Multi-Column Ocean Grid (MCOG) in the Community Earth System Model

CPT: Ocean Mixing Processes Associated with High Spatial Heterogeneity in Sea Ice and the Implications for Climate Models

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Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

- Motivation
- Questions to be answered
- Implementation
- Experiments and Results
- Summary and Future Work

Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

- Motivation
  - Earlier studies in single-column ice-ocean models showed that resolving high spatial variability in ice-ocean brine exchange has important effects on ocean mixing and resulting sea-ice mass budgets
  - Existing climate models do not fully resolve these ice-ocean exchanges

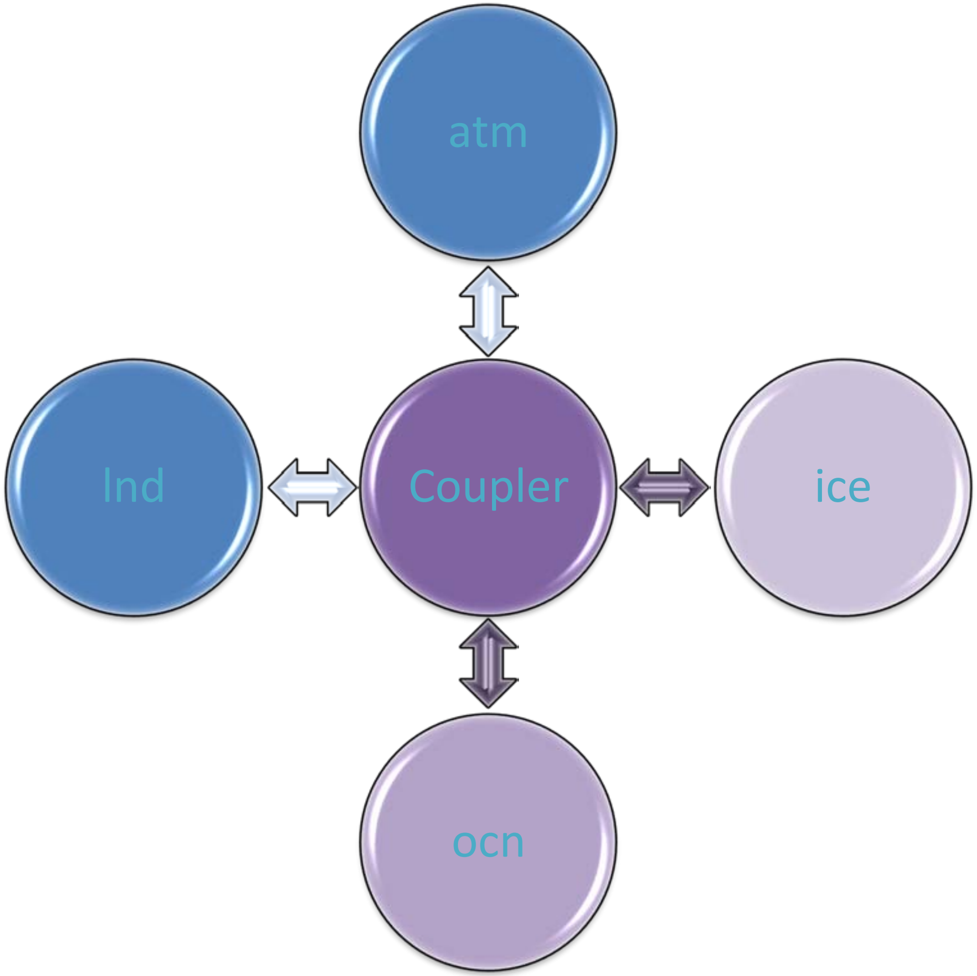
Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

- Questions to be answered

1. How does MCOG work during the ice growth period?
2. How can MCOG be implemented in 3D climate models?
3. How does MCOG influence physical and biogeochemical tracers that have fluxes between ice and ocean?
4. How much can MCOG reduce uncertainties in climate models?
5. What is the importance of explicitly representing the high ice/ocean flux spatial heterogeneity in climate processes and feedbacks?
6. How will representing this sub-gridscale variability reduce uncertanties in climate models?

Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

Simplified CESM Conceptual Diagram



- Implementation

  Ice-Coupler-Ocean Communication in Standard and MCOG CESM

  - **Sea-ice model (cice)**
    - computes five categories of sea-ice thickness in each grid box, plus fluxes and stresses associated with each:
      - zonal and meridional ocean/ice stress
      - penetrating shortwave flux
      - freshwater flux
      - salt flux
      - ice/ocean heat flux
    - sends an aggregate ice fraction value, fluxes, and stresses to coupler once per ice/cpl communication interval.
    - MCOG also sends all individual category fluxes and fields, plus open-ocean fraction (36 in all)

- Implementation

Ice-Coupler-Ocean Communication in Standard and MCOG CESM

- **Coupler (cpl)**
  - receives stresses and fluxes from component models; also receives ice fraction from cice
  - merges, time averages, regrids
  - sends to ocean every cpl/ocn communication interval
  - MCOG: ditto for all individual categories fluxes and fields, plus open-ocean ice-fraction and open-ocean meridional and zonal wind stresses and shortwave flux

Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

- Implementation

  Ice-Coupler-Ocean Communication in Standard and MCOG CESM

  – **Ocean (POP)**
    - receives total ice fraction and merged fields/fluxes from cpl (surface stress; water, salt, heat, radiation fluxes; ice fraction)
    - MCOG also receives category-specific fields & fluxes, plus open-ocean zonal and meridional wind stresses and shortwave flux
    - <…> computes Kpp vertical mixing coefficients using standard input from cpl <…>
    - MCOG also computes Kpp vertical mixing coefficients from individual ice-category information, then creates ice-fraction weighted averages of the coefficients
    - returns fields & fluxes to cpl (U,V,tracers, sfc pressure gradient)

Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

- Implementation:
  - presently, the MCOG KPP computes vertical mixing coefficients for each category *and* with standard information; this is a testing feature that will be eliminated once the MCOG code is fully merged into the standard CESM
    - MCOG version makes seven trips through KPP coefficient routine
    - computing KPP coefficients is one of the most expensive parts of CESM POP
    - additional cost for identically configured gx1v6 POP MCOG-only (six trips) run is roughly 50%, but precise timing is difficult to obtain
  - still need a few nonstandard modifications to the CESM $CASE setup before an MCOG case will work “out of the box,” but mods are minimal
  - do not yet have all of the mods needed to support reduced number of ice categories exported from cice

- Implementation: Technical Challenges
  - MCOG developments ported through multiple code bases: cesm1.0.4 through cesm1_1 beta versions to cesm1.1
    - troubleshooting new version of coupler "custom fields" support
    - transition to new namelist functionality in models
    - transition from first scalar implementation to final vector version in ocean and ice models
  - bluefire to yellowstone port
  - can now specify additional fields and fluxes to be exchanged via namelist: custom_fields. Good news, but it gets ugly…

Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

- Implementation

  Ugliness defined:

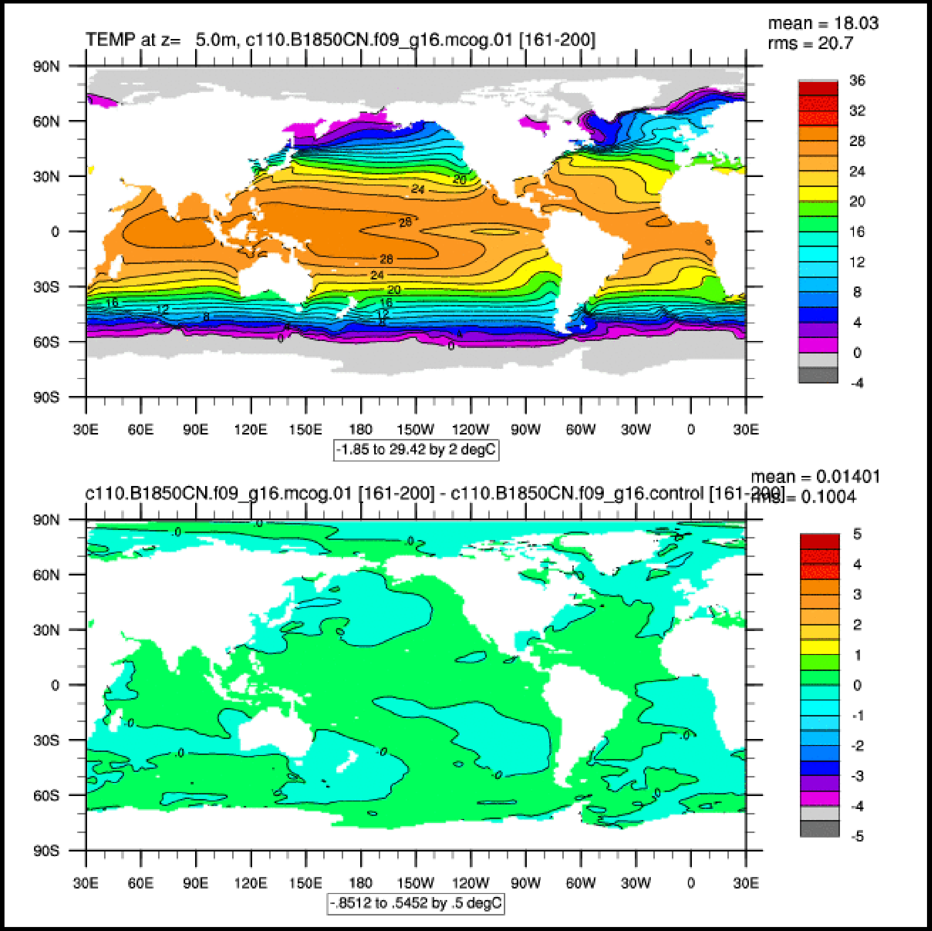
- 'Si_ifrac0->i2x',
- 'Si_ifrac1->i2x',
- 'Si_ifrac2->i2x',
- 'Si_ifrac3->i2x',
- 'Si_ifrac4->i2x',
- 'Si_ifrac5->i2x',
- 'Si_ifrac0->x2o',
- 'Si_ifrac1->x2o',
- 'Si_ifrac2->x2o',
- 'Si_ifrac3->x2o',
- 'Si_ifrac4->x2o',
- 'Si_ifrac5->x2o',

