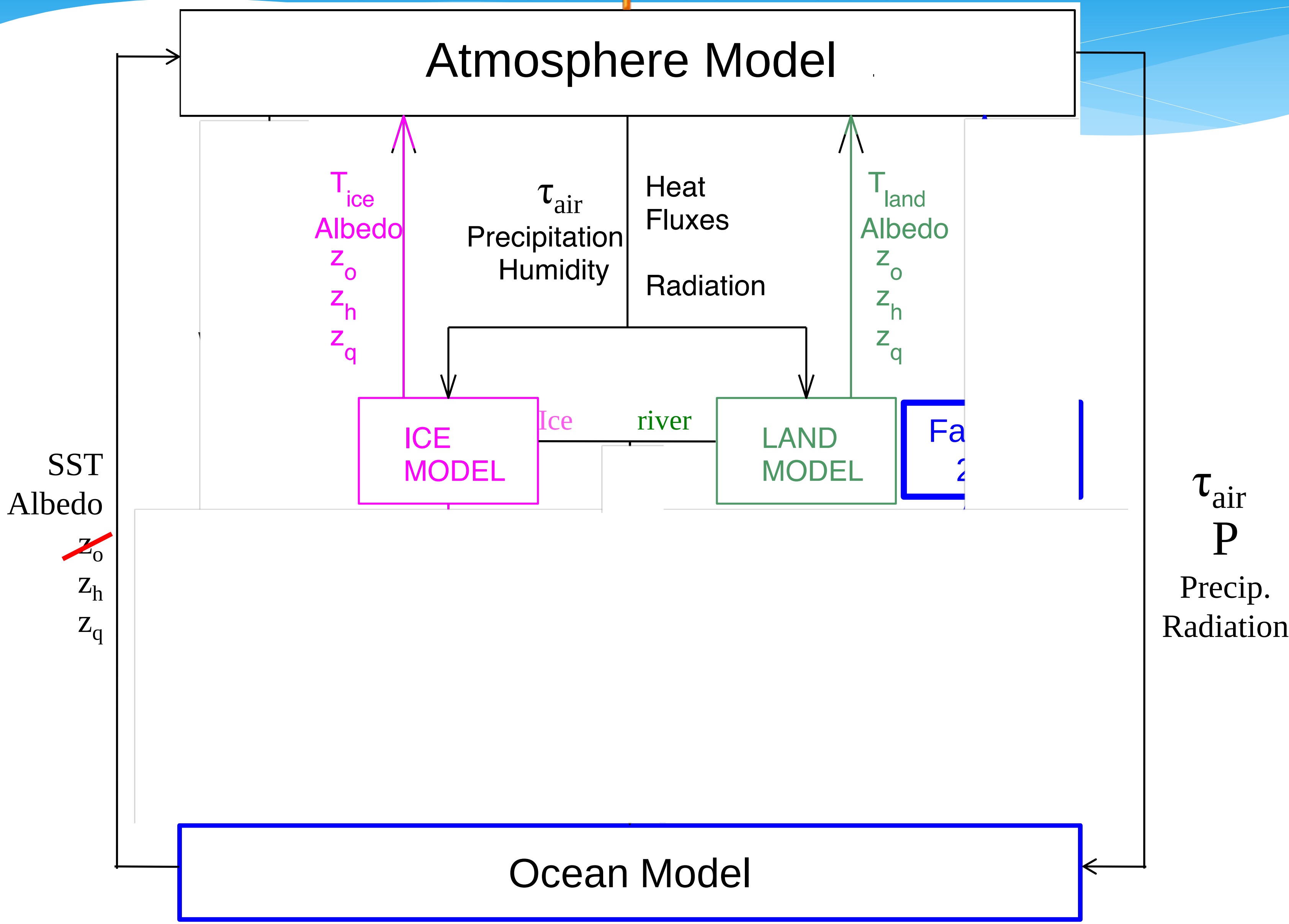
Ocean Surface Gravity Waves and Climate Modeling

Yalin Fan[1] and Steve Griffies[2]

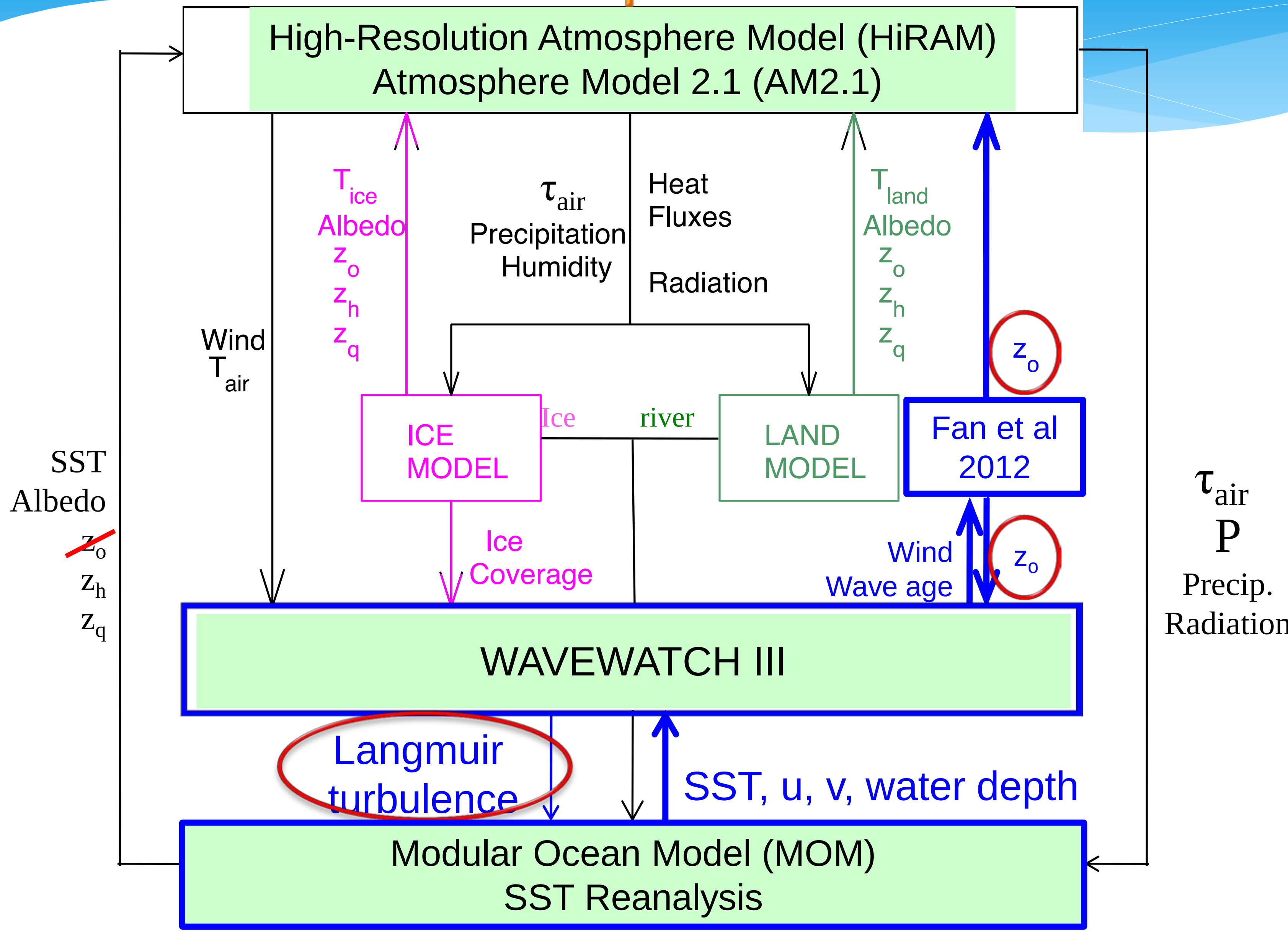
[1]Princeton University / [2]NOAA/GFDL

GFDL Coupled Model

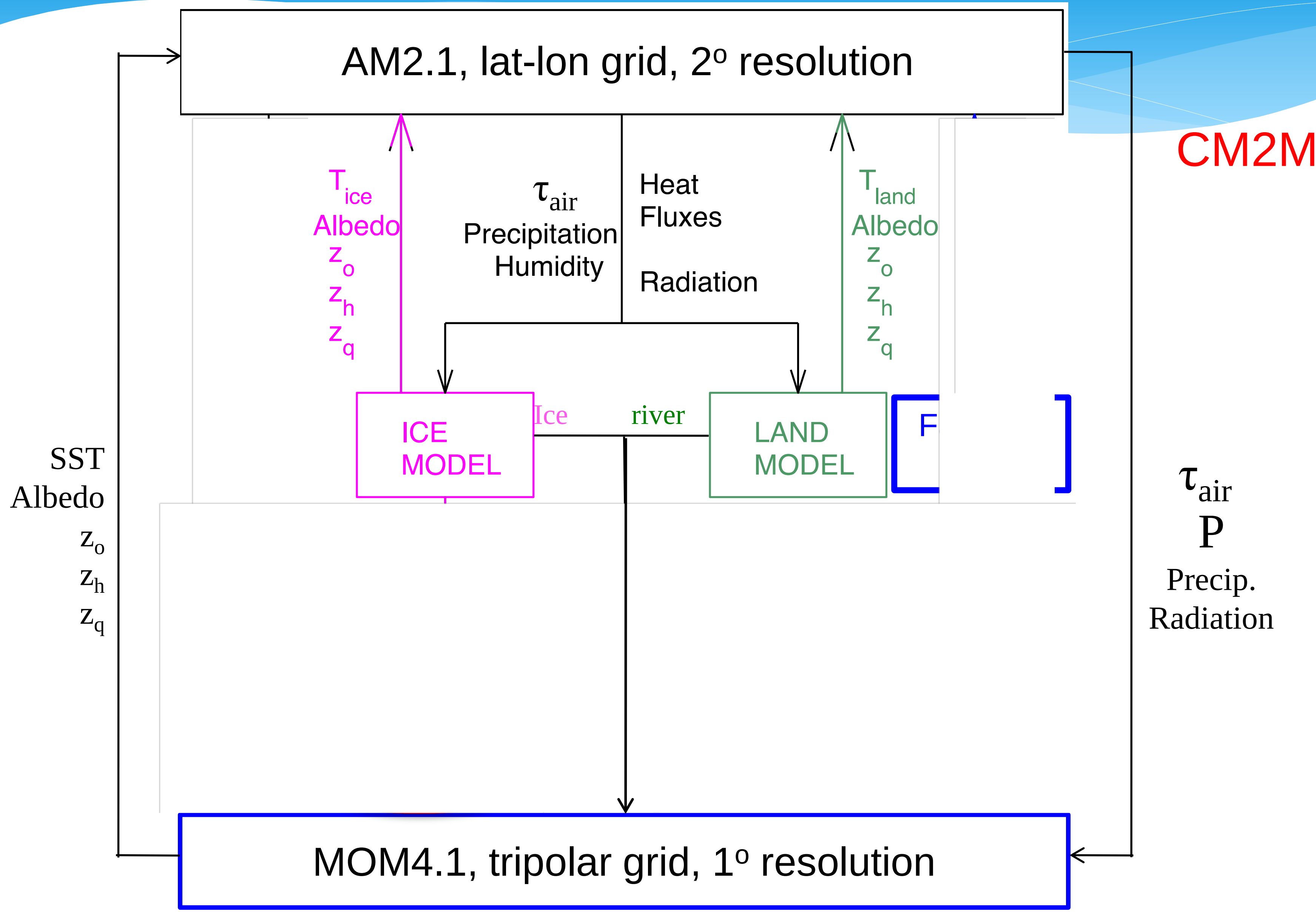


(Fan et al 2012, J. Clim.)

GFDL Coupled Model



Fully Coupled Model simulations



Fully Coupled Model simulations – Experiments

1990 control integration following Delworth et al (2006)

- Aerosol and trace gas concentrations, insolation, and distribution of land cover types are taken to represent the 1990 values
- Do not vary from year to year

Four experiments:

Control experiment: Original CM2M

Ep1: Wave Coupled CM2M using McWilliams & Sullivan (2000) Langmuir Turbulence Parameterization

Ep2: Wave Coupled CM2M using Smyth et al (2002) Langmuir Turbulence Parameterization

Ep3: Wave Coupled CM2M using Qiao et al (2004) non-breaking wave Parameterization

- Results are averages from year 101 to 200

Conclusions

- The Smyth et al (2002) parameterization works the best for our wave coupled CM2M model. It is distinguished from the McWilliams and Sullivan (2000) parameterization by adding a stratification effect to restrain the turbulent enhancement under weak stratification conditions and magnified under strong stratification conditions.

Fully Coupled Model simulations
– Langmuir Turbulence Parameterization

McWilliams & Sullivan (2000)

$$W = \frac{k u_*}{\phi} \cdot F_{lt}, \qquad F_{lt} = \left[1 + \frac{A_w}{La^{2\alpha}} \right]^{1/\alpha}$$

Turbulent Velocity scale (W)

Langmuir turbulence Enhancement factor (F_{lt})

Turbulent Langmuir Number ($\sqrt{u_* / u_s}$) (McWilliams et al 1997)

$$\gamma = -A_\gamma \frac{F_Q(0)}{Wh}$$

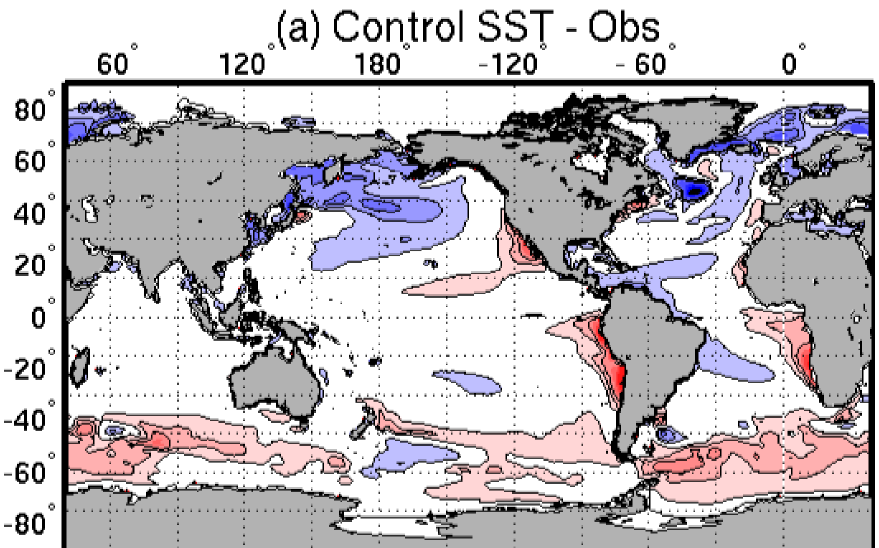
Non-gradient flux (γ)

$$A_w = 0.08; \quad \alpha = 2; \quad A_\gamma = 1.04$$

$$Ri_b = \frac{gh \left| \Delta \left[\langle \rho \rangle \right] \right|}{\rho_0 \left(\left| \Delta \left[\langle u \rangle \right] \right|^2 + W^2 \right)}$$

