MPAS consists of geophysical fluid-flow solvers based on unstructured centroidal Voronoi (hexagonal) meshes using C-grid staggering and selective grid refinement.

**MPAS-Atmosphere:**
- Nonhydrostatic global atmospheric model
- Time integration as in Advanced Research WRF
- Spatial discretization similar to ARW except for Voronoi mesh accommodations.

Regional refinements embedded within global models will be the first nonhydrostatic climate applications.

Bill Skamarock, NCAR/MMM
What problems are we trying to circumvent with MPAS?

• Expense of climate/weather simulations – regional refinement cuts costs by an order of magnitude

• Problems with traditional nesting
  Nested-grid systems are non-conforming
  Abrupt changes in resolution are bad
  Fixes are ad hoc (e.g. sponge layers)

• Regional climate/weather modeling problems
  Different driving models and different physics lead to solution mismatches at the lateral boundaries
  Global driving solution, nest solution can diverge over long simulations
  Fixes are ad hoc (e.g. spectral nudging)
Application question:
Can a global variable-resolution convection permitting model provide extended range severe weather guidance?

Modeling question:
Will the physics behave appropriately in the different regions of the mesh (coarse, fine, and transition region)?
Hazardous Weather Testbed
Spring Experiment 2015, 2016
Forecasts Results from MPAS

MPAS meshes:

50 – 3 km (2015) and 15-3 km (2016) variable resolution.
CONUS is the 3 km regions.

MPAS Physics:

- **WSM6 cloud microphysics (2015)**
- **Thompson microphysics (2016)**
- Grell-Freitas convection scheme (scale-aware)
- Monin-Obukhov surface layer
- MYNN PBL
- Noah land-surface
- RRTMG lw and sw.

2015-2016: One step closer to the HRRR physics
Grell-Freitas Convection Scheme in MPAS

Scale-aware/aerosol-aware (Grell and Freitas, 2014, ACP)
• Stochastic scheme (Grell and Devenyi, 2002).
• Scale aware by adapting the Arakawa et al approach (2011).
  o Relates vertical convective eddy transport to convective updraft/downdraft fraction $\sigma$.

$$\rho w \psi = (1 - \sigma)^2 M_c (\psi_c - \bar{\psi})_{adj} \quad \text{with} \quad M_c \equiv \rho \sigma w_c$$

o GF: $\sigma$ is the fractional area covered by active updraft and downdraft plume.

$$\sigma = \frac{\pi R^2}{A_{\text{grid cell}}}$$, $R_{\text{conv}} = 0.2 \frac{\text{km}}{\varepsilon} \Theta_{\text{max}} \approx 100.5 \text{m}^{-1}$

o At convection-permitting resolution, parameterized convection becomes much shallower – cloud tops near 800 mb (down from 200-300 mb).

o Temperature & moisture tendencies decrease as resolution increases.
Precipitation rate over the period 00 UTC 11 Jan and 00 UTC 14 Jan 2014
Fowler et al (2016, MWR)

Grell-Freitas Convection Scheme in MPAS

TRMM precipitation analysis

50-3 km var-res MPAS using Grell-Freitas convective scheme
Grell-Freitas Convection Scheme in MPAS

TRMM precipitation analysis

50-3 km var-res MPAS using Grell-Freitas convective scheme

4 and 8 km cell spacing (red contours)
Grell-Freitas Convection Scheme in MPAS

Fowler et al (2016, MWR)
1-31 May 2016 Accumulated Precipitation
MRMS Analysis and MPAS Forecasts

Accumulated precipitation (in)

0-24h MPAS forecasts
24-48h MPAS forecasts
48-72h MPAS forecasts
72-96h MPAS forecasts
96-120h MPAS forecasts
Hazardous Weather Testbed
Spring Experiment 2015, 2016
Forecasts Results from MPAS

Verification region

[Map showing the verification region in the United States]
Hazardous Weather Testbed
Spring Experiment 2015, 2016

Forecasts Results from MPAS

Hourly Precipitation Rate
1 - 31 May 2015 (31 forecasts)
MPAS 50-3 km mesh, daily 5-day 00 UTC forecasts
Central US analysis region

Hourly Precipitation Rate
1 - 31 May 2016 (31 forecasts)
MPAS 15-3 km mesh, daily 5-day 00 UTC forecasts
Central US analysis region

Forecasts Lead Time (hours)
Hazardous Weather Testbed
Spring Experiment 2015, 2016
Forecasts Results from MPAS

Precipitation Rate PDF
1 - 31 May 2015, 2016 (31 forecasts each year)
MPAS 50-3 and 15-3 km meshes, daily 5-day 00 UTC forecasts
Central US analysis region

[Graphs showing precipitation rate probability distribution for 2015 and 2016, with MPAS forecast and MRMS analysis lines]
Hazardous Weather Testbed
Spring Experiment 2015, 2016

Forecasts Results from MPAS

Equitable Threat Score and Bias
1 - 31 May 2015 (31 forecasts)
MPAS 50-3 km mesh, daily 5-day 00 UTC forecasts
Central US analysis region

Equitable Threat Score and Bias
1 - 31 May 2016 (31 forecasts)
MPAS 15-3 km mesh, daily 5-day 00 UTC forecasts
Central US analysis region
Variable-resolution, nonhydrostatic-scale atmospheric simulations are viable

- Variable-resolution mesh is producing clean solutions in the mesh transition region.
- GF convection scheme appears to be viable for hydrostatic-nonhydrostatic scale-aware applications. Further work/tuning needed, particularly in the tropics.
- Fidelity of convection similar to that in ARW.
- Simulation rates >100 days/day are attainable.
  (operational centers could do this today)

Challenges

Scale-aware physics:
- Convection
- Microphysics
- Boundary layer

Data assimilation on variable meshes.

Physics for climate applications?
Community Earth System Model (CESM)
- MPAS-A is an atmospheric dynamical core in CAM
- NWP testing is underway, focused on tropical cyclones
- Coupled model simulations are underway (w/ocean)
- Physics evaluation for NWP is major focus of early testing
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Regional MPAS-Atmosphere
- We are constructing a regional version of MPAS-A
- General release (MPAS Version 6) mid-late 2017
MPAS Development Plans

Community Earth System Model (CESM)

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MPAS-Atmosphere and Data Assimilation

• DA work underway with DART and NCEP/GSI

MPAS-Atmosphere and shared model components

• We are developing a common physics repository for MPAS and WRF
• We are planning to link CAM build to MPAS-A from the MPAS-A development/release repository

MPAS-Atmosphere drives regional WRF (one-way) – MPAS V5 release (late 2016).

MPAS-Atmosphere optimizations

• Current development dycore is now multithreaded and hybrid (OpenMP and MPI), and is bit-reproducible regardless of parallel configuration
• Recent optimizations – development dycore is twice as fast as current (V4) release. Available in V5 release.
• Ongoing work for next generation architectures (Intel MIC, GPUs)