75 custom fields in total

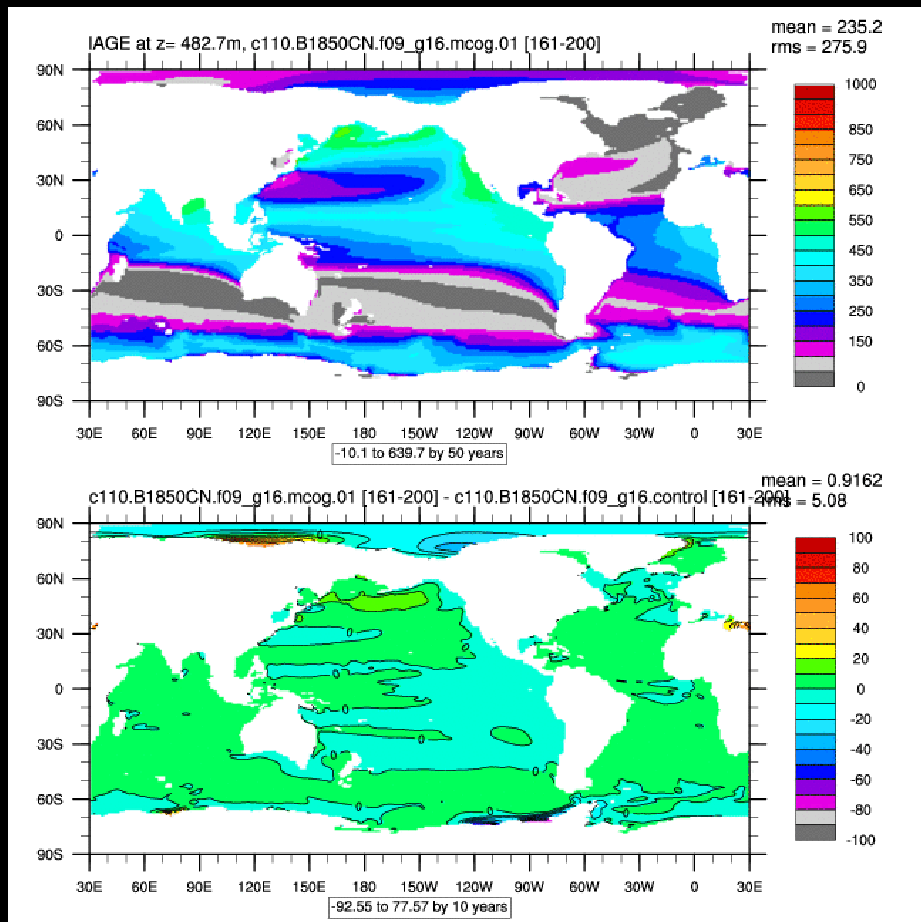
- 'PFioi_swpen1->i2x',
- 'PFioi_swpen2->i2x',
- 'PFioi_swpen3->i2x',
- 'PFioi_swpen4->i2x',
- 'PFioi_swpen5->i2x',
- 'PFioi_swpen1->x2o',
- 'PFioi_swpen2->x2o',
- 'PFioi_swpen3->x2o',
- 'PFioi_swpen4->x2o',
- 'PFioi_swpen5->x2o',

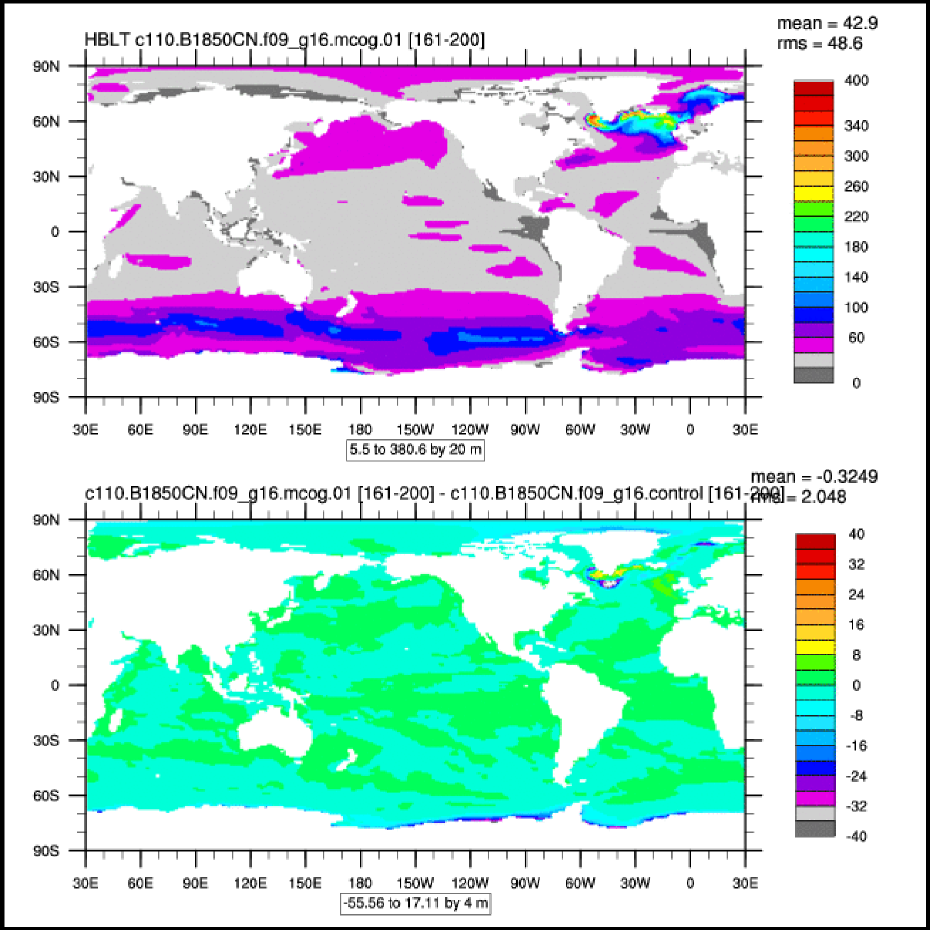
Multi-Column Ocean Grid (MCOG) in the Community Earth System Model (CESM)

