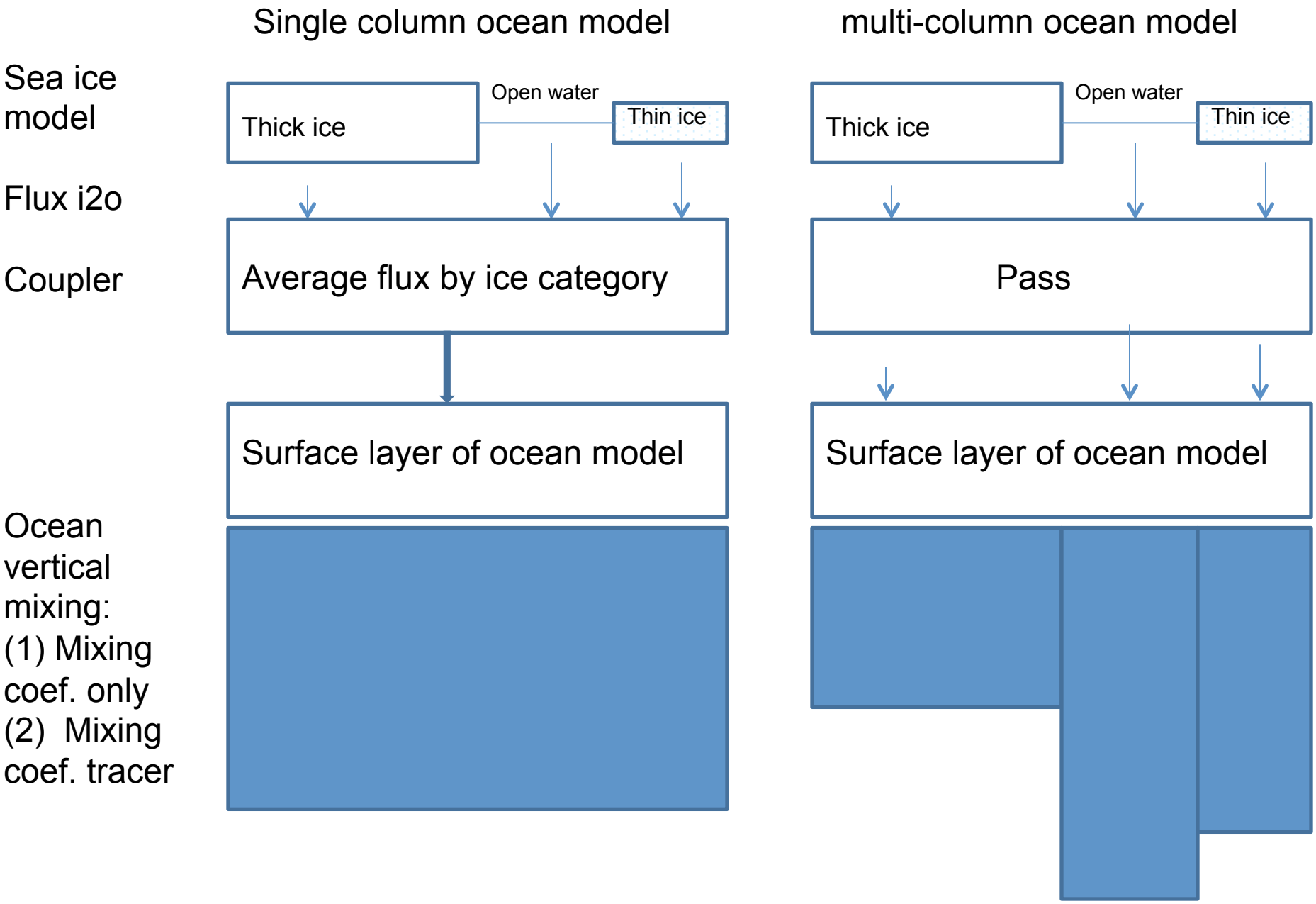
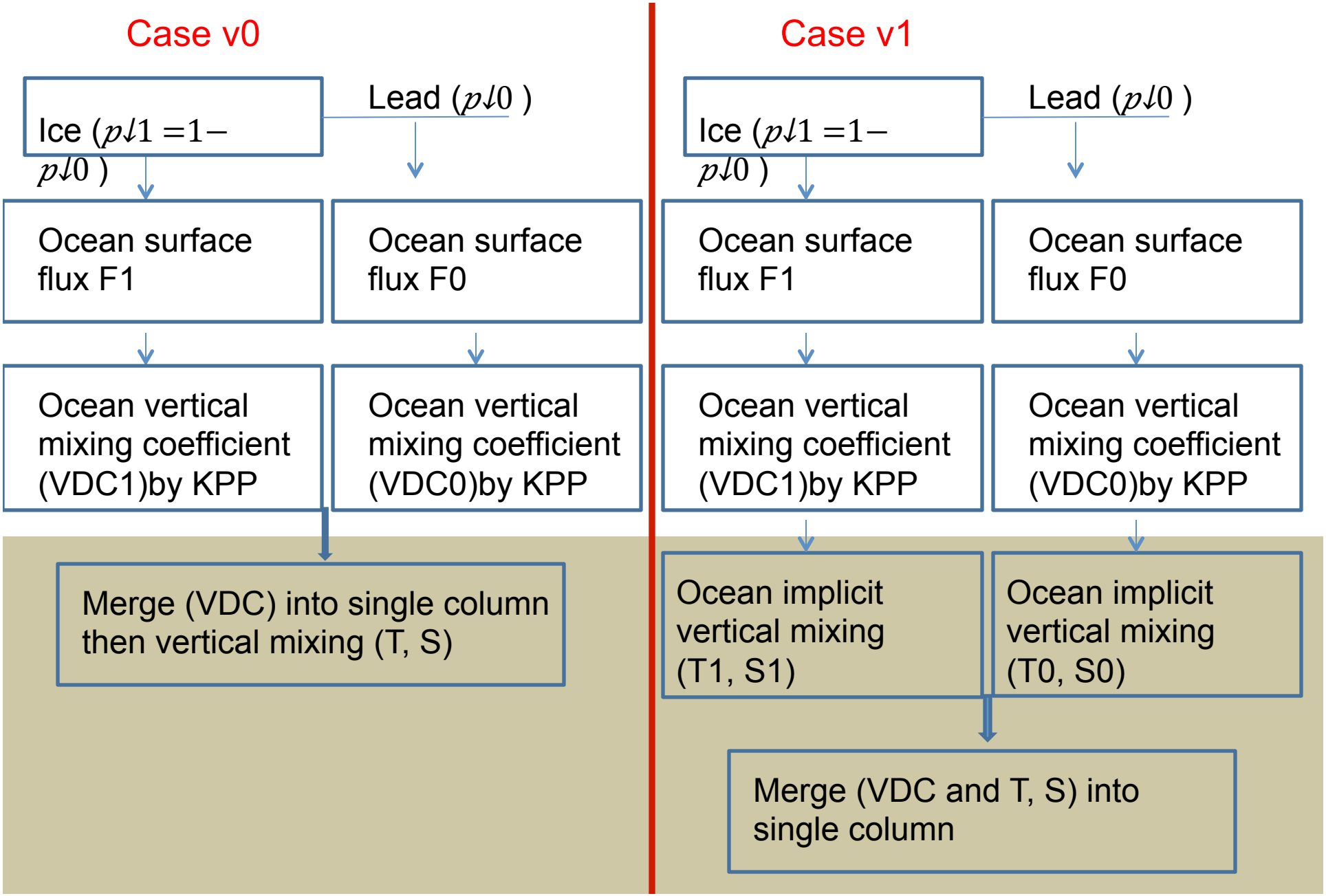
Multi-column ocean grid for ocean mixing under sea ice in CESM

Meibing Jin

International Arctic Research Center (IARC)
University of Alaska Fairbanks


Single column ocean model
multi-column ocean model
Sea ice model
Flux i2o
Coupler
Ocean vertical mixing:
(1) Mixing coef. only
(2) Mixing coef. tracer
Thick ice
Open water
Thin ice
Average flux by ice category
Surface layer of ocean model
Thick ice
Open water
Thin ice
Pass
Surface layer of ocean model

2-column ocean grid (2cog) experiments scheme



Case settings

Model: POP-CICE active on GX1 grid
CORE 2 forcing data from 1948 to 2009

Parameters are default CESM 1_1_1 setting except:

1) Control case, surface flux (heat and salt) $F = F\downarrow 0\ p\downarrow 0 + F\downarrow 1\ p\downarrow 1$

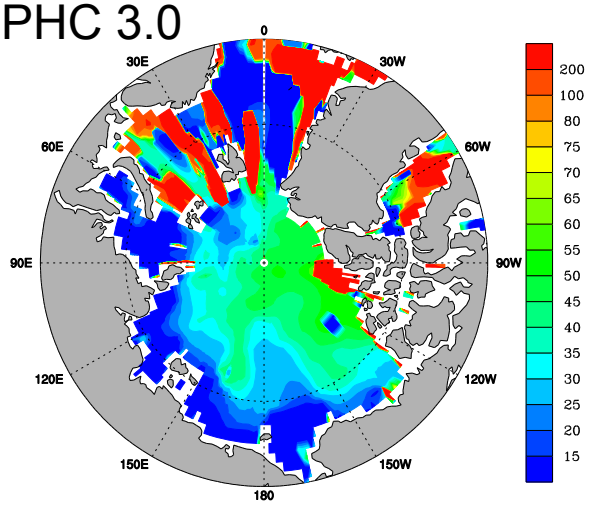
2) Case v0 and v1, $p\downarrow 0 = 1 - \sum\uparrow \blacksquare g\downarrow n$ is lead fraction and $p\downarrow 1 = 1 - p\downarrow 0$ is ice concentration.

