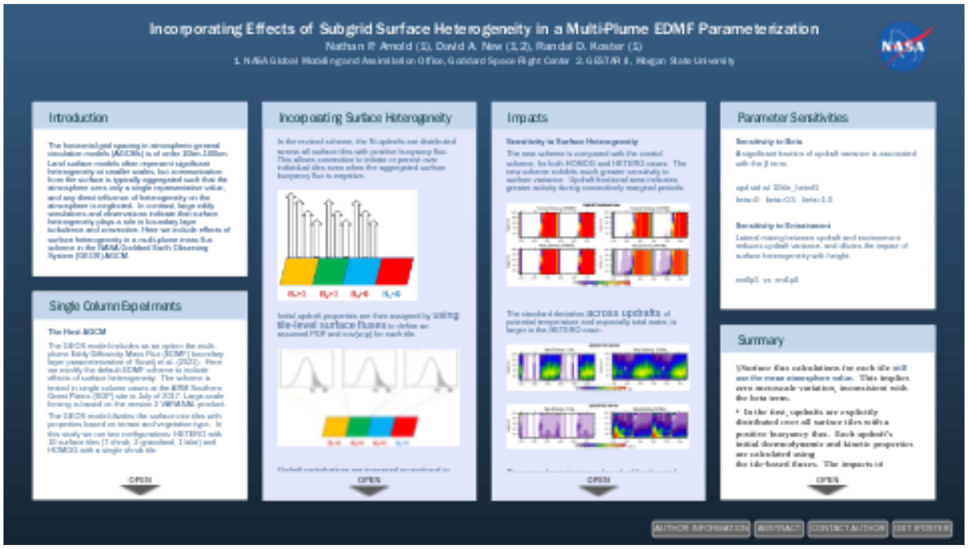
# Incorporating Effects of Subgrid Surface Heterogeneity in a Multi-Plume EDMF Parameterization

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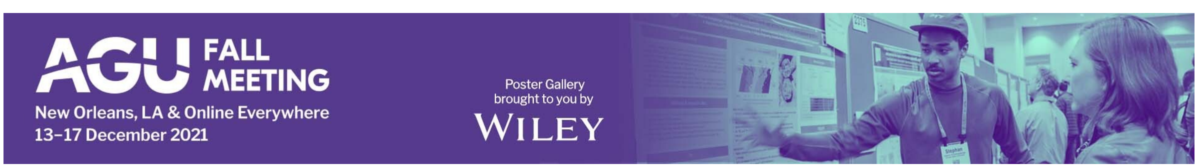


# INTRODUCTION

The horizontal grid spacing in atmospheric general circulation models (AGCMs) is of order 10km-100km. Land surface models often represent significant heterogeneity at smaller scales, but communication from the surface is typically aggregated such that the atmosphere sees only a single representative value, and any direct influence of heterogeneity on the atmosphere is neglected.  In contrast, large eddy simulations and observations indicate that surface heterogeneity plays a role in boundary layer turbulence and convection. Here we include effects of surface heterogeneity in a multi-plume mass flux scheme in the NASA Goddard Earth Observing System (GEOS) AGCM.

# SINGLE COLUMN EXPERIMENTS

**The Host AGCM**

The GEOS model includes as an option the multi-plume Eddy Diffusivity Mass Flux (EDMF) boundary layer parameterization of Suselj et al. (2021). Here we modify the default EDMF scheme to include effects of surface heterogeneity. The scheme is tested in single column cases at the ARM Southern Great Plains (SGP) site in July of 2017. Large-scale forcing is based on the version 2 VARANAL product (Tang et al. 2019).

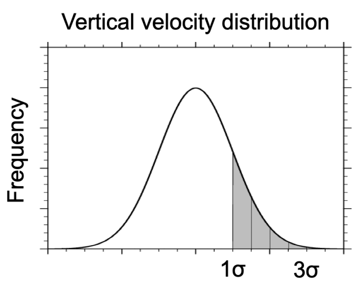
The GEOS model divides the land surface into tiles with properties based on terrain and vegetation type.

We run two configurations: **HETERO** with 10 surface tiles (7 shrub, 2 grassland, 1 lake) and **HOMOG** with a single shrub tile.

