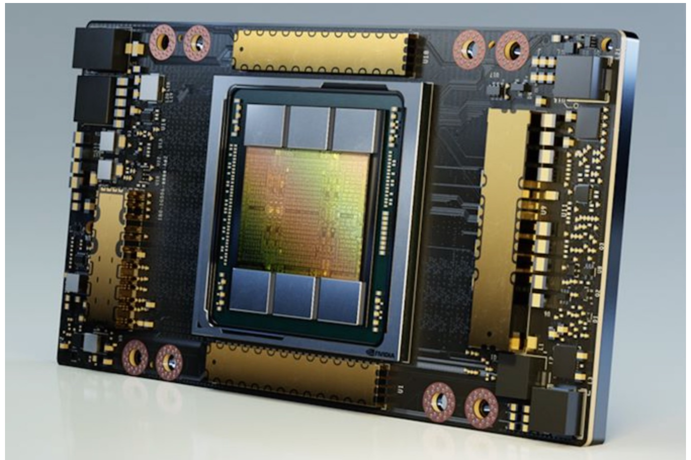
The Model for Prediction Across Scales Atmosphere

MPAS
Model for Prediction Across Scales

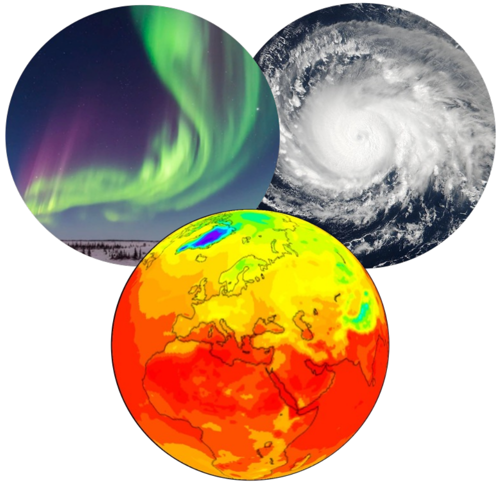
MPAS-Atmosphere and the future

MPAS-A and GPUs

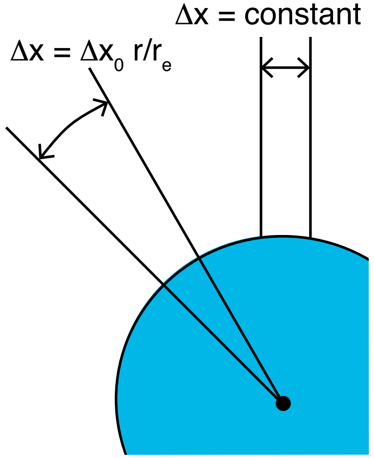


NVIDIA Ampere A100 GPU

MPAS-A in an Earth System Model



Deep-Atmosphere MPAS-A



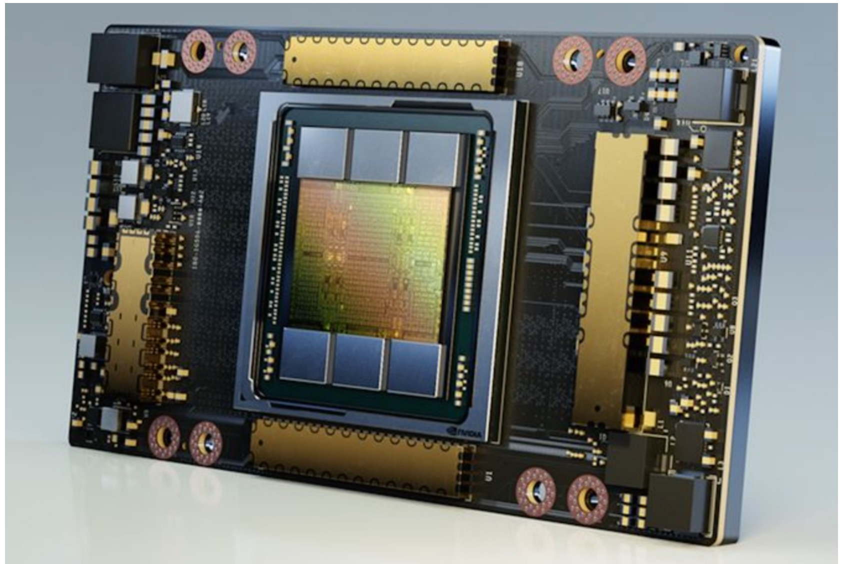
Bill Skamarock, NCAR/MMM, for the MMM-MPAS team and many community collaborators