3) Case fix, $p\downarrow 0$ is a constant (0.001%) when sea ice present.
When $F\downarrow 0 salt = E - P + F\downarrow BR\_new\_ice$, the results are almost identical to that of the control. The following discussion, $F\downarrow 0 salt = E - P + F\downarrow BR\_all\_ice$,
4) Case n5 is a single column case with parameterization n=5 (Nguyen 2009, Jin 2012):

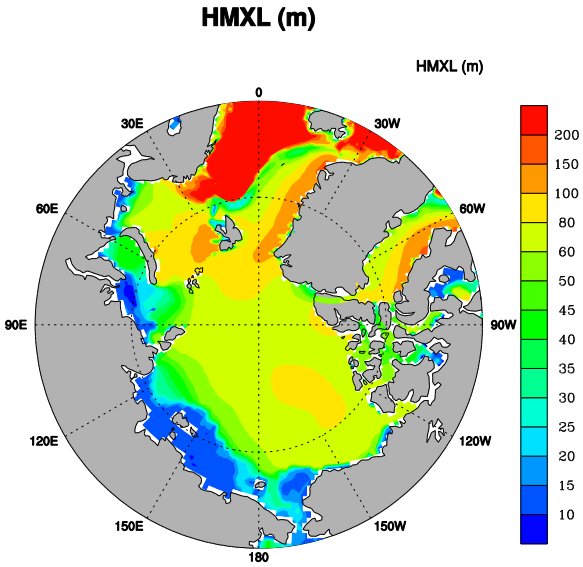
$$\Delta S(z) = Az^n; \qquad \int_0^{MLD} \Delta S dz = Total\ brine\ rejection$$