**EDMF Plume Initialization**

The default EDMF scheme assumes a normal distribution of vertical velocity in the surface layer, with updraft initial values drawn from the 1-3σ range. The 1-3σ range is evenly segmented among N updrafts, with updraft i having initial vertical velocity:

$w_i = \sigma_w + 2\sigma_w \left(\frac{i-1/2}{N}\right)$ and a fractional area based on the relative frequency of $w_i$ implied by the PDF.




Initial thermodynamic properties are calculated as perturbations from the mean, using the updraft $w_i$ and the covariances taken from the grid-mean surface fluxes:

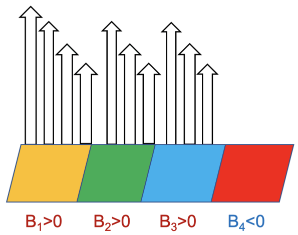
$$\theta_u = \overline{\theta} + \alpha w_i \frac{\sigma_\theta}{\sigma_w} \qquad \sigma_\theta = c_\theta \frac{\overline{w'\theta'}|_s}{w^*}$$

$$\sigma_w = c_w w^* \qquad w^* = \left( \frac{gh\ \overline{w'\theta'_v}|_s}{\overline{\theta}_{v,s}} \right)^{1/3}$$

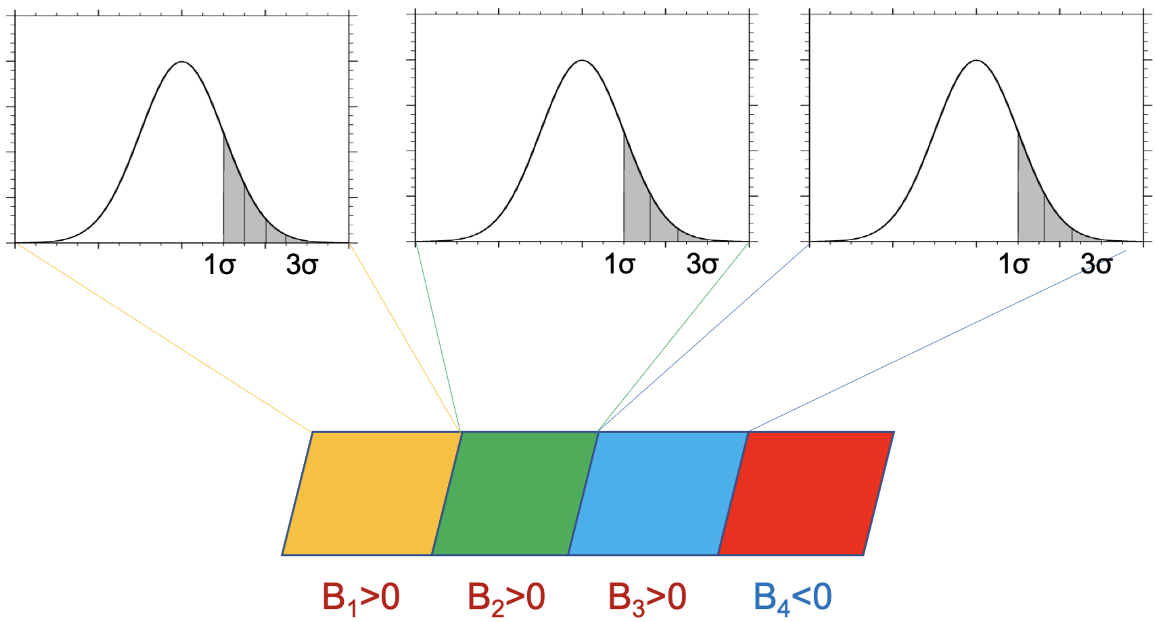
where $\overline{w'\theta'}|_s$ is the surface sensible heat flux, and $\overline{w'\theta'_v}|_s$ is the surface buoyancy flux. *The default mass flux scheme is active only when the grid-mean surface buoyancy flux is positive.*

# INCORPORATING SURFACE HETEROGENEITY

In the revised scheme, the N updrafts are distributed across all surface tiles with positive buoyancy flux. This allows convection to initiate or persist over individual tiles even when the aggregated surface buoyancy flux is negative.




Initial updraft properties are then assigned by using tile-level surface fluxes to define an assumed PDF and cov(w,φ) for each tile.