Coming in the next release (Version 8):

- Physics updates
- Clean-up in dynamics parallelization
- Support for the use of MPAS-A dynamics in CESM
- New I/O library (SMIOL); alternative to PIO
- New halo exchange infrastructure (support GPUs)
- Updates to LBCs in regional MPAS to improve robustness
- Additional post-processing capabilities

MPAS and GPUs

We released the GPU-enabled MPAS-Atmosphere in October 2020 as a branch from MPAS Version 6.1. We have a Version 7 update but it has not been released.



NVIDIA Ampere A100 GPU

What is in current (2020) release:

- GPU-enabled MPAS dynamical core using OpenACC directives.
- Some GPU-enabled physics (e.g. YSU, WSM6, M-O, scale-aware nTiedtke)
- Asynchronous execution capability on heterogenous architectures - currently radiation (lagged) and NOAH land model on CPUs, all else on GPUs
- Configurations tested and validated on IBM POWER9 architectures and on AMD architectures employing NVIDIA V100 and A100 GPUs.

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MPAS and GPUs

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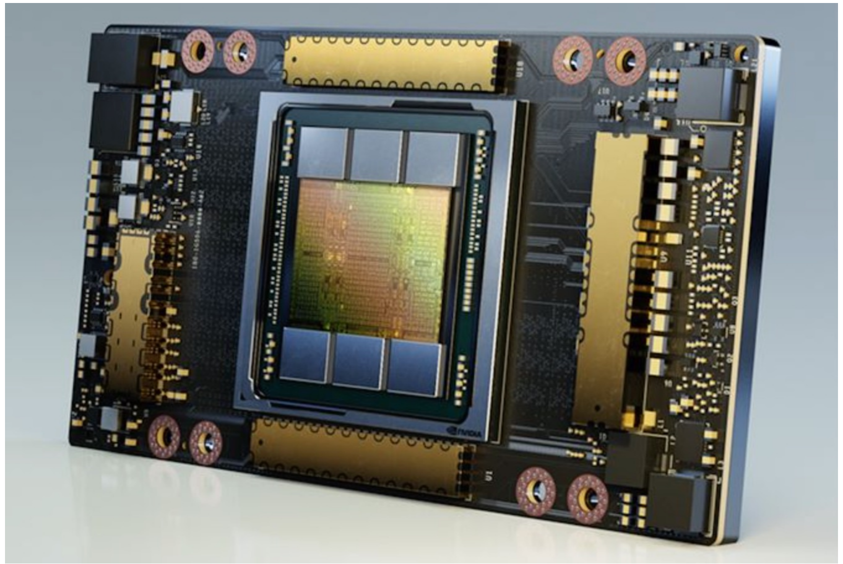


NVIDIA Ampere A100 GPU

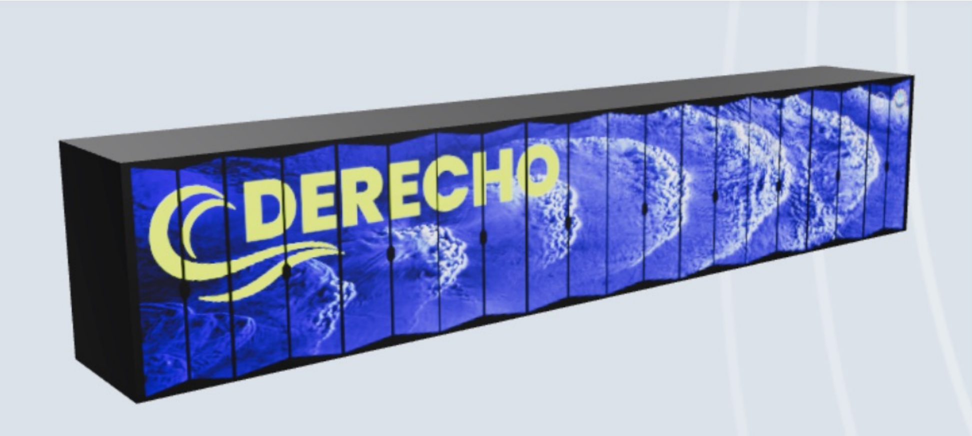
What is *NOT* in this release:

- Regional capability
- Most of the physics options

Extending the global GPU capability to regional is straightforward. Additional physics ports to GPUs take significant time and resources; we are leveraging other projects to enable additional GPU physics.

