

i.fusion.hpf, implementation of the High Pass Filter

Additive (HPFA) Image Fusion Technique

Python script add-on for GRASS-GIS

Nikos Alexandris

November 16, 2014

Remote Sensing Scientist, Dr

Themidos 3, 42100, Trikala, Greece

GPG Key Fingerprint 6F9D4506F3CA28380974D31A9053534B693C4FB3

nik @ nikosalexandris.net

i.fusion.hpf is a GRASS-GIS module to combine high-resolution panchromatic data with lower resolution multispectral data, resulting in an output with both excellent detail and a realistic representation of original multispectral scene colors.

The process involves a convolution using a High Pass Filter (HPF) on the high resolution data, then combining this with the lower resolution multispectral data.

Optionally, a linear histogram matching technique is performed in a way that matches the resulting Pan-Sharpened imaged to them statistical mean and standard deviation of the original multi-spectral image.

Source: ?

Thanks to Moritz Lennert on implementing the linear histogram matching technique

Algorithm description

1. Computing ratio of low (Multi-Spectral, hereafter noted as MSx) to high (Panchromatic) resolutions
2. High Pass Filtering the Panchromatic Image
3. Resampling MSx image to the higher resolution
4. Adding weighted High-Pass-Filetered image to the upsampled MSx image
5. Optionally, matching histogram of Pansharpened image to the one of the original MSx image

From the original paper

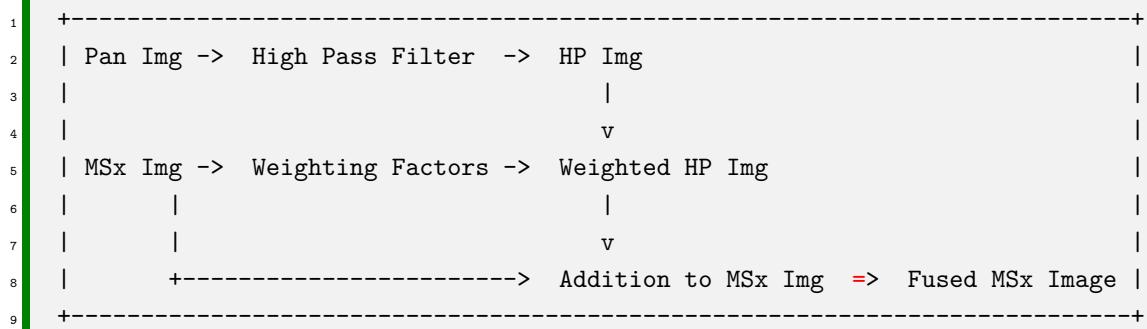
Step 1: HP Filtering of the High-resolution Image to Extract the Structural Detail

Step 2: Adding the HP Filtered Image to Each Band of the Multispectral Image Using a Standard Deviation-based Injection Model

Step 3: Linear Histogram Match to Adapt SD and Mean of the Merged Image Bands to Those of the Original MS Image Bands

Figure 1:

.



Installation

Requirements

see [GRASS Addons SVN repository](#), [README file](#), [Installation - Code Compilation](#)

Steps

Making the script `i.fusion.hpf` available from within any GRASS-GIS ver. 7.x session, may be done via the following steps:

1. launch a GRASS-GIS' ver. 7.x session
2. navigate into the script's source directory
3. execute `make MODULE_TOPDIR=$GISBASE`

Usage

After installation, from within a GRASS-GIS session, see help details via `i.fusion.hpf --help` – also provided here:

```

1 Description:
2   Fusing high resolution Panchromatic and low resolution \
      Multi-Spectral data based on the High-Pass Filter Addition \
      technique (Gangkofner, 2008)
3
4 Keywords:
5   imagery, fusion, HPF, HPFA
6

```

```
7 Usage:  
8 i.fusion.hpf [-l2] pan=string msx=string[,string,...]  
9   outputprefix=string [ratio=value] [center=string] [center2=\  
10    string]  
11   [modulation=string] [modulation2=string] [--help] [--verbose]  
12   [--quiet]  
13  
14 Flags:  
15   -1  Linearly match histogram of Pan-sharpened output to \  
16     Multi-Spectral input  
17   -2  2-Pass Processing (recommended) for large resolution ratio\  
18     (>=5.5)  
19   --h  Print usage summary  
20   --v  Verbose module output  
21   --q  Quiet module output  
22  
23 Parameters:  
24   pan  High resolution panchromatic image  
25   msx  Low resolution multi-spectral image(s)  
26   outputprefix  Prefix for the Pan-Sharpened Multi-Spectral \  
27     image(s)  
28       default: hpf  
29   ratio  Custom ratio overriding standard calculation  
30       options: 1.0-10.0  
31   center  Center cell value of the High-Pass-Filter  
32       options: low,mid,high  
33       default: low  
34   center2  Center cell value for the second \  
35     High-Pass-Filter (use -2 flag)  
36       options: low,mid,high  
37       default: low  
38   modulation  Level of modulating factor weighting the HPF \  
39     image to determine crispness  
40       options: min,mid,max  
41       default: mid  
42   modulation2  Level of modulating factor weighting the second \  
43     HPF image to determine crispness (use -2 flag)  
44       options: min,mid,max  
45       default: mid  
46       min: Minimum: 0.25  
47       mid: Mid: 0.35  
48       max: Maximum: 0.5
```

Remarks

- requires (currently) manual color rebalancing (e.g. by using i.colors.enhance)
- easy to use, i.e.: for one band i.fusion.hpf pan=Panchromatic msx=\${Band}
for multiple bands i.fusion.hpf pan=Panchromatic msx=Red,Green,Blue,NIR

- easy to test various parameters that define the High-Pass filter's kernel size and center value
- should work with any kind of imagery (think of bitness)

Examples

Landsat

```
1 i.fusion.hpf -l -c --o pan=lsat7_2000_80 msx=lsat7_2000_10,\n    lsat7_2000_20,lsat7_2000_30 center=high modulation=max
```

The above command calls `i.fusion.hpf` to pan-sharpen the multispectral images `lsat7_2000_10`, `lsat7_2000_20`, `lsat7_2000_30` based on the panchromatic `lsat7_2000_80` with the parameters

- `center=high` to increase the impact of the high pass filter
- `modulation=max` to increase the crispness of the output images
- `-l` and `-c` to respectively match the histogram and color table of the sharpened output images to their corresponding original multi-spectral
- `--o` to overwrite raster maps with the same name as the to-be-produced output, which are essentially left-overs from previous sharpening attempts

