How can SWOT data improve representation of lakes, reservoirs, and wetlands in weather prediction and climate models?

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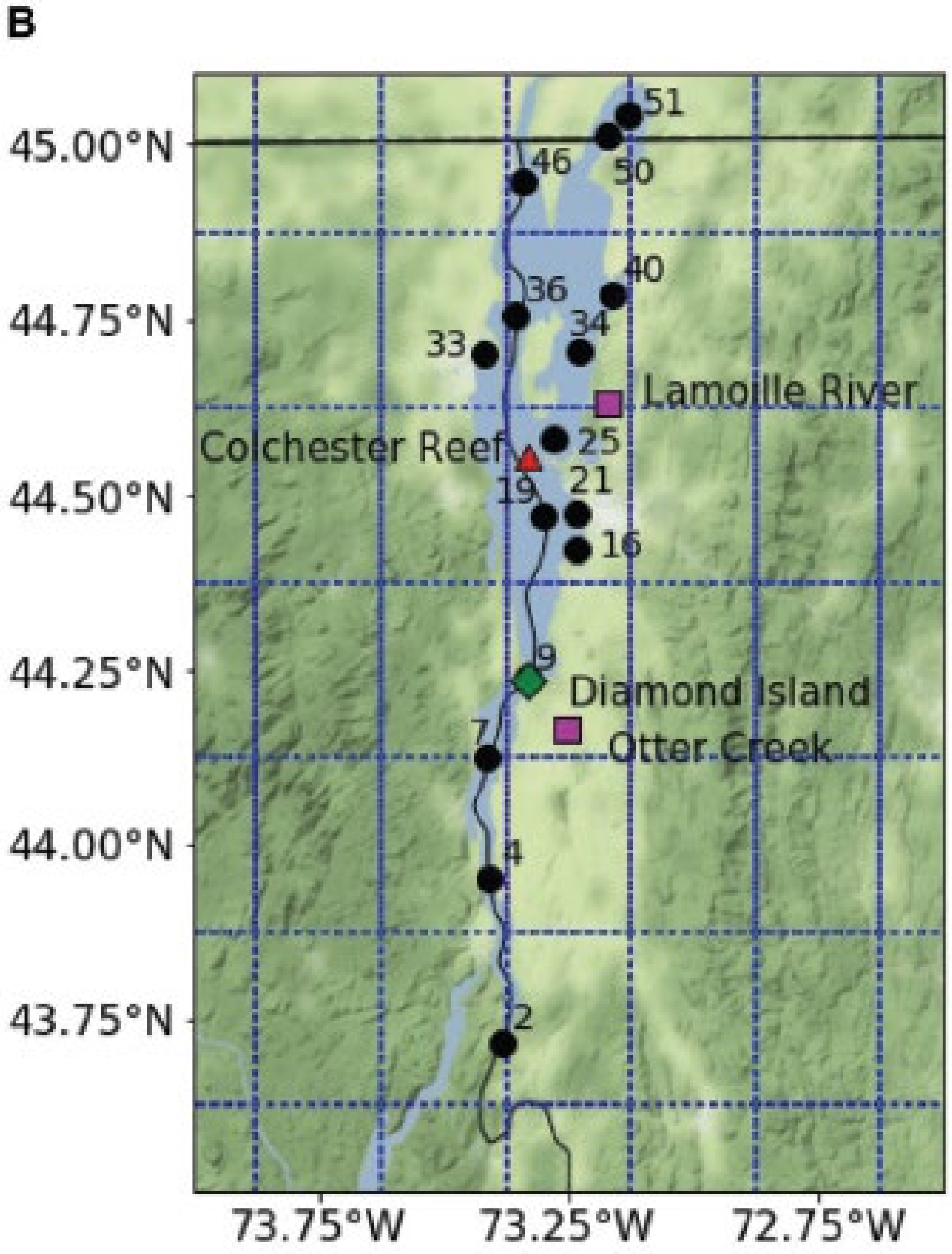
What does a land surface model (LSM) do?

- In its most basic form, partitions net radiation at the land surface into latent, sensible, and ground heat flux
- Hence provides a lower boundary condition for the (coupled) atmosphere model
- This was the early motivation, however ET and latent heat are related to each other by a constant, and ET depends on soil moisture, hence the water balance
- Hence the role of the land surface water balance (hydrology). Note that in the long run, ET = precipitation – runoff
- The major advance (in the context of coupled models) will be better estimates of global surface water storage variations (although all-weather estimates of variations in surface extent will offer an advance over estimates based on visible sensors).