Model-data comparison of Mixed-layer depth (MLD) in March

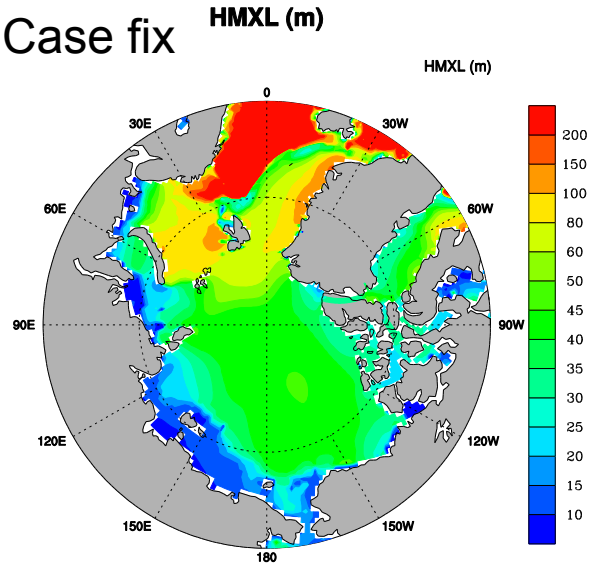
PHC 3.0



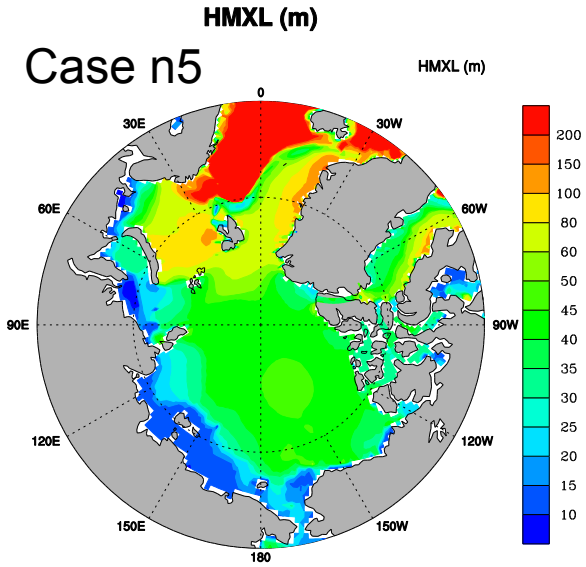
POP-CICE, Control



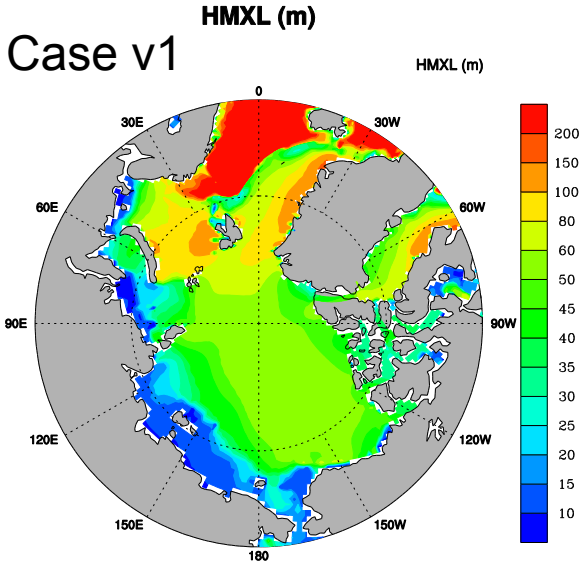
Case fix



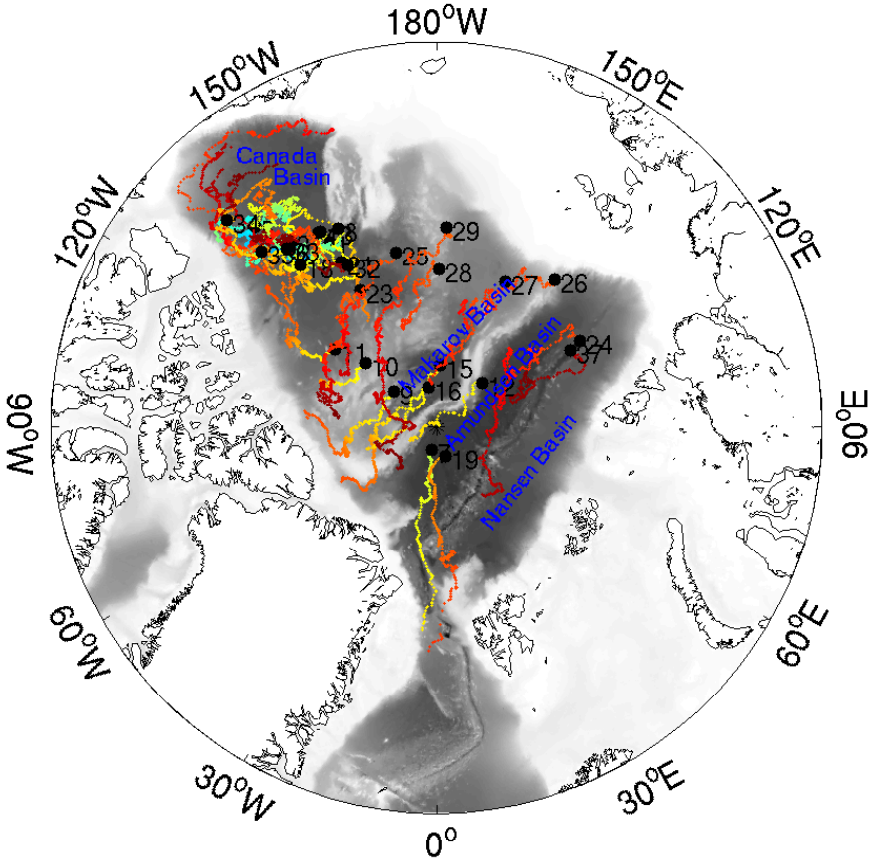
Case n5

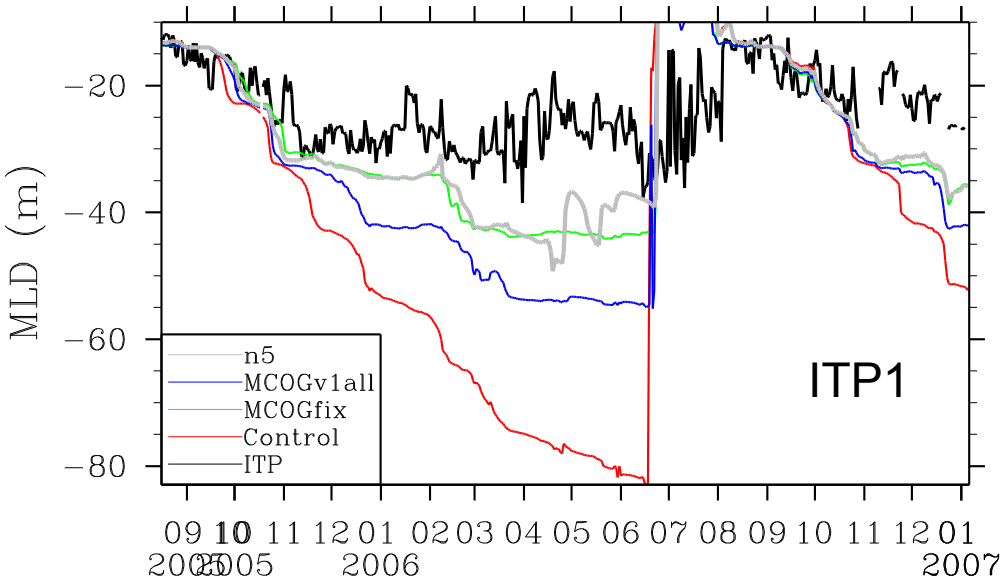


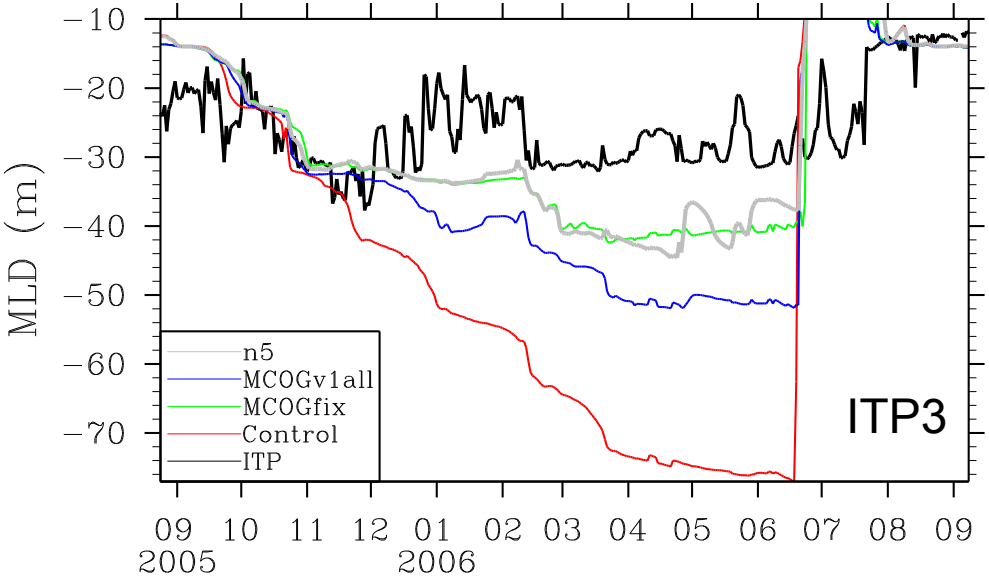
Case v1

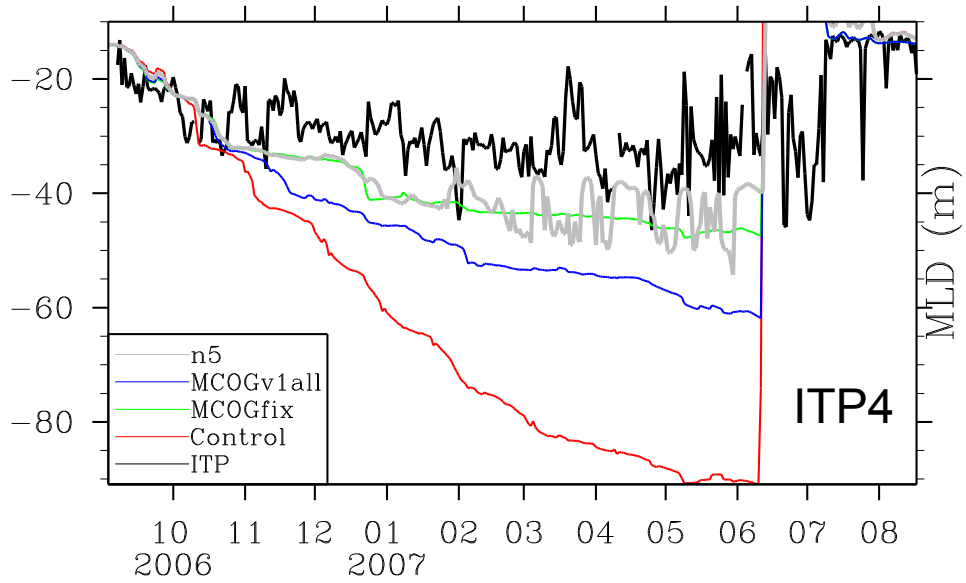


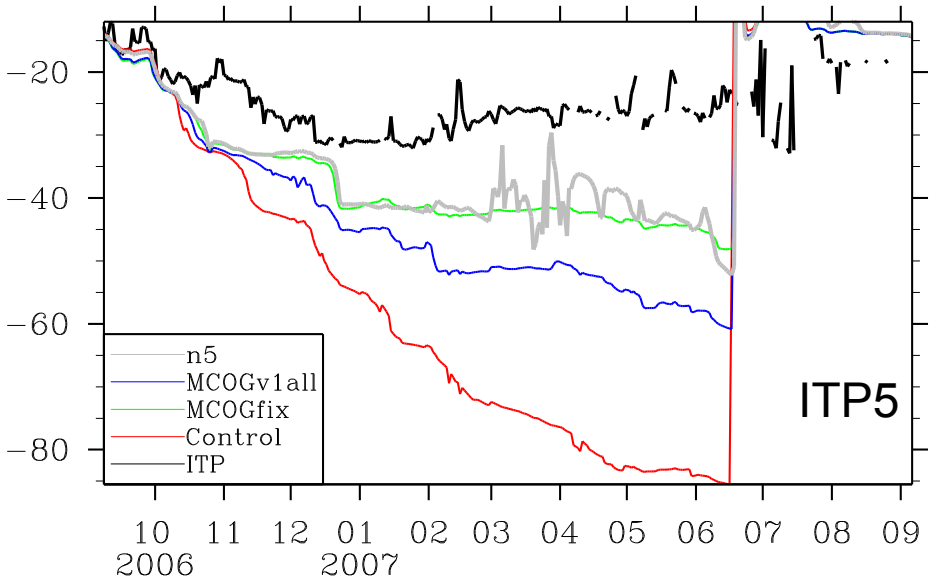
Comparison of model MLD with 29 ITP datasets

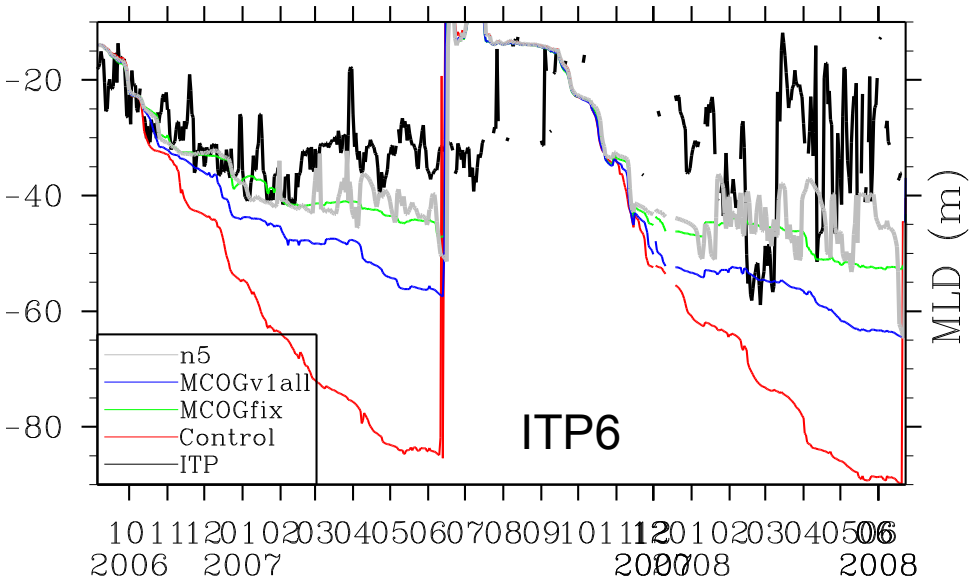







−20
−40
−60
−80
MLD (m)
n5
MCOGv1all
MCOGfix
Control
ITP
ITP4
10 11 12 01 02 03 04 05 06 07 08
2006
2007