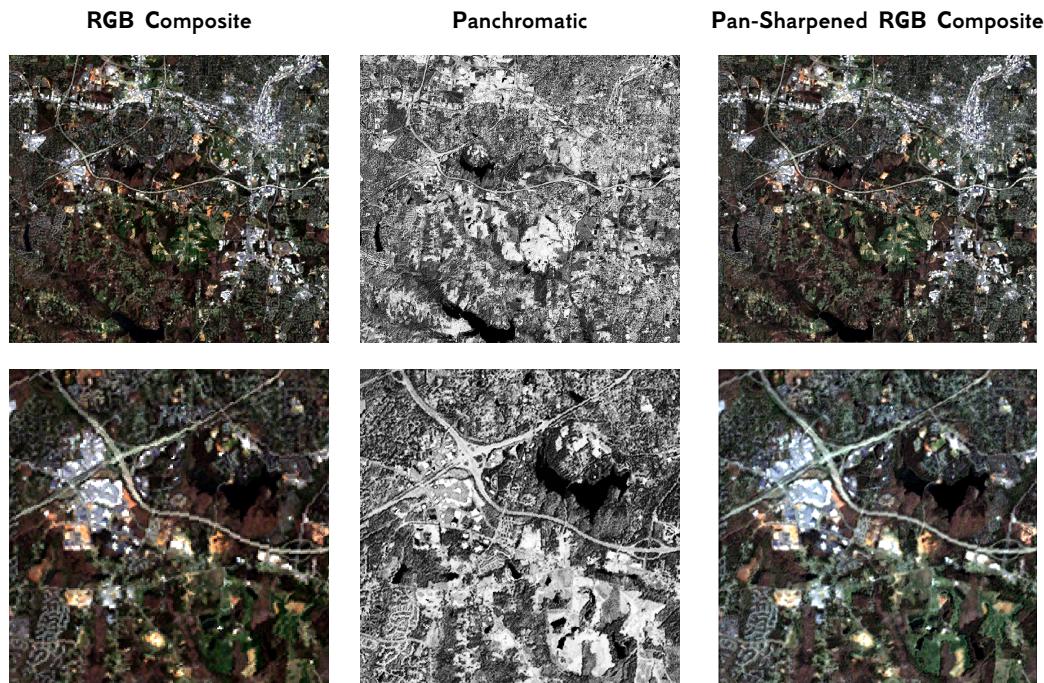


Figure 1: Fragment from a Landsat7 ETM acquisition (p016r035_7p20000331_z17_nc_spm_wake.tif) over New Delhi, India (available at [GRASS-GIS' Sample Data website](#) section, see [CREDITS.txt](#) for details)

IKONOS

To add

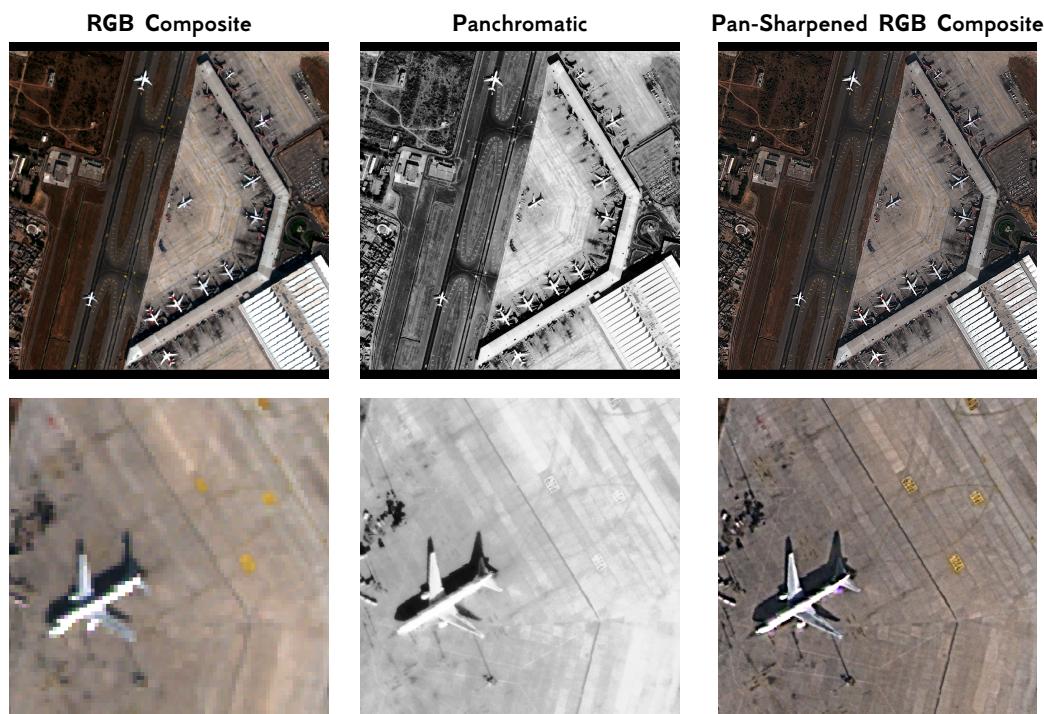
QuickBird2

*To add (some samples already published in GRASS-Wiki: [GRASS-Wiki](#),
[QuickBird](#), [HPFA based sharpening](#))*

WorldView(2, 3)

To add

GeoEye



Implementation notes

- First commit on Sat Oct 25 12:26:54 2014 +0300
- Working state reached on Tue Nov 4 09:28:25 2014 +0200

Figure 2: Fragment from a GeoEye acquisition (12DEC02053124) over New Delhi, India (available for demonstration purposes, see sections §?? and §?? for license details)

Remarks

- currently requires manual color rebalancing (e.g. by using `i.landsat.rgb`)
- easy to use, i.e.:
 - for one band `i.fusion.hpf pan=Panchromatic msx=${Band}`
 - for multiple bands `i.fusion.hpf pan=Panchromatic msx=Red,Green,Blue,NIR`
- easy to test various parameters that define the High-Pass filter's *kernel size* and *center value*
- should work with any kind of imagery (think of bitness)

To Do

- Go through <http://trac.osgeo.org/grass/wiki/Submitting/Python>
- Use `format()` instead of the `%` operator (?)
 - Sources:
 - * http://chimera.labs.oreilly.com/books/123000000393/ch02.html#solution_33
 - * <https://docs.python.org/3/library/string.html#format-spec>
- Proper command history tracking. Not all "r" modules do it... ?
- Add timestamps (`r.timestamp`)
- Deduplicate code where applicable
- Make `-v` messages shorter, yet more informative (i.e. report center cell value)

Questions

- Will it compile in other systems?
- Checking options to integrate in `i.pansharpen`. Think of FFM methods vs. Others?
- Utilise the existing histogram matching code in `i.pansharpen`? It performs histogram matching using the Standard Deviation and Mean of the reference image.

