Irregular grids

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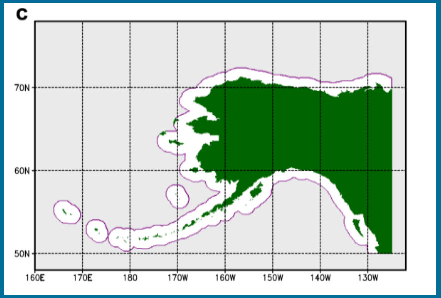
Covered in this lecture:

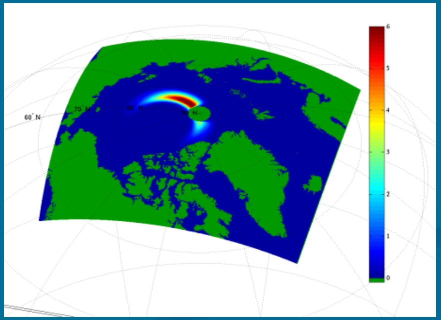
- Introduction to grid types, with focus on irregular grids
- Documentation
- User input
- Calculation method
- Example applications
  - Cartesian (meters) grids
  - Spherical (degrees) grids
- Multi-grid implementation
  - Methods
  - Example application: Arctic grids

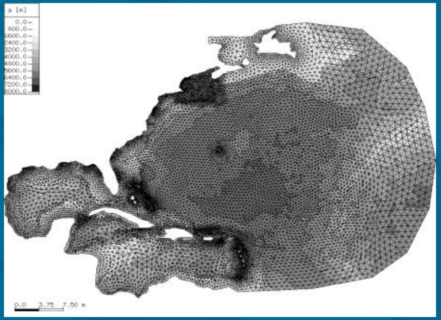
Grid types: introduction

- regular grids
  - WW3 v3.14 is limited to these types
  - user specifies x0,y0,dx,dy,nx,ny
  - this describes x(i) and y(j)
- irregular grids
  - new in v4.01 (in development trunk)
  - user specifies x(i,j) and y(i,j)
- unstructured grids
  - new in v4.xx (in development trunk)
  - user specifies a “GMESH” grid file containing node and element lists.

All three can be applied with spherical (degrees lat/lon) or Cartesian (meters) coordinate system.

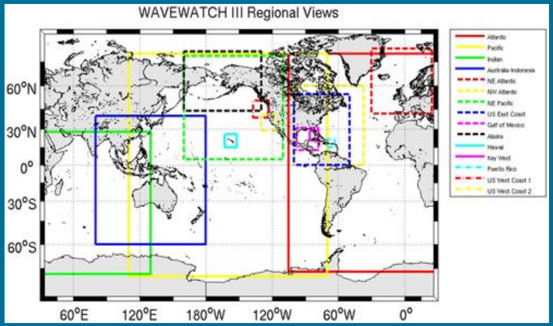




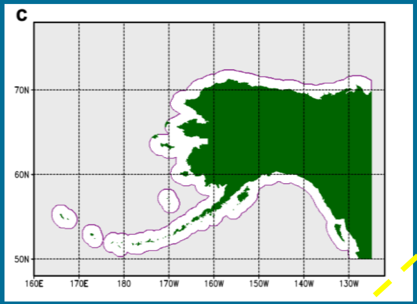


Grid methods: overview

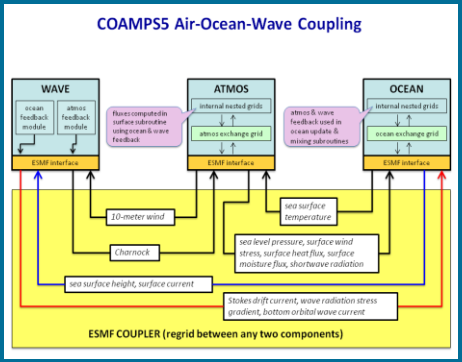
NCEP (NWS): multi-grid modeling



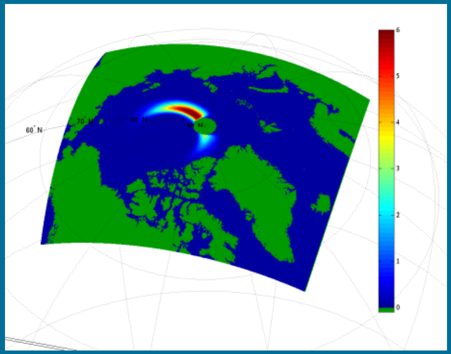
NCEP (NWS): regular grids w/irregular boundaries (coastal domains)



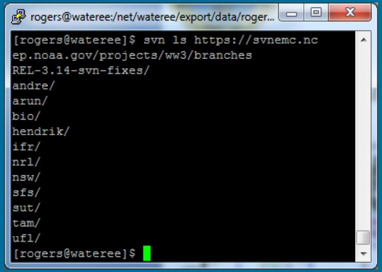
NRL: ESMF integration



NRL: irregular (e.g. curvilinear) grids

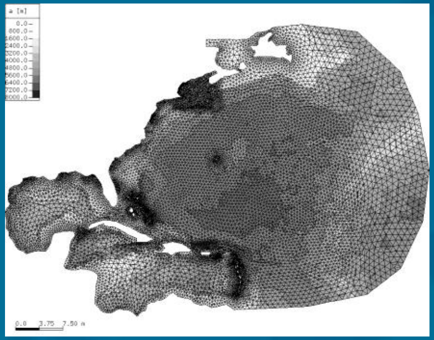


version control



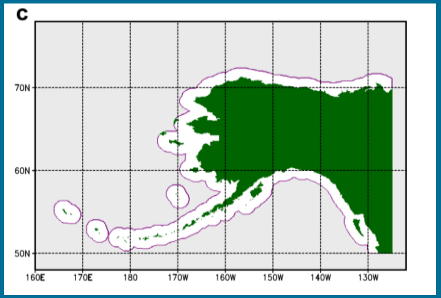

```
[rogers@wateree]$ svn ls https://svnemc.nc
ep.noaa.gov/projects/ww3/branches
REL-3.14-svn-fixes/
andre/
arun/
bio/
hendrik/
ifr/
nrl/
nsw/
sfs/
sut/
tam/
ufl/
[rogers@wateree]$
```

Ifremer (France): unstructured grids



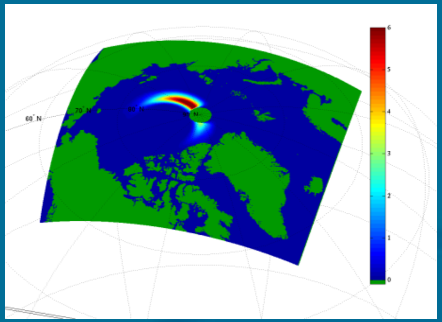
Grid types: introduction

- regular grids
  - most primitive type of grid
  - traditionally this type of grid is wasteful, e.g. high resolution where it isn't required
  - …but with WW3, this isn't actually the case (example shown of coastal grid)



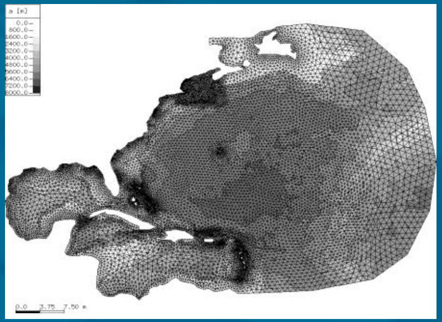
Grid types: introduction

- irregular grids
  - common type: coastline following grid.
    - effective for simple coastlines
    - not as effective with islands in grid
  - another common type: larger scale grids designed so that grid spacing is roughly uniform in real distances (example shown)
    - commonly used by meteorologists



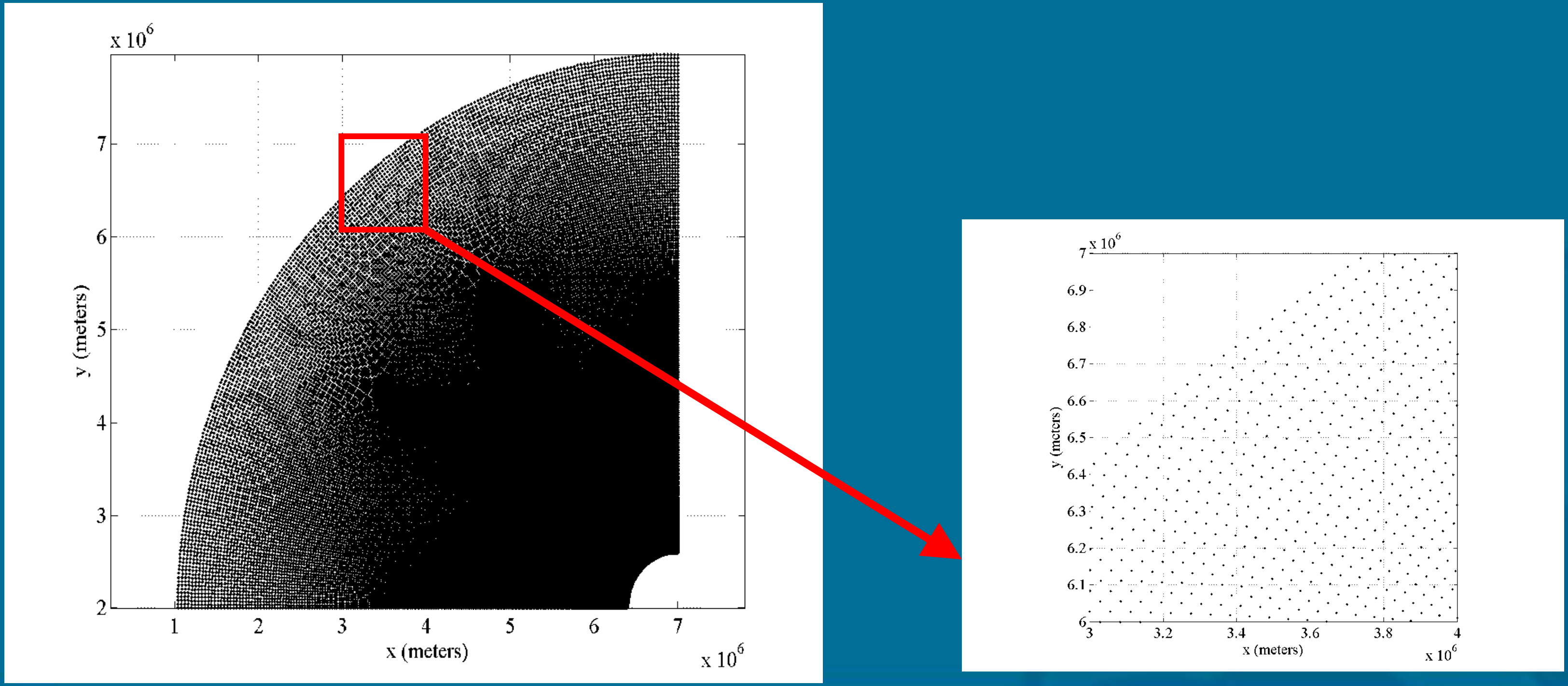
Grid types: introduction

- unstructured grids
  - highly effective in cases with islands etc. scattered around the grid
  - better resolution in shallow water
  - not uncommon w/circulation models
  - specialized software used to create grids
  - mass conservation is often a special difficulty (though not necessarily in WW3 implementation)



Irregular grids: introduction

Logically rectangular (i,j)
- user specifies x(i,j) and y(i,j), i=1..ni, j=1..nj
- “i-axis” can be oriented in any direction at various points of the grids, and similar for “j-axis” (not tied to x or y). Formally, these are the “p” and “q” axes.