Fully Coupled Model simulations
– SST bias
why do we need Langmuir turbulent mixing

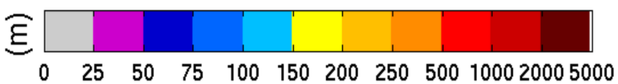
Control: CM2M



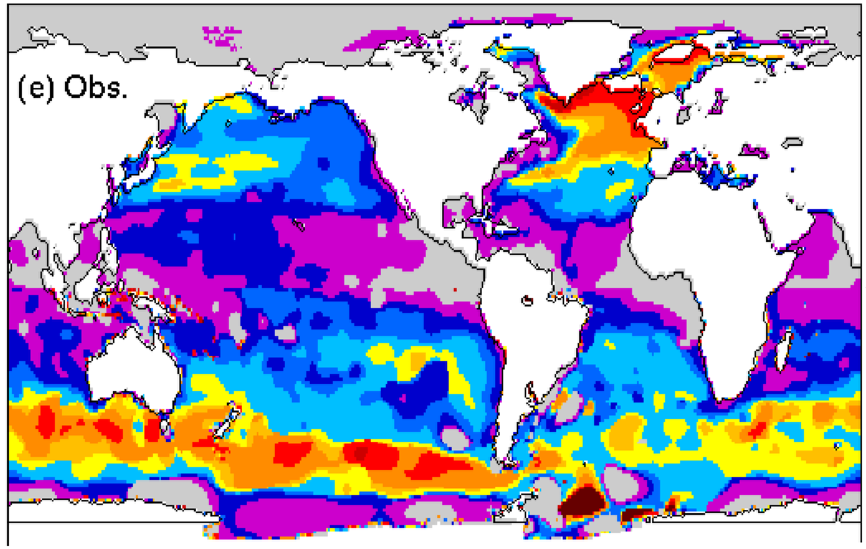
RMSE Global, 1.24 °C ; 90S - 30S, 1.30 °C
30S - 30N, 0.99 °C ; 30N - 90N, 1.71 °C

Fully Coupled Model simulations – Winter MLD

$\Delta\sigma < 0.125 kg/m^3$
estimated based on world ocean atlas data from the national oceanographic data center



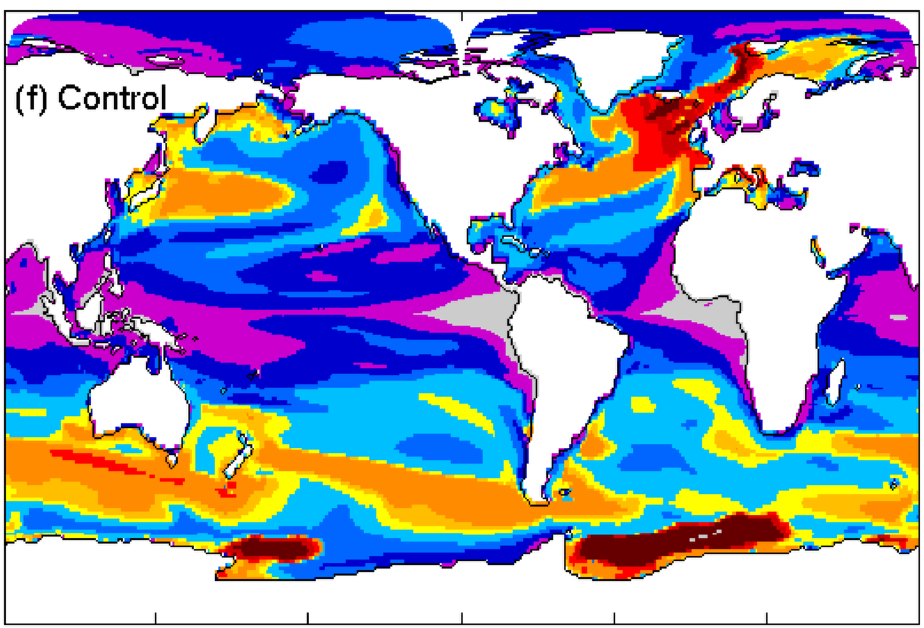
Winter (JFM) Mixed Layer depth



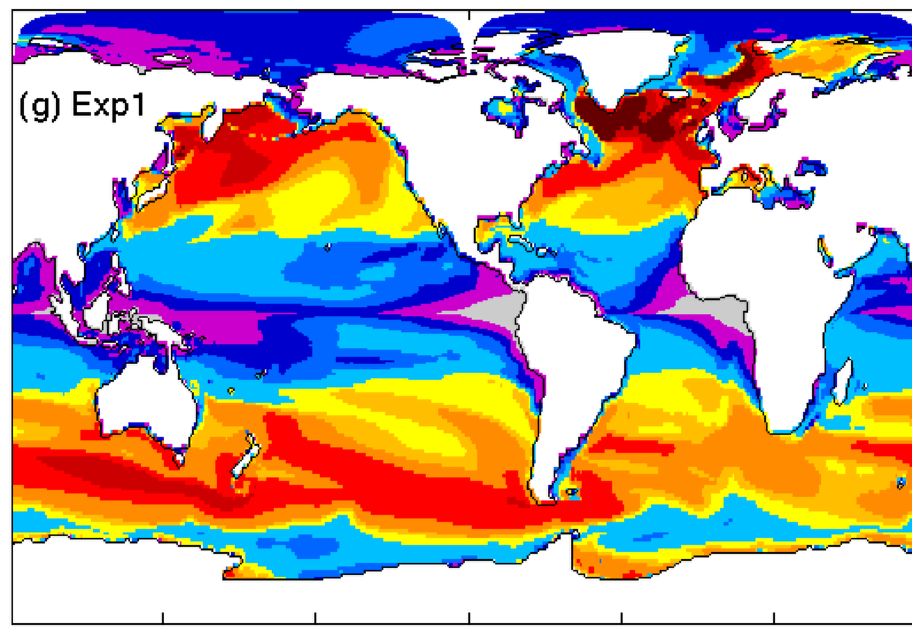
JFM

JAS

Control

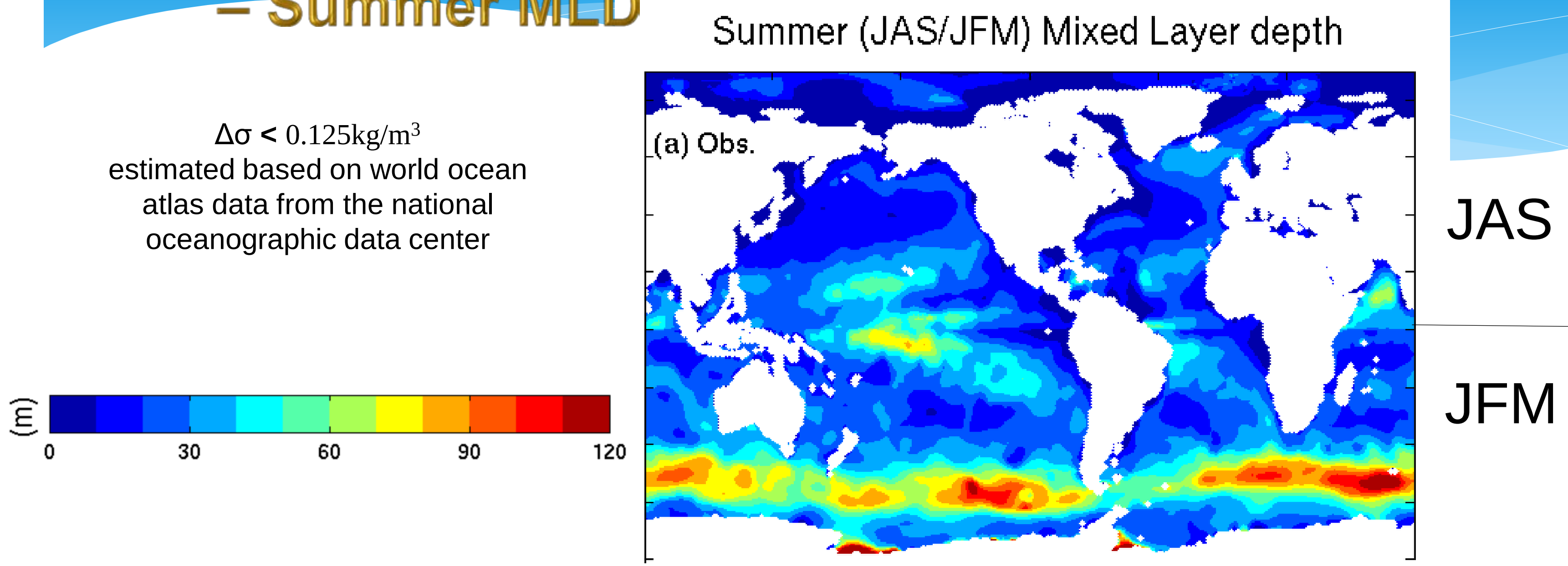


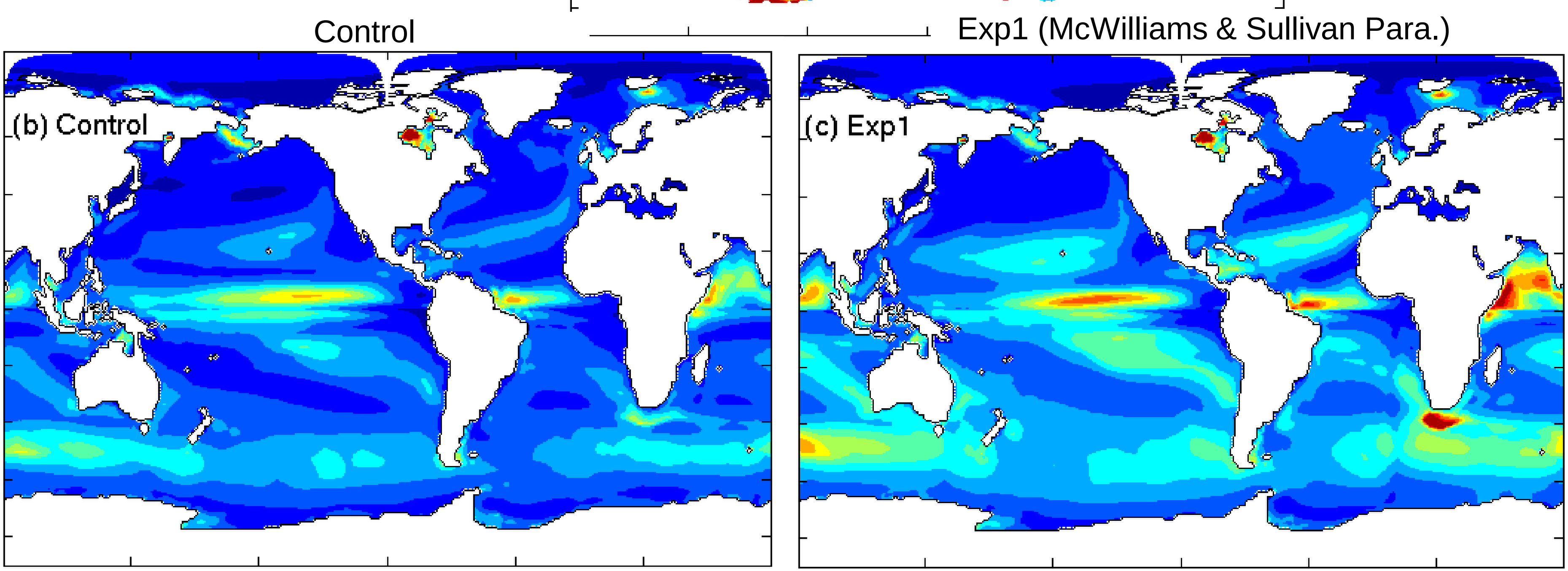
Exp1 (McWilliams & Sullivan Para.)



Fully Coupled Model simulations – Summer MLD

$\Delta\sigma < 0.125 kg/m^3$
estimated based on world ocean atlas data from the national oceanographic data center





Fully Coupled Model simulations
– Smyth et al (2002) Langmuir turbulence Par.

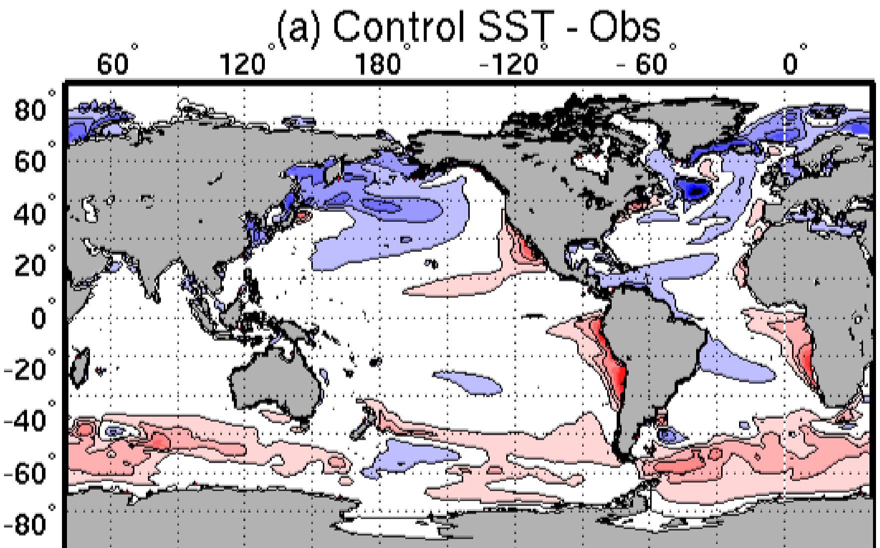
$$W = \frac{ku_*}{\phi} \cdot F_{lt}, \qquad F_{lt} = \left[1 + \frac{A_w}{La^{2\alpha}} \right]^{1/\alpha}$$

"The reduction in daytime warming is insufficient to reproduce the LES results quantitatively, while the application of the McWilliams & Sullivan (2000) parameterization during nocturnal convection causes unrealistically rapid mixing throughout the mixed layer."