Construct of LSMs

- Most are grid-based (consistent with atmosphere and ocean representations). See visual from Betts et al. application of FLAKE to Lake Champlain.
- Soil depths can be fixed or variable
- Subgrid heterogeneity (in elevation, vegetation, soils) often handled by a “tile” structure, e.g., all vegetation of a given type in a grid cell is aggregated in a single tile
- Neither grid cells nor tiles generally communicate laterally, aside from connectivity through a simplified “connect the dots” channel system. Hence exchanges are primarily with the atmosphere (vertically)
- There’s been a general trend over the last 10-20 years toward more complexity, e.g. representation of more complicated surfaces (e.g., urban areas, glaciers, etc) and inclusion of C- and N- cycles in addition to water.

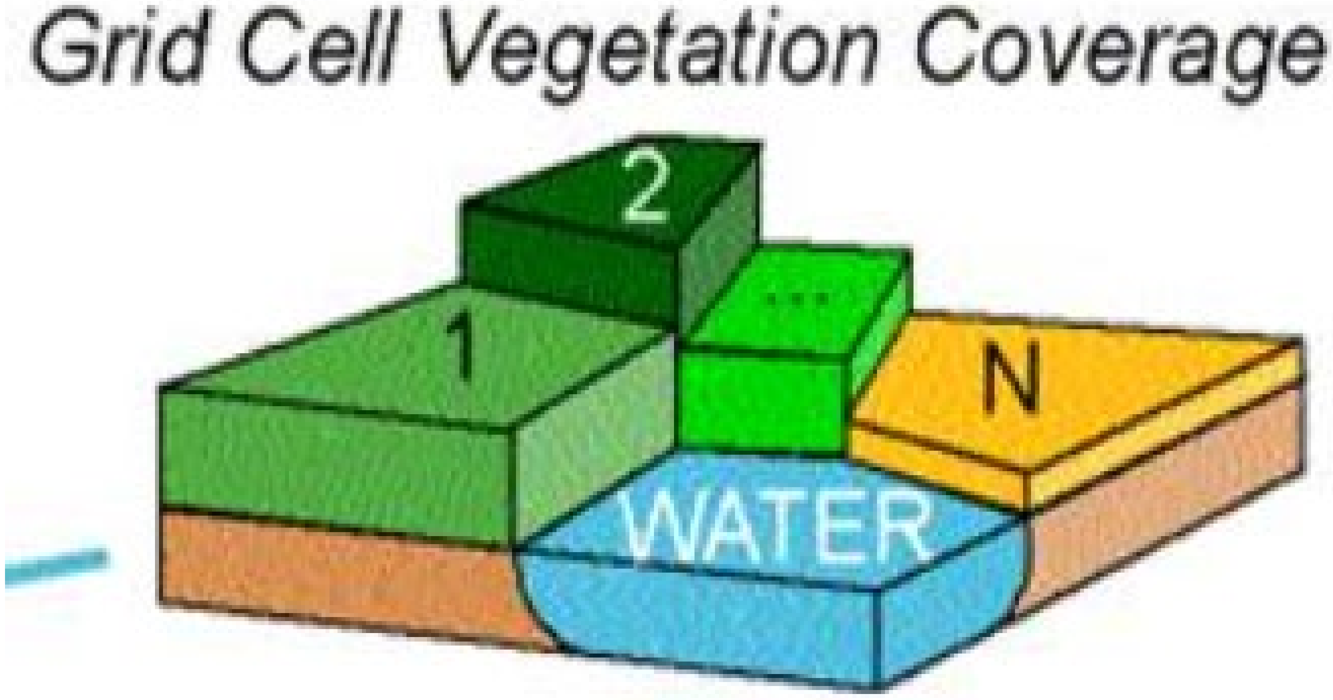
FLAKE implementation in ERA5 showing 0.25^o model grid cells, with Lake Champlain as an example. From Betts et al., 2000



How are water bodies represented in LSMs?

- Most obvious approach is to specify a tile type as surface water
- Reasonable as a first approximation (and better than ignoring), given that surface water (lakes, reservoirs wetlands – ignore stream channels here) accounts for well less than 10% of the global land area
- But, there are complications relative to other land cover (e.g., vegetation) classes:
  - Lakes that cross grid cell boundaries are not logically represented as being independent (as are vegetation classes)
  - Lakes may (or may not) be connected to the stream channel system, and functioning is fundamentally different for lakes with or without a channel outlet
  - Reservoirs can be considered a special class of lakes (that mostly are connected to the channel system), but reservoir storage changes depend on human decisions, rather than natural functioning
  - Wetlands likewise have unique controls, and may or may not communicate with the channel system (and if so, this communication may only be at high water levels – e.g., Alaska North Slope, Mackenzie Delta.