See discussion(s) in mailing list and trac.

References

- **To Add:** replication of ERDAS Imagine's parameters.

Ευχαριστώ

- Nikos Ves
- Ranjith, https://class.coursera.org/interactivepython-005/forum/profile?user_id=9361576
- Anonymous on coursera's discussion forums
- Pietro Zambelli
- StackExchange contributors
 - <http://stackoverflow.com/a/1140966/1172302>
 - <http://stackoverflow.com/a/275025/1172302>
- Yann Chemin
- Participants in grass-user, grass-dev mailing lists

Code

Listing 1: i.fusion.hpf.py

```
1 #!/usr/bin/env python
2 # -*- coding: utf-8 -*-
3
4 """
5 MODULE:      i.fusion.hpf
6
7 AUTHOR(S):   Nikos Alexandris <nik@nikosalexandris.net>
8             Converted from a bash shell script | Trikala, Nov. 2014
9
10 PURPOSE:    HPF Resolution Merge -- Algorithm Replication in GRASS GIS
11
12         Module to combine high-resolution panchromatic data with
13         lower resolution multispectral data, resulting in an output
14         with both excellent detail and a realistic representation of
15         original multispectral scene colors.
16
17
18         The process involves a convolution using a High Pass Filter
19         (HPF) on the high resolution data, then combining this with
20         the lower resolution multispectral data.
```

```

21
22     Optionally, a linear histogram matching technique is performed
23     in a way that matches the resulting Pan-Sharpened imaged to
24     them statistical mean and standard deviation of the original
25     multi-spectral image. Credits for how to implement this
26     technique go to GRASS-GIS developer Moritz Lennert.
27
28
29     Source: "Optimizing the High-Pass Filter Addition Technique for
30     Image Fusion", Ute G. Gangkofner, Pushkar S. Pradhan,
31     and Derrold W. Holcomb (2008)
32
33     Figure 1:
34
35 +-----+
36 | Pan Img -> High Pass Filter -> HP Img
37 |           |
38 |           v
39 | MSx Img -> Weighting Factors -> Weighted HP Img
40 |           |
41 |           v
42 |           +-----> Addition to MSx Img => Fused MSx Image
43 +-----+
44
45 COPYRIGHT: (C) 2013 by the GRASS Development Team
46
47 This program is free software under the GNU General Public
48 License (>=v2). Read the file COPYING that comes with GRASS
49 for details.
50 """
51
52 #Module
53 # description: Fusing high resolution Panchromatic and low resolution Multi-Spectral data based on\
54     the High-Pass Filter Addition technique (Gangkofner, 2008)
55 # keywords: imagery, fusion, HPF, HPFA
56 #End
57
58 #%flag
59 #% key: l
60 #% description: Linearly match histogram of Pan-sharpened output to Multi-Spectral input
61 #%end
62
63 #%flag
64 #% key: 2
65 #% description: 2-Pass Processing (recommended) for large resolution ratio (>=5.5)
66 #%end
67
68 #%flag
69 #% key: c
70 #% description: Match color table of Pan-Sharpened output to Multi-Spectral input
71 #%end

```

```
71 #>option G_OPT_R_INPUT
72 #> key: pan
73 #> key_desc: filename
74 #> description: High resolution Panchromatic image
75 #> required : yes
76 #>%end
77
78
79 #>option G_OPT_R_INPUTS
80 #> key: msx
81 #> key_desc: filename(s)
82 #> description: Low resolution Multi-Spectral image(s)
83 #> required: yes
84 #> multiple: yes
85 #>%end
86
87 #>option G_OPT_R_BASENAME_OUTPUT
88 #> key: outputsuffix
89 #> key_desc: suffix string
90 #> type: string
91 #> label: Suffix for output image(s)
92 #> description: Names of Pan-Sharpened image(s) will end with this suffix
93 #> required: yes
94 #> answer: hpf
95 #>%end
96
97 #>option
98 #> key: ratio
99 #> key_desc: rational number
100 #> type: double
101 #> label: Custom ratio
102 #> description: Custom ratio overriding standard calculation
103 #> options: 1.0-10.0
104 #> guisection: High Pass Filter
105 #> required: no
106 #>%end
107
108 #>option
109 #> key: center
110 #> key_desc: string
111 #> type: string
112 #> label: Center cell value
113 #> description: Center cell value of the High-Pass-Filter
114 #> descriptions: Level of center value (low, mid, high)
115 #> options: low,mid,high
116 #> required: no
117 #> answer: low
118 #> guisection: High Pass Filter
119 #> multiple : no
120 #>%end
121
```

```

122  #>%option
123  #>% key: center2
124  #>% key_desc: string
125  #>% type: string
126  #>% label: 2nd Pass center cell value
127  #>% description: Center cell value for the second High-Pass-Filter (use -2 flag)
128  #>% descriptions: Level of center value for second pass
129  #>% options: low,mid,high
130  #>% required: no
131  #>% answer: low
132  #>% guisection: High Pass Filter
133  #>% multiple : no
134  #>%end

135
136  #>%option
137  #>% key: modulation
138  #>% key_desc: string
139  #>% type: string
140  #>% label: Modulation level
141  #>% description: Modulation level weighting the HPF image determining crispness
142  #>% descriptions: Levels of modulating factors
143  #>% options: min,mid,max
144  #>% required: no
145  #>% answer: mid
146  #>% guisection: Crispness
147  #>% multiple : no
148  #>%end

149
150  #>%option
151  #>% key: modulation2
152  #>% key_desc: string
153  #>% type: string
154  #>% label: 2nd Pass modulation level (use -2 flag)
155  #>% description: Modulation level weighting the second HPF image determining crispness (use -2 flag)
156  #>% descriptions: mid;Mid: 0.35;min;Minimum: 0.25;max;Maximum: 0.5;
157  #>% options: min,mid,max
158  #>% required: no
159  #>% answer: mid
160  #>% guisection: Crispness
161  #>% multiple : no
162  #>%end

163
164
165  # required librairies -----
166
167  import os
168  import sys
169  sys.path.insert(1, os.path.join(os.path.dirname(sys.path[0]),
170                                'etc', 'i.fusion.hpf'))
171  import atexit
172