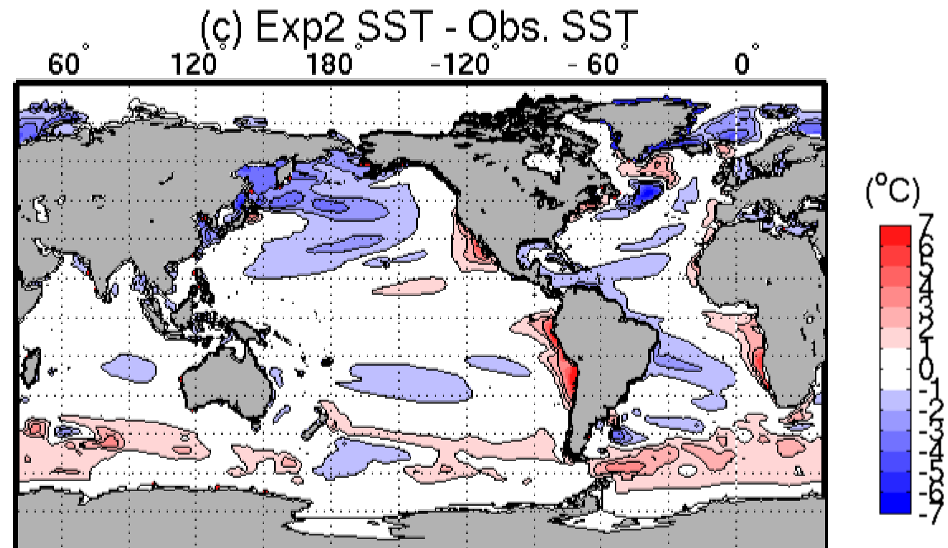
Fully Coupled Model simulations – SST

Control: CM2M

Exp2: wave coupled with Smyth et al (2002)



RMSE Global, 1.24 °C ; 90S - 30S, 1.30 °C
30S - 30N, 0.99 °C ; 30N - 90N, 1.71 °C

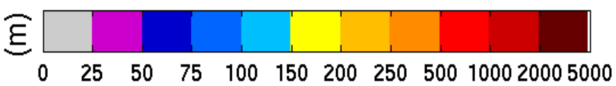


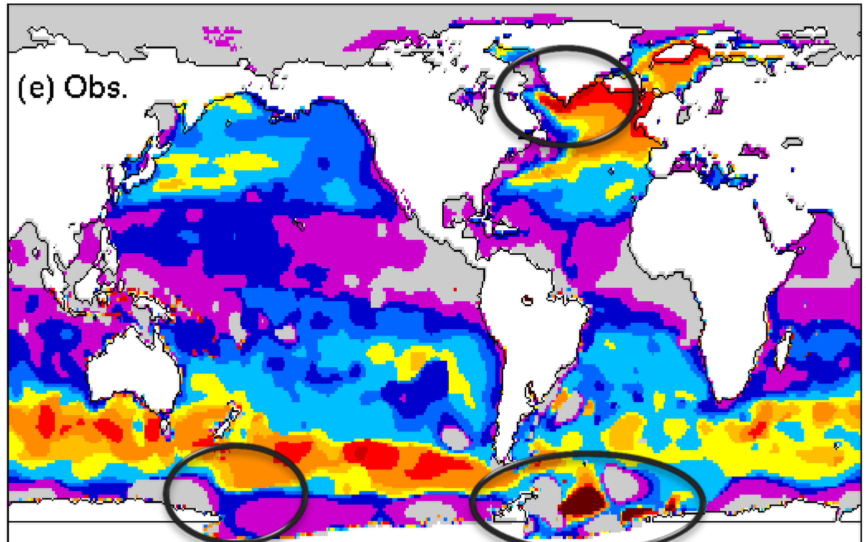
RMSE Global, 1.18 °C ; 90S - 30S, 1.09 °C
30S - 30N, 1.04 °C ; 30N - 90N, 1.65 °C

Fully Coupled Model simulations – Winter MLD

Winter (JFM) Mixed Layer depth

$\Delta\sigma < 0.125 kg/m^3$
estimated based on world ocean atlas data from the national oceanographic data center

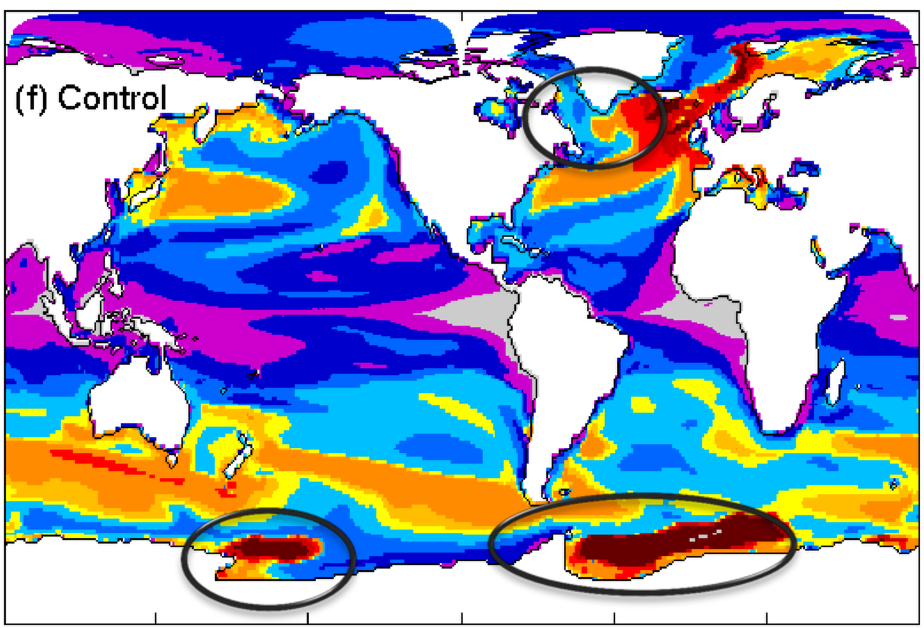




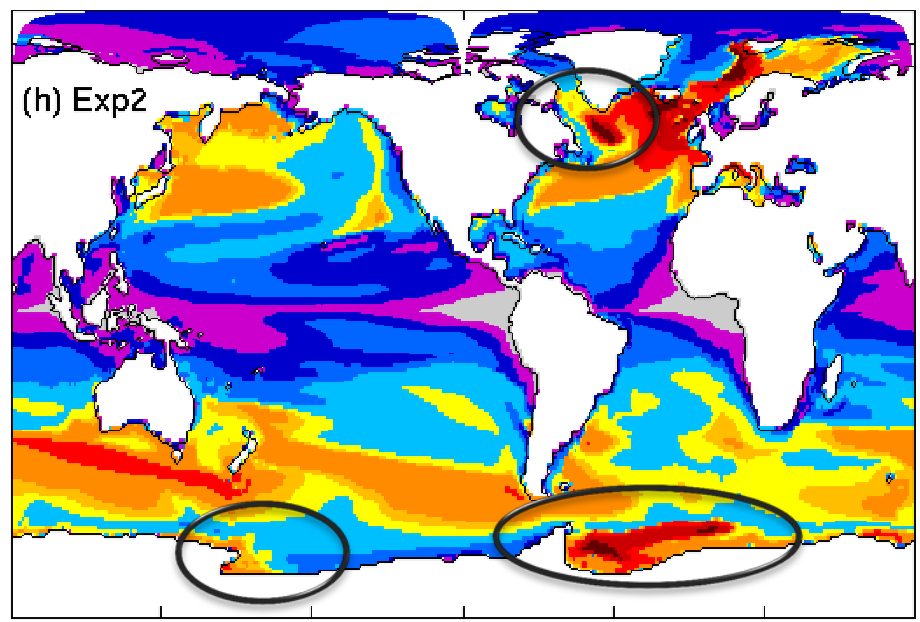
JFM

JAS

Control

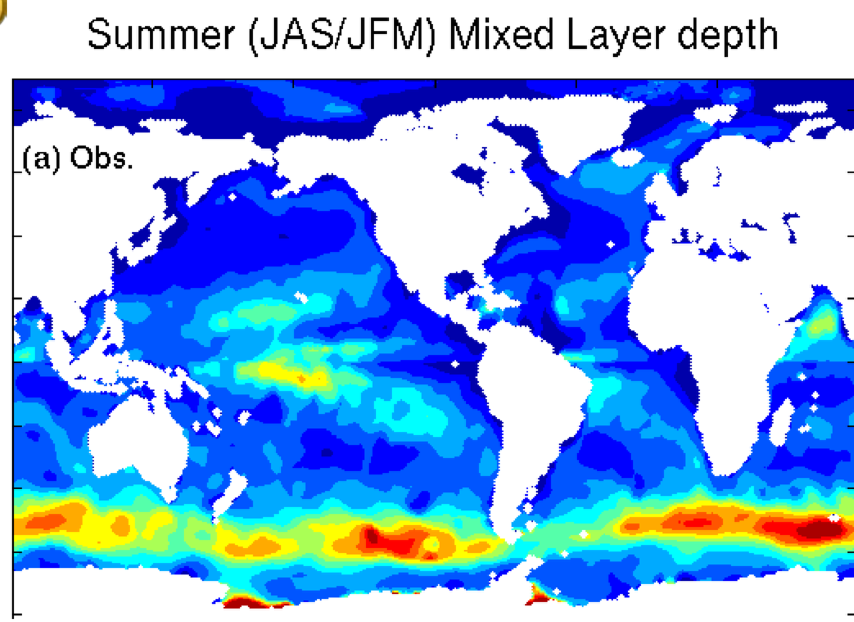


Exp2 (Smyth et al Para.)



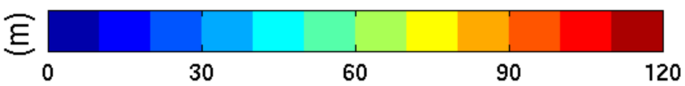
Fully Coupled Model simulations – Summer MLD

Δσ < 0.125kg/m^3
estimated based on world ocean atlas data from the national oceanographic data center



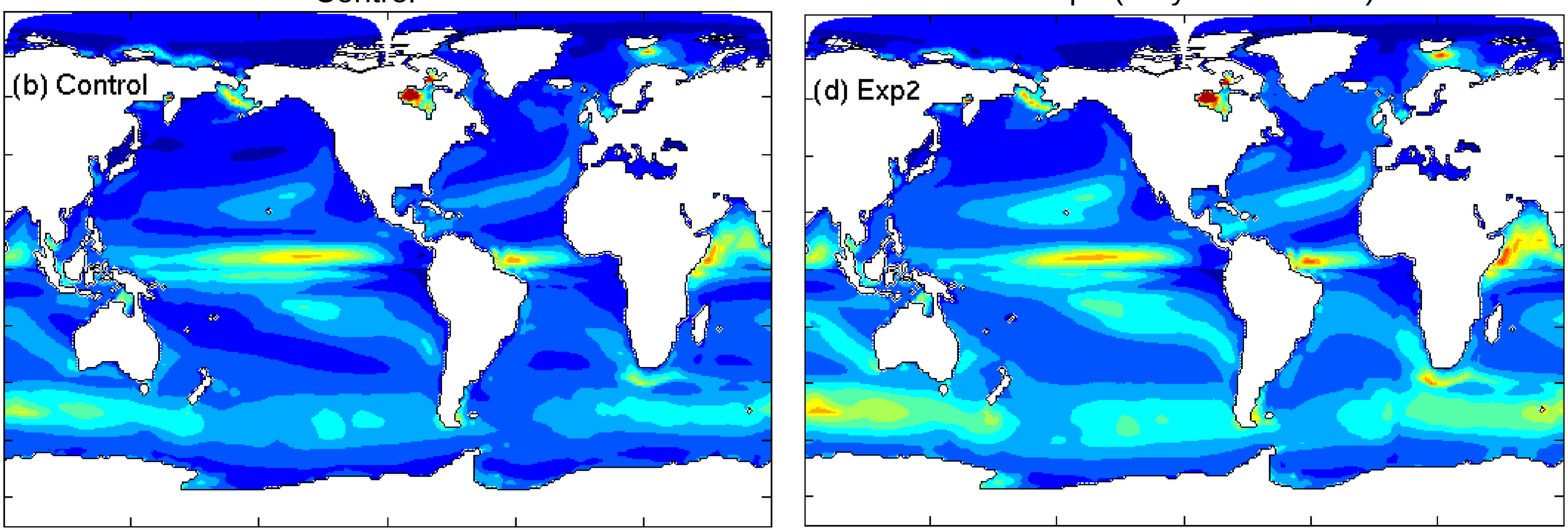
JAS

JFM



Control

Exp2 (Smyth et al Para.)



Fully Coupled Model simulations
– Qiao et al (2004) non-breaking wave effect

$$B_V = l_w^2 \cdot \frac{\partial}{\partial z}\left[\iint_{\vec{k}} \omega^2 E\left(\vec{k}\right)\exp\left(2kz\right) d\vec{k}\right]^{\frac{1}{2}}$$

Mixing Length

frequency

Energy spectra

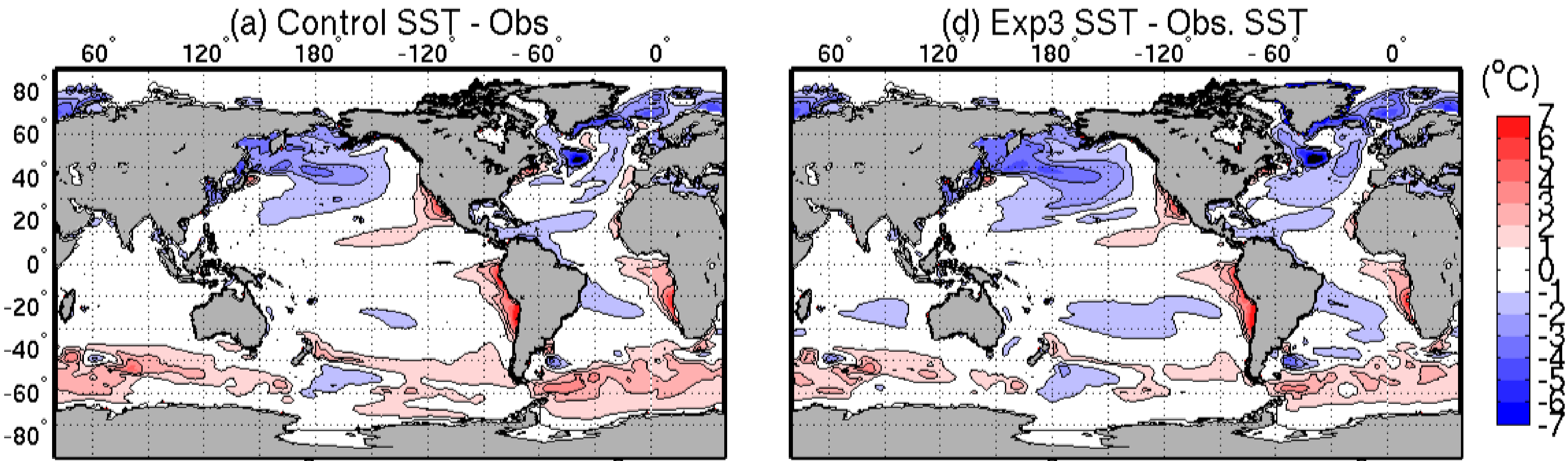
Wave number

$$l_w^2 = \alpha \iint_{\vec{k}} E\left(\vec{k}\right)\exp\left(2kz\right) d\vec{k}$$

Fully Coupled Model simulations – SST

Control: CM2M

Exp3: wave coupled with Qiao et al (2004)



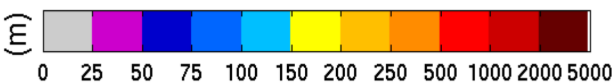
RMSE Global, 1.24 °C ; 90S - 30S, 1.30 °C
30S - 30N, 0.99 °C ; 30N - 90N, 1.71 °C

