Using randomly-generated subcolumns to treat non-linearity in microphysics calculations

Robert Pincus, University of Colorado/NOAA Earth System Research Laboratory, Boulder, CO

Here's the problem

Some parameterizations in global models assumes that variables follow a distribution within each grid cell. The parameters of that distribution may be specified, diagnosed, or predicted.

The grid-mean rate for *local* process (one that depends only on the distribution within a single grid cell) can be computed by integrating the rate across the distribution. But
1) this only works for certain combinations of assumed distribution and process rates, and
2) it can't treat non-local processes, especially radiation and precipitation.

A general but slow solution

Process rates can be computed by
1) drawing a random set of subcolumns from the distribution of states implied by
*) the distribution in each grid cell and
*) overlap assumptions, then
2) averaging the process rate computed in each subcolumn

Subcolumns work equally well with any subgrid distribution, process rate, and/or overlap rules.

There's a tradeoff - more subcolumns means better sampling but slower calculation.

Old and new tricks

We developed a fast algorithm for radiation:
match each subcolumn to a different spectral interval (McICA).

We've been looking for a practical way to use subcolumns in microphysics calculations.

Here I'm trying a new approach:
generate a large number of subcolumns but compute rates for just a few.

Those few are chosen by doing quadrature over the distribution of liquid+ice water path.

Prototype microphysics

I'm doing microphysics calculations with the scheme used by AM2. This includes
*) Manton-Cotton autoconversion (strongly non-linear once a water content threshold is overcome)
*) partitioning of falling precipitation into clear and cloudy areas

Generating variable subcolumns

For each profile I mimic the radiation scheme by
*) diagnosing a PDF of cloud water and ice within each cell based on cloud fraction and mean cloud content
*) applying overlap assumptions

From these I generate 100 subcolumns.

Reference and approximate algorithms

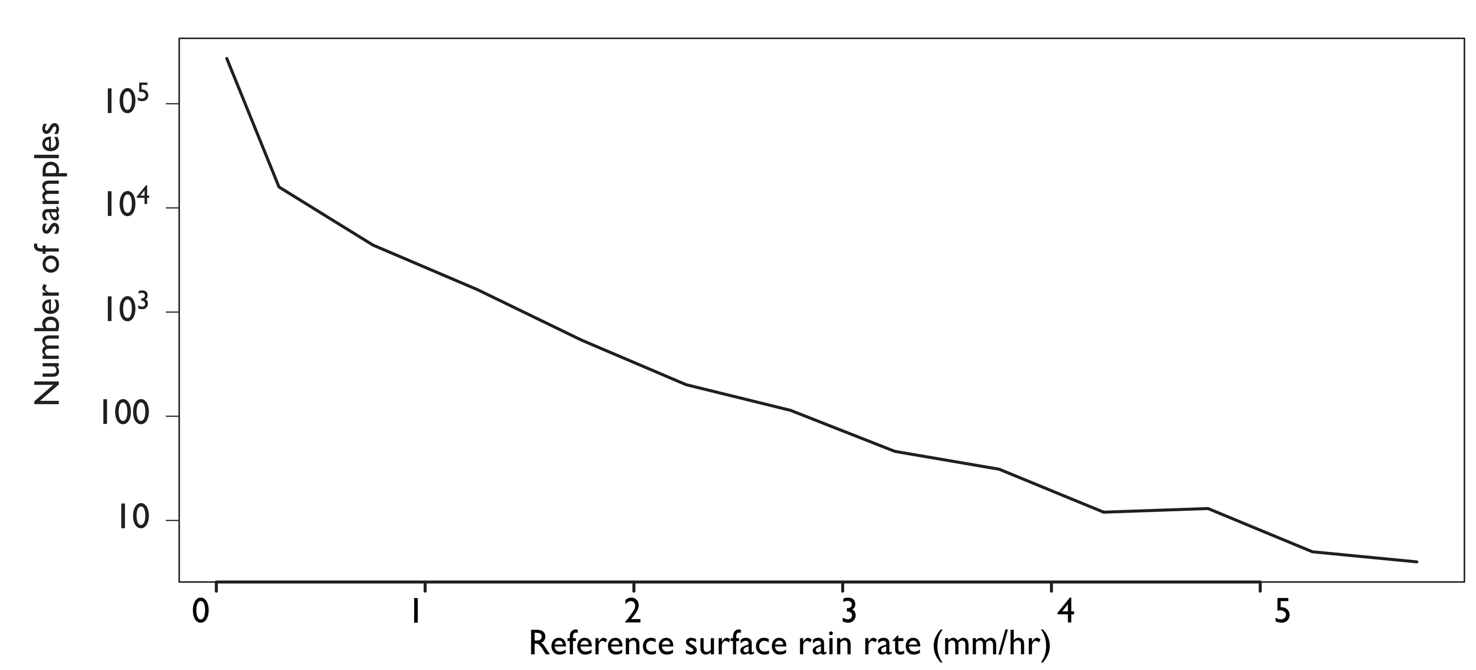
Microphysical rates are computed in each column. The average of these columns is the "truth", though it still contains some amount of sampling noise.

