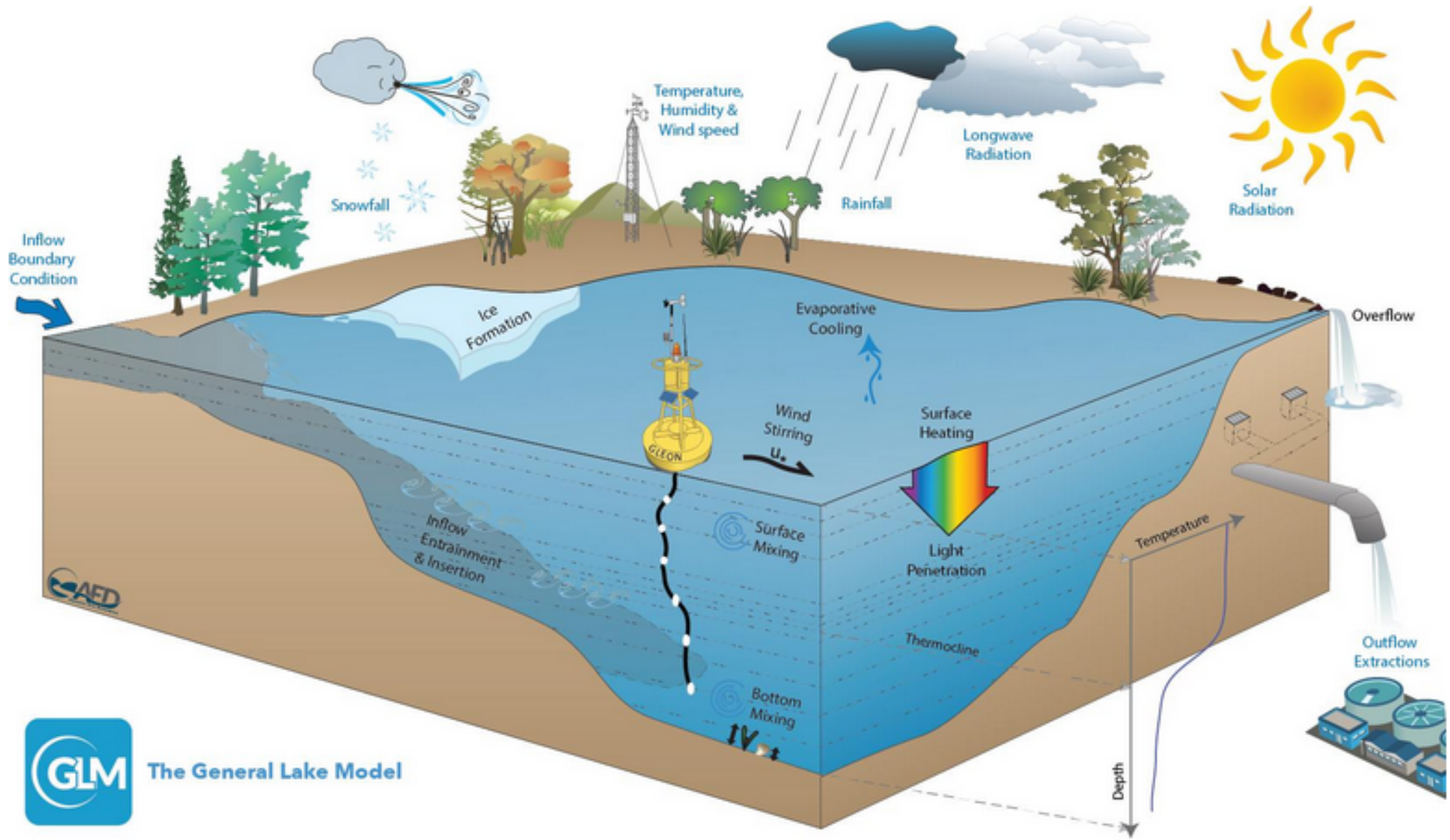
Generic Lake Model (GLM)



High Profile Water Quality Issues

The New York Times

NATIONAL GEOGRAPHIC

To Save Olympic Sailing Races, China Fights Algae

EyePress, via Associated Press

dao, site of the Olympic sailing regatta in August, was surrounded by algae last week. The Chinese have
eanup effort.

, 2008

Tap Water Ban for Toledo Residents

The discovery of high toxin levels in water from Lake Erie had residents in Toledo, Ohio, relying on bottled water while local supplies were being tested. Joshua Lott/Reuters

Model Summary

- Lagrangian layer structure allowing layers to expand, contract, split or merge depending on available energy and required energy to establish/overcome density gradients
- Within a layer, water quality properties are homogeneous (more layers during stratified period)
- Diffusion between layers below the surface mixed layer
- Chemical constituents subject to mixing, diffusion, atmospheric exchange, sediment fluxes, phytoplankton uptake, respiration, mineralization, etc.
- Sediment fluxes described by a Monod equation modified by Arrhenius temperature scaling

