Impact of atmospheric forcing on Antarctic shelf water masses

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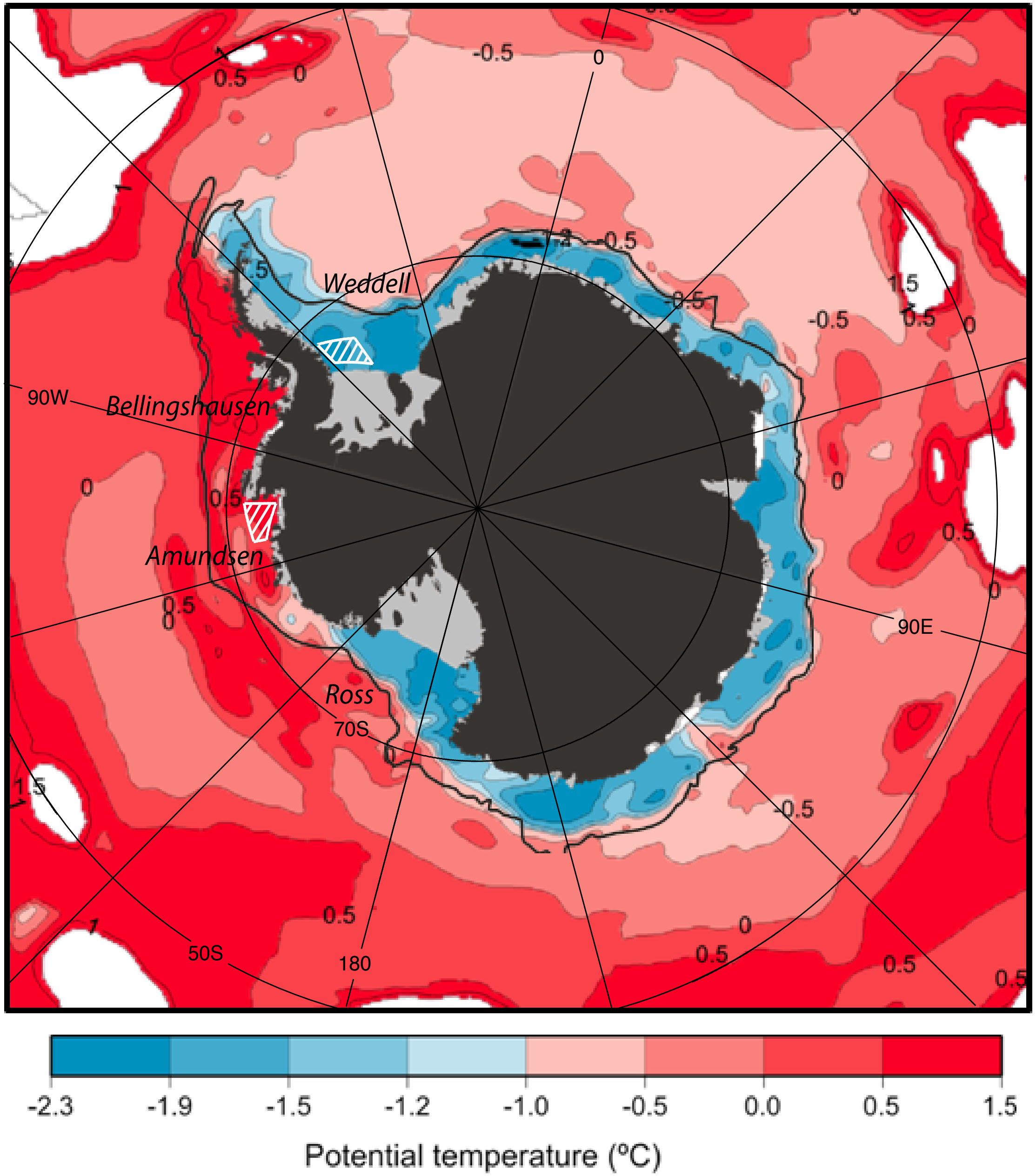
Petty et al., 2012 (SUBMITTED TO JGR)

1. COLD shelf waters in the WEDDELL and Ross.

2. WARM shelf waters in the AMUNDSEN and Bellingshausen.

Use the WEDDELL and AMUNDSEN seas as test cases.