```

```
173 import grass.script as grass
174 from grass.pygrass.modules.shortcuts import general as g
175 from grass.pygrass.raster.abstract import Info
176
177 from high_pass_filter import High_Pass_Filter
178
179 if "GISBASE" not in os.environ:
180     print "You must be in GRASS GIS to run this program."
181     sys.exit(1)
182
183
184 # globals -----
185 ratio = float()
186 tmp = ''
187 tmp_hpf_matrix = ''
188 modulator = float()
189 modulator_2 = float()
190
191
192 # helper functions -----
193 def cleanup():
194     """Clean up temporary maps"""
195     grass.run_command('g.remove', flags='f', type="rast",
196                      pattern='tmp.%s*' % os.getpid(), quiet=True)
197
198
199 def run(cmd, **kwargs):
200     """Pass quiet flag to grass commands"""
201     grass.run_command(cmd, quiet=True, **kwargs)
202
203
204 def avg(img):
205     """Retrieving Average (or name it: Mean) of input image"""
206     uni = grass.parse_command("r.univar", map=img, flags='g')
207     avg = float(uni['mean'])
208     return avg
209
210
211 def stddev(img):
212     """Retrieving Standard Deviation of input image"""
213     uni = grass.parse_command("r.univar", map=img, flags='g')
214     sd = float(uni['stddev'])
215     return sd
216
217
218 def hpf_weight(lo_sd, hpf_sd, mod, pss):
219     """Returning an appropriate weighting value for the
220     High Pass Filtered image. The required inputs are:
221     - StdDev of Low resolution image
222     - StdDev of High Pass Filtered image
223     - Appropriate Modulating Factor determining image crispness
```

```

224     - Number of Pass (1st or 2nd)"""
225
226     if pss == 1:
227         wgt = lo_sd / hpf_sd * mod # mod: modulator
228         msg = "    >> Weighting = %.2f / %.2f * %.2f = %.2f" % \
229             (lo_sd, hpf_sd, mod, wgt)
230         g.message(msg, flags='v')
231
232     if pss == 2:
233         wgt = lo_sd / hpf_sd * mod # mod: modulator
234         msg = "    >> 2nd Pass Weighting = %.3f / %.3f * %.3f = %.3f" % \
235             (lo_sd, hpf_sd, mod, wgt)
236         g.message(msg, flags='v')
237
238
239
240     def hpf_ascii(center, filter, tmpfile, pss):
241         """Exporting a High Pass Filter in a temporary ASCII file"""
242
243         if pss == 1:
244             global modulator
245             modulator = filter.modulator
246             msg_ps2 = ''
247
248         elif pss == 2:
249             global modulator_2
250             modulator_2 = filter.modulator_2
251             msg_ps2 = '2nd Pass '
252
253         # structure informative message
254         msg = "    > %sFilter Properties: size: %s, center: %s" % \
255             (msg_ps2, filter.size, center)
256         g.message(msg, flags='v')
257
258         # open, write and close file
259         asciif = open(tmpfile, 'w')
260         asciif.write(filter.filter)
261         asciif.close()
262
263
264
265     def main():
266
267         global tmp_hpf_matrix
268
269         pan = options['pan']
270         msxlst = options['msx'].split(',')
271         outputsuffix = options['outputsuffix']
272         custom_ratio = options['ratio']
273         center = options['center']
274         center2 = options['center2']

```

```
275     modulation = options['modulation']
276     modulation2 = options['modulation2']
277     histogram_match = flags['l']
278     second_pass = flags['2']
279     color_match = flags['c']
280
281     # # Check & warn user about "ns == ew" resolution of current region =====
282     # region = grass.region()
283     # nsr = region['nsres']
284     # ewr = region['ewres']
285     #
286     # if nsr != ewr:
287     #     g.message(">>> Region's North:South (%s) and East:West (%s)"
288     #             "resolutions do not match!" % (nsr, ewr), flags='w')
289     # =====
290
291
292     # -----
293     # List images and their properties
294     # -----
295
296     mapset = grass.gisenv()['MAPSET'] # Current Mapset?
297
298     imglst = [pan]
299     imglst.extend(msxlst) # List of input imagery
300
301     images = {}
302     for img in imglst: # Retrieving Image Info
303         images[img] = Info(img, mapset)
304         images[img].read()
305
306     panres = images[pan].nsres # Panchromatic resolution
307
308     grass.use_temp_region() # to safely modify the region
309     run('g.region', res=panres) # Respect extent, change resolution
310     g.message("!! Region's resolution matched to Pan's (%f)" % panres)
311
312     # -----
313     # Loop Algorithm over Multi-Spectral images /////////////////
314     # -----
315
316     for msx in msxlst:
317
318         global tmp
319
320         # Inform
321         g.message("\nProcessing image: %s" % msx)
322
323         # Tracking command history -- Why don't do this all r.* modules?
324         cmd_history = ''
```

```

326     # -----
327     # 1. Compute Ratio
328     # -----
329
330     g.message("\n|1 Determining ratio of low to high resolution")
331
332     # Custom Ratio? Skip standard computation method.
333     if custom_ratio:
334         global ratio
335         ratio = float(custom_ratio)
336         g.message('Using custom ratio, overriding standard method!', flags='w')
337
338     # Multi-Spectral resolution(s), multiple
339     else:
340         # Image resolutions
341         g.message("    > Retrieving image resolutions")
342
343         msxres = images[msx].nsres
344         if panres == msxres:
345             grass.fatal(_("The Panchromatic's image resolution (%s) "
346                         "equals to the Multi-Spectral's one (%s). "
347                         "Obviously, something isn't right! "
348                         "Please check your input images."
349                         "% (panres, msxres)"))
350             ratio = msxres / panres
351             msg_ratio = '    >> Low (%.3f) to high resolution (%.3f) ratio: %.1f' \
352                         % (msxres, panres, ratio)
353             g.message(msg_ratio)
354
355
356     # 2nd Pass requested, yet Ratio < 5.5
357     if second_pass and ratio < 5.5:
358         g.message("    >>> Ratio < 5.5 -- WON'T perform 2nd pass! "
359                     "Use <ratio> option to override.",
360                     flags='i')
361         second_pass = bool(0)
362
363     # -----
364     # 2. High Pass Filtering
365     # -----
366
367     g.message('\n|2 High Pass Filtering the Panchromatic Image')
368
369     # ====== Temporary files ======
370     tmpfile = grass.tempfile() # Temporary file - replace with os.getpid?
371     tmp = "tmp." + grass.basename(tmpfile) # use its basename
372     tmp_pan_hpf = "%s_pan_hpf" % tmp # HPF image
373     tmp_msx_blnr = "%s_msx_blnr" % tmp # Upsampled MSx
374     tmp_msx_hpf = "%s_msx_hpf" % tmp # Fused image
375
376     tmp_hpf_matrix = grass.tempfile() # ASCII filter

