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

GO-ESSP Workshop 2007
Jussieu, Paris

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

[1]Princeton University

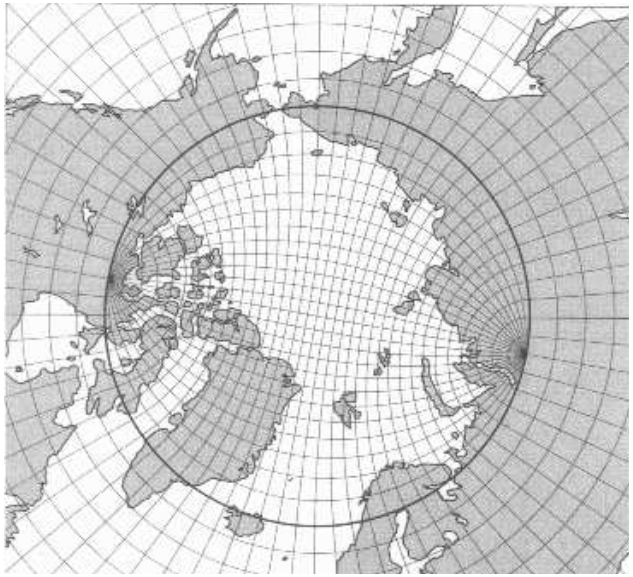
[2]RSIS Inc.

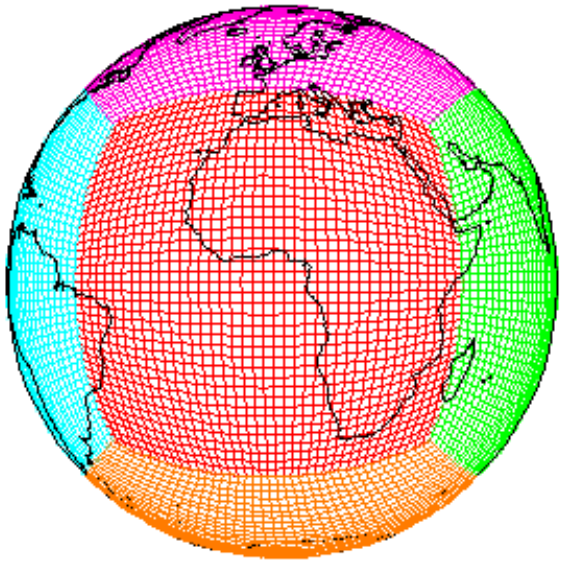
11 June 2007

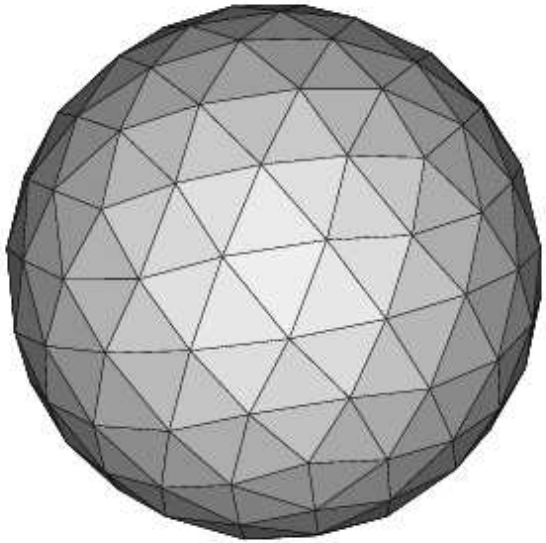
Talk outline. . .

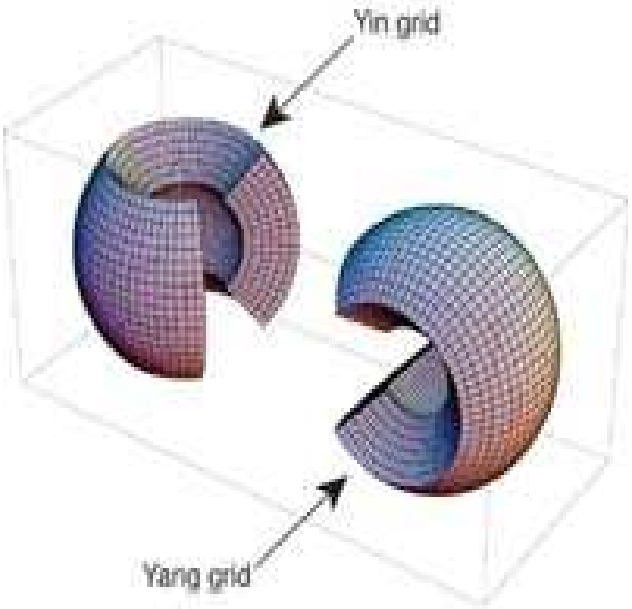
Talk outline . . .