MPAS and GPUs – Plans

NCAR’s next supercomputer will have significant GPU capabilities.
DERECHO – 82 GPU nodes
(4 A100 GPUs per node).



As DERECHO becomes available

- Test and release global configurations
- Enable regional configurations, test and release
- Bring in other GPU-capable physics as they become available
  - RRTMG-P
  - Other microphysics (MG3/PUMAS)
- MPAS single-source release of the of the dynamical core, separate GPU and CPU physics

Issue: Moving (physics community) developers to GPU code.

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System for Integrated Modeling of the Atmosphere (SIMA)

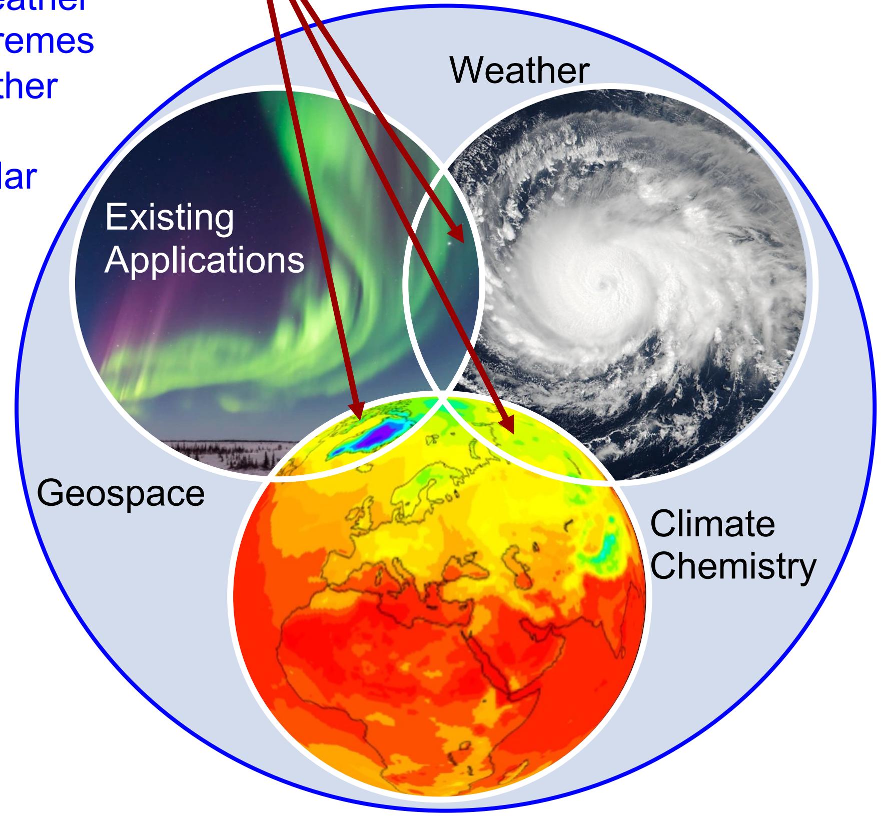
SIMA is composed of common atmospheric model components & infrastructure embedded in an earth-system model

SIMA Vision

- Encompass Climate, Weather, Chemistry & Geospace
- Prediction (Initialized and Forecast) capabilities
- Complement & extend existing applications (CESM/WRF/MPAS)
- Shared infrastructure for efficiency
- Minimal set of components
- ‘Center Wide’ project including education, observations, computation

