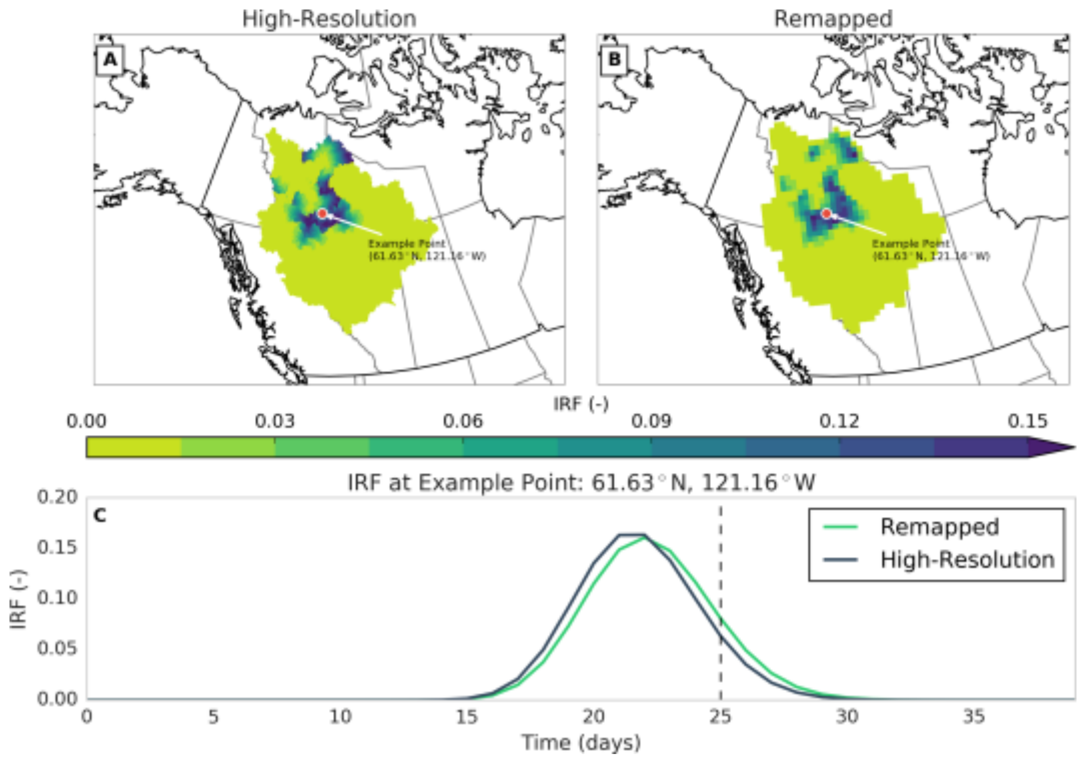

Figure 2. (top) (a) High-resolution and (b) remapped IRFs for the MacKenzie River upstream of the Arctic Red River observation location for a single time step (time step 25). The IRF indicates what fraction of the flow generated at time t=0 reaches the Red River location at time t=25. (bottom) IRFs from the high-resolution (blue) and remapped (green) grids at the example location (61.62ºN, 121.16ºW). From Hamman et al. [2017].

RASM simulations with the RVIC routing algorithm were used to create a data set of streamflow estimates at all coastal locations in the Arctic. This data set was described in *Hamman et al. [2017]* and can be used for comparison with other model data sets (such as CFSR) or as an input to standalone ocean model simulations in the Arctic.

RVIC has been used in a number of other applications developed by our research team at the UW, including for streamflow routing in the Columbia River Basin and for an NSF-funded project in which it has been used for streamflow routing in the southeastern United States.

Over the past year we have advised a team from Wageningen University in the Netherlands on the implementation of the routing algorithm directly into VIC and this routing extension will be available in the soon to be released VIC 5.1 (https://github.com/UW-Hydro/VIC).

References

Hamman, J., B. Nijssen, A. Roberts, A. Craig, W. Maslowski, and R. Osinski, 2017: The coastal streamflow flux in the Regional Arctic System Model. *Journal of Geophysical Research: Oceans*, doi:10.1002/2016JC012323.

Lohmann, D., R. Nolte-Holube, and E. Raschke, 1996: A large-scale horizontal routing model to be coupled to land surface parametrization schemes. *Tellus Series a-Dynamic Meteorology and Oceanography*, 48, 708-721, doi:10.1034/j.1600-0870.1996.t01-3-00009.x.

4. Highlights of Accomplishments

- Development of RVIC: a stand-alone routing model which provides improved functionality and is more user-friendly than the previous Lohmann routing model.

- Inclusion of the routing algorithm into RASM, a regional climate model based on NCAR's Community Earth System Model (CESM).

- Inclusion of the routing algorithm directly into VIC, so that routing can be performed in VIC, rather than as a post-processor.

- Publication of RVIC and VIC source codes in online source code repositories (https://github.com/UW-Hydro).

- Documentation of RVIC (http://rvic.readthedocs.io/en/latest/) and VIC (http://vic.readthedocs.io/en/latest/).

- Publication of a model-based data set of streamflow for all arctic coastal locations based on routed flows from RASM simulations.

5. Transitions to Applications

RVIC is publicly available as a standalone application at https://github.com/UW-Hydro/RVIC. In the last few years, we have changed the VIC model infrastructure to allow for the routing code to be implemented directly into VIC (rather than as a post-processor as it was used before). We have advised a team from Wageningen University in the Netherlands on the implementation of the routing algorithm directly into VIC and this routing extension will be available in the soon-to-be released VIC 5.1 (https://github.com/UW-Hydro/VIC). The implementation of the same routing algorithm within RASM is available upon request.

No transition to applications outside research projects has taken place to date.

6. Publications from the Project

None directly (UW only had a small advisory role and small budget), but work under this project contributed to

Hamman, J., B. Nijssen, A. Roberts, A. Craig, W. Maslowski, and R. Osinski, 2017: The coastal streamflow flux in the Regional Arctic System Model. *Journal of Geophysical Research: Oceans*, doi:10.1002/2016JC012323.

and to

Hamman, J., B. Nijssen, T.J. Bohn, D. R. Gergel, and Y. Mao, 2018: The Variable Infiltration Capacity (VIC) Model, Version 5.0 - Improvements and New Applications. *Geoscientific Model Development*, ***in preparation***.

7. PI Contact Information

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