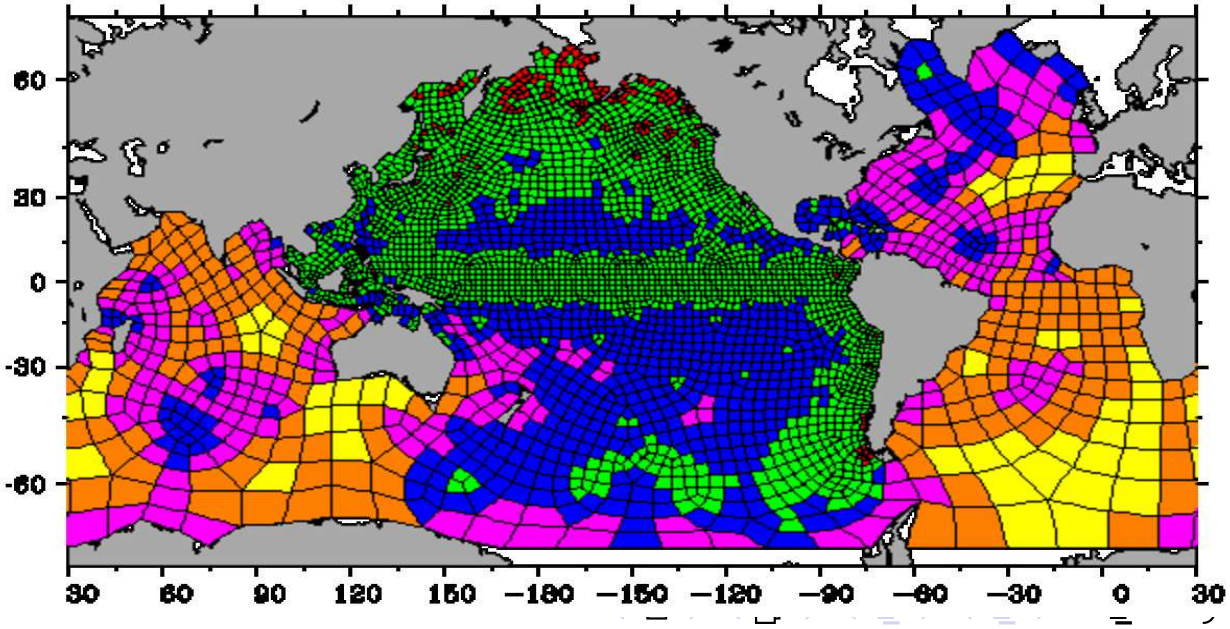
Horizontal grids in use in ESMs











Horizontal grids: a taxonomy

LRG logically rectangular grid.

STG structured triangular grid.

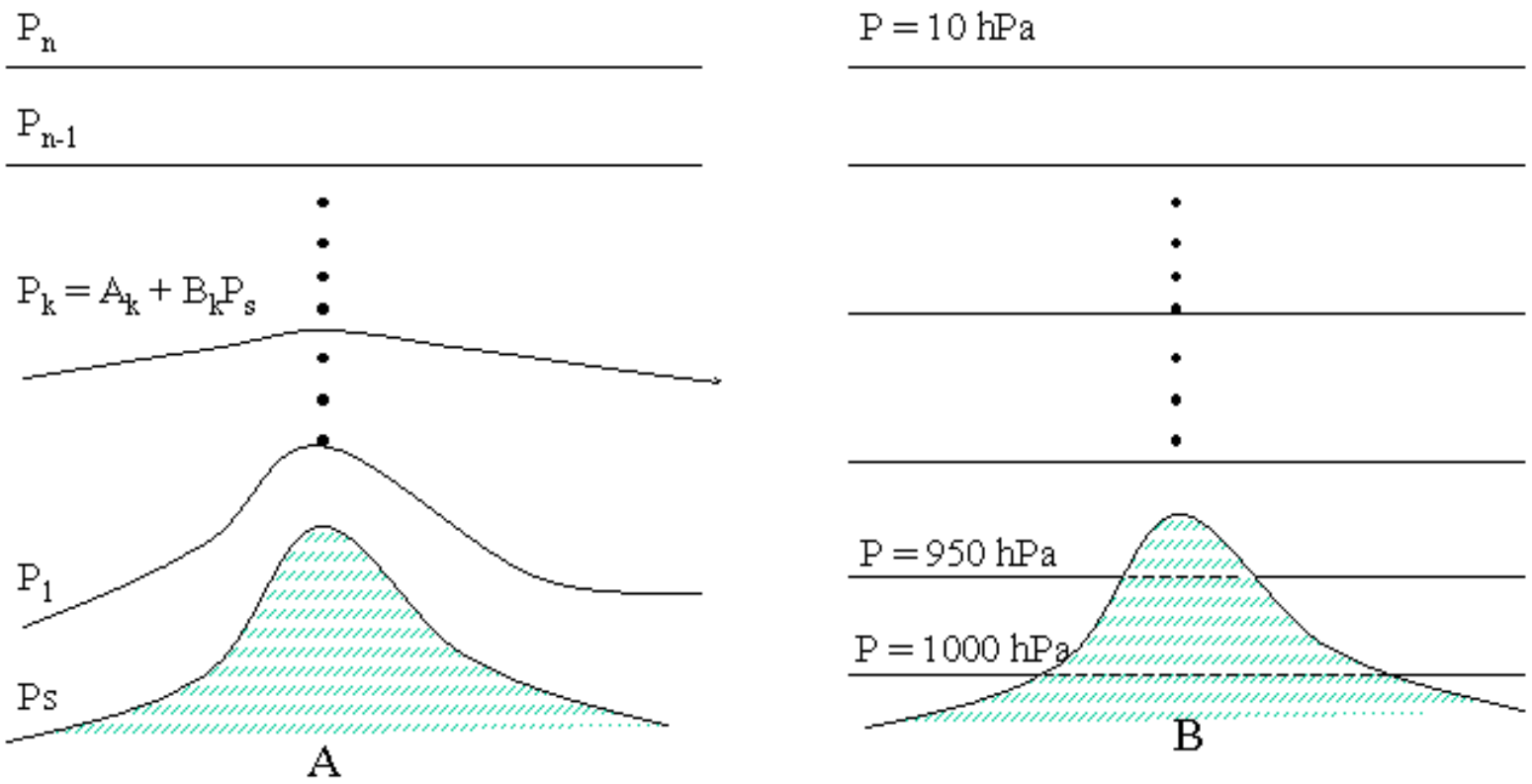
UTG unstructured triangular grid.

