A two-moment microphysics scheme in SAM: Initial results

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Background

The cloud resolving model that represents subgrid processes in the CSU multi-scale modeling framework (MMF) has a relatively simple representation of cloud microphysics. This scheme is fast, but it does not allow for the explicit representation of freezing/melting of hydrometeors, size sorting of falling precipitation and aerosol effects on clouds (also known as aerosol indirect effects).

Objective

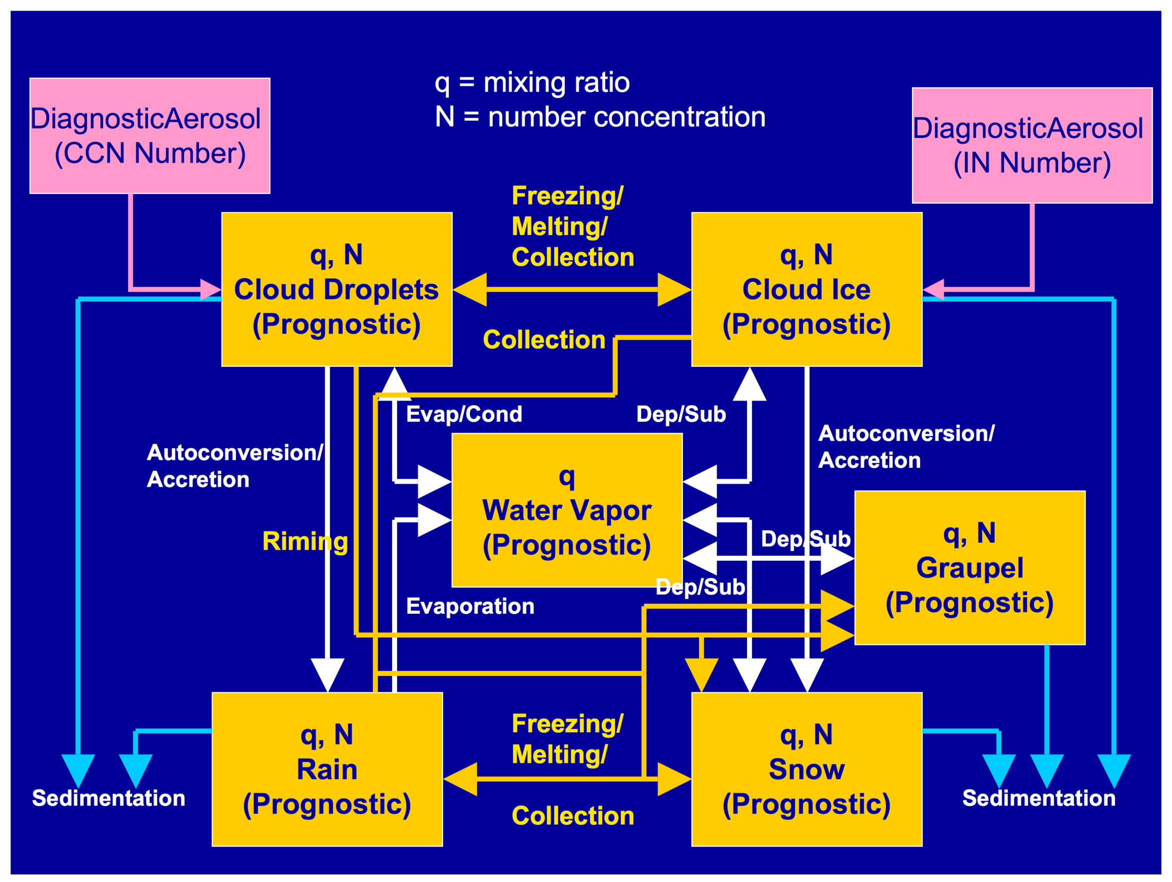
We add a more complex representation of microphysical processes (Morrison et al 2005, also described below) as an option in SAM, and we compare its behavior with that of default SAM in three cloud regimes (drizzling stratocumulus, precipitating shallow cumulus and deep convection). The new microphysical scheme should enable SAM to represent aerosol effects on clouds and to more faithfully simulate the vertical structure of clouds and precipitation.