VIC tile structure including lake representation



How can SWOT help?

- One way is to provide data sets that help determine best conceptualizations of lakes, reservoirs, and wetlands in LSMs
- Keeping in mind (going back to Suki Manabe's rationale for using a simple bucket LSM) that there needs to be a balance in the complexity of the different elements of coupled land-atmosphere models.
- But, as an alternative first use of SWOT data, rather than dealing with complexity, why not develop data sets that help evaluate how well (or poorly) current LSMs do in representing surface water storage and area variations?

What would such a SWOT-based data set look like?

- First off, needs to include all surface water (take as lakes, reservoirs, and wetlands for now) surface area and storage variations
- Notwithstanding that SWOT represents a huge advance in terms of the fraction of surface water storage it can "see" (relative to other data sources) – e.g. order 60% vs 20% globally, the remaining 40% has to be represented to be consistent with LSM output
- This clearly means a composite of direct observations and alternative estimation methods (scaling relationships perhaps being the most obvious, basically extending SWOT observations to smaller spatial scales.
- For surface area, other sources can be leveraged (e.g. Landsat) to get to smaller spatial scales. One major advantage of SWOT is that it's (near) all-weather, so should have way fewer temporal gaps.

Some questions for the modeling community

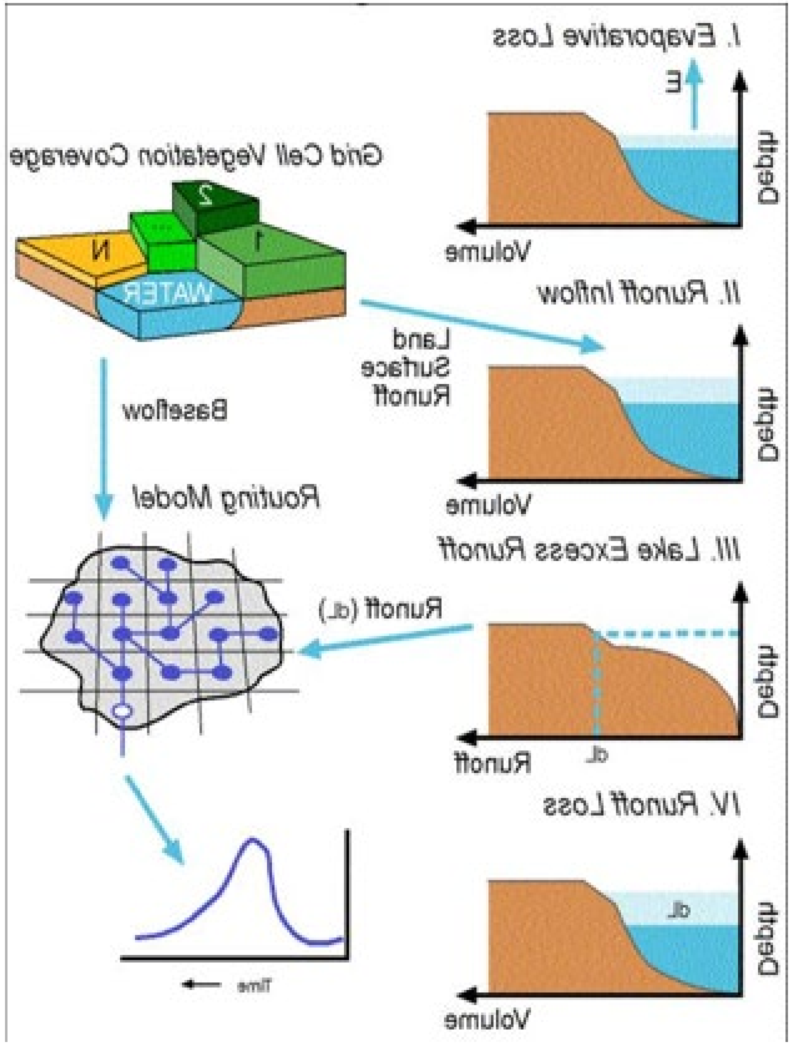
- How well (or poorly) does the “equivalent lake” concept work (this amounts to lumping all of the lakes in a grid cell into a single “equivalent lake” with a single volume/surface area relationship (which has to come from somewhere).
- Is there a threshold for the equivalent lake approach in terms of mean lake area (or volume) relative to grid cell size?
- At what point (if any) do lakes that cover multiple grid cells need to be represented as a single entity (rather than represented as parts of multiple grid cells (see Betts et al example for Lake Champlain).
- How well (or poorly) do generic reservoir operating rules (which depend on primary operating purposes, e.g., flood control, power generation, irrigation) work, and how can they be improved (see e.g. Ingjerd Haddeland’s dissertation papers c. 2006-7)
- What to do about wetlands, given that wetland area is estimated as several times that of lakes and reservoirs, and their particular observation issues (due in part to emergent vegetation)? Can we develop a SWOT-based strategy for estimation of surface area and volume changes for these water bodies?

