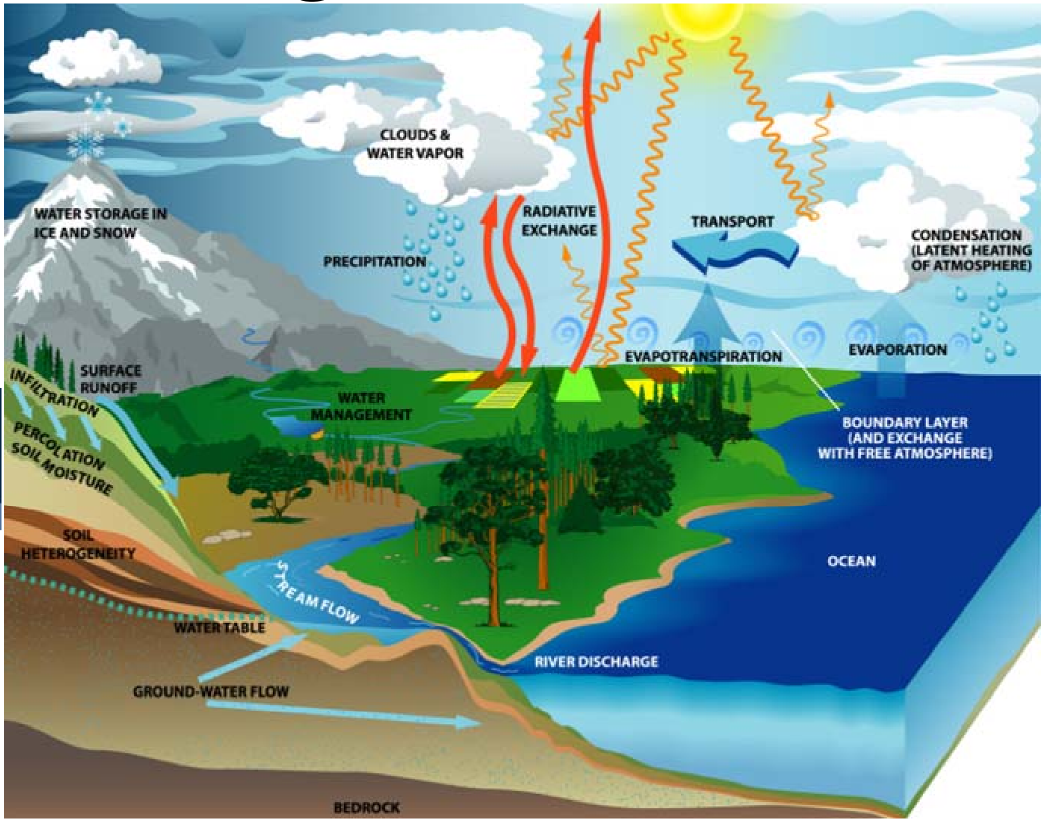
VIC Hydrology Model Training Workshop – Part II: Building a model

11-12 Oct 2011

Centro de Cambio Global
Pontificia Universidad Católica
de Chile



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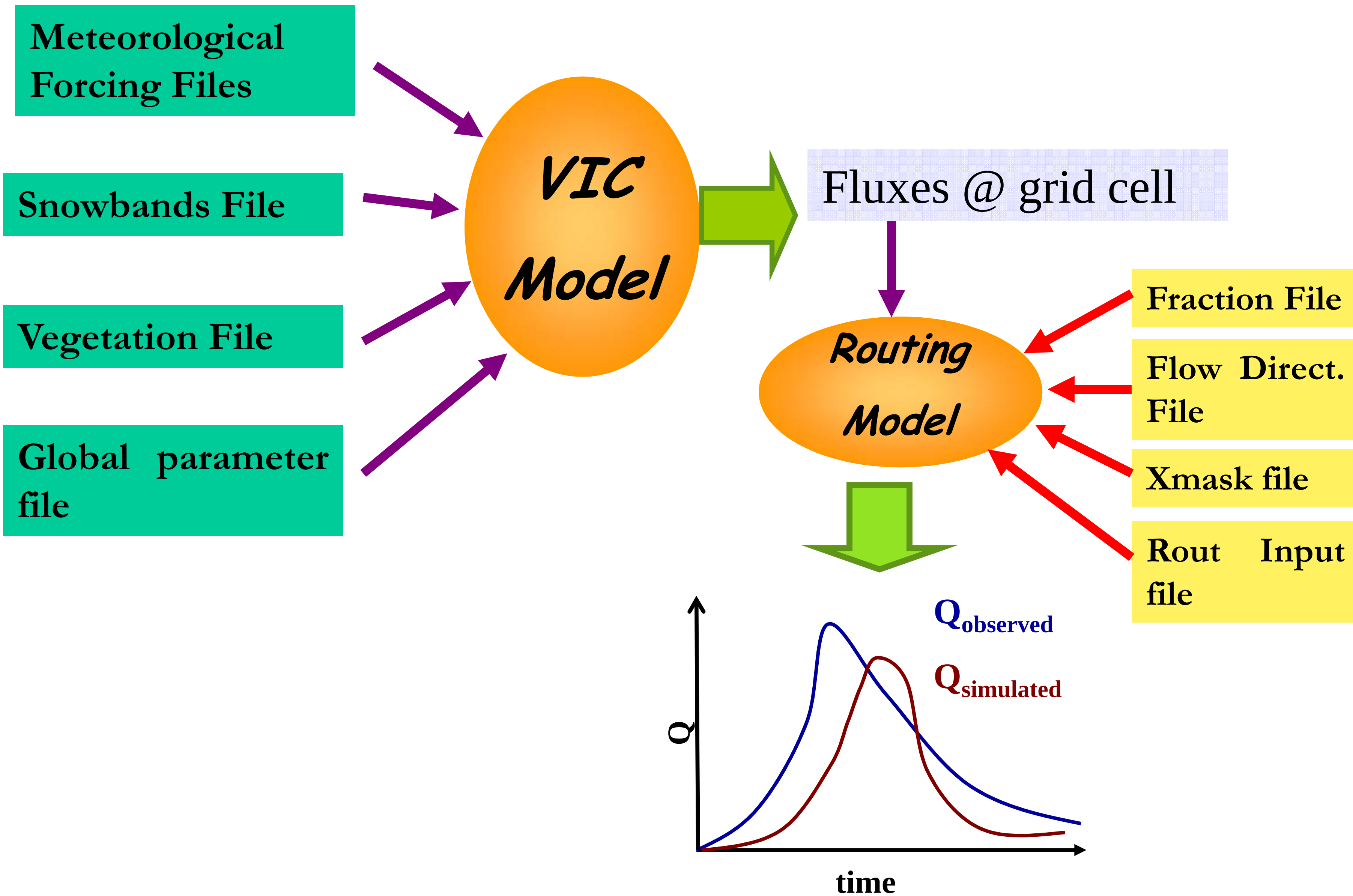
Based on original workshop materials generously provided by Alan Hamlet, U. Washington, with contributions by A. Wood, J. Adam, T. Bohn, and F. Su.

Constructing a VIC model

1. Define region or basin
2. Select VIC modeling resolution
   - Global typically 1/4°-1° (25 km – 100 km)
   - Regional (where meteorological observations are dense) 1/16°-1/4° (6 km – 25 km)
3. Build land surface parameterization files*
   - Elevation (grid cell mean and sub-grid bands)
   - Soil (large input file)
   - Vegetation/Land cover (library and parameter files)
4. Assemble driving meteorological data*
   - Station data
   - Gridded data
   - Sub-grid variability