Process rates are estimated using quadrature in liquid+ice water path L+IWP:
one-point quadrature uses the subcolumns with the median value of L+IWP;
three-point quadrature uses the average of the subcolumns with the quartile values of L+IWP, etc.

Clear columns are included in the distribution.

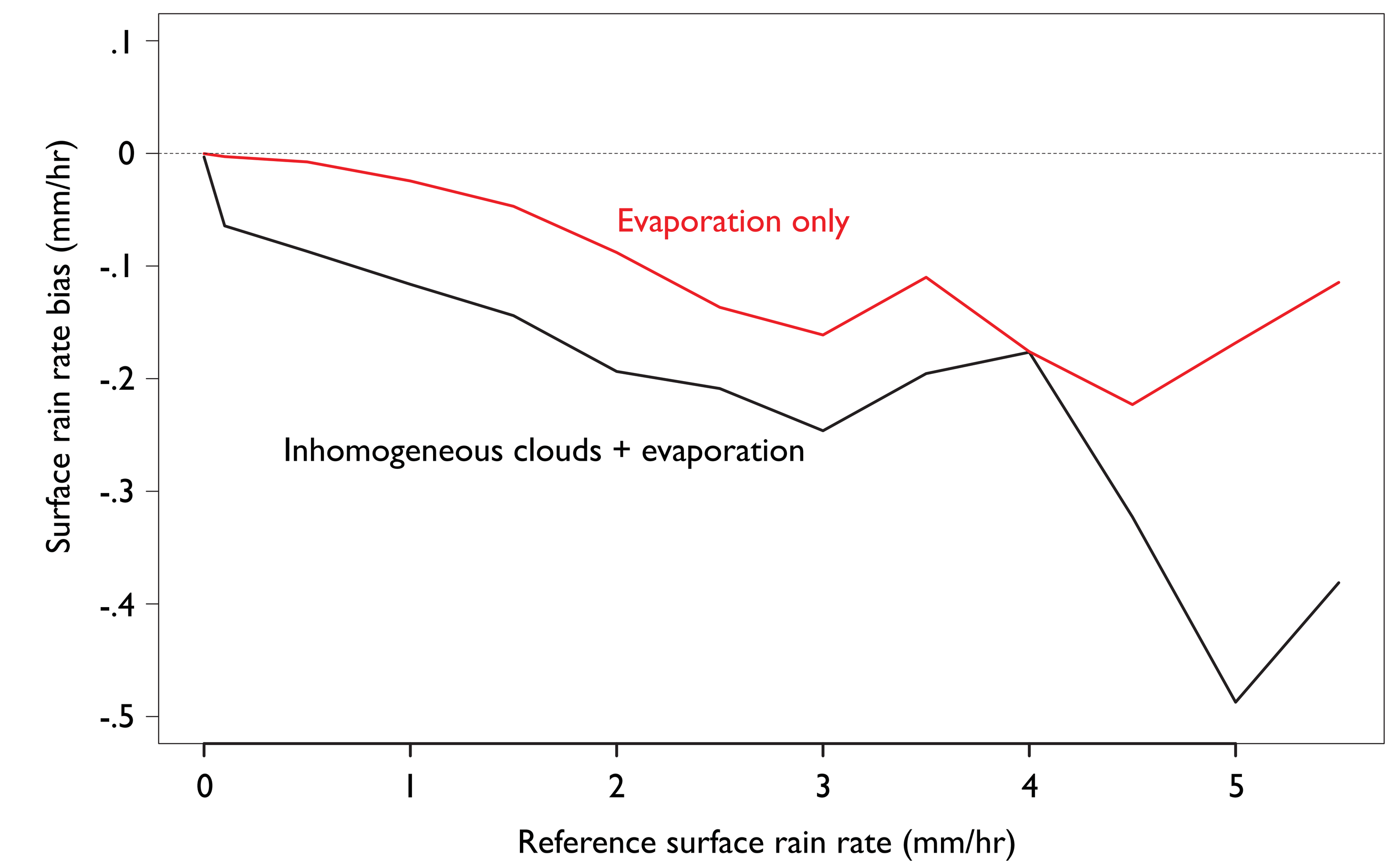
Sample calculations: surface rain rate

Calculations are done on profiles extracted from a model run every time step (30 min) over the course of a year at five locations. Rain rates are not the same as in the free-running model because every process besides microphysics is ignored.