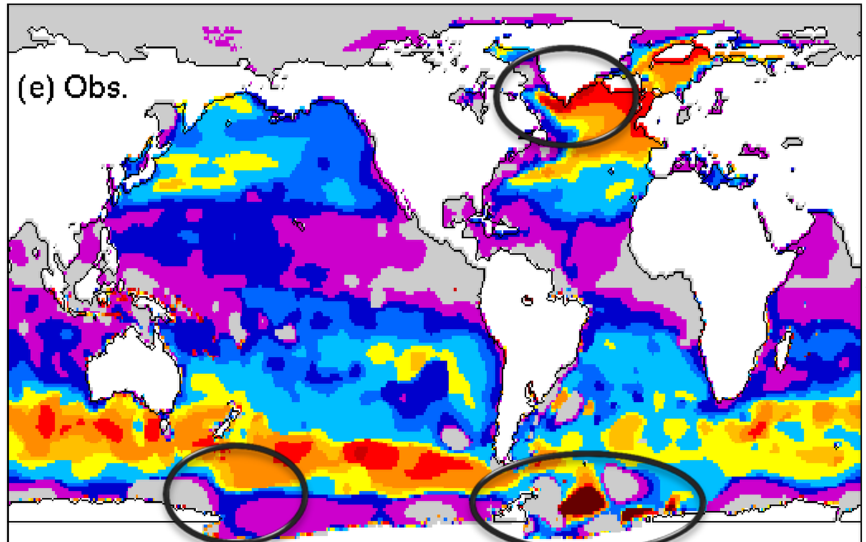
RMSE Global, 1.30 °C ; 90S - 30S, 1.11 °C
30S - 30N, 1.05 °C ; 30N - 90N, 2.08 °C

Fully Coupled Model simulations – Winter MLD

Winter (JFM) Mixed Layer depth

$\Delta\sigma < 0.125 kg/m^3$
estimated based on world ocean atlas data from the national oceanographic data center

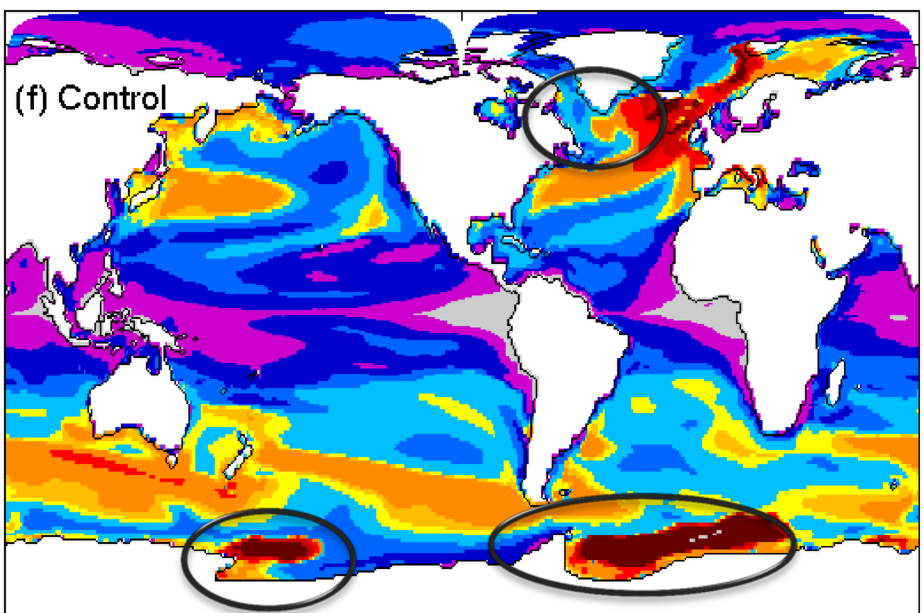




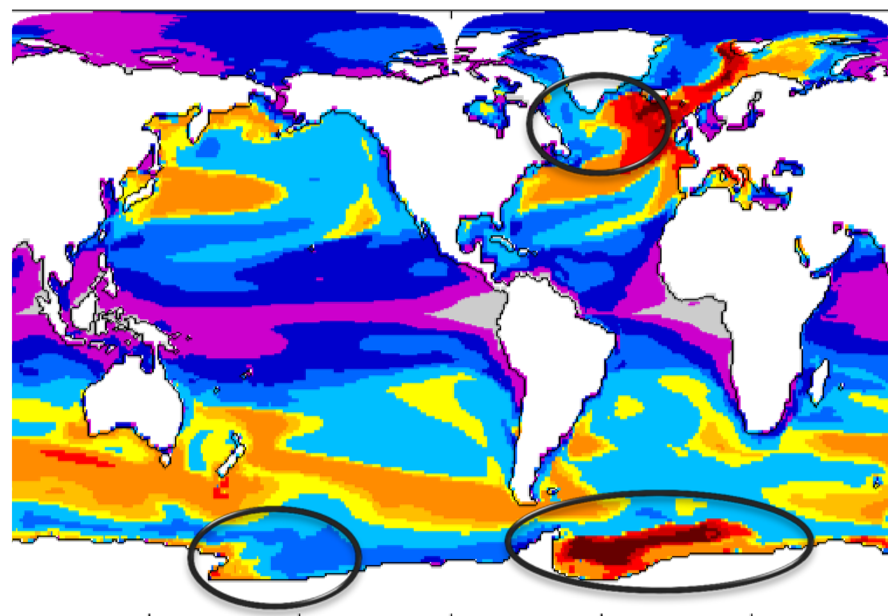
JFM

JAS

Control

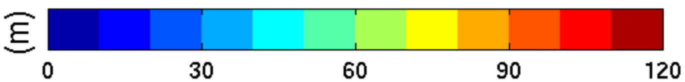


Exp3 (Qiao et al Para.)

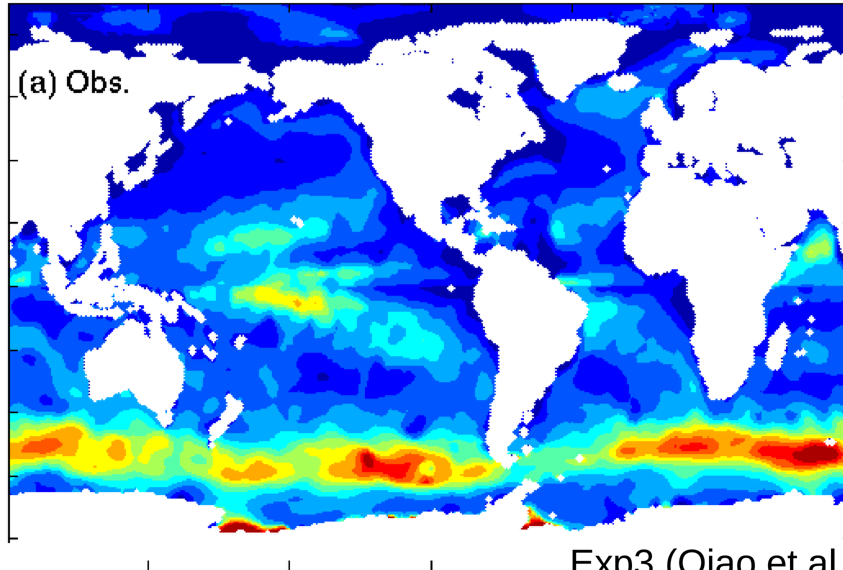


Fully Coupled Model simulations
– Summer MLD

$\Delta\sigma < 0.125 kg/m^3$
estimated based on world ocean atlas data from the national oceanographic data center



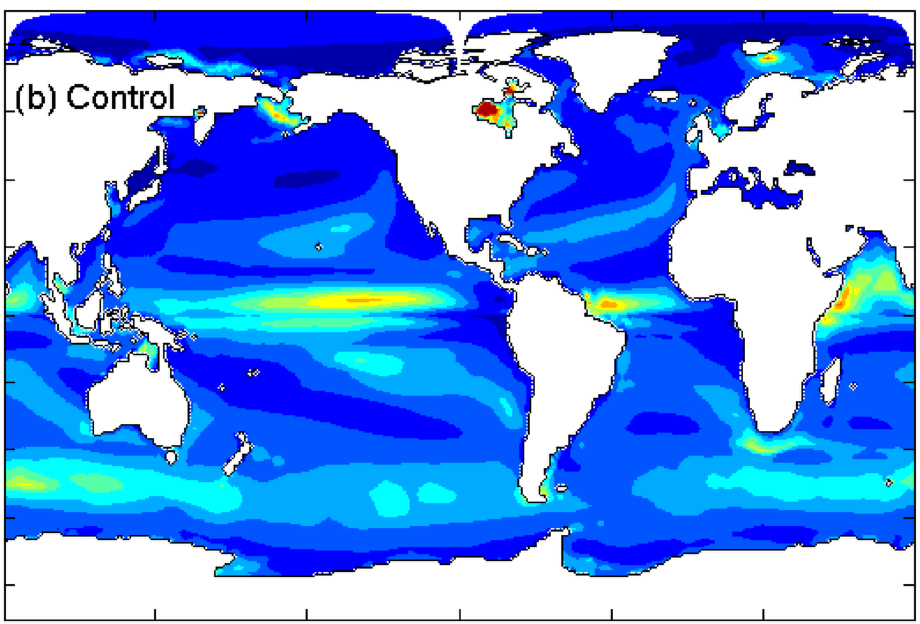
Summer (JAS/JFM) Mixed Layer depth



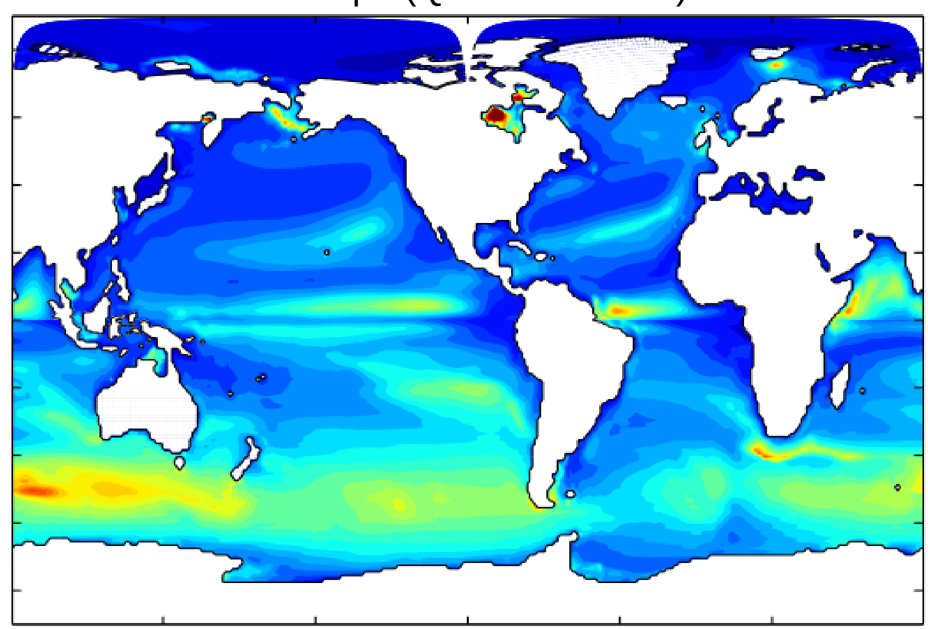
JAS

JFM

Control



Exp3 (Qiao et al Para.)



Fully Coupled Model simulations

Overall, Smyth et al (2002) works best for CM2M !

Next, we are going to focus on two interesting regions:

#1. The Labrador Sea, where the MLD was deepened in Exp2

#2. The Ross and Weddle Sea, where the MLD was reduced in Exp2

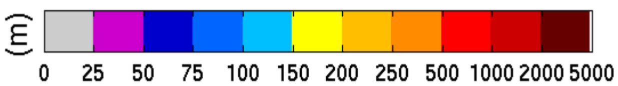
Comparison between Exp2 (Smyth et al Para) and the control run

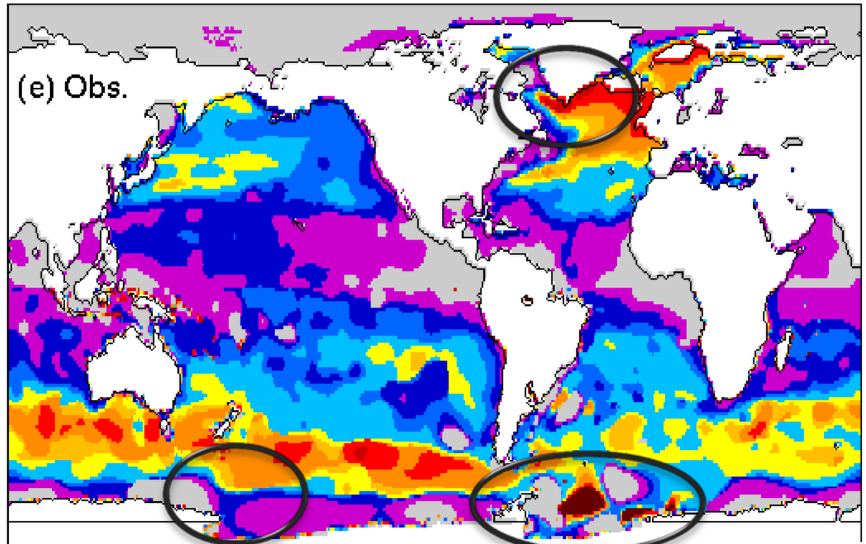
Results averaged from model year 101 to 200

Fully Coupled Model simulations – Winter MLD

Winter (JFM) Mixed Layer depth

$\Delta\sigma < 0.125 kg/m^3$
Polar Science Center Hydrographic Climatology potential temperature and Salinity