**existing VIC setups are available globally and for some regions*

Running VIC in a nutshell



Slide courtesy of E. de Maria

Defining modeling domain: Basin

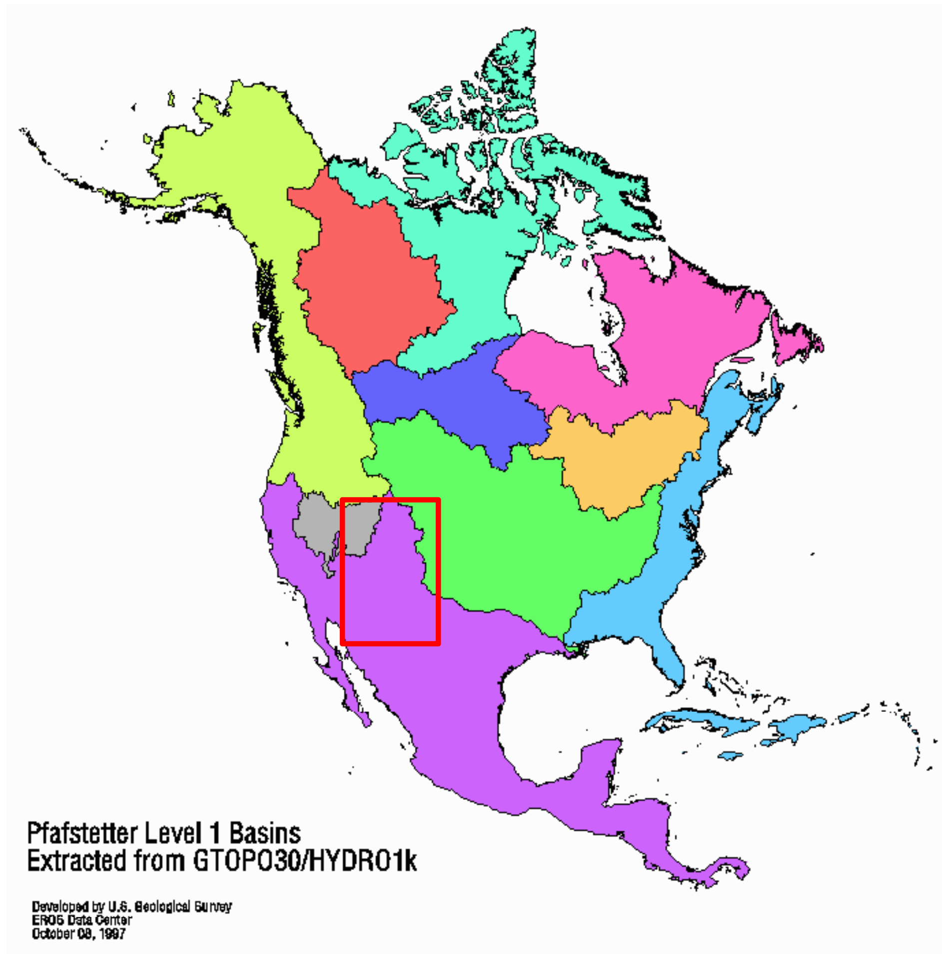
Select basin from existing data

or

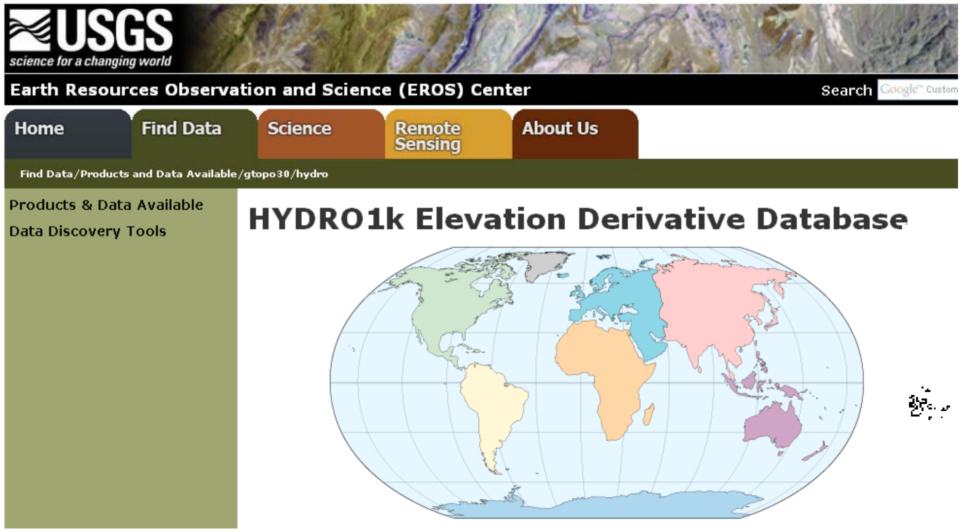
Define rectangle of interest

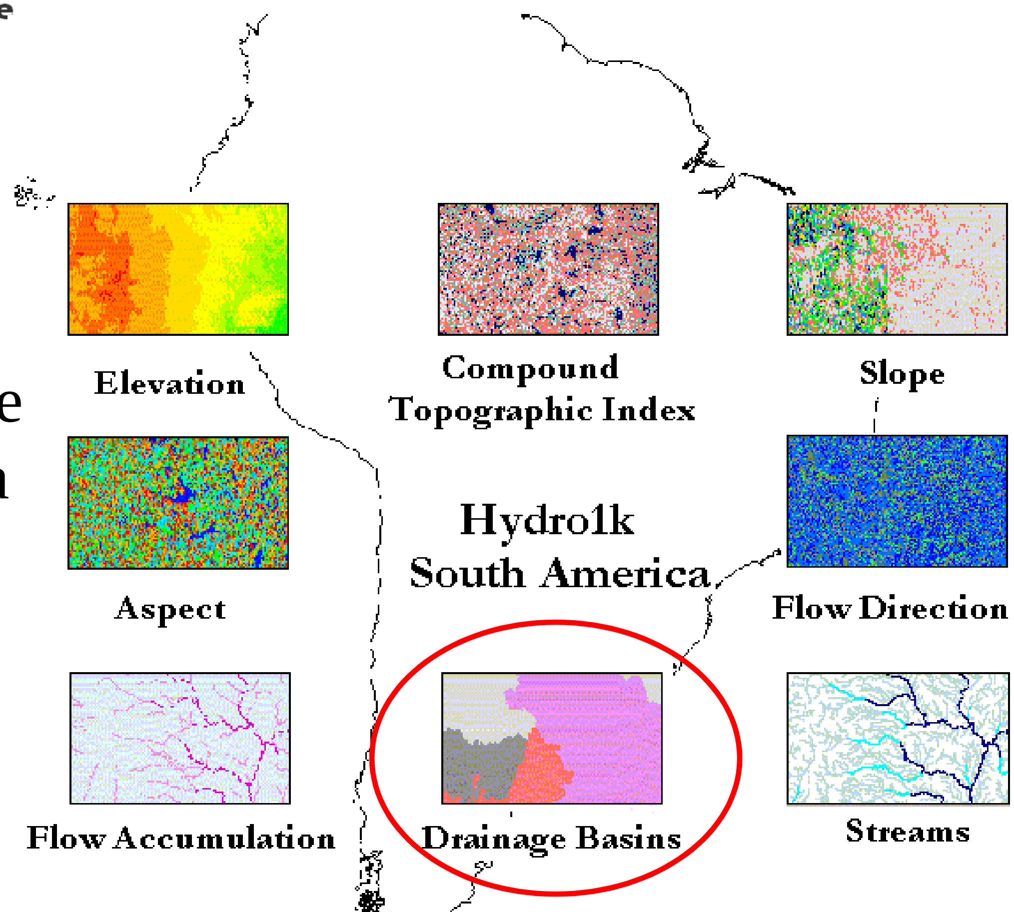
Select VIC modeling resolution

Note: VIC doesn't know about basin boundaries – you can model a larger area than needed, as long as it contains your basin



Pre-defined basin boundaries





Hydro1k is a popular data source derived from 1 km elevation data

Newer **HydroSheds** data set is based on finer scale elevation data

http://hydrosheds.cr.usgs.gov/

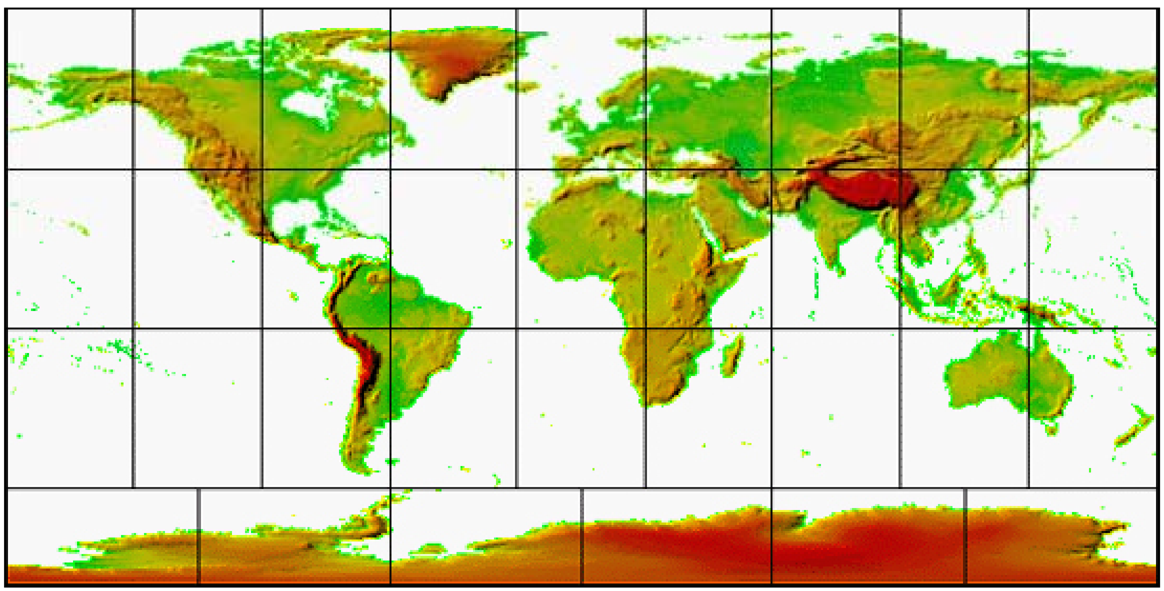
http://eros.usgs.gov/#/Find_Data/Products_and_Data_Available/gtopo30/hydro

Digital Elevation Models

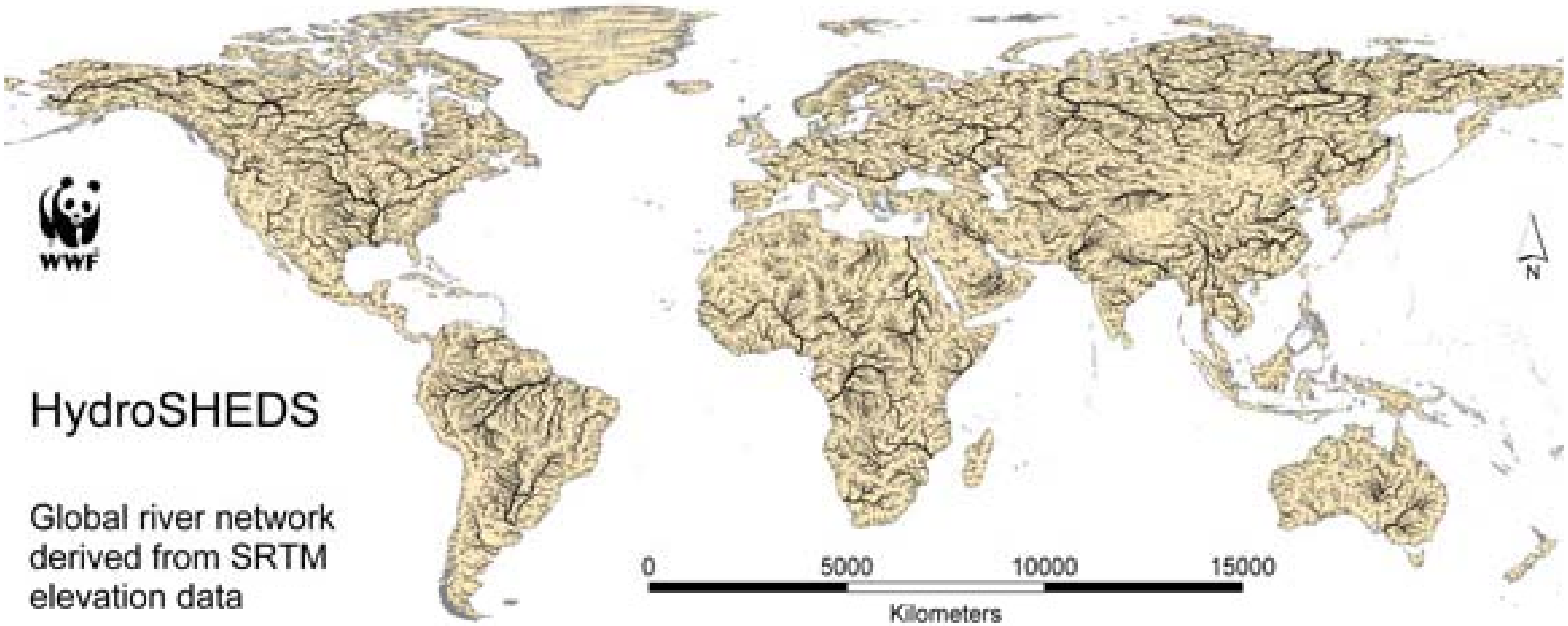
- Hydro1k: equal area projection, 1 km resolution
- Gtopo30 or SRTM30: geographic projection, 30 arc-seconds (~ 1 km)

