MPAS Ocean Testing and Testbed Plan: Requirements and Design

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Chapter 1

Summary

This document describes an overall test plan for verifying and validating the MPAS Ocean model and to a lesser extent, ocean models in general. A hierarchy of such tests is described. This document should evolve as more tests are defined and when new failure modes are identified, related tests should be added to this test suite.

Chapter 2

Requirements

2.1 Initial Condition Generator

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Contributors: (Doug Jacobsen, others?)

Because of the variety of initial conditions and grids required for the various test cases, an initial condition generator will be developed. This code will include routines for modifying existing grids, removing portions of the grid, as well as applying initial conditions for all fields required to run a test case.

2.2 Unit Tests

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Contributors: (Phil Jones)

When possible, specific modules or operators should have a defined unit test that can test the behavior against an analytic or known result. While this may be difficult for more complex operators or parameterizations, it should be possible for much of the infrastructure routines and well-defined operations like the equation of state for which reference values are available.

2.3 Intermediate tests

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Contributors: (Doug Jacobsen, Phil Jones)

Well-defined test cases should be defined for partial or simpler configurations that test more than one aspect of the code base. Examples include advection tests and shallow water test cases. Results from these tests may not be simple objective evaluations (e.g. tradeoffs between dispersion, diffusion and monotonicity in advection), but should provide a framework and quantitative measures within which the configuration can be judged.

2.4 System tests

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Contributors: (Doug Jacobsen, Phil Jones)

Full system tests are required to provide a validation of the model against observational data.

2.5 Regression Tests

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Some subset of the above test, including all of the unit tests, should be included in an automated test suite with a script that can perform and evaluate each tests on a regular (e.g. nightly) basis. Such tests require a method for a simple pass/fail evaluation of each included test.

Chapter 3

Design and Implementation

3.1 Initial Condition Generator

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Contributors: (Doug Jacobsen, Others?)

This tools is expected to read in an MPAS grid file. Based on user input, a suitable test case will be selected, which can be either pre-defined or user-defined. Pre-defined examples include those described in this document, where a user-defined one might be something specific a user would want to run. On reading in the grid file, the geometry needs to be modified to fit the test case of interest. For example, if a basin or channel test case is to be used portions of the grid will be removed to build a basin or channel geometry.

After the geometry is initialized for the test case, the initial conditions will be generated for that test case. These will include fields such as fluid thickness, number of layers, initial velocity, temperature, salinity, etc. Finally, the new grid file using the modified geometry and initial conditions will be written to a new grid file which will be readable by MPAS.

The tool will be written and documented to allow a user to easily use it to generate grid for specific test cases, as well as add new test cases to it. After this tool is complete module_test_cases.F can be removed from both core_sw and core_ocean as all test cases for these two cores will be included in the tool.

The layout of the program will be as follows.

```
Read in input parameters.
        Could contain things like what test case to use.
```

```
Read in input grid file.
        To perform grid cutting we only really need to store
        the coordinates of cells, edges, and vertices.

Using coordinates, build masks for cells edges and vertices.

Build a new grid by applying the masks.

Copy the needed grid data to the new grid file.

Generate initial conditions required for test case.
        Need to ensure all fields are created that are
        required for MPAS to run.
```

To begin, a single ocean test case will be implemented to allow testing of ocean branches. Shallow water test cases should be easily implemented. Afterwards, the rest of the ocean test cases can be implemented.

The test case of choice could be a compile time parameter, or a run time parameter. Each has it's own benefits. Test cases can also be developed as classes, which might allow easier development of new ones.

3.2 Unit Tests

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Contributors: (Doug Jacobsen, Phil Jones)

Unit tests can be defined for the following modules.

3.2.1 Halo Updates

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A test case for testing the validity of values in the halo region for halo updates should be defined. This test should include a variety of grids and decompositions to cover any previous failure modes and potentially problematic combinations of grids and decompositions.

3.2.2 Global Reductions

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A test case for ensuring accurate computation of global reductions of a known field should be defined. Tests for all supported interfaces (e.g. integer, real, double, logical fields) and all supported reduction operators (sum, min, max, masked sum) should be included. If a bit-reproducible implementation is available, bit-reproducibility across different node/processor counts should be tested.