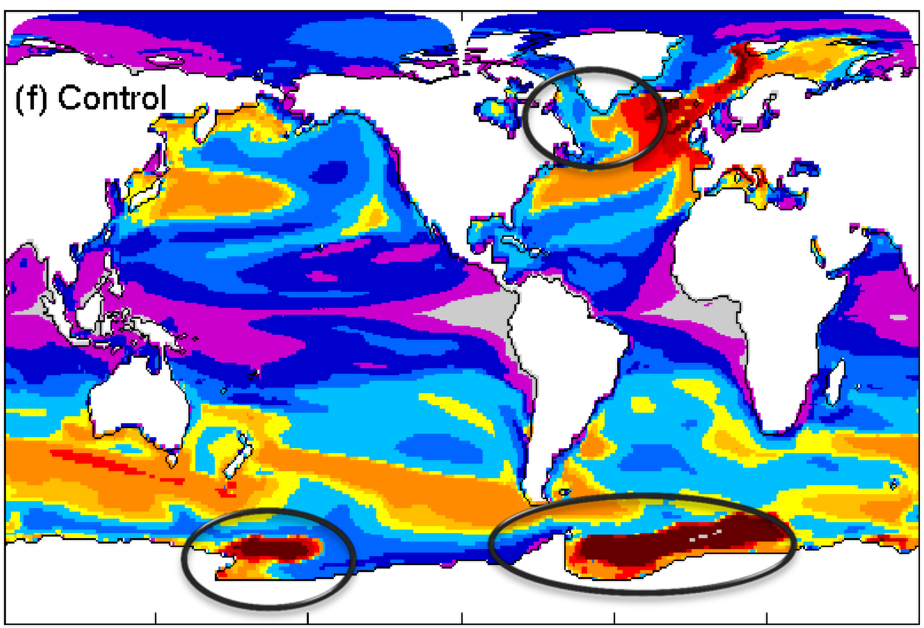




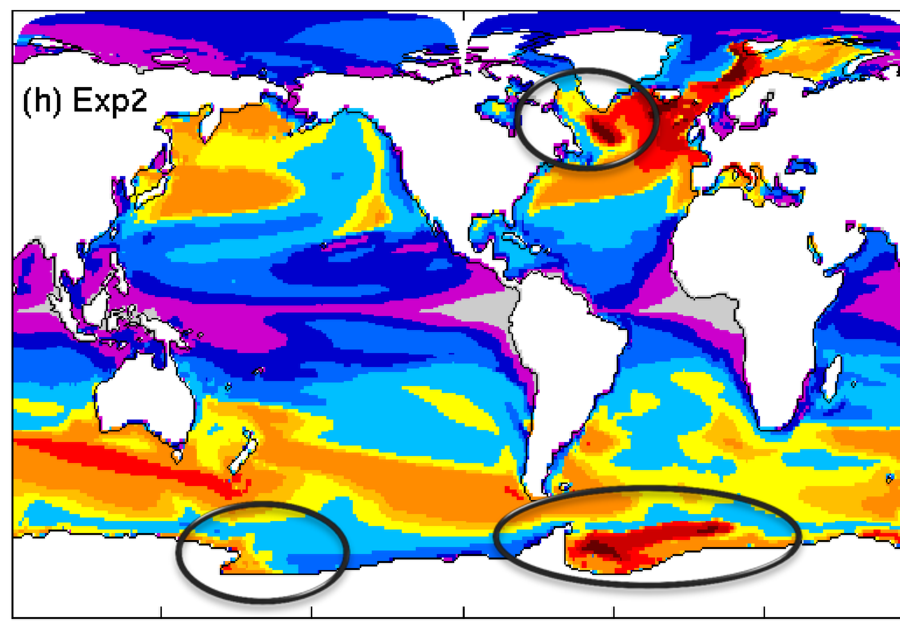
JFM

JAS

Control



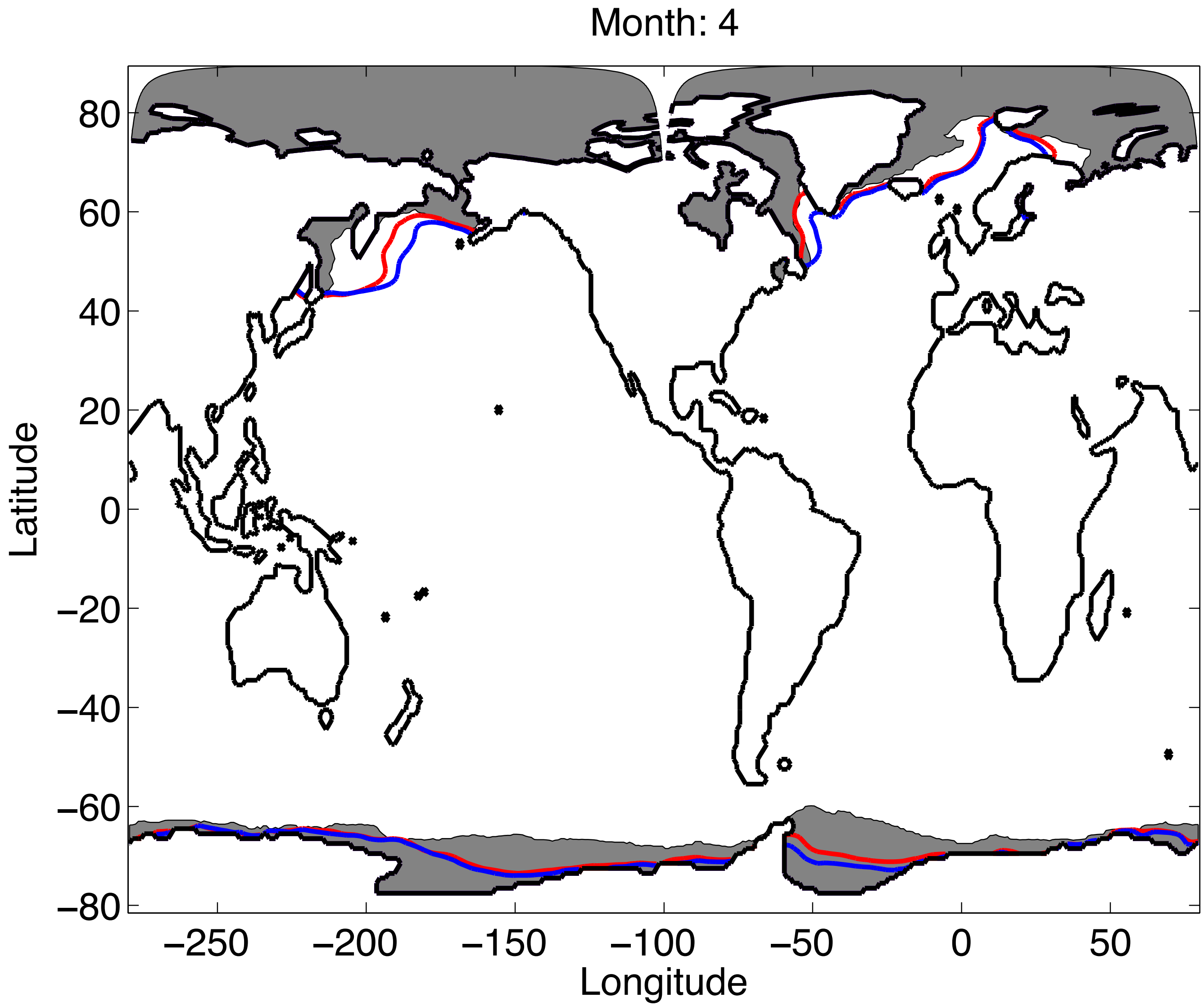
Exp2 (Smyth et al Para.)



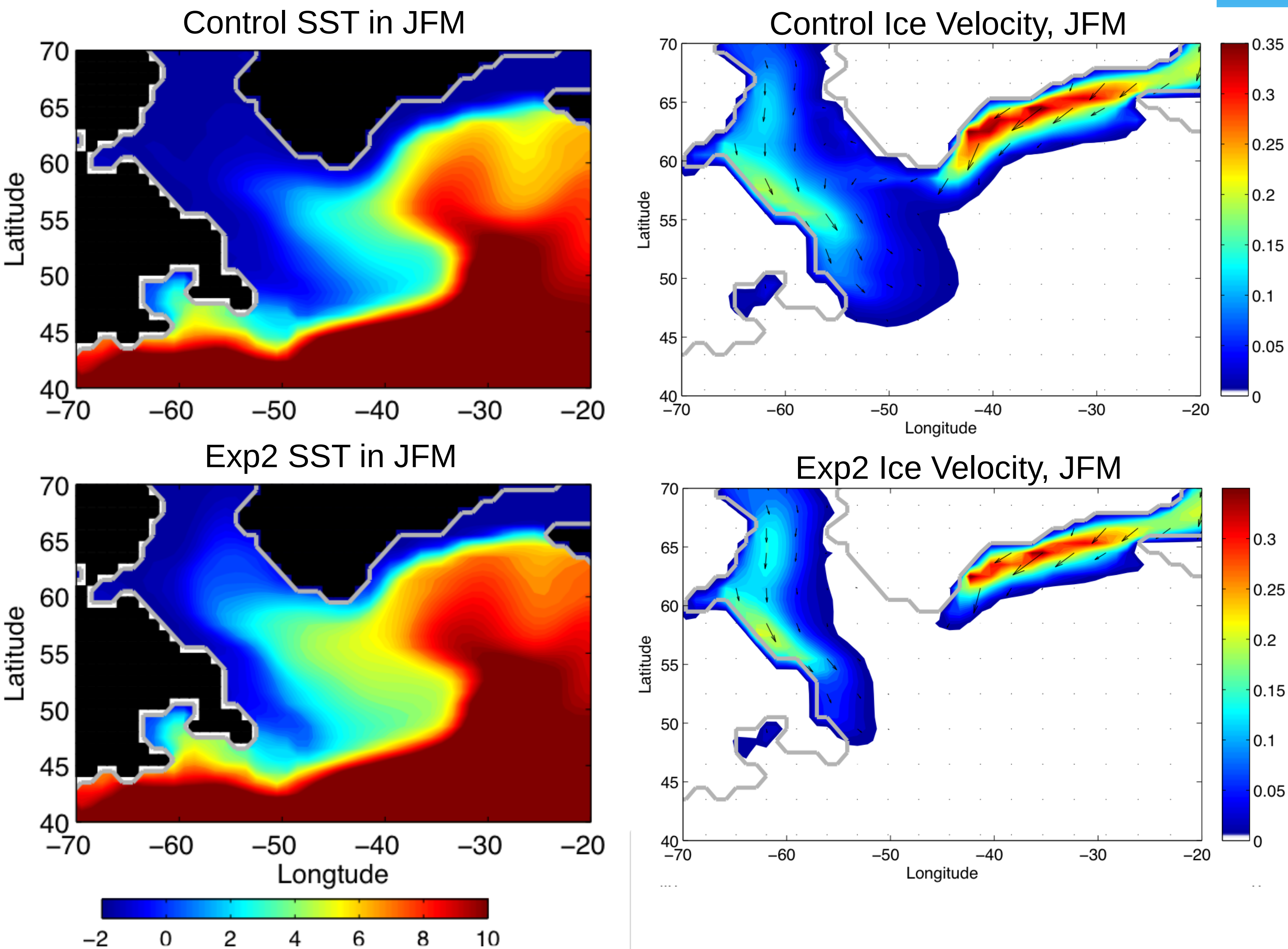
Fully Coupled Model simulations
– Labrador Sea Ice Concentration

15% Ice Concentration

- Exp2 (red)
- Control (blue)



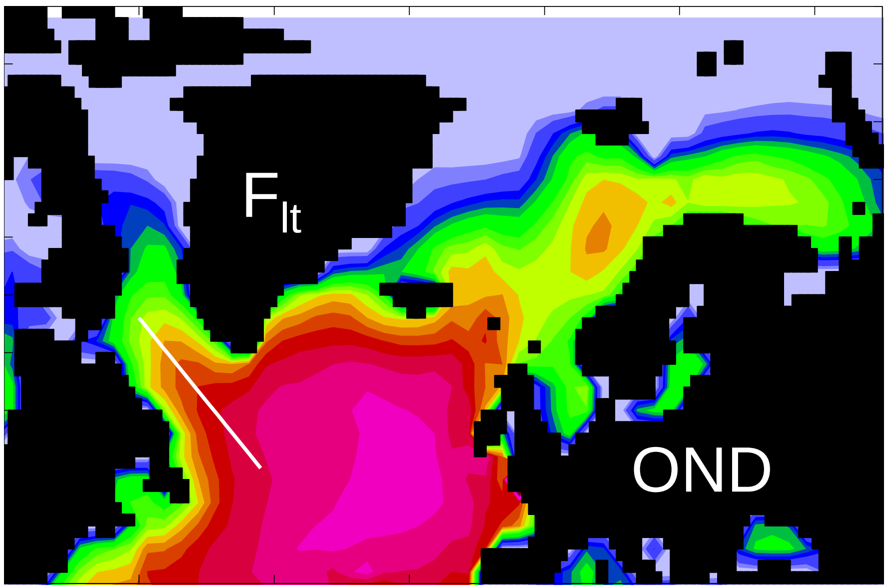
Fully Coupled Model simulations – Labrador Sea SST and Ice Vel.



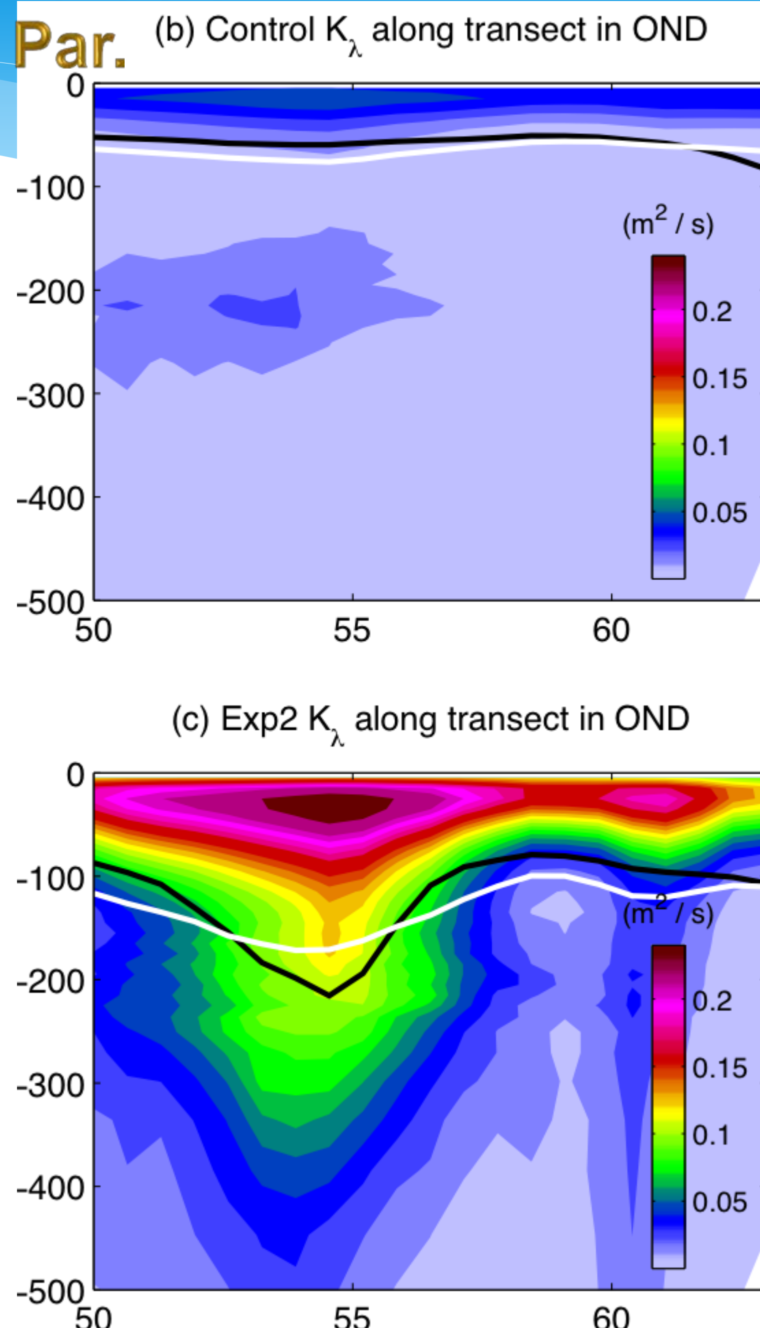
Fully Coupled Model simulations – Labrador Sea Turbulence Par.