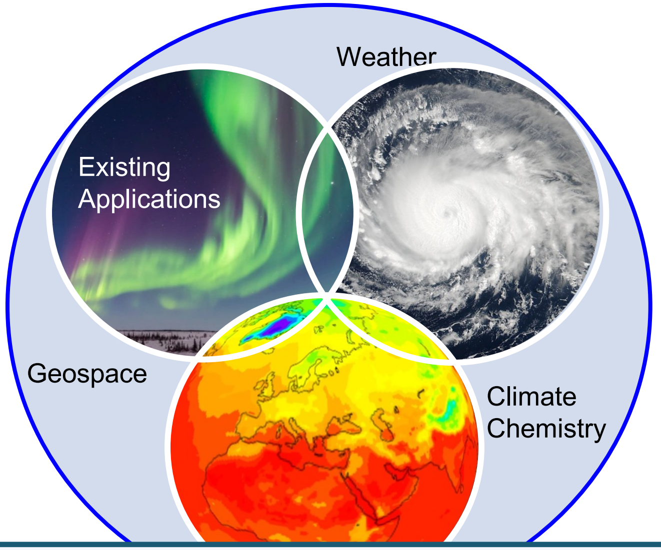
SIMA Frontier Applications

- Coupled Weather
- Climate Extremes
- Space Weather
- Air Pollution
- Coupled Polar



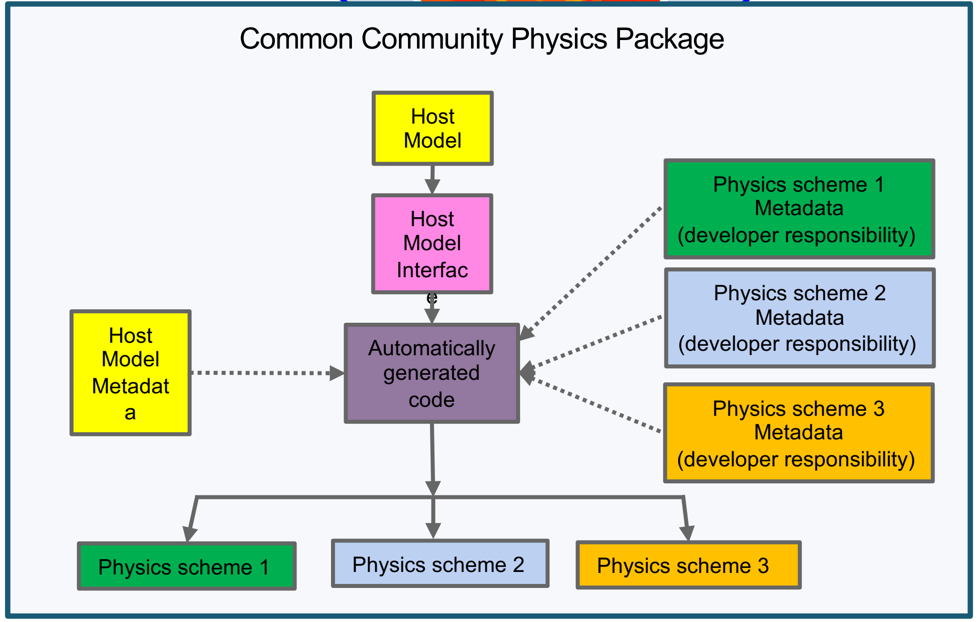
System for Integrated Modeling of the Atmosphere (SIMA)

MPAS
Model for Prediction Across Scales



(1) MPAS-Atmosphere in an Earth System Model (ESM), using CESM components. Other ESM components: ocean, land, land and sea ice, chemistry

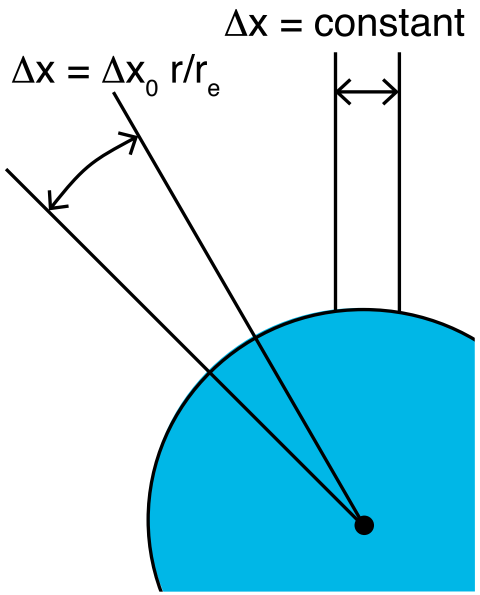
(2) WRF/MPAS physics in an ESM using the Common Community Physics Package (CCPP) interface.