Irregular grids: documentation

Rogers and Campbell (NRL Memorandum Report, 2009)

- direct link: http://www7320.nrlssc.navy.mil/pubs/2009/rogers1-2009.pdf
- indirect link: http://www7320.nrlssc.navy.mil/pubs.php

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NRL/MR/7320--09-9193

Implementation of Curvilinear Coordinate System in the WAVEWATCH III Model

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Other documentation:
1) WW3 manual, section on “curvilinear grids”
2) WW3 manual, section on the “grid preprocessor”
3) /inp/ww3_grid.inp

Note added by Erick Feb 12 2013 (after class ended) : Some content on this slide is not legible via projector. Prior to use in a subsequent class, the “screen grabs” should be converted to larger font powerpoint text boxes.

User input

```
$ Define grid ------------------------------------------------------- $
$
$ Five records containing :
$
$  1 Type of grid, coordinate system and type of closure: GSTRG, FLAGLL,
$    CSTRG.  Grid closure can only be applied in spherical coordinates.
$      GSTRG  : String indicating type of grid :
$               'RECT'  : rectilinear
$               'CURV'  : curvilinear
$      FLAGLL : Flag to indicate coordinate system :
$               T  : Spherical (lon/lat in degrees)
$               F  : Cartesian (meters)
$      CSTRG  : String indicating the type of grid index space closure :
$               'NONE'  : No closure is applied
$               'SMPL'  : Simple grid closure : Grid is periodic in the
$                       : i-index and wraps at i=NX+1. In other words,
$                       : (NX+1,J) => (1,J). A grid with simple closure
$                       : may be rectilinear or curvilinear.
$               'TRPL'  : Tripole grid closure : Grid is periodic in the
$                       : i-index and wraps at i=NX+1 and has closure at
$                       : j=NY+1. In other words, (NX+1,J<=NY) => (1,J)
$                       : and (I,NY+1) => (MOD(NX-I+1,NX)+1,NY). Tripole
$                       : grid closure requires that NX be even. A grid
$                       : with tripole closure must be curvilinear.
$  2 NX, NY. As the outer grid lines are always defined as land
$    points, the minimum size is 3x3.
$
$ Branch here based on grid type
```

```
$ ELSE IF ( CURVILINEAR GRID ) THEN
$
$  3 Unit number of file with x-coordinate.
$    Scale factor and add offset: x <= scale_fac * x_read + add_offset.
$    IDLA, IDFM, format for formatted read, FROM and filename.
$      IDLA : Layout indicator :
$                  1   : Read line-by-line bottom to top.
$                  2   : Like 1, single read statement.
$                  3   : Read line-by-line top to bottom.
$                  4   : Like 3, single read statement.
$      IDFM : format indicator :
$                  1   : Free format.
$                  2   : Fixed format with above format descriptor.
$                  3   : Unformatted.
$      FROM : file type parameter
$               'UNIT' : open file by unit number only.
$               'NAME' : open file by name and assign to unit.
$
$    If the above unit number equals 10, then the x-coord is read from this
$    file.  The x-coord must follow the above record.  No comment lines are
$    allowed within the x-coord input.
$
$  4 Unit number of file with y-coordinate.
```

rogers@wateree.nrlssc.navy.mil: /net/wateree/export/data/rogers/WW3/ncep_multigtype...

```
bash-4.1$ pwd
/net/wateree/export/data/rogers/WW3/ncep_multigtype/regtests/ww3_tp2.1/inp
ut
bash-4.1$  head -n 30 ww3_grid_c.inp | tail -n 15
END OF NAMELISTS
$
  'CURV' F 'NONE'
  226  331
$
$ UNITNUM SCALEFAC OFFSET IDLA IDFM, 3 strings
  20 1.0 0.0 1 1 '(....)' 'NAME' './../input/xgrd.IDLA1.dat'
  21 1.0 0.0 1 1 '(....)' 'NAME' './../input/ygrd.IDLA1.dat'
$
$    10.E3   10.E3  1.
$   -60.E3  -60.E3  1.
$
  -5. 5.75  10  -2500. 4 1 '(....)' 'UNIT' 'input'
$
   74806*1
bash-4.1$
```

within ww3_grid.inp,
- regular grids are referred to here as “rectilinear grids” (RECT)
- irregular grids are referred to as “curvilinear grids” (CURV)

Basic mathematical approach

$$\frac{\partial x}{\partial p} \approx 0.5(x_{i+1,j} - x_{i-1,j})$$

$$\frac{\partial y}{\partial p} \approx 0.5(y_{i+1,j} - y_{i-1,j})$$

$$\frac{\partial x}{\partial q} \approx 0.5(x_{i,j+1} - x_{i,j-1})$$

$$\frac{\partial y}{\partial q} \approx 0.5(y_{i,j+1} - y_{i,j-1})$$

Method taken from Petit, van Vledder, as used in "PHIDIAS" model

$$\sqrt{G} = \frac{\partial x}{\partial p}\frac{\partial y}{\partial q} - \frac{\partial x}{\partial q}\frac{\partial y}{\partial p}$$

Recall that:

- *p* corresponds to *i*
- *q* corresponds to *j*

This is the Jacobian used to modify wave action density and wave propagation velocity in the propagation routine.

For the special case of a regular grid, these derivatives become:

$$\left(\frac{\partial p}{\partial x}\right)_{rect} = \frac{1}{\Delta x} \;;\; \left(\frac{\partial p}{\partial y}\right)_{rect} = 0 \;;\; \left(\frac{\partial q}{\partial x}\right)_{rect} = 0 \;;\; \text{and} \; \left(\frac{\partial q}{\partial y}\right)_{rect} = \frac{1}{\Delta y}$$