Autumn, Oct. – Dec.

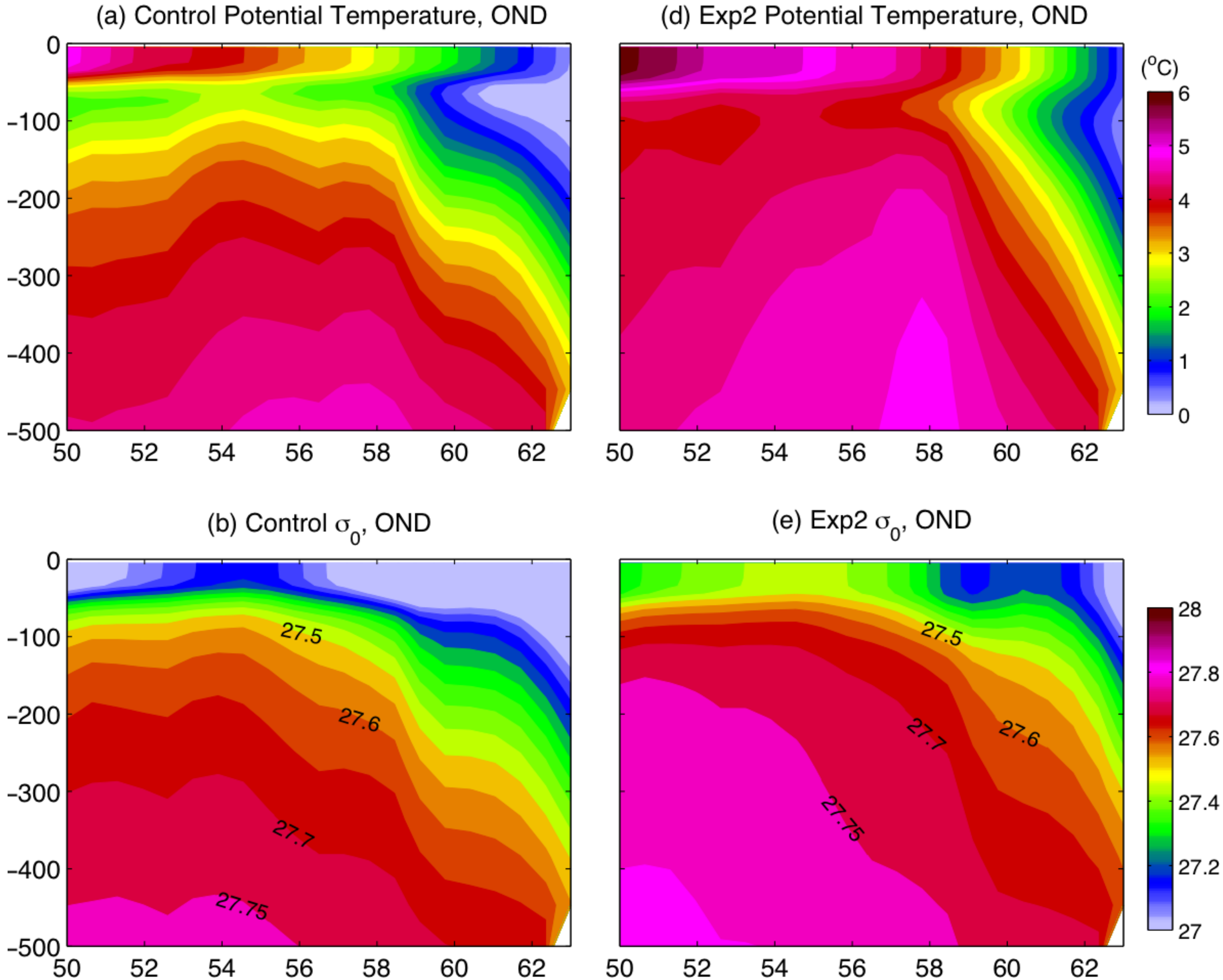
Langmuir Turbulence Enhancement Factor, F_{lt}



$$W = \frac{k u_*}{\phi} \cdot F_{lt}, \qquad F_{lt} = \left[1 + \frac{A_w}{La^{2\alpha}} \right]^{1/\alpha}$$



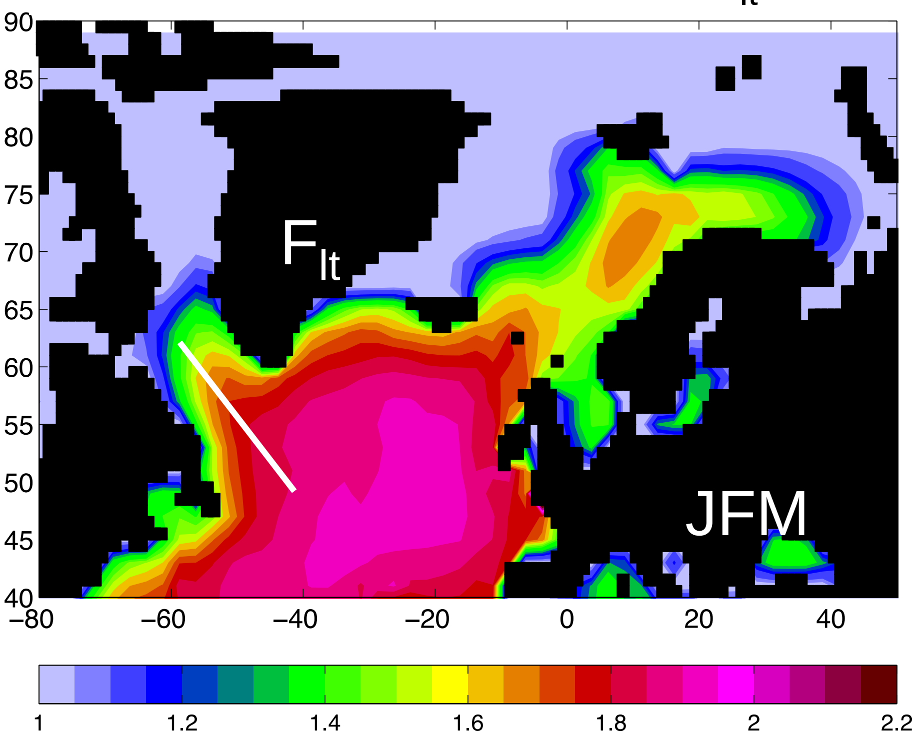
Fully Coupled Model simulations – Labrador Sea Potential Temperature and Density



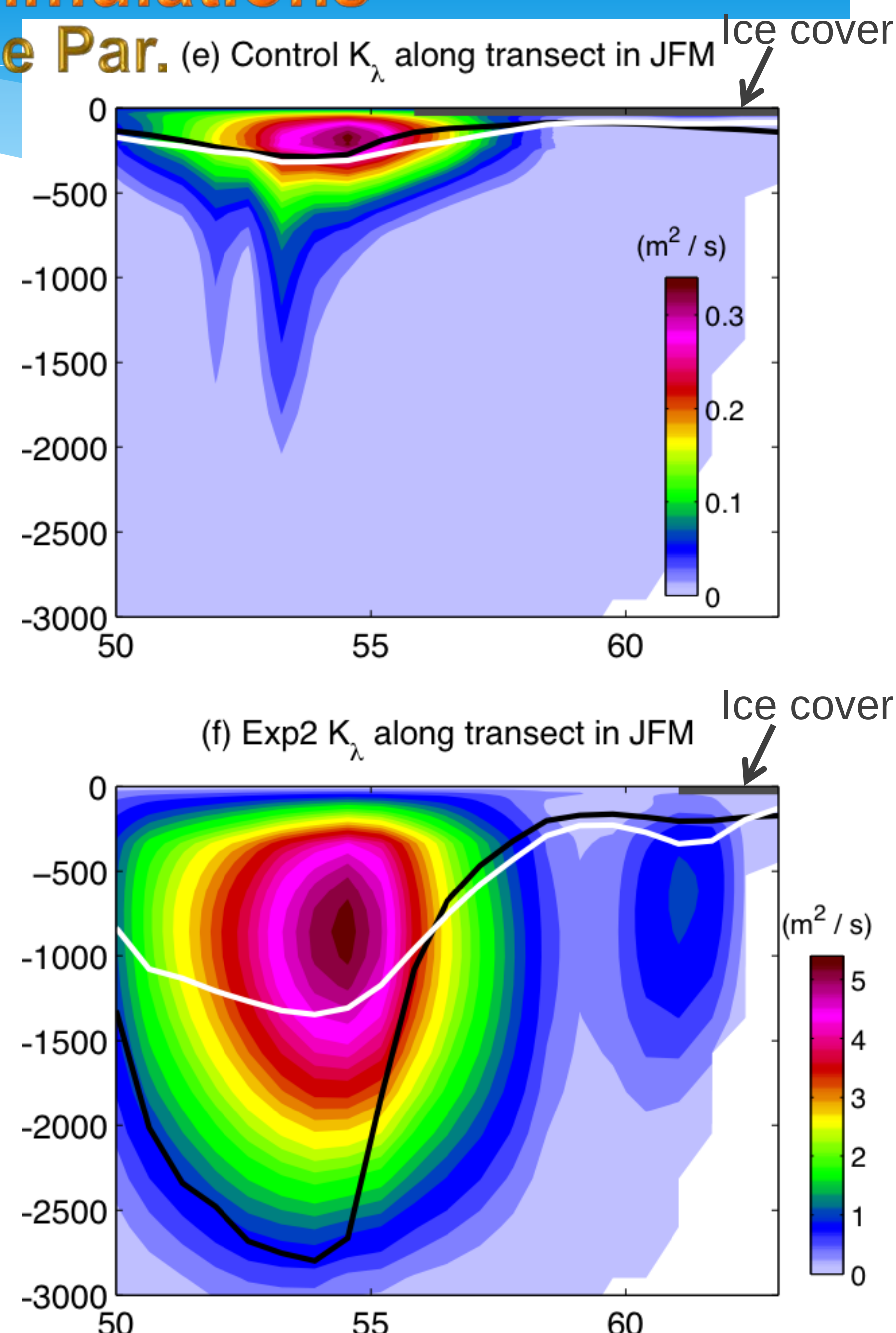
Fully Coupled Model simulations – Labrador Sea Turbulence Par.

Winter, Jan. – Mar.

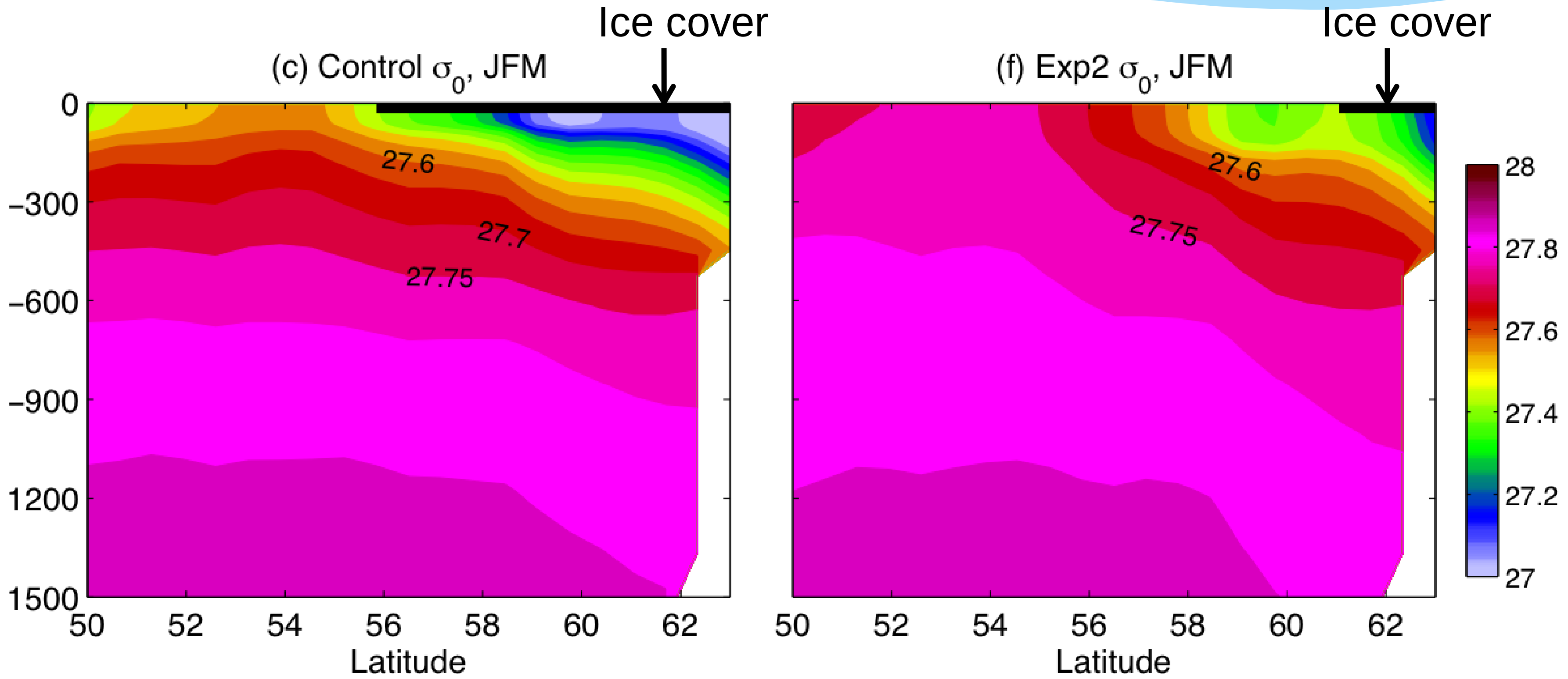
Labrador Sea Langmuir Turbulence Enhancement Factor, F_{lt}