Adapted from Orsi et al., 2005

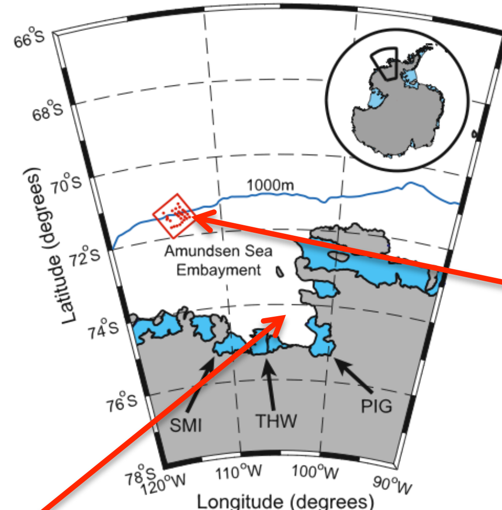
What data do we have for the two regions?

Amundsen Sea

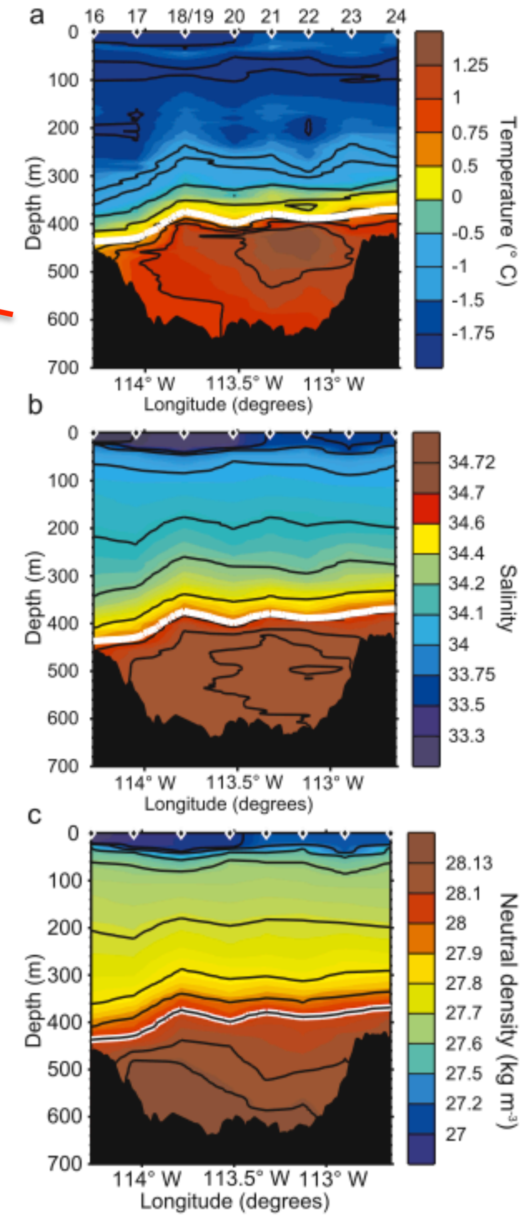
Data shows Amundsen shelf flooded with CDW right up to Pine Island Glacier.

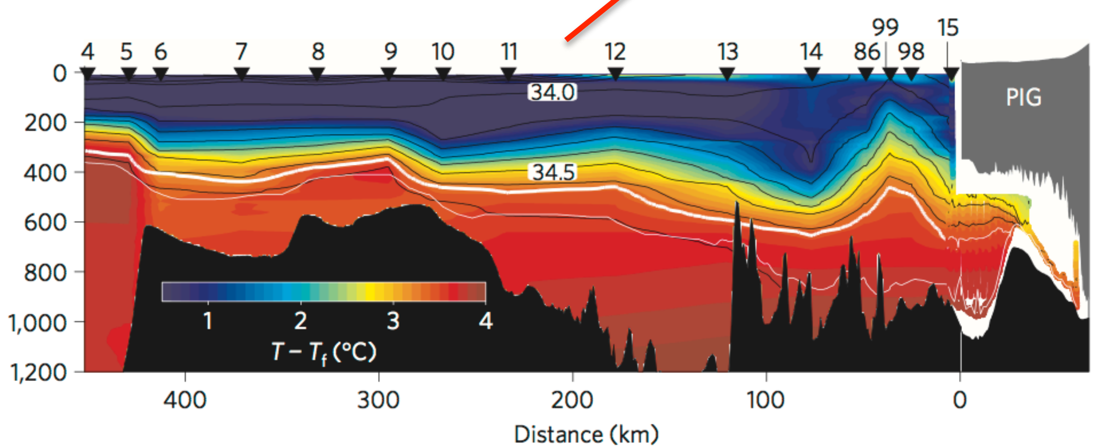
Implicated in THINNING of ice shelves from below.