Irregular grids: introduction

Logically rectangular (i,j)
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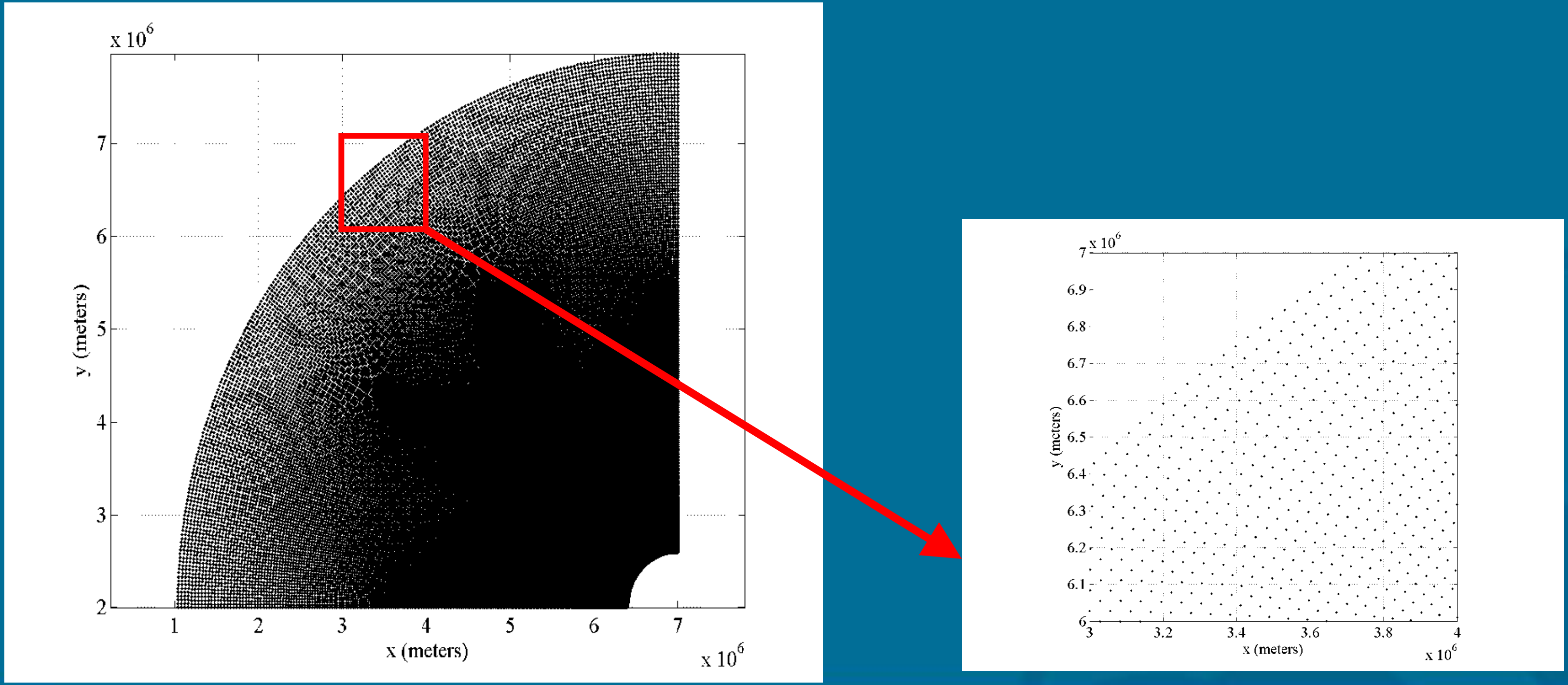
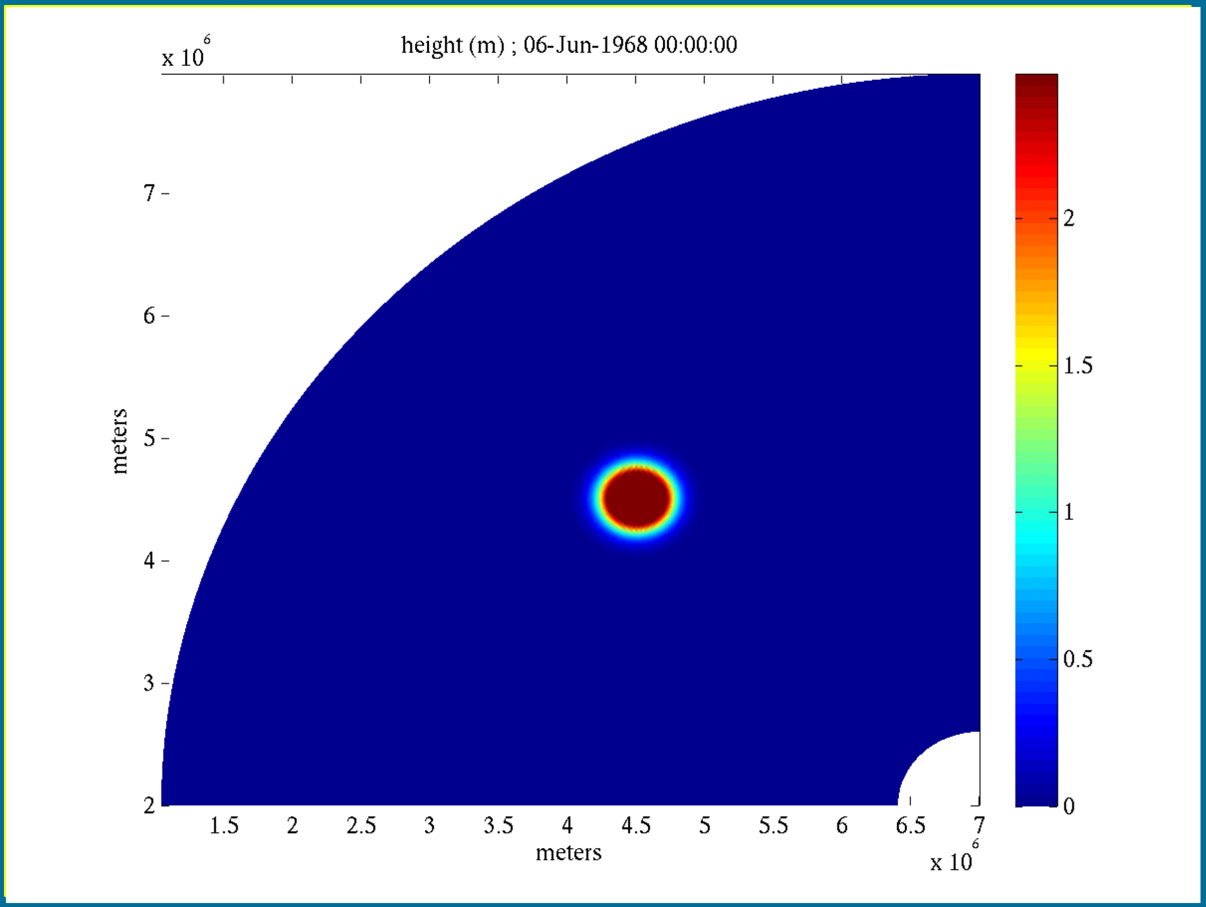
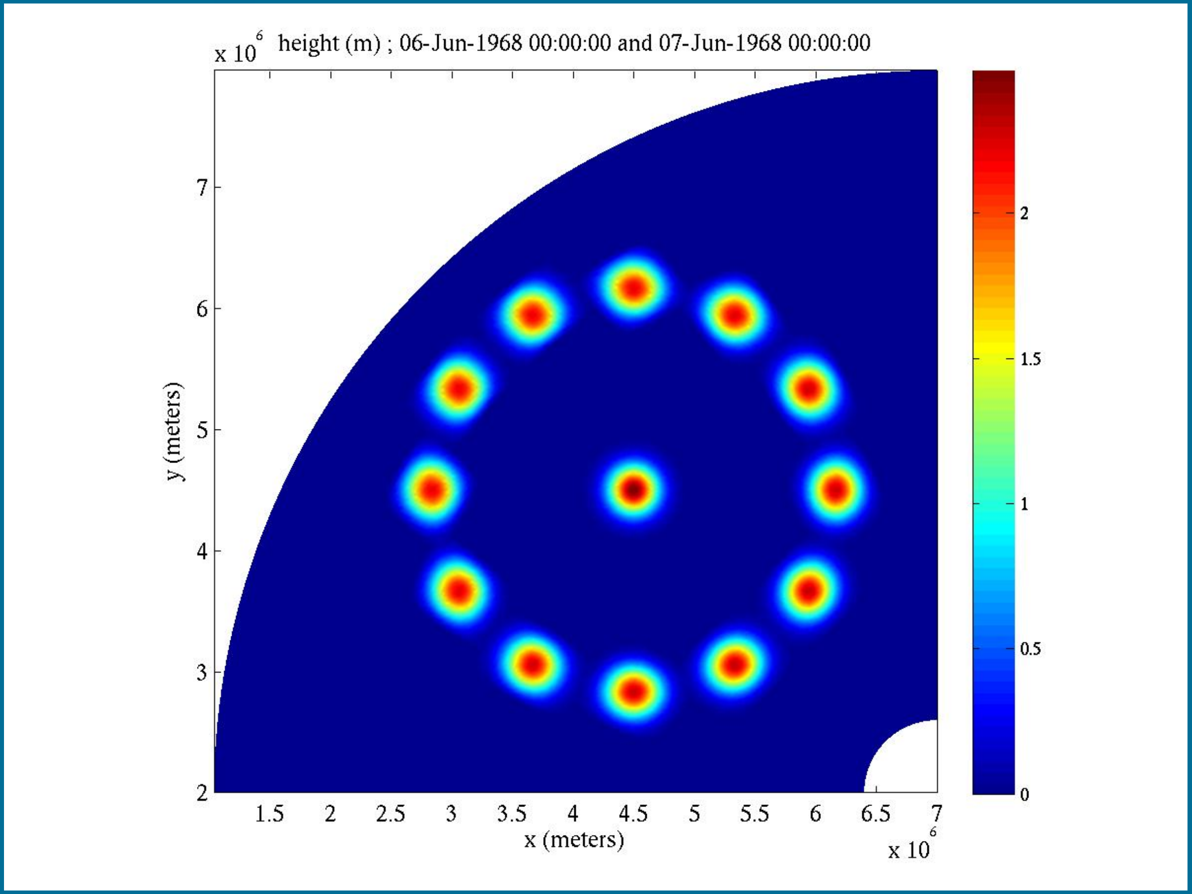


Cartesian (meters) grid example



Animation: WW3 result without GSE correction (PR2 diffusion strength=0)

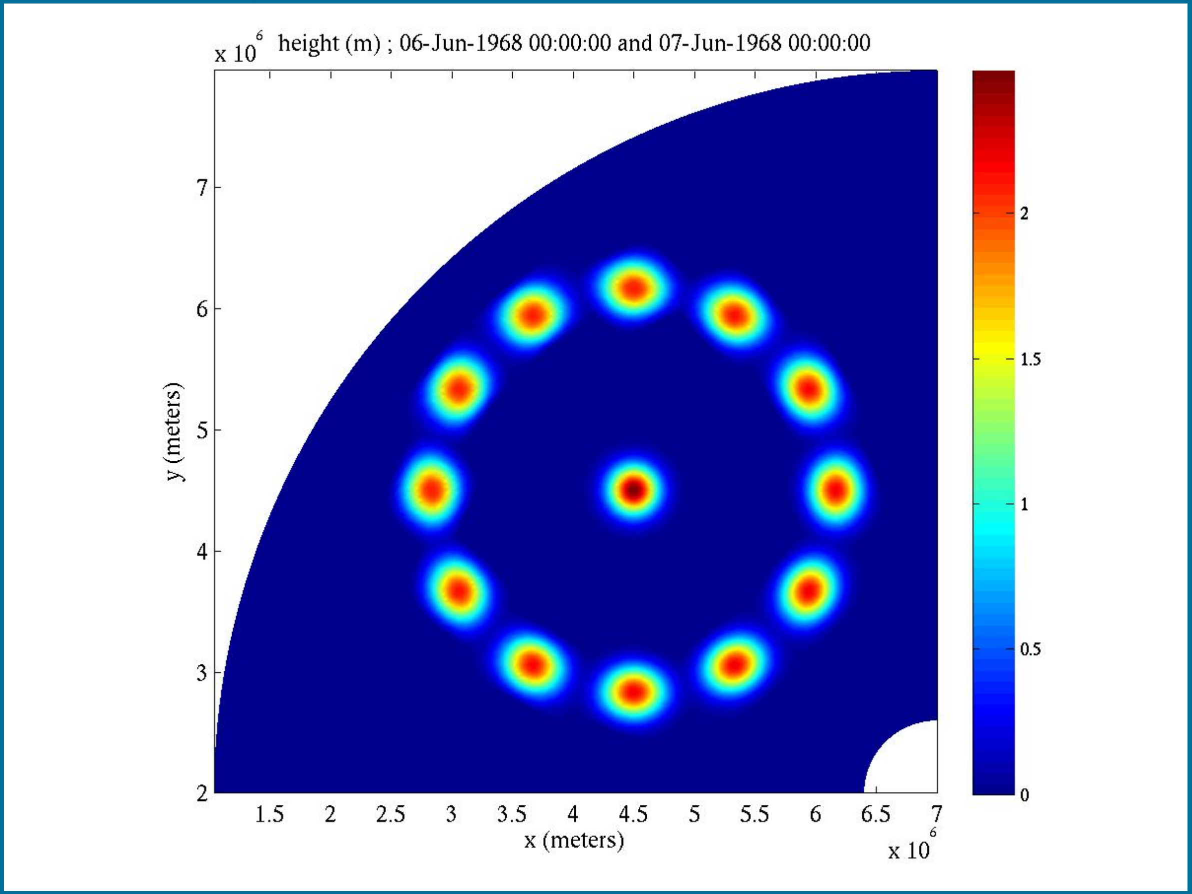
Cartesian (meters) grid example



WW3 result without GSE correction (PR2 diffusion strength=0.5 hrs)