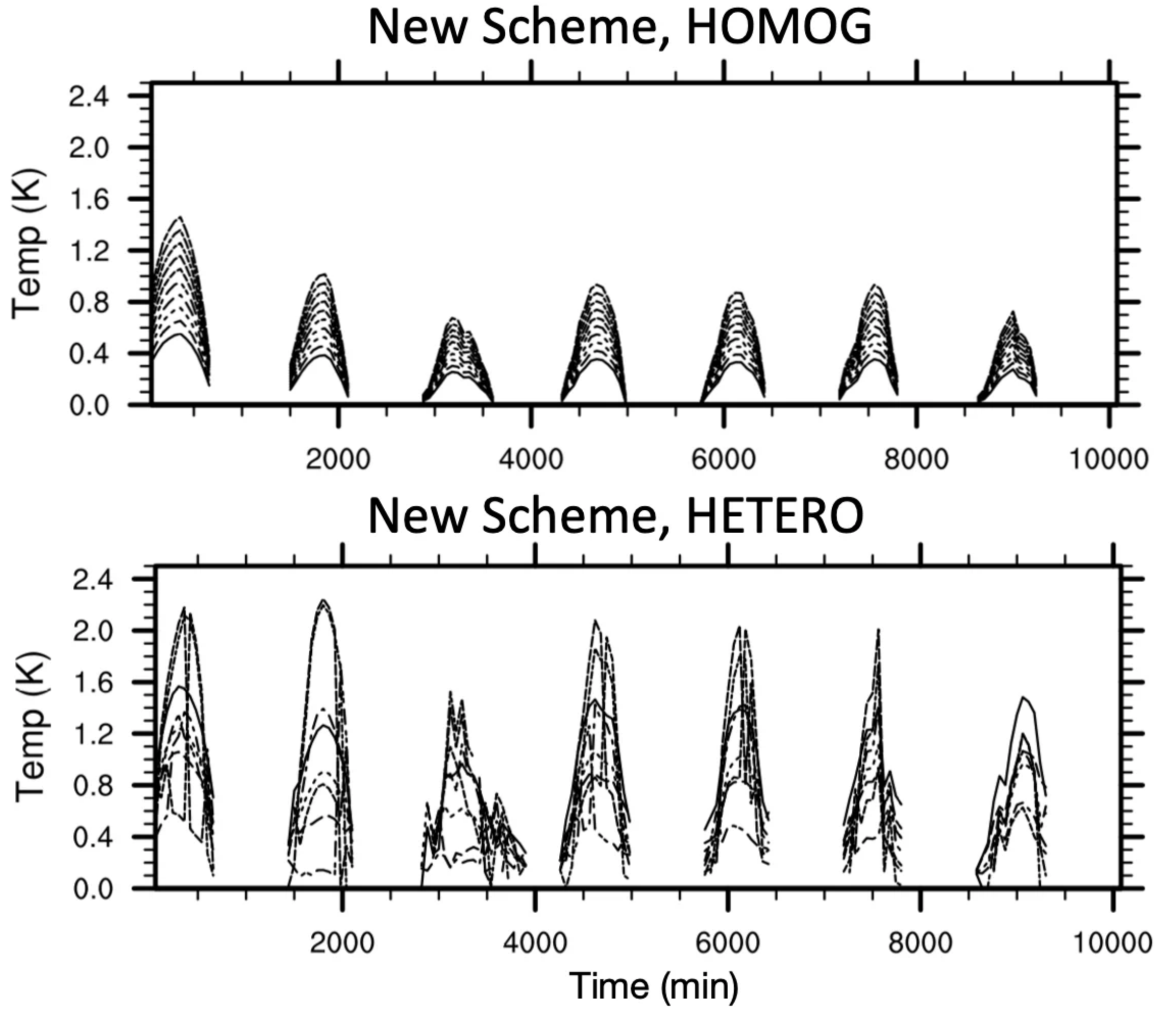



The surface layer mean is expected to covary with the surface properties, e.g., a warmer surface layer over a warm surface tile. To account for this tile-scale atmospheric variability, updraft perturbations are increased proportional to the tile surface anomaly:

$$\theta_{u,i} = \overline{\theta} + \alpha w_i \frac{\sigma_\theta}{\sigma_w} + \beta \Delta T_s \qquad \Delta T_{s,i} = T_{s,i} - \overline{T_s}$$

where $T_{s,i}$ is the surface temperature of the tile associated with updraft i, $T_s$ is the mean surface temperature (of all tiles), and β is a proportionality constant set to 0.5.