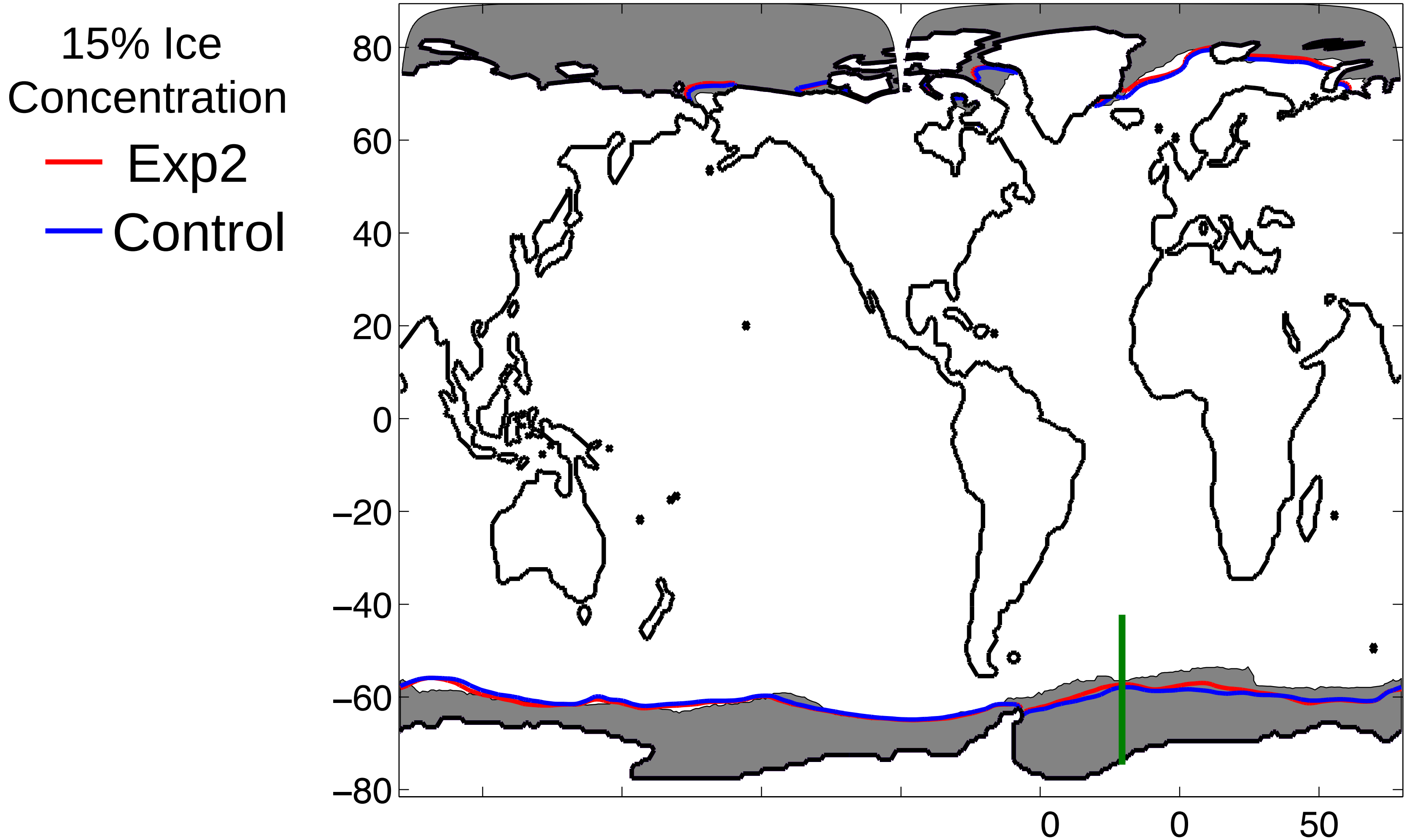
$$W = \frac{ku_*}{\phi} \cdot F_{lt}, \qquad F_{lt} = \left[1 + \frac{A_w}{La^{2\alpha}}\right]^{1/\alpha}$$



Fully Coupled Model simulations
– Labrador Sea Potential Density

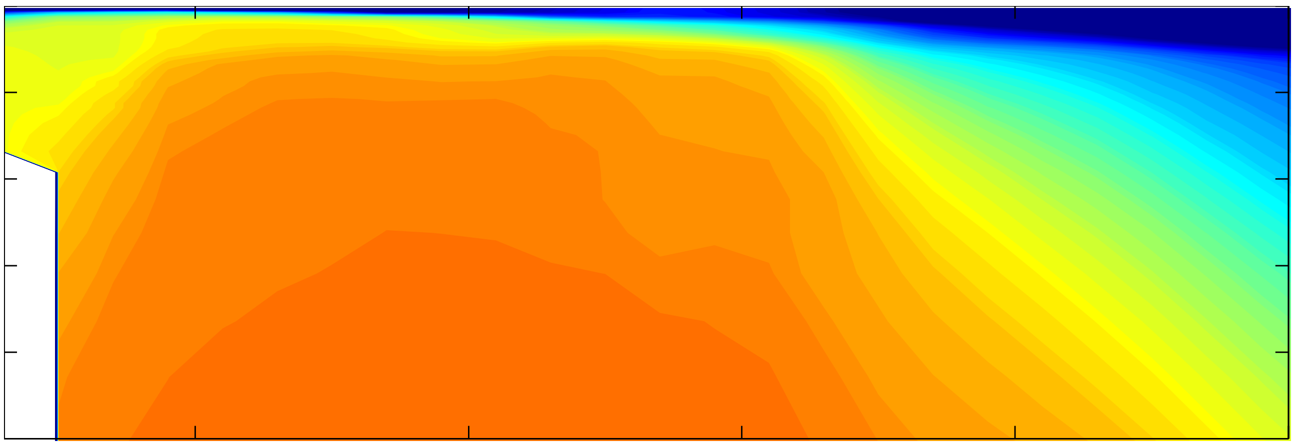


Fully Coupled Model simulations
– Weddell Sea Ice Concentration

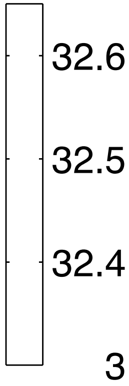


Fully Coupled Model simulations
– Weddell Sea Transect Initial Potential Density

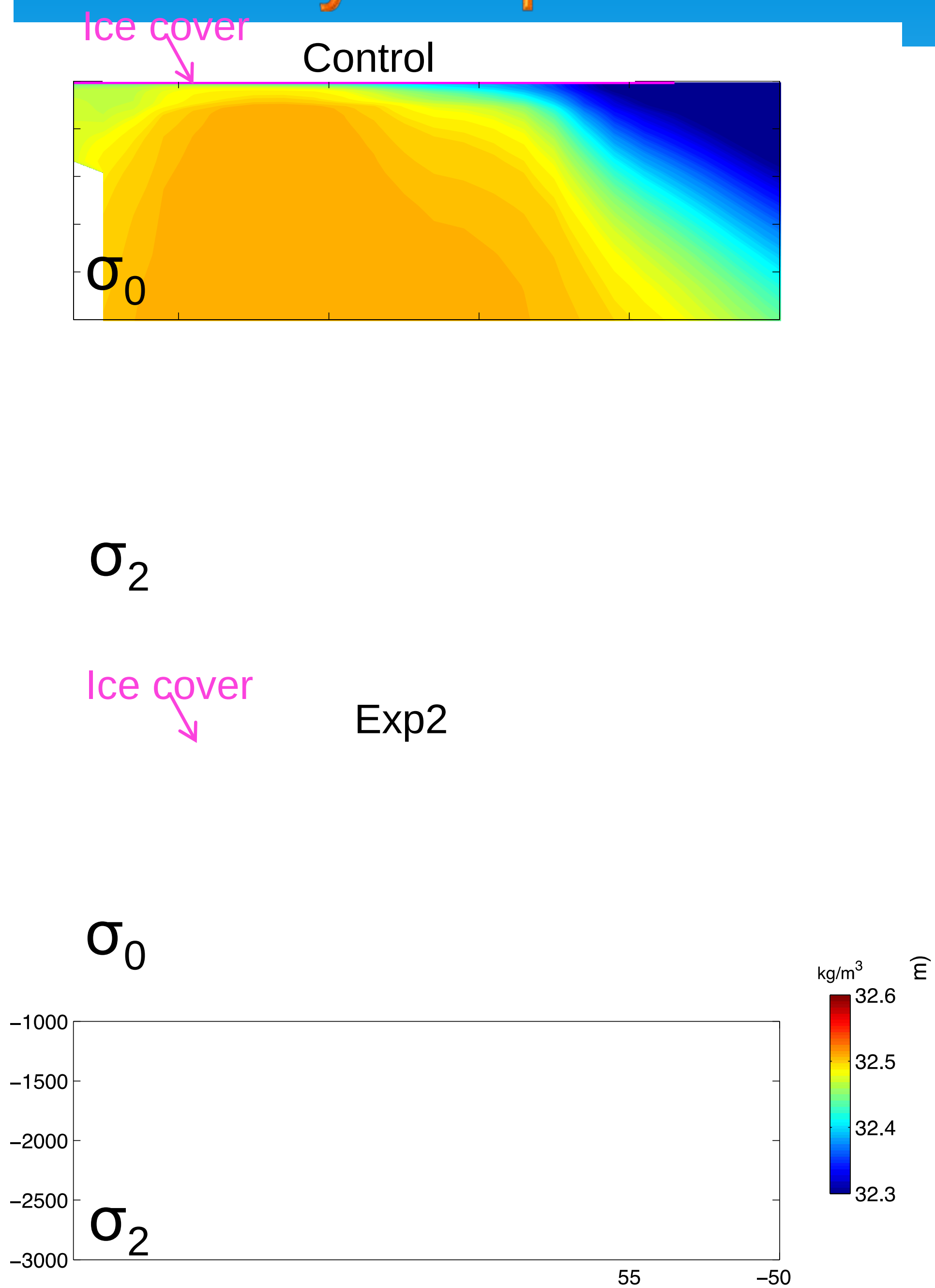
Initial Condition for Weddell Sea Transect, σ_0

