CaMa-Flood

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CaMa-Flood

Catchment-based Macro-scale Floodplain model,

a global river routing model for continental-scale rivers

- explicit representation of the floodplain
- computationally highly efficient

`https://github.com/global-hydrodynamics/CaMa-Flood_v4`

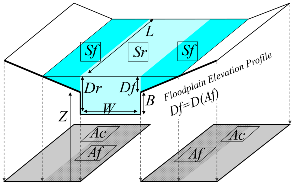
Yamazaki, D, et al, (2011), *A physically based description of floodplain inundation dynamics in a global river routing model,* Water resources Research, Volume **47,** Issue 4, `https://doi.org/10.1029/2010WR009726`

CaMa-Flood

- global river routing requires coarse resolutions due to expensive computations
- on the other hand, statements about flood areas and flood depths require a finely resolved orography
- CaMa-Flood approach: run hydrology on a coarse grid, which implicitely encodes features of a more highly resolved topographic map

Model

- terminology: a grid cell is a cell on the coarser grid
- each grid cell has a river channel reservoir (pale blue) and a floodplain reservoir (more intense blue)
- the *unit catchment* is an irregular area on the highly resolved topographic map whose runoff flows into the grid cells river channel (see figure (b) on slide 6)



parameters:

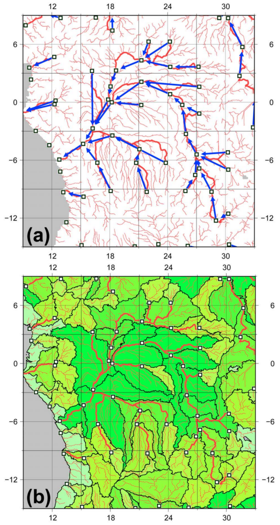
L	channel length	X	distance to downstream cell
W	channel width	A_c	unit catchment area
B	bank height	n	Manning's roughness coefficient**
Z	surface altitude (of outlet pixel*)		

* terminology: a pixel is a point on the high resolution DEM

** in the river channel n is always $0.03\,\mathrm{m}^{-1/3}/\mathrm{s}$, while the floodplain value is always $0.10\,\mathrm{m}^{-1/3}/\mathrm{s}$

Derivation of parameters I

1. determine outlet pixel on DEM, e.g. by FLOW, for each grid cell (little white squares) Yamazaki, D., et al, (2009), *Deriving a global river network map and its sub-grid topographic characteristics from a fine-resolution direction map* Hydrol. Earth Syst. Sci., **13**, 2241–2251, `https://doi.org/10.5194/hess-13-2241-2009`
2. create a river network by connecting the grid cells, e.g. by FLOW method (blue arrows)
3. determine elevation Z for each grid cell by determining elevation of outlet pixel
4. determine channel length L in each grid cell (length of red “lines” in (b))



Derivation of parameters II

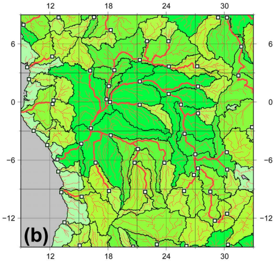
5. determine unit catchment area A_c for each outlet pixel, catchments are delineated by black lines in (b)

   By adapting "gird-vector hybrid river network map" which corresponds one irregular-shaped unit-catchment to one rectangular grid-box, both realistic parameterization of sub-grid topography and easy data handling are achieved. (documentation v4.0.0)

   - river flow simulation is done on the basis of these unit catchments instead of the traditional rectangular grid cells (optionally, it is possible to use traditional rectangular grids)
   - each unit catchment receives input water mass from the input grid cells which overlap the unit catchment. The input water mass F_i into the grid cell i is calculated by

$$F_i = \sum_N A_{i,j} R_j$$

$A_{i,j}$: area overlap between the unit catchment of grid cell i and runoff grid cell j, R_j: runoff forcing from grid cell j