http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html

http://topex.ucsd.edu/WWW_html/srtm30_plus.html



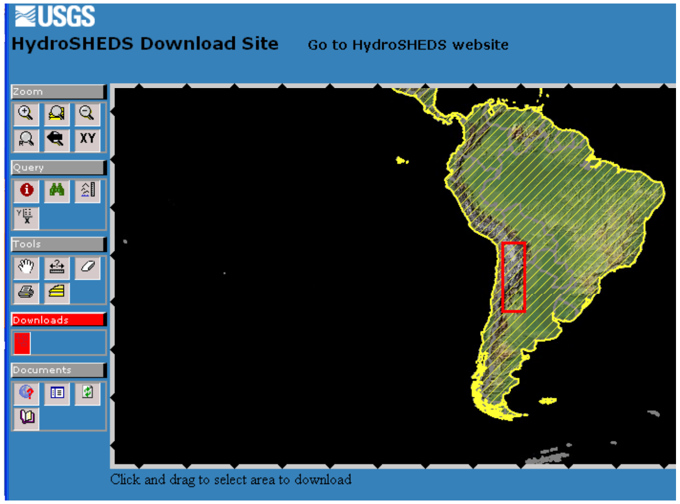
Newer, higher resolution elevation data

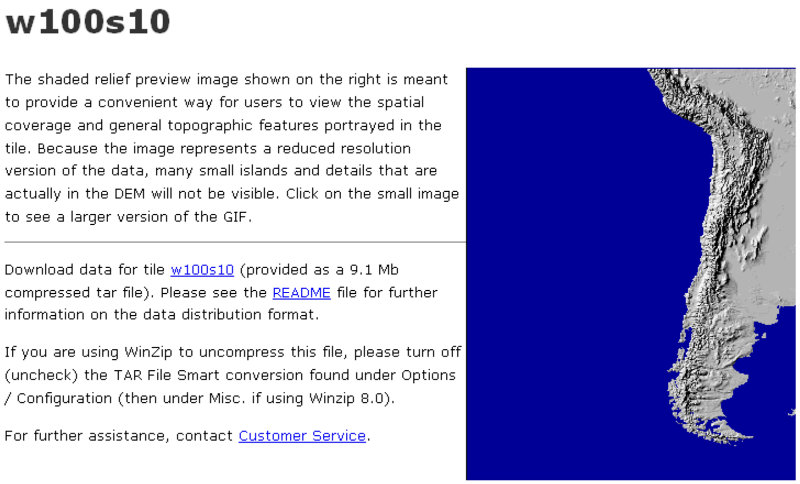


- Derived from elevation data of the Shuttle Radar Topography Mission (SRTM) at 3 arc-second resolution (~90m)
- Stream networks, watershed boundaries, flow direction and accumulation
- **http://hydrosheds.cr.usgs.gov**

Extract Elevation Information for Basin/Region

- Extract/clip elevation data to basin or region
- Project to geographic (if necessary)
- Aggregate it to the VIC modeling resolution
- Retain fine-scale elevation data for elevation band definition (sub-grid scale detail)





Elevation derivatives (available from Hydro1k and HydroSheds)

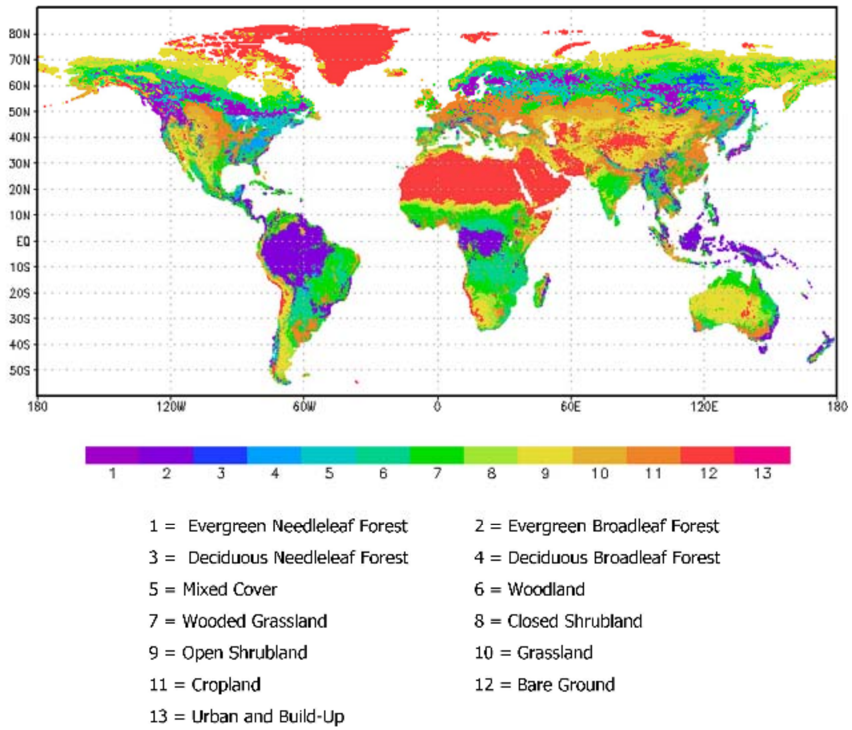
- From elevation data source, it may also be useful to download, for the identical domain:
  - Basin boundaries
  - Flow directions
  - Flow accumulations
  - Rivers
- While these can be derived from elevation using GIS, obtaining from the same source guarantees consistency
- These can also be used in later processing steps.

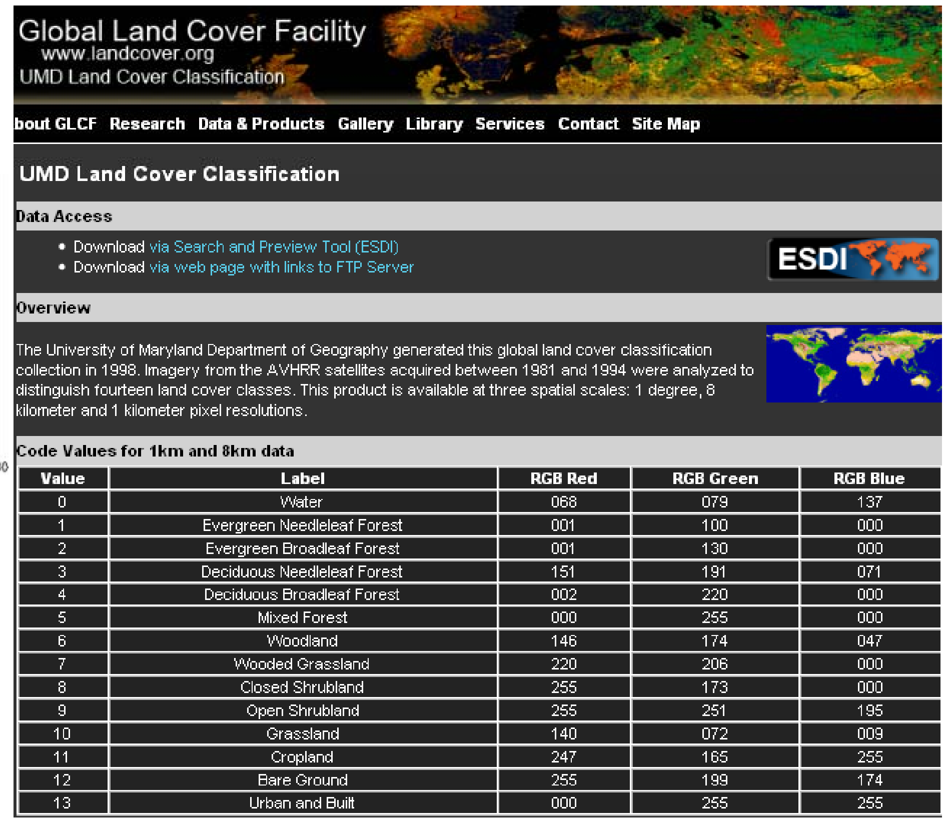
Describing Land Cover

- Two files describe this in VIC
  1. Vegetation library file: describes hydrologically important characteristics of different land cover types
  2. Vegetation parameter file: contains the spatial variability of land cover

Land Cover Classification

- U. Maryland AVHRR, 1 km global product
  - http://glcf.umiacs.umd.edu/data/landcover/





Global Land Cover Facility
www.landcover.org
UMD Land Cover Classification

bout GLCF Research Data & Products Gallery Library Services Contact Site Map

UMD Land Cover Classification

Data Access

- Download via Search and Preview Tool (ESDI)
- Download via web page with links to FTP Server

ESDI

Overview

The University of Maryland Department of Geography generated this global land cover classification collection in 1998. Imagery from the AVHRR satellites acquired between 1981 and 1994 were analyzed to distinguish fourteen land cover classes. This product is available at three spatial scales: 1 degree, 8 kilometer and 1 kilometer pixel resolutions.