Model Description (SAM)

We use the System for Atmospheric Modeling (SAM 6.6β) (Khairoutdinov & Randall 2003), an anelastic model with bulk microphysics and prognostic equations for liquid–ice static energy $s_{li} = C_pT + gz - L_c(q_c + q_r) - L_s(q_i + q_s + q_g)$, total water (vapor+cloud) and precipitating water. Phases of condensed water are diagnosed from temperature. When applied (only for KWAJEX here), radiation computations used the scheme from CAM3.

MOR Microphysics

This scheme (Morrison et al 2005) explicitly represents the mass mixing ratios and number concentrations of cloud water, cloud ice, rain, snow and graupel, along with the mass mixing ratio of water vapor. The transformations between these species are represented in the diagram below. Prognostic equations for each of these species are solved (for 12 in total vs. 3 for SAM).



Drizzling Stratocumulus: DYCOMS-II RF02

GCSS intercomparison case organized by Andy Ackerman (NASA) for average conditions during second DYCOMS-II research flight in marine stratocumulus near San Diego, CA.

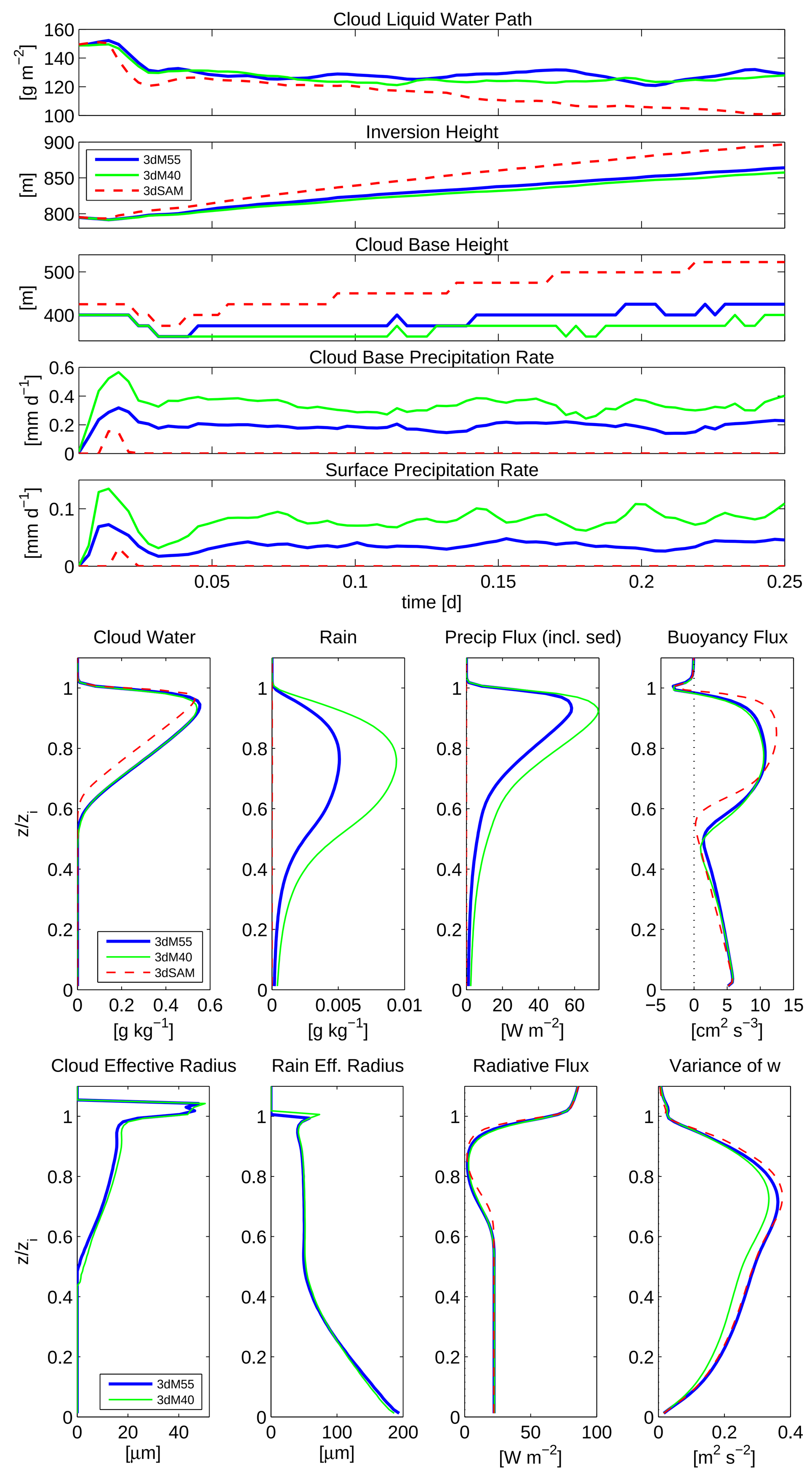
Cloud Resolving Model (CRM) Setup

3D Runs w/$N_x \times N_y \times N_z \sim$ 96x96x96, Δx=Δy=50m and Δz=5-25m in boundary layer. Steady forcings: prescribed surface fluxes (SHF=16 Wm^{-2}, LHF=93 Wm^{-2}), large-scale subsidence (D=3.75$\cdot$10^{-6} s^{-1}) and Stevens (2005) interactive radiation.

Microphysics Setup

SAM: Warm rain Kessler with a threshold of 1 g/kg. No cloud droplet sedimentation.
MOR: Khairoutdinov-Kogan (KK) drizzle scheme w/fixed cloud number conc. ($N_c = 55, 40$ cm^{-3}). **No ice.**

Timeseries, Time-avg. (4–6 hr) Profiles



Conclusions

- High SAM autoconversion threshold shuts off drizzle.
- MOR runs have thicker cloud, less entrainment and a stronger cloud base buoyancy flux than SAM.

Precipitating Shallow Cumulus: RICO

GCSS case organized by Margreet van Zanten et al. (KNMI) of average conditions during three weeks of RICO, the Rain In Cumulus over the Ocean experiment from Dec. 2004–Jan. 2005 near Antigua and Barbuda.

