Hydgrography90m: a new and extendable global watershed and stream network delineation using GRASS-GIS

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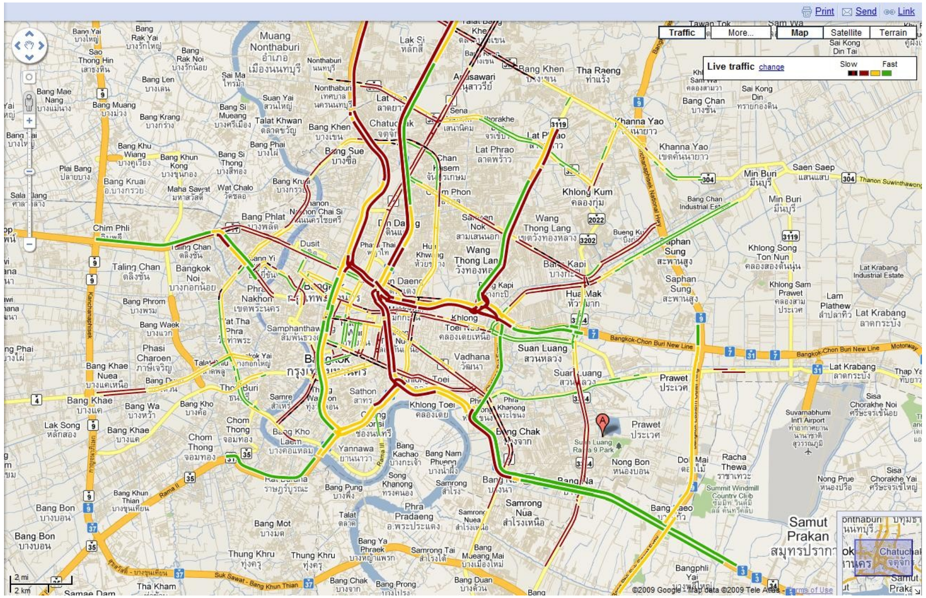
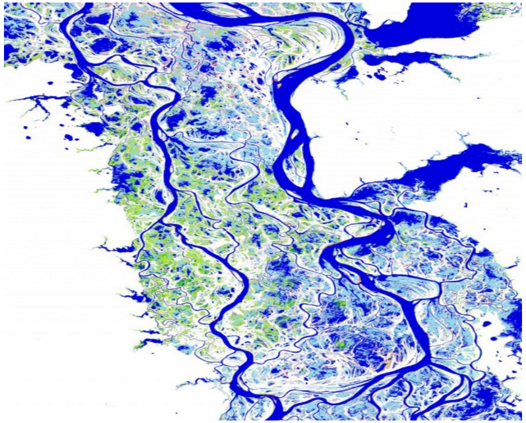
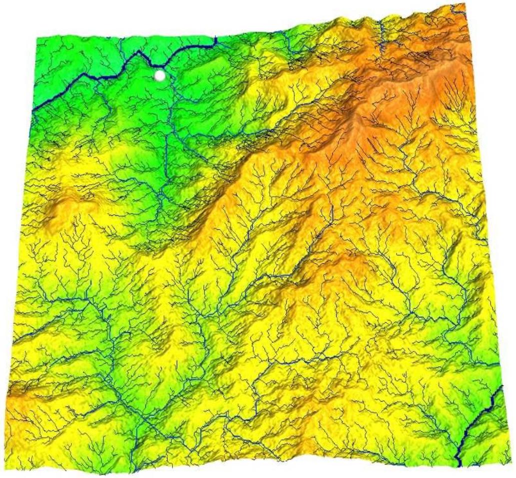
Real-time traffic map



What about real-time freshwater map at global level?



J.F. Pekel et al., 2017

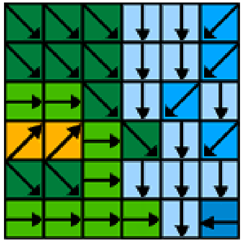


Flow routing algorithms

Given that the water flow follows the steepest downstream slopes.