Status:

- *MPAS-A in CESM is being tested.*
- *Only CESM/CAM physics will be available in this first release.*
- *CCPP implementation in MPAS and CESM is not yet complete.*
- *Initial release (experimental) TBD.*

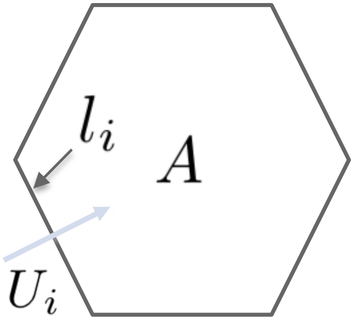
Deep Atmosphere: Geometry



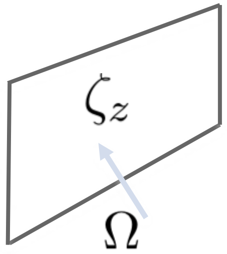
$$\frac{\partial \tilde{\rho}}{\partial t} = \nabla_\zeta \cdot \mathbf{V_H} + \frac{\partial \Omega}{\partial \zeta} \qquad \tilde{\rho} = \frac{\rho}{\zeta_z}, \quad \mathbf{V_H} = (U, V) = (\tilde{\rho} u, \tilde{\rho} v), \quad \Omega = \tilde{\rho}\dot{\zeta}$$

(shallow atmosphere)

Hexagonal grid cell:



horizontal



vertical

$$\frac{\partial \tilde{\rho}}{\partial t} = \frac{1}{A_0} \sum_{i=1}^{n} U_i l_{0_i} + \frac{\Delta \Omega}{\Delta \zeta}$$

$A_0, l_{0_i} =$ Cell area and edge lengths at surface

Shallow Atmosphere: $\tilde{\rho} = \frac{\rho}{\zeta_z}, \quad U_i = \tilde{\rho} u_i, \quad \Omega = \tilde{\rho}\dot{\zeta} \quad (A = A_0, \quad l_i = l_{0_i})$

Deep Atmosphere: $\tilde{\rho} = \frac{A}{A_0}\frac{\rho}{\zeta_z}, \quad U_i = \frac{A_0}{A}\frac{l_i}{l_{0_i}} \tilde{\rho} u_i, \quad \Omega = \tilde{\rho}\dot{\zeta}$

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Deep Atmosphere: Gravity and Ω

Shallow atmosphere

$$\frac{\partial U}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\nabla_\zeta\left(\frac{p}{\zeta_z}\right) + \rho_m g\,\nabla_\zeta z\right] - \eta\,\mathbf{k}\times\mathbf{V}_H - \mathbf{v}_H\nabla_\zeta\cdot\mathbf{V} - \frac{\partial\Omega\mathbf{v}_H}{\partial\zeta} - \tilde{\rho}_d\nabla_\zeta K + \mathbf{F}_{V_H}$$

$$\frac{\partial W}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\frac{\partial p}{\partial\zeta} + g\tilde{\rho}_m\right] - \left(\nabla\cdot\mathbf{v}\,W\right)_\zeta + F_W$$

Deep atmosphere

$$\frac{\partial U}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\nabla_\zeta\left(\frac{p}{\zeta_z}\right) + \rho_m g\left(\frac{r_e}{r}\right)^2\nabla_\zeta z\right] - \eta\,\mathbf{k}\times\mathbf{V}_H - \mathbf{v}_H\nabla_\zeta\cdot\mathbf{V} - \frac{\partial\Omega\mathbf{v}_H}{\partial\zeta} - \tilde{\rho}_d\nabla_\zeta K + \mathbf{F}_{V_H} - \left(eW\cos\alpha_r + \frac{uW}{r}\right)$$

$$\frac{\partial W}{\partial t} = -\frac{\rho_d}{\rho_m}\left[\frac{\partial p}{\partial\zeta} + g\left(\frac{r_e}{r}\right)^2\tilde{\rho}_m\right] - \left(\nabla\cdot\mathbf{v}\,W\right)_\zeta + F_W + \left[\frac{uU+vV}{r} + e\left(U\cos\alpha_r - V\sin\alpha_r\right)\right]$$

Additional terms

Gravity (blue)
Coriolis (red)