−20
−40
−60
−80
n5
MCOGv1all
MCOGfix
Control
ITP
ITP5
10 11 12 01 02 03 04 05 06 07 08 09
2006
2007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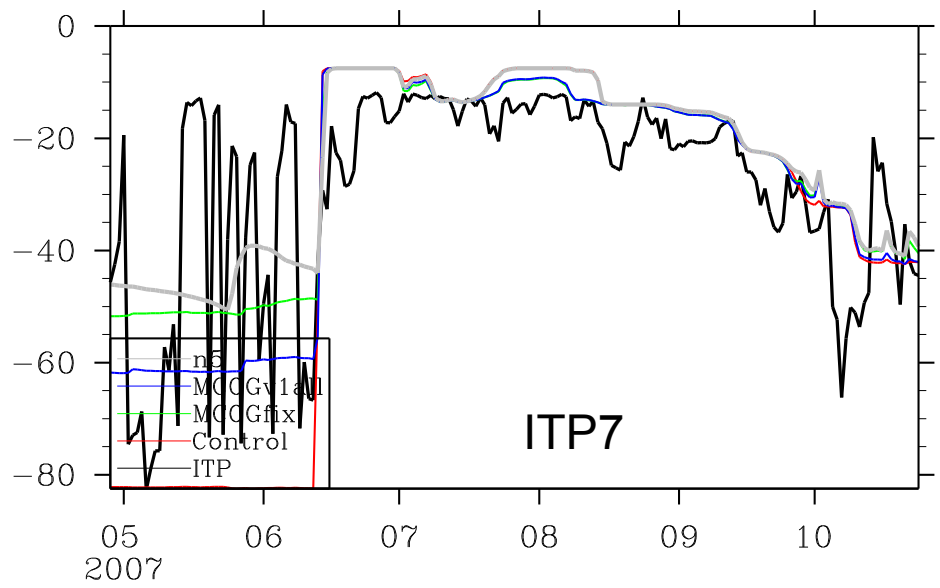
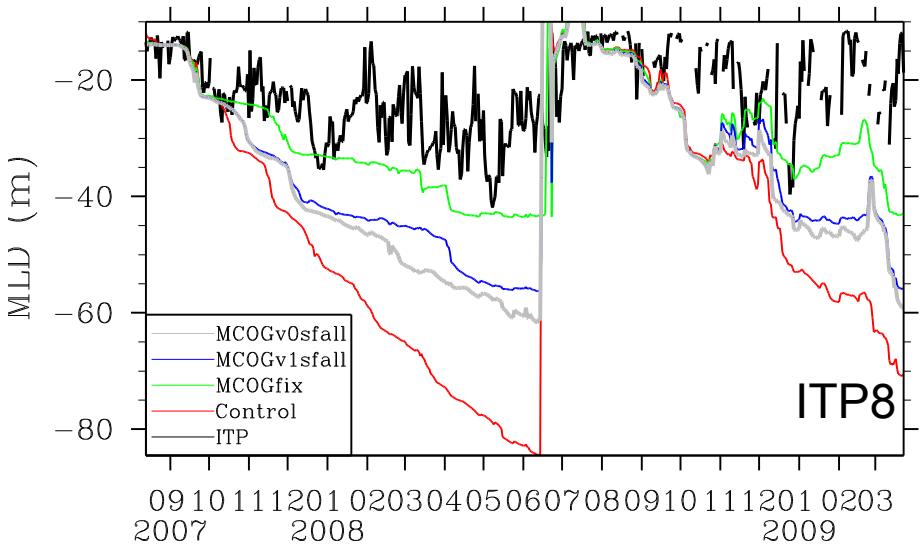
−40
−60
−80
MLD (m)
n5
MCOGv1all
MCOGfix
Control
ITP
ITP6
2006
2007
2008


0
−20
−40
−60
−80
n5
MCOGv1all
MCOGfix
Control
ITP
ITP7
05 06 07 08 09 10
2007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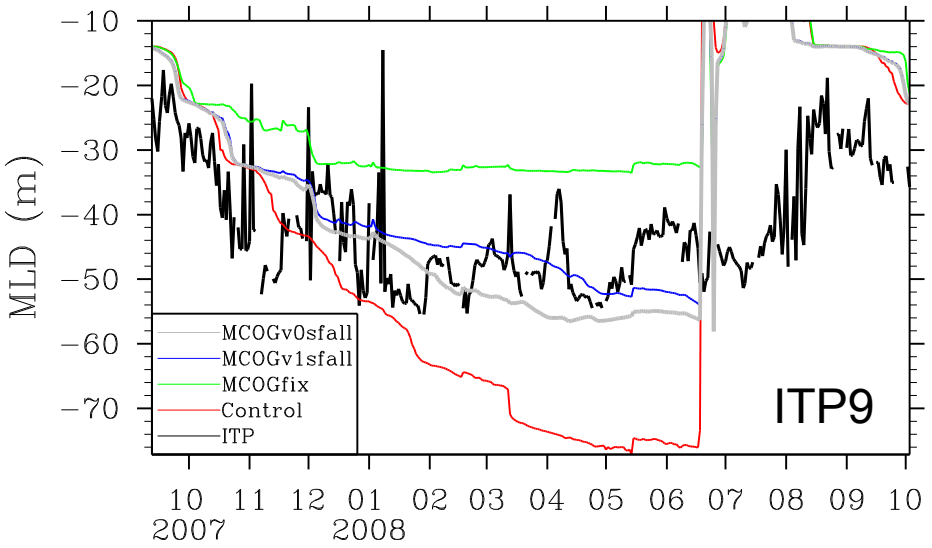
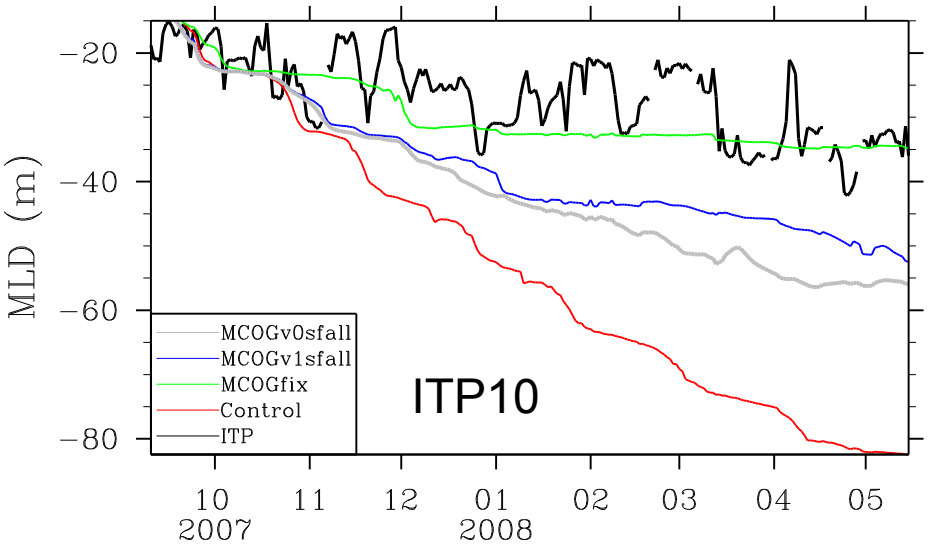
−40
−60
−80
MCOGv0sfall
MCOGv1sfall
MCOGfix
Control
ITP
ITP8
09 10 11 12 01 02 03 04 05 06 07 08 09 10 11 12 01 02 03
2007
2008
2009


MLD (m)
−10
−20
−30
−40
−50
−60
−70
MCOGv0sfall
MCOGv1sfall
MCOGfix
Control
ITP
ITP9
10 11 12 01 02 03 04 05 06 07 08 09 10
2007
2008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−40
−60
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MCOGv0sfall
MCOGv1sfall
MCOGfix
Control
ITP
ITP10
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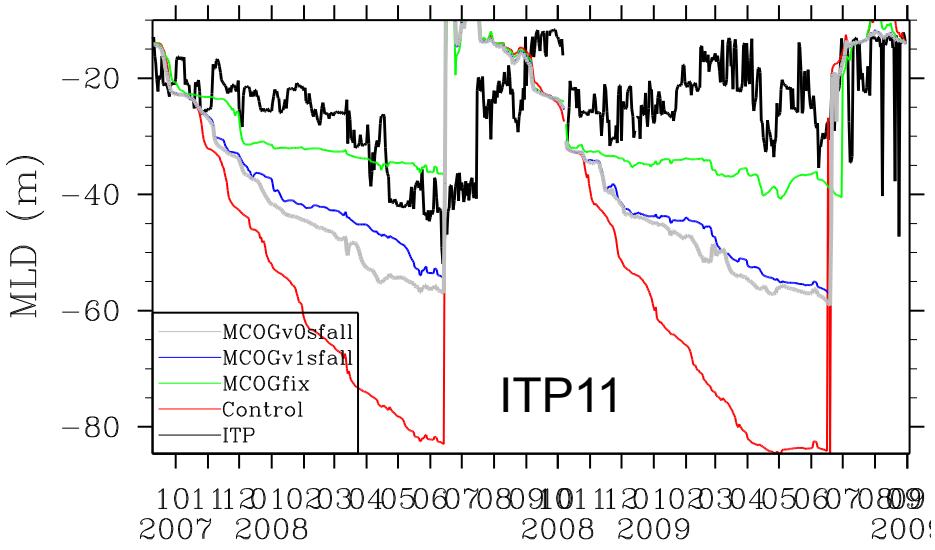
2007
2008