Flow accumulation involves three sequential algorithms:

- determining flow directions,
- resolving depressions and flat areas,
- finally, calculating flow accumulation.

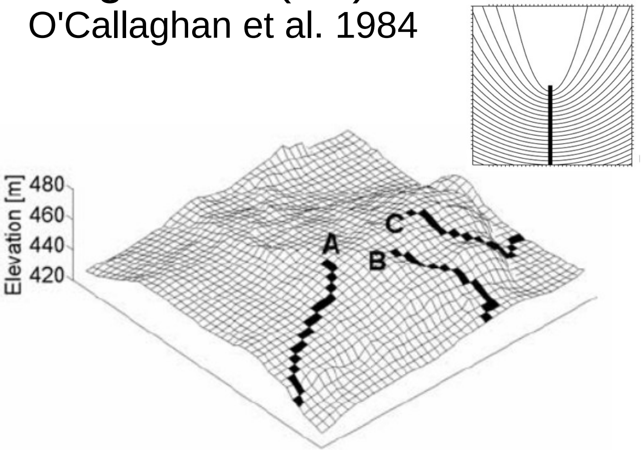


Flow direction

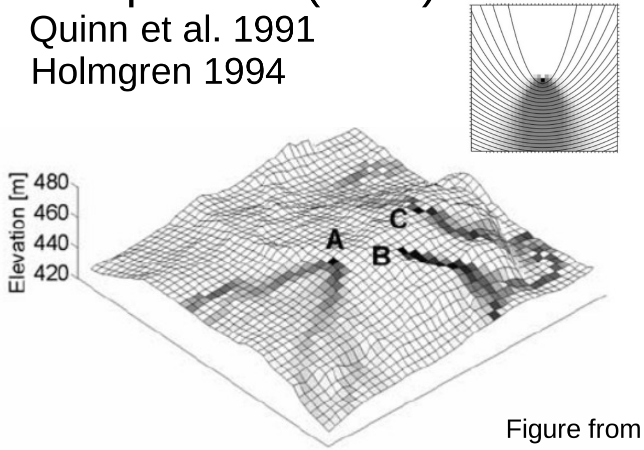
0	0	0	0	0	0
0	1	1	2	2	0
0	3	7	5	4	0
0	0	0	20	0	1
0	0	0	1	24	0
0	2	4	7	35	1

Flow accumulation

Single-flow (D8)
O'Callaghan et al. 1984



Multiple-flow (MD8)
Quinn et al. 1991
Holmgren 1994



Triangular-single-flow (D∞)
Tarboton 1997

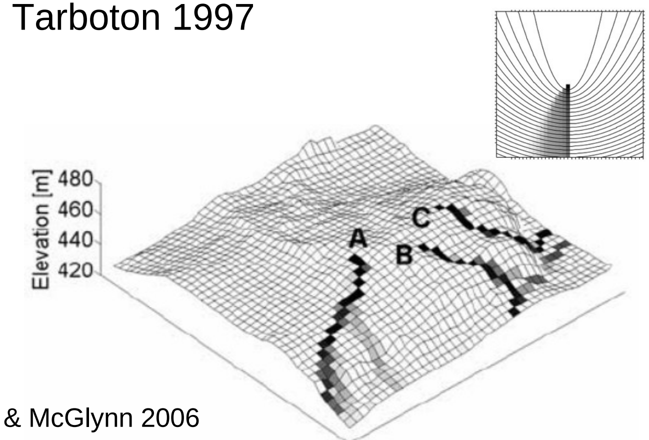


Figure from Seibert & McGlynn 2006

DEM-derived stream network at global level

DEM	Flow routing algorithms	Upstream contributing area	Product name	Author
GTOPO30 DEM at 30arc	D8	1000 km^2	HYDRO1K	USGS 1997
SRTM DEM at 15arc	D8	10 km^2	HydroSHEDS	Lehner et al. 2008
MERIT Hydro at 3arc	D8	5 km^2	River Channel Width	Yamazaki et al. 2019
MERIT Hydro at 3arc	D8	1 km^2	MERIT Hydro-Vector	Lin et al. 2019

Objectives:

Produce global stream network (90m res) and its geophysical and morphological properties.