Sparse data – no time series!



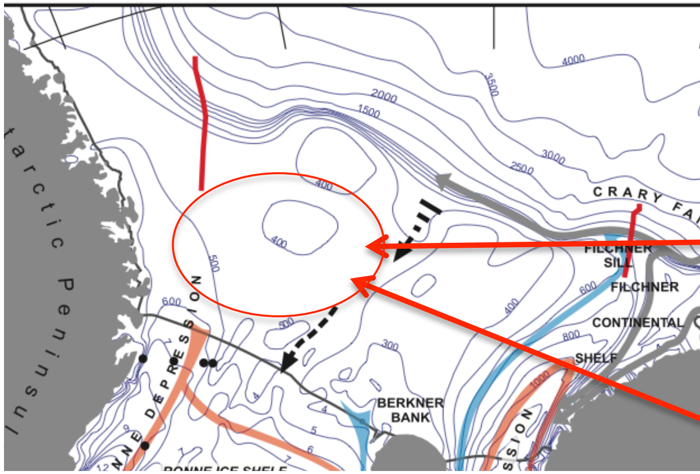
Map and data from March 2003 [Walker et al., 2007]



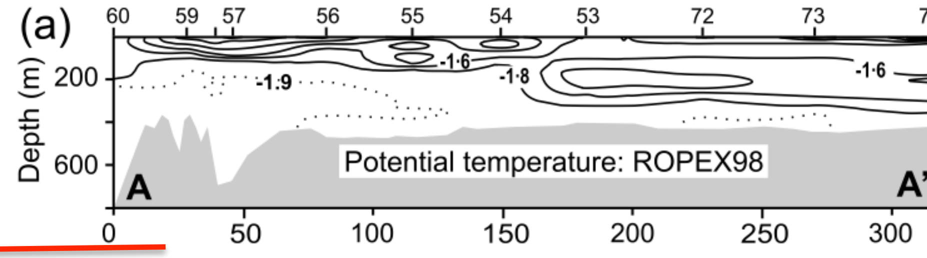


CTD Data (summer 2009) [Jacobs et al., 2011]