Derivation of parameters III

6. CaMa-Flood provides maps for the channel height B and width W. They are estimated from observed runoff/discharges.

   - R_{up} is the maximum of the 30-day-moving window of the upstream runoff, Q_{ave} is the annual average discharge

     $$\begin{aligned} W &= \max\left(0.70 \times R_{\text{up}}^{0.75}, 10.0\right) \quad \text{v.3.6.2} \\ B &= \max\left(0.14 \times R_{\text{up}}^{0.40}, 2.0\right) \quad \text{v.3.6.2} \\ W &= \max\left(W_{\text{min}}, c_{\text{w}} Q_{\text{ave}}^{p_{\text{W}}} + W_0\right) \quad \text{v.4.0.0} \\ B &= \max\left(B_{\text{min}}, c_{\text{b}} Q_{\text{ave}}^{p_{\text{B}}} + B_0\right) \quad \text{v.4.0.0} \end{aligned}$$

     (the v.4.0.0 parameters $W_{\text{min}}, c_{\text{W}}, \ldots$ are predefined)

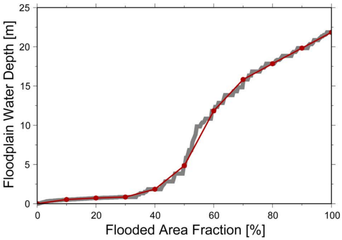
   - this is rather in flux, for three CaMa-Flood versions I found three sets of formulas
   - CaMa-Flood also offers channel widths based on satellite data
   - *"... note that the uncertainty in these cross-section parameters is still very high, so extensive calibration is recommended when you set up a new simulation."*

     (documentation v4.0.0)

Derivation of parameters IV

7.

- for each unit catchment, determine the cell's floodplain elevation profile *D*(*A*), i.e. which water depth results from a certain share of the grid cell covered in water, from the DEM (gray line in the plot on the right)
- simplified to be increasing, there are no local depressions; this is also necessary to make the system of equations involved solvable



- to reduce computational load every tenth percentile ($0.1A_c$, $0.2A_c$, … is flooded) is determined and then linearly connected (red line in the plot on the right)

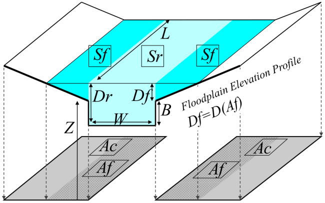
All these parameters are calculated before the run.

Hydrology I

$$S_i^{t+\Delta t} = S_i^t + \sum_k^{\text{upstream}} Q_k^t \,\Delta t - Q_i^t \,\Delta t + A_{c_i} F_i^t \,\Delta t$$

S_i, the water storage in the channel in grid cell i, is the only prognostic variable. Its change is determined by

- the unit catchment i's runoff F_i
- the discharge in the channel Q_i (outflow)
- the discharge in the upstream channels Q_k (inflow)



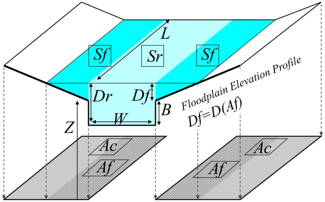
Optionally, the floodplain water can be routed downstream, too ($Q = B\,W\,v$, where v is the water's velocity in the channel).

Hydrology II

All other variables can be obtained from S, the parameters and $D(A)$.

$S \leq B\,W\,L$ (there is no flood)

$$
\begin{aligned}
S_r &= S \\
D_r &= \frac{S_r}{W\,L} \\
S_f &= 0 \\
D_f &= 0 \\
A_f &= 0
\end{aligned}
$$

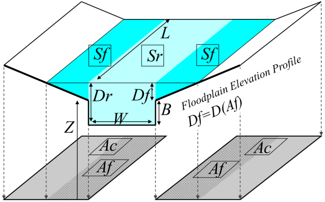


Hydrology III

All other variables can be obtained from S, the parameters and $D(A)$.

$S > B\,W\,L$ (there is a flood)

$$
\begin{aligned}
S_r &= S - S_f \\
D_r &= \frac{S_r}{W\,L} \\
S_f &= \int_0^{A_f} (D_f - D(A))\,\mathrm{d}A \\
D_f &= D_r - B \\
A_f &= D^{-1}(D_f)
\end{aligned}
$$



Postprocessing

- CaMa-Flood can downscale the flood depths to the higher resolutions of the DEM