Δt=90 s

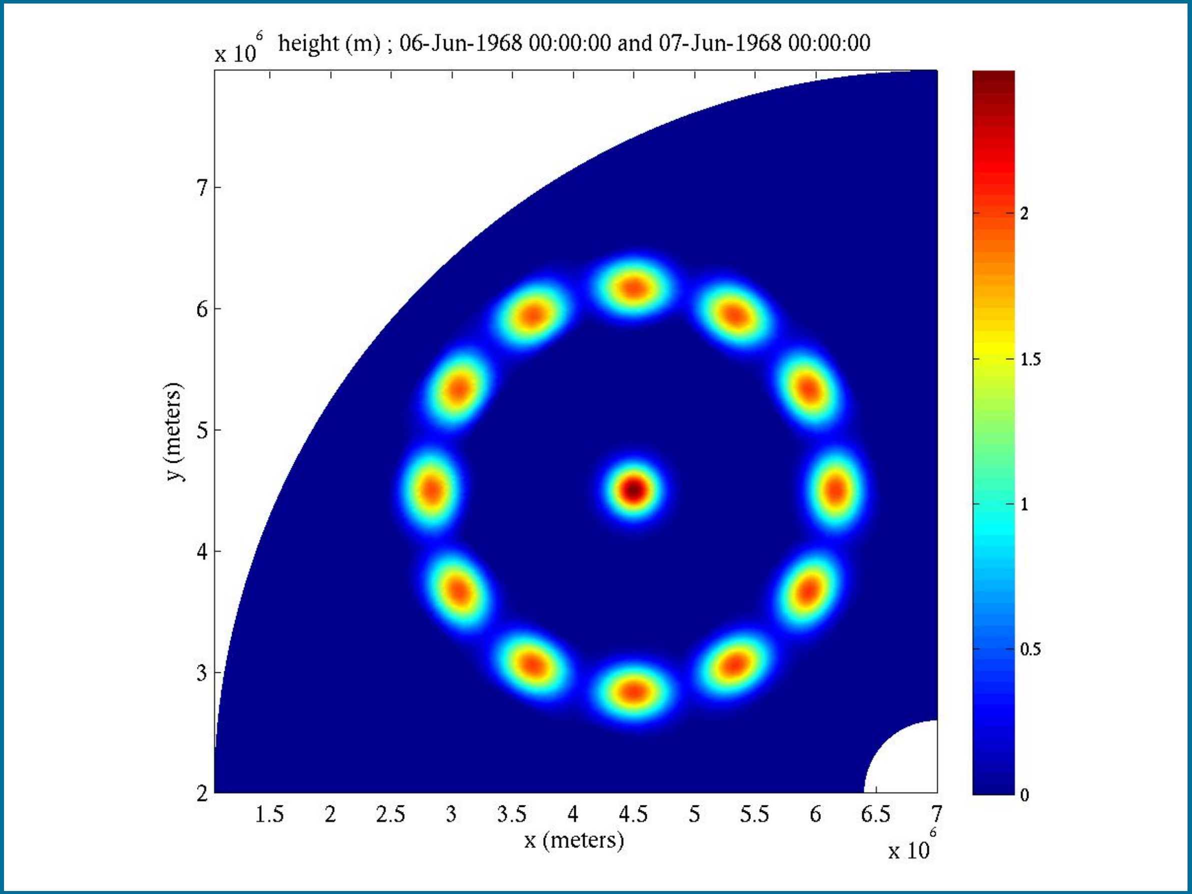
Cartesian (meters) grid example



WW3 result without GSE correction (PR2 diffusion strength=1 hrs)

Δt=90 s

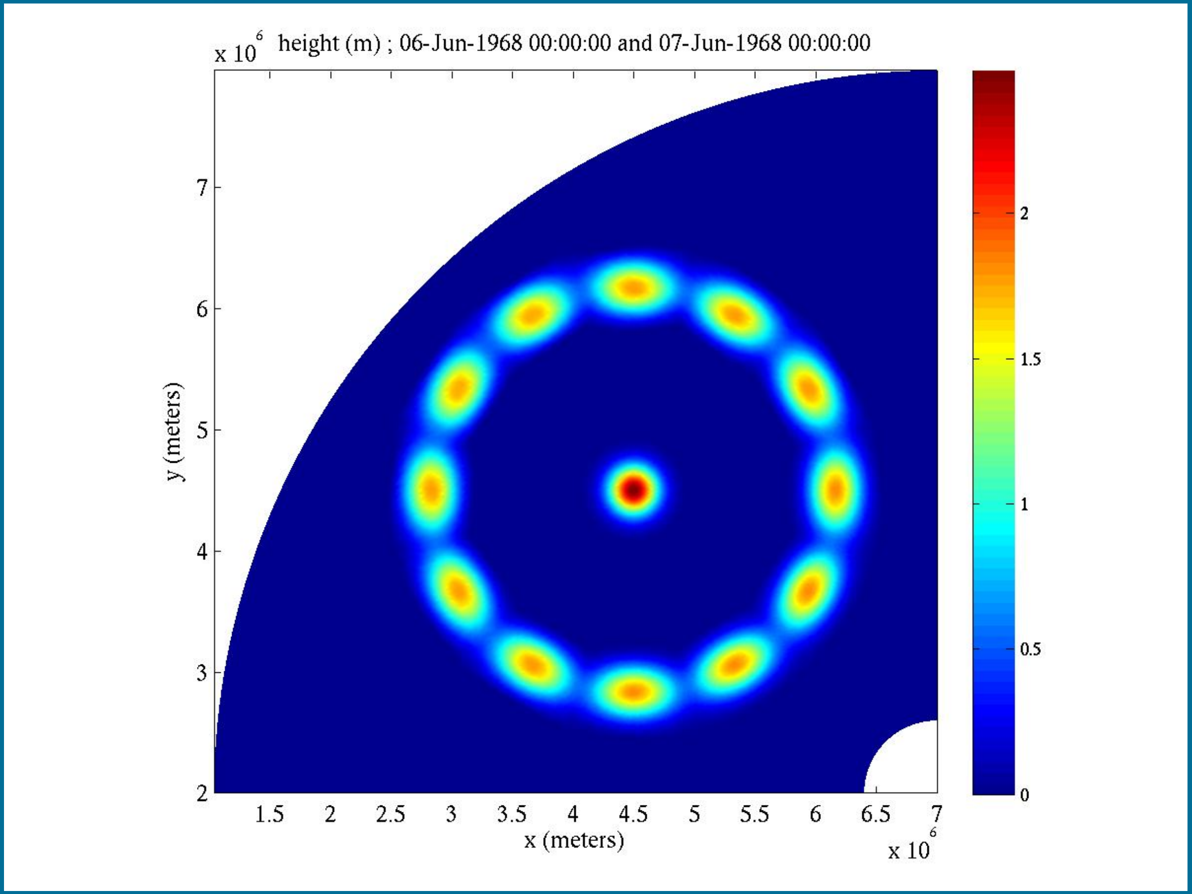
Cartesian (meters) grid example



WW3 result without GSE correction (PR2 diffusion strength=2 hrs)

Δt=90 s

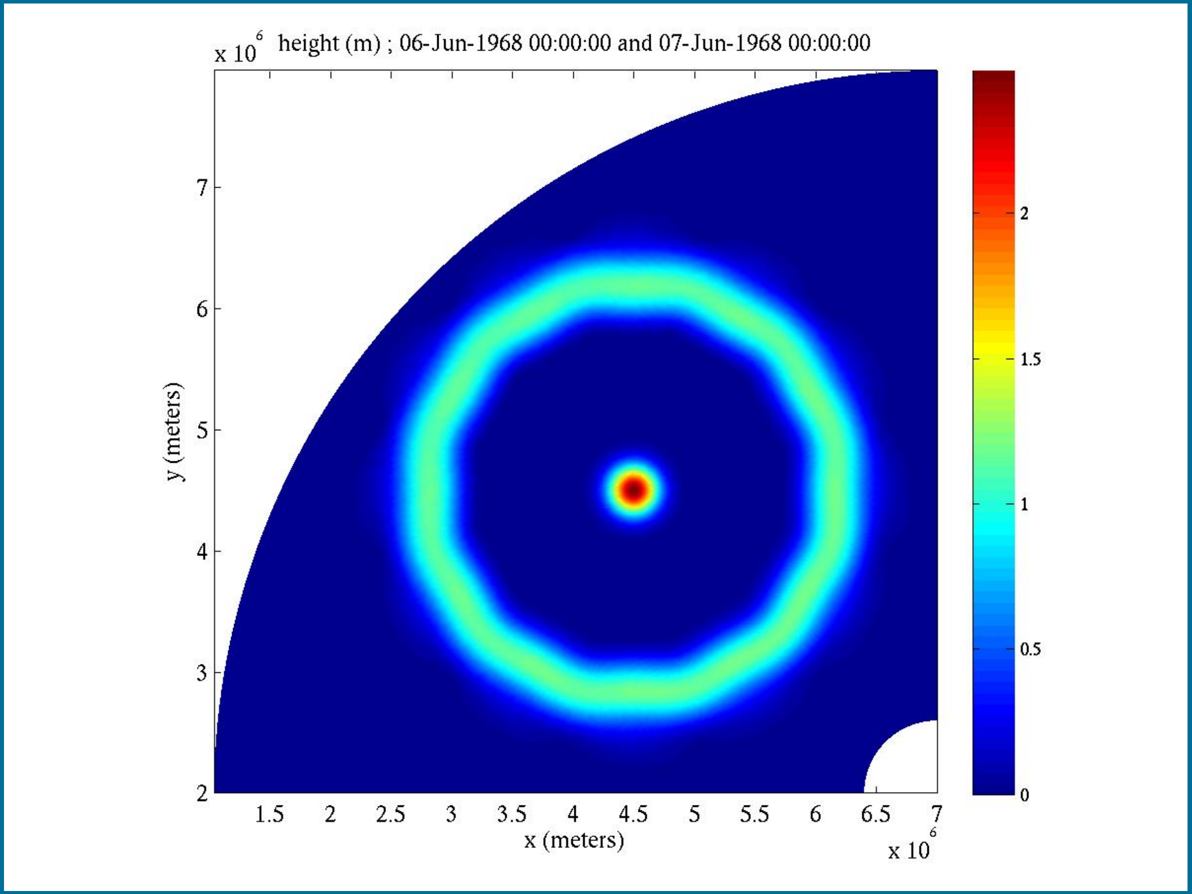
Cartesian (meters) grid example



WW3 result without GSE correction (PR2 diffusion strength=4 hrs)