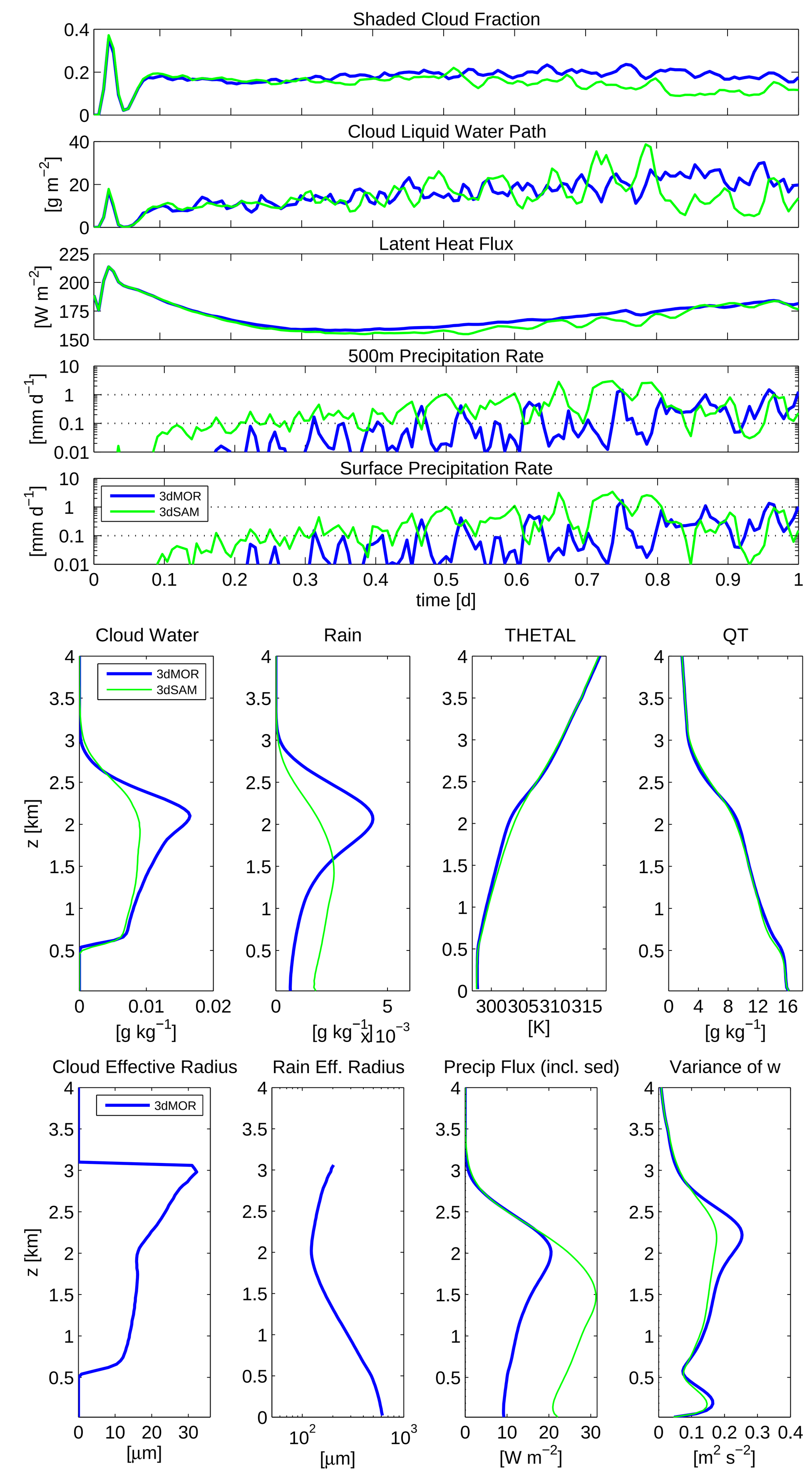
Cloud Resolving Model (CRM) Setup

3D Runs w/$N_x \times N_y \times N_z \sim$ 128x128x128, Δx=Δy=100m and Δz=40m. Steady forcings: Prescribed SST=299.8K, large-scale horizontal advection and subsidence. No interactive radiation. Interactive fluxes.

Microphysics Setup

SAM: Warm rain Kessler with a threshold of 1 g/kg.
MOR: KK drizzle scheme w/prognostic cloud droplet number N_c. **No ice.** Power law CCN activation (Rogers & Yau) w/$CCN \sim 100S^{0.4}$ where CCN is cloud condensation nuclei (cm^{-3}) and S supersaturation (%).

Timeseries, Time-avg. (16–24 hr) Profiles



Conclusions

- More variability in CWP, less evaporation in SAM.
- MOR has more rain near cloud top, more evaporation than SAM.

Deep Convection: KWAJEX

The Kwajalein experiment (KWAJEX) observed conditions around Kwajalein (on the eastern edge of the West Pacific warm pool) from July–Sept. 1999.

