P3 Microphysics in the SCREAM project

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E3SM All-Hands, March 19-21, 2019
What is P3 microphysics?

• P3 is a parameterization of microphysical processes in clouds, that represents the formation and sedimentation of condensed water. (P3, Morrison and Milbrandt, 2015 J. of Atmos. Sciences).

• The processes represented in P3 are an essential closure of cloud processes following the macrophysics scheme (SHOC in the case of SCREAM).

• P3 was designed for weather forecasting models that currently run at or near CRM resolution.
  – SCREAM leverages experience using P3 from the Weather Research and Forecasting (WRF) model community and will feed our experience back to them. This has already happened.

• Our version P3 of balances physical complexity with computational efficiency by simplifying away physical processes that are inconsequential for climate.
  – E.g. We have collapsed the number of ice categories in P3 down to one.
Accomplishments

• Integrated a simple base version of P3 into E3SM
  – Simplified P3-WRF optimized to focus computational effort on climate relevant processes
  – Assumed constant droplet concentration
  – No subgrid cloud variability (cloud-fraction is assumed to 0 or 1 at the grid-scale)
• Extended the base version of P3 to include fractional cloudiness
  – Normalize liquid, ice and rain mass/number mixing ratio by cloud fraction when calculating microphysical processes and determining sedimentation fall-speed
• Extended the base version of P3 to include aerosol activation of droplets and ice particles
• Performed SCM and climate simulation tests to ensure that simulations are physically reasonable
  – check_energy option turned on to ensure energy and water mass is conserved
Porting to E3SM and Feedback to P3-WRF

• Corrected an inconsistency in P3 between WRF and E3SM in the vertical coordinate system
  – Led to water and energy conservation violations
  – Corrected by changing the equations of sedimentation from being $dz$ based to $dp$ based

• Fixed a bug in interpolation of rain fall speed values a lookup table*

• Corrected an inconsistent update of potential temperature that used $\theta/T$ instead of the Exner function*

• Removed unused microphysics tendencies*
  – nchetc, nimul, nrhetc, qchetc, qrhetc, qrmul, qcmul

* fix reported and integrated in updates to community P3 models
Single Column Simulations

Objective

- To determine the physical correctness of modifications to the parameterizations
  - Do modifications to the physics have the expected consequence?
- Simpler/faster to test in the single column rather than global context
Precipitating Shallow Cumulus Clouds (RICO)

- Rain In Cumulus over the Ocean (RICO, Van Zanten et al., 2011)
- Including subgrid cloudiness and aerosol activation in P3 brings cloud fractions closer to those predicted by MG.
- Cloud-fraction is diagnosed based on RH, so the increased cloud fraction in P3-Base indicates higher moisture in the cloud layer.
Precipitating Shallow Cumulus Clouds (RICO)

- The higher moisture in P3-Base is a symptom of the scheme producing no precipitation (a sink on total-water content).
- The lack of precipitation in P3-Base is in turn a symptom of the built in assumption of no sub-cloud variability.
  - This is particularly acute in this case because of RICO’s low cloud fractions.
Precipitating Shallow Cumulus Clouds (RICO)

- The onset of precipitation predicted by P3-SubCld + Aerosol is similar to that predicted by the MG2 scheme.
Climate Simulations

• Objective:
  - To determine if modifications to the model yield simulations that are stable and Earth like.
    • Simulations are carried out at 1-degree resolution.
    • P3 was designed for NWP models run at near or near CRM resolution. We have done no model tuning, so we expect potentially large biases in cloud radiative forcing.
Global annual precipitation

P3 with sub-grid clouds and aerosol activation

P3 baseline

MG2 – for reference
Global annual short wave cloud forcing

P3 with sub-grid clouds and aerosol activation

MG2 – for reference

P3 baseline
Next Steps

• Review saturation adjustment in P3-microphysics and make it consistent with CLUBB and SHOC
• Final clean-up of P3 codebase
  – Check for any lingering bugs or inconsistencies
• Combine P3 and SHOC and examine results
• Port P3 codebase to C++ SCREAM codebase
Extra Slides:
(RICO) Relative Humidity

The diagram illustrates the relative humidity (RELHUM) across different pressure levels (P in hPa) and percent values ranging from 30 to 100. The lines represent different scenarios:
- MG, 9.7526e+01
- P3-Base, 9.7369e+01
- P3-SubClD+Aero, 9.6975e+01

The graph shows how the relative humidity changes with decreasing pressure and increasing percent values.