Coupling
Nuts and Bolts

David Bailey, NCAR
Anthony Craig, FA
Andrew Roberts, LANL
Alice DuVivier, NCAR
Elizabeth Hunke, LANL
Why might you need to couple?

- The coupled response *may* be different with a fully-active atmosphere-ocean-land system is different than the standalone CICE response.
- Address feedbacks in the fully-coupled system.
- To provide forecasts or projections from all the Earth system components.
- Particular process studies require interactions between fully-active components.
- The Earth system is very complex and coupling is a non-trivial part of a model.
Examples of coupled studies.

- You want to implement the impact of icebergs on Antarctic sea ice but need to account for ocean temperatures below the surface.
  - (https://doi.org/10.1029/2010JC006588)

- You want to trace water isotopes throughout the Earth System so you’ll need to know the isotopic precipitation onto sea ice.
  - (https://doi.org/10.1029/2019MS001663)

- You want to know the spectral radiation incident on the sea ice and pass back the reflected longwave and shortwave radiation.
  - (NCAR Tech. Note NCAR/TN-472+ STR)
What is coupling?

- Formal connection of distinct components
- Many potential methods
  - Through a hub coupler or mediator (e.g. CESM, E3SM, RASM) using an established top level protocol like
    - CPL, CIME, CMEPS, NEMS
What is coupling?

- Formal connection of distinct components
- Many potential methods
  - Through a hub coupler or mediator (e.g. CESM, E3SM, RASM) using an established top level protocol like
    - CPL, CIME, CMEPS, NEMS
  - Direct coupling using an established top level protocol like
    - NUOPC, ESMF
What is coupling?

• Formal connection of distinct components
• Many potential methods
  • Through a hub coupler or mediator (e.g. CESM, E3SM, RASM) using an established top level protocol like
    • CPL, CIME, CMEPS, NEMS
  • Direct coupling using an established top level protocol like
    • NUOPC, ESMF
  • Coupling via an established in-line protocol like
    • OASIS
What is coupling?

- Formal connection of distinct components
- Many potential methods
  - Through a hub coupler or mediator (e.g. CESM, E3SM, RASM) using an established top level protocol like
    - CPL, CIME, CMEPS, NEMS
  - Direct coupling using an established top level protocol like
    - NUOPC, ESMF
  - Coupling via an established in-line protocol like
    - OASIS
  - Direct calls (i.e. Models call each other directly or a top level driver calls into models directly via less formal interfaces)
    - FMS
What is coupling?

• Formal connection of distinct components
• Many potential methods
  • Through a hub coupler or mediator (e.g. CESM, E3SM, RASM) using an established top level protocol like
    • CPL, CIME, CMEPS, NEMS
  • Direct coupling using an established top level protocol like
    • NUOPC, ESMF
  • Coupling via an established in-line protocol like
    • OASIS
  • Direct calls (i.e. Models call each other directly or a top level driver calls into models directly via less formal interfaces)
    • FMS
• Note that underlying software interfaces are used in a number of these such as MCT and ESMF.
• There can be multiple layers here which are often intertwined.
Coupling considerations

- Coupling of gridded fields (inputs and outputs)
- Coupling of scalar fields (inputs and outputs)
- Units, sign conventions, vector basis (rotation)
Coupling considerations

- Coupling of gridded fields (inputs and outputs)
- Coupling of scalar fields (inputs and outputs)
- Units, sign conventions, vector basis (rotation)
- Sequencing, model time-stepping, coupling frequency, accumulation, averaging, and lags
- Where fluxes between components are computed
- Method for coupling data (i.e. shared memory blocks, interfaces arguments, files, pointers, etc.)
- Initialization and consistency of grids and masks
- Interpolation and merging
- Conservation
- Performance, scaling, concurrency, and load balance
Coupling considerations

- Coupling of gridded fields (inputs and outputs)
- Coupling of scalar fields (inputs and outputs)
- Units, sign conventions, vector basis (rotation)
- Sequencing, model time-stepping, coupling frequency, accumulation, averaging, and lags
- Where fluxes between components are computed
- Method for coupling data (i.e. shared memory blocks, interfaces arguments, files, pointers, etc.)
- Initialization and consistency of grids and masks
- Interpolation and merging
- Conservation
- Performance, scaling, concurrency, and load balance
- Synchronization of sun angles
  - via orbital parameters
  - between the radiation calculation and the surface albedo calculations
- Synchronization of calendars, date, and time
- Synchronization of model restart for exact restart
Coupling in CICE6

- Implementation generally consists of top level init, run, and finalize interfaces consistent with top level coupling. That same strategy is used to create the standalone driver.

- A coupling cap is a top level layer (vs a standalone driver) that supports the required coupling protocol and drives CICE via the coupling layer.

- Several coupling interfaces are included in `cicecore/drivers/`
  - CESM1/RASM with CPL/MCT cap
  - CESM2 with CIME/MCT cap
  - CESM2 with CIME/CMEPS/NUOPC cap
  - DMI with NUOPC cap
  - HadGEM using direct coupling (historical implementation)
  - Standalone via a custom driver

- One driver layer is built per application

- There is some overlap in source code between driver implementations

- Please consider adding your driver layer and creating a PR to the consortium repo
Typical CICE coupling fields

Inputs

• Ocean temperature, salinity, current, top level depth, roughness length, sea surface slope, ocean freeze/melt heat flux, tracer fluxes

• Atmosphere bottom level height, temperature, potential temperature, humidity, winds, density, longwave and shortwave radiation, rain, snow, tracer fluxes

• Date and time, restart flags, next radiation time, initialization strategy, orbital information, cross component parameters
Typical CICE coupling fields

Inputs
- Ocean temperature, salinity, current, top level depth, roughness length, sea surface slope, ocean freeze/melt heat flux, tracer fluxes
- Atmosphere bottom level height, temperature, potential temperature, humidity, winds, density, longwave and shortwave radiation, rain, snow, tracer fluxes
- Date and time, restart flags, next radiation time, initialization strategy, orbital information, cross component parameters

Outputs
- Ice fraction, snow depth, surface temperature, 2m reference temperature and height, roughness, albedo, longwave up, latent and sensible heat flux, evaporation, surface ice/atm (wind) stress, penetrating heat flux, heat and water (salt) flux due to freezing/melting, ice/ocean stress, tracer fluxes
- Grid information, date and time, cross component parameters
Typical CICE coupling fields

**Inputs**
- Ocean temperature, salinity, current, top level depth, roughness length, sea surface slope, ocean freeze/melt heat flux, tracer fluxes
- Atmosphere bottom level height, temperature, potential temperature, humidity, winds, density, longwave and shortwave radiation, rain, snow, tracer fluxes
- Date and time, restart flags, next radiation time, initialization strategy, orbital information, cross component parameters

**Outputs**
- Ice fraction, snow depth, surface temperature, 2m reference temperature and height, roughness, albedo, longwave up, latent and sensible heat flux, evaporation, surface ice/atm (wind) stress, penetrating heat flux, heat and water (salt) flux due to freezing/melting, ice/ocean stress, tracer fluxes
- Grid information, date and time, cross component parameters

Depends on coupling application!
- Note that CICE has a sophisticated subgrid (multi-category ice) capability.
- The atm/ice and ice/ocn fluxes should be computed in the CICE model or the atmosphere and ocean must be made aware of the subgridscale (e.g. HadGEM).
- A similar thing is done in land models.