3.2.3 I/O

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Contributors: (Doug Jacobsen, Phil Jones)

Tests of the I/O system should validate whether fields are accurately written and read to a file. Multiple grid and processor configurations should be included.

3.2.4 Equation of State

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Contributors: (Doug Jacobsen, Phil Jones)

A unit test for returning the proper values of the ocean equation of state should be included. Reference density values for a few specific p,T,S combinations are known and published for the typical equation of state implementations.

3.3 Intermediate Tests

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Contributors: (Doug Jacobsen, Phil Jones)

Several intermediate tests are either published or commonly used. Some have analytic results while others must be compared to reference simulations, typically at high resolution.

3.3.1 Lock Exchange/Dam break Test

2-Dimensional domain:

- X direction: $0 \leq x \leq L$ and $L = 64km$
- Y direction: $-H \leq z \leq 0$ and $H = 20m$

No rotation.

Constant sailinty: $35psu$
Temperature profile:

- $0 \leq x < L/2$ - $T = 5^oC$
- $L/2 \leq x \leq L$ - $T = 35^oC$

Linear equation of state.

Horizontal grid spacing:

- $\Delta x = 500m$, $1km$, $2km$, $4km$.

Vertial grid spacing (Z-level):

- $\Delta z = 1m$, $2m$, $4m$, $10m$.

Vertical grid (Isopycnal): 21 layers

Time step: $1s$

Lateral Laplacian Viscosity: $10^{-2}m^2/s$
Vertical Viscosity: $10^{-4}m^2/s$

17 hour simulation.

3.3.2 Re-entrant Channel with Baroclinic Eddies Test

3-Dimensional domain:

- Latitudinal extent: $500km$
- Longitudinal extent: $160km$
- Vertical extent: $1000m$ - flat bottom

Temporal Extent: 200 Days
f-plane - Coriolis parameter: $1.2 * 10^{-4}$ (55^o Latitude)

Bottom drag - Quadratic: $C_d = 0.01$.

Horizontal grid spacing: $1km$, $4km$, $10km$.

Barotropic time step: $200s$, $10s$

Horizontal Viscosity: $20m/s^2$

Linear Density
Salinity: 35.0
Temperature Profile:

Step 1: Initialize with stratified temperatures.

- Surface Temp: 13.1^oC
- Bottom Temp: 10.1^oC

Parameters:

- y_0 = 200.0km
- x_0 = 0km
- x_1 = 160.0km
- x_2 = 110.0km
- x_3 = 130.0km
- α = 40.0km

Step 2: Add temperature gradient.

- For each cell.
- $cff1 = \alpha * sin(6 * \pi * (xCell - x_0)/(x_1 - x_0))$
- If $(yCell > y_0 - cff1)$
  - $temp = temp - 1.2$

- Else if $(yCell \geq y_0 - cff1 \;\&\; yCell \leq y_0 - cff1 + \alpha)$
    - $temp = temp - 1.2 * (1.0 - (yCell - (y_0 - cff1))/(1.0 * \alpha))$

Step 3: Add Instability.

- For each cell.
- $cff1 = 0.5 * \alpha * sin(1.0 * \pi * (xCell - x_2)/(x_3 - x_2))$
- If $(yCell \geq y_0 - cff1 - 0.5 * \alpha \;\&\; yCell \leq y_0 - cff1 + 0.5 * \alpha$
- $\&\; xCell \geq x_2 \;\&\; xCell \leq x_3)$
    - $temp = temp + 0.3 * (1.0 - ((yCell - (y_0 - cff1))/(0.5 * \alpha)))$

3.3.3 Overflow Test

2-Dimension Domain:

- Horizontal Extent: $200km$
- Vertical Extent: $2km$
- Temporal Extend: $6hr$

Horizontal Spacing: $1km$
Vertical Spacing: $40m$, $30.3m$, $20m$

Vertical Levels:

$$n = N*(1.0/4.0)+0.5*(N*(3.0/4.0))*(1.0+tanh\,(yCell - 40000.0)/7000.0))) \tag{3.1}$$

n is the number of vertical levels in a cell, and N is the max number of vertical levels, defined by the vertical extent and spacing.

