Philippe Lucas-Picher (picher@sca.uqam.ca),
Département des sciences de la terre et de l'atmosphère,
Université du Québec à Montréal (UQAM),
201 Président-Kennedy Ave.,
BO 8888, succ. Centre-Ville, Montréal.
Québec, H3C 3P8, Canada.

7 February 2002

Dr. Harold Ritchie,
Dartmouth, NS.

Subject: Contribution for the next report in the WGNE series

Dear Dr. Ritchie,

Please find attached with this letter our two page contribution for the next issue of "Research Activities in Atmospheric and Oceanic Modelling" produced by WGNE.

This article would fit well into the section related to "Development of and studies with regional and smaller-scale atmospheric models ".

We have included the title, author names, affiliations, and email addresses of all authors.

Yours sincerely,

Philippe Lucas-Picher.

Incorporating river routing in the Canadian Regional Climate Model

Philippe Lucas-Picher[1], Vivek K. Arora[2], Daniel Caya[1], and René Laprise[1]

[1]Département des sciences de la terre et de l'atmosphère, UQAM, Montréal, Québec, Canada.
[2]Canadian Centre for Climate modelling and Analysis (CCCma), Meteorological Service of Canada, University of Victoria, Victoria, British Columbia, Canada.

The framework for incorporating river flow routing in the Canadian Regional Climate Model (CRCM) is described. The incorporation of river routing in the CRCM will allow to simulate streamflow and model freshwater flux from the land surface to the ocean at the continental edges, which is an important contribution to ocean forcing.

The CRCM uses a semi-implicit, semi-Lagrangian scheme to solve the fully elastic non-hydrostatic Euler equations (Caya and Laprise, 1999) and, at its boundaries, may be driven by data from any general circulation model (GCM) or reanalyses. The horizontal resolution of the CRCM is approximately 45 km and it contains 30 levels in the vertical.

The discretization of major river basins at 5' resolution by Graham et al. (1999) is used as a template to define river basins at CRCM resolution. CRCM grid cells are assigned to major river basins as follows: (1) the 5' cells, corresponding to different river basins, lying within each CRCM cells are counted; (2) the CRCM cell is assigned to a river basin with the maximum number of 5' cells; (3) the resulting areas of the river basins at the CRCM resolution are compared with the original areas at 5' resolution, and any major discrepancy between these two areas is minimized by adding or subtracting CRCM cells to or from a given river basin. The region chosen for this study covers most of the North America (see Fig. 1). Graham et al. (1999) discretized 10 major river basins over North America and the discretization of these river basins at the CRCM resolution is shown in Fig. 1. The drainage areas of the major river basins at the CRCM resolution are compared with drainage areas based on 5' discretization of Graham et al. (1999) in Table 1.

Table 1: Comparison of drainage areas of river basins discretized at the CRCM resolution with drainage areas based on 5' discretization of Graham et al. (1999).

River Basin	Drainage area (km^2) Graham et al.	CRCM	Percentage Difference
Mississippi	3,218,720	3,228,415	0.30
Mackenzie	1,735,635	1,748,230	0.73
Nelson	1,303,641	1,305,674	0.16
Columbia	1,106,969	1,106,439	-0.05
St-Lawrence	1,090,564	1,087,952	-0.24
Yukon	884,867	882,128	-0.31
Rio Grande*	856,547	149,144	-82.59
Colorado*	770,829	616,827	-19.98
Churchill	296,190	300,800	1.56
Fraser	262,854	260,419	-0.93

*The CRCM drainage areas for Colorado and Rio Grande do not compare well with Graham et al. (1999) values since these two river basins do not lie completely within the CRCM domain.

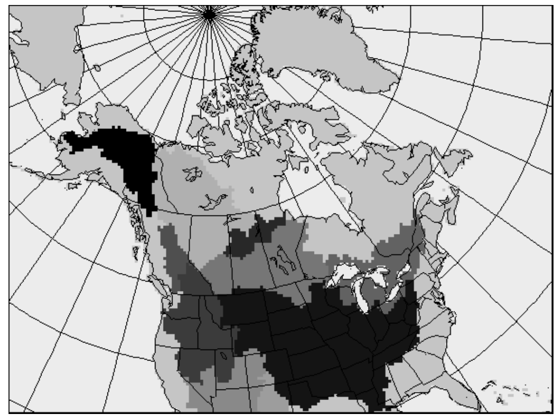

Figure 1: The domain of the CRCM shown in polar-stereographic projection. The discretization of major river basins (listed in Table 1) is shown in different shades of gray.

The river flow directions at the CRCM resolution are estimated using 5' flow directions obtained by Graham et al. [1999] and a methodology that requires minimal manual intervention (see Fig. 2). The original 5' flow directions were obtained by using mean elevations of the grid cells and assuming that the water drains in the direction characterized by the steepest slope. At spatial scales comparable to CRCM grid cells, the mean elevations of grid cells are not representative of their river flow directions. This is because rivers tend to flow in localized areas of low elevation, and the mean elevations of the grid cells are not representative of river bed profiles. Interpolation of 5' flow directions at the CRCM resolution is also difficult since the projection of CRCM is polar-steoreographic, while the 5' flow directions are projected on a latitude-longitude grid. Therefore river flow directions are assigned to CRCM grid cells as follows: (1) the northern, eastern, southern, and western corners of the CRCM grid cell are identified; (2) these corners are used to outline a latitude-longitude grid box that encloses the CRCM grid cell; (3) a uniformly distributed unit amount of runoff is generated within this new grid box and allowed to find its way out of the box following the 5' flow directions; (4) the direction in which maximum amount of water is drained is identified; (5) by identifying the CRCM grid cell that receives this outflow, a river flow direction is assigned. Tests are made to ensure that flow continuity is maintained and that water does not flow between basins. The methodology used here for river basin discretization and obtaining flow directions is similar to the one used by Arora and Boer (1999).