MLD (m)
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−40
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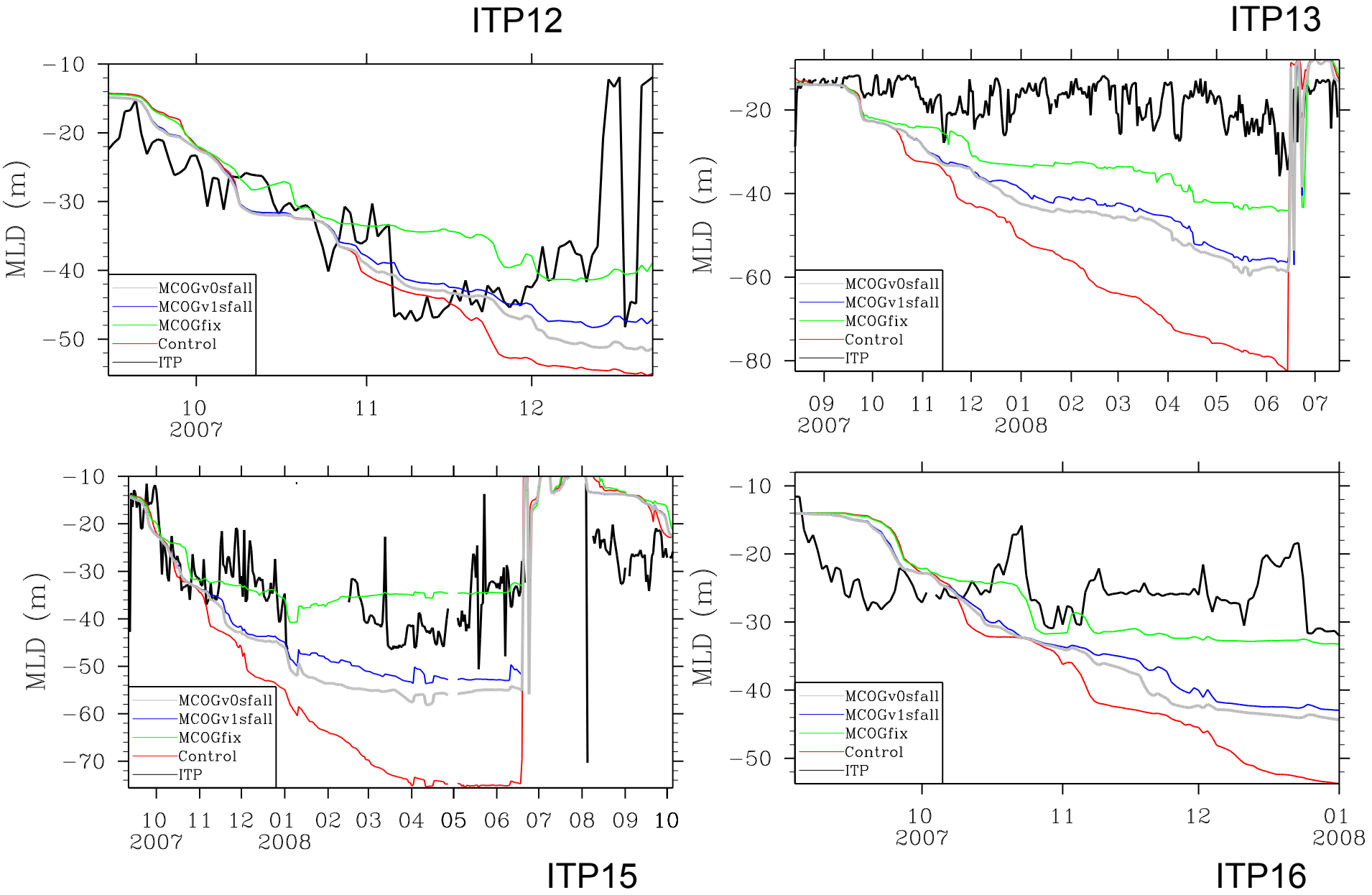
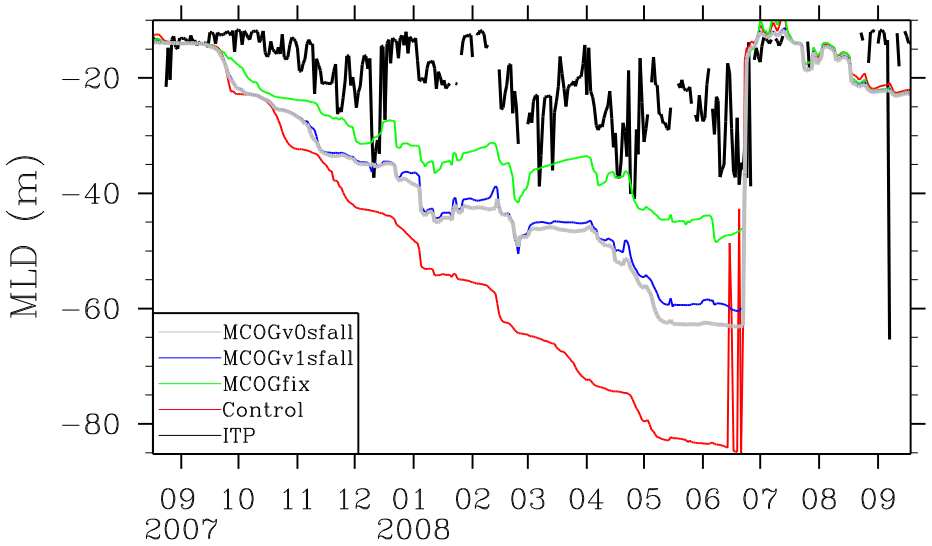
−80
MCOGv0sfall
MCOGv1sfall
MCOGfix
Control
ITP
ITP11
2007
2008
2009


ITP12
ITP13
ITP15
ITP16
MLD (m)
MCOGv0sfall
MCOGv1sfall
MCOGfix
Control
ITP
2007
2008

ITP18



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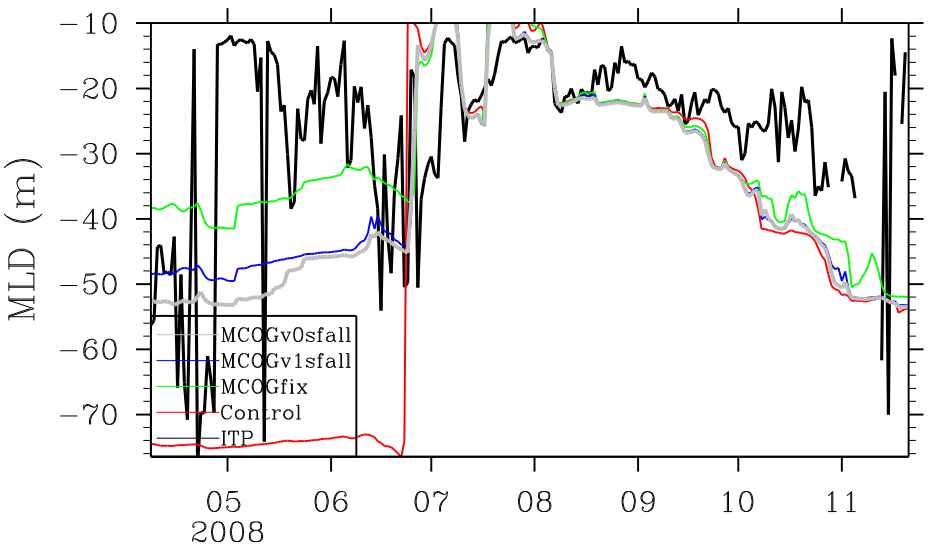

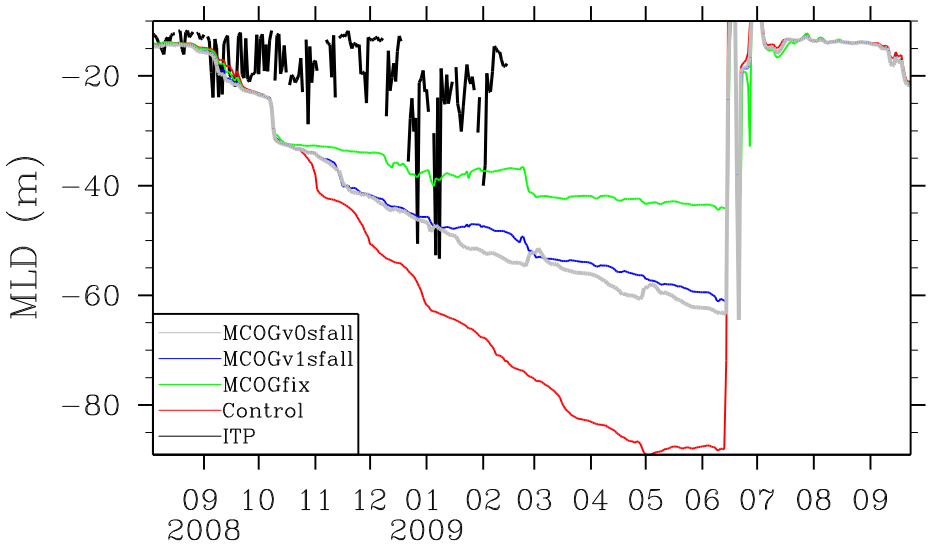

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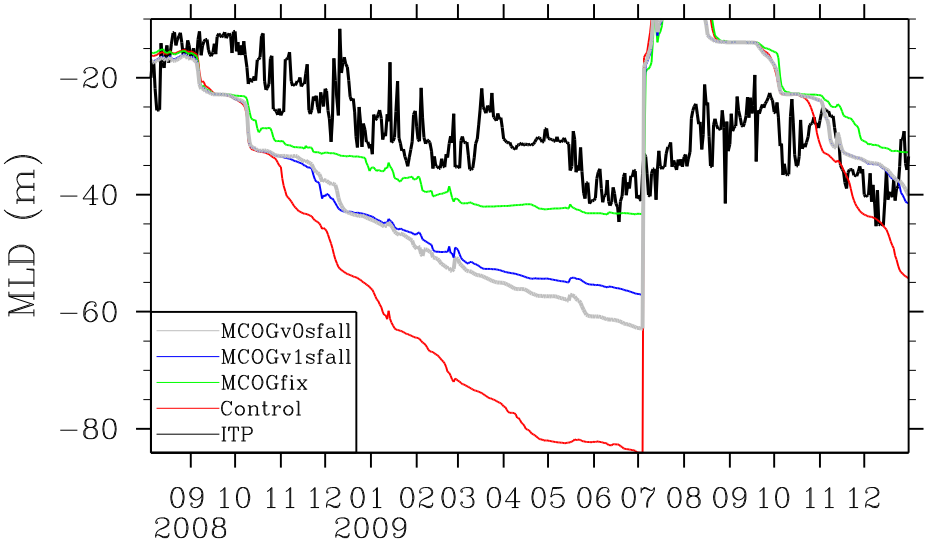