Code Values for 1km and 8km data

Value	Label	RGB Red	RGB Green	RGB Blue
0	Water	068	079	137
1	Evergreen Needleleaf Forest	001	100	000
2	Evergreen Broadleaf Forest	001	130	000
3	Deciduous Needleleaf Forest	151	191	071
4	Deciduous Broadleaf Forest	002	220	000
5	Mixed Forest	000	255	000
6	Woodland	146	174	047
7	Wooded Grassland	220	206	000
8	Closed Shrubland	255	173	000
9	Open Shrubland	255	251	195
10	Grassland	140	072	009
11	Cropland	247	165	255
12	Bare Ground	255	199	174
13	Urban and Built	000	255	255

- IGBP global product
  - http://landcover.usgs.gov/globallandcover.php

Sources of land cover parameters

Literature

- Many potential sources
- Use functions to derive from NDVI

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SECHIBA, a New Set of Parameterizations of the Hydrologic Exchanges at the Land–Atmosphere Interface within the LMD Atmospheric General Circulation Model

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(Manuscript received 8 March 1991, in final form 3 March 1992)

TABLE 3. In SECHIBA, canopy parameters that are prescribed.

Canopy parameters	Tundra	Grassland	Grassland + shrub cover	Grassland + tree cover	Deciduous forest	Evergreen forest	Rain forest
Leaf area index (LAI)							
Summer	1	2	2.5	3.5	5	4	8
Winter	0	1.5	1	1.5	0	3	8
Architectural resistance (r_0; $s \cdot m^{-1}$)	10	2	2.5	3	40	50	25
k_0 ($kg\ m^{-2}\ s^{-1}$) (in calculation of canopy resistance)	5.0×10^{-5}	30.0×10^{-5}	25.0×10^{-5}	28.0×10^{-5}	25.0×10^{-5}	12.0×10^{-5}	24.0×10^{-5}

Assembled databases

- e.g., LDAS (http://ldas.gsfc.nasa.gov)
- Available in gridded format at 1/4° spatial resolution globally

http://ldas.gsfc.nasa.gov/nldas/web/web.veg.table.html

	Minimum Stomatal Resistance [sec m-1] (Average)
0. Water / Goode's Interrupted Space	175
1. Evergreen Needleleaf Forest	175
2. Evergreen Broadleaf Forest	150
3. Deciduous Needleleaf Forest	175
4. Deciduous Broadleaf Forest	175
5. Mixed Cover	175
6. Woodland	173.51
7. Wooded Grassland	169.15
8. Closed Shrubland	175
9. Open Shrubland	178.87
10. Grassland	165
11. Cropland	117.1085
12. Bare Ground	175
13. Urban and Built-Up	154.84

Vegetation-related parameters

	Vegetation type	Albedo	Rmin (sm^{-1})	LAI	Rough (m)	Displacement （m）
1	Evergreen needleleaf forest	0.12	250	3.4-4.4	1.476	8.04
2	Evergreen broadleaf forest	0.12	250	3.4-4.4	1.476	8.04
3	Deciduous needleleaf forest	0.18	150	1.52-5	1.23	6.7
4	Deciduous broadleaf forest	0.18	150	1.52-5	1.23	6.7
5	Mixed forest	0.18	200	1.52-5	1.23	6.7
6	Woodland	0.18	200	1.52-5	1.23	6.7
7	Wooded grasslands	0.19	125	2.2-3.85	0.495	1
8	Closed shrublands	0.19	135	2.2-3.85	0.495	1
9	Open shrublands	0.19	135	2.2-3.85	0.495	1
10	Grasslands	0.2	120	2.2-3.85	0.0738	0.402
11	Crop land (corn)	0.1	120	0.02-5	0.006	1.005

Index vegetation characteristics to classification.

Vegetation library file format

- One 58-column file used for all VIC model grid cells

VIC Vegetation Library File

Vegetation parameters needed for each vegetation type used in the VIC model are provided in a column format ASCII file as described in this document. Parameters are given for different vegetation types, and are referenced by the vegetation parameter file, which provides information about the number of vegetation types per grid cell, and their fractional coverage. A header may be added to the top of the file if the first column contains a '#'. Comments can also be added to the end of each line in the vegetation library file.

Vegetation Library File Format

Column	Variable Name	Units	Number of Values	Description
1	veg_class	N/A	1	Vegetation class identification number (reference index for library table)
2	overstory	N/A	1	Flag to indicate whether or not the current vegetation type has an overstory (TRUE for overstory present [*e.g.* trees], FALSE for overstory not present [*e.g.* grass])
3	rarc	s/m	1	Architectural resistance of vegetation type (~2 s/m)
4	rmin	s/m	1	Minimum stomatal resistance of vegetation type (~100 s/m)
5 : 16	LAI		12	Leaf-area index of vegetation type
17 : 28	albedo	fraction	12	Shortwave albedo for vegetation type
29 : 40	rough	m	12	Vegetation roughness length (typically 0.123 * vegetation height)
41 : 52	displacement	m	12	Vegetation displacement height (typically 0.67 * vegetation height)
53	wind_h	m	1	Height at which wind speed is measured. **If using snow interception routines please read the information page**
54	RGL	W/m^2	1	Minimum incoming shortwave radiation at which there will be transpiration. For trees this is about 30 W/m^2, for crops about 100 W/m^2.
55	rad_atten	fract	1	Radiation attenuation factor. Normally set to 0.5, though may need to be adjusted for high latitudes.
56	wind_atten	fract	1	Wind speed attenuation through the overstory. The default value has been 0.5.
57	trunk_ratio	fract	1	Ratio of total tree height that is trunk (no branches). The default value has been 0.2.
58	comment	N/A	1	Comment block for vegetation type. Model skips end of line so spaces are valid entrys.

Sample vegetation library file

relates land cover class to vegetation characteristics

```
#Class  OvrStry Rarc    Rmin    JAN-LAI FEB-LAI MAR-LAI APR-LAI MAY-LAI JUN-LAI JUL-LAI AUG-LAI SEP-LAI OCT-LAI NOV-LAI DEC-LAI JAN-ALB FEB_A
LB      MAR-ALB APR-ALB MAY-ALB JUN-ALB JUL-ALB AUG-ALB SEP-ALB OCT-ALB NOV-ALB DEC-ALB JAN-ROU FEB-ROU MAR-ROU APR-ROU MAY-ROU JUN-ROU JUL-R
OU      AUG-ROU SEP-ROU OCT-ROU NOV-ROU DEC-ROU JAN-DIS FEB-DIS MAR-DIS APR-DIS MAY-DIS JUN-DIS JUL-DIS AUG-DIS SEP-DIS OCT-DIS NOV-DIS DEC-D
IS      WIND_H  RGL     SolAtn  WndAtn  Trunk   COMMENT
#This file was obtained from Keith Cherkauer on Wed Jul 21 1999.  It was originally named LDAS_veg_lib
1       1       60.0    250.    3.400   3.400   3.500   3.700   4.000   4.400   4.400   4.300   4.200   3.700   3.500   3.400   0.12    0.12
        0.12    0.12    0.12    0.12    0.12    0.12    0.12    0.12    0.12    0.12    1.476   1.476   1.476   1.476   1.476   1.476   1.476
        1.476   1.476   1.476   1.476   1.476   8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04
        50.0    30      0.5     0.5     0.2     Evergreen Needleleaf
2       1       60.0    250.    3.400   3.400   3.500   3.700   4.000   4.400   4.400   4.300   4.200   3.700   3.500   3.400   0.12    0.12
        0.12    0.12    0.12    0.12    0.12    0.12    0.12    0.12    0.12    0.12    1.476   1.476   1.476   1.476   1.476   1.476   1.476
        1.476   1.476   1.476   1.476   1.476   8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04    8.04
        50.0    30      0.5     0.5     0.2     Evergreen Broadleaf
3       1       60.0    150.    1.680   1.520   1.680   2.900   4.900   5.000   5.000   4.600   3.440   3.040   2.160   2.000   0.18    0.18
        0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    1.230   1.230   1.230   1.230   1.230   1.230   1.230
        1.230   1.230   1.230   1.230   1.230   6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70
        50.0    30      0.5     0.5     0.2     Deciduous Needleleaf
4       1       60.0    150.    1.680   1.520   1.680   2.900   4.900   5.000   5.000   4.600   3.440   3.040   2.160   2.000   0.18    0.18
        0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    1.230   1.230   1.230   1.230   1.230   1.230   1.230
        1.230   1.230   1.230   1.230   1.230   6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70
        50.0    30      0.5     0.5     0.2     Deciduous Broadleaf
5       1       60.0    200.    1.680   1.520   1.680   2.900   4.900   5.000   5.000   4.600   3.440   3.040   2.160   2.000   0.18    0.18
        0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    1.230   1.230   1.230   1.230   1.230   1.230   1.230
        1.230   1.230   1.230   1.230   1.230   6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70
        50.0    50      0.5     0.5     0.2     Mixed Cover
6       1       60.0    200.    1.680   1.520   1.680   2.900   4.900   5.000   5.000   4.600   3.440   3.040   2.160   2.000   0.18    0.18
        0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    0.18    1.230   1.230   1.230   1.230   1.230   1.230   1.230
        1.230   1.230   1.230   1.230   1.230   6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70    6.70
        50.0    50      0.5     0.5     0.2     Woodland
7       0       40.0    125.    2.000   2.250   2.950   3.850   3.750   3.500   3.550   3.200   3.300   2.850   2.600   2.200   0.19    0.19
        0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.495   0.495   0.495   0.495   0.495   0.495   0.495
        0.495   0.495   0.495   0.495   0.495   1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00
        5       75.     0.5     0.5     0.2     Wooded Grasslands
8       0       50.0    135.    2.000   2.250   2.950   3.850   3.750   3.500   3.550   3.200   3.300   2.850   2.600   2.200   0.19    0.19
        0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.495   0.495   0.495   0.495   0.495   0.495   0.495
        0.495   0.495   0.495   0.495   0.495   1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00
        5       75.     0.5     0.5     0.2     Closed Shrublands
9       0       50.0    135.    2.000   2.250   2.950   3.850   3.750   3.500   3.550   3.200   3.300   2.850   2.600   2.200   0.19    0.19
        0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.19    0.495   0.495   0.495   0.495   0.495   0.495   0.495
        0.495   0.495   0.495   0.495   0.495   1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00    1.00
```