- Using the best available global DEM: MERIT-Hydro
- Implementing Multiple-flow (MD8)
- Seting upstream contributing area at 0.05 km^2 (small headwaters)
- Solving computation limits (manly RAM requirements)
- Globally seamless products without tiles border effects.
- Standardized and aligned raster tiles for all the products
- Produce raster files that can be re-ingested into GRASS-GIS to produce ancillary hydrographical features.

Methodology steps

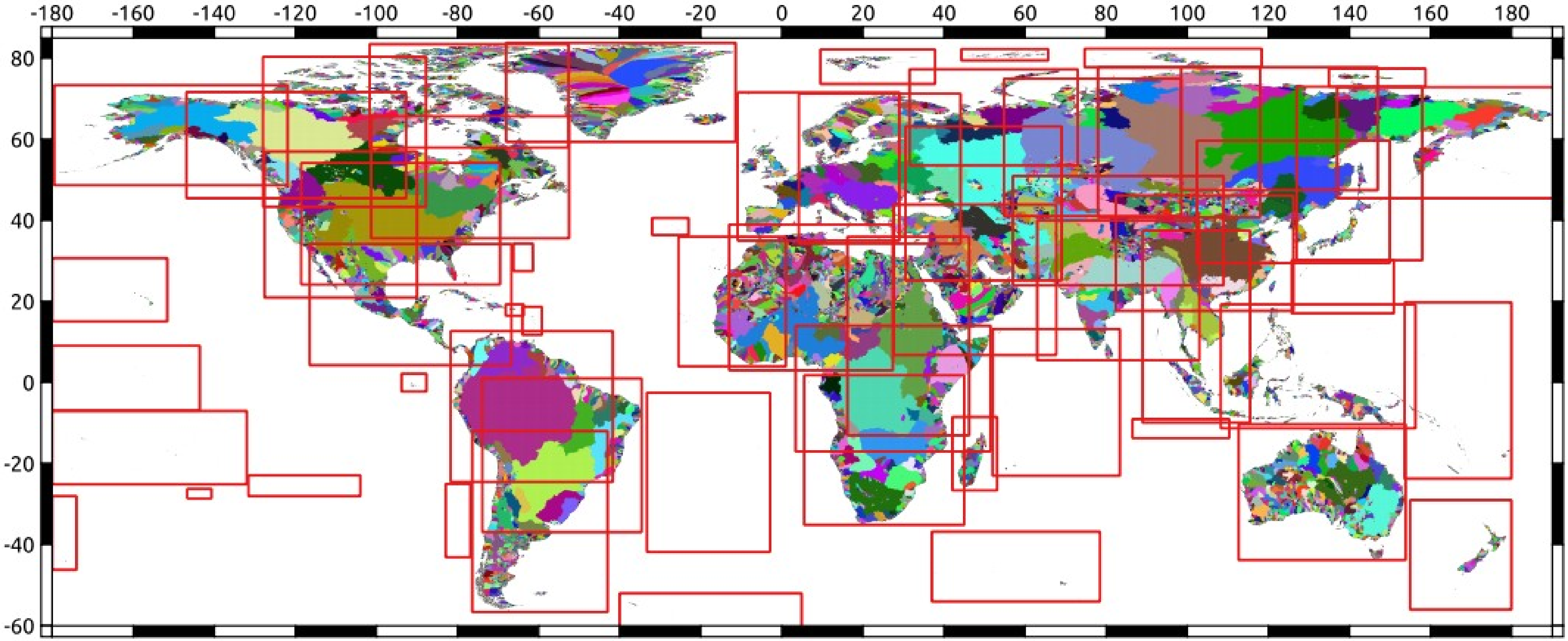
The overall computation for the global hydrography can be split into four steps:

- Splitting the DEM into smaller spatial units to achieve computational scalability
- Computing flow accumulation and direction, and the subsequent extraction of stream channels and basins
- Validation of the spatial distribution of stream channels and basins using independent data sources.
- Computing geophysical, morphological and topological properties of the stream channels and basins

Global tiling system:

in red irregular tiles (< ~2 billion cells, that requires ~67 GB of RAM)

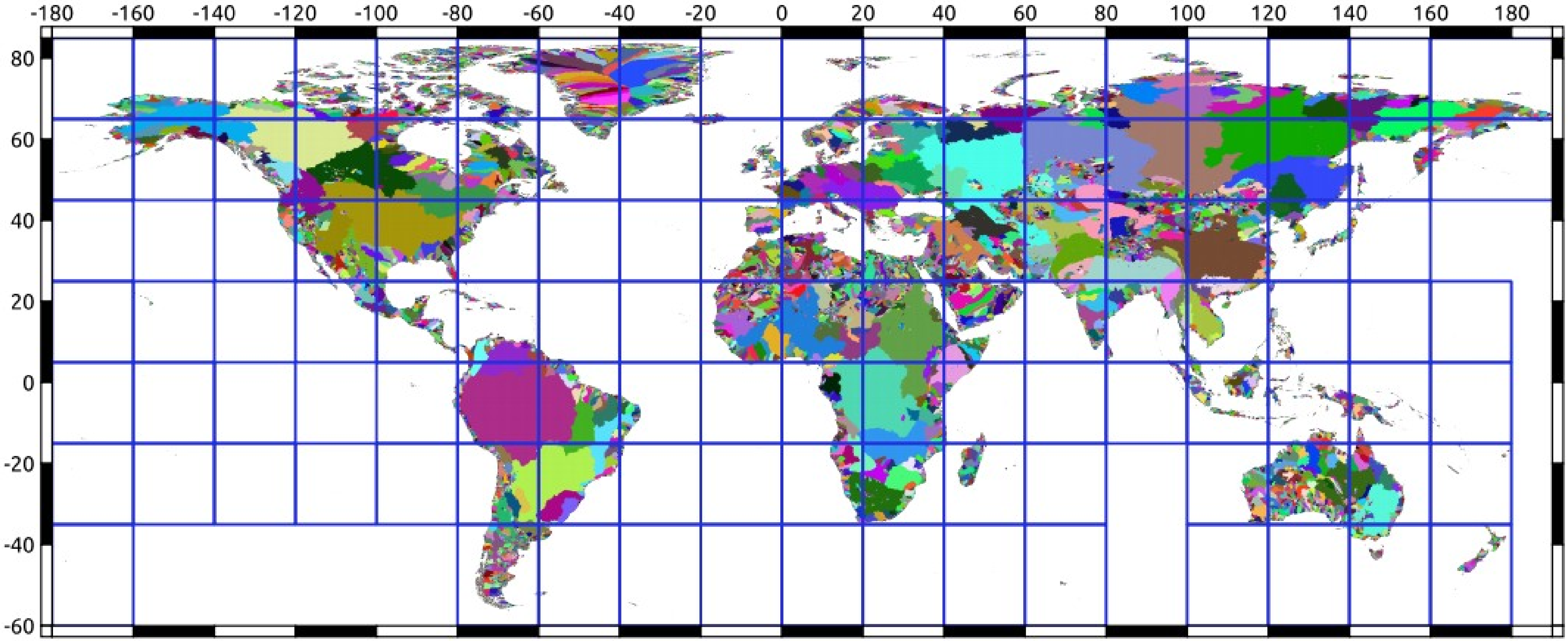
random colors drainage basins



Global tiling system:

in blue regular tile

random colors drainage basins



Computation methodology

task / module

intermediate output layer

final output layer

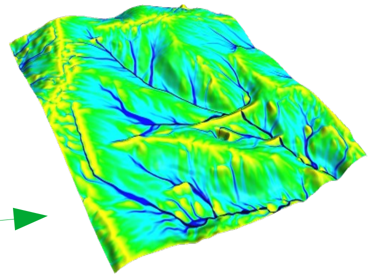
First phase

Irregular tiles system

task / module	output layer
flow accumulation / r.watershed streams extraction / r.stream.extract basins delineation / r.stream.basins	flow accumulation streams basins
remove truncated basins remove truncated flow accumulation	completed basins completed flow accumulation