```

```
377
378     if second_pass and ratio > 5.5: # 2nd Pass?
379         tmp_pan_hpf_2 = "%s_pan_hpf_2" % tmp # 2nd Pass HPF image
380         tmp_hpf_matrix_2 = grass.tempfile() # 2nd Pass ASCII filter
381
382     # Temporary files =====
383
384     # Construct Filter
385     hpf = High_Pass_Filter(ratio, center, modulation, False, None)
386     hpf_ascii(center, hpf, tmp_hpf_matrix, 1)
387
388     # Construct 2nd Filter
389     if second_pass and ratio > 5.5:
390         hpf_2 = High_Pass_Filter(ratio, center2, None, True, modulation2)
391         hpf_ascii(center2, hpf_2, tmp_hpf_matrix_2, 2)
392
393     # Filtering
394     run('r.mfilter', input=pan, filter=tmp_hpf_matrix,
395         output=tmp_pan_hpf,
396         title="High Pass Filtered Panchromatic image",
397         overwrite=True)
398
399     # 2nd Filtering
400     if second_pass and ratio > 5.5:
401         run('r.mfilter', input=pan, filter=tmp_hpf_matrix_2,
402             output=tmp_pan_hpf_2,
403             title="2-High-Pass Filtered Panchromatic Image",
404             overwrite=True)
405
406     # -----
407     # 3. Upsampling low resolution image
408     # -----
409
410     g.message("\n|3 Upsampling (bilinearly) low resolution image")
411
412     run('r.resamp.interp',
413         method='bilinear', input=msx, output=tmp_msx_blnr, overwrite=True)
414
415     # -----
416     # 4. Weighting the High Pass Filtered image(s)
417     # -----
418
419     g.message("\n|4 Weighting the High-Pass-Filtered image (HPFi)")
420
421     # Compute (1st Pass) Weighting
422     msg_w = "    > Weighting = StdDev(MSx) / StdDev(HPFi) * " \
423             "Modulating Factor"
424     g.message(msg_w)
425
426     # StdDev of Multi-Spectral Image(s)
427     msx_avg = avg(msx)
```

```

428     msx_sd = stddev(msx)
429     g.message("    >> StdDev of <%s>: %.3f" % (msx, msx_sd))
430
431     # StdDev of HPF Image
432     hpf_sd = stddev(tmp_pan_hpf)
433     g.message("    >> StdDev of HPFi: %.3f" % hpf_sd)
434
435     # Modulating factor
436     g.message("    >> Modulating Factor: %.2f" % modulator)
437
438     # weighting HPFi
439     weighting = hpf_weight(msx_sd, hpf_sd, modulator, 1)
440
441     # -----
442     # 5. Adding weighted HPF image to upsampled Multi-Spectral band
443     # -----
444
445     g.message("\n|5 Adding weighted HPFi to upsampled image")
446
447     fusion = "%s = %s + %s * %f" \
448             % (tmp_msx_hpf, tmp_msx_blnr, tmp_pan_hpf, weighting)
449     grass.mapcalc(fusion)
450
451     # history ****
452     cmd_history += "Weigthing applied: %.3f / %.3f * %.3f | " \
453             % (msx_sd, hpf_sd, modulator)
454
455     if second_pass and ratio > 5.5:
456         # -----
457         # 4+ 2nd Pass Weighting the High Pass Filtered image
458         # -----
459         g.message("\n|4+ 2nd Pass Weighting the HPFi")
460
461         # Compute 2nd Pass Weighting
462         # Formula? Don't inform again...
463
464         # StdDev of HPF Image #2
465         hpf_2_sd = stddev(tmp_pan_hpf_2)
466         g.message("    >> StdDev of 2nd HPFi: %.3f" % hpf_2_sd)
467
468         # Modulating factor #2
469         g.message("    >> 2nd Pass Modulating Factor: %.2f" % modulator_2)
470
471         # 2nd Pass weighting
472         weighting_2 = hpf_weight(msx_sd, hpf_2_sd, modulator_2, 2)
473
474         # -----
475         # 5+ Adding weighted HPF image to upsampled Multi-Spectral band
476         # -----
477
478         g.message("\n|5+ Adding small-kernel-based weighted 2nd HPFi "

```



```

530     msx_nam = ("%s.%s" % (msx.split('@')[0], outputsuffix))
531     run("g.rename", rast=(tmp_msx_hpf, msx_nam))
532
533     # visualising-related information
534     grass.del_temp_region() # restoring previous region settings
535     g.message("\n! Region's resolution restored!")
536     g.message("\n>>> Rebalancing colors "
537             "(i.colors.enhance) may improve appearance of RGB composites!",
538             flags='i')
539
540 if __name__ == "__main__":
541     options, flags = grass.parser()
542     atexit.register(cleanup)
543     sys.exit(main())

```

License(s) of Data

DIGITALGLOBE(r) PRODUCT

END USER LICENSE AGREEMENT

This END USER LICENSE AGREEMENT ("Agreement") is made between DigitalGlobe, Inc. ("DigitalGlobe") and you or, if you represent an entity or other organization, that entity or organization (in either case, "You"). You have ordered or otherwise expressed an interest in obtaining a license to certain products of DigitalGlobe, including, without limitation, aerial or satellite photography, imagery or orthophotos, vector, attribute or other data, or other related documentation, information or content. DigitalGlobe is willing to provide You with a license to those products of DigitalGlobe described in the confirmation of Your order provided by DigitalGlobe (Your "Confirmation") or otherwise provided to You in connection with this Agreement (collectively, the "Product") if You agree to be bound by the terms and conditions of this Agreement.