Δt=90 s

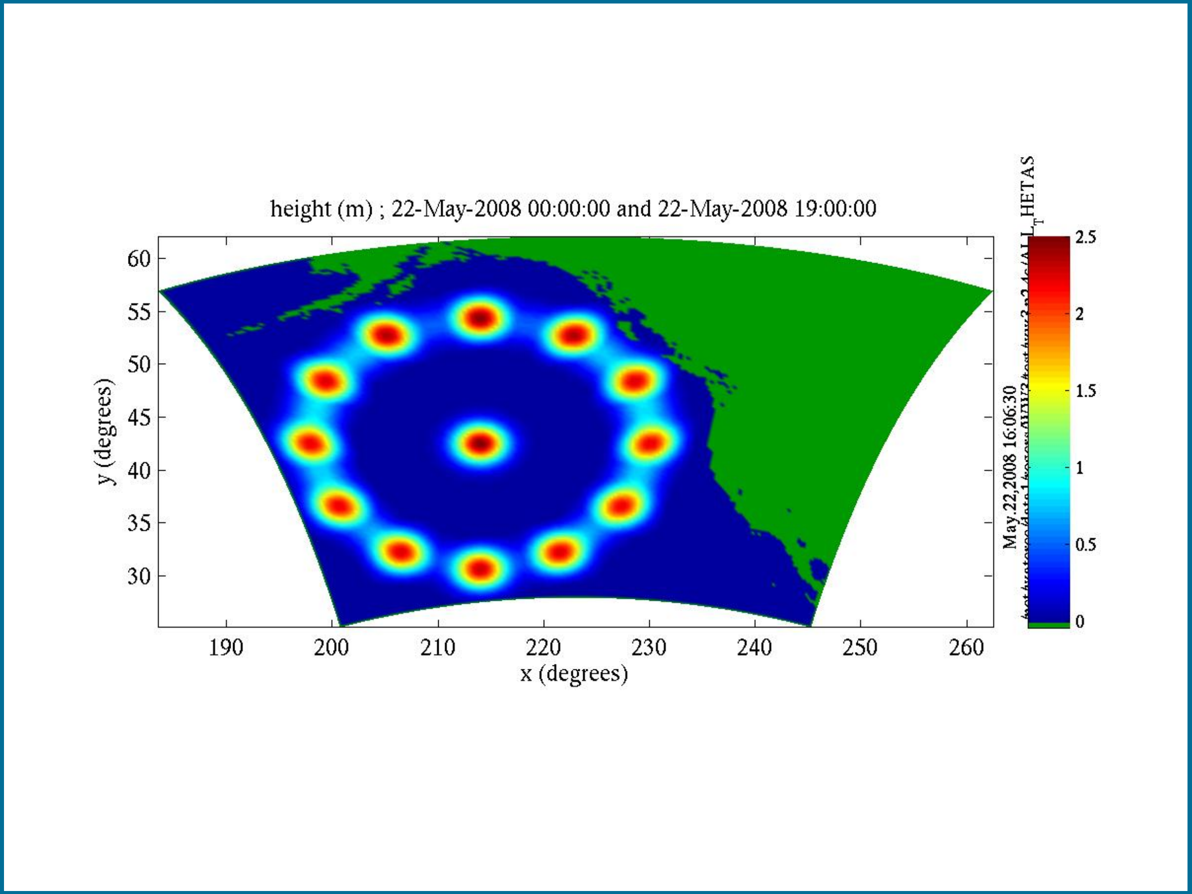
Cartesian (meters) grid example



WW3 result without GSE correction (PR2 diffusion strength=24 hrs)

