Gridspec: A standard for the description of grids used in Earth System models

GO-ESSP Workshop 2008
Seattle WA

V. Balaji[1] Zhi Liang[2] Alistair Adcroft[1]

[1]Princeton University

[2]HPTi Inc.

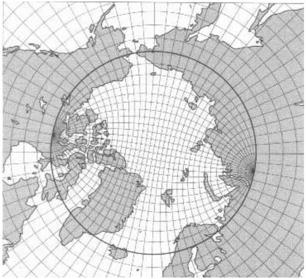
17 September 2008

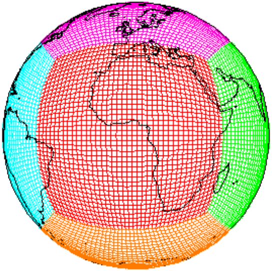
Talk outline...

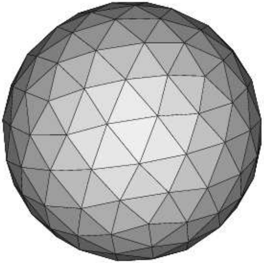
1. Examples of grids in use in ESMs
   - Horizontal coordinates
   - Vertical coordinates
2. Why a grid standard?
   - Model makers
   - Model data users
3. The Gridspec
   - Geometry
   - Mosaics and tiles
   - Supergrids
4. Gridspec implementations
5. Gridspec tools
   - Grid creation
   - Regridding
   - Analysis and Visualization
6. Outstanding issues

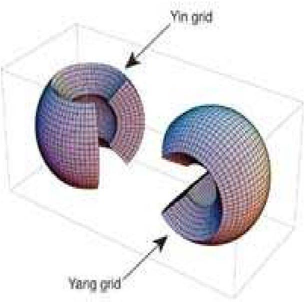
Talk outline . . .

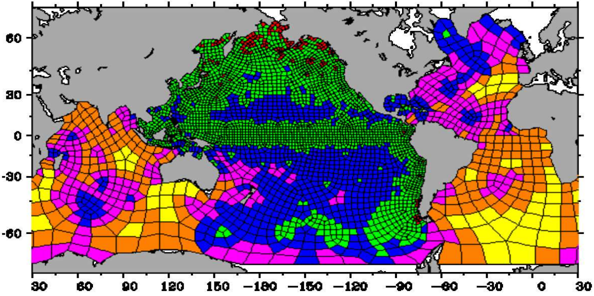
Horizontal grids in use in ESMs



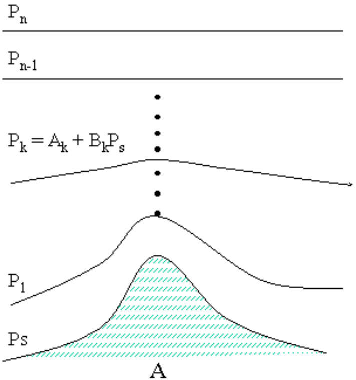


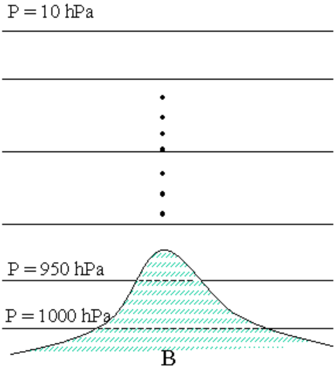






Vertical coordinates



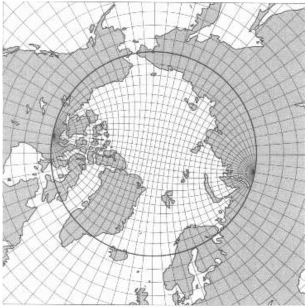


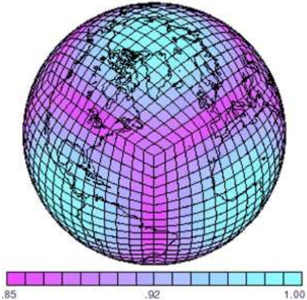
The taxonomy of vertical coordinates distinguishes mass-based and space-based vertical coordinates. There is often an attempt to do something in the spirit of geo-referencing: invoking a "standard" reference grid: usually based on pressure levels in the atmosphere, and depth in the ocean.

Talk outline . . .

Earth system models are built from components

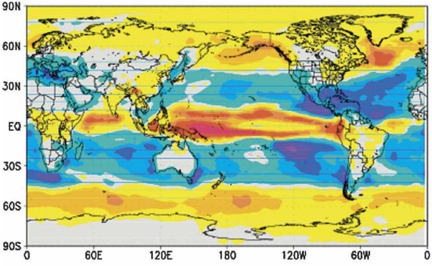
- Earth system models nowadays are built from components: subsystems that may be independently discretized.
- Even when all components are built by a cohesive community, the different components must have some conventions to share grid information.
- Furthermore, these days it is increasingly common to build ESMs out of components of independent provenance.



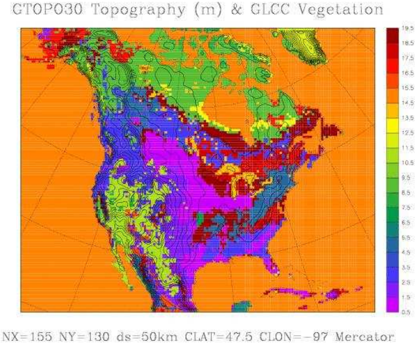


Dependencies across data from many models

- Model intercomparisons have become a primary research avenue for consensus and uncertainty estimates of anthropogenic climate change. This plot is a composite across the entire AR4 archive.



- Model chaining: output from one model used as forcing for another “downstream”.



Grid metadata

To be of use by models as well as for interpreting model output, the standard must enable vector calculus and conservative regridding. The following aspects of a grid must be included in the specification:

- distances between gridpoints, to allow differential operations;
- angles of grid lines with respect to a reference, usually geographic East and North, to enable vector operations. One may also choose to include an arc type (e.g "great circle"), which specifies families of curves to follow while integrating a grid line along a surface.
- areas and volumes for integral operations. This is generally done by defining the boundaries of a grid cell represented by a point value. Below we will also consider fractional areas and volumes in the presence of a mask, which defines the sharing of cell between two or more components.

Talk outline . . .

Geometry and coordinate systems

- The underlying geometry: sphere, spheroid, geoid, plane… In general transformations between different geometries are not well-defined.
- "Sphere" geometries permit geo-referencing: mapping to "canonical" coordinates: geographic longitude and latitude.
- Vertical geometry: mass- or space-based. Again, transformations between these are not well-posed, or must be user-defined functions.
- Analogue of geo-referencing is community-defined standard model levels.
- Vertical coordinates may need terrain information: reference surface is a digital elevation map of the planetary surface. (Dependency on external dataset).

Geometry and coordinate systems

- The underlying geometry: sphere, spheroid, geoid, plane... In general transformations between different geometries are not well-defined.
- “Sphere” geometries permit geo-referencing: mapping to “canonical” coordinates: geographic longitude and latitude.
- Vertical geometry: mass- or space-based. Again, transformations between these are not well-posed, or must be user-defined functions.
- Analogue of geo-referencing is community-defined standard model levels.
- Vertical coordinates may need terrain information: reference surface is a digital elevation map of the planetary surface. (Dependency on external dataset).

Geometry and coordinate systems

- The underlying geometry: sphere, spheroid, geoid, plane... In general transformations between different geometries are not well-defined.
- "Sphere" geometries permit geo-referencing: mapping to "canonical" coordinates: geographic longitude and latitude.
- Vertical geometry: mass- or space-based. Again, transformations between these are not well-posed, or must be user-defined functions.
- Analogue of geo-referencing is community-defined standard model levels.
- Vertical coordinates may need terrain information: reference surface is a digital elevation map of the planetary surface. (Dependency on external dataset).

Geometry and coordinate systems

- The underlying geometry: sphere, spheroid, geoid, plane. . . In general transformations between different geometries are not well-defined.
- "Sphere" geometries permit geo-referencing: mapping to "canonical" coordinates: geographic longitude and latitude.
- Vertical geometry: mass- or space-based. Again, transformations between these are not well-posed, or must be user-defined functions.
- Analogue of geo-referencing is community-defined standard model levels.
- Vertical coordinates may need terrain information: reference surface is a digital elevation map of the planetary surface. (Dependency on external dataset).

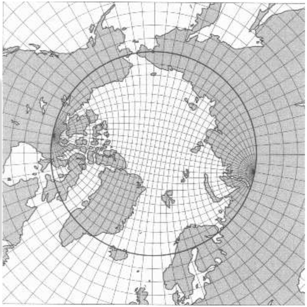
Geometry and coordinate systems

- The underlying geometry: sphere, spheroid, geoid, plane… In general transformations between different geometries are not well-defined.
- “Sphere” geometries permit geo-referencing: mapping to “canonical” coordinates: geographic longitude and latitude.
- Vertical geometry: mass- or space-based. Again, transformations between these are not well-posed, or must be user-defined functions.
- Analogue of geo-referencing is community-defined standard model levels.
- Vertical coordinates may need terrain information: reference surface is a digital elevation map of the planetary surface. (Dependency on external dataset).

Projections

- polar_stereographic, lambert_conformal, mercator, none, etc.
- May need auxiliary information: e.g north_pole attribute that is not the geographic North Pole. (a “rotated pole” is not a mapping or a projection but an attribute!)
- Sometimes stored under grid_mapping.

The tripolar grid of Murray (1996) is composed of tiles with different projections: two polar stereographic projections with different poles, and a spherical coordinate system below the polar latitude.



Discretizations

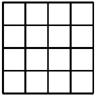
Discretization expresses how to represent coordinate space in arrays.

- The most commonly used discretization in Earth system science is logically rectangular.
  A discretization is logically rectangular if the coordinate space (x, y, z) is translated one-to-one to index space `(i,j,k)`. Note that the coordinate space may continue to be physically curvilinear; yet, in index space, grid cells will be rectilinear boxes.
  The discretization is regular if in addition we can construct coordinate arrays `x(i)`, `y(j)`, `z(k)`.
- Triangular discretizations (and often, irregular LRGs) are often expressed as unstructured grids (`x(i)`, `y(i)`, `z(k)`).
- Mappings are methods of recovering coordinate locations from a functional form based on the discretization. The current CF `grid_mapping` does that, but also seems to be a container for projection information.

Mosaics

The mosaic is a simple but powerful abstraction that allows one to cleanly express complex grids as collections of tiles.

- Starting with a simple grid tile. . .



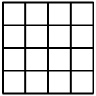
- you can make a simple mosaic. . .

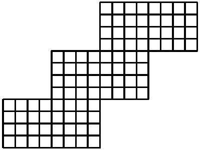
- add refinement. . .

Mosaics

The mosaic is a simple but powerful abstraction that allows one to cleanly express complex grids as collections of tiles.

- Starting with a simple grid tile…





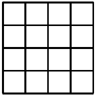
- you can make a simple mosaic…

- add refinement…

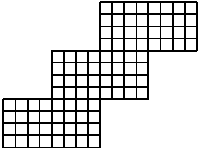
Mosaics

The mosaic is a simple but powerful abstraction that allows one to cleanly express complex grids as collections of tiles.

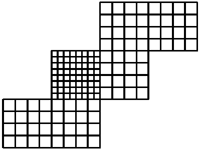
- Starting with a simple grid tile. . .



- you can make a simple mosaic. . .

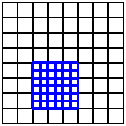


- add refinement. . .

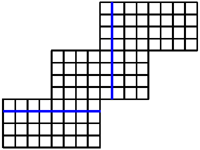


More with mosaics

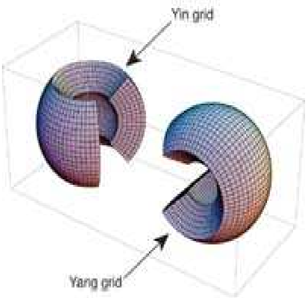
- You can also express nested grids. . .



- grids with halos. . .

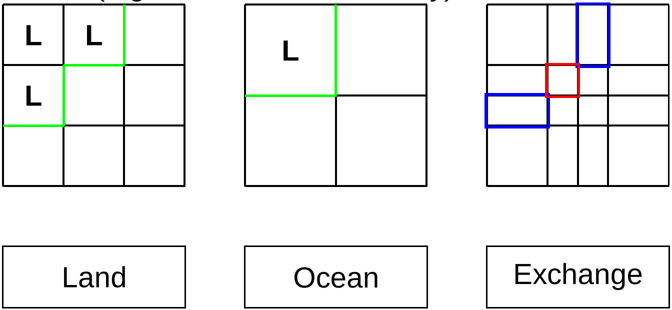


- and complex grids.



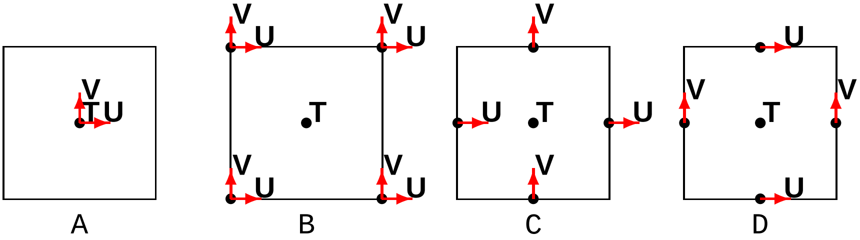
Contact regions

- The connection between the tiles in the mosaic is either a boundary or an overlap.
- Boundary specification: anchor points, orientations.
- Overlap specification: exchange grid. Also where to resolve masks (e.g the land-sea boundary).



- Since mosaics are recursive, we can specify a complete coupled model. . .

Staggering and supergrids



- If the "staggered" quantities are placed on independent coordinate sets $(x,y),(x_u,y_u),(x_v,y_v)$ their relationships are lost.
- We instead define the supergrid: the set of all the points on the grid where physical quantities might be defined.
- Variables are defined on subsets of points on the supergrid.

Talk outline . . .

Implementations of Gridspec

- The Gridspec is to some degree language-neutral: if netCDF-3, then it can be entirely done in netCDF-3. Current implementations include the GENIE Implementation in XML (Ian Henderson: `http://www.genie.ac.uk`) and the GFDL implementation (Zhi Liang: `http://www.gfdl.noaa.gov/˜vb/grids`).
- It can be expressed in various data formats as well as in XML schema: we are still hedging our bets as to whether this will get put in netCDF files or in some "aggregation layer".
- So... it's nice to see that the two prototype implementations are in XML and netCDF-3...

Talk outline . . .

Specifying a grid tile

A command-line tool for creating a horizontal grid file for `horizontal_grid_type = spectral_grid, regular_lonlat_grid, tripolar_grid, conformal_cubic_grid, gnomonic_cubic_grid, simple_cartesian_grid`, e.g

- `make_hgrid -grid_type regular_lonlat_grid -nlon 0,1,3,...360 -nlat -90,-88.2,...` creates a lat-lon grid with non-uniform spacing.
- `make_hgrid -grid_type conformal_cubic_grid -nlon 48 -nratio 2`: created $48 \times 48 \times 6$ cubic grid.

A similar tool called `make_vgrid` for vertical grids.

Specifying mosaics

- `make_solo_mosaic -num_tiles ntiles -tile_file gridtile`
  will look for a set of `ntiles` tile gridspec netCDF files named `gridtile#.nc` and make a mosaic file `mosaic.nc` that specifies their linkages.
- `make_topog -mosaic mosaic.nc -topog_type realistic -topog_file /archive/fms/mom4/input_data/OCCAM_p5degree.nc -topog_field TOPO`
  specifies the topography/bathymetry.
- `make_coupler_mosaic -atmos_mosaic atm_mosaic.nc -ocean_mosaic ocean_mosaic.nc -ocean_topog ocean_topog.nc [-land_mosaic land_mosaic.nc] [-sea_level sea_level] [-interp_method 1] [-mosaic_name mosaic_name]` generates a coupler mosaic with land-sea mask, etc.

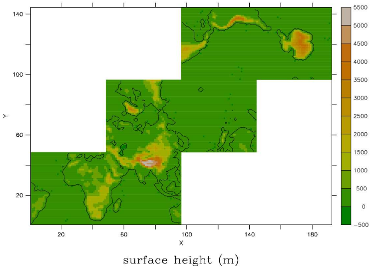
Regridding

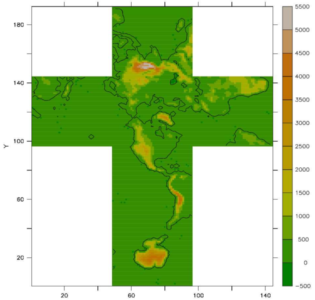
`fregrid` is a command-line utility for regridding.

- `fregrid -input_mosaic input_mosaic.nc - nlon M -nlat N -input_file input_file -field_name temp,salt`
- `fregrid -input_mosaic input_mosaic.nc -output_mosaic output_mosaic.nc -input_file input_file -field_name temp,salt`

fregrid is now prototyped as a “web service” (see demo by Kevin tomorrow)! We could potentially offer server-side regridding, allowing fields to be stored and manipulated on their native grids, but output data on a different grid if desired.

Analysis and visualization





- `ferret`, a widely-used analysis and plotting utility is now capable of interpreting gridspec files and displaying the associated mosaic datasets. A "native" capability within `ferret` is being built.
  `http://www.gfdl.noaa.gov/~atw/ferret/cubed_sphere/`
- The `MoDAVE` project funded by DoE is building mosaic visualization capability within the `VisIT` tool, to be demo'd by Alex Pletzer of Tech-X tomorrow.

Talk outline . . .

1. Examples of grids in use in ESMs
   - Horizontal coordinates
   - Vertical coordinates
2. Why a grid standard?
   - Model makers
   - Model data users
3. The Gridspec
   - Geometry
   - Mosaics and tiles
   - Supergrids
4. Gridspec implementations
5. Gridspec tools
   - Grid creation
   - Regridding
   - Analysis and Visualization
6. Outstanding issues

Outstanding issues

- There is no agreed-upon method for remapping of vector fields: this is still an open research question. *In particular for CMIP-5, the question of defining "poleward transport" for ocean models with non-spherical native grids is unresolved.*
- Gridspec is still not in the "CF process". This is mostly my fault: some of this stems from my uncertainty as to how to proceed. Perhaps "standardizing" the tools and APIs would be a start? Especially the ability to read mosaics into web services and ESMF/PRISM data structures. . .
- Handling of Gridspec as an external reference: CF still doesn't do this cleanly. e.g in CMIP-3: `sea_cell_area` and `ocean_cell_volume` are stored in the static table and referenced in the 2D and 3D tables through free-text `comment` attributes.
- Unstructured grids have special issues, and should be a separate but coordinated track.