Some examples of LSM lake and wetland conceptualizations

VIC lake model

Key characteristics:

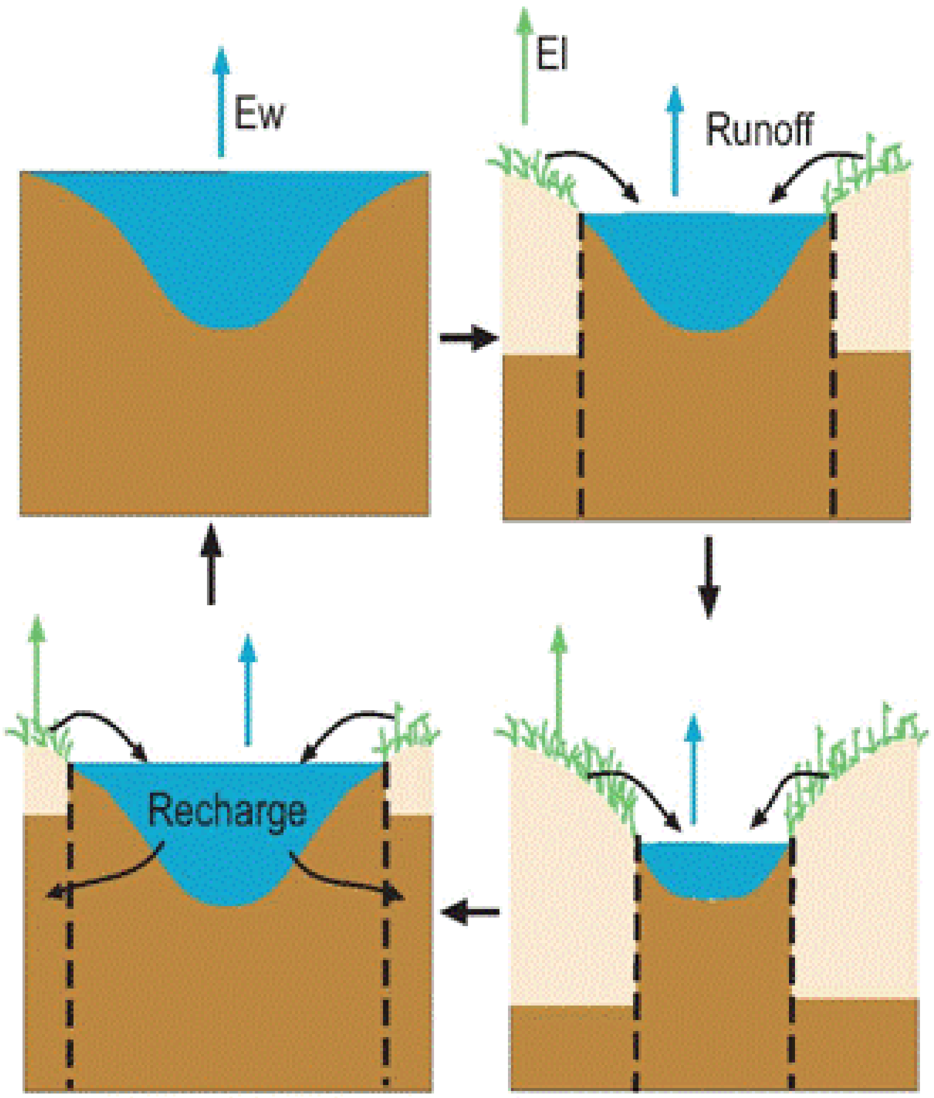
- Multi-layer model based on the (2-D) model of Hostetler and others
- One equivalent lake per grid cell
- Full Energy balance model, simulated surface energy exchanges and lake temperature profile
- Dynamic lake area as a function of storage (prescribed)
- Lakes can be linked directly to channel network and receive inflows both locally from the surrounding drainage area and channel flows from upstream
- Lakes drain directly into the channel network. Lake outflows consist of both channel flow regulated by a broad-crested weir and subsurface flow



VIC wetland model

Key characteristics:

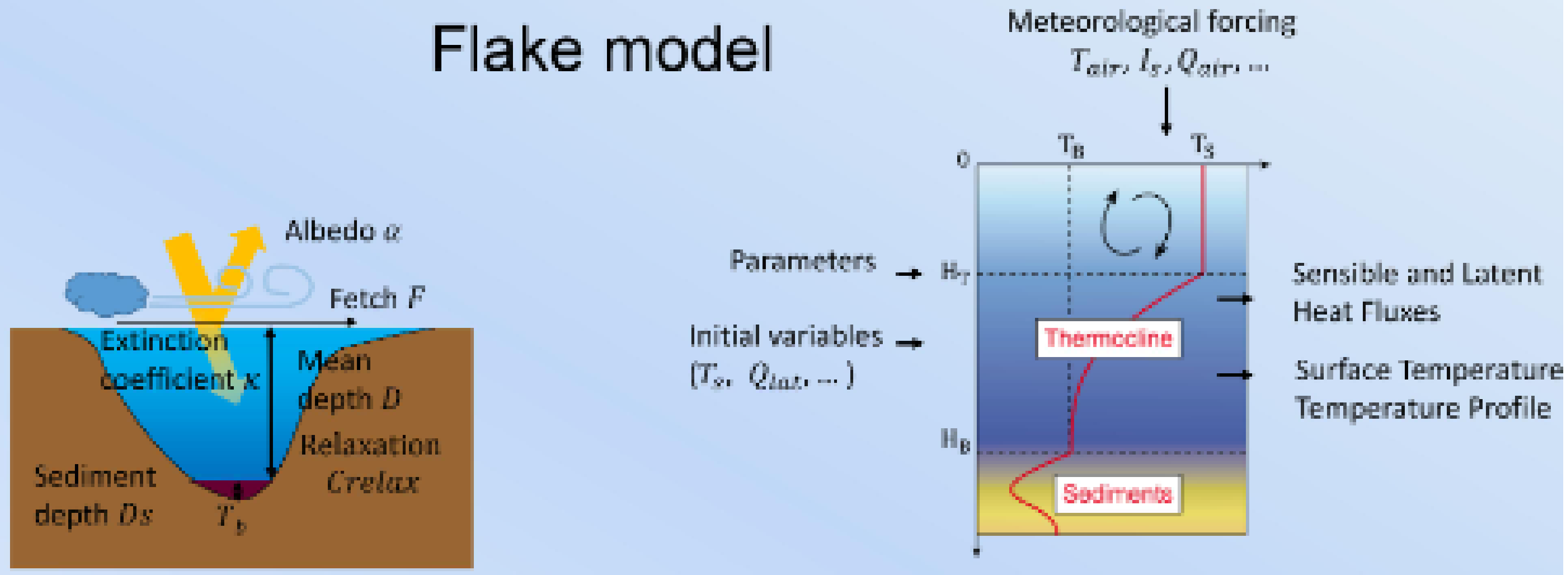
- Wetlands are assumed to be linked dynamically to a lake which they surround (the “lake” may just be the seasonally varying open water part of the wetland)
- Lakes/ wetlands exist as separate land cover classes within a grid cell
- Dynamic wetland area = tile area - dynamic lake area
- Allows seasonal inundation of wetlands as lake grows and shrinks
- Wetland moisture/energy flux computations are similar to those of upland tiles
- Wetland soils will tend to be wetter than upland soils due to frequent inundation and recharge by the lake
- Formulation tailored for boreal regions and may not be appropriate for other wetlands



FLAKE lake model (Meteo France)

Key characteristics:

- Lake area and geometry apparently are prescribed (model is primarily intended for weather applications)
- Emphasis is mostly on (surface) temperature prediction for use in turbulent flux estimates
- Not clear how lakes that cross grid cell boundaries are dealt with, and whether small lakes are aggregated into “equivalent lakes”



7 parameters: depth, albedo, extinction coeff., fetch, relaxation coeff., sediment layer depth and bottom temperature
- Constant in standard configuration
- Estimation of sources of uncertainties partly linked to seasonal variations

Summary

1. While SWOT data will no doubt lead to improvements in lake, reservoir, and wetland representations in coupled models, in the near term a (gridded global) data set that will allow evaluation of the ability of such models to produce realistic variations (seasonal and interannual) in surface water volume (changes) and surface area (changes) should be a priority.
2. To be useful, such a data set needs to represent a large fraction (say 90%) of total volume and surface area changes at a grid resolution appropriate to evaluation of coupled models. Therefore, leveraging from direct SWOT observations to smaller spatial scales (e.g., by application of scaling relationships) will be necessary.
3. Thought needs to be given especially to wetlands, given estimates that wetland water storage variations may well exceed those of lakes and reservoirs.