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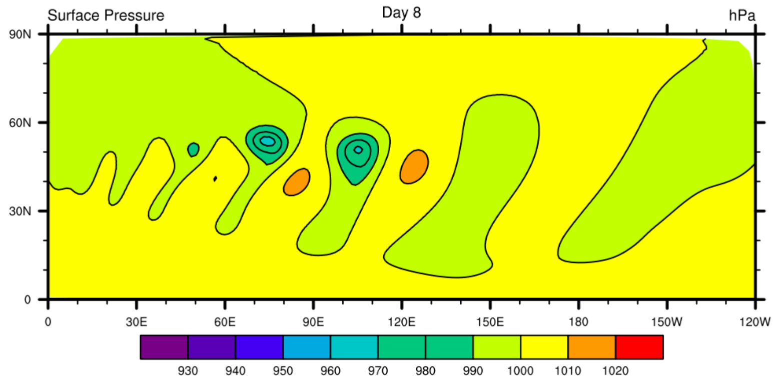
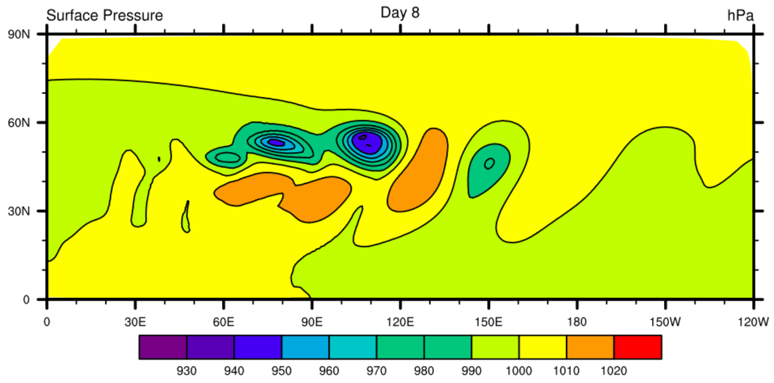
Baroclinic wave test, reduced radius sphere
(radius = $r_e/20$, $\Omega = 20\,\Omega_e$)