Regular tiles system

task / module	output layer
merge completed flow accumulation	global flow accumulation



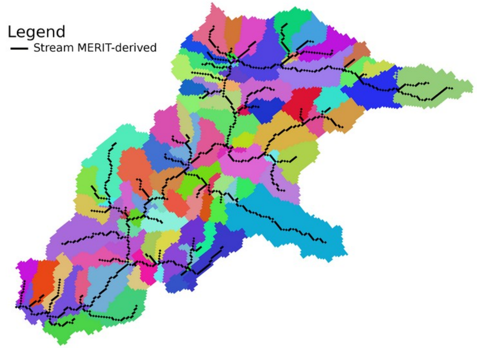
Second phase

Irregular tiles system

task / module	output layer
streams extraction / r.stream.extract basins, sub-catchments delineation / r.stream.basins	streams, flow direction basins, sub-catchments
remove uncompleted basins, sub-basin remove uncompleted streams remove uncompleted flow direction	completed basins, sub-catchments completed stream completed flow direction
reclassify basins from 1 to *n*	reclassified basins

Regular tiles system

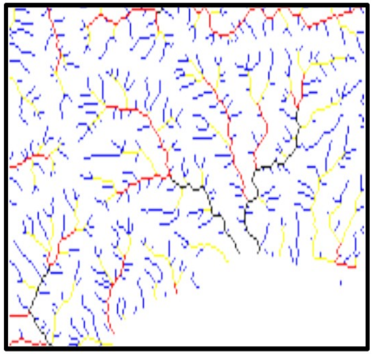
task / module	output layer
mosaic flow direction mosaic reclassified basins mosaic stream mosaic sub-catchments	global flow direction global reclassified basins global streams global sub-catchments
reclassify basins from 1 to *n* reclassify stream from 1 to *n* reclassify sub-catchments from 1 to *n*	global unique basins global unique stream global unique sub-catchments



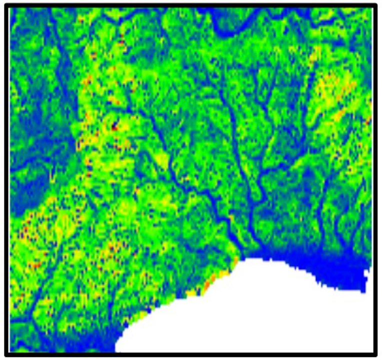
Geophysical and morphological properties

(computed with r.stream.distance, r.stream.dorder, r.stream.slope, r.stream.channel; just plotting few of them)