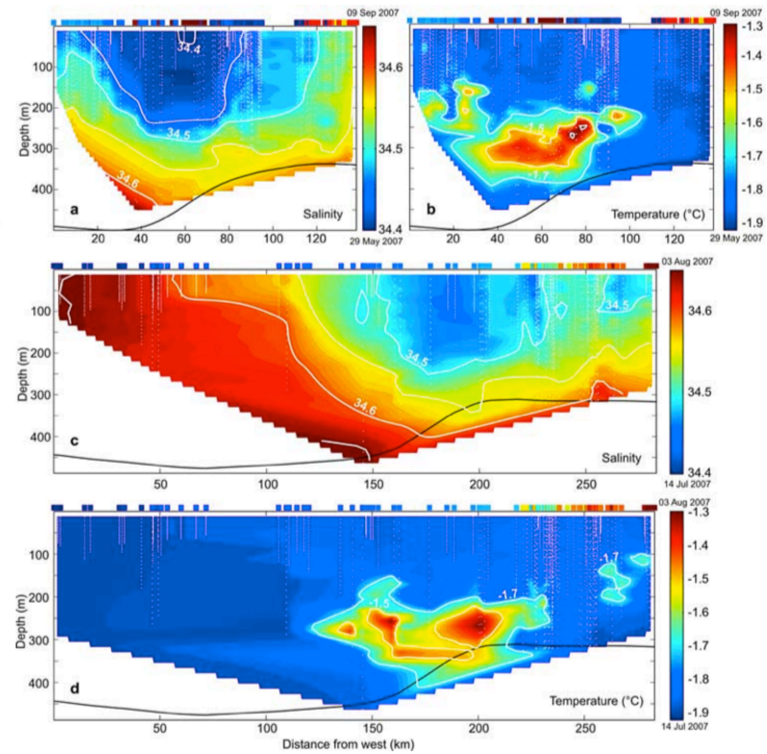
Weddell Sea



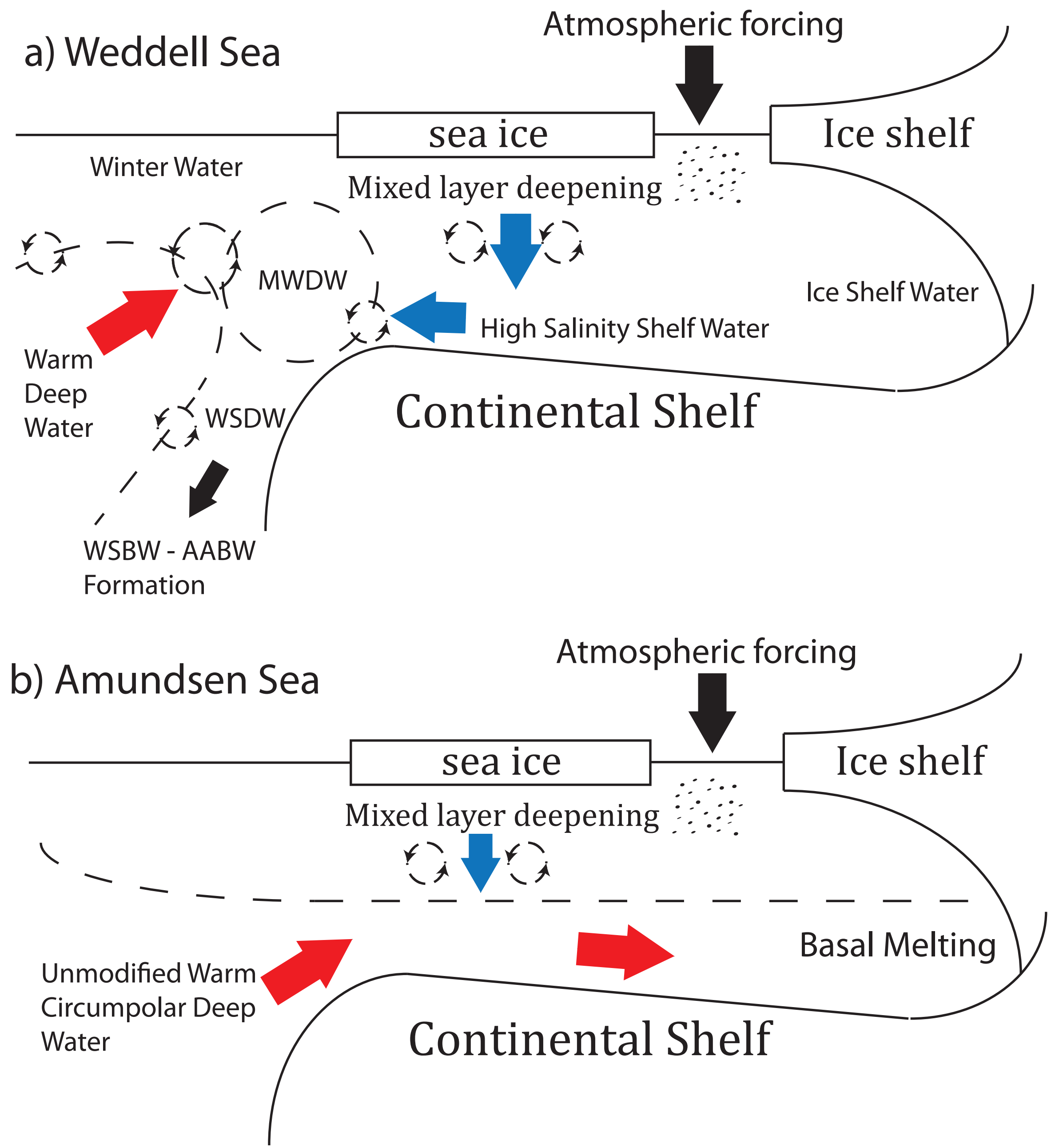
Taken from Nicholls et al. [2009]