Time-series of updraft temperature perturbations are shown below for the HOMOG and HETERO cases:

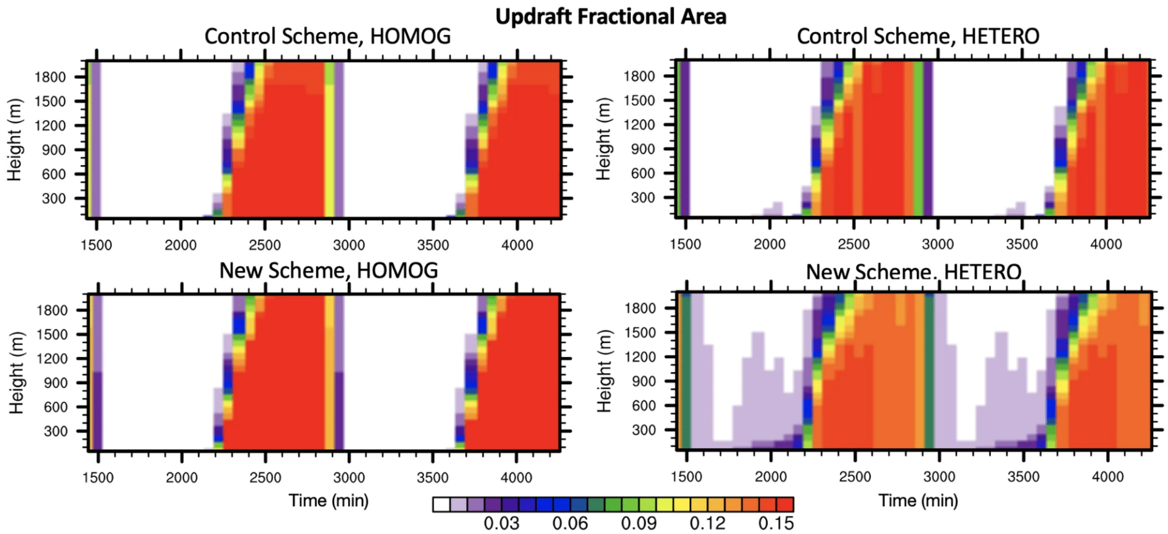



Over a single surface tile, the heterogeneous scheme converges to the original. Over multiple surface tiles, the updraft variability reflects the varied surface conditions.

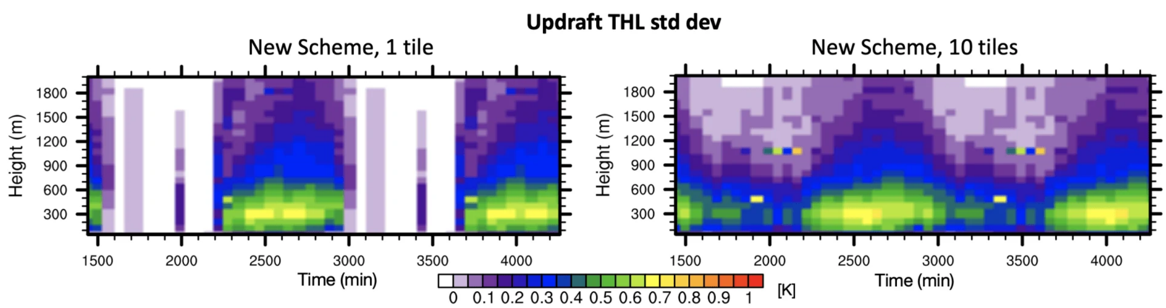
# IMPACTS

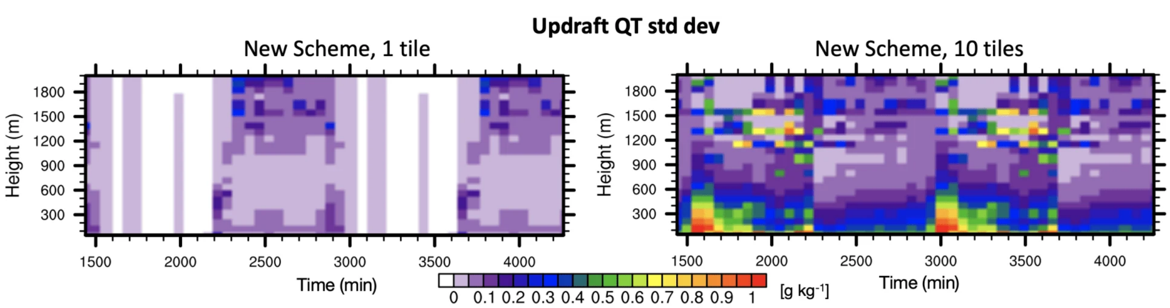
**Sensitivity to Surface Heterogeneity**