$\Delta t=10$ s

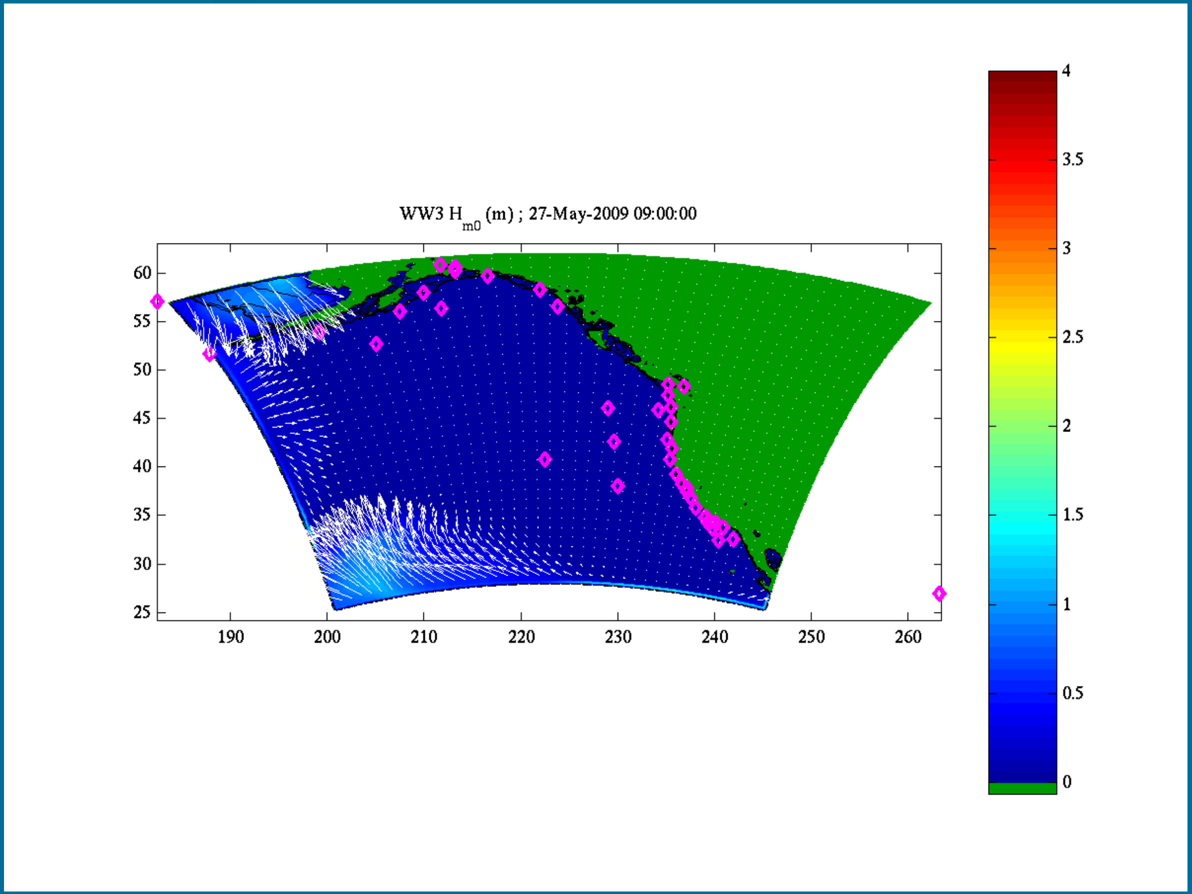
Lambert Conformal grid example



Resolution ~ 0.2°

Grid here corresponds to COAMPS (atmospheric model) grid

Lambert Conformal grid example

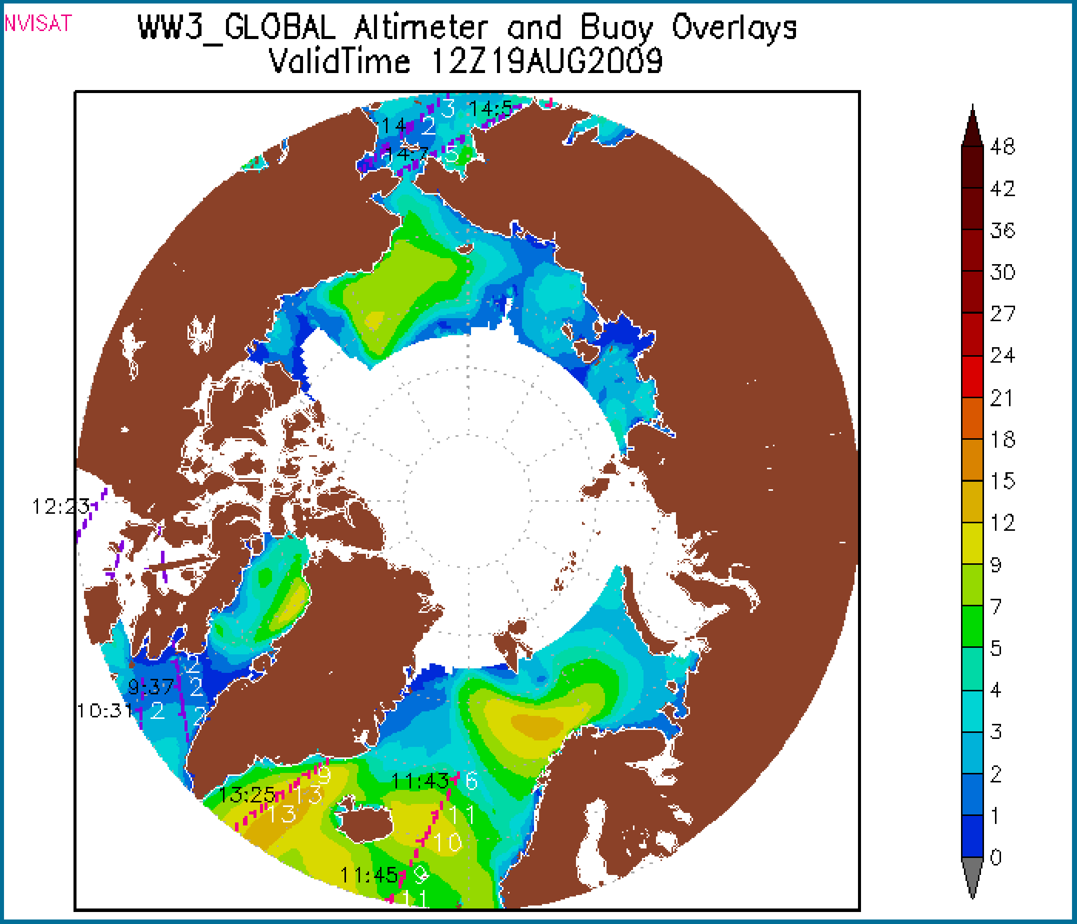


Resolution ~ 0.2°

One-way nesting (ww3_shel) with irregular grid

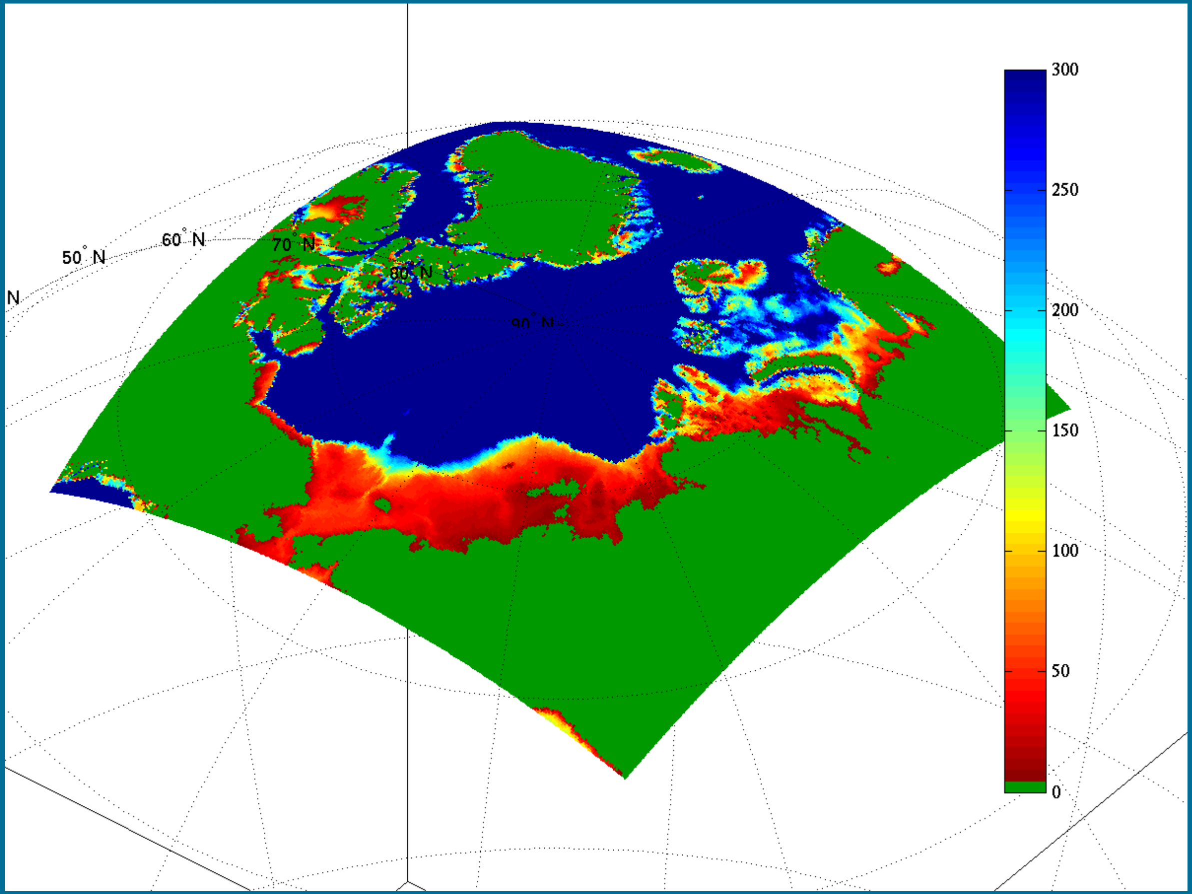
Animation: WW3 propagation (boundary forcing only) on Lambert Conformal EPAC grid. Waveheight in meters.

Lead-in to polar stereographic grid example



The standard operational FNMOC global WW3 model, Arctic view. This model is on a regular 0.5° grid. The model stops at 78° N because the convergence of the meridians implies that resolution in real space becomes higher near the poles; due to the conditionally stable propagation scheme of WW3, extending the grid further north would require that the model use a smaller time step for the entire global grid (i.e. significant waste of computational resources).

Polar stereographic grid example



Bathymetry for wave model mapped onto COAMPS polar stereographic (curvilinear) grid. Depths in meters.

Polar stereographic grid example

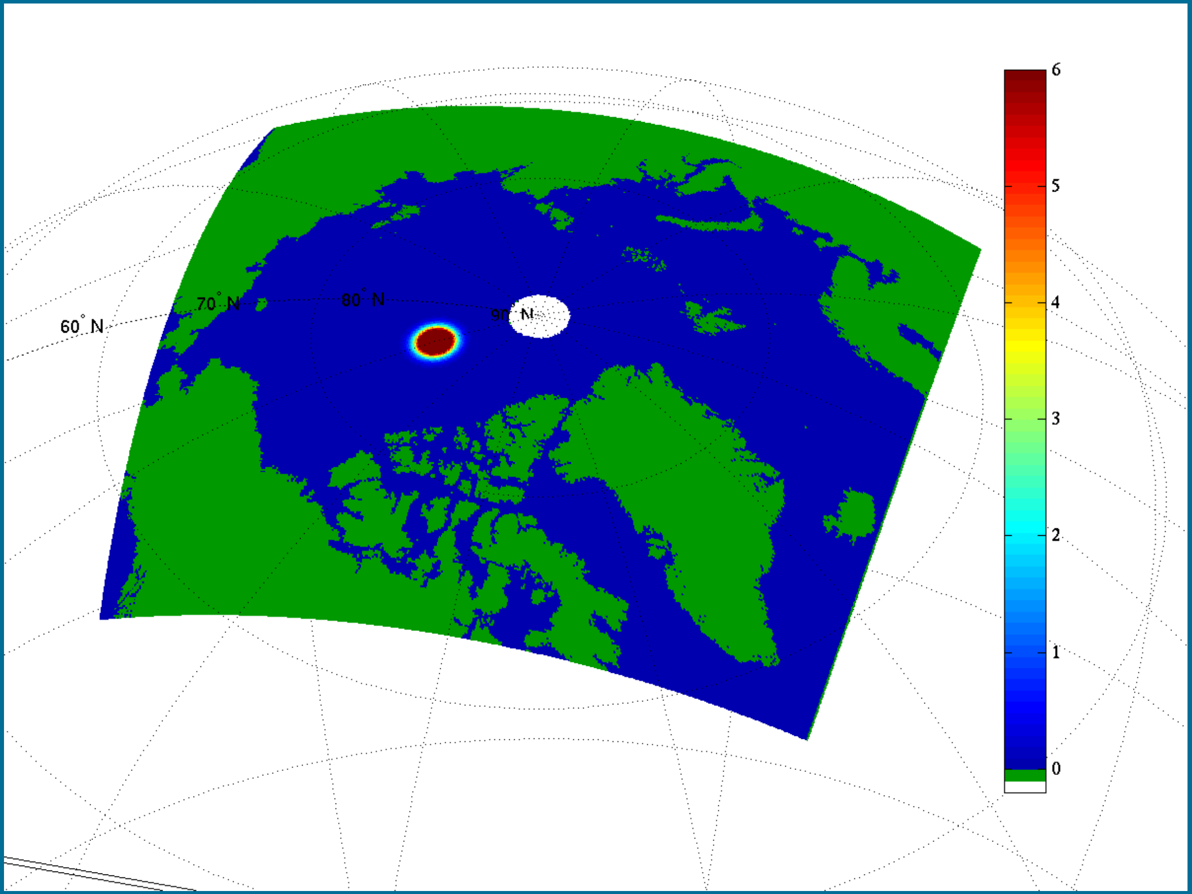


Figure: Waveheight in meters. Initial condition for WW3 propagation test on same grid as used by FNMOC Arctic COAMPS [*nx*=*ny*=361; spacing~20 km]. Hypothetical scenario: Arctic is ice-free south of 88° N.