ROPEX data (summer 1998) [Nicholls et al., 2003]



Seal-tagged data, (winter 2007) [Nicholls et al., 2008]



a) Weddell Sea
Atmospheric forcing
sea ice
Ice shelf
Winter Water
Mixed layer deepening
MWDW
Ice Shelf Water
High Salinity Shelf Water
Warm
Deep
Water
WSDW
Continental Shelf
WSBW - AABW
Formation
b) Amundsen Sea
Atmospheric forcing
sea ice
Ice shelf
Mixed layer deepening
Basal Melting
Unmodified Warm
Circumpolar Deep
Water
Continental Shelf

Scientific Question:

WHY THE BIMODAL DISTRIBUTION?!

Possible Reasons

DIRECT MECHANISMS

1. Regionally varying SURFACE FLUXES — PRIMARY FOCUS
   - atmosphere results in more/less sea ice production (and thus brine release).

2. Regionally … CEAN DYNAMICS
   - r … arm waters being tra… on-shelf.

FEEDBA…

3. Oce … CTING sea ic…
   - e.g … arm shelf water… n.

4. Sea ice production AFFECTING on-shelf tr…
   - e.g. der e she … aters preventing on-shelf transport of warm waters.

5. Warmer waters induce ice-shelf melt, suppressing mixing.

LET’S LOOK AT THE REANALYSIS DATA.

(and hope it shows a considerable regional difference…)

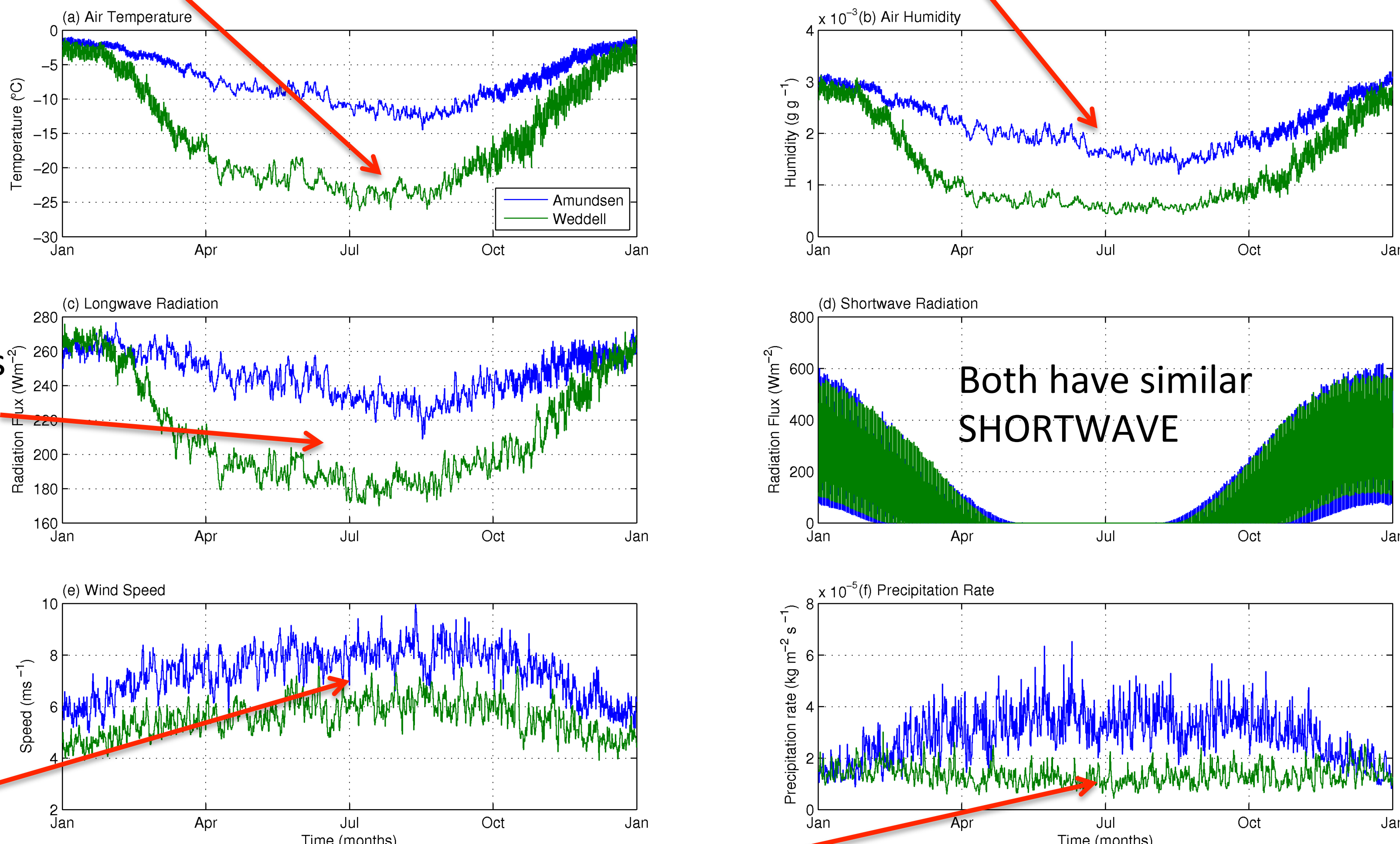
WEDDELL has ~10°C colder winter AIR TEMPERATURE

