Task-Based Climate Modeling

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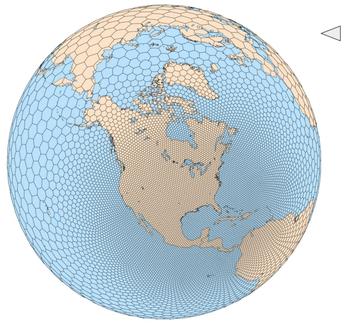
Motivation

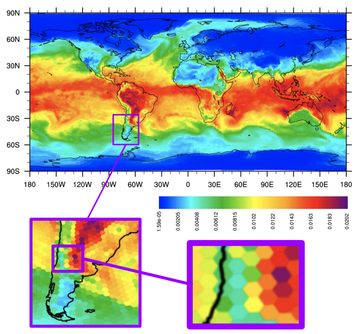
Earth System Models (ESMs) simulate global and regional climate through an integration of atmosphere, ocean, land, ice, and biosphere interactions.

ESMs can **predict changes in climate** caused by humans, as well as heighten our understanding of natural variations of weather patterns.



◁ Voronoi mesh cell grid from the Model for Prediction Across Scales (MPAS), an ESM built by the Los Alamos National Labs and the National Center for Atmospheric Research [1]

Example MPAS output; horizontal cell plot with individual cell polygons colored according to their field value [1] ▽



PROBLEM:
Existing models are **legacy systems**:

- ➢ Fail to take advantage of modern hardware
- ➢ CPU-based
- ➢ Explicitly parallel

GOAL:
Build atmospheric framework for an **implicitly parallel ESM in Regent**, targeting heterogeneous systems. Use the Model for Prediction Across Scales (MPAS) as a reference. Ultimately, achieve **higher performance with less code.**

Background

In Regent programs are composed of **tasks** — functions that automatically execute in parallel if mutually independent.

Regent implements **logical regions** and a rich **partitioning system** for working with collections of data.

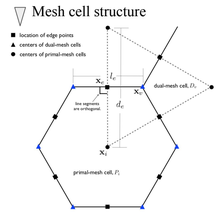
Applications for our project:

- ➢ task-based structure provides machine portability
- ➢ code generation for both CPUs and GPUs
- ➢ smaller codebase

Methods

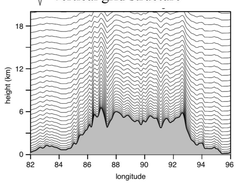
MPAS	vs.	Regent
Fluid and Thermodynamic Functions		
- subroutines + modules		- tasks
Data Structures		
- conglomerate variable “pools” - core storage/retrieval		- field spaces and regions
Parallelization		
- blocks - threads - start/end cells - start/end vertices - start/end edges - halos		- implicit

▽ Mesh cell structure




```
<var_struct name="mesh" time_levs="1">
    <var name="latCell" type="real" dimensions="nCells" units="rad"
         description="Latitude of cells"/>
    <var name="lonCell" type="real" dimensions="nCells" units="rad"
         description="Longitude of cells"/>
    <var name="indexToCellID" type="integer" dimensions="nCells" units="-"
         description="Mapping from local array index to global cell ID"/>
    ....vertex, edge, fluid dynamic fields...
</var_struct>
```

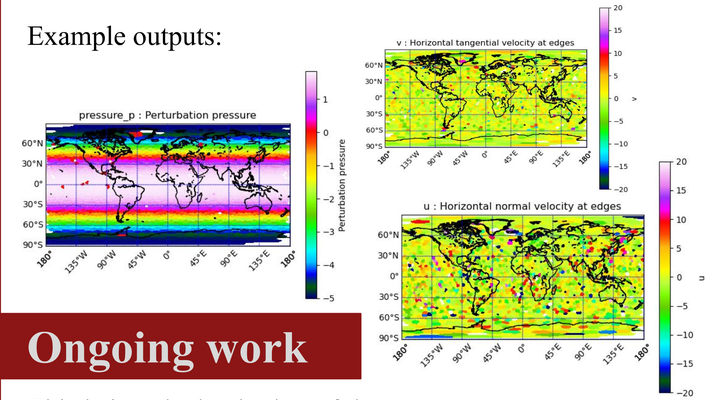
▽ Vertical grid structure



Results

- ➢ ~⅔ of atmospheric functions converted to Regent
- ➢ Initial end-to-end framework of atmospheric model
  - ○ Read mesh file
  - ○ Vertical initialization
  - ○ Runge-Kutta timestep loop
  - ○ Output plotted
- ➢ CPU-based with GPU code generation in progress

Example outputs:



Ongoing work

This is just the beginning of this project!
Still to go:

- ➢ Completion of atmospheric task ports
- ➢ Integration of Ocean, Sea-Ice, Land-Ice, and Shallow Water modules
- ➢ Real data start-state
- ➢ Extending Regent compiler for projections of regions

Acknowledgements & Sources

Thank you to Elliot Slaughter for his technical guidance on Regent usage.

[1] *MPAS-Atmosphere User’s Guide*. Duda, M., Fowler, L. , Skamarock, B., Roesch, C., Jacobsen, D., Ringler, T., (2019).
[2] *Regent: A High-Productivity Programming Language for HPC with Logical Regions.* E. Slaughter, W. Lee, S. Treichler, M. Bauer and A. Aiken, (2015).
[3] https://mpas-dev.github.io/
[4] https://github.com/MPAS-Dev/MPAS-Model