Polar stereographic grid example

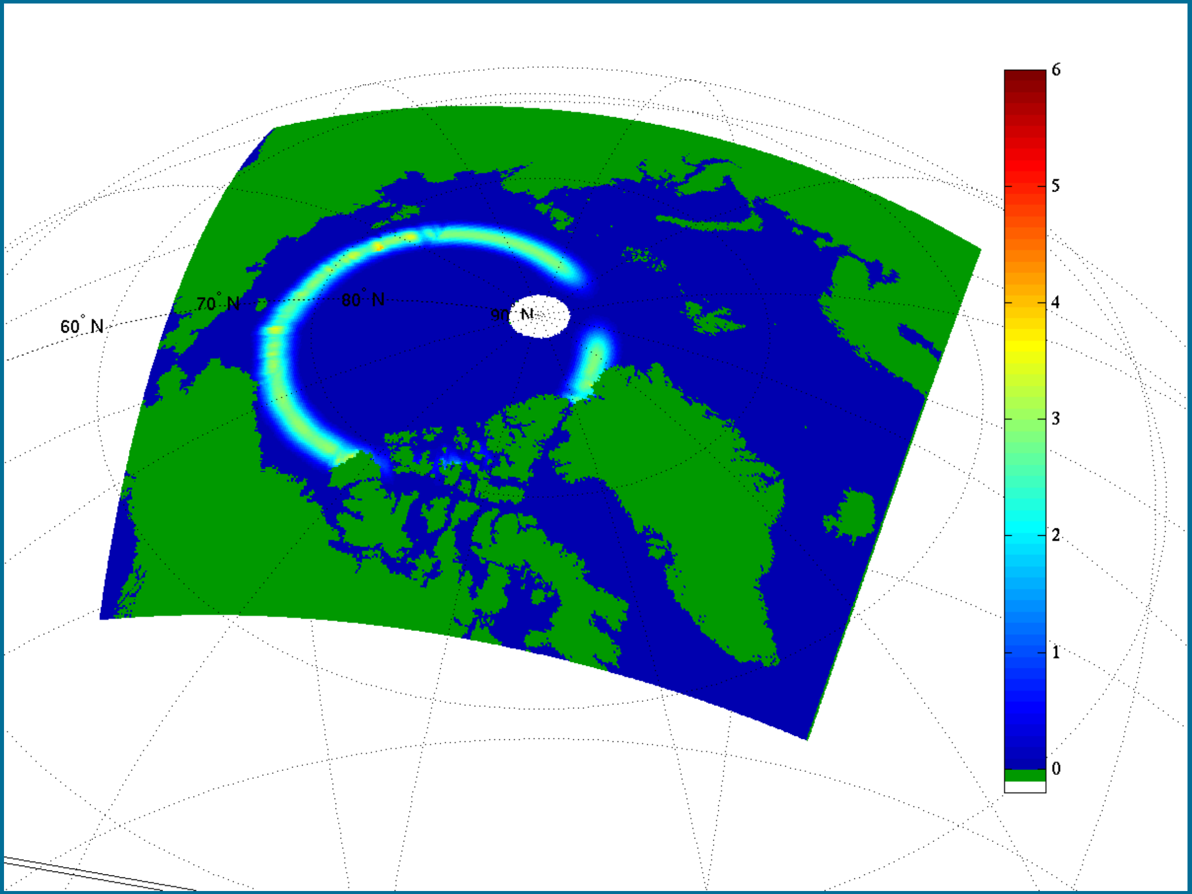
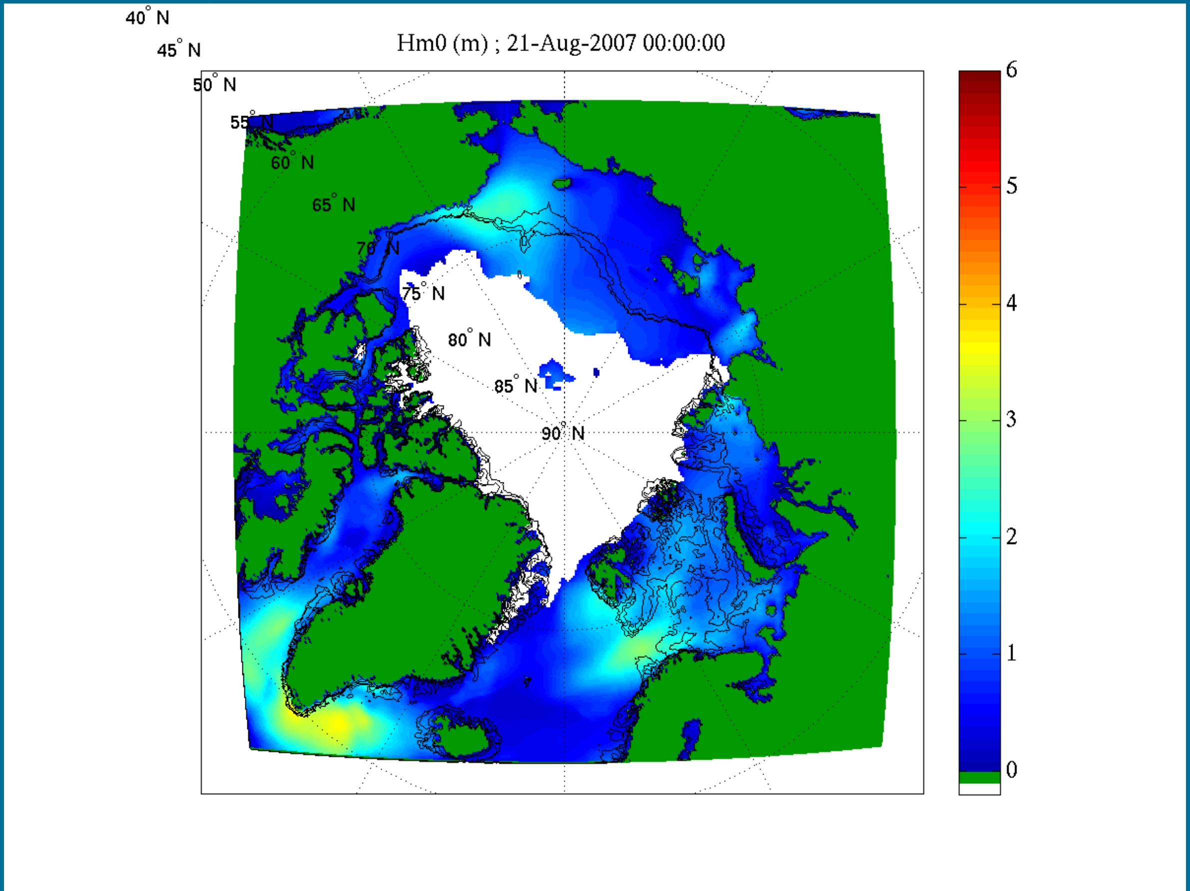


Figure: WW3 propagation test after 17 hrs. Waveheight in meters.

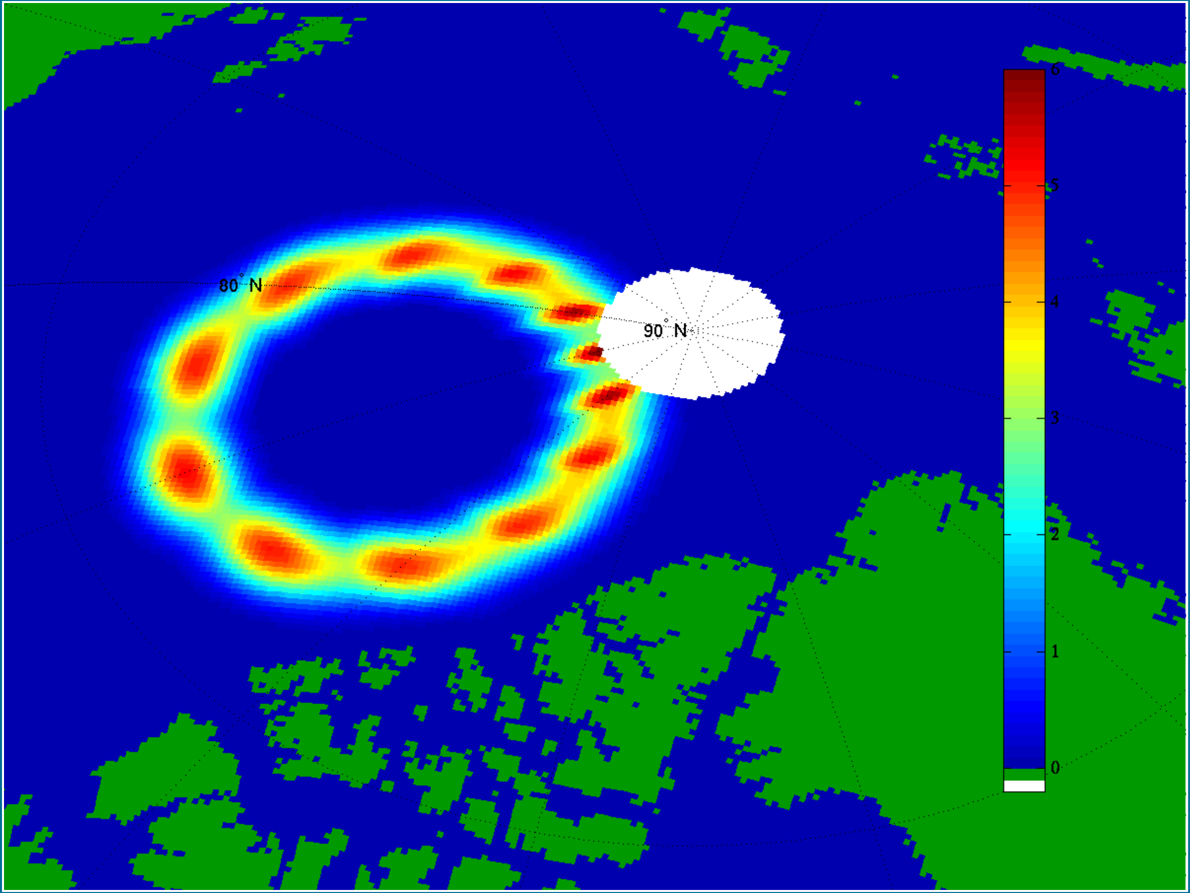
Polar stereographic grid example



Convergence of meridians leads to stability problems for conventional (regular) grids. No such issues here.

Animation: WW3 propagation and source term test on COAMPS Arctic grid. Waveheight in meters.

Polar stereographic grid example



Unresolved singularity at North Pole. (Dev. team needs to generalize model equations to allow alternate references for directional distribution of wave spectra.)

Figure: WW3 propagation test after 8 hrs with relatively coarse directional resolution (30°). Waveheight in meters.

Model features: timeline

Multi-grid or "mosaic grid" feature in WAVEWATCH III
Implemented in code in 2006 (Tolman Tech. Note 2007; OM 2008).
Available in the last public release (v3.14)

Irregular-grid feature in WAVEWATCH III
Implemented in code in 2008 (Rogers and Campbell, NRL report 2009).
Exists in NCEP WW3 development code trunk (v4.01)

Irregular-grid feature & multi-grid working simultaneously* (2011)
Exists in NCEP WW3 development code trunk (v4.10)

Unstructured grids & multi-grid working simultaneously*
Exists in NCEP WW3 development code branch (v4.11+)

*equal rank grids not permitted (not coded yet)