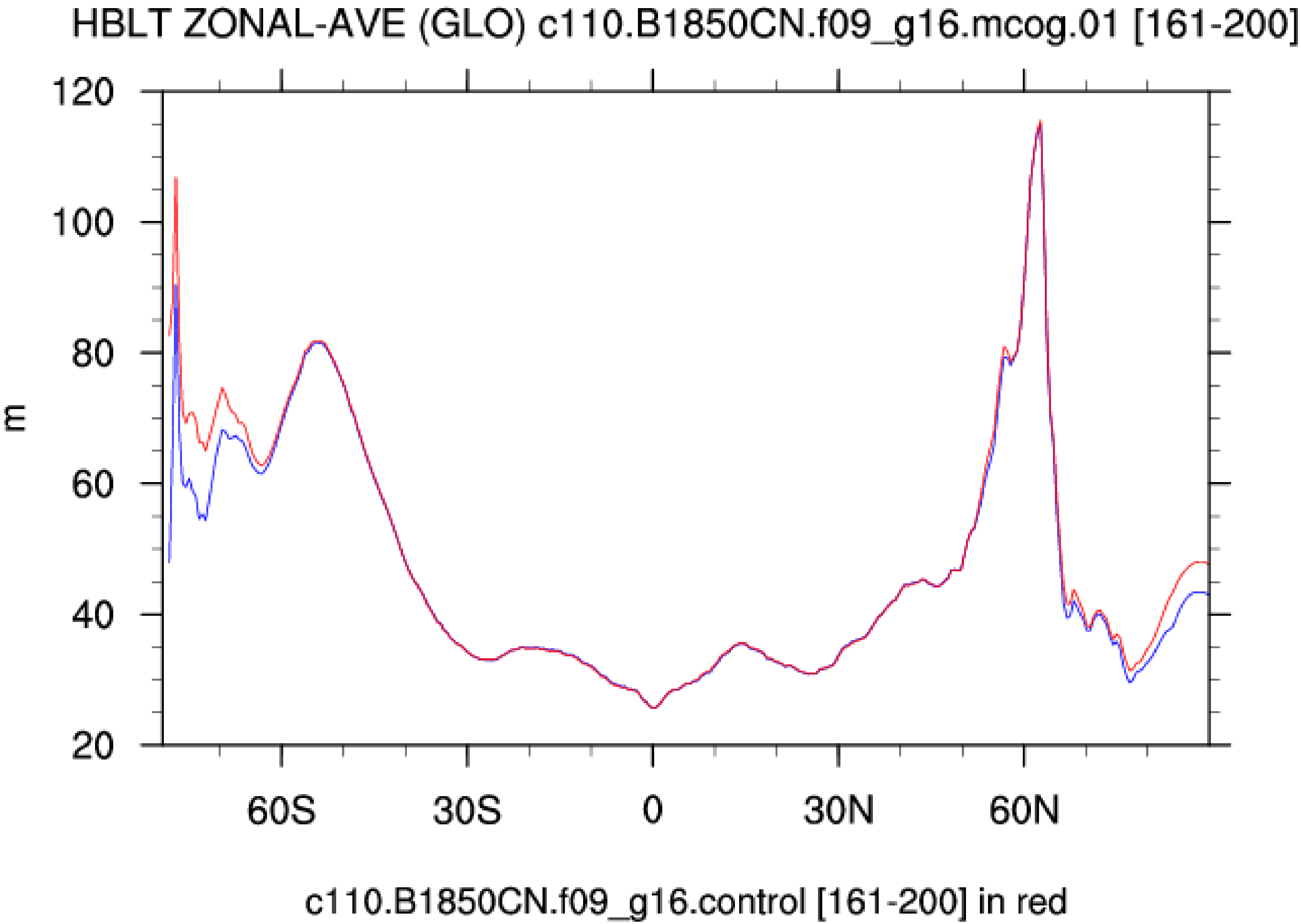
- Scientific Experiments
  - ice-ocean; 1-degree resolution (gx1v6); interannual forcing; 60 years branched from previous run; 20-year average; bluefire; control and MCOG; cesm1_1_beta17
  - fully coupled B1850CN; 1-degree ocn,ice,atm,lnd; 200 years branched from control run; 40-year average; yellowstone; control and MCOG; cesm1.1