UPG unstructured polygonal grid.

PCG pixel-based catchment grid.

If geo-referencing information is available, it is possible to define relations and transformations between these grids, and to the "canonical" grid: the latitude-longitude grid.

Vertical coordinates

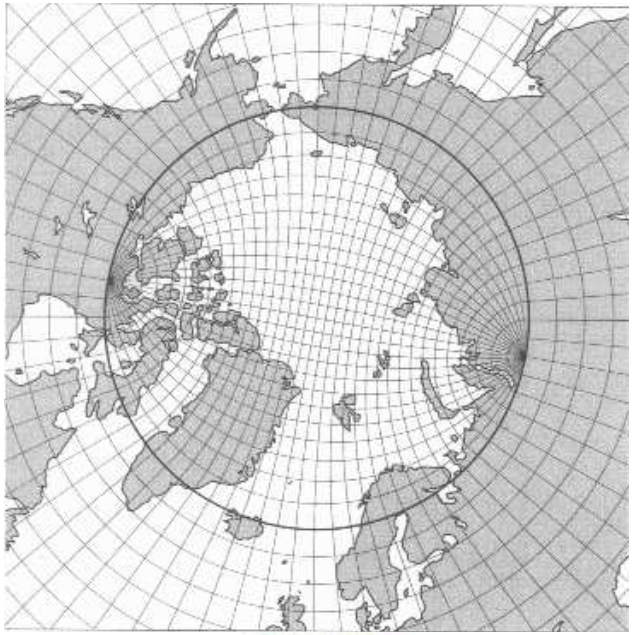


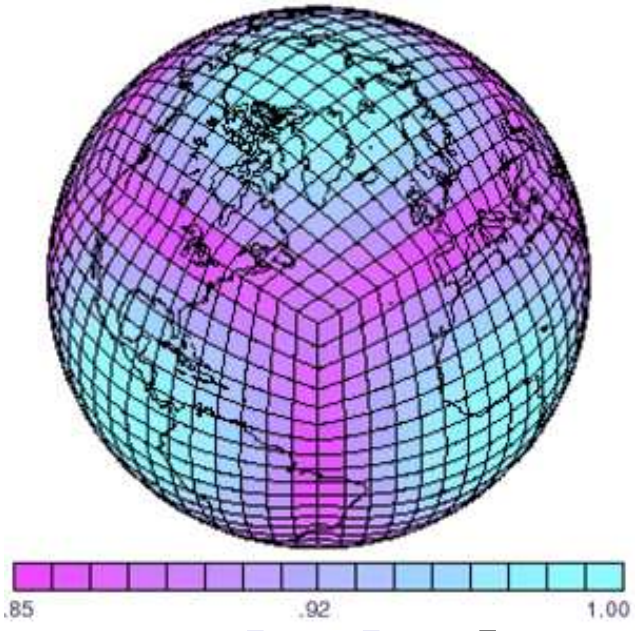
The taxonomy of vertical coordinates distinguishes mass-based and space-based vertical coordinates. There is often an attempt to do something in the spirit of geo-referencing: invoking a “standard” reference grid: usually based on pressure levels in the atmosphere, and depth in the ocean.

Talk outline . . .

Earth system models are built from components

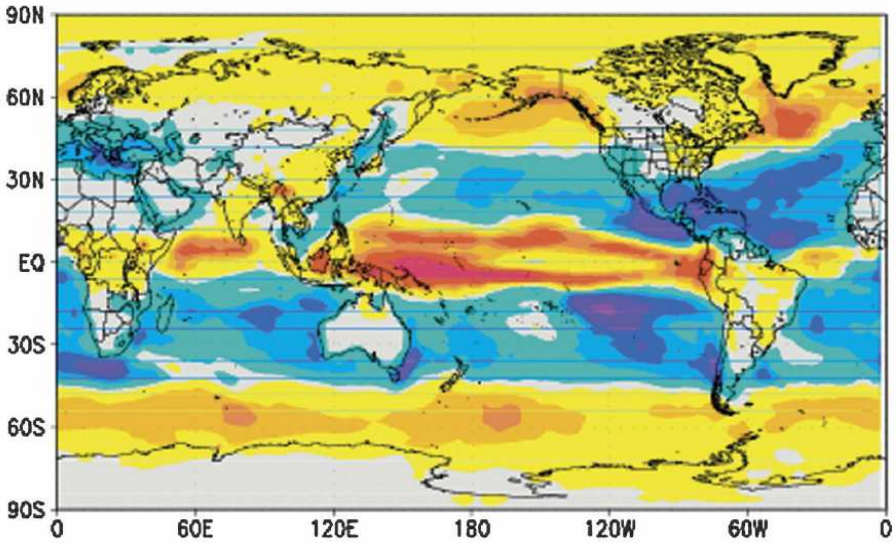
- Earth system models nowadays are built from components: subsystems that may be independently discretized.
- Even when all components are built by a cohesive community, the different components must have some conventions to share grid information.
- Furthermore, these days it is increasingly common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



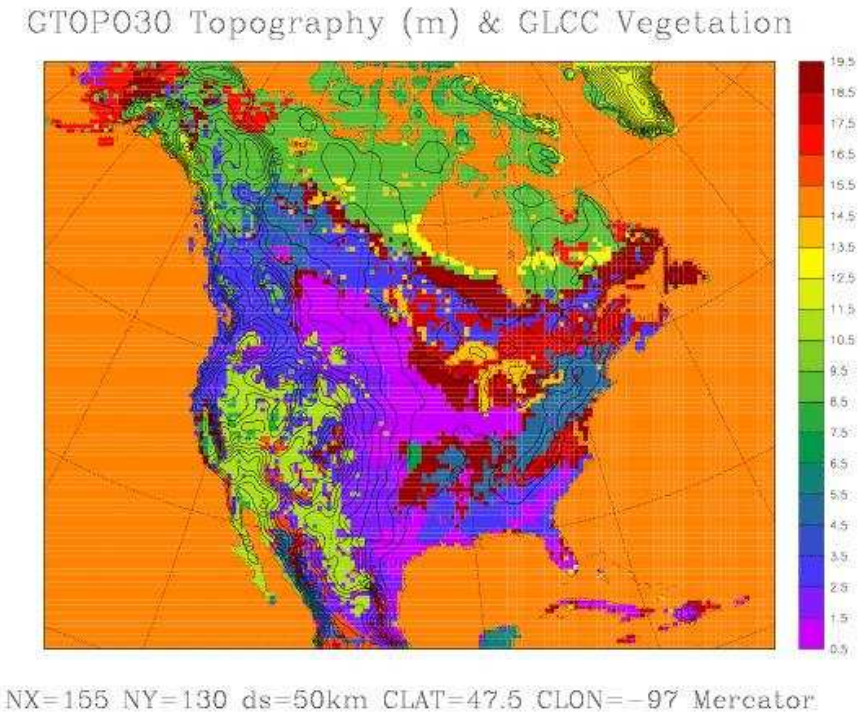


Dependencies across data from many models

- 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).

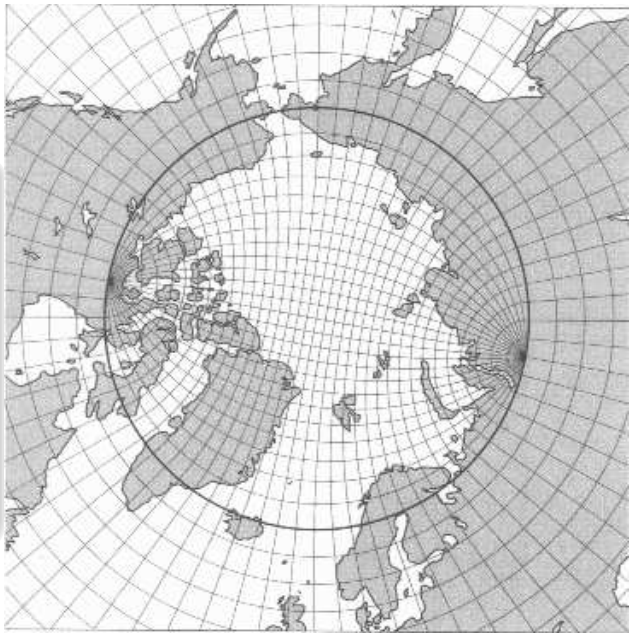
Geometry and coordinate systems

- 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.



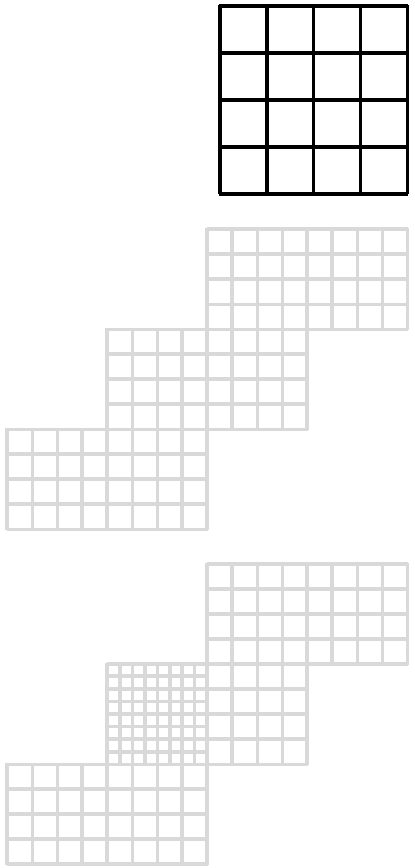
Discretizations

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.

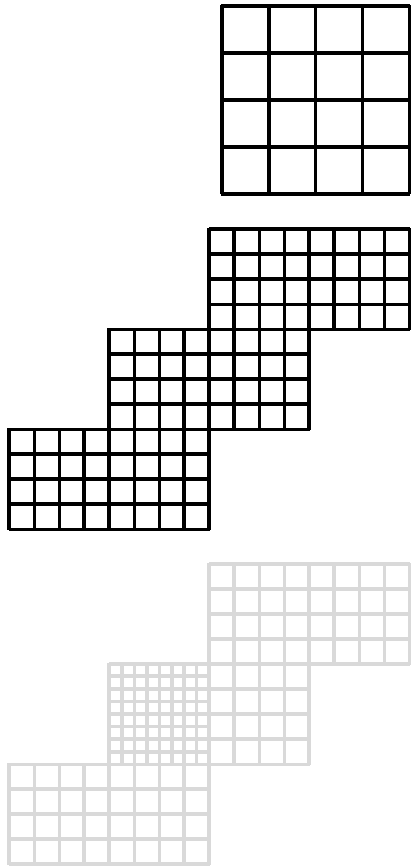


- Starting with a simple grid tile. . .
- you can make a simple mosaic. . .
- add refinement. . .

Mosaics

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

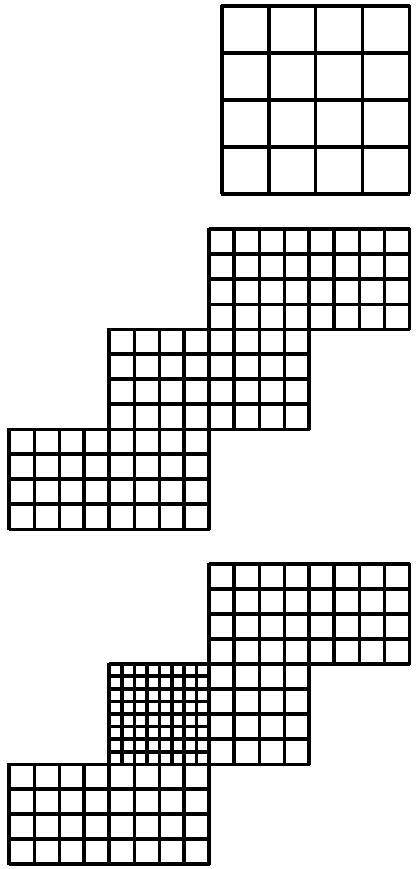
- Starting with a simple grid tile. . .
- you can make a simple mosaic. . .
- add refinement. . .



Mosaics

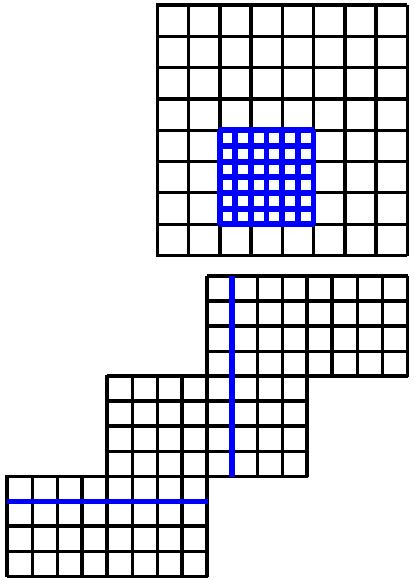
The mosaic is a simple but powerful abstraction that allows one to cleanly express complex grids as collections of tiles.

- Starting with a simple grid tile. . .
- you can make a simple mosaic. . .
- add refinement. . .

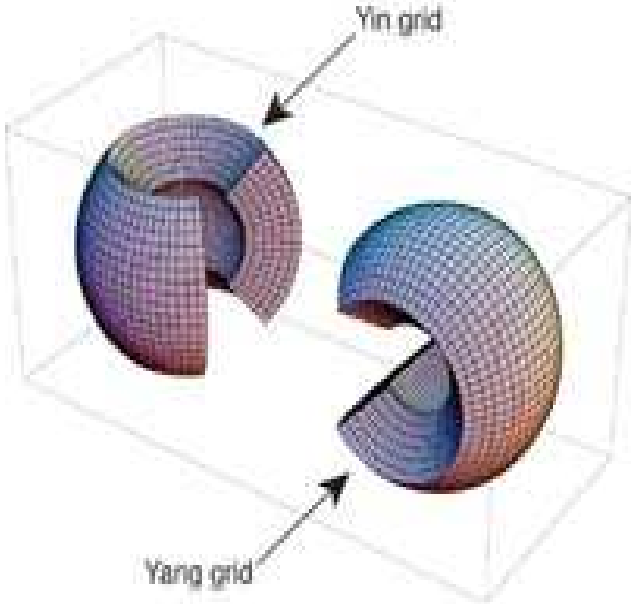


More with mosaics

- You can also express nested grids. . .



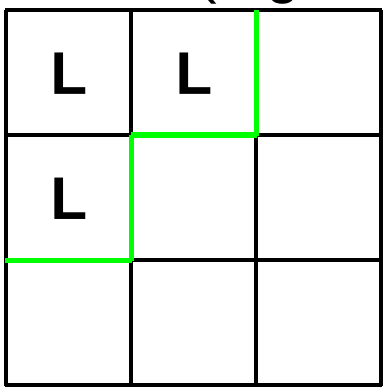
- grids with halos. . .

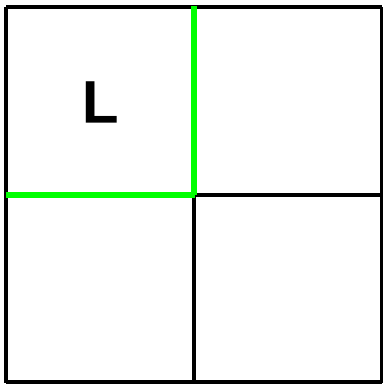


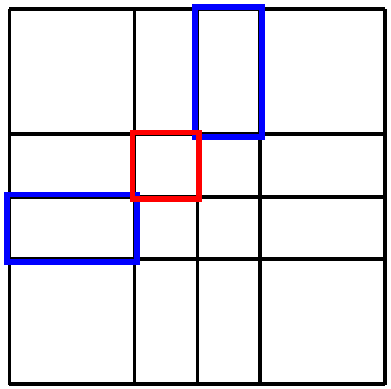
- and complex grids.

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).



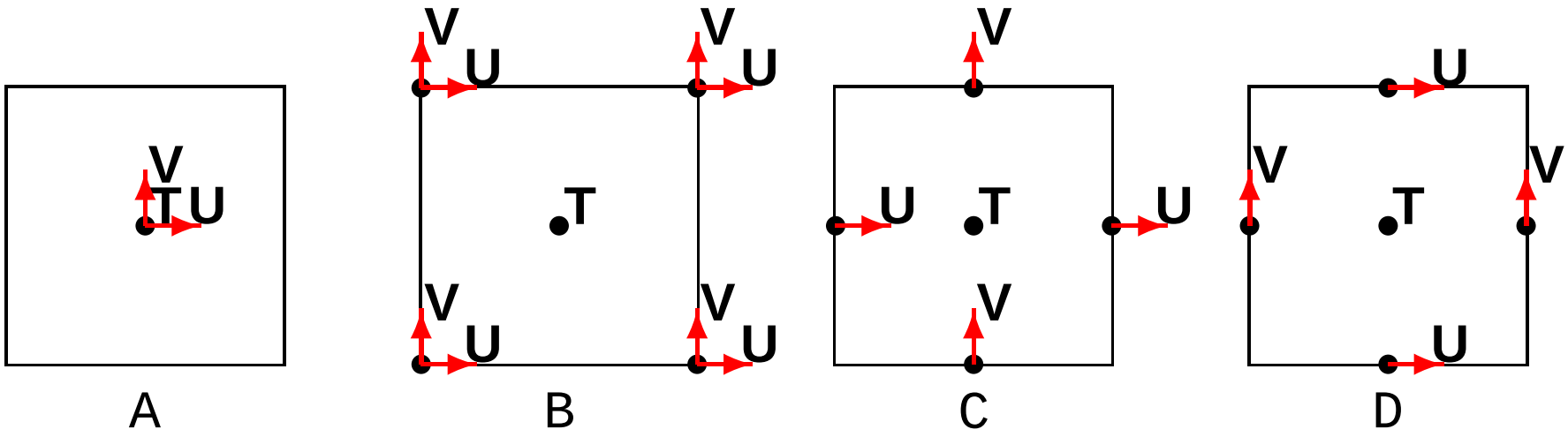




Land | Ocean | Exchange

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

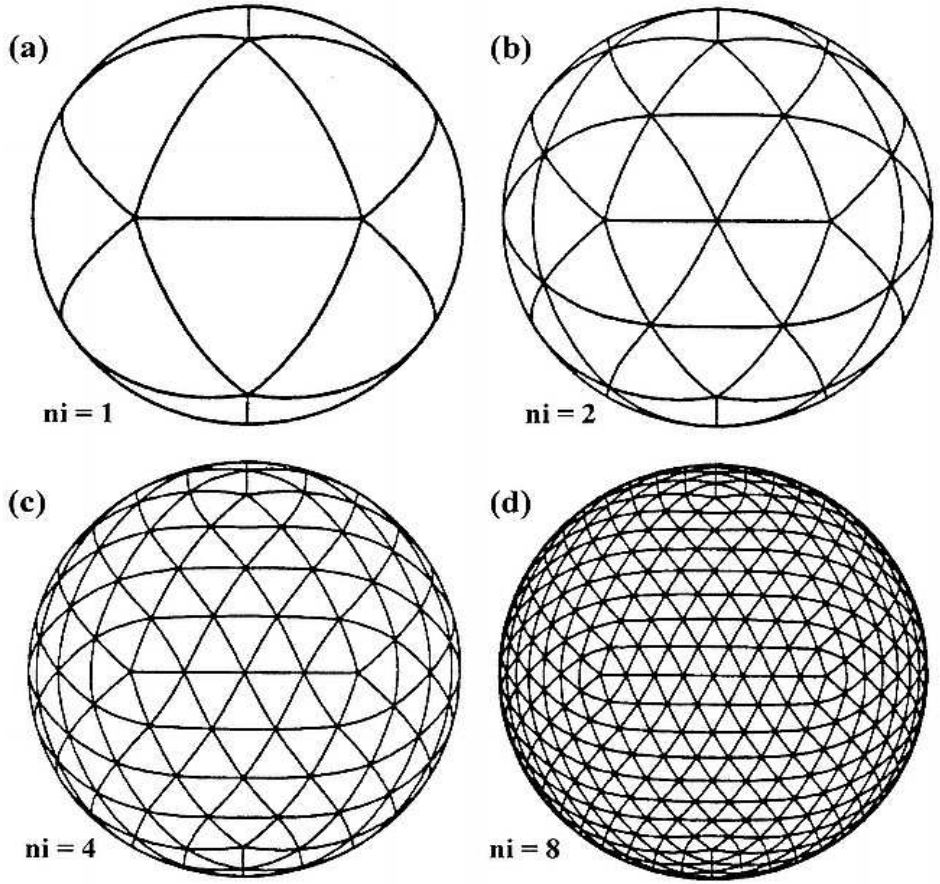
Staggering and supergrids

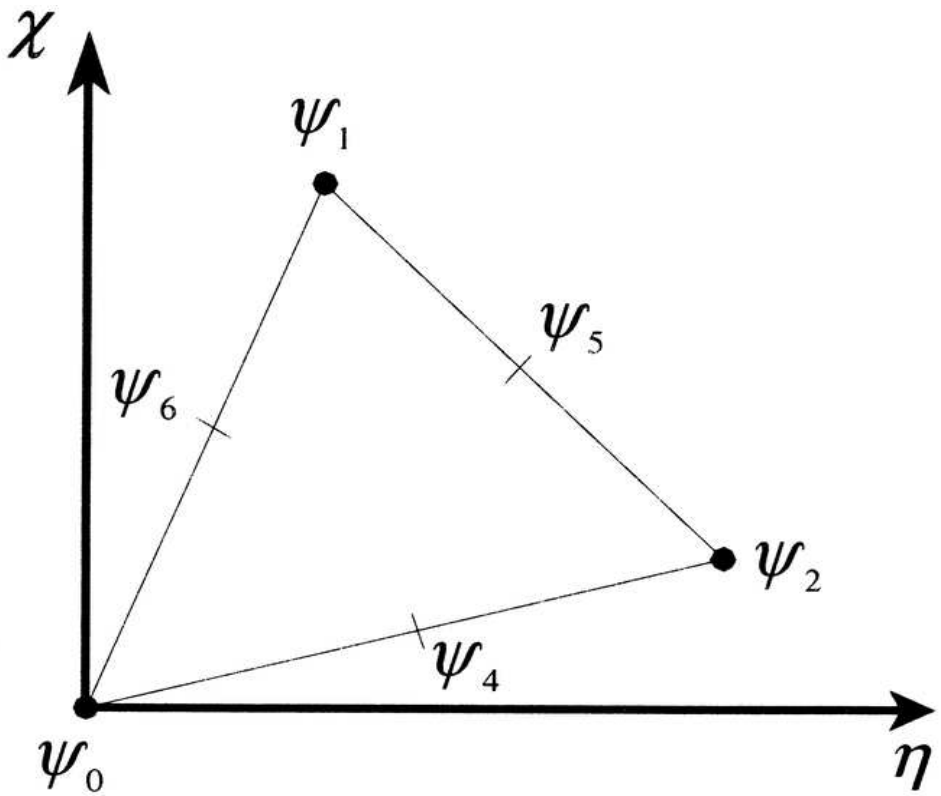


- If the “staggered” quantities are placed on independent coordinate sets $(x, y), (x_u, y_u), (x_v, y_v)$ their relationships are lost.
- We instead define the supergrid: the set of all the points on the grid where physical quantities might be defined.
- Variables are defined on subsets of points on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

Triangular supergrids

Triangular grid algorithms also use concepts like cell-, face- or vertex-centered quantities, which can be encapsulated within a supergrid.





Not in the Gridspec (yet)

A few things have been proposed for the Gridspec but still being mulled over. . .

- A `bounding_box` attribute for a grid tile. Useful optimization, easy for simple grid tiles. Might there be tricky issues with unstructured grids, where the assumption of simply connected tiles breaks down?
- Spectral “grids”: should there be a standard representation of wavenumber space? (Integer “coordinates”, `truncation` attribute, etc). Still not convinced that the wavenumber domain needs to be standardized: most sharing from spectral models is done in physical space, which is fully represented, Gaussian grids, etc.

Example: boundaries and overlaps

Consider an example of a coupled model with a cubed-sphere atmosphere and a tripolar ocean.

Boundary

Mosaic: `c48`
Tiles: `face1...face6`
Contact:

```
c48:face1::c48:face2
    orientation Y:Y
    anchor (90,1)::(1:1)
```

...(12 such)

Overlap

Mosaic: `om3`
Tiles: `global`
Contact:

```
c48:face1::om3:global
    ncells=1476
    frac_area(2,ncells)
```

...(6 such)

Example: Fields on a supergrid

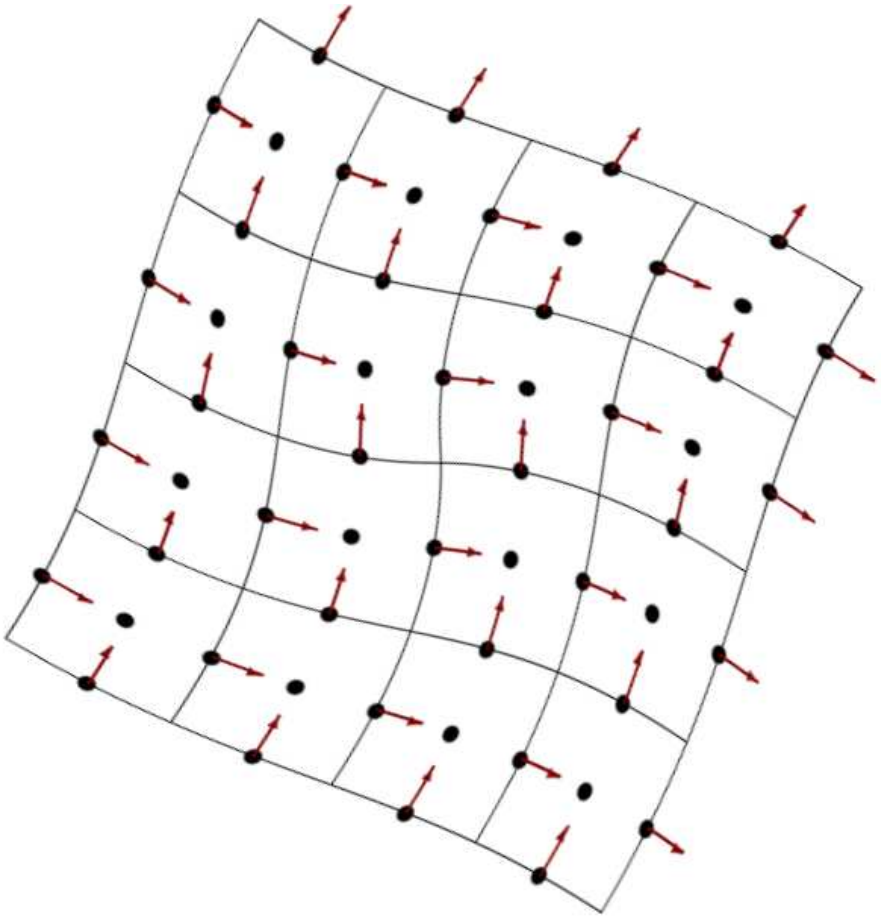
Consider a u velocity on a C-grid on this supergrid:

Gridspec file

```
ni=9, nj=9
lon(ni,nj), lat(ni,nj)
dx(ni-1,nj), dy(ni,nj-1)
...
```

Data file

```
nx=5, ny=4
int nx_u(nx), ny_u(ny)
nx_u = 1,3,5,7,9
ny_u = 2,4,6,8
float u(nx,ny)
gridspec = "foo.nc"
```



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.
- 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. . .

The GENIE Implementation (Ian Henderson)

The GENIE project: `http://www.genie.ac.uk`

- Goal: build a Grid[1]-based ESM from components on their own mosaics
- Gridspec will be used coupler code and transformations using BFG.
- Gridspec has been used to generate an XML schema describing GENIE ESM.

[1] that other kind of Grid. . .

The GFDL Implementation (Zhi Liang)

`http://www.gfdl.noaa.gov/~vb/grids`
`http://www.gfdl.noaa.gov/~vb/gridstd/gridstd.html`

- The 0.2 specification has been used to build a coupled model from a cube-sphere atmosphere, tripolar ocean, and lat-lon land models.
- Tools include: `generate_grids`, `generate_mosaic`, `generate_mosaic_topog`, `generate_xgrids`, `read_mosaic`, `horiz_interp`
- Sample data and gridspec files available there.

(I unlinked from the web after finding what I'd uploaded was 0.1 and not 0.2. . . will correct upon return to Princeton).

Talk outline . . .

Issues for CF Conventions Committee

Gridspec could be considered in several tracks, to make it more digestible:

- Refinement of `grid_mapping`: to separate out geometry and projection issues, and reserve mapping for functional generation of grid metrics.
- Aside from this issue, the definition of a tile, without staggering, is consistent with current CF.
- Handling of Gridspec as an external reference;
- Evaluate mosaic spec for offline or “server-side” regridding.
- Evaluate the use of supergrids: single reference grid with data fields defined on subsets of gridpoints.
- Unstructured grids have special issues, and should be a separate but coordinated track.