WEDDELL has ~0.001 drier winter HUMIDITY

WEDDELL has ~50 W/m² less winter LONGWAVE

Both have similar SHORTWAVE

AMUNDSEN has ~2 m/s higher WIND SPEED



AMUNDSEN has ~1.5 kg/m²/s more winter PRECIPITATION

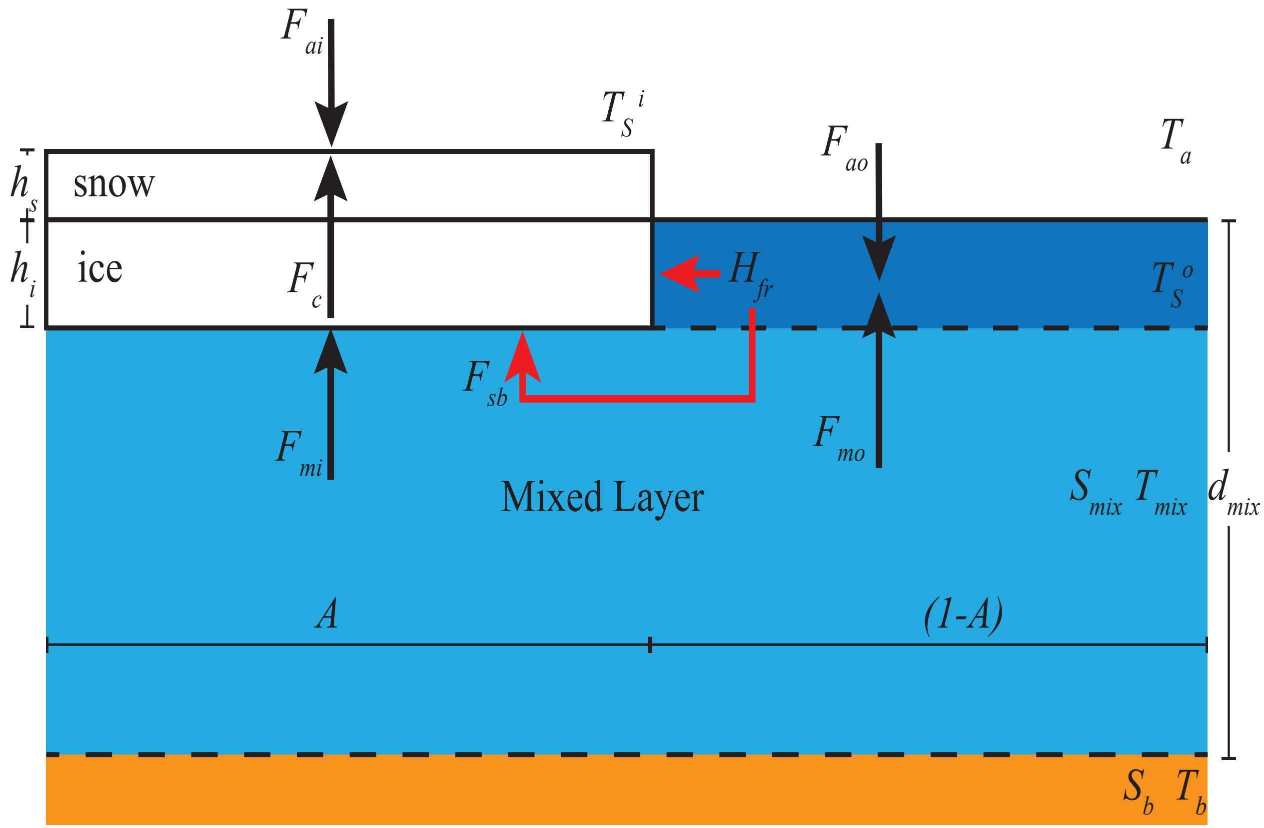
32 year [1979-2010] climatology, taken from NCEP CFSv1 reanalysis

