# Annual Seminar 2015

# Physical processes in present and future large-scale models

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## Summary

**Land surface schemes - Aaron Boone**

### Introduction

Land surface models (LSMs) were originally implemented in numerical weather prediction (NWP) models to provide interactive lower boundary conditions for atmospheric radiation and turbulence schemes, therefore they compute the fluxes of heat, mass and momentum between the land and the atmosphere. In the past two decades, LSMs have evolved considerably to include more physical processes in order to meet the growing demands of both the research and the user communities. Processes such as photosynthesis and the associated Carbon fluxes, aerosol emissions, soil moisture prediction (estimate of drought severity, initial values for flash flood prediction), vegetation phenology (biomass evolution, net primary production), surface runoff and exchanges with ground water, atmosphere-lake exchanges, snow pack dynamics and coverage, and near surface urban meteorology. LSMs are expected to be valid over a wide range of spatial scales, from the parcel (so-called « local scale », on the order of $10^2$ to $10^4$ $m^2$), up to areas in excess of $10^4$ $km^2$ (the potential maximum area of a modern NWP model grid cell). Thus, the LSM parameterization treats unresolved scale-dependent processes as a function of some grid-average state variable though a combination of conceptual and empirical relationships. Model parameterization development has greatly benefited in the past two decades from international collaborative efforts, such as the Project for the Inter-comparison of Land Surface Schemes (PILPS), which owing to it's success, spawned numerous other similar such projects, notably, multiple phases of the Global Soil Wetness Project, GSWP, which provided the first global multi-model state-of-the-art estimates of surface state variables and fluxes. These projects were done in so-called « stand-alone » mode (uncoupled with an atmospheric host model) using a blend of observational and model output data as boundary conditions. This framework greatly simplifies model evaluation and development, but it places a very strong constraint on the modeled fluxes. There is a growing effort in the scientific community to promote efforts to evaluate such schemes in fully coupled mode (van den Hurk et al., 2011), despite the additional complexity.

### Overview

One of the main difficulties of representing the land surface is the high spatial heterogeneity, even at relatively small scales. The most basic form of heterogeneity is that associated with land use or land cover. Most LSMs use the same basic physics but a different set of empirical parameters in order to differentiate the different surface types. Some NWP models use the « dominant class » approach to represent the surface properties in a particular grid box. The obvious advantage is the ease of implementation, however, such a scheme is highly scale dependent. A first order approximation of representing this sub-grid heterogeneity is to use aggregated parameters, for which data from a presumably higher spatial resolution database are averaged using relationships which are consistent with the surface fluxes. In recent years, many NWP centers have moved towards using the so-called tile approach, which amounts to an explicit representation of the various land cover classes or plant functional types. This method also permits different physics to be used for different surfaces (urban areas, lakes…).

Despite the obvious conceptual interest in this method, the two main drawbacks of such approaches are the i) lack of geo-referencing, not to mention that there is no description of the spatial distribution of the tiles, which can have a significant impact on unresolved meteorological circulations, and ii) the impact of the different fluxes on a mean blending height : in the real world, different boundary layers and free-atmosphere entrainment rates are likely to develop over contrasting surfaces. However, it should be noted that as some NWP centers move towards hectometric horizontal grid resolutions, dominant or aggregated land class methodologies will be sufficient, however, global deterministic, ensemble forecast, and climate models will continue to be used at resolutions of at least 1 km for the foreseeable future, thus the need for robust representations of heterogeneity are still needed. Finally, LSMs use analytical probability density functions (PDFs) for certain processes, the most common being sub-grid canopy water interception, precipitation and surface runoff/infiltration. But the moments needed to define the distributions for the first two examples on a global scale have yet to be defined in a manner which is general enough to be applied to NWP. The PDFs describing surface runoff, however, can be related to sub-grid topographic variability and even soil characteristics. Such schemes have been shown to have a strong influence on equilibrium soil moisture (and thus the Bowen ration) and stream flow, thus they have become popular in recent years and are now used in many operational NWP models (e.g. Pappenberger et al., 2010). In addition, runoff is increasingly being used in lateral transfer schemes coupled to LSMs. While water in rivers is not likely to have a noticeable impact on NWP forecasts, river discharge is a very useful quantity for evaluating LSMs as it represents a spatially integrated quantity which can be related to gridded LSM variables. Discharge at river outlets can also be used as a more realistic boundary condition for coupled ocean models. Many of the aforementioned recent developments have been made possible by ever-improving land datasets ; higher resolution topography, such as from STRM, more recent soil databases containing information on soil organic Carbon content (HWSD), and global lake depth datasets to name a few. Very promising innovations have also been developed which optimally combine satellite data and LSMs using data assimilation techniques in order to determine spatially distributed model parameters.

## Summary and Prospective

Despite considerable progress in the past two decades in terms of representing land surface processes in greater detail, certain issues linger. Models still can produce very different Bowen ratios, in particular in water-limited regions, and this is one of the key aspects of the land surface which modulates the coupling with the atmosphere. These differences are related to differences in soil water update by bare soil and transpiration, but they are also strongly modulated by the representation of sub-grid hydrology. Sub-grid snow covered fractional area, SCFA, is highly empirical in most coupled land-atmosphere models, with little or no consideration of some of the main features controlling snow spatial distribution (sub-grid variability of elevation and exposition). Shortcomings in the SCFA can offset much of the gains made from using more sophisticated physics. LSMs are increasingly including detailed phenology parameterizations for short to seasonal forecast timescales, but inclusion of such schemes will likely contribute to more inter-model spread over the foreseeable (or longer) future since they have many (difficult to directly observe in many cases) empirical parameters. In addition, not only do they have considerable feedbacks with other aspects of the land surface, but with the atmosphere as well. To help address these issues, the international community is embarking on efforts to improve LSM benchmarking (Best et al., 2014). Such actions are urgently needed in order to meet the ever growing list of processes required of earth system models. Anthropization has been highlighted as an important area for future work, including time dependent land cover changes (such as crop harvest) and irrigation (which then requires the modeling of irrigation sources such as aquifers, rivers and reservoirs). Finally, over the longer term, LSMs will likely need to include improved aerosol emissions and more detailed biogeochemical processes (and the inclusion of fluxes of additional gases beyond water vapor and Carbon dioxide). As more forecast centers move towards a so-called « seamless » approach across time and spatial scales, the line between those processes deemed important for climate and numerical weather prediction will be increasingly blurred so the need for global coverage of high resolution datasets (both for input and evaluation of LSMs) and scale-adaptable parameterizations will be needed.

## References

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