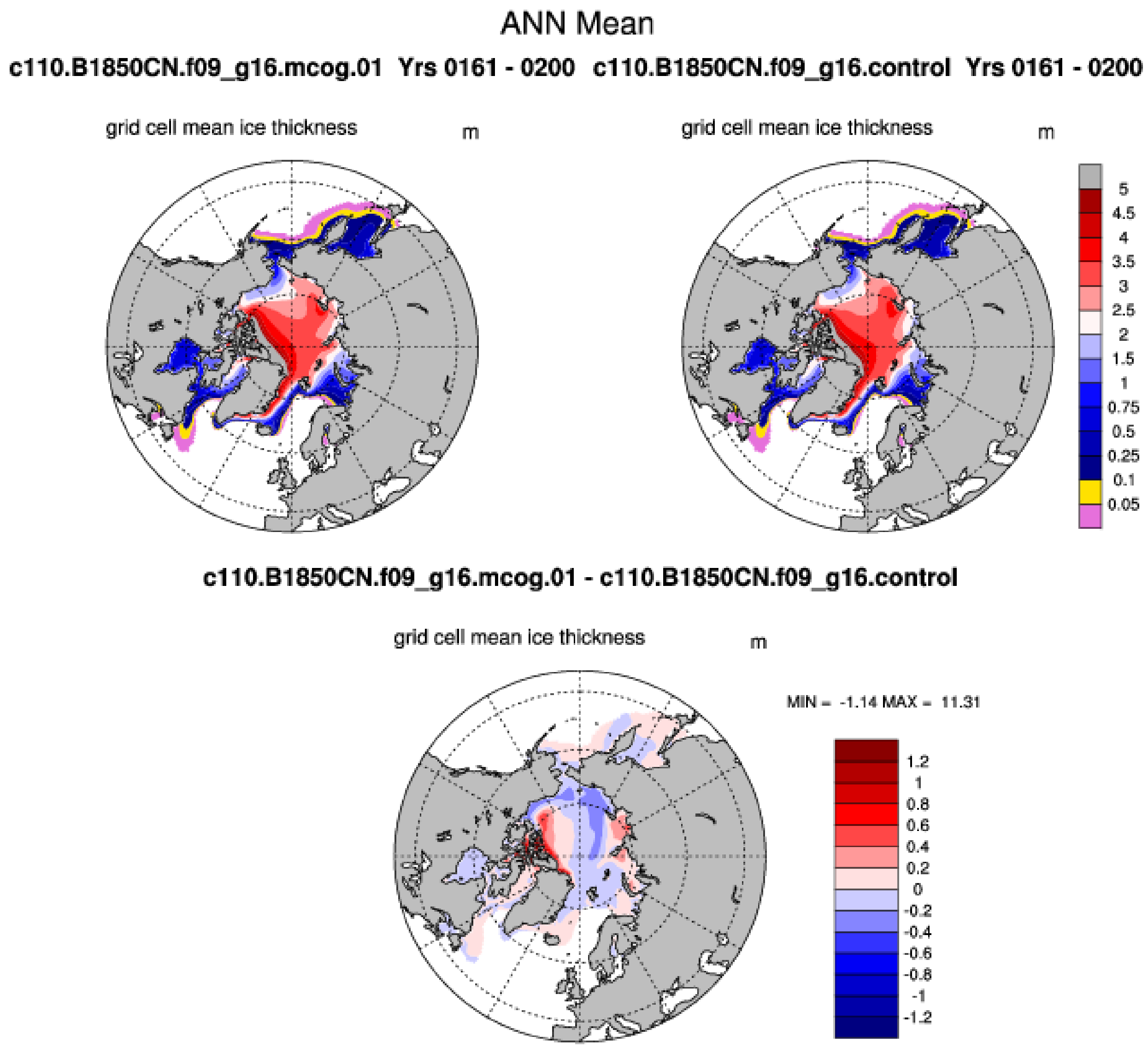
TEMP at z= 5.0m, c110.B1850CN.f09_g16.mcog.01 [161-200]
mean = 18.03
rms = 20.7
-1.85 to 29.42 by 2 degC
c110.B1850CN.f09_g16.mcog.01 [161-200] - c110.B1850CN.f09_g16.control [161-200]
mean = 0.01401
rms = 0.1004
-.8512 to .5452 by .5 degC

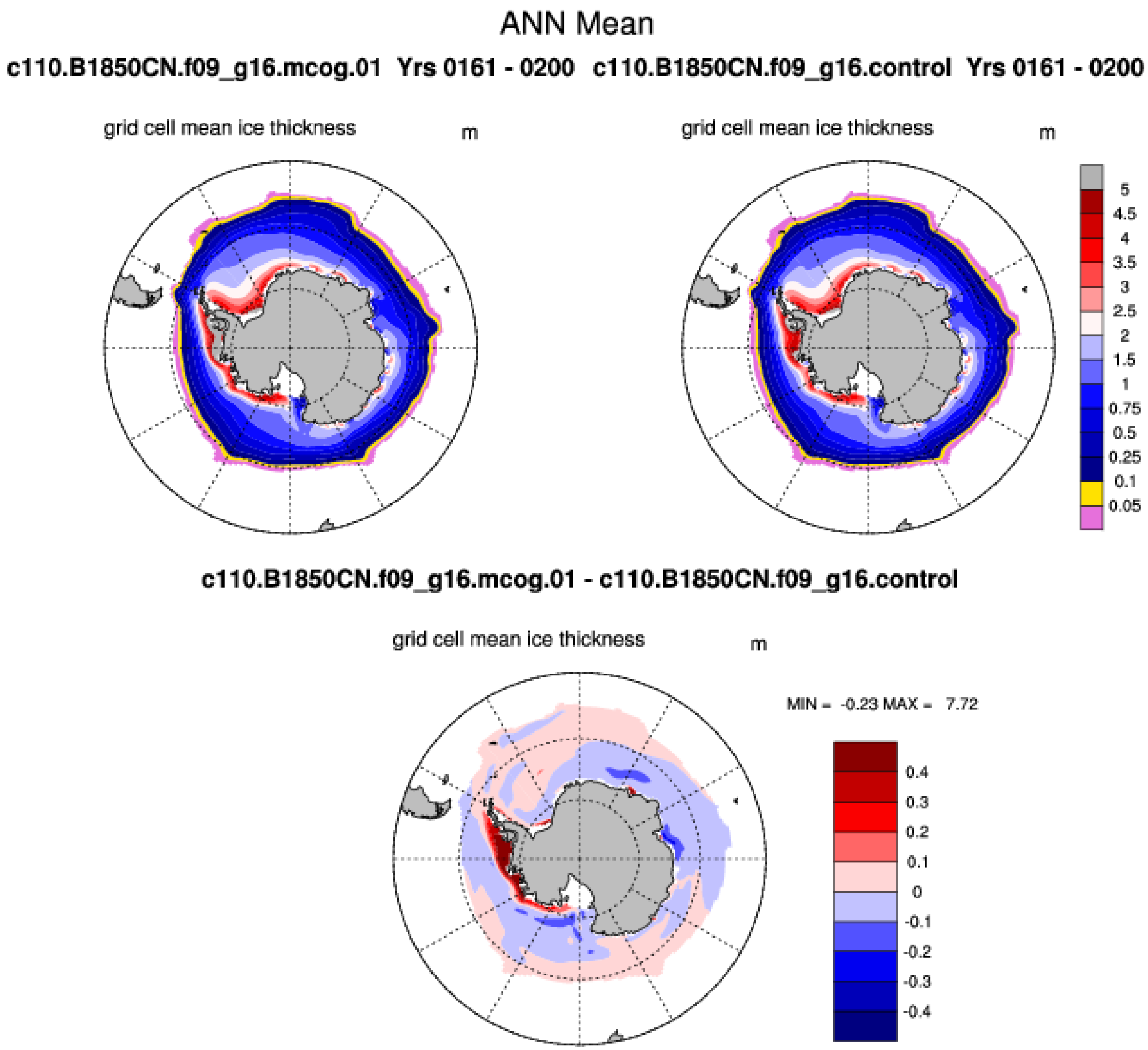

IAGE at z= 482.7m, c110.B1850CN.f09_g16.mcog.01 [161-200]
mean = 235.2
rms = 275.9
90N
60N
30N
0
30S
60S
90S
30E
60E
90E
120E
150E
180
150W
120W
90W
60W
30W
0
30E
1000
850
750
650
550
450
350
250
150
0
-10.1 to 639.7 by 50 years
c110.B1850CN.f09_g16.mcog.01 [161-200] - c110.B1850CN.f09_g16.control [161-200]
mean = 0.9162
rms = 5.08
100
80
60
40
20
0
-20
-40
-60
-80
-100
-92.55 to 77.57 by 10 years


HBLT c110.B1850CN.f09_g16.mcog.01 [161-200]
mean = 42.9
rms = 48.6
5.5 to 380.6 by 20 m
c110.B1850CN.f09_g16.mcog.01 [161-200] - c110.B1850CN.f09_g16.control [161-200]
mean = -0.3249
rms = 2.048
-55.56 to 17.11 by 4 m



HBLT ZONAL-AVE (GLO) c110.B1850CN.f09_g16.mcog.01 [161-200]
120
100
80
60
40
20
m
60S
30S
0
30N
60N
c110.B1850CN.f09_g16.control [161-200] in red


ANN Mean
c110.B1850CN.f09_g16.mcog.01 Yrs 0161 - 0200 c110.B1850CN.f09_g16.control Yrs 0161 - 0200
grid cell mean ice thickness
m
grid cell mean ice thickness
m
5
4.5
4
3.5
3
2.5
2
1.5
1
0.75
0.5
0.25
0.1
0.05
c110.B1850CN.f09_g16.mcog.01 - c110.B1850CN.f09_g16.control
grid cell mean ice thickness
m
MIN = -1.14 MAX = 11.31
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
-1.2


ANN Mean
c110.B1850CN.f09_g16.mcog.01 Yrs 0161 - 0200 c110.B1850CN.f09_g16.control Yrs 0161 - 0200
grid cell mean ice thickness
m
grid cell mean ice thickness
m
5
4.5
4
3.5
3
2.5
2
1.5
1
0.75
0.5
0.25
0.1
0.05
c110.B1850CN.f09_g16.mcog.01 - c110.B1850CN.f09_g16.control
grid cell mean ice thickness
m
MIN = -0.23 MAX = 7.72
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4

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- Summary
  - MCOG is implemented in CESM1.1
  - almost no differences in GIAF MCOG and standard version
  - subtle differences in B1850CN MCOG
  - need to study seasonal and regional differences
- Future Work