Example Chemical Mass Balance

State variable mass balance equation:

$$\frac{dO_2}{dt} = \pm f_{atm}^{O_2} - f_{sed}^{O_2} - \frac{f_{miner}^{DOC}}{\chi_{C:O_2}^{miner}} - \frac{f_{nitrif}}{\chi_{N:O_2}^{nitrif}} + \sum_{a}^{N_{PHY}} \left(\frac{f_{uptake}^{PHY\_C_a}}{\chi_{C:O_2}^{PHY}} \right) - \sum_{a}^{N_{PHY}} \left(\frac{f_{resp}^{PHY\_C_a}}{\chi_{C:O_2}^{PHY}} \right) - \sum_{z}^{N_{ZOO}} \left(\frac{f_{resp}^{ZOO_z}}{\chi_{C:O_2}^{ZOO}} \right)$$

= ± atmospheric O_2 exchange
± sediment O_2 demand
– O_2 consumption by mineralisation of DOC (bacterial respiration)
– O_2 consumption by nitrification
+ O_2 production by photosynthesis
– O_2 consumption by phytoplankton respiration
– O_2 consumption by zooplankton respiration

Dissolved Oxygen:
State Variable

Ex. Wind Speed (t)
Driver Variable

Half saturation constant:
Parameter

Process parameterisations:

$$f_{atm}^{O_2} = \begin{cases} \dfrac{c_{atm}^{O_2}([O_2]_{atm} - [O_2]_z)}{dz_s} & if\ z = z_s \\ 0 & if\ z \neq z_s \end{cases}$$

atmospheric oxygen exchange

$$f_{sed}^{O_2} = F_{max}^{O_2} \frac{O_2}{K_{sed}^{O_2} + O_2} \left(\theta_{sed}^{O_2}\right)^{T-20} \left(\frac{\widehat{A_z}}{dz_z}\right)$$

sediment oxygen demand (SOD)

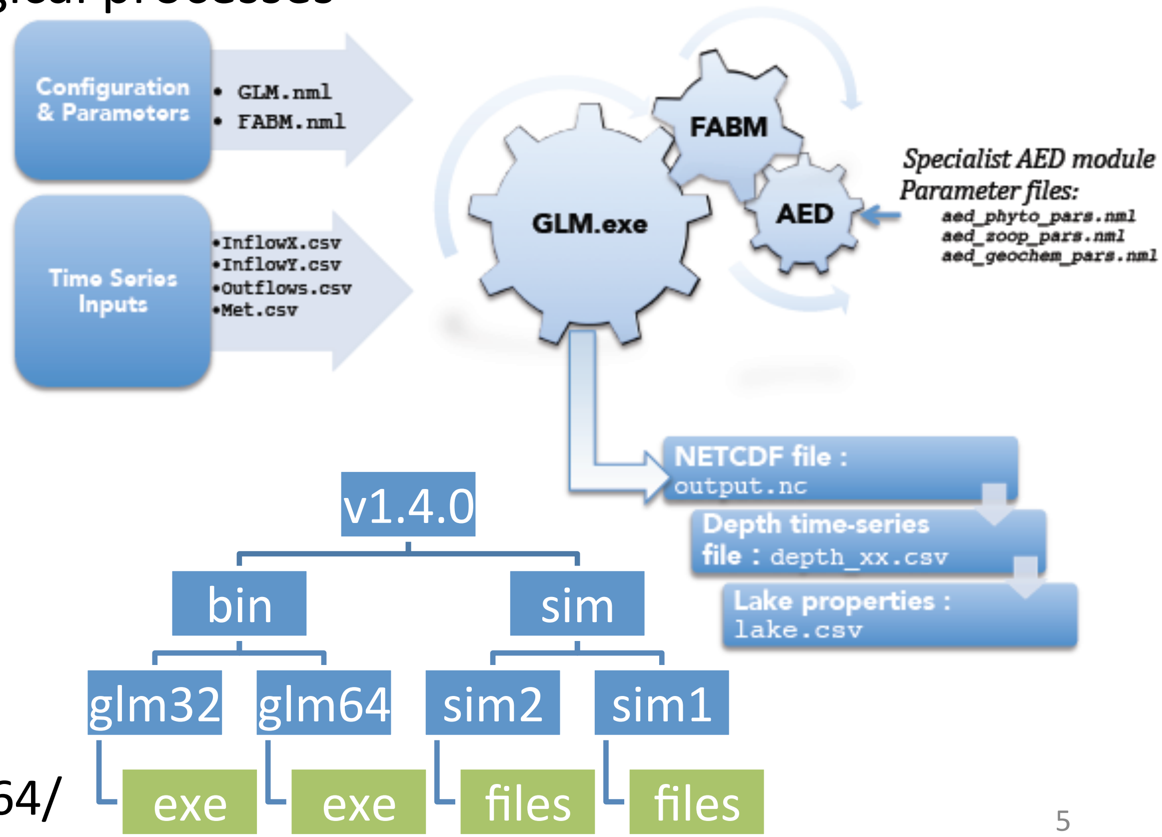
where $\widehat{A_z} = A_z^{ben} / A_z$ and dz_z is the thickness of the z^{th} layer/cell.