Vegetation parameter file

- One large file describing land cover contents of each grid cell
- Format described on VIC web site
- Can include "global LAI" information, describing monthly LAI for each vegetation type at each grid cell

VIC Vegetation Parameter File

Vegetation parameters needed for the different VIC model set-ups are listed below. Number of vegetation tiles

Vegetation Parameter File Format

Variable Name	*Units*	*Description*
gridcel	N/A	Grid cell number
Nveg	N/A	Number of vegetation tiles in the grid cell

Repeats for each vegetation tile in the grid cell:

Variable Name	*Units*	*Description*
veg_class	N/A	Vegetation class identification number (reference index to vegetation library) NOTE 1: It is common practice to define only one tile for each vegetation class in the grid cell. But this is not strictly necessary. It is OK to define multiple tiles having the same vegetation class. NOTE 2: As of VIC 4.1.1, if you are simulating lakes, you MUST designate one of the tiles from each grid cell as the tile that contains the lake(s). This designation happens in the lake parameter file. You can either choose an existing tile to host the lakes, or insert a new tile (just make sure that the sum of the tile areas in the grid cell = 1.0). This extra lake/wetland tile may have the same vegetation class as one of the other existing tiles (see NOTE 1). For advice on how to prepare your vegparam and lakeparam files, click here.
Cv	fraction	Fraction of grid cell covered by vegetation tile

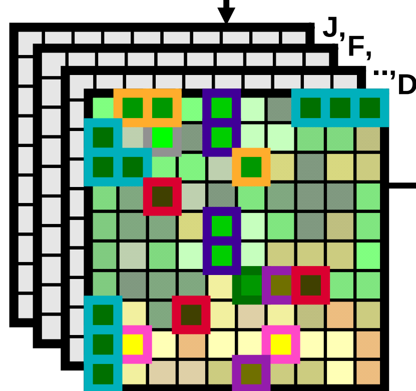
For each vegetation tile, repeats for each defined root zone:

Variable Name	*Units*	*Description*
root_depth	m	Root zone thickness (sum of depths is total depth of root penetration)
root_fract	fraction	Fraction of root in the current root zone.

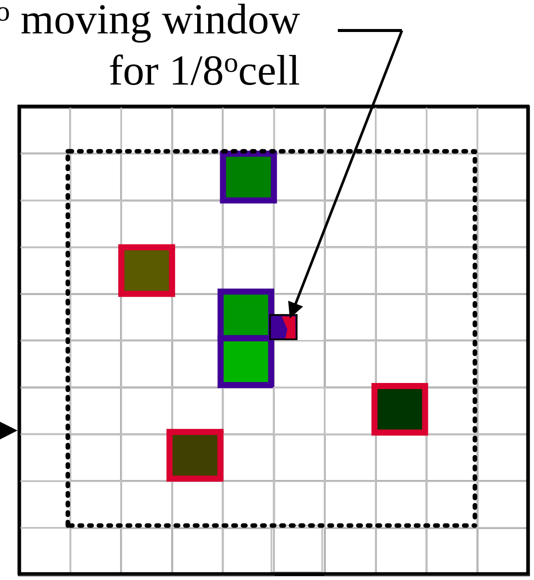
LAI Calculation

UMD 1km Land Classification provides basis for fractional land cover description

1/4º Monthly LAI for each cell with dominant (>80%) one type of land cover

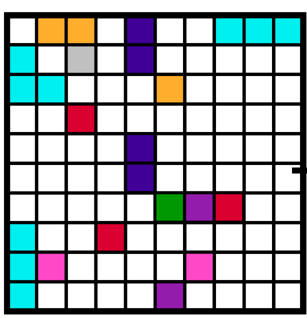


2º moving window for 1/8ºcell



Each land cover in each 1/8º cell based on average of dominant class LAI by month

1/4º monthly LAI database from Myneni, et al. Provides monthly LAIs



Sample lines from vegetation parameter file

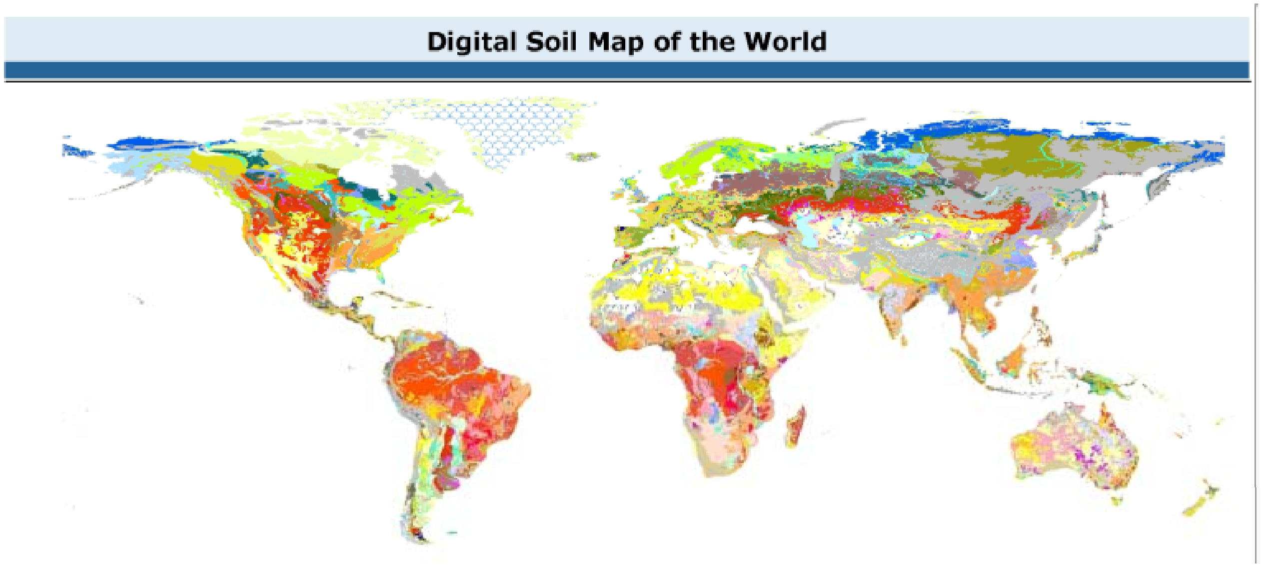
```
1    4
          5    0.459    0.100    0.050    1.000    0.450    5.000    0.500
      0.138    0.225    0.438    0.837    3.612    5.650    5.725    5.525    4.912    3.025    0.512    0.300
          6    0.317    0.100    0.100    1.000    0.650    1.000    0.250
      0.225    0.288    0.288    0.288    0.775    1.538    2.487    2.562    1.475    0.600    0.237    0.225
          7    0.082    0.100    0.100    1.000    0.650    1.000    0.250
      0.487    0.525    0.237    0.237    0.475    1.062    1.825    1.875    0.900    0.338    0.225    0.350
         11    0.123    0.100    0.100    0.750    0.600    0.500    0.300
      0.087    0.150    0.112    0.188    0.888    2.375    4.000    4.562    3.125    0.700    0.112    0.150

2    6
          1    0.036    0.100    0.050    1.000    0.450    5.000    0.500
      4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425
          3    0.070    0.100    0.050    1.000    0.450    5.000    0.500
      4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425
          5    0.386    0.100    0.050    1.000    0.450    5.000    0.500
      0.138    0.225    0.438    0.837    3.612    5.650    5.725    5.525    4.912    3.025    0.512    0.300
          6    0.286    0.100    0.100    1.000    0.650    1.000    0.250
      0.225    0.288    0.288    0.288    0.775    1.538    2.487    2.562    1.475    0.600    0.237    0.225
          7    0.131    0.100    0.100    1.000    0.650    1.000    0.250
      0.487    0.525    0.237    0.237    0.475    1.062    1.825    1.875    0.900    0.338    0.225    0.350
         11    0.066    0.100    0.100    0.750    0.600    0.500    0.300
      0.087    0.150    0.112    0.188    0.888    2.375    4.000    4.562    3.125    0.700    0.112    0.150

3    5
          1    0.011    0.100    0.050    1.000    0.450    5.000    0.500
      4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425    4.425
          5    0.660    0.100    0.050    1.000    0.450    5.000    0.500
      0.138    0.225    0.438    0.837    3.612    5.650    5.725    5.525    4.912    3.025    0.512    0.300
          6    0.212    0.100    0.100    1.000    0.650    1.000    0.250
      0.225    0.288    0.288    0.288    0.775    1.538    2.487    2.562    1.475    0.600    0.237    0.225
          7    0.041    0.100    0.100    1.000    0.650    1.000    0.250
      0.487    0.525    0.237    0.237    0.475    1.062    1.825    1.875    0.900    0.338    0.225    0.350
         11    0.046    0.100    0.100    0.750    0.600    0.500    0.300
      0.087    0.150    0.112    0.188    0.888    2.375    4.000    4.562    3.125    0.700    0.112    0.150
```