PLEASE READ THE TERMS AND CONDITIONS OF THIS AGREEMENT PROVIDED BELOW CAREFULLY. BY ACCESSING OR USING THE PRODUCT, YOU ACKNOWLEDGE THAT YOU HAVE READ, AND AGREE TO BE BOUND BY THE TERMS AND CONDITIONS OF, THIS AGREEMENT.

IF YOU DO NOT AGREE TO THE TERMS AND CONDITIONS OF THIS AGREEMENT, DIGITALGLOBE IS NOT WILLING TO LICENSE THE PRODUCT TO YOU. IF THE PRODUCT WAS DELIVERED TO YOU ON A TANGIBLE MEDIUM SUCH AS A CD, THEN YOU MUST RETURN THE PRODUCT IN ITS ORIGINAL PACKAGING, WITHOUT BREAKING THE SEAL. IF THE PRODUCT WAS MADE AVAILABLE TO YOU IN AN ELECTRONIC FORMAT, THEN YOU MUST NOT DOWNLOAD, ACCESS OR USE THE PRODUCT. IF YOU DO NOT RETURN THE PRODUCT OR IF YOU DOWNLOAD, ACCESS OR USE THE PRODUCT, AS SPECIFIED ABOVE, YOU ACKNOWLEDGE AND AGREE TO BE BOUND BY THE TERMS AND CONDITIONS OF THIS AGREEMENT.

This Agreement will be entered into as of the date You first download, access or use the Product (the "Effective Date"). This Agreement consists of these terms and conditions

and Your Confirmation (which is incorporated herein and made a part hereof). Unless otherwise amended as set forth herein, this Agreement represents the entire agreement and understanding between You and DigitalGlobe as to the matters set forth herein and will exclusively govern Your access to and use of the Product and will supersede any oral or written proposal, agreement or other communication between You and DigitalGlobe regarding the Product. Your acceptance of this Agreement is expressly limited to the terms and conditions set forth herein. Any additional or inconsistent terms provided by You in any other documents such as a purchase order will not have any legally binding effect on DigitalGlobe. This Agreement may be modified only by a binding written instrument entered into by You and DigitalGlobe. All waivers under this Agreement must be in writing. Any waiver or failure to enforce any provision of this Agreement on one occasion will not be deemed a waiver of any other provision or of such provision on any other occasion.

- I. Definitions. For purposes of this Agreement, the following definitions apply. Any capitalized terms in this Agreement not listed below will have the meanings given to them in this Agreement or, if not defined in this Agreement, will have their plain English (US) meanings.
 - a. Commercial Purpose. Redistribution, retransmission or publication in exchange for a fee or other consideration, which may include, without limitation: (i) advertising; (ii) use in marketing and promotional materials and services on behalf of a customer, client, employer, employee or for Your own benefit; (iii) use in any materials or services for sale or for which fees or charges are paid or received (e.g., textbook supplemental materials, books, syllabi, course packs); and (iv) use in any books, news publication or journal without an Educational Purpose.
 - b. Customer Group.
 - i. one individual;
 - ii. one company, corporation, or similar legal entity (excluding affiliates or subsidiaries which will be treated as a separate Customer Group);
 - iii. one subsidiary or affiliate of an entity;
 - iv. one department of a federal agency at the U.S. Cabinet level (e.g., office of the U.S. Dept. of Agriculture or U.S. Dept. of Interior, but excluding sub-agencies);
 - v. one civilian federal agency below the U.S. Cabinet level;
 - vi. one department of the four branches of the military, a defense agency, one of the unified commands, one of the non-Dept. of Defense entities identified in 50 U.S.C. Section 401a or the State Department;
 - vii. one department of a foreign military or an international defense or intelligence agency;
 - viii. one state or provincial agency;
 - ix. one county or local government;
 - x. one non-governmental organization or non-profit organization;
 - xi. one department within a single educational organization within a single country;
 - xii. one international agency such as NATO, but excluding the United Nations and the European Union;
 - xiii. one office or department within the United Nations or the European Union; or

- xiv. any one entity equivalent to any of the entities listed above, located outside the United States.
 - c. Demonstration Purpose. Any non-Commercial Purpose for demonstration, promotional or training purposes for a period of no more than 90 days from Product shipment.
 - d. Derivative. Any addition, improvement, update, modification, translation, transformation, adaptation or derivative work of or to the Product, authored, created or developed by or on behalf of You, including, without limitation, any reformatting of the Product into a different format or media from which it is delivered to You, any addition of data, information or other content to the Product, or any copy or reproduction of the Product.
 - e. Educational Purpose. Any non-Commercial Purpose undertaken for study or research solely in furtherance of education.
 - f. Federal Civil Government Agency. Any government agency at the federal level, EXCLUDING all U.S. Department of Defense agencies and those agencies defined under U.S. Code Title 50. The U.S. Army Corp of Engineers is included in the definition of Federal Civil Government Agency under this Agreement.
 - g. Fees. The fees set forth in Your Confirmation.
 - h. Joint Project. An undertaking between You and one or more other Customer Groups based on a contractual relationship existing as of the Effective Date.
 - i. Purpose. As may be indicated in Your Confirmation, Demonstration Purposes or Educational Purposes.
 - j. State and Local Government Agency. Any government agency at the state and local level. With regard to the United States, the term "state" includes the 50 United States and the United States' territories and possessions.
 - k. User. Employees or contractors of You or, as applicable, a Customer Group.
2. Grant of License. Subject to Your compliance with the terms and conditions of this Agreement, including, without limitation, payment of all applicable Fees, DigitalGlobe grants to You a non-exclusive, non-transferable, limited license to allow the number of Users identified on Your Confirmation to access, reproduce, store, display and create Derivatives of the Product, solely for the Purpose indicated in Your Confirmation or, if no Purpose is indicated in Your Confirmation, solely for Your own internal business purposes.
- a. If You are not a Federal Civil Government Agency or a State and Local Government Agency, You may post the Product and Derivative on Your website at a resolution no better than 10 meters in a static, non-downloadable, non-distributable, non-interactive fashion and in a manner that does not allow a third party to extract or access the Product as a standalone file;
 - b. If You are a Federal Civil Government Agency, You may post the Product and Derivative to publicly accessible Internet web sites provided that: (a) the quality of the image data available for download is presented in a color composite jpeg or a 50:1 compressed file format without associated geospatial information; and (b) the Product or Derivative posted to publicly accessible websites is in a secure format that allows printing and viewing at no better than ten meter resolution. The Product and any Derivatives may be posted to secure Intranet websites and may be used only for the purposes of a Joint Project and subject to Section 3;