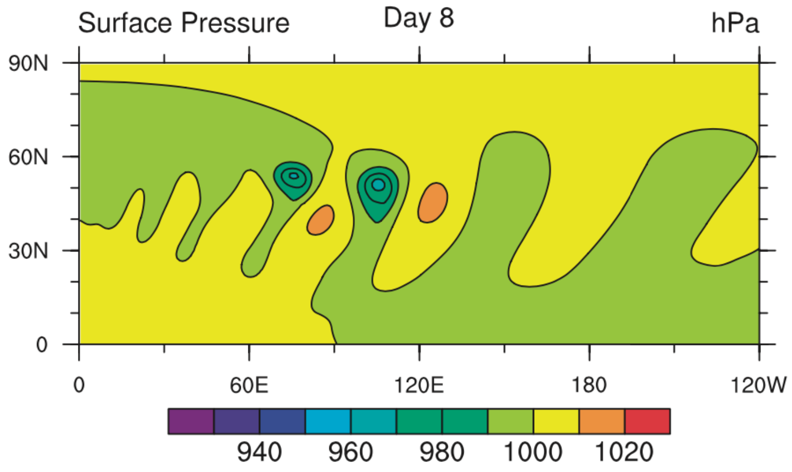
Shallow atmosphere | Deep atmosphere

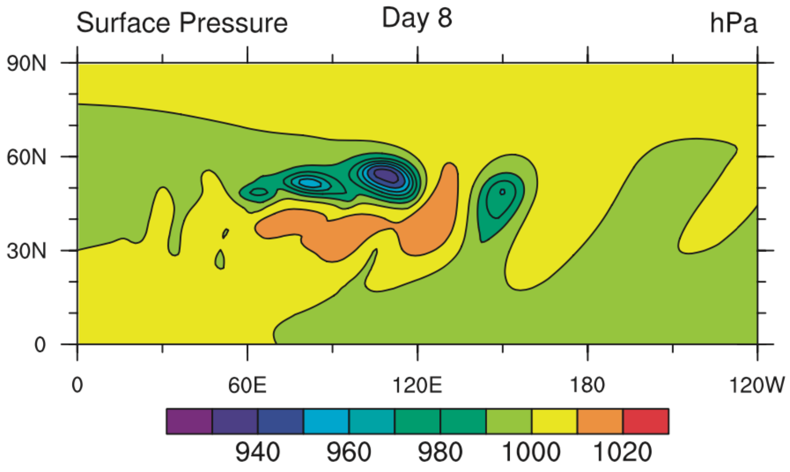
MPAS





MCore



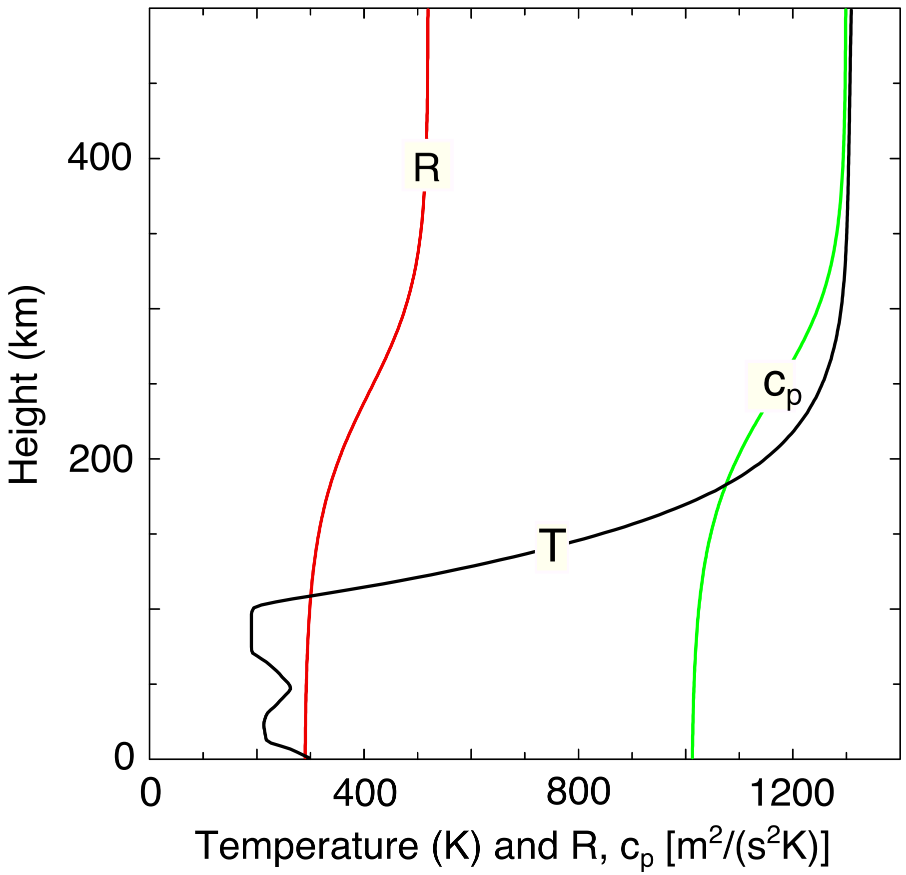


(Ullrich et al 2013, JAMES)

Further out:

- Development and release of a geospace – capable solver (2D prototype design and testing are largely complete).
  - Variable (prognostic) constituents (O, O_2, N_2);
    doi:10.1029/2021MS002499 (JAMES 2021)
  - Constant pressure upper boundary condition to accommodate thermospheric diurnal heating/cooling;
    doi:10.1175/MWR-D-21-0328.1 (MWR 2022)
  - Numerics for large physical viscosities
  - Geospace physics

2D (x,z) MPAS prototype



Also under development…

LES capabilities – we have an LES branch that incorporates a 3D Smagorinsky (diagnostic) scheme and a 1.5 order prognostic TKE scheme.

Scalar transport in physics parameterizations (convection, boundary layer)

Prognostic ozone

Mesh generation, global and regional

Coming Events

Version 8 release - before the WRF-MPAS Workshop this June (2023)

WRF-MPAS workshop
Tues-Fri 20-23 June 2023 (in person). Registration opens 15 May

MPAS + MPAS-JEDI tutorial, 18-22 September 2023 (in person)

We’ve begun work on an MPAS NCAR Technical Note. Available sometime 2024