CICE: The LANL sea-ice model

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Model overview

- Structured quadrilateral ‘B’ grid
  - Both components of velocity at vertices
  - Ice concentration and mass a cell centres
- Fortran 90
- Parallelized via a grid decomposition with MPI or OpenMP
- Netcdf output and input

Dynamics

- Solve sea-ice momentum equation for u and v components of velocity at cell vertices
  - Air stress, ocean stress, sea surface tilt, Coriolis force, internal stress
  - (W. D. Hibler. A dynamic thermodynamic sea ice model. J. Phys. Oceanogr., 9:817–846, 1979)
- Internal stress uses explicit variational scheme for horizontal operators
  - (E. C. Hunke and J. K. Dukowicz. The Elastic-Viscous-Plastic sea ice dynamics model in general orthogonal curvilinear coordinates on a sphere—Effect of metric terms. Mon. Wea. Rev., 130:1848–1865, 2002.)
- Sea-ice rheology
  - Elastic-viscous-plastic (E. C. Hunke and J. K. Dukowicz. An elastic-viscous-plastic model for sea ice dynamics. J. Phys. Oceanogr., 27:1849–1867, 1997.)
  - Elastic-anisotropic-plastic (A. V.Wilchinsky and D. Feltham. Modelling the rheology of sea ice as a collection of diamond-shaped floes. J. Non-Newtonian Fluid Mech., 138:22–32, 2006.)
- Incremental remapping advection
  - Conservative, second order accurate, monotone (limiting scheme), efficient for extra tracers (needed for BGC!)
  - (W. H. Lipscomb and E. C. Hunke. Modeling sea ice transport using incremental remapping. Mon. Wea. Rev., 132:1341–1354, 2004.)

Vertical thermodynamics

- Semtner ‘zero’ layer model
  - Single sea-ice layer
    - A. J. Semtner. A model for the thermodynamic growth of sea ice in numerical investigations of climate.J. Phys. Oceanogr., 6:379–389, 1976.
- Bitz & Lipscomb thermodynamics
  - Prognosed vertical temperature profile, accounts for salinity effect on specific heat capacity
    - C. M. Bitz and W. H. Lipscomb. An energy-conserving thermodynamic sea ice model for climate study. J. Geophys. Res.–Oceans, 104:15669–15677, 1999.
- ‘Mushy physics’
  - Prognosed vertical temperature and bulk salinity profiles, gravity drainage, flushing, realistic snow-ice formation
    - A. K. Turner, E. C. Hunke, and C. M. Bitz. Two modes of sea-ice gravity drainage: a parameterization for large-scale modeling. J. Geophys. Res., 118:2279–2294, doi:10.1002/jgrc.20171, 2013.

Melt ponds

- Melt ponds have several representations
  - CESM formulation
    - Simple formulation
      - M. M. Holland, D. A. Bailey, B. P. Briegleb, B. Light, and E. Hunke. Improved sea ice shortwave radiation physics in CCSM4: The impact of melt ponds and aerosols on arctic sea ice. J. Clim., 25:14131430, 2012.
  - Topographic formulation
    - Melt water runs to thinnest category
      - D. Flocco, D. L. Feltham, and A. K. Turner. Incorporation of a physically based melt pond scheme into the sea ice component of a climate model. J. Geophys. Res., 115:C08012, doi:10.1029/2009JC005568, 2010.
  - Level ice ponds
    - Preferential ponds over level ice
    - Drainage through mush
      - E. C. Hunke, D. A. Hebert, and O. Lecomte. Level-ice melt ponds in the Los Alamos Sea Ice Model, CICE. Ocean Mod., 71:26–42, 2013.

Ice thickness distribution

- Sea-ice represented as ice thickness distribution
  - Typically 5 thickness categories
- Mechanical redistribution
  - Convergence of sea ice causes ridging thickness moved from thin ice categories to thick
  - W. H. Lipscomb, E. C. Hunke, W. Maslowski, and J. Jakacki. Improving ridging schemes for highresolution sea ice models. J. Geophys. Res.–Oceans, 112:C03S91, doi:10.1029/2005JC003355, 2007.

Radiation

- CCSM3
  - Albedo depends on temperature and thickness of ice
  - Albedos chosen to fit SHEBA field experiment
  - Beer's law for penetrating radiation
- Delta-Eddington
  - Multiple scattering radiative transfer
  - Albedos determined from inherent optical properties of sea-ice
  - B. P. Briegleb and B. Light. A Delta-Eddington multiple scattering parameterization for solar radiation in the sea ice component of the Community Climate System Model. NCAR Tech. Note NCAR/TN-472+STR, National Center for Atmospheric Research, 2007.

Other stuff

- Ice age, level (undeformed) ice fraction and first year ice fraction tracers
- Aerosols
- Biogeochemistry
- Forcing by time varying atmospheric and oceanic data for stand-alone simulations
- Diagnostics output
- Documentation
  - Many published papers describing algorithms
  - 116 page manual

Recent/future development paths

- MPAS-seaice
  - New sea-ice model using Voronoi tessellation grids – variable resolution
  - Will be released in ~18-24 months
- Column physics
  - All column physics (vertical thermo, shortwave, mechanical redist., BGC, aerosols) in CICE placed into “column physics package” – self contained library
  - Same column code used by CICE and MPAS-seaice

Community model aspects: CICE5

- Availability
  - CICE5 publically released (avail. from website)
  - no major new releases planned
- Support
  - CICE v5 maintained (bug fixes, brief questions answered)
  - no active development (future LANL focus is on MPAS-seaice)
  - Support to general users is minimal since it is heavily tested and vetted by close collaborators before release and is well documented (including working test configurations to get you started)

Community model aspects: "Columnized" CICE

- Availability
  - Not publically released
  - Available through collaboration agreement
  - Being implemented and tested in several models
    - RASM, CESM, HiLat (DoE)
- Support
  - Maintained and the "column package" is being actively developed
  - Collaborator changes to column package will be tested and incorporated