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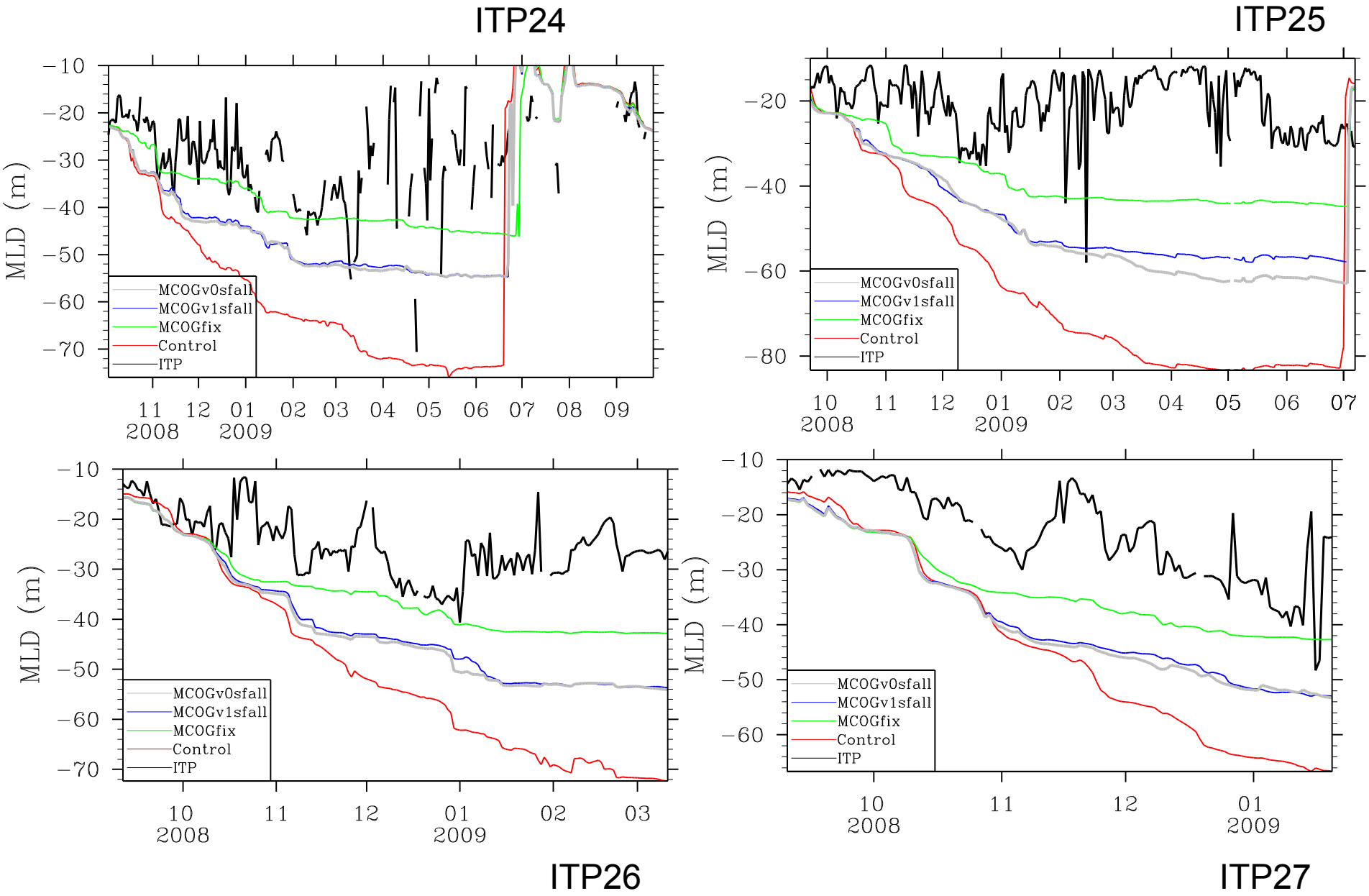
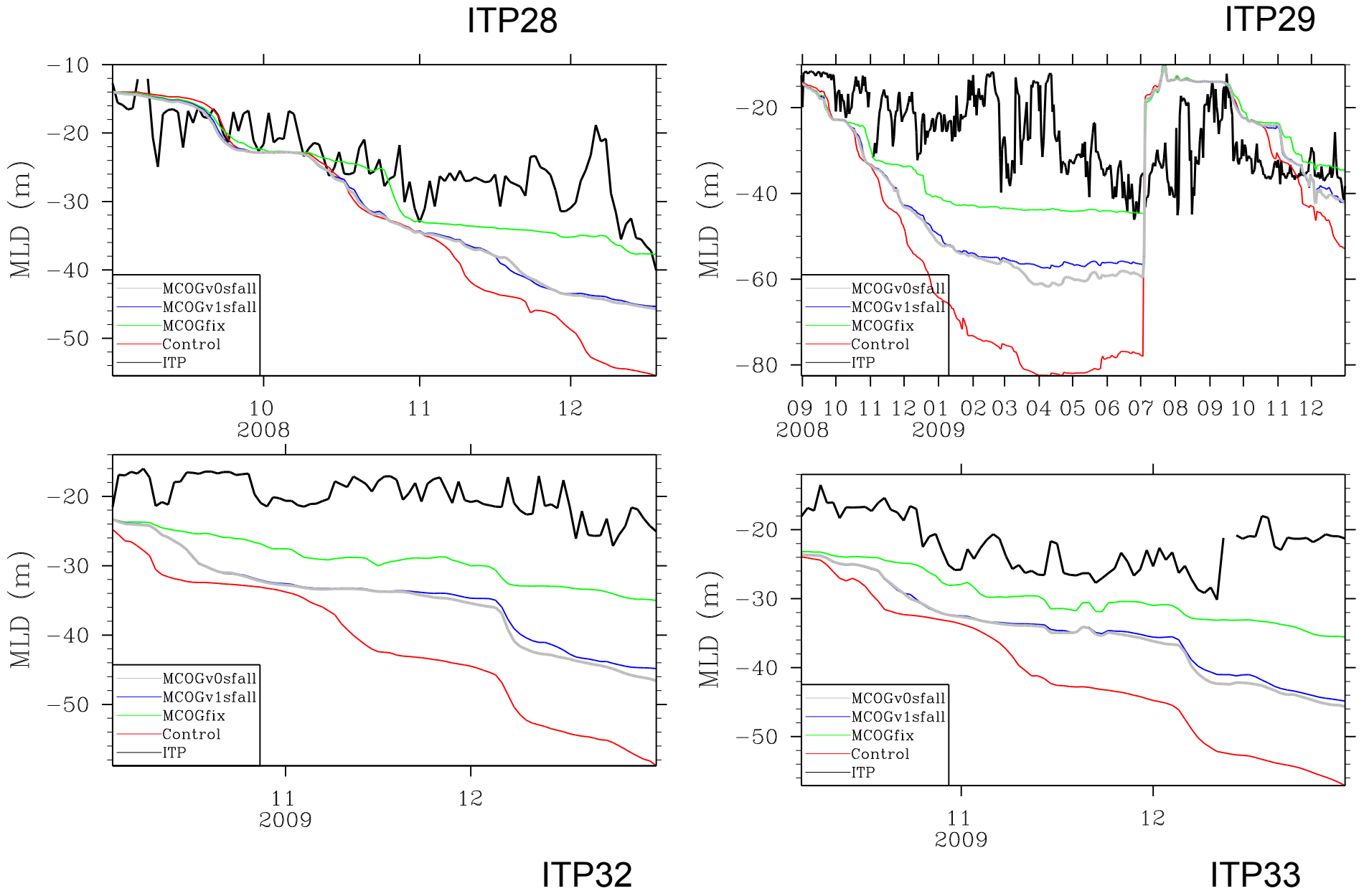
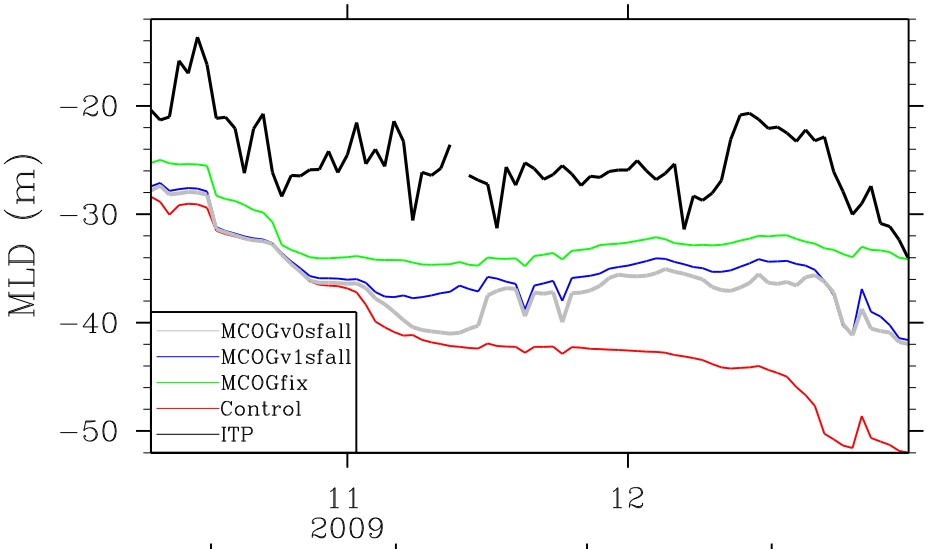

ITP24
ITP25
ITP26
ITP27
MLD (m)
MCOGv0sfall
MCOGv1sfall
MCOGfix
Control
ITP
2008
2009