- c. If You are a State and Local Government Agency, You may post the Product and any Derivatives on Your website at full resolution for non-Commercial Purposes, in a non-downloadable, non-distributable fashion, and in a manner that does not allow a third party to extract or access the Product as a standalone file;
3. Sublicense. Subject to Your compliance with the terms and conditions of this Agreement, including, without limitation, payment of all applicable Fees, You may grant sublicenses of the rights granted to You under Section 2 to access, reproduce, store, and display the Product to Customer Groups engaged in a Joint Project with You solely for the internal business purposes of the Customer Group in completing the Joint Project with You. All Customer Groups will be identified by You and confirmed by DigitalGlobe (on Your Confirmation or otherwise) in advance of any sublicense by You. The number of permitted Users within each Customer Group sublicensed hereunder will be limited to the type of license You have purchased as follows:

Type of License Purchased

Number of Permitted Users Within Sublicensed Customer Group

Base

Up to 5

Group

From 6 to 10

Enterprise

From 11 to 25

Enterprise Premium

More than 25

Educational

1

Demonstration

1

If the number of individuals of a sublicensed Customer Group using or accessing the Product exceeds the number of Users permitted under this Section 3, the Customer Group will be counted as multiple sublicensees based on the number of individuals using the Product, for purposes of determining compliance with the table above. If a sublicensed Customer Group is involved in multiple Joint Projects with You, the Customer Group will be counted as multiple sublicensees based on the number of Joint Projects involved for purposes of determining compliance with the table above. Each sublicense must require the sublicensee to agree to be bound by this Agreement. You will remain responsible for any noncompliance by any sublicensee and sublicensee's breach of this Agreement shall be deemed to be Your breach of this Agreement.

4. Restrictions. You recognize and agree that the Product is the property of DigitalGlobe and contains valuable assets and proprietary information of DigitalGlobe. Accordingly, except as expressly permitted in Sections 2 or 3, You will not, and will not permit any User or third party to: (a) publish, transmit, reproduce, create Derivatives of or otherwise utilize the Product in any form, format or media; (b) merge the Product with any other data, information or content; (c) reverse engineer or otherwise attempt to derive the algorithms, databases or data structures upon which the

Product is based; (d) distribute, sublicense, rent, lease or loan the Product; (e) use the Product for the business needs of any third person or entity, including without limitation, providing any services to any third parties; (f) remove, bypass or circumvent any electronic or other forms of protection measure included on or with the Product; (g) alter, obscure or remove any copyright notice, copyright management information or proprietary legend contained in or on the Product; or (h) otherwise use or access the Product or any Derivatives for any purpose not expressly permitted under this Agreement, including, without limitation, for Commercial Purposes.

Excepting Advanced Ortho Aerial Products or other Products consisting of Microsoft Aerial Imagery or Derivatives consisting of Microsoft Aerial Imagery, all Products and Derivatives must contain the following copyright notice conspicuously displayed in connection with the Product or Derivative Work: "(c) DigitalGlobe, Inc. All Rights Reserved" for the Product, and "Includes copyrighted material of DigitalGlobe, Inc., All Rights Reserved" for Derivatives. All Advanced Ortho Aerial Products and Derivatives containing Microsoft Aerial Imagery must include, on or near the Licensed Image, the attribution, "Available Exclusively by DigitalGlobe" as well as the following copyright notice in an "About" page, "Terms of Use", End User License Agreement, or similar medium: "Image (c) 20xx Microsoft Corporation" annotating the applicable year. You acknowledge that You need to obtain a separate distribution license from DigitalGlobe in order to distribute or publish the Product or any Derivative Work in any form not expressly permitted under Section 2 or 3.

5. Ownership. The Product, and all worldwide intellectual property and proprietary rights therein and related thereto, including, without limitation, all patents, copyrights, trademarks, trade secrets, moral rights, sui generis rights and other right in databases, and all rights arising from or pertaining to the foregoing rights, are and will remain the exclusive property of DigitalGlobe and its suppliers. All rights in and to the Product not expressly granted to You are reserved by DigitalGlobe and its suppliers. This Agreement does not grant You title to the Product or any copies of the Product. Any rights of Customer in any Derivative do not provide Customer with any rights in or to any Product used or incorporated in that Derivative except as granted under this Agreement.
6. Confidentiality. The Product includes metadata and other confidential and proprietary information of DigitalGlobe ("Confidential Information"). You will not use any Confidential Information for any purpose not expressly permitted hereunder and will disclose Confidential Information only to Your employees and permitted sublicensees who have a need to know for purposes of this Agreement and who are under a duty of confidentiality no less restrictive than Your duty hereunder. You will protect the Confidential Information from unauthorized use, access, or disclosure in the same manner as You protect Your own confidential or proprietary information of similar nature and with no less than reasonable care.
7. Audit. At DigitalGlobe's request, You will provide assurances acceptable to DigitalGlobe that You are using the Product consistent with the terms of this Agreement. Upon notice, DigitalGlobe may inspect Your records, accounts and books relating to the use of the Product to ensure that the Product is being used in accordance with this Agreement.
8. Term and Termination. This Agreement remains in full force until terminated as provided below. DigitalGlobe has the right to terminate this Agreement, effective immediately upon notice to You, if You breach any provision of this Agreement. Upon termination of this Agreement, all rights granted to You hereunder shall immediately

cease and You and Your sublicensees will: (a) discontinue all use of the Product; (b) if the Product was delivered on a tangible medium, return to DigitalGlobe the Product and all copies thereof; (c) purge all copies of the Product or any portion thereof from all computer storage devices or medium on which You have placed or permitted others to place the Product; and (d) give DigitalGlobe a written certification that You have complied with all of Your obligations hereunder.