Simultaneous use of multi-grid and irregular grid features

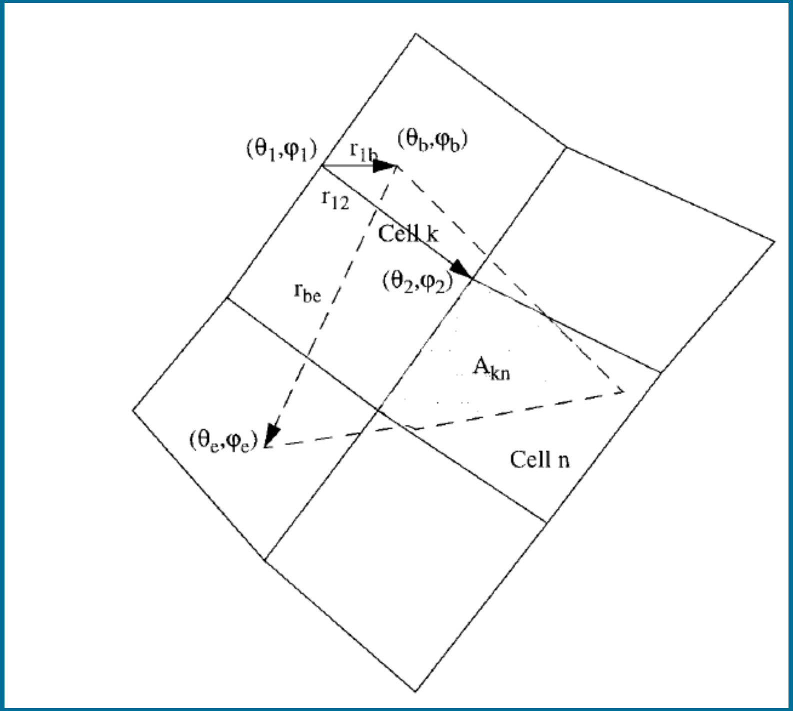
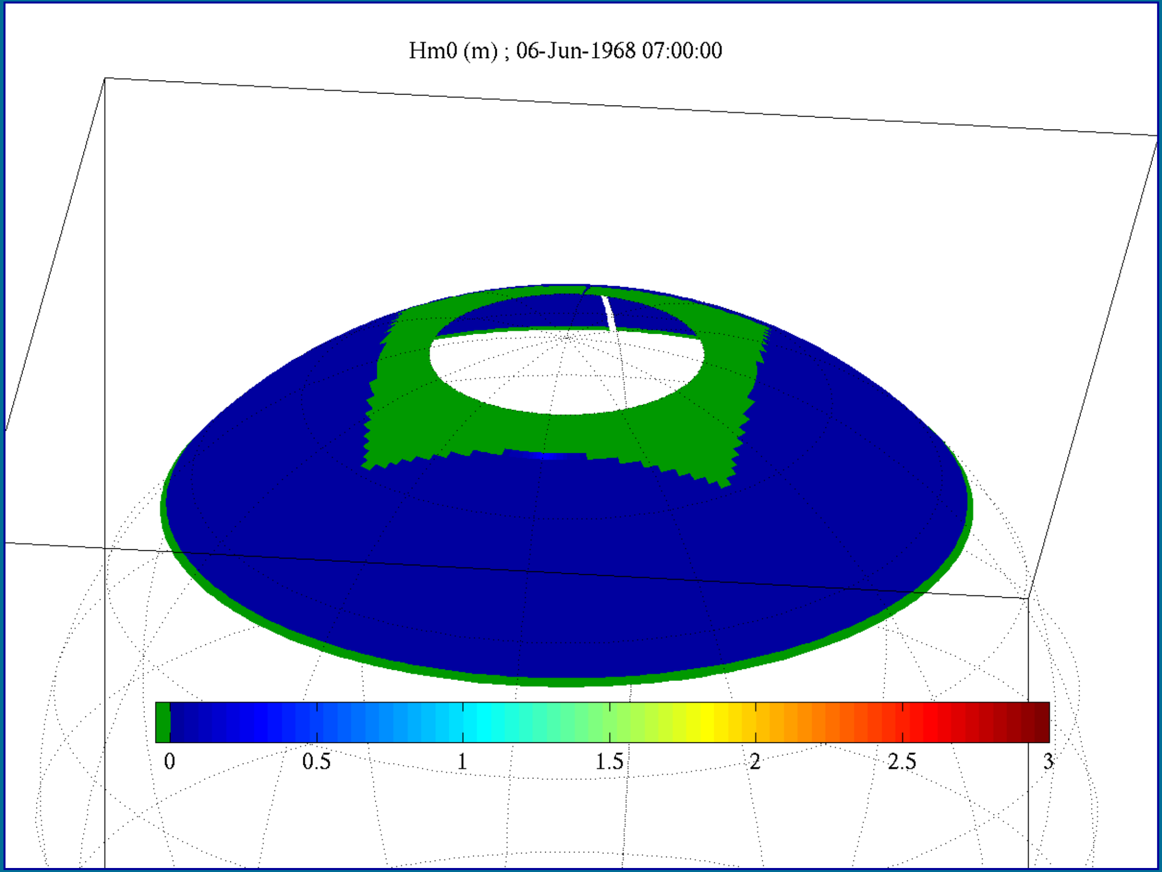


Figure: conservative remapping from Jones (MWR 1999)

- Primary challenge: conservative remapping
- Method used: Jones (MWR 1999)
- This exists as “SCRIP”, 3rd party software optionally compiled with (and called from) WW3
- SCRIP is serial-only: will likely be phased out as ESMF layer is fully implemented within WW3
- ESMF = Earth System Modeling Framework, has parallel conservative remapping routines

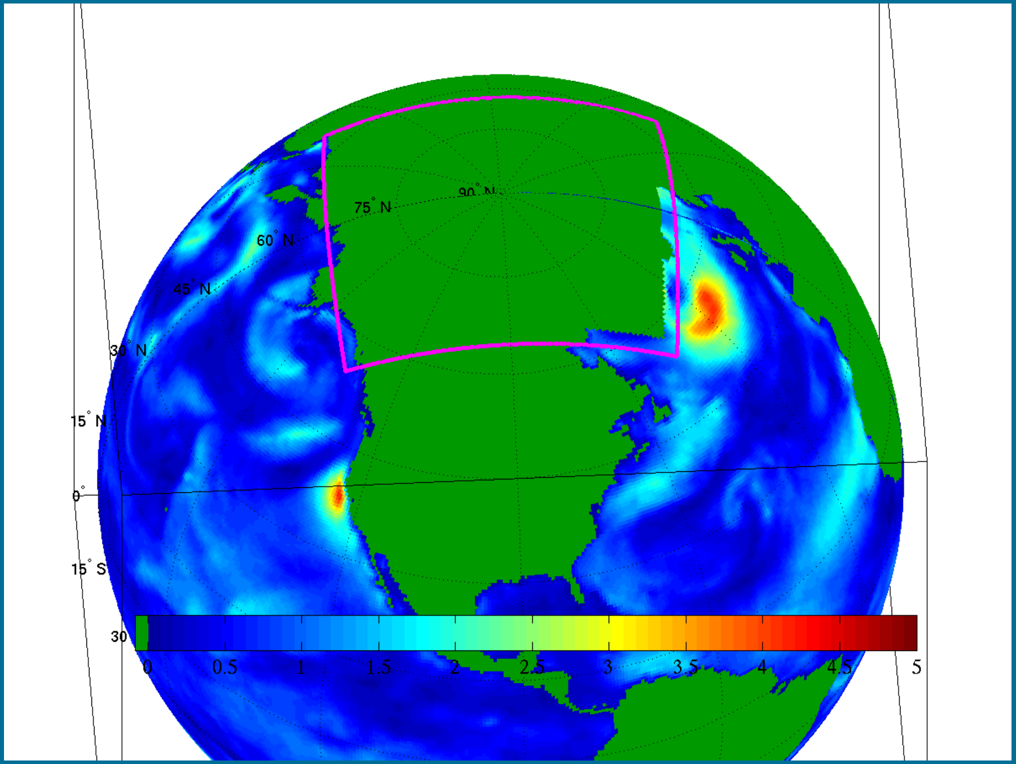
Simultaneous use of multi-grid and irregular grid features



WAVEWATCH III: code adapted to allow use of curvilinear and multi-grid features simultaneously

Animation: WW3 two-way nesting test (propagation only) with COAMPS Arctic grid (~16 km resolution) and a simplified global grid. Waveheight in meters.

Simultaneous use of multi-grid and irregular grid features



New system: WW3 two-way nesting test (propagation + wind + ice) with COAMPS Arctic grid (~16 km resolution) and full (0.5°) global grid. Waveheight in meters. The regular (global) grid is plotted. Masked areas are shown in green and include: land, ice, and areas covered by the curvilinear grid. Thus, the global model is not computing in areas covered by the Arctic grid (read: increased efficiency).

Result at May 25 2009 12Z, after a 12 hour simulation (from cold start). The boundary of the Arctic grid is shown with a magenta line. Ice is taken from PIPS and winds are taken from NOGAPS. Thus, this setup is very similar to what it would be for an operational model.

Simultaneous use of multi-grid and irregular grid features

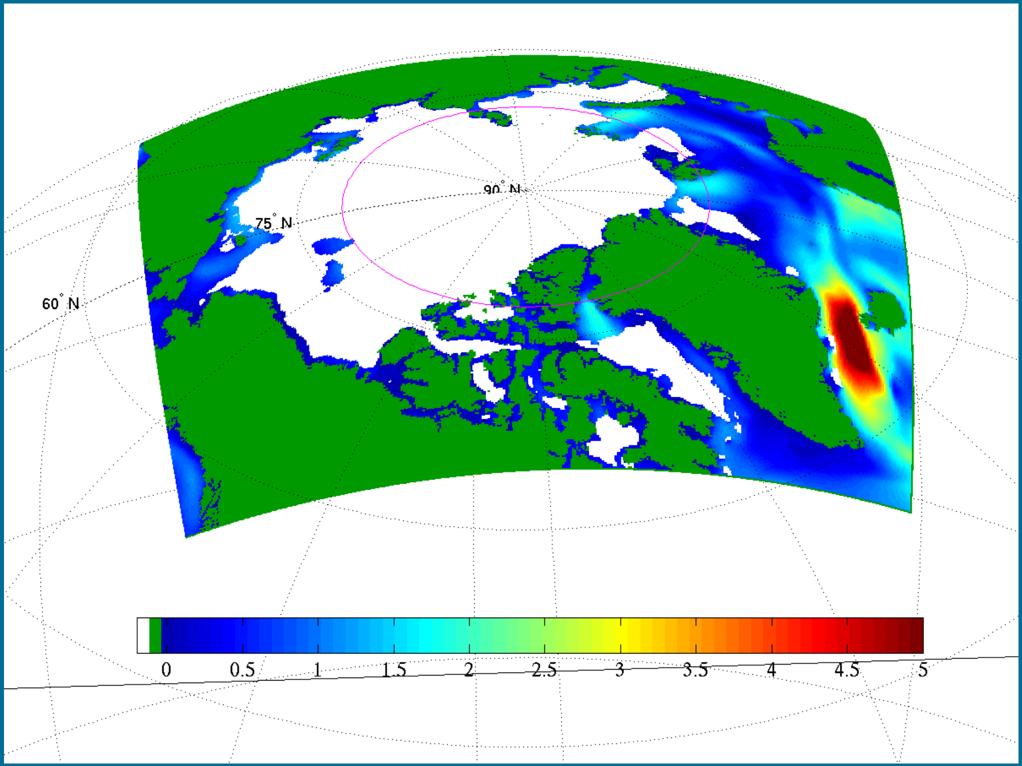


Figure: Results within the Arctic grid.

masked areas are denoted as either

- land (green)
- or ice with concentration of 0.75 or greater (white).

magenta line indicates 78 deg N, which is the upper limit of the operational global WW3 at FNMOC.

Wave energy propagates in both directions across the boundaries between the regional grid shown here and the global grid. The grids run simultaneously within the same machine executable.

Cautions, warnings, and things that won’t work :

- Irregular grids: traditional CFL limitations still apply.
- Arctic grids: as noted earlier, singularity a North Pole: user should mask region north of 88 or 89° until this is addressed
- Multi-grid + irregular grids: exchanges between equal-rank grids not implemented yet; for forcing fields, “native grid” method should be used vs. “input grid” methods (latter still to be implemented)
- Multi-grid + unstructured grids: working in serial mode in dev branch but under quarantine since mpi hangs with this version.
- Pre-calculation of weights: in development

The end

End of lecture