Soil Information

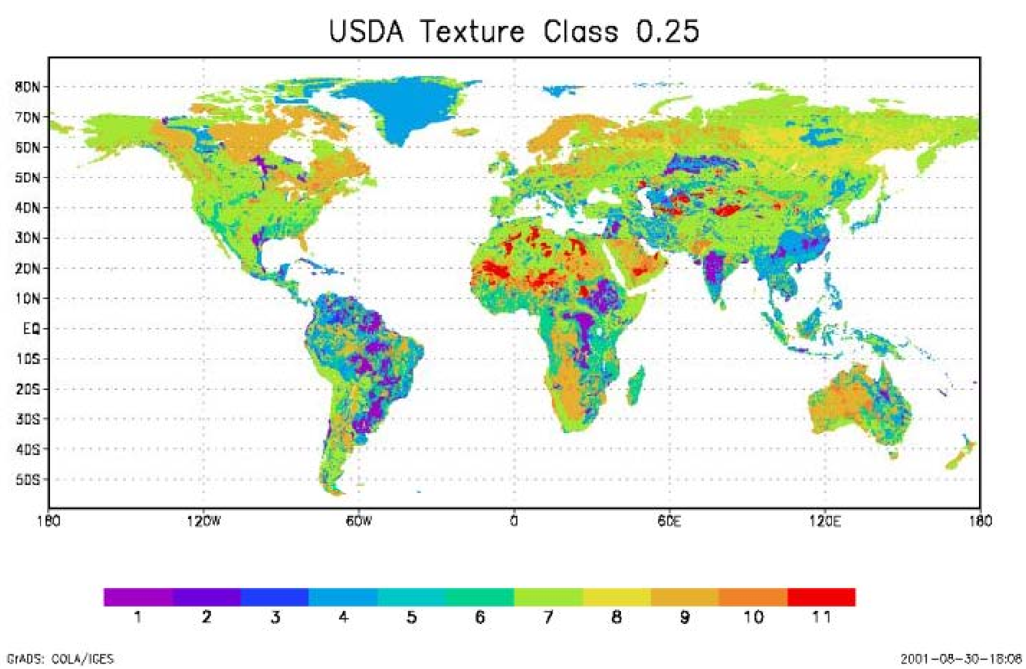
- UNESCO/FAO global soil maps
  - http://www.fao.org/geonetwork
  - Available as 5 arc-min grid (~8km resolution)



- IGBP-DIS data
  - http://daac.ornl.gov/SOILS/igbp.html
  - Includes derived data products

Using LDAS data

- As with vegetation data, LDAS has pre-processed soil data for the US and globally
- http://ldas.gsfc.nasa.gov/gldas/GLDASsoils.php



Translating soil composition/texture to hydraulic properties

SAMPLE INDEX OF SOIL HYDRAULIC PROPERTIES*

USDA Class	Soil Type	% Sand	% Clay	Bulk Density g/cm^3	Field Capacity cm^3/cm^3	Wilting Point cm^3/cm^3	Porosity fraction	Saturated Hydraulic Conductivity cm/hr	Slope of Retention Curve (in log space) b**
1	s	94.83	2.27	1.49	0.08	0.03	0.43	38.41	4.1
2	ls	85.23	6.53	1.52	0.15	0.06	0.42	10.87	3.99
3	sl	69.28	12.48	1.57	0.21	0.09	0.4	5.24	4.84
4	sil	19.28	17.11	1.42	0.32	0.12	0.46	3.96	3.79
5	si	4.5	8.3	1.28	0.28	0.08	0.52	8.59	3.05
6	l	41	20.69	1.49	0.29	0.14	0.43	1.97	5.3
7	scl	60.97	26.33	1.6	0.27	0.17	0.39	2.4	8.66
8	sicl	9.04	33.05	1.38	0.36	0.21	0.48	4.57	7.48
9	cl	30.08	33.46	1.43	0.34	0.21	0.46	1.77	8.02
10	sc	50.32	39.3	1.57	0.31	0.23	0.41	1.19	13
11	sic	8.18	44.58	1.35	0.37	0.25	0.49	2.95	9.76
12	c	24.71	52.46	1.39	0.36	0.27	0.47	3.18	12.28

* Source is "Average hydraulic properties of ARS soil texture classes," draft dated February, 2000 by J. Schaake. This expanded the work of others and included a total of 2128 soil samples. Wilting point is the fractional water content at 15 bar tension; field capacity is the fractional water content at 1/3 bar tension.

**b is as used in Campbell's equation. ref: Cosby et al., A Statistical exploration of the relationships of soil moisture characteristics to the physical properties of soils, *Water Resources Research* 20(6): 682-690, 1984.

Constructing the soil file

- This is the principal input file:
  - connects cell location to cell number
  - defines which cells to run
- Number of columns depends on number of soil layers.
- For 3 soil layers, 53 or 54 columns is typical.
- Some columns only used in energy balance mode, may contain any arbitrary value if not used
- Main calibration parameters are in this file
- One approach outlined at http://www.hydro.washington.edu/~nathalie/VIC_FILES/VIC_SoilVeg_processing.html

VIC Soil Parameter File

Soil hydrologic and thermal parameters needed for the different VIC model set-ups are listed below. All columns of the input file must be filled, but ce be defined if the full energy or frozen soil models are activated. Red text indicates parameters needed for the energy balance model. Violet text indic the frozen soil model. Header lines can be added by starting the line with a '#'.

In previous versions certain parameters were read as average values for the entire soil column. In version 4.0 all soil parameter values are now read the soil parameter file from older model versions, should simply require copying column average values to separate columns for each soil moisture la

To help in understanding this file, an example file has been attached at the bottom of this page.

Column	Variable Name	Units	Number of Values	Description
1	run_cell	N/A	1	1 = Run Grid Cell, 0 = Do Not Run
2	gridcel	N/A	1	Grid cell number
3	lat	degrees	1	Latitude of grid cell
4	lon	degrees	1	Longitude of grid cell
5	infilt	N/A	1	Variable infiltration curve parameter (b_{infilt})
6	Ds	fraction	1	Fraction of Dsmax where non-linear baseflow begins
7	Dsmax	mm/day	1	Maximum velocity of baseflow
8	Ws	fraction	1	Fraction of maximum soil moisture where non-linear baseflow occurs
9	c	N/A	1	Exponent used in baseflow curve, normally set to 2
10 : (Nlayer+9)	expt	N/A	Nlayer	Exponent *n* (=3+2/lambda) in Campbell's eqn for hydraulic conductivity, HBH 5.6 (where *lambda* = soil pore size distribution parameter). Values should be > 3.0.
(Nlayer+10) :(2*Nlayer+9)	Ksat	mm/day	Nlayer	Saturated hydrologic conductivity
(2*Nlayer+10): (3*Nlayer+9)	phi_s	mm/mm	Nlayer	Soil moisture diffusion parameter

Sample Soil File

- 1 column per parameter, 1 row per grid cell

1	1	53.4185	123.9790	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	2	53.2428	121.5170	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	3	53.1700	123.3350	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	4	52.9184	125.1020	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	5	52.8867	120.5130	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	6	52.7300	122.2750	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	7	52.5250	124.0500	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	8	52.3050	125.8000	0.100	0.050	10.000	0.800	2.000	13.500	13.500	13.500	292.0
1	9	52.2850	121.2350	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	10	52.0900	123.0000	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	11	51.8750	124.7550	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	12	51.7862	120.3740	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	13	51.6500	126.4170	0.100	0.050	10.000	0.800	2.000	13.500	13.500	13.500	292.0
1	14	51.6500	121.9650	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	15	51.4450	123.7100	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	16	51.2250	125.4450	0.100	0.050	10.000	0.800	2.000	13.500	13.500	13.500	292.0
1	17	51.1950	120.9450	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	18	51.0050	122.6800	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	19	51.0050	126.9610	0.100	0.050	10.000	0.800	2.000	19.340	19.340	19.340	211.6
1	20	50.7950	124.4050	0.100	0.050	10.000	0.800	2.000	13.500	13.500	13.500	292.0
1	21	50.7298	119.9400	0.100	0.050	10.000	0.800	2.000	13.500	13.500	13.500	292.0
1	22	50.5700	126.1200	0.100	0.050	10.000	0.800	2.000	19.340	19.340	19.340	211.6
1	23	50.5600	121.6650	0.100	0.050	10.000	0.800	2.000	13.660	13.660	13.660	242.7
1	24	50.3600	123.3800	0.100	0.050	10.000	0.800	2.000	13.500	13.500	13.500	292.0
1	25	50.1921	127.4370	0.100	0.050	10.000	0.800	2.000	13.500	13.500	13.500	292.0
1	26	50.2341	119.3390	0.100	0.050	10.000	0.800	2.000	19.340	19.340	19.340	211.6
1	27	50.1400	[illegible]	0.100	0.050	10.000	0.800	2.000	19.340	19.340	19.340	211.6

Meteorological Data

- Individual meteorological data file for each grid cell
- Obtained by:
  - Interpolating observed data onto VIC grid
  - Using existing gridded data sources
  - Combining existing gridded data with additional information from observations

Meteorological input is flexible

VIC Meteorological Forcings File

Forcing Data Files

The user must give VIC all of the relevant details necessary to read the forcing files (e.g., file type - ascii or binary, file "endian-ness", which variables are in the file and in what order, the units of the variables, and start date of the file). This must be done by inserting this information into the forcings section of the global parameter file.

VIC needs the following meteorological variables, at the model timestep, to run: precipitation, air temperature, wind speed, atmospheric pressure and density, vapor pressure (or vapor pressure deficit or relative humidity or specific humidity), incoming shortwave (solar) radiation, and incoming longwave (or thermal) radiation. However, VIC can estimate some of these quantities internally, so that the user need not supply all of them.