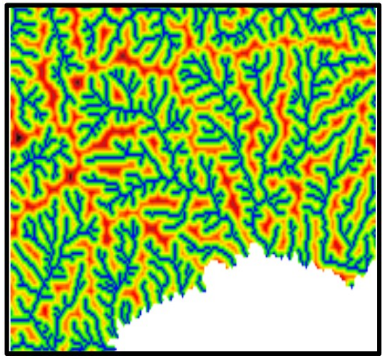
Strahler's stream order



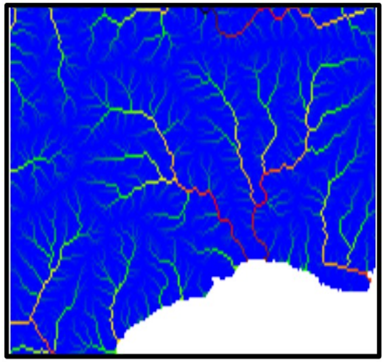
Local downstream gradient difference



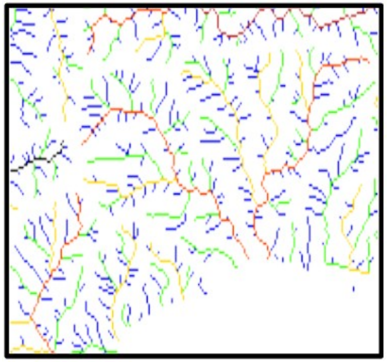
Euclidean distance from the streams



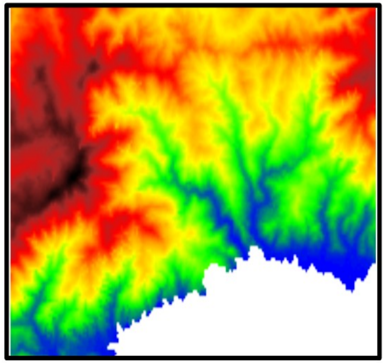
Distance of the longest path from a stream pixel to the divide



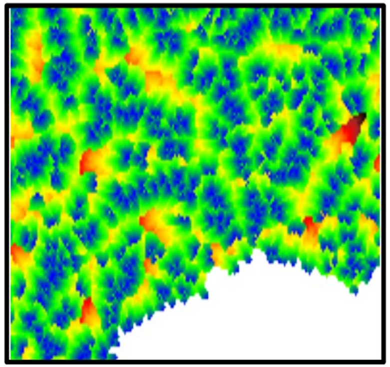
Horton's stream order



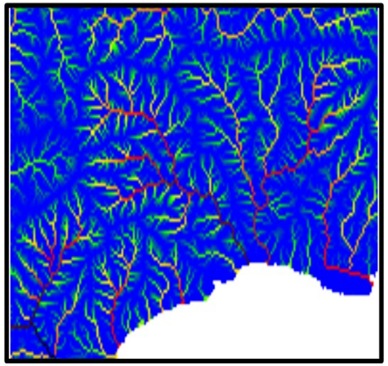
Distance of the longest path from the divide to reach an outlet pixel



Elevation difference of the longest path from the divide to reach a stream node pixel