The number of samples gets smaller fast as rain rate goes down, do don't take the results at large rain rates too seriously.

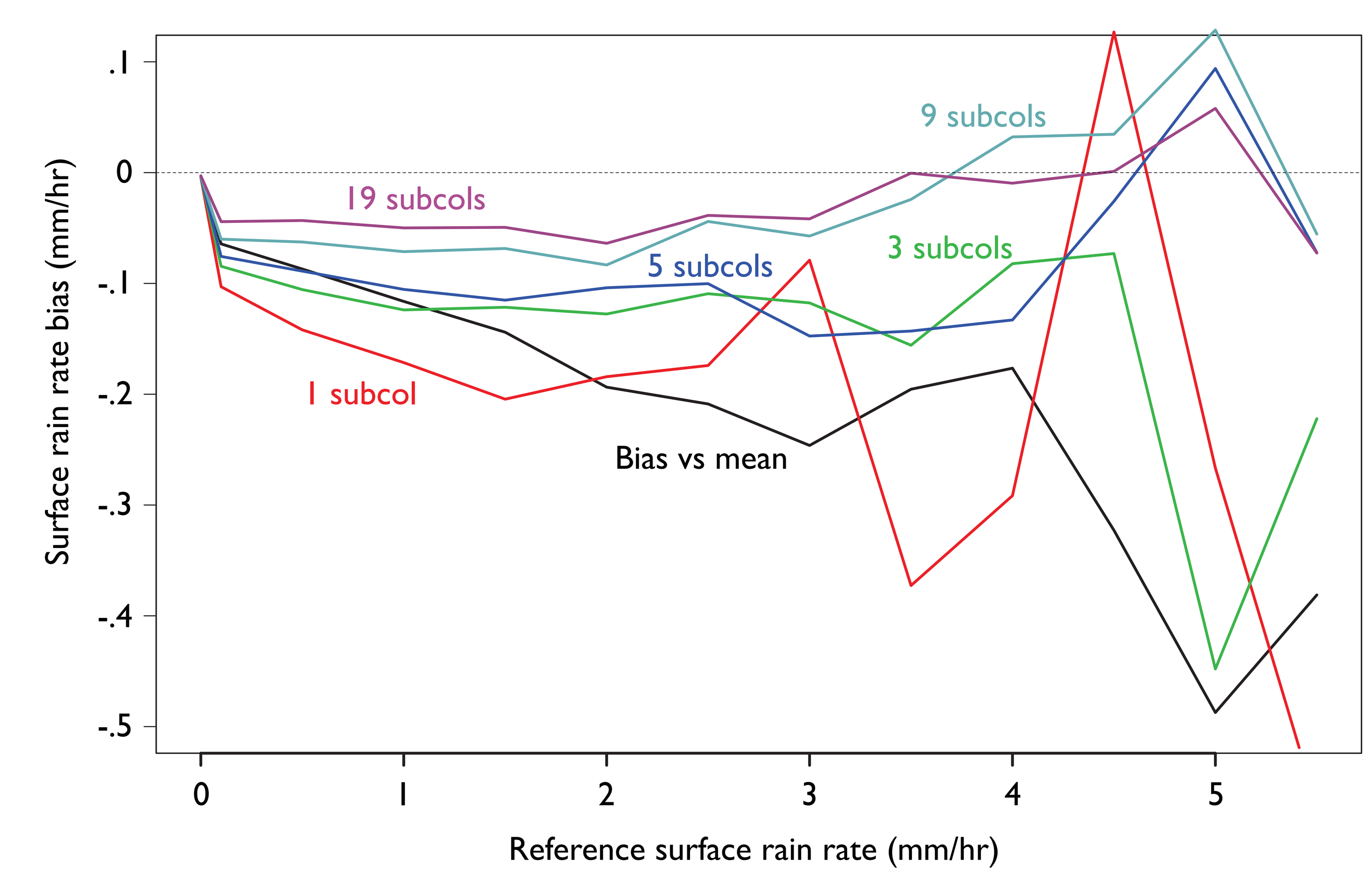
Inhomogeneous clouds have a modest bias



The AM2 scheme for treating precipitation evaporation (based on subcolumn results) has a modest bias.

When in-cloud inhomgeneity is assumed autoconversion, accretion, and evaporation are all affected, and the bias is about twice as large (10% of the total).

Quadrature works well (if a little slowly)



It's possible to remove most of the bias using as few as 10 subcolumns, but that's still lots more calculation then we're doing now.

We're going to try restricting the quadrature to cloud columns only, but don't expect dramatic improvements (overcast skies are common in AM2).

We're going to try the Morrison-Gettleman CAM microphysics, which treats in-cloud processes analytically but homogenizes fluxes at each layer boundary.