Algorithm Specification – VIC Area Updating

Version 1.2.0

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1 Background

This specification details the method for updating the VIC model snowband and vegetation parameter files following glacier updating. One of the main features in the coupling of the VIC model of the UBC Regional Glaciation model (RGM) is the feedback of glacier area and surface elevation from the RGM to VIC. Changes in glacier area (passed from RGM to VIC as an updated glacier mask) and surface elevation are incorporated into the VIC model via updating of the vegetation parameter file and the elevation band (or snowband) file. Specifically, the snowband file is updated to reflect changes in surface topography (due to changes in glacier thickness) and the vegetation parameter file is updated to reflect changes in glacier cover. Note that the vegetation parameter file describes the distribution of Hydrologic Response Units (HRUs) by providing a fractional area for different land cover types within specific elevation bands. The RGM only explicitly describes changes in the area of a single land cover type: glaciers. Consequently, changes in the area of other land cover types in the same band as the affected glacier HRU must be inferred. In order to do so, we make the following assumptions:

1. If a glacier HRU shrinks in area, and non-glacier HRUs also occupy the same elevation band, then
    a. An existing "open ground" HRU is expanded to fill the band; or
    b. A new "open ground" HRU is added to fill the band.
2. If a glacier HRU expands in area, and non-glacier HRUs also occupy the same elevation band, then:
    a. An existing "open ground" HRU is shrunk; and/or
    b. Each of any vegetated HRUs is shrunk by an amount proportional to the original vegetated HRU area.
3. If a glacier HRU changes size/area, and no other HRUs occupy the current band, then only the glacier HRU area is modified.

The identification of the appropriate land cover type to use for "open ground" will be specified by the user via the global parameter file.

Although the snowband and vegetation parameter files are updated separately, the area information in both files must be consistent. The updated band area in the snowband file must equal the updated area of all HRUs in the same band *b* in the vegetation parameter file. This is described mathematically as follows:

$$A_b[t^*] = \sum_{h=1}^{H(b)} A_h[b, t^*]$$

where t^* is the state after updating, $A_b[t^*]$ is the band area, $A_h[b, t^*]$ is the area of HRU *h*, and $H(b)$ is the number of HRUs in band *b*.

The specifications that follow are broken into two sections: Section 2 deals with snowband updating, Section 3 deals with HRU area updating during model integration and Section 4 deals with HRU area updating during model initialization.

2 Update Snowband File

2.1 Pseudo-code

Conceptually, the updating of VIC elevation bands from state *t* to *t** following glacier updating with the RGM follows the following general steps:

1. Calculate elevation hypsometry for a given grid cell; i.e. bin RGM pixels by elevation band for state t*
2. Calculate area fractions for each band
3. Calculate median elevations for each band

This procedure is described using the following pseudo-code:

```
for (c in cells) { //Loop through cells
    #Build elevation hypsometry, i.e. construct histogram of number of RGM pixels per elevation band
    for (b in bands) { //Loop through elevation bands (e.g. index 0 to index B-1)
        # Calculate band area and band median elevation from histogram; Equations (1), (2), and (3)
        # Replace band area and elevation (state t) with updated area and elevation (state t*)
    }
}
#Write updated snow band file
```

2.2 Equations

For a given VIC cell, the area of band *b* at state *t** is calculated as

$$A_b[t^*] = \frac{\sum_{p=1}^{P} \mathbf{1}_b\left(z_p[t^*]\right)}{\sum_{p=1}^{P} 1} \tag{1}$$

where $z_p[t^*]$ is the elevation of RGM pixel *p* (for pixels *p* = 1, …, *P*) at state *t**, and $\mathbf{1}_b\left(z_p\right)$ is the indicator function given as

$$\mathbf{1}_b\left(z_p\right) = \begin{cases} 1 & if\ z_p \in b \quad (i.e.\ \ z_b^- \le z_p < z_b^+) \\ 0 & if\ z_p \notin b \quad (i.e.\ \ z_p < z_b^-\ or\ \ z_p \ge z_b^+) \end{cases} \tag{2}$$

where z_b^- and z_b^+ are the lower and upper elevation, respectively, of band *b*. For a given VIC cell, the median elevation of band *b* is calculated as[1]

$$Median\{z_p \in b\} \tag{3}$$

[1] Assuming that python contains some convenient function for calculating medians

3 Vegetation Parameter File

3.1 Pseudo-code

Conceptually, the updating of VIC HRU areas from state *t* to *t** following glacier updating with the RGM follows the following general steps:

1. Calculate updated glacier area fraction for band *b* at state *t**
2. If glacier area changes in band *b* then:
    a. Calculate band residual area fraction for band *b* (change in non-glacier area)
    b. Update area of "open ground" HRU, if present in band
    c. Update area of remaining "vegetated" HRUs
    d. Update HRU areas for band *b* at state *t**
3. Update vegetation parameter file