The minimum set of variables that VIC requires the user to supply are: daily total precipitation (rain and/or snow), daily max and min temperature, and daily average wind speed. In this case, VIC uses the MTCLIM algorithms (Kimball et al., 1997; Thornton and Running, 1999) to convert daily min and max temperature to humidity and incoming shortwave radiation. VIC then uses the Tennesee Valley Authority algorithm (Bras, 1990) to deduce incoming longwave radiation from humidity and temperature. VIC also computes atmospheric pressure and density from grid cell elevation and global mean pressure lapse rate. Finally, VIC converts these daily quantities into sub-daily by:

1. making some assumptions about what time of day the min and max air temperatures occur
2. interpolating the time series of min and max air temperature with a spline
3. distributing the shortwave (solar) radiation throughout the day according to solar zenith angle
4. assuming vapor pressure, atmospheric pressure and density, and wind speed are constant throughout the day
5. computing sub-daily longwave from sub-daily temperature and constant vapor pressure
6. computing sub-daily vapor pressure deficit as sub-daily saturation pressure (at sub-daily air temperature) - sub-daily (constant) vapor pressure
7. dividing daily total precipitation into equal sub-daily amounts

VIC also accepts more than these minimum 4 variables. If the user wishes to supply more than the minimum set of variables, for example sub-daily {precip, air temp, pressure, humidity, wind speed, and sw/lw radiation} terms from a reanalysis product, or sub-daily observations from a meteorological station, this is also OK. In fact, most combinations of variables are acceptable, as long as the user supplies VIC with at least the minimum 4 variables mentioned above. For example, the user could supply daily {precip, tmin, tmax, wind} in one forcing file and sub-daily sw and lw radiation in another file (i.e. the two files need not have the same time step - as long as the sub-daily file is at the same timestep as the model timestep).

In all cases, the user must list the variables contained in the forcing files, by their names (listed below) and in the exact order in which they appear in the forcing files. This is done in the global parameter file using the FORCE_TYPE parameter. Possible forcing file data types and units are:

Variable Name	Definition	Default Units	ALMA units
AIR_TEMP	sub-daily air temperature	deg C	K
ALBEDO	surface albedo	fraction	fraction
CRAINF	convective rainfall	mm per step	mm/s == kg/m^2/s
CSNOWF	convective snowfall	mm per step	mm/s == kg/m^2/s
DENSITY	atmospheric density	kg/m^3	kg/m^3
LONGWAVE	incoming longwave (thermal infrared) radiation	W/m^2	W/m^2
LSRAINF	large-scale rainfall	mm per step	mm/s == kg/m^2/s
LSSNOWF	large-scale snowfall	mm per step	mm/s == kg/m^2/s
PREC	total precipitation	mm per step	mm/s == kg/m^2/s
PRESSURE	atmospheric pressure	kPa	Pa
QAIR	specific humidity	kg/kg	kg/kg
RAINF	total rainfall	mm per step	mm/s == kg/m^2/s
REL_HUMID	relative humidity	fraction	fraction
SHORTWAVE	incoming shortwave (solar) radiation	W/m^2	W/m^2
SNOWF	total snowfall	mm per step	mm/s == kg/m^2/s
TMAX	daily maximum temperature	deg C	K
TMIN	daily minimum temperature	deg C	K
TSKC	cloud cover	fraction	fraction
VP	atmospheric vapor pressure	kPa	Pa
WIND	wind speed	m/s	m/s
WIND_E	East component of wind speed	m/s	m/s

Daily VIC Model Forcing Data - Typical

Forcing Data based on observations:

- **Precipitation (mm)**
- **Daily maximum temperature (°C)**
- **Daily minimum temperature (°C)**
- **Wind speed (m/s) (from reanalysis)**

Other (less well observed variables) estimated using parameterizations (Kimball et al., 1997, Thornton and Running, 1999):

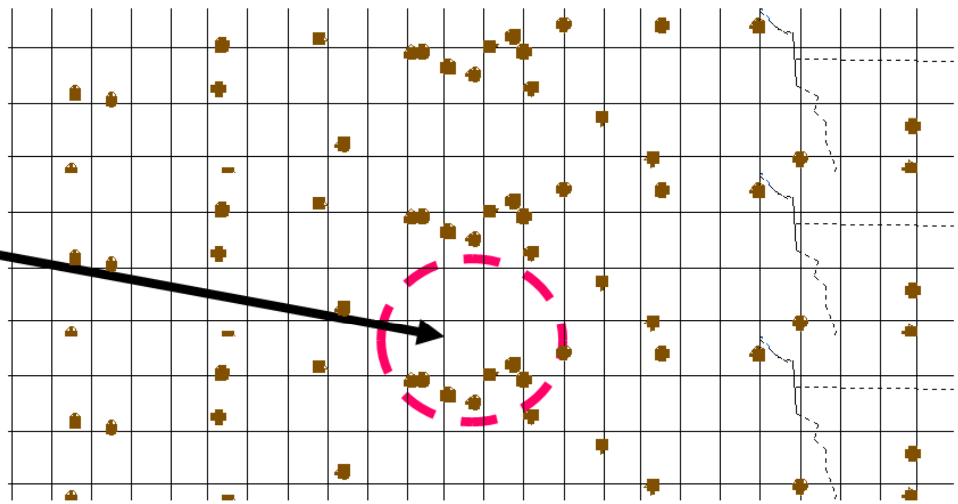
Humidity (Vapor Pressure): uses **MTCLIM - T_{dew} estimated from T_{min} (with aridity index based on P_{annual} and R_{solar})**

Downward Solar Radiation: transmissivity estimated from T_{dew}, $T_{max} - T_{min}$

Downward Longwave Radiation: estimated from $T_{average}$, humidity, atm. transmissivity

Interpolating Temperature and Precipitation Data

Precipitation and Temperature from gauge observations gridded to 1/8°



Avg. Station density:

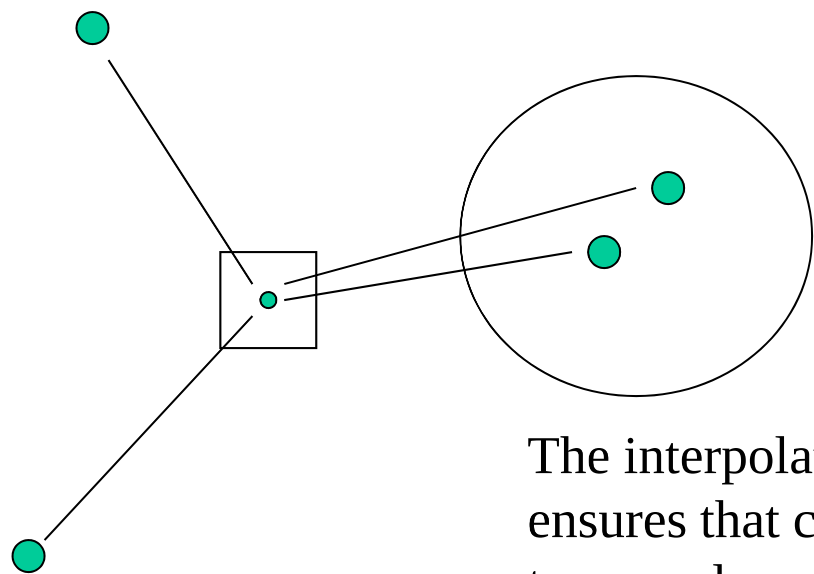
Area	Km²/station
U.S.	700-1000
Canada	2500
Mexico	6000

Within the U.S.:

- Precipitation adjusted for time-of-observation
- Precipitation re-scaled to match PRISM mean for 1961-90

Regridding Details

Symap regridding algorithm accounts for station proximity via an inverse square weighting, but also accounts for the independence of the stations from one another.



The interpolation scheme ensures that collectively these two nearly coincident stations are assigned about the same weight as each of the other two stations.

Tools for gridding observations

Gridding Meteorological Data from the National Climatic Data Center

This document provides a brief explanation of the methodology involved in developing a gridded meteorological data set (daily precipitation, maximum and minimum temperatures, and daily average wind speed) for the hydrology VIC model using data over the U.S. The process includes two general steps, based on two data sources: 1) taking raw data from the EarthInfo National Climate Data Center (NCDC) CDs and converting them into VIC input files, and 2) appending more recent data downloaded from the NCDC On-Line Web Site. The core of the gridding process is the interpolation routine called SYMAP (Shepard, D.S., Computer Mapping: the SYMAP Interpolation Algorithm, In: *Spatial Statistics and Models*, Gaile and Willmott, eds., 1984). For precipitation, all the interpolated data are scaled to match long-term monthly means from the PRISM monthly precipitation dataset. For 10 meter daily wind data, gridded data are obtained from the NCEP/NCAR Reanalysis, and linearly interpolated to the VIC grid resolution.

The preprocessing steps are performed using Unix shell scripts and programs written both in C and in Fortran. A basic knowledge of Unix, C and Fortran is presumed, although the programs should not require alteration.

The source code of the programs used, and documentation (in MS Word and PDF format) descriping in detail the necessary steps to build a VIC meteorological input dataset, is downloadable from this website.

Download the file GRID_2000.TAR.gz, also available on the download page under the section "Programs for gridding meteorological data from the National Climatic Data Center". This file contains all the necessary source code and documentation for gridding meteorological data.

The main program involved in gridding the met data is called "regrid". As of 1/10/2001, the regrid program has been revised. The new version, included in GRID_2000.TAR.gz, can be compiled on FreeBSD machines. The previous version used dynamic memory allocation, but could only be compiled and run on HP-UX systems.

The file GRID_2000.TAR.gz is compressed together with TAR and gzip.