9. Limited Warranty; Disclaimer. DigitalGlobe warrants that, for a period of 30 days after Your receipt of the Product, the Product will perform substantially in accordance with its applicable specifications. DigitalGlobe's sole obligation and Your entire remedy for breach of the above warranty is for DigitalGlobe, at its sole option and expense, to: (a) repair or replace the non-conforming Product returned during the warranty period; or (b) refund all fees paid by You for the non-conforming Product returned during the warranty period. This limited warranty is void if any non-conformity has resulted from any accident, abuse, misuse, misapplication, or modification of or to the Product or any breach of this Agreement. EXCEPT AS EXPRESSLY PROVIDED IN THIS SECTION 9, ALL PRODUCT IS PROVIDED "AS IS" WITHOUT ANY REPRESENTATIONS OR WARRANTIES OF ANY KIND AND ALL WARRANTIES, WHETHER EXPRESS OR IMPLIED, ORAL OR WRITTEN, ARISING BY LAW OR OTHERWISE, ARE EXPRESSLY DISCLAIMED AND EXCLUDED BY DIGITALGLOBE, INCLUDING, WITHOUT LIMITATION ALL IMPLIED WARRANTIES OF MERCHANTABILITY, TITLE, NON-INFRINGEMENT, AND FITNESS FOR A PARTICULAR PURPOSE. DIGITALGLOBE DOES NOT WARRANT THAT THE PRODUCT WILL BE ACCURATE, CURRENT OR COMPLETE, THAT THE PRODUCT WILL MEET YOUR NEEDS OR EXPECTATIONS, OR THAT THE OPERATION OF THE PRODUCT WILL BE ERROR FREE OR UNINTERRUPTED. DIGITALGLOBE PROVIDES ALL CONTENT AS A SERVICE TO YOU. SPATIAL, SPECTRAL, AND TEMPORAL ACCURACY CANNOT BE GUARANTEED. DIGITALGLOBE RESERVES THE RIGHT, AT ITS SOLE DISCRETION, TO MODIFY CERTAIN IMAGE CHARACTERISTICS OF THE CONTENT INCLUDING, BUT NOT LIMITED TO, WATERMARKING AND DIMENSIONS.
10. Limitation of Liability. IN NO EVENT WILL DIGITALGLOBE OR ITS SUPPLIERS BE LIABLE FOR ANY INCIDENTAL, CONSEQUENTIAL, SPECIAL, EXEMPLARY, OR INDIRECT DAMAGES (INCLUDING LOST PROFITS OR LOST DATA) ARISING FROM, OR RELATING TO, THIS AGREEMENT OR THE PRODUCT, EVEN IF DIGITALGLOBE OR ITS SUPPLIERS HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. DIGITALGLOBE AND ITS SUPPLIERS' TOTAL CUMULATIVE LIABILITY IN CONNECTION WITH THIS AGREEMENT AND THE PRODUCT, WHETHER IN CONTRACT OR TORT OR OTHERWISE, WILL NOT EXCEED THE AMOUNT OF FEES PAID TO DIGITALGLOBE FOR THE PRODUCT. THIS SECTION 10 SHALL BE GIVEN FULL EFFECT EVEN IF THE WARRANTY PROVIDED IN SECTION 9 IS DEEMED TO HAVE FAILED OF ITS ESSENTIAL PURPOSE.
11. Indemnification. You will indemnify, defend, and hold harmless DigitalGlobe and its subsidiaries, affiliates and subcontractors, and their respective owners, officers, directors, employees and agents, from and against any and all direct or indirect claims, damages, losses, damages, liabilities, expenses, and costs (including reasonable attorneys' fees) arising from or out of: (1) Your use of the Product for any purpose; (2) Your actual or alleged breach of any provision of this Agreement; or (3) damage to property or injury to or death of any person directly or indirectly caused by You.

DigitalGlobe will provide You with notice of any such claim or allegation, and DigitalGlobe has the right to participate in the defense of any such claim at its expense.

12. Export Control. You will not export or re-export any Software in violation of the U.S. Export Administration regulations or other applicable laws and regulations. You will defend, indemnify, and hold harmless DigitalGlobe from and against all fines, penalties, liabilities, damages, costs, and expenses incurred by DigitalGlobe as a result of any violation of such laws and regulations by You or any of Your agents or employees.

13. Additional Terms.

a. You acknowledge that any actual or threatened breach of Section 2, 3, 4, or 6 will constitute immediate and irreparable harm to DigitalGlobe for which monetary damages would be an inadequate remedy. Therefore, without limiting any other remedy available at law or in equity, upon any such breach or any threat thereof, DigitalGlobe will be entitled to seek injunctive relief against You as remedy for such breach. To the fullest extent not prohibited by applicable law, any action brought for such relief may be brought by DigitalGlobe upon ex parte application and without notice or posting of any bond, and You expressly waive any requirement for notice or the posting of any bond. If any action is brought to enforce this Agreement, the prevailing party will be entitled to receive its reasonable attorney's fees, court costs, and other collection expenses, in addition to any other relief it may receive.

b. Failure to require performance of any provision of this Agreement does not waive DigitalGlobe's right to subsequently require full and proper performance of such provision. If any provision of this Agreement is determined to be invalid or unenforceable, such provision will to the extent possible be deemed amended by limiting and reducing it to the minimum extent necessary to make such provision valid and enforceable and the remaining provisions of this Agreement shall continue to be valid and enforceable and will be liberally construed to carry out the provisions and intent hereof. The invalidity or unenforceability of any provision of this Agreement in any jurisdiction will not affect the validity or enforceability of such provision in any other jurisdiction, nor will the invalidity or unenforceability of any provision of this Agreement with respect to any person affect the validity or enforceability of such provision with respect to any other person.

c. Neither this Agreement nor any of the rights or obligations hereunder may be assigned or transferred by You (by operation of law or otherwise) without the prior written consent of DigitalGlobe. This restriction on assignment or transfer shall apply to assignments or transfers by operation of law, as well as by contract, merger or consolidation. Any attempted assignment or transfer in violation of the foregoing will be null and void.

d. This Agreement shall be governed by the laws of the State of Colorado, U.S.A., without regard to conflicts of law principles that would require the application of the laws of any other state or jurisdiction. The United Nations Convention on Contracts for the International Sale of Goods does not apply to this Agreement. Any action or proceeding arising from or relating to this Agreement must be brought in the federal courts or state courts for Boulder County, Colorado, and each party irrevocably submits to the jurisdiction and venue of any such court in any such action or proceeding.

e. Any notices to DigitalGlobe relating to this Agreement shall be in writing and delivered by personal delivery or U.S. certified mail (return receipt requested) to the address provided below and will be effective upon receipt by DigitalGlobe:

DIGITALGLOBE, INC.

ATTN: LEGAL DEPT.

1601 Dry Creek Dr., Suite 260

Longmont, CO 80503, USA

All notices to You relating to this Agreement shall be delivered by personal delivery, electronic mail, facsimile transmission or by U.S. certified mail (return receipt requested) to the address DigitalGlobe has on file for You, and will be deemed given upon personal delivery, 5 days after deposit in the mail, or upon acknowledgment of receipt of electronic transmission.