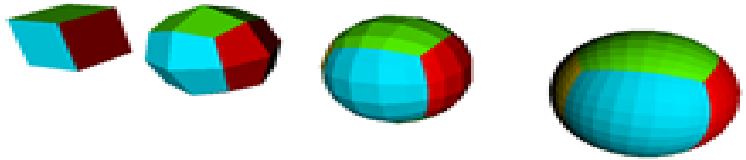
Interpolating climate data using CDAT



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Paul Durack, Charles Doutriaux, Jeff Painter, and Dean Williams (LLNL) – CDAT, CMIP5

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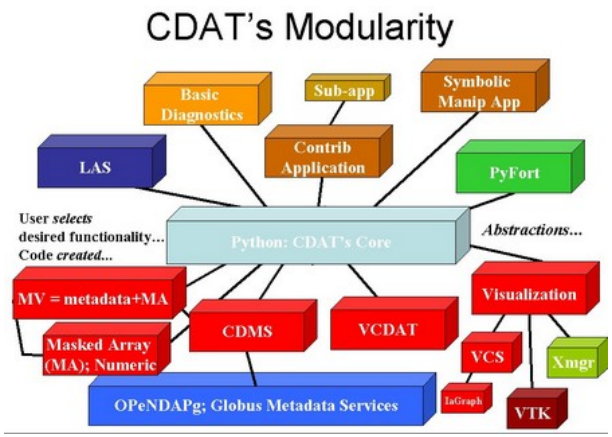
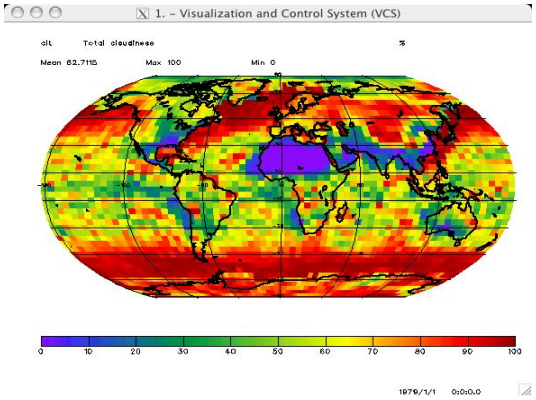
TECH

CDAT = Climate Data Analysis Tools



>Written in Python
>Understands data conforming to Climate Forecast (CF) conventions
>Ultra Visualization (UV)-CDAT brings together CDAT, VisIt, Paraview, VisTrails, R, ...
>Run CDAT engine on Earth System Grid to serve climate data

```
>>> import cdms2
>>> f = cdms2.open('./contrib/ZonalMeans/Test/test_data.nc')
>>> f.listvariables()
['bounds_depth', 'bounds_time', 'bounds_y', 'bounds_x', 'O2']
>>> o2 = f('O2')
>>> o2.listattributes()
['units', 'long_name', 'name']
>>> o2.units
'mol/m^3'
>>> o2.shape
(12, 5, 150, 180)
```



http://www2-pcmdi.llnl.gov/cdat

CDAT can easily be extended, leveraging a vast body of third party Python modules

- CDAT builds many packages including scipy, ipython, Pmw, PyQt, ... Extending CDAT can be as simple as typing "`python setup.py install`"

- Examples:
  - `mpi4py` (Message Passing Interface for Python)
  - `petsc4py` (sparse matrix solvers, non-linear equations, time steppers, ...) [Lisandro Dalcin]
  - `PyGNL`
  - `PyLog` (PROLOG engine)
  - `nltk` (Natural Language Toolkit)

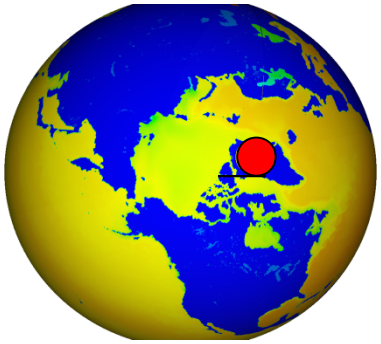
Our focus here is interpolation

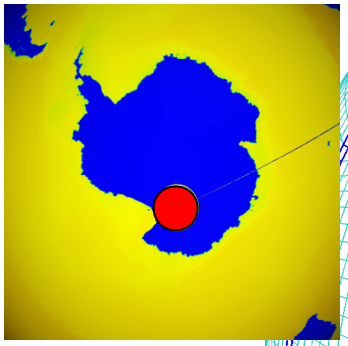
- Explore different interpolation options provided *within* CDAT
  - `Module regrid2`
- `Module gsRegrid`: new in CDAT 6.0
- `ESMP`: Earth System Modeling Framework (ESMF) interpolation (not part of CDAT)