The new scheme is compared with the control scheme for both HOMOG and HETERO cases. The new scheme exhibits much greater sensitivity to surface variance. Diurnal composites of updraft fractional area indicate greater updraft activity during convectively marginal periods in the early morning and late evening:

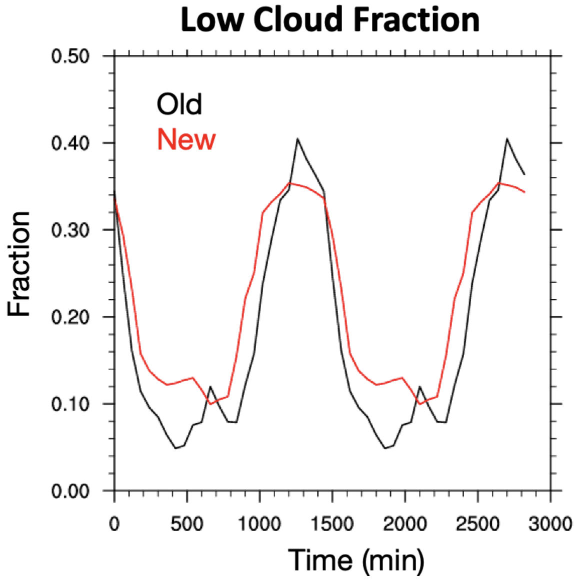


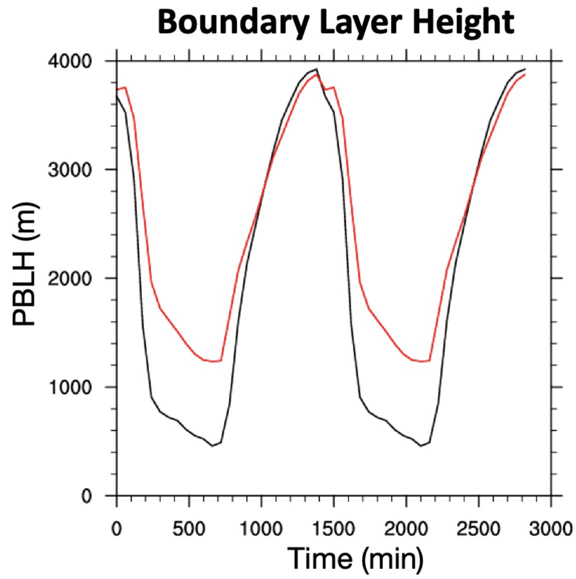

The standard deviation across updrafts of potential temperature and especially total water, is larger in the HETERO case:



The new scheme increases low cloud fraction and boundary layer height during convectively marginal periods. The old and new scheme compared for HETERO case:

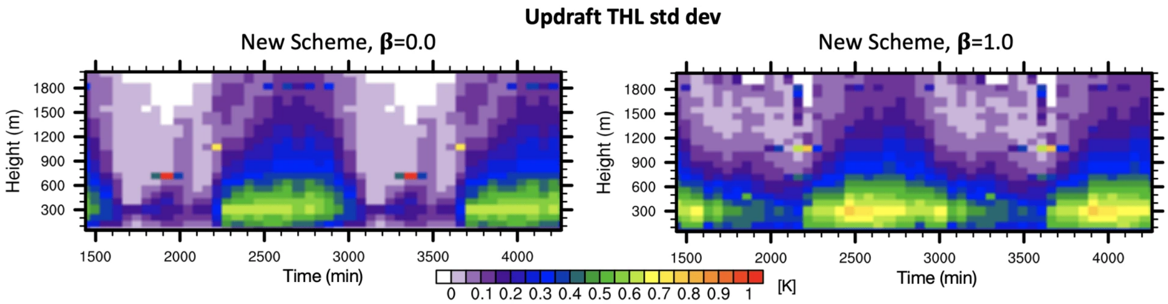


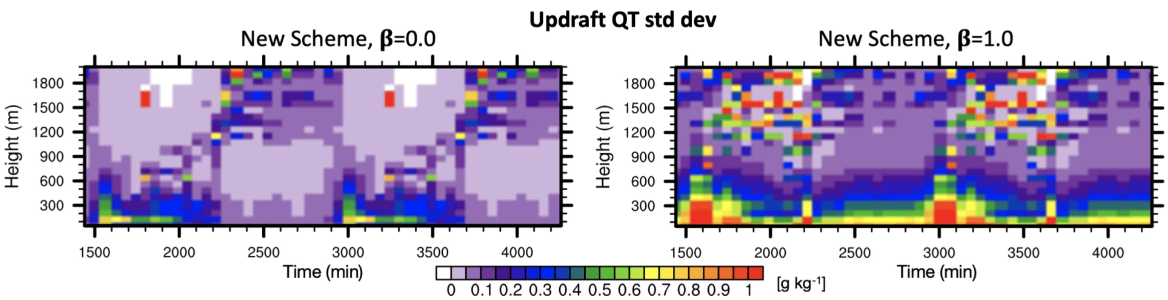



# PARAMETER SENSITIVITIES

**Sensitivity to β**

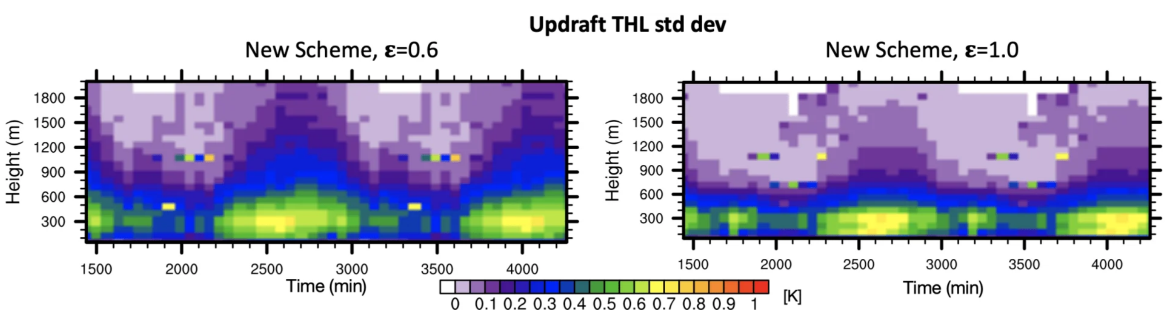
A significant fraction of updraft variance is associated with beta term. The sensitivity of updraft standard deviation to the beta parameter is shown below:




**Sensitivity to Entrainment Rate**

Lateral mixing between updraft and environment reduces updraft variance, and dilutes the impact of surface heterogeneity with height. The impact of increasing the entrainment rate is shown below:



# SUMMARY

- We have modified the initial updraft properties in the GEOS EDMF parameterization to incorporate heterogeneous surface information.
- The new scheme converges to the original approach over a single surface tile, but increases updraft variance when run with a heterogeneous surface.
- The new scheme allows updrafts to remain active over individual surface tiles with positive buoyancy flux, even when the aggregate surface buoyancy flux is negative.
- The expanded updraft activity in marginal time periods leads to deeper PBL mixing depth and increased cloud fraction.

**Ongoing work**

- Impacts of the heterogeneous scheme are being assessed using high resolution WRF simulations.
- We are implementing and evaluating an alternative approach, in which the initial updraft properties follow an assumed PDF that is directly adjusted using surface statistics.

# ABSTRACT

The horizontal grid spacing in atmospheric general circulation models is of order 10km-100km, depending on the application. Surface models often represent significant heterogeneity at smaller scales, but communication from the surface is typically aggregated such that the atmosphere sees only a single representative value, and any direct influence of heterogeneity on the atmosphere is neglected. In contrast, large eddy simulations and real-world observations indicate that surface heterogeneity plays a role in both boundary layer turbulence and the triggering and properties of atmospheric convection.

Here we incorporate effects of surface heterogeneity in a multi-plume mass flux scheme, following two approaches. In the first, updrafts are explicitly distributed over all surface tiles with a positive buoyancy flux. Each updraft's initial thermodynamic and kinetic properties are calculated using the tile-based fluxes. In the second, a statistical approach is used to define a distribution of updraft properties based on the tile-level fluxes. The impacts of heterogeneity on convective triggering, depth, and boundary layer turbulence are documented in a set of single column experiments. The approaches are shown to convey surface heterogeneity into the boundary layer and to increase updraft activity during marginal time periods.