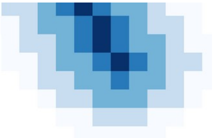


Elevation difference of the longest path from a stream pixel to the divide



Stream Network validation using NHDplus

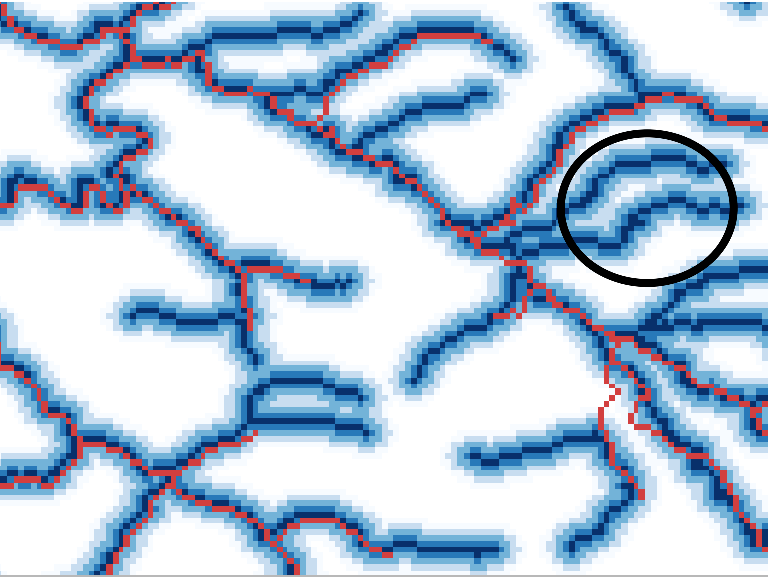
NHDplus buffer distance 0-400m

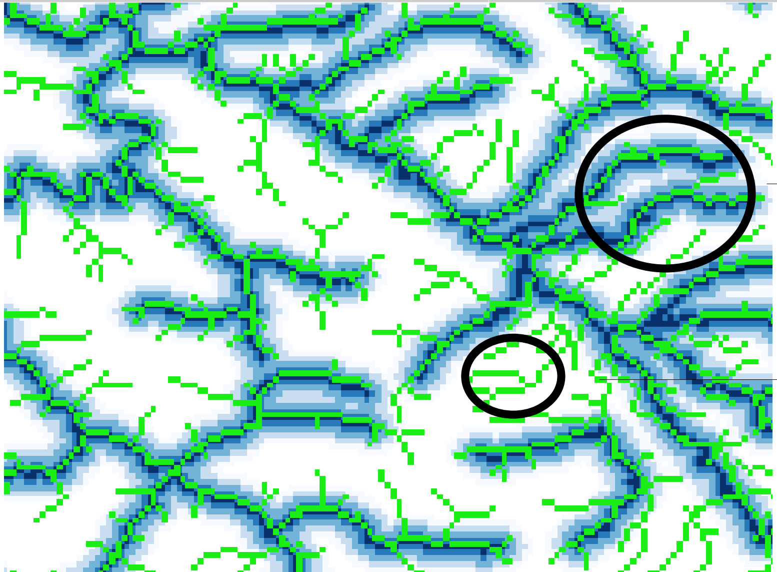


MERIT Hydro-Vector Lin et al. 2019

Hydrography90m Amatulli et al. 2022

Dataset	Percentage of overlapping pixel in each buffer distance				
	0m	100m	200m	300m	400m
MERIT Hydro-Vector Lin et al. 2019	25	16	3	1	1
Hydrography90m Amatulli et al. 2022	38	27	14	14	12



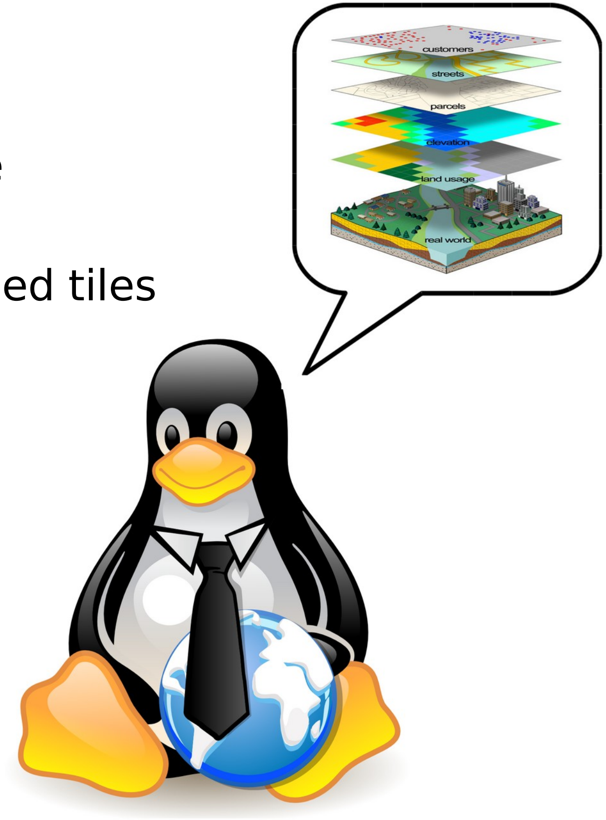


Better accuracy of headwaters streams

Probably overestimation of streams channels; pruning after estimation of monthly water discharge

Computation features

- High performance computing (HPC)
  of the Center for Research Computing, Yale University.
- GDAL, GRASS, PKTOOLS glued together under Bash Language
- Scripts that launch each other in a cascading manner
- Series of single batch jobs, or as job arrays in accordance to the computational task
- Precise tile extent (at degree level) to avoid pixel shift and aligned tiles merging



Conclusion

- Hydrography90m is going to be released in 2021

  (preprint and publication in Earth System Science Data)
- The r.stream.* modules in GRASS-GIS are suitable for massive computation
- Quite complex procedure is need to deal with the high memory requirements.
-
- Geomorpho90m (Amatulli et al. 2020) + Hydrography90m (Amatulli et al. 2022) full harmonized and comprehensive dataset usefull for different earth system application