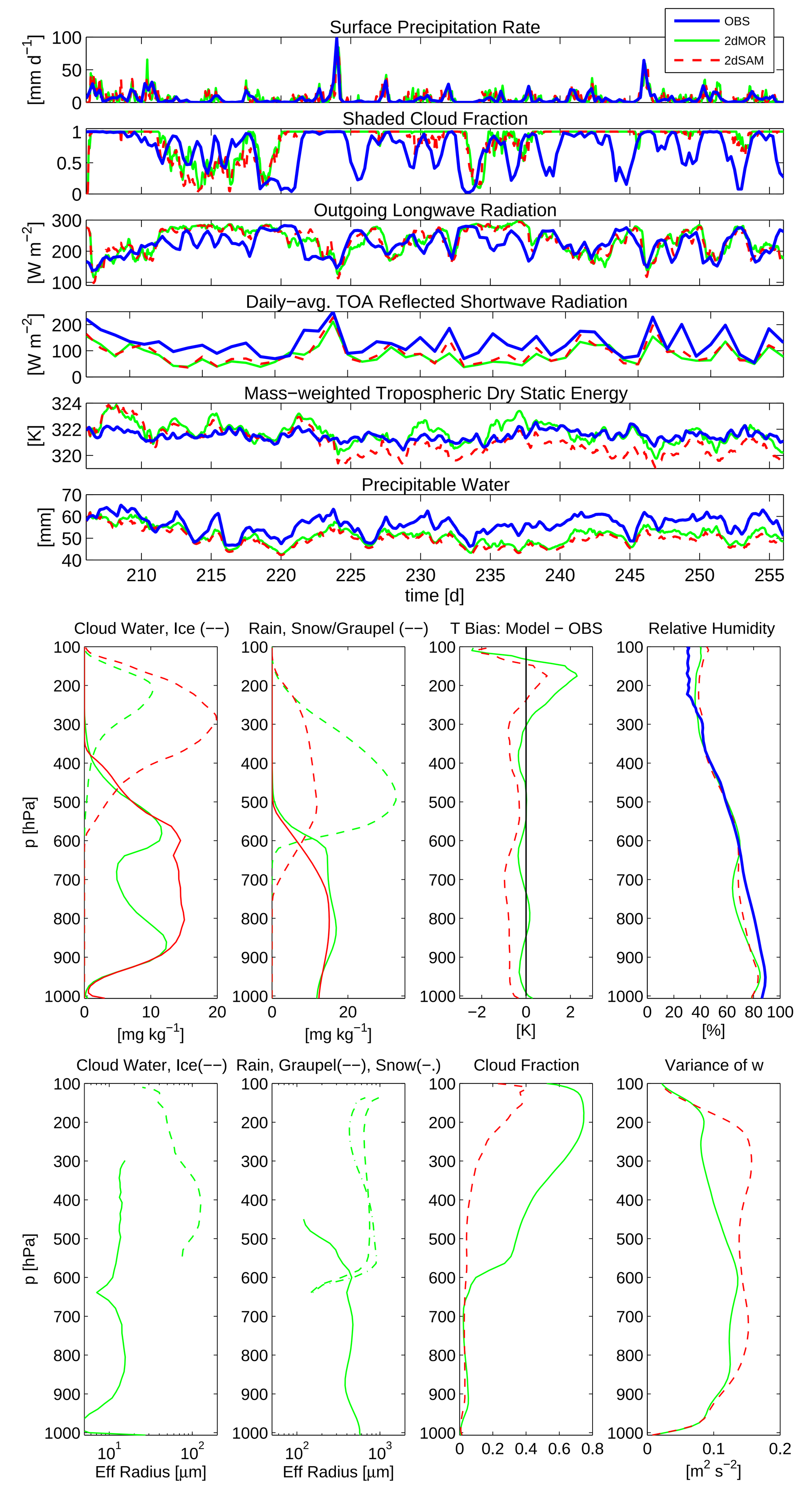
Cloud Resolving Model (CRM) Setup

2D Runs w/$N_x \times N_z \sim$ 1024x96, Δx=500m and Δz=75-250m in troposphere. Time-varying forcings supplied by Minghua Zhang: Prescribed LHF/SHF, large-scale horizontal advection/vertical motion. Interactive radiation using CAM3.0 scheme. (MOR effective radii not yet used in radiation scheme.)

Microphysics Setup

SAM: Phases (ice/liquid) diagnosed from temperature.
MOR: Includes ice processes. Prognostic N_c with power law CCN activation $CCN \sim 120S^{0.4}$.

Timeseries, 51-day Time-avg. Profiles



Conclusions

- MOR has smaller cold bias and larger high cloud fraction than SAM.
- Both models have high OLR bias during days 212–217 and 234–237.

Acknowledgments: Thanks to Marat Khairoutdinov for providing SAM, some feedback on these runs and a new interface that allows alternate microphysics schemes to be easily added to SAM. Work supported by CMMAP (Blossey/Bretherton) and NCAR/ASP (Morrison).