WHAT CAN WE DO WITH THIS?..

USE IT TO FORCE A MODEL!

A Sea Ice-Mixed Layer Model

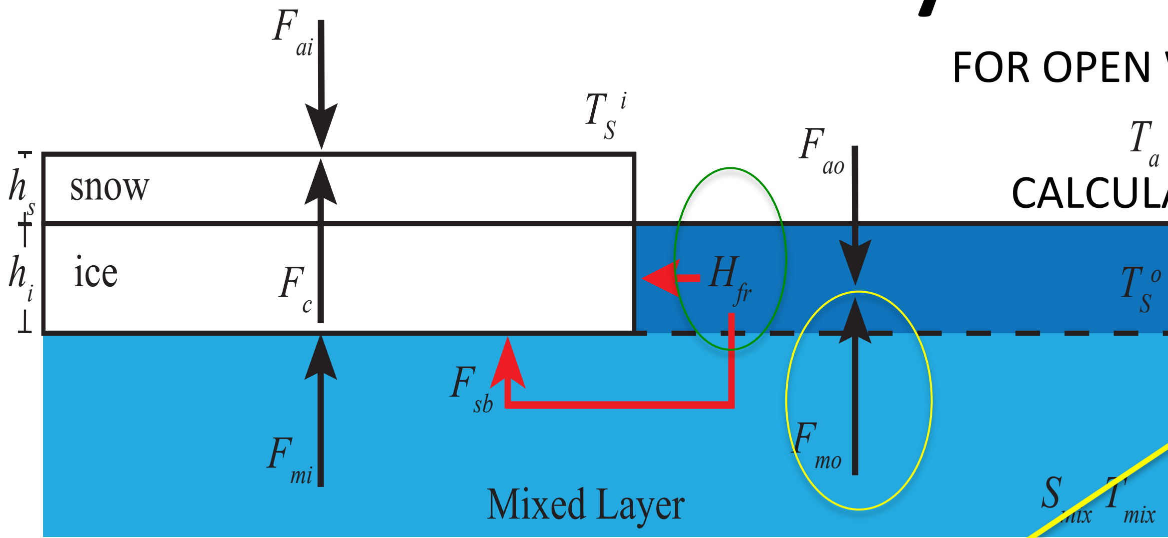
- Semtner (1976) 0-layer sea ice component.
- Kraus Turner 0D bulk mixed layer component.
- A prescribed ocean profile below the mixed layer.
- Parameters for:
  - ice divergence
  - ocean relaxation
- i.e. A VERY IDEALISED MODEL



Sea Ice Thermodynamics

FOR OPEN WATER FRACTION:

CALCULATE SURFACE TEMP



SURFACE HEAT POTENTIAL

MIXED LAYER TO OPEN WATER SURFACE HEAT FLUX

$$\boxed{H_{fr}} = \boxed{F_{mo}(T_S^o) - F_{mo}(T_f)} = K(T_f - T_S^o)$$

1. $T_s^o < T_f$, $A < A_{max}$:
   USE SURFACE HEAT TO GROW ICE LATERALLY

2. $T_s^o < T_f$, $A = A_{max}$:
   GROW SEA ICE LATERALLY BUT REDISTRIBUTE VERTICALLY

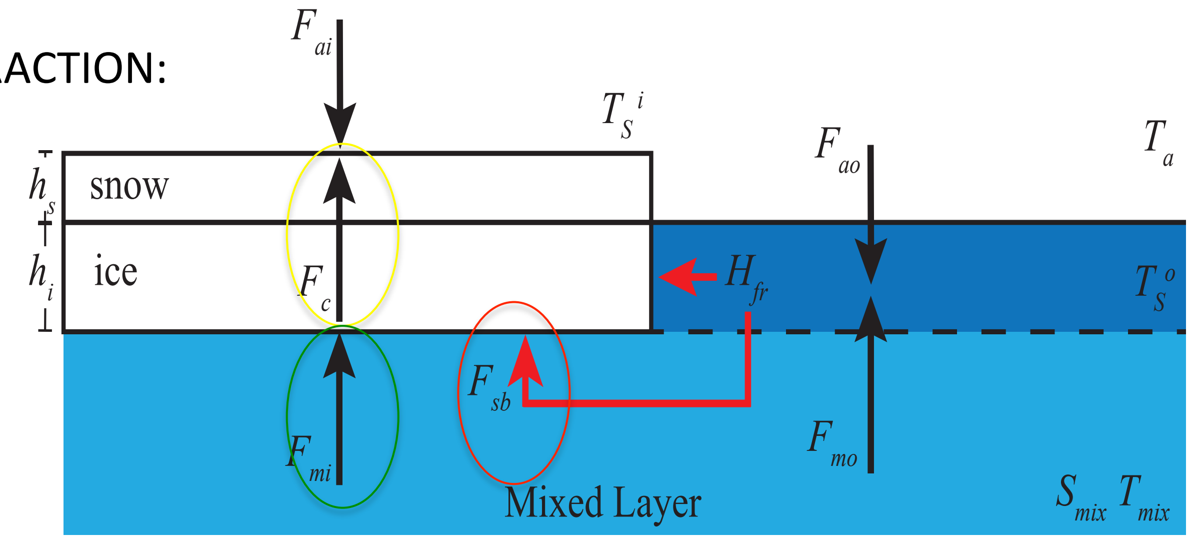
4. $T_s^o > T_f$, $A \neq 0$:
   USE FRACTION OF SURFACE HEAT TO MELT LATERALLY (REST FOR BASAL MELTING – NEXT SLIDE!)

3. $T_s^o > T_f$, $A = 0$:
   HEAT THE MIXED LAYER

Sea Ice Thermodynamics

FOR SEA ICE FRACTION:

CALCULATE SURFACE TEMP



BALANCE FLUXES AT BASE OF SEA ICE…

$$dh_i/dt = K(\boxed{F_c} - \boxed{F_{mi}} - \boxed{F_{sb}})$$

CONDUCTIVE HEAT FLUX THROUGH THE SEA ICE

HEAT FLUX FROM MIXED LAYER TO SEA ICE

SURFACE HEAT PARTITIONED FOR BASAL MELTING

Mixed Layer Entrainment

ENERGY REQUIRED TO ENTRAIN DENSE WATER FROM BELOW

ENERGY SINK FROM MIXED LAYER TURBULENCE

$$P_E = P_w + P_B - P_m$$

ENERGY INPUT TO THE MIXED LAYER FROM WIND STIRRING

ENERGY INPUT TO THE MIXED LAYER FROM BUOYANCY FLUXES

Rearranging the above gives the mixed layer entrainment rate…

$$w = \frac{dd_{mix}}{dt} = \frac{1}{\boxed{d_{mix}\Delta b} + \boxed{c_m^2}}\left[\boxed{c_1 u_\star^3} + \boxed{c_2 d_{mix} B_0}\right]$$