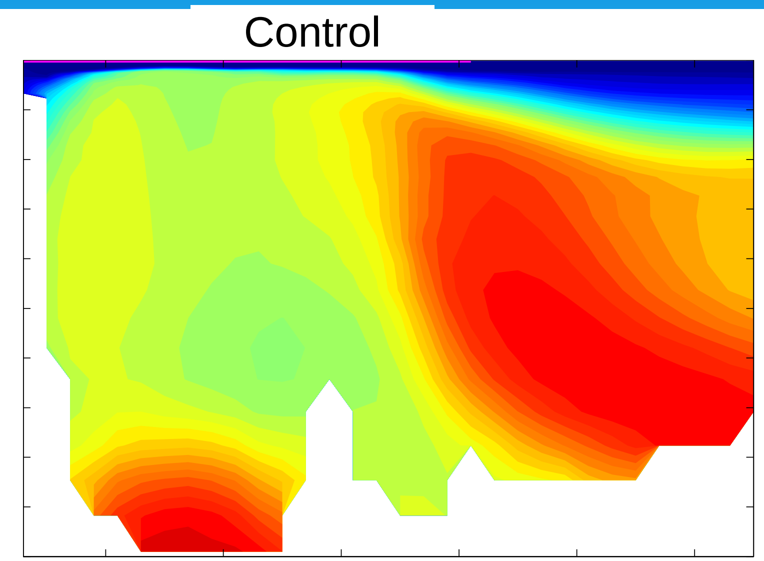


Initial Condition for Weddell Sea Transect, σ_2

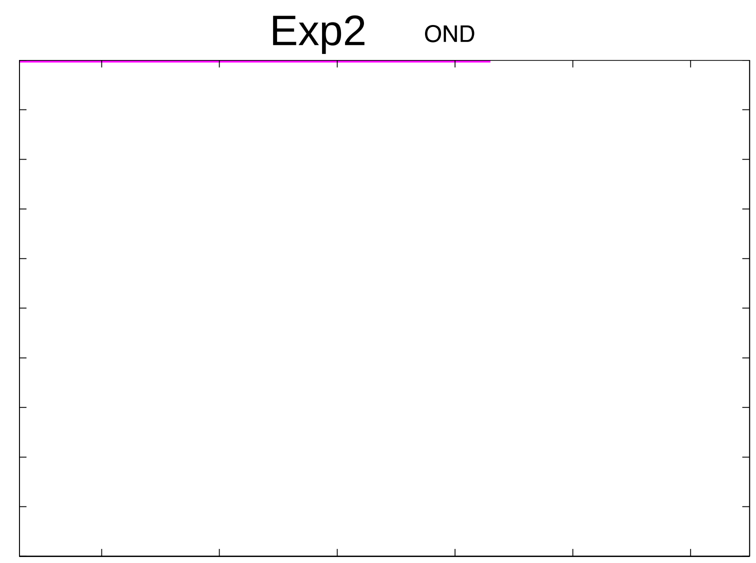


Fully Coupled Model simulations

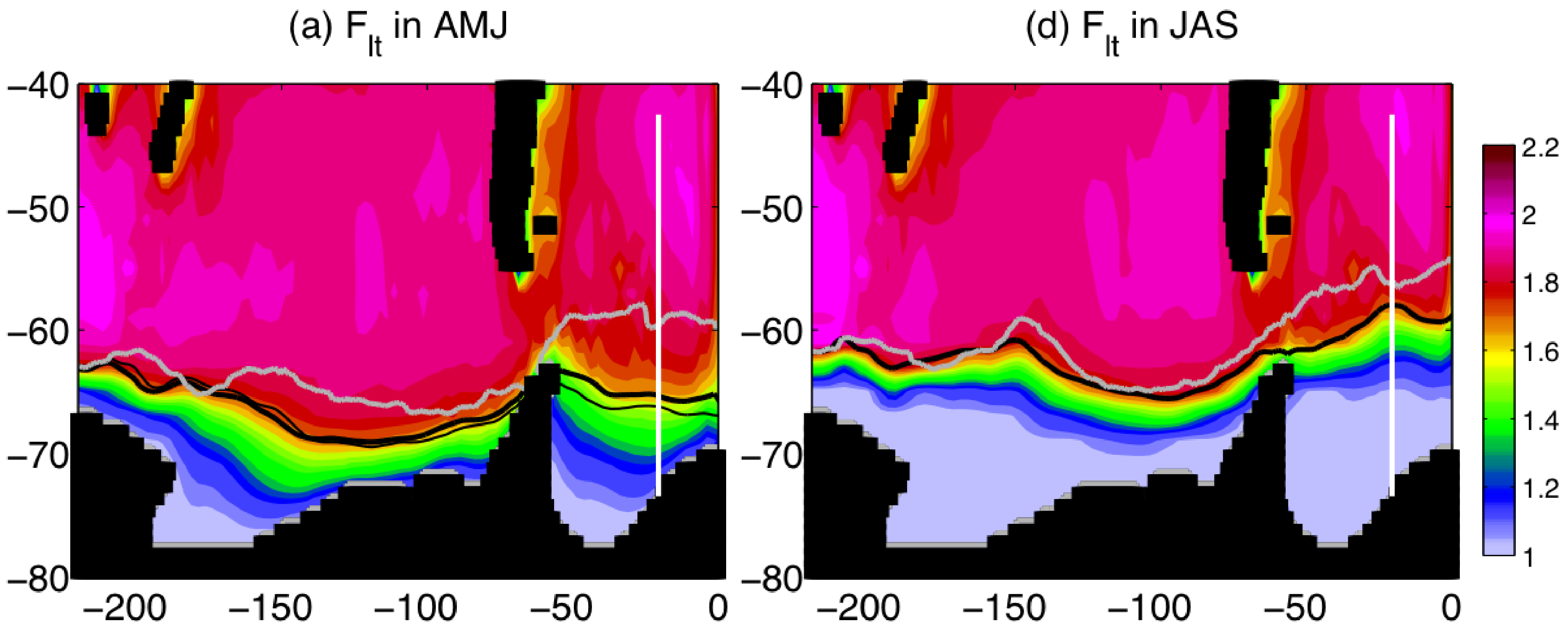




Averaged from model year 181 – 200



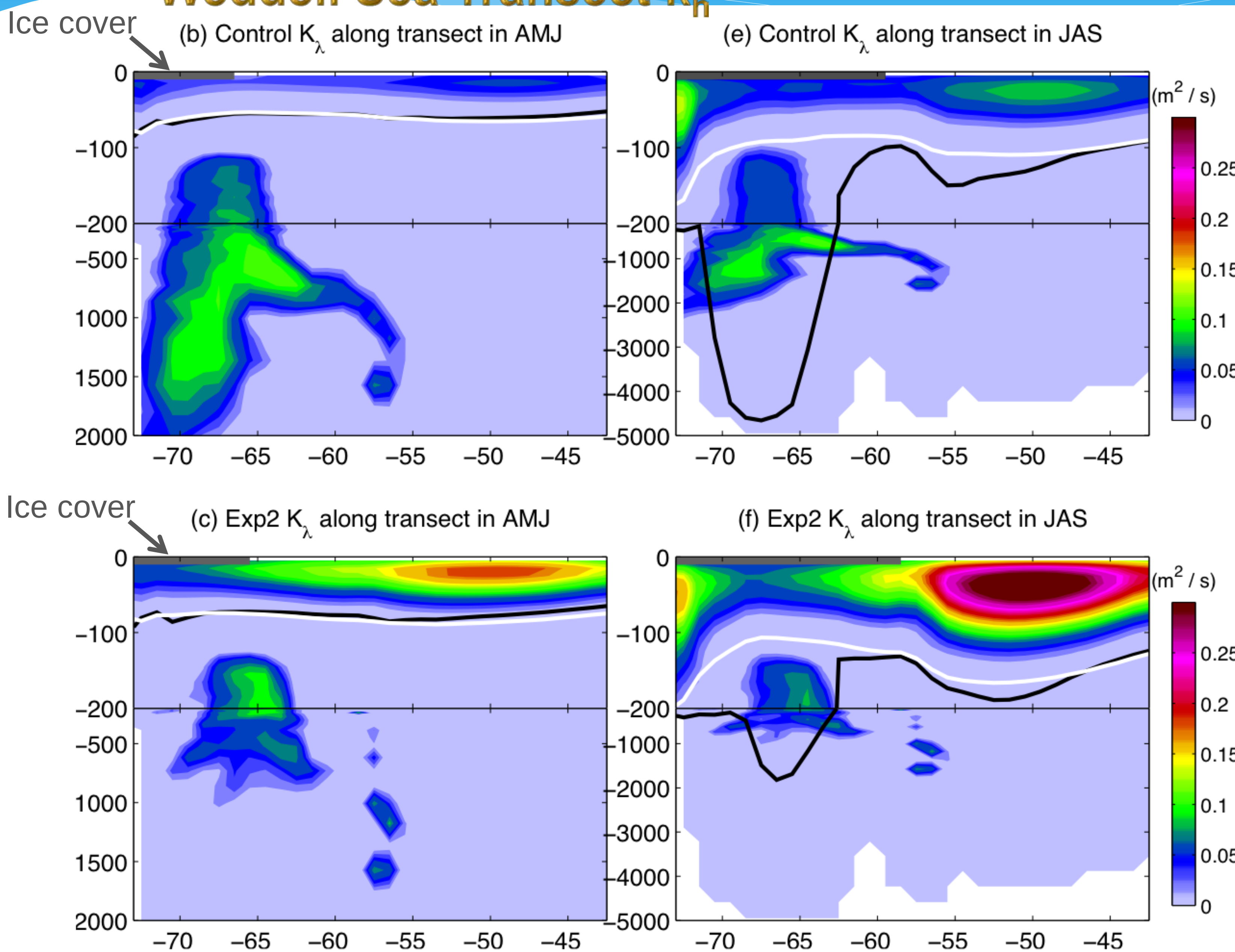
Fully Coupled Model simulations
– Weddell Sea Transect k_h



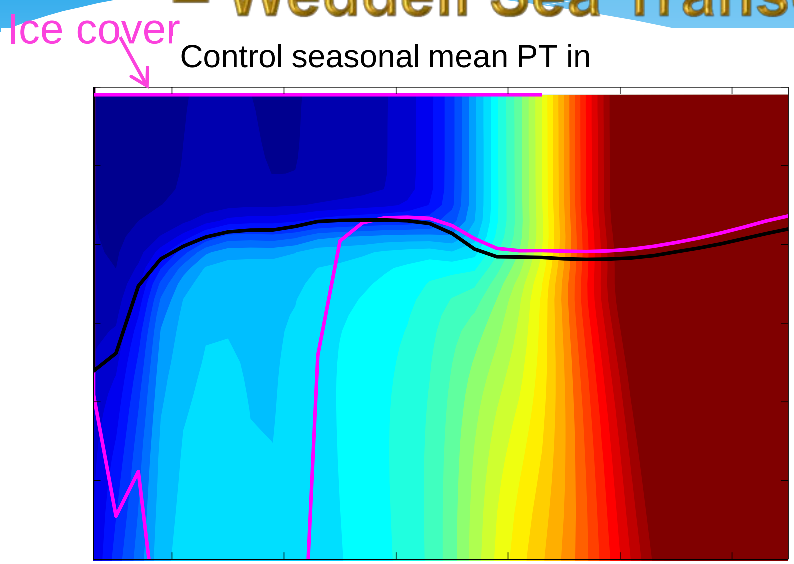
$$W = \frac{ku_*}{\phi} \cdot F_{lt}, \qquad F_{lt} = \left[1 + \frac{A_w}{La^{2\alpha}}\right]^{1/\alpha}$$

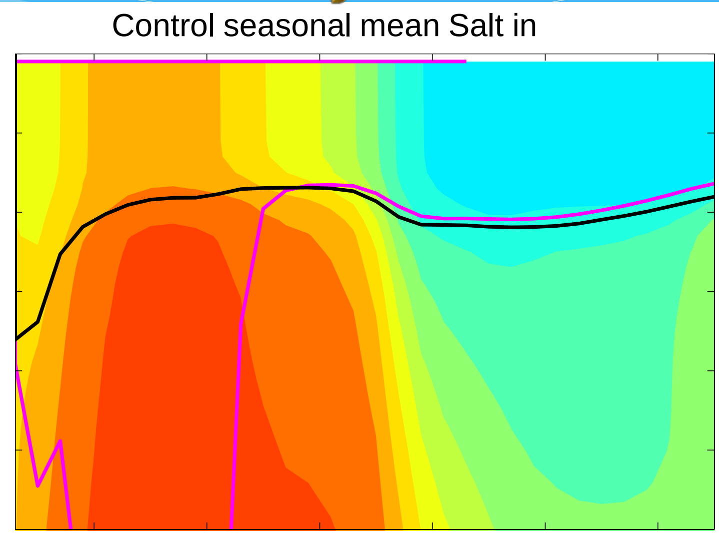
Fully Coupled Model simulations

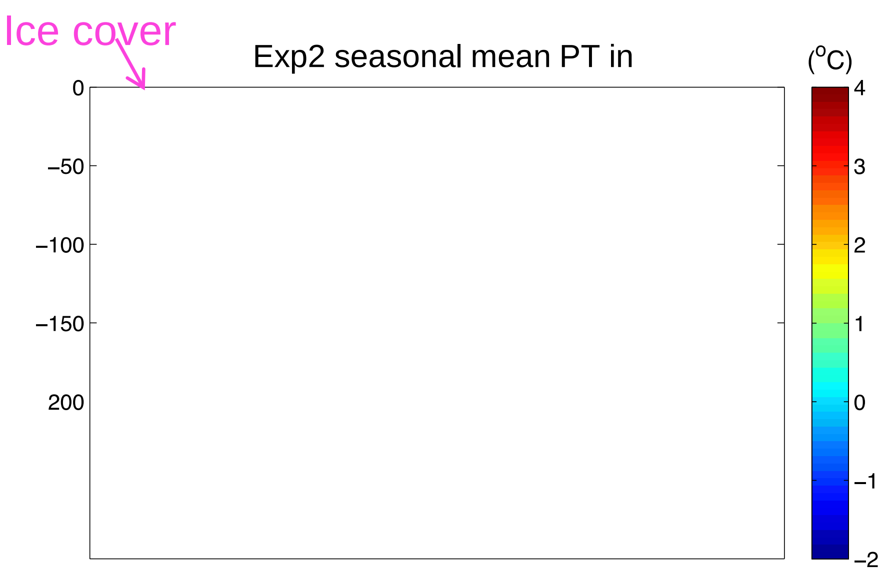
– Weddell Sea Transect k_h

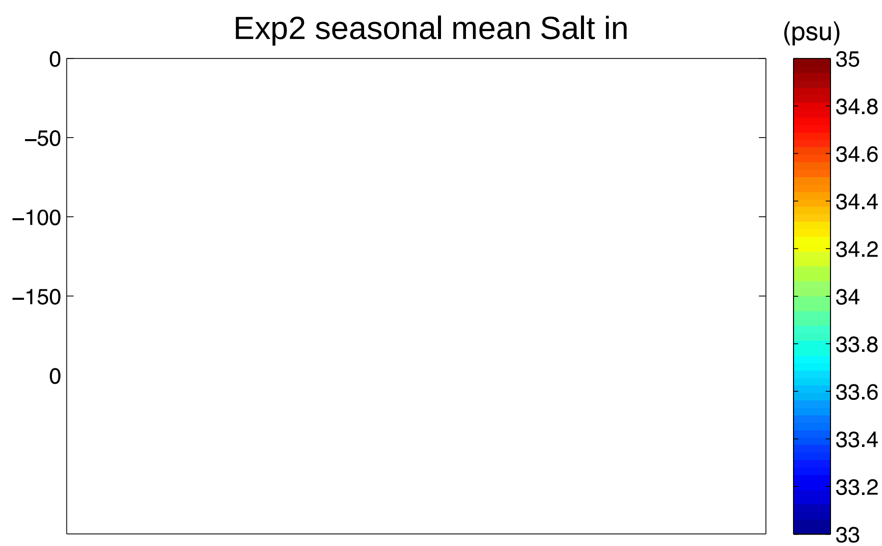


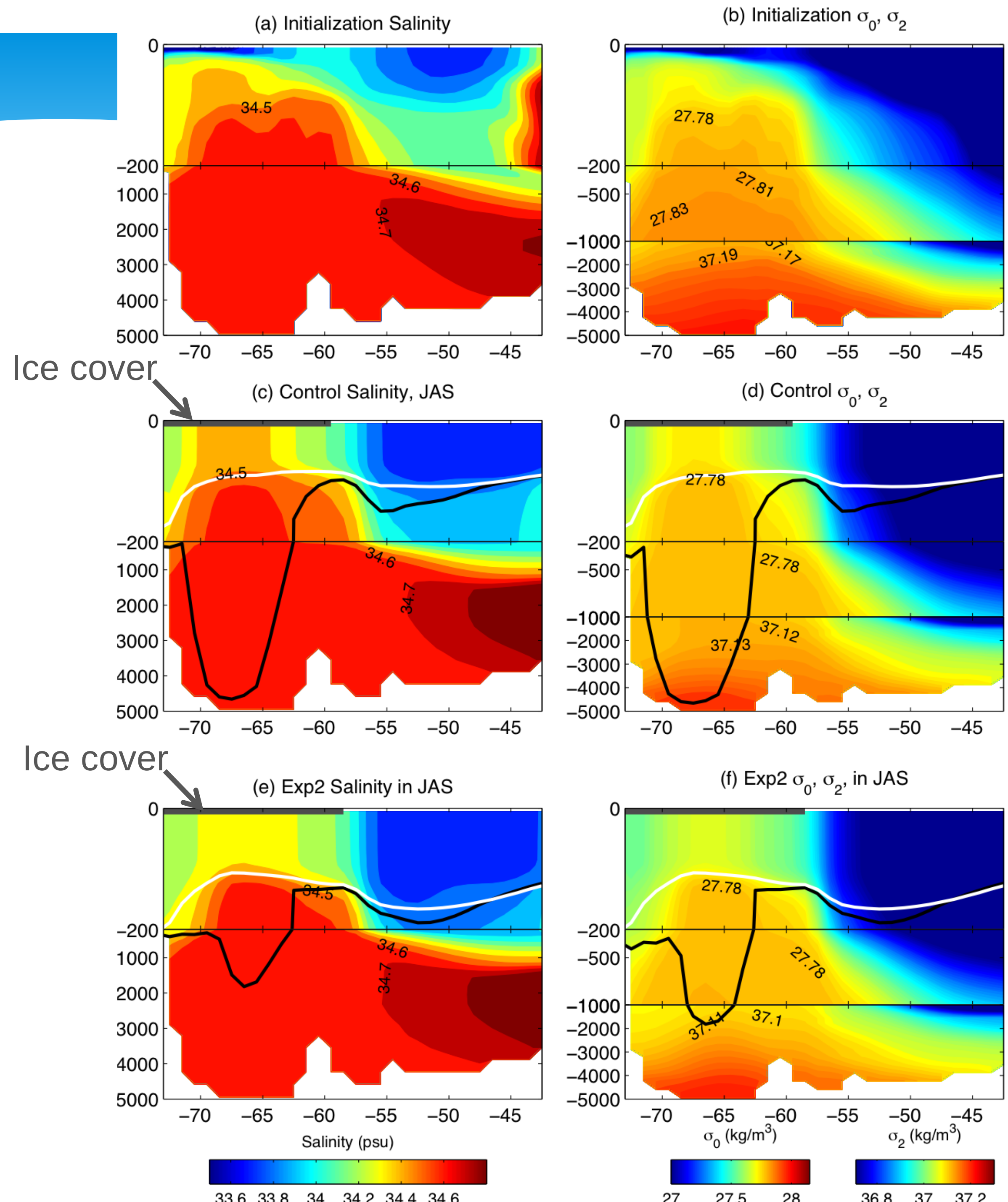
Fully Coupled Model simulations – Weddell Sea Transect θ_0 and Salinity











(a) Initialization Salinity
(b) Initialization σ_0, σ_2
Ice cover
(c) Control Salinity, JAS
(d) Control σ_0, σ_2
Ice cover
(e) Exp2 Salinity in JAS
(f) Exp2 σ_0, σ_2, in JAS
Salinity (psu)
σ_0 (kg/m^3)
σ_2 (kg/m^3)

Concluding Remarks

- Our understanding of surface wave effect in upper ocean turbulent mixing is still very limited. So far, the LES experiments are limited to small regions. LES experiments at representative locations through the whole globe are needed to derive a better parameterization for global models.

- What’s next …