The updating of the vegetation parameter file is demonstrated using the following pseudo-code:

```
for (c in cells) {  //Loop through cells
    for (b in bands) { //Loop through elevation bands (e.g. index 0 to index B-1)
        #Calculate A_g[b, t*] using Equation (4)
        if (!A_g[b, t]) then A_g[b, t]=0
        if (A_g[b, t*] != A_g[b, t]) { //Glacier HRU in band b changes area
            #Calculate A_ng[t*], and A_r[b, t*] using Equations (5), and (6)
            if (!A_open[b, t]) then A_open[b, t]=0
            # Calculate A_open[b, t*] using equation (7)
            # Calculate area changes in remaining vegetated HRUs using equations (8), (9) and (10)
            if A_g[b, t*] + A_ng[b, t*] ≠ A_b[t*] then exception/warning
            # Replace HRU areas (state t) with updated areas (state t*)
        }
    }
}
#Write updated vegetation parameter file
```

3.2 Equations

For a given VIC cell, the glacier area in band *b* at state *t** is calculated as

$$A_g[b, t^*] = \frac{\sum_{p=1}^{P[b]} m_p[t^*]}{\sum_{p=1}^{P} 1} \quad (4)$$

where m_p[t*] is the glacier mask for RGM pixel *p* at state t* (where $m_p[t^*] \rightarrow \{0, 1\}$), *P*[*b*] is the number of pixels in band *b*, and *P* is the total number of pixels in the VIC cell.

The non-glacier area in band *b* at state *t** is

$$A_{ng}[b, t^*] = A_b[t^*] - A_g[b, t^*] \quad (5)$$

The residual non-glacier area fraction (i.e. change in non-glacier area) for band *b* at state t* is

$$A_r[b, t^*] = A_{ng}[b, t^*] - A_{ng}[b, t] \quad (6)$$

where *t* is the state prior to the current iteration of glacier updating. If glacier area in band *b* changes then the priority is to first adjust the area of any "open ground" HRUs that may be present in the same band. The updated area of the open ground HRU is calculated as

$$A_{open}[b, t^*] = max\{0, A_{open}[b, t] + A_r[b, t^*]\}. \quad (7)$$

Following changes in the area of any the open ground HRU (if present), the remaining HRUs (i.e. vegetated HRUs) each change area proportionately by an amount given by

$$\Delta A_v[b, t^*] = \Delta A_{veg}[b, t^*] \cdot \frac{A_v[b, t]}{A_{ng}[b, t] - A_{open}[b, t]} \quad (8)$$

where *v* is the index of the any remaining vegetated HRUs (*v* = 1, …, *V*), and the change in "vegetated area", $\Delta A_{veg}[b, t^*]$, is given by

$$\Delta A_{veg}[b, t^*] = min\{0, A_{open}[b, t] + A_r[b, t^*]\}. \quad (9)$$

Hence, the updated area for each remaining HRU *v* is

$$A_v[b, t^*] = A_v[b, t] + \Delta A_v[b, t^*]. \quad (10)$$

Note that if $\Delta A_{veg}[b, t^*]$ is equal to zero, either because $A_r[b, t^*]$ is positive (glacier shrinks) or $A_{open}[b, t] + A_r[b, t^*]$ is greater than zero (glacier expands, but only bare ground affected), then $\Delta A_v[b, t^*]$ is also zero and $A_v[b, t^*]$ will simply equal $A_v[b, t]$.

4 Vegetation Parameter File – Model Initialization

4.1 Pseudo-code

This section provides the specifications for modifying HRU areas in order to accommodate changes in initial surface topography and glacier mask prior to running the coupled VIC-RGM models. These specifications are necessary as the coupled VIC-RGM model may be required to start from a surface topography and glacier mask that differs from the contemporary surface topography and glacier mask used to provide the baseline VIC model parametrizations (i.e. snowband file and vegetation parameter file).

Conceptually, the initialization of VIC HRU areas in order to accommodate modifications in the study domain surface topography follows the general steps:

1. Calculate updated glacier area fraction for band *b* at state *t**
2. Calculate band residual area fraction for band *b* (change in non-glacier area)
3. Update area of "open ground" HRU, if present in band
4. Update area of remaining "vegetated" HRUs
5. Update HRU areas for band *b* at state *t**
6. Update vegetation parameter file

The initialization of the vegetation parameter file is demonstrated using the following pseudo-code:

```
for (c in cells) {  //Loop through cells
    for (b in bands) { //Loop through elevation bands (e.g. index 0 to index B-1)
        #Calculate A_g[b, t*] using Equation (4)
        #Calculate A_ng[t*], and A_r[b, t*] using Equations (5), and (6)
        if (!A_open[b, t]) then A_open[b, t]=0
        # Calculate A_open[b, t*] using equation (7)
        # Calculate area changes in remaining vegetated HRUs using equations (8), (9) and (10)
        if A_g[b, t*] + A_ng[b, t*] ≠ A_b[t*] then exception/warning
        # Replace HRU areas (state t) with updated areas (state t*)
        }
    }
}
#Write updated vegetation parameter file
```