Model Components

- GLM: General Lake Model; 1-D lake water balance, energy budget, vertical stratification
- FABM: Framework for Aquatic Biogeochemical Models; couples hydrodynamics and biogeochemistry
- AED: Aquatic Ecodynamics; set of **modules** describing chemical and biological processes

Required Files:

- Driver Data
  - inflow file(s)
  - outflow file(s)
  - meteorological file
- Configuration Files
  - glm.nml
  - fabm.nml
  - aed_phyto_pars.nml (?)
  - aed_zoop_pars.nml (?)
- Application/Executables
  - Located at ../../bin/glm64/



What you need…

- GLM input files and application files
- R (& RStudio?)
- Package: ncdf4 (http://github.gleon.io/)
- Package: rGLM (no longer available online)
- Package: glmtools (
  https://github.com/USGS-R/glmtools)
- Package: pragma27 (local from Gabriel)

Reading modeled data from NetCDF

- Model outputs data to NetCDF in 4 dimensions: latitude, longitude, depth, and time
- Because 1-D model, lat and long are fixed (essentially 2-D output through depth and time)
- ncvar_get {ncdf4} extracts a matrix (2D) of state variable values in each layer (up to max layers) and at each time step (interval controlled by nsave in glm.nml)
- Using other GLM output data (number of layers [NS] and height top of layer above bottom [z]), the functions of interest (getTempGLMnc, get_temp, get_state_var) convert this information to rounded elevation or depth information

Example

Sample temperature data from ncvar_get:

Layer #\timestep	t1	t2	t3	t4
1	5.0	5.1	5.2	5.3
2	5.4	5.5	5.6	5.7
3…	6.0	6.1	6.2	6.3
…71	23.2	23.3	24.1	24.2
72…	24.1	NA	24.3	24.5
…1000	NA	NA	NA	NA

- Matrix "z" has same dimensions (and same missing value positions), and can be used to convert layer # to depth from lake surface
- 9.96e+36 value is the missing value

R tools: rGLM [getTempGLMnc]

--Old function for getting temperature data from NetCDF

Usage: getTempGLMnc(GLMnc, lyrDz, ref, z.out)

GLMnc: [NC object] as returned by nc_open()

lyrDz: [numeric value] depth interval

ref: [character string] either "surface" or "bottom"; determines 0 reference (depth or elevation)

z.out: [numeric vector] optional; vector of discrete depths to interpolate (lyrDz not used if z.out is supplied)

R tools: glmtools [get_temp]

-- New function for getting temperature data from NetCDF

Usage: get_temp(file, reference, z.out, t.out)

file: [character string] path to the 'output.nc' file

reference: [character string] same as 'ref' for getTempGLMnc

z_out: [numeric vector] vector of discrete depths at which data should be interpolated

t_out: [POSIXct vector] optional vector of datetimes for which to return data (if missing, all available time points returned)

R tools: pragma27 [get_state_var]

-- General function to get any state variable data from the NetCDF

Usage: get_state_var(nc_file, var_name, reference, lyrDz, z_out, t_out, precision)

nc_file: [character string] path to ‘output.nc’ file
var_name: [character string] name of state variable in the NetCDF
reference: [character string] same as get_temp
lyrDz: [numeric value] same as getTempGLMnc
z_out: [numeric vector] optional; same as get_temp
t_out: [POSIXct vector] optional; same as get_temp
precision: [character string] optiona; one of “hour” or “day”; not imporant here..

Differences between functions

- Whether NC object is saved in R memory (getTempGLMnc) or not (get_temp, get_state_var)
- Whether depths must be explicitly specified (get_temp) or inferred from an increment and lake depth (getTempGLMnc, get_state_var)
- Whether times can be specified (get_temp, get_state_var) or all available times are automatically extracted (getTempGLMnc)

- Important thing is how the NetCDF data (& NC object) are handled, how depths are interpolated, and how data is converted from *height above bottom* to *depth below surface*

Compute Times

- getTempGLMnc: 5.8 seconds
- get_temp: 3.2 seconds
- get_state_var: 3.6 seconds

- All return the same data:
  - data.frame with datetime in first column and time series data at discrete depths in the subsequent columns

Challenge

- Design a function that minimizes the time to return a data frame of the same format from get_temp or get_state_var
- Focus on:
  - Handling of NC object
  - Interpolation of data
  - Switching reference from bottom to surface of lake

- 3-D lake model diagram: http://aed.see.uwa.edu.au/research/models/GLM/
- Lake aerial view: pinnest.net/wordsworth-lake/
- Louisiana Fishkill (+ NG logo): http://news.nationalgeographic.com/news/2010/09/100916-fish-kill-louisiana-gulf-oil-spill-dead-zone-science-environment/
- Toledo Water: http://www.nytimes.com/2014/08/04/us/toledo-faces-second-day-of-water-ban.html
- Qingdao Algae Bloom (+ NY Times logo): http://www.nytimes.com/2008/07/01/world/asia/01algae.html?_r=0
- Example chemical mass balance from GLM user manual for v1.3.2 (now see v1.4.0 manual): http://aed.see.uwa.edu.au/research/models/GLM/documentation
- Cogs diagram: http://aed.see.uwa.edu.au/research/models/GLM/