Salinity: 35
Temperature Profile:

- if $(yCell < 20000)$ then
    - $Temperature = 10^oC$
- else
    - $Temperature = 20^oC$

No Rotation

3.3.4 Internal Wave Test

2-Dimensional Domain:

- Horizontal Extent: $250km$
- Vertical Extent: $500m$ - Flat Bottom
- Temporal Extent: $200 Days$

Horizontal Spacing: $5km$, $25km$
Vertical Spacing: $25m$
Time step: 300s

Salinity: 35

Temperature Profile:

- Surface Min: 10.1^oC
- Surface Max: 20.1^oC
- $Temperature = (surfMax - surfMin) * ((-z + totalZ)/totalZ) + surfMin$

Anomoly:

- $y_a = 50.0e3$
- $y_0 = 150.0e3$
- $A_0 = 0.2, 2.0$
- If $(|yCell - y_0| < y_a$
  - $\beta = -A_0 * (\cos(0.5 * \pi * (yCell - y_0)/y_a) * \sin(1.0 * \pi * (z - 0.5 * (totalZ/N))/totalZ))$
  - $Temperature = Temperature + \beta$

No Rotation

3.3.5 Re-entrant Channel with Ridge

3-Dimension Domain:

- Longitudinal Extent: $320km$
- Latitudinal Extent: $160km$
- Vertical Extent: $2km$
- Temporal Extent: 150 years?

Horizontal Spacing: $80km$, $40km$, $20km$, $10km$
Vertical Spacing: $80m$, $50m$
Time step: ??

Salinity: 35
Temperature Profile:

- If top three levels
  - $Temperature = 7.0{+}5.0{*}tanh(2{*}(yCell{-}ymid)/(ymax{-}ymid))$
- Remainder of domain is linear to bottom
  - $Temperature = (3.5 - Temperature@(k = 3)) * (k - 3)/(40 - 3) + Temperature@(k = 3)$

@(k=3) means in the third level.

Surface Temperature and Salinity restoring equal to the top level.

Wind stress:
$\tau = u_src_max * e^(- (yEdge - ymid) * *2/(r * *2))$
$r = 3.0e5m$
$u_src_max = 0.1$

$\beta = 1.4e - 11$
$f0 = -1.1e - 4$
$\Omega = 7.29212e - 5$

3.3.6 Advection Tests

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Contributors: (Doug Jacobsen, Phil Jones)

Advection algorithms are often tested by advecting a shape around the surface of the Earth. Such a test should be included. Add details on specific test case...

3.3.7 Shallow Water Test Cases

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Contributors: (Doug Jacobsen, Phil Jones)

Add specifics here

3.3.8 Channel Test Case

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Contributors: (Doug Jacobsen, Phil Jones)

A channel configuration is a good test of eddy processes and ACC flow. A standard configuration is defined as (dimensions, forcing)....

N. Atlantic variant

Variants of the channel case are useful. For example, adding a North Atlantic basin (simple box) can be used.

3.3.9 Double-gyre

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Contributors: (Doug Jacobsen, Phil Jones)

The double-gyre configuration is a commonly explored case in the ocean community and can be used to test both boundary interactions and viscosity formulations. A variety of configurations can be used.

Double-gyre variant 1

Double-gyre variant 2

3.3.10 Mixed layer tests

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Vertical mixing and mixed/boundary layer parameterizations can be tested using a simple 2-d configuration with depth as one dimension and space/time as the second. A variation in surface buoyancy forcing can be imposed in the space/time direction to mimic either spatial variability or diurnal cycling.

3.3.11 Equatorial Pacific

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An equatorial Pacific configuration is also a good test of vertical mixing in a configuration that includes both wind and buoyancy forcing as well as realistic ocean conditions. Specifics to be added...

3.3.12 Overflows

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An overflow test case is useful to explore both vertical coordinate choices as well as any specific overflow parameterizations. More details here (DOME configuration?).

3.4 Full System Tests

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3.4.1 CORE forced case

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The Common Ocean Reference Experiment (CORE) defines a useful test case for a full ocean simulation and comparisons with existing models can be performed. More detail...

3.4.2 Variable resolution tests?

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3.4.3 High resolution tests?

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