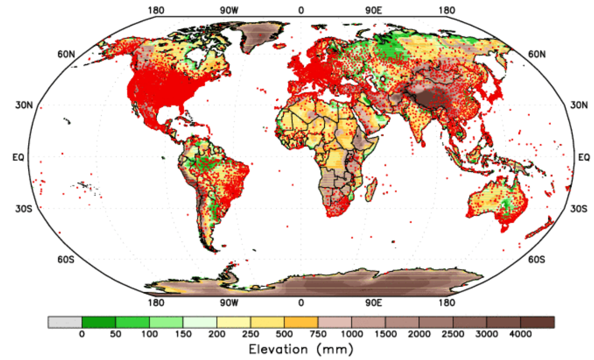
To uncompress use: gzip -d GRID_2000.TAR.gz

To extract the files use: tar -xfv GRID_2000.TAR

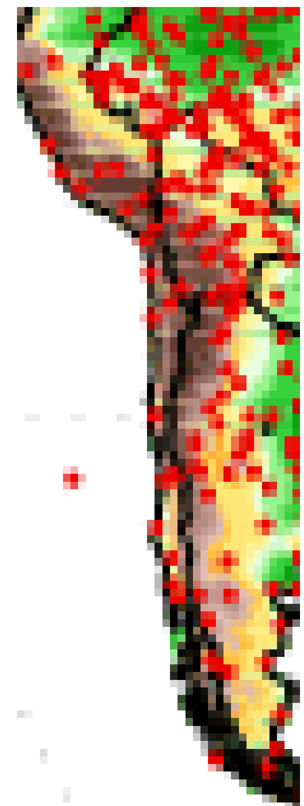
There is also daily meteorological data for Canada on CDs available from Environment Canada, entitled "Canada Daily Climate Data." Programs to process the downloaded data are stored in the file CANADA_MET.TAR.gz, also available on the download page under the section "Programs for gridding meteorologicaldata from the National Climatic Data Center". This includes a README file describing the steps to downloading and processing the data for input to VIC.

The University of Washington takes no responsibility for any damage or errors that these programs contain or may produce.

Global meteorology



Densities lower for much of globe
Daily records from ~17,000 stations, but important areas lack coverage
Gridded data relies on a variety of sources



CPC/NCEP/NOAA

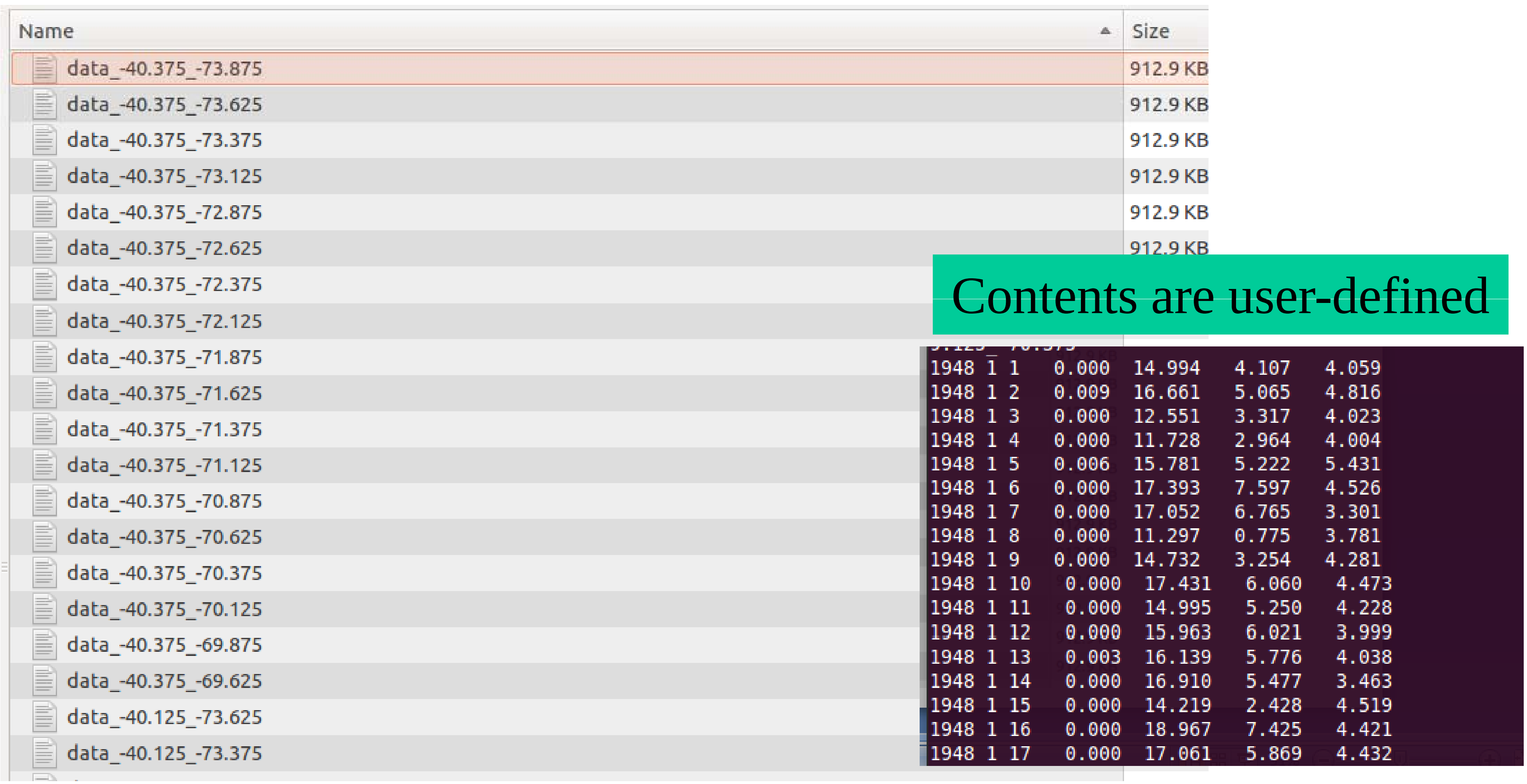
Table 2. Data sources to create the 1/2-degree gridded global meteorological data for 1950 through 1999.

Description	Reference	Variable	Time Step	Period of Use	Application
University of Delaware Climate Data	Willmott and Matsuura (2001)	Precipitation	Monthly Time Series	1950–1999	To create monthly precipitation variability
East Anglia Climatic Research Unit Climate Data	New et al. (2000) and Mitchell et al. (2004)	Tmax and Tmin	Monthly Time Series	1950–1999	To create monthly temperature variability
University of Washington Gauge Catch Corrections	Adam and Lettenmaier (2003)	Precipitation	Monthly Climatology	1950–1999	To apply to the monthly precipitation time series to correct for systematic bias
Princeton University corrections to NCEP/NCAR reanalysis	Sheffield et al. (2006)	Precipitation, Tmax, Tmin	Daily Time Series	1950–1995	To create daily variability by rescaling these data to match the monthly variability of the above time series
University of Washington stochastically-generated climate data	Nijssen et al. (2001a)	Precipitation, Tmax, Tmin	Daily Time Series	1996–1999	To create daily variability by rescaling these data to match the monthly variability of the above time series
NCEP/NCAR reanalysis data	Kalnay et al. (1996)	Windspeed	Daily Time Series	1950–1999	To create daily variability for wind speed

Maurer et al., 2009

Final meteorological files

Each grid cell has its own met data file.
File name must be of format **<filename_prefix>_<lat>_<lon>**



Sub-grid topography: elevation (snow) bands

Especially important in snow-dominated areas

VIC Elevation Band Parameter File

This file contains information needed to define the properties of each elevation band used by the snow model. Snow elevation bands are used to improve the model's performance in areas with pronounced topography, especially mountainous regions, where the effects of elevation on snow pack accumulation and ablation might be lost in a large grid cell.

The number of snow elevation bands (*option.SNOW_BAND*) to be used with the model is defined in the global parameter file. The elevation band (or snow band) file is only read if the number of snow elevation bands is greater than 1.

It is not necessary that all grid cells in a basin have the same number of elevation bands. *SNOW_BAND* is simply the maximum number of elevation bands anywhere in the basin. For relatively flat grid cells, some of the elevation bands will have *AreaFract* values of 0. For these zero-area bands, a value of 0 may be supplied for *elevation* and *Pfactor*.

Elevation Band File Format

Column	Variable Name	Units	Number of Values	Description
1	cellnum	N/A	1	Grid cell number (should match numbers assigned in soil parameter file)
2 : (SNOW_BAND+1)	AreaFract	fraction	SNOW_BAND	Fraction of grid cell covered by each elevation band. Sum of the fractions must equal 1.
(SNOW_BAND+2) : (2*SNOW_BAND+1)	elevation	m	SNOW_BAND	Mean (or median) elevation of elevation band. This is used to compute the change in air temperature from the grid cell mean elevation.
(2*SNOW_BAND+2) : (3*SNOW_BAND+1)	Pfactor	fraction	SNOW_BAND	Fraction of cell precipitation that falls on each elevation band. Total must equal 1. To ignore effects of elevation on precipitation, set these fractions equal to the area fractions.

Next Steps to run VIC

1. Prepare VIC Global Control File
   - Identifies soil, vegetation, meteorology files
   - Gives location for output files
   - Sets modes for VIC operation
   - Supplies global parameter values
   - Supplies meteorological input file format
   - Selects variables to output
2. Run VIC
3. Route runoff and baseflow to a stream point
4. Compare to observed streamflow and calibrate VIC

Soil parameters that are typically adjusted during calibration

1. **Infiltration parameter (bi)**
2. **The lower two soil layer thicknesses (z_2, z_3)**
3. **Three baseflow parameters:**
   - **Maximum velocity of baseflow (Dsmax):**
   - **The fraction of maximum baseflow (Ds),**
   - **The fraction of maximum soil moisture content of the third layer (Ws) at which a nonlinear baseflow response is initiated.**

Other parameters that can be included in calibration

- T max for snow
- T min for rain
- Precipitation scaling
- Orographic effects