ITP28
ITP29
ITP32
ITP33
MLD (m)
MCOGv0sfall
MCOGv1sfall
MCOGfix
Control
ITP
2008
2009

ITP34



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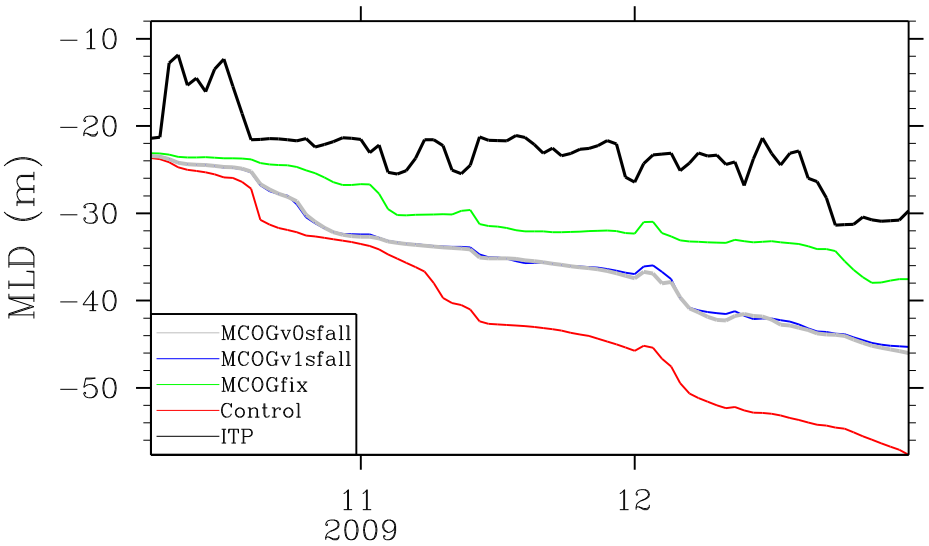
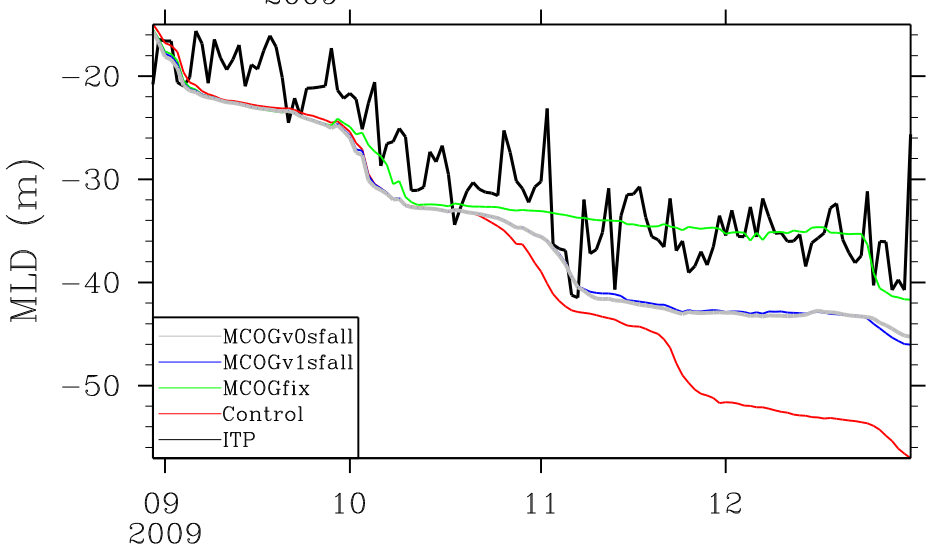


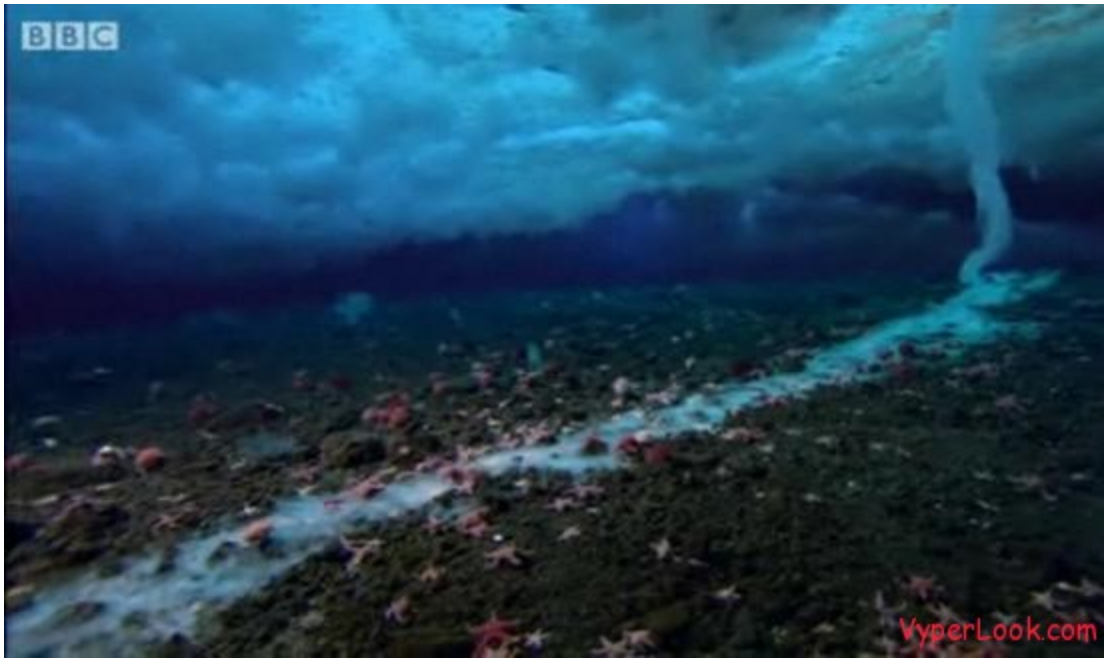


ITP37

Why we need $F\downarrow 0 salt = E - P + F\downarrow BR\_all\_ice$,
instead of $F\downarrow 0 salt = E - P + F\downarrow BR\_new\_ice$

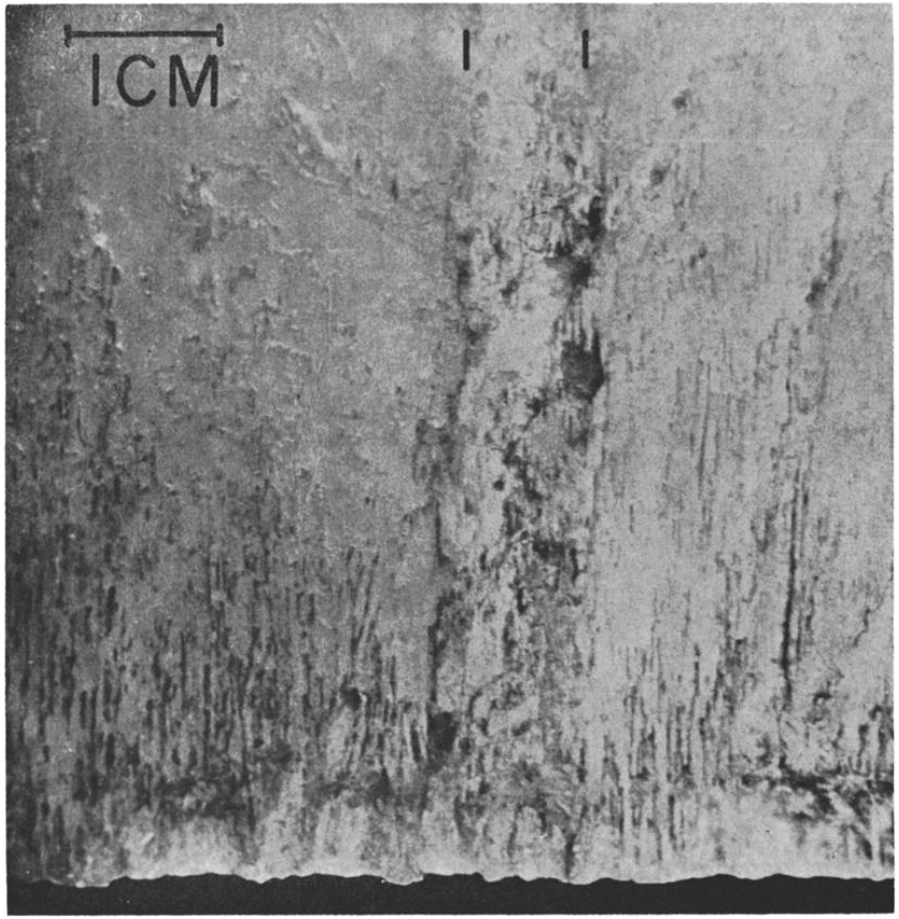
The brine rejection in real world are spatially patchy under sea ice, and more observations are needed.