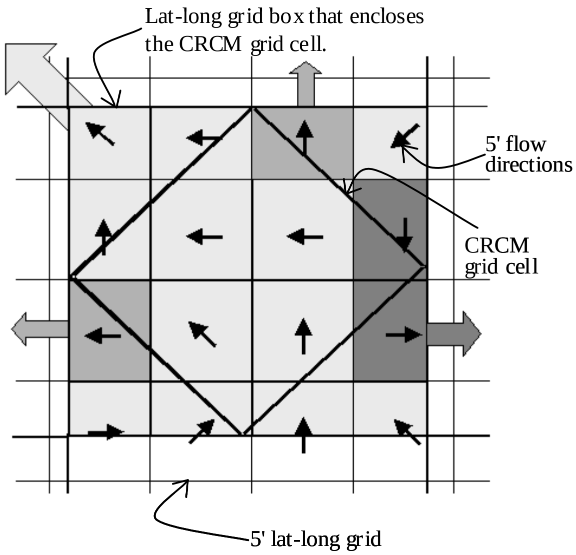

Figure 2: Methodology adopted to assign river flow direction to a CRCM grid cell. This CRCM grid cell, for example, was assigned the north-west direction because most of the 5' cells drain in this direction.

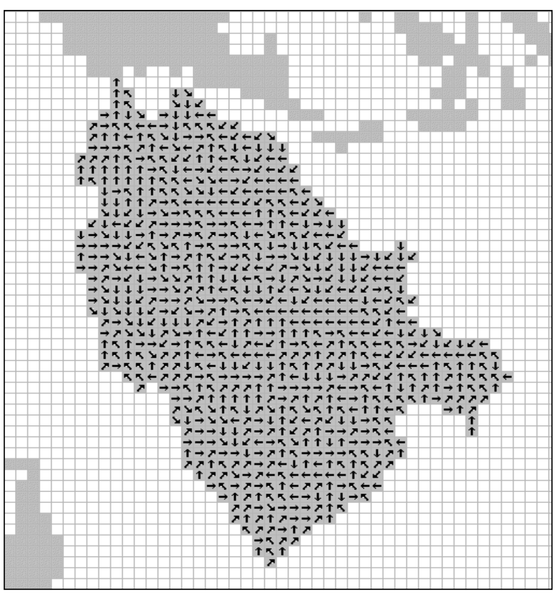

Figure 3: The river flow directions for the Mackenzie River basin at the CRCM resolution.

As an example, Fig. 3 shows the flow directions obtained for the Mackenzie River basin at the CRCM resolution using this methodology. Although tests are made to ensure the continuity of flow and that all grid cells eventually drain to the ocean, this does not ensure that the digital flow networks are realistic. The adequacy of digital flow networks is assessed by visually comparing the plots of river "order" with actual river networks. The grid cell where a stream originates is assigned an order 1. The union of two streams of order *n* creates a stream of order *n*+1. Figure 4 shows the river order for land cells in the CRCM domain. Higher river orders are represented by darker shades. The digital river network shown in Fig. 4 compares well with the actual river network from atlases.

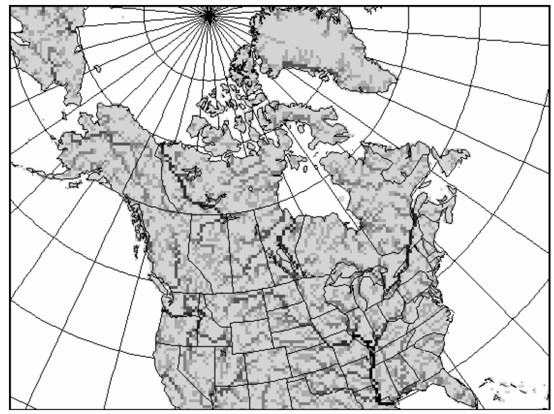

Figure 4: River order, which varies between 1 and 6 in this case, for the digital river networks obtained at the CRCM resolution.

The framework illustrated here is intended to be used with the flow routing scheme of Arora and Boer (1999) to obtain streamflow for 8 major North American Rivers. The Colorado and Rio Grande River basins are excluded since they do not lie completely within the CRCM domain. The simulated streamflow will allow assessment of the performance of the CRCM at river basin scales via comparisons with observed streamflow. This framework also gives the ability to assess the impact of climate change on streamflow. When runoff from control and enhanced greenhouse gas warming simulations of the CRCM are used as input into the flow routing scheme, the differences in simulated streamflow can be analyzed to assess possible impacts of change in climate on the hydrology of major North American rivers. These analyses are the subject of future research.

References

Arora, V. K. and G. J. Boer, 1999, A variable velocity flow routing algorithm for GCMs. *J. Geophys. Res.*, 104, 30965-30979.

Caya, D. and R. Laprise, 1999, A semi-implicit semi-Lagrangian regional climate model: The Canadian RCM. *Mon. Wea. Rev.*, 127, 341-362.

Graham, S. T., J. S. Famiglietti and D. R. Maidment, 1999, Five-minute, 1/2° and 1° data sets of continental water sheds river networks for use in regional and global hydrologic and climate system modeling studies. *Water Resour. Res.*, 35, 583-58.

Address any correspondence to Philippe Lucas-Picher (picher@sca.uqam.ca), Vivek Arora (vivek.arora@ec.gc.ca), Daniel Caya (caya.daniel@uqam.ca) or René Laprise (laprise.rene@uqam.ca).