- Evaluate each approach using native Coupled Model Intercomparison Program Phase 5 (CMIP-5) data from various models
  - *Source grids are typically not latitude-longitude*

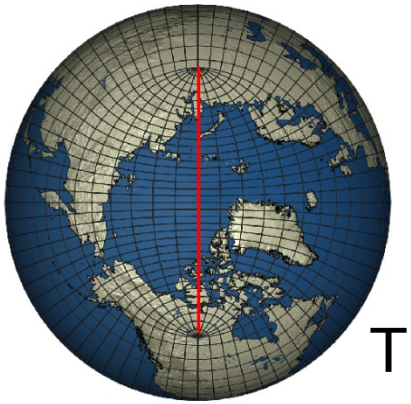
Some of the challenges of CMIP-5 and other grids

- **Models use non-uniform grids to avoid numerical problems and over-resolution near poles**

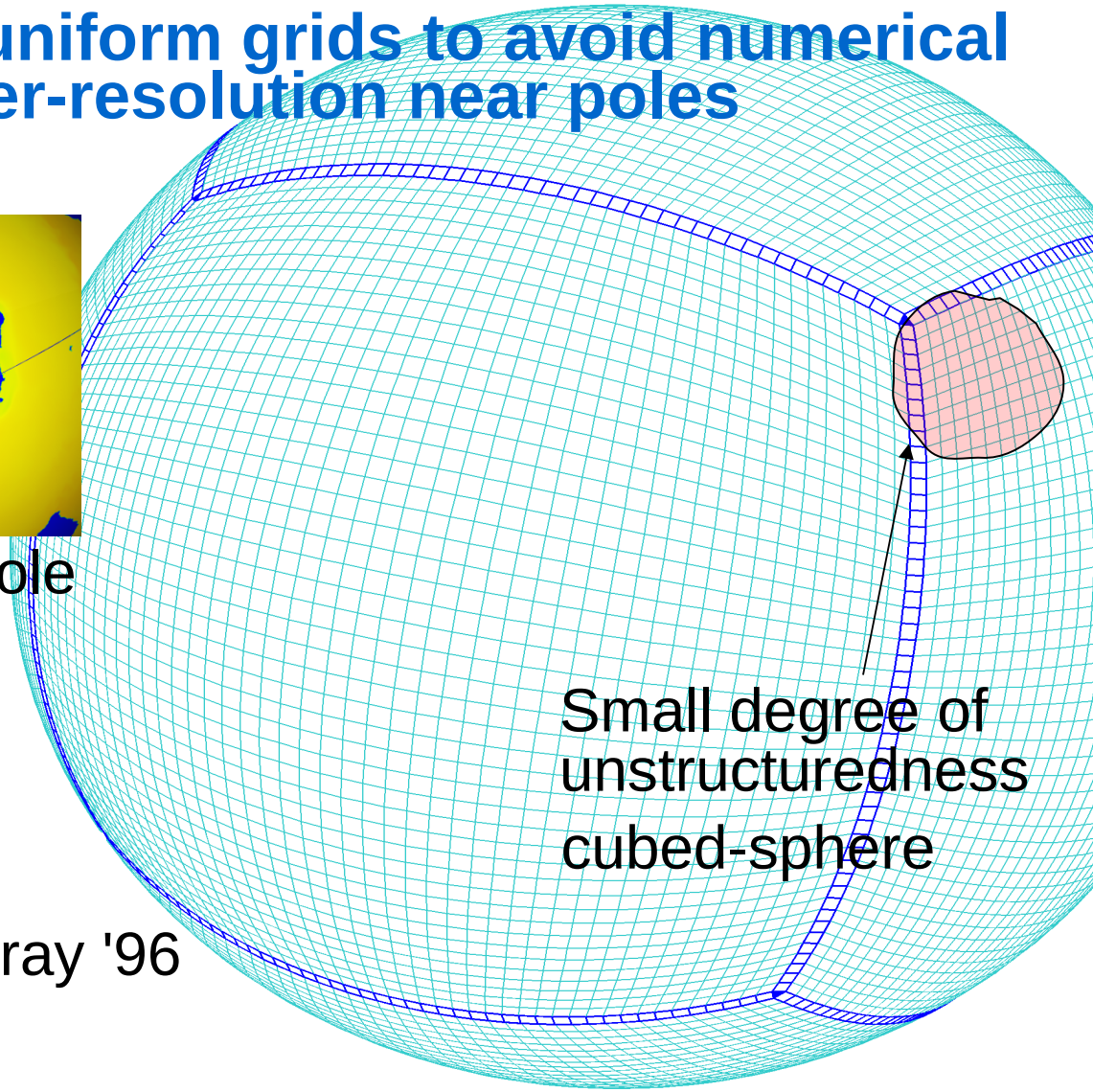




Rotated pole



Tripolar, Murray '96

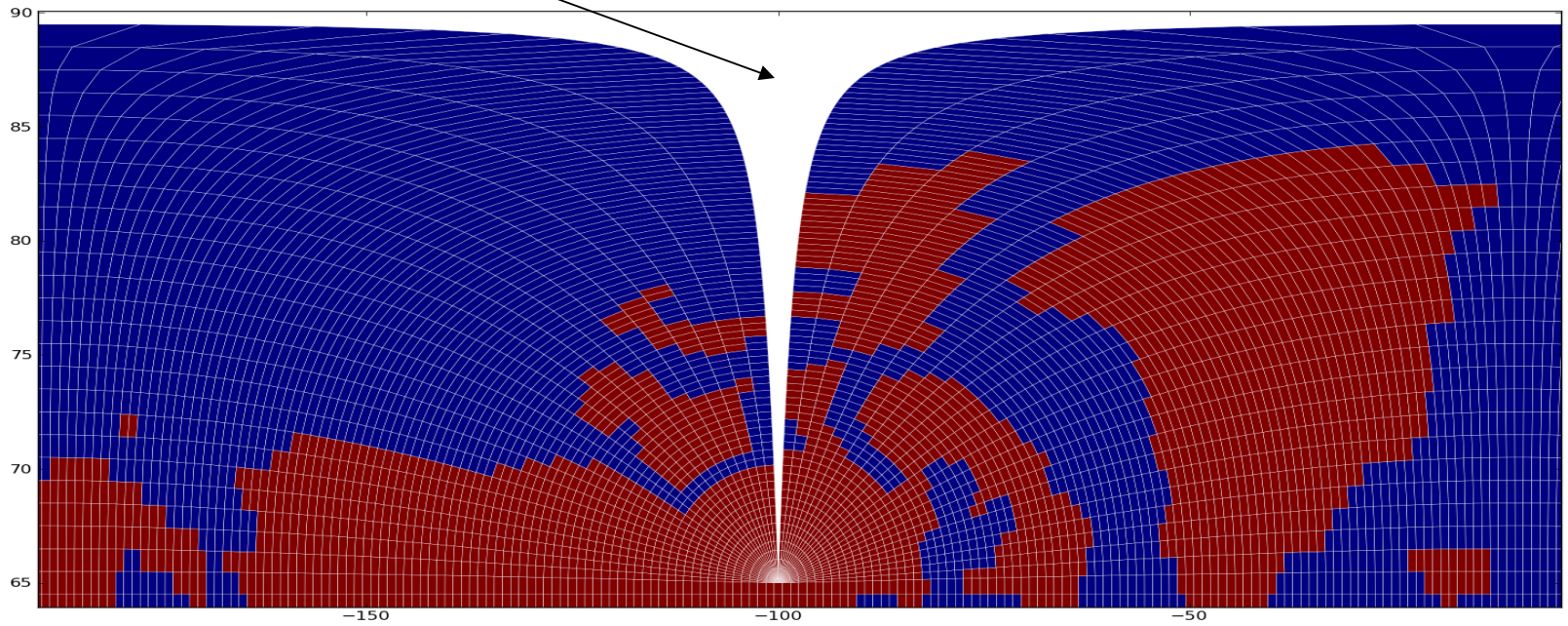


Small degree of unstructuredness

cubed-sphere

Interpolation must be able to handle...

- Extremely flat cells near poles
- Recognize longitudes as periodic coordinate
- Nodal versus cell centered data
- Gap of tripolar grid near pole



Currently available options for regridding in Python/CDAT

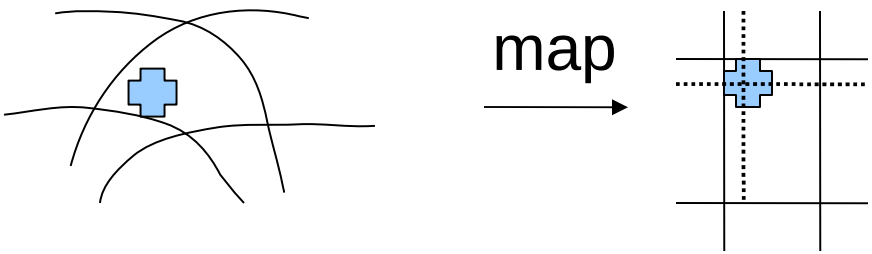
- regrid2 (in CDAT 5.2)
  - 2D, horizontal grid is a cross product of axes

- SCRIP (in CDAT 5.2)
  - 2D, curvilinear grids, conservative/linear/spline. Lacks documentation (was not able to use)

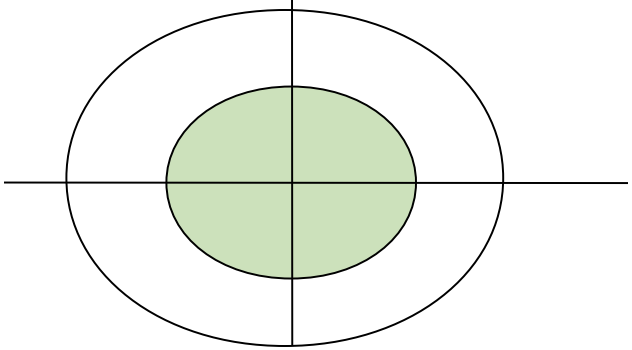
- LibCF
  - Multi-dimensional but only linear (in CDAT 6.0). Interface to C library using `ctypes`.
- ESMF/ESMP
  - 2D/3D, option between linear, conservative, Python interface recently made available by Ryan O'Kuinghttons. Interface to C ESMF (ESMC) via `ctypes`.

LibCF regridding/interpolation

- Linear interpolation using nearest neighbors only
  - No over-shooting
  - Straightforward to parallelize
- Pseudo-Newton search of position in index space
  - Only one iteration required for uniform, rectilinear grids
- Line search to improve convergence
- Use previous index location as initial guess when regridding from structured to structured grids
- Handles dateline, can be anywhere
- Pole remains a problem
- Has support for masking

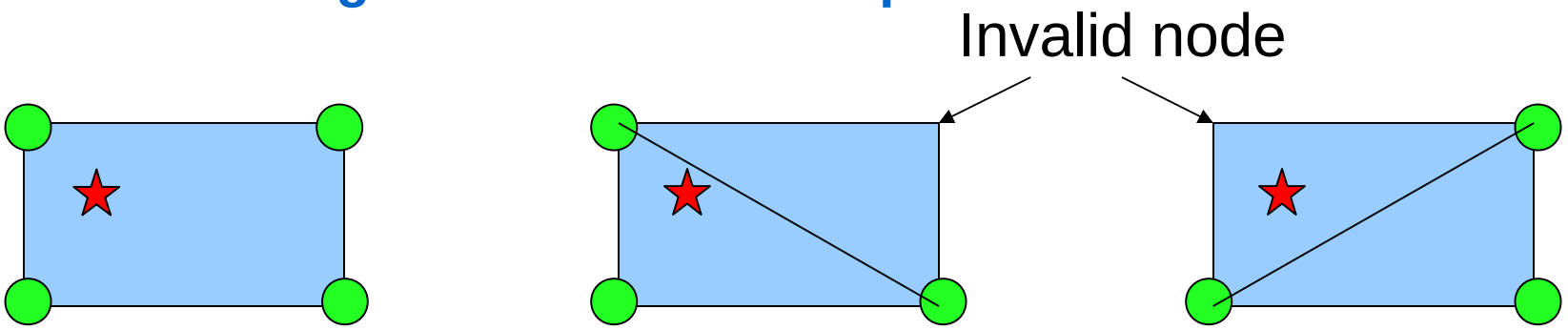


Pathological case has zero cell volume in lon-lat space



How LibCF deals with masking

- Will do its best to interpolate in the presence of masked (or invalid) values
- 3 cases:
  - All values in a cell are valid
  - Some invalid values
    - Switch from quadrilateral/hexahedron to triangle/tetrahedron interpolation



All nodal values are valid

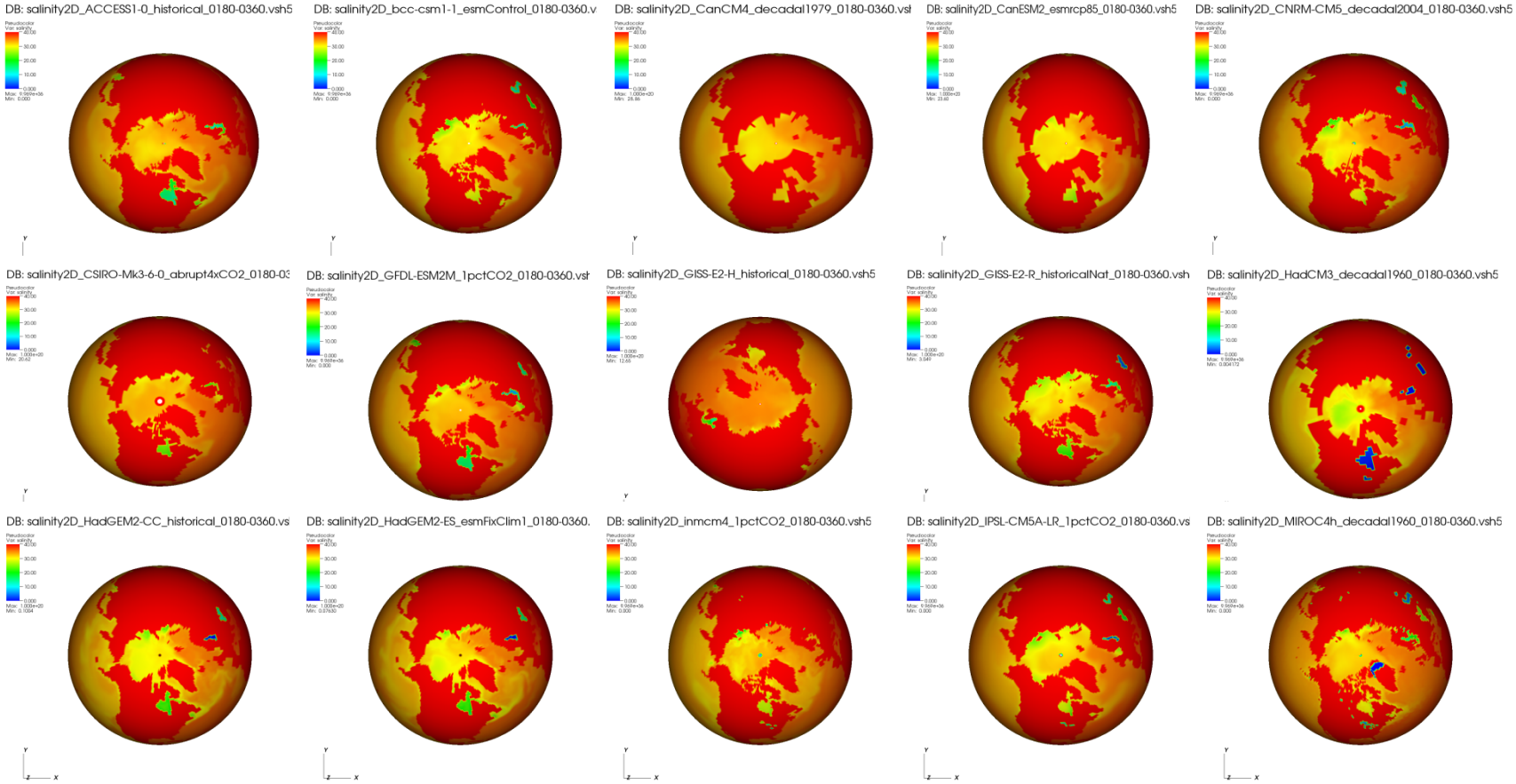
One missing value interpolation is still possible

Not possible to interpolate

How to call LibCF regrid from CDAT

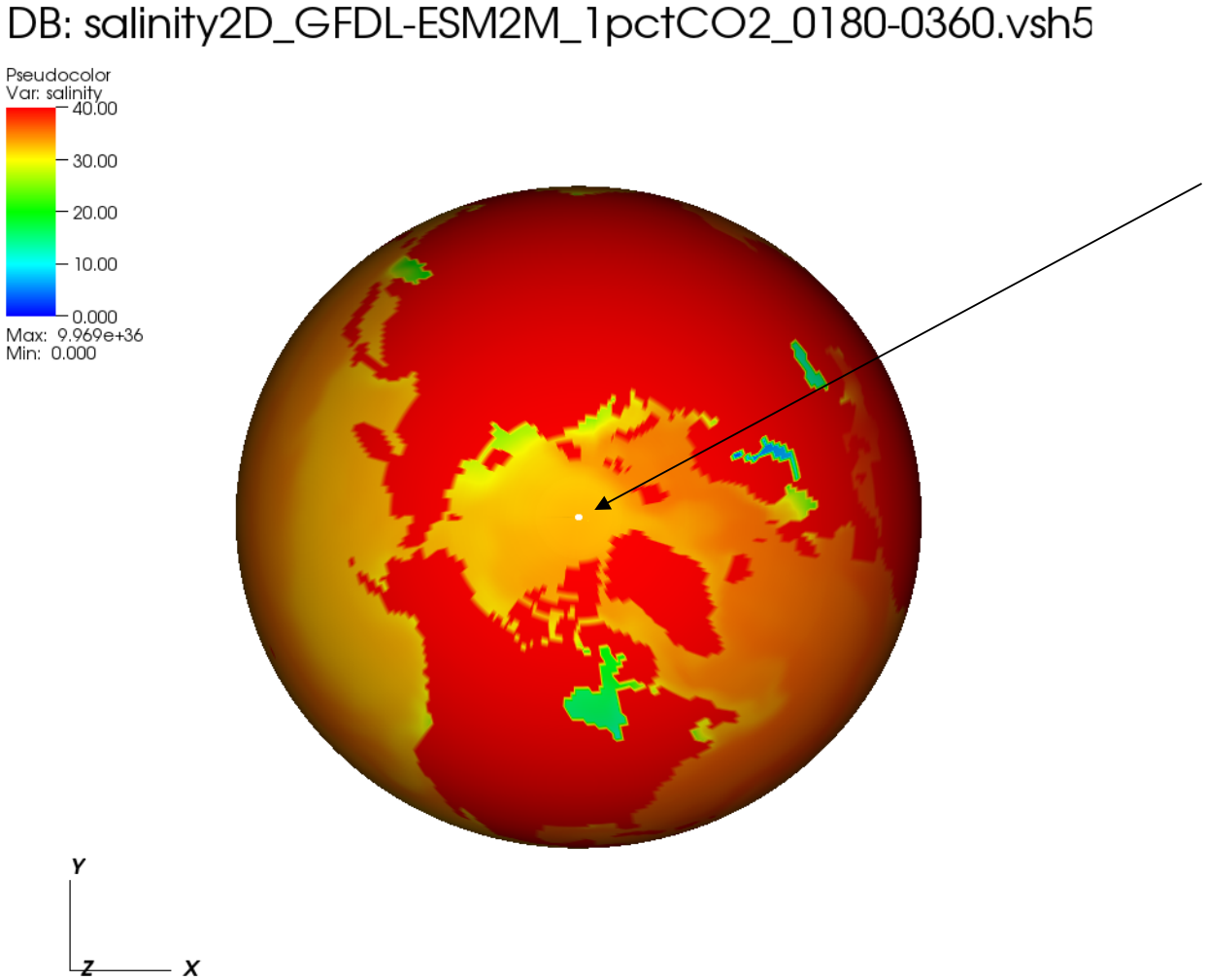
```
from cdms2 import gsRegrid
...
# .... src_y, src_x can be curvilinear coordinates
# or axes, ditto for dst_y, dst_x, ....
# takes numpy or cdat cdms2 type variables
src_grd = [..., src_y, src_x]
dst_grd = [..., dst_y, dst_x]

# constructor
rg = gsRegrid.Regrid(src_grd, dst_grid,
                     mkCyclic = False,
                     handleCut = False,
                     src_bounds = None)

# compute interpolation weights
rg.computeWeights(nitermax=20, tolpos=0.01)

# interpolate src_field, result is dst_field
rg(src_var, dst_var)
```

LibCF: 2D interpolation was tested on 23 ocean models



... etc.

LibCF: GFDL model was made cyclic and additional row was added to fill in gap

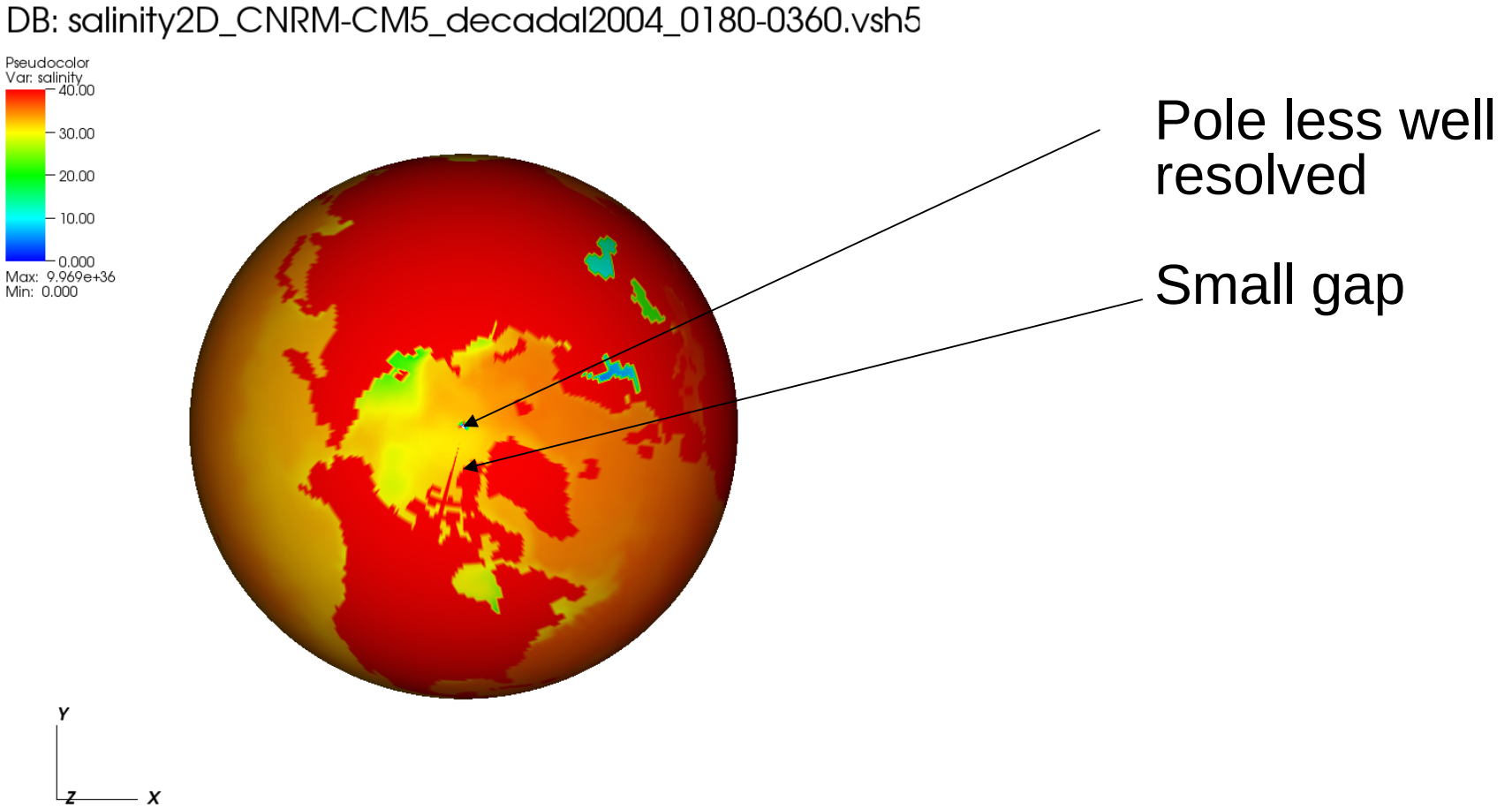


Pole is well resolved

Tripolar grid, no Gap

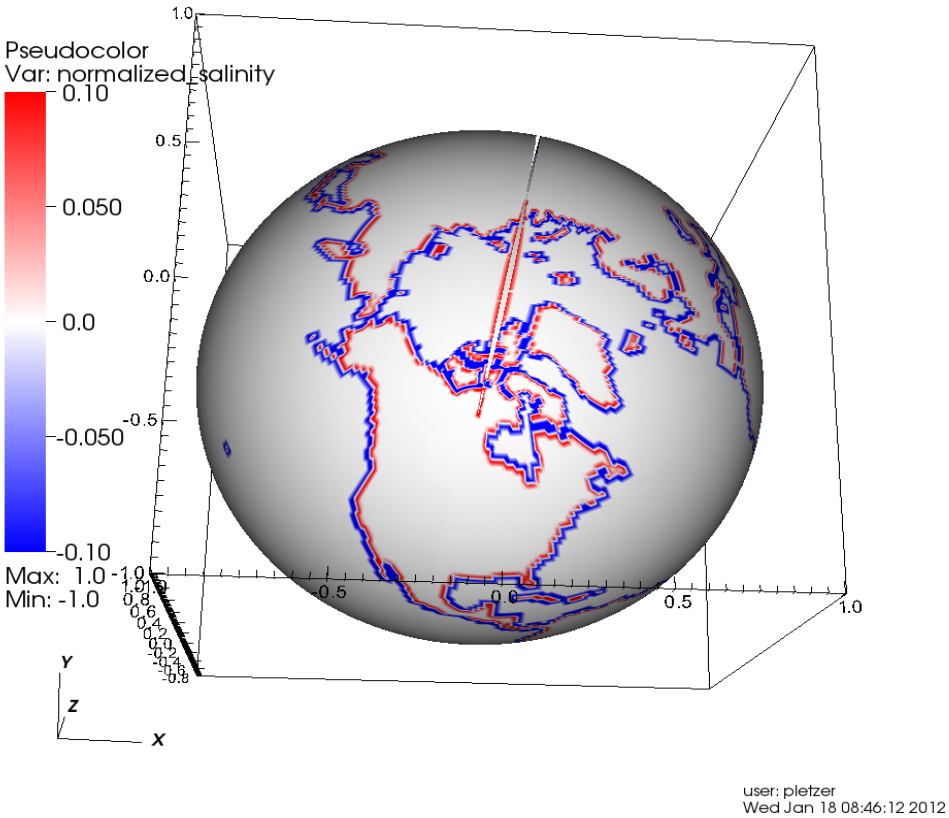
No dateline problem

LibCF: interpolation of CNRM model shows small gap



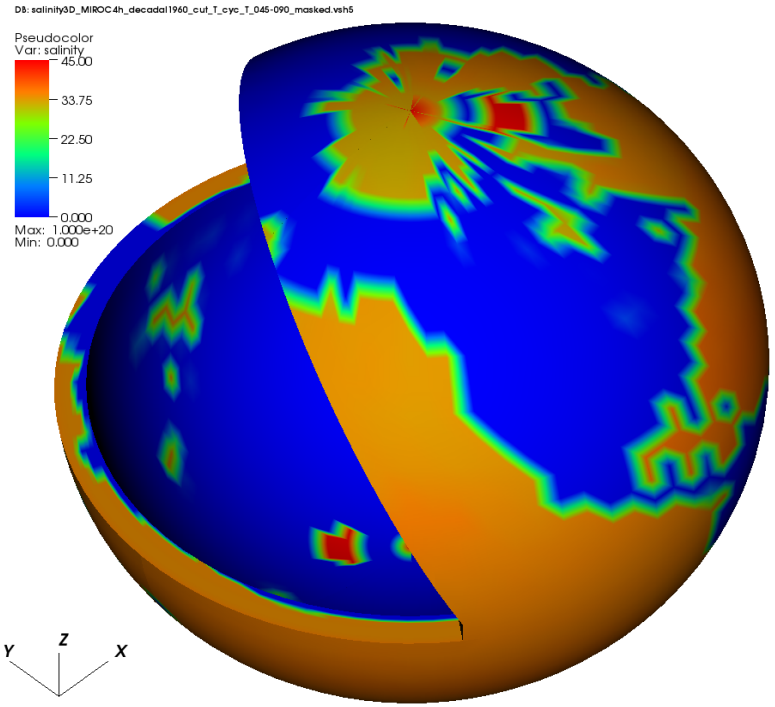
Interpolation error after interpolating back onto the source grid

- Error is mostly near the coast line



LibCF: 3D test cases

- Takes ~ 20-60 seconds (only 10 levels)
- MIROC hi-res model



Summary

- Highly distorted lat-lon grids present challenges for interpolation software
  - Cuts
  - Jump in longitude
  - Pole
- LibCF interpolation has benefited from being exposed to “real” datasets
- Timings: `gsRegrid` takes ~ few seconds for 2D, ~40 seconds for 3D (need to understand why 3D takes so much longer)
- Can apply domain decomposition and MPI parallelization to accelerate weight computation (embarrassingly parallel)
- Lack of conservation ~ 2%. Can be “fixed” globally by multiplying weights by a constant factor

Summary (2)

- ESMF interpolation likely to offer best solution when conservation is required
  - Actively working with ESMF developers to extend Python API
  - Work by Peggy Li [ESMF Offline Regrid Generator Performance Comparison with SCRIP] shows good scalability and accuracy for atmospheric model