E.g., photo and film from BBC: frozen planet,
Vertical ‘brinicle’ ice finger formed in 5-6 hours



Salt Rejection by Sea ice during growth (Lake and Lewis, 1970)

Sea ice section were taken from Cambridge Bay (69N, 105W).
Small tubes (2-3cm high) occupy 5% of interface area
Major channels (far up into ice interior) accounts for 0.2% in every 180 cm^2 over the area of $1m^2$



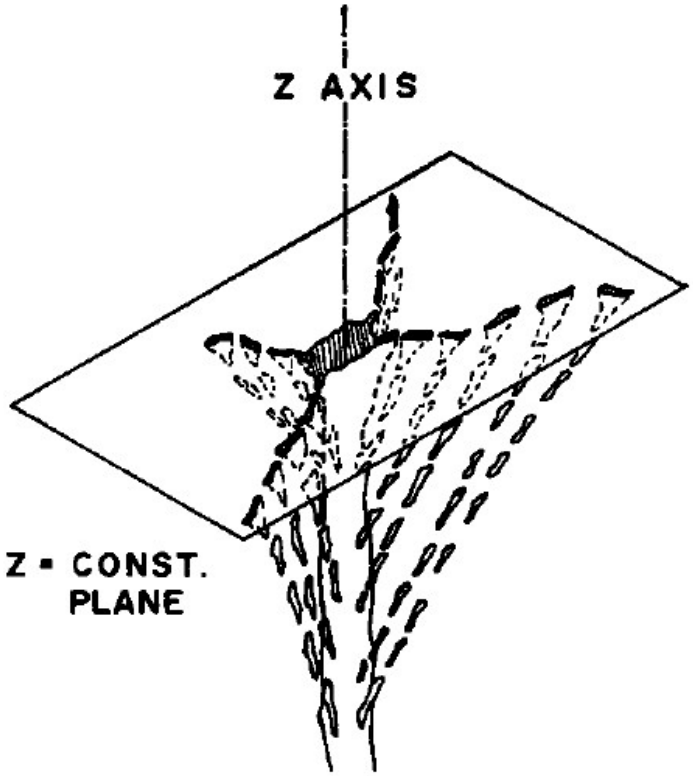
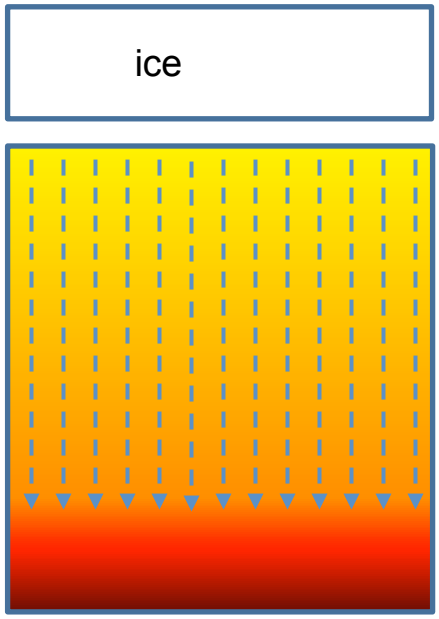


Fig. 8. Schematic drawing of a brine drainage channel and its feed arms. Feed arms are formed of inclusions inclined to the vertical at angles in the range 40°–54°.

Bring rejection distribution under ice

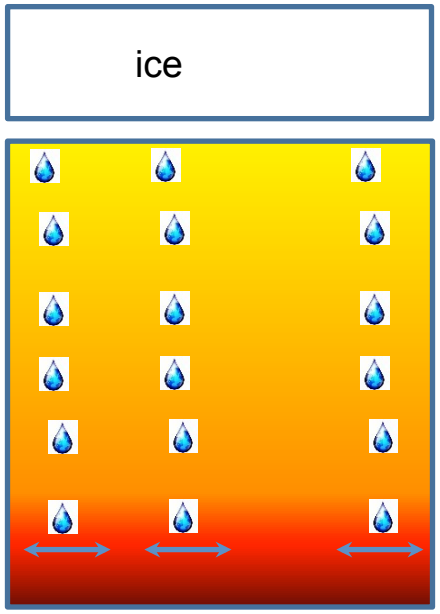
Vertical mixing of brine rejection

Horizontally even



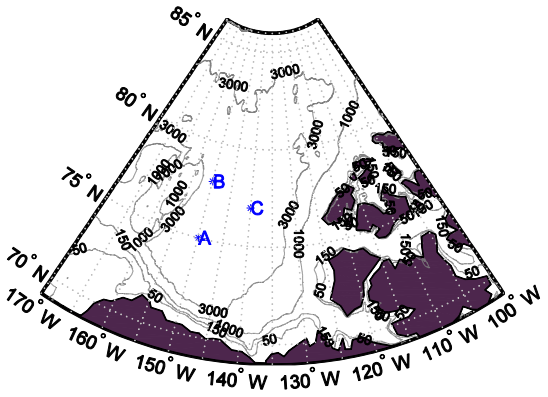
Mixing of brine occurs everywhere

Horizontally uneven



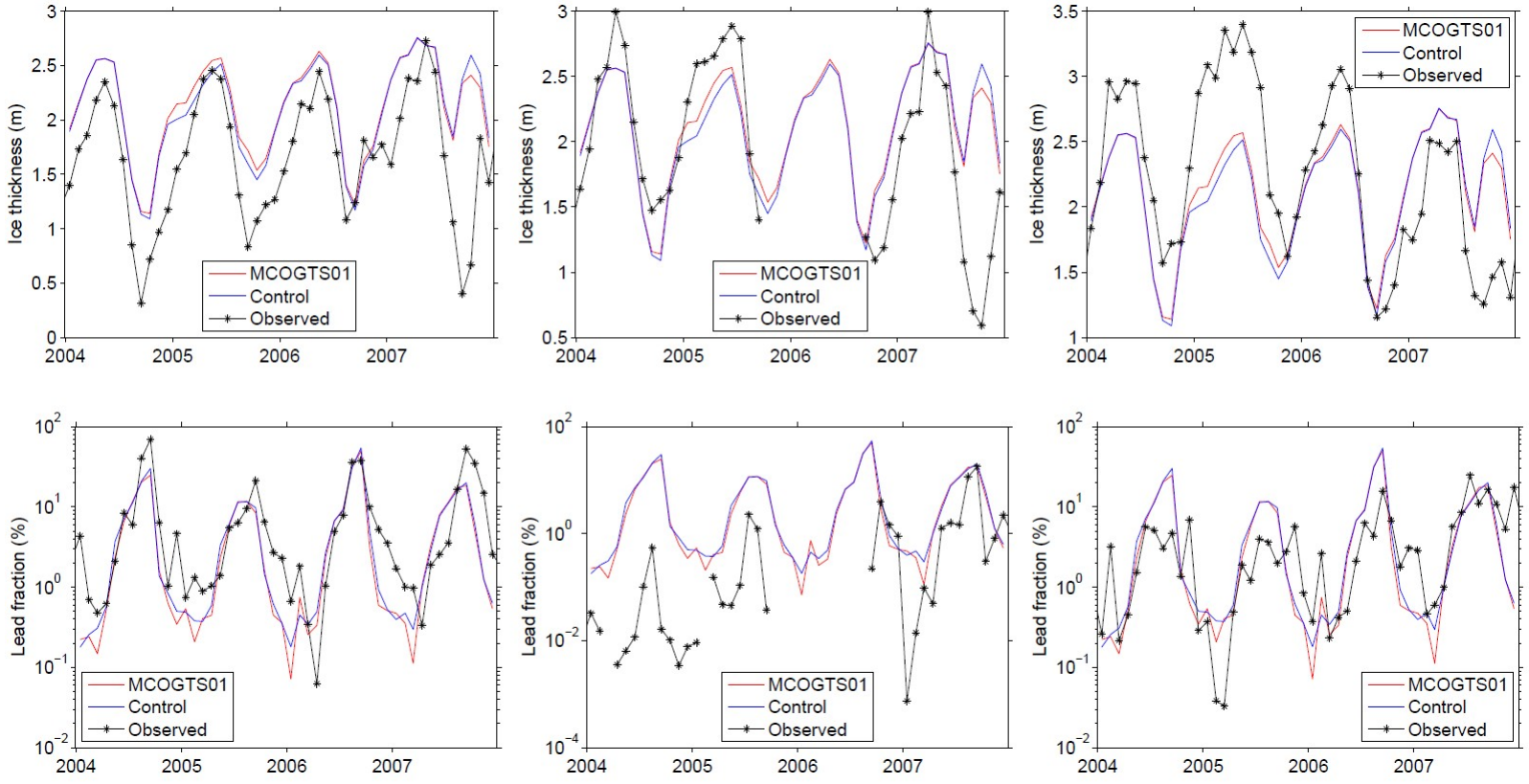
Mixing of brine only occurs in area $p \downarrow 0 \ll 1\%$

CESM control and MCOGTS01 runs --- Comparison with time series of ice thickness and lead fraction



Ice thickness

Lead Fraction



A B C

Summary

- A multi-column ocean grid (MCOG) scheme (2-column here) is tested in a global coupled POP_CICE setting in CESM 1_2.
- Sensitivity studies showed significant model improvements of simulated MLD when brine rejection salt flux is applied to a small portion of the grid area.

Completed works, challenges and future directions

Completed works:

- Identifying the model errors related to the ocean mixing process under sea ice using observations and idealized model experiments.
- Finding optimum solutions including various parameterization schemes and implementing multi-column ocean grid (MCOG).

Challenges:

- Analysis of the impact of the MCOG method on other parts of the climate models.
- Observations are needed to confirm some hypothesis.

Future works:

- Reorganize/ standardize model code implementation in CESM for broad community users.
- Conduct fully coupled runs and results analysis.
- Have the schemes tested and compared with GFDL model

Acknowledgments.
NSF Climate Process Team (CPT) project ARC-0968676, NSF ARC-0652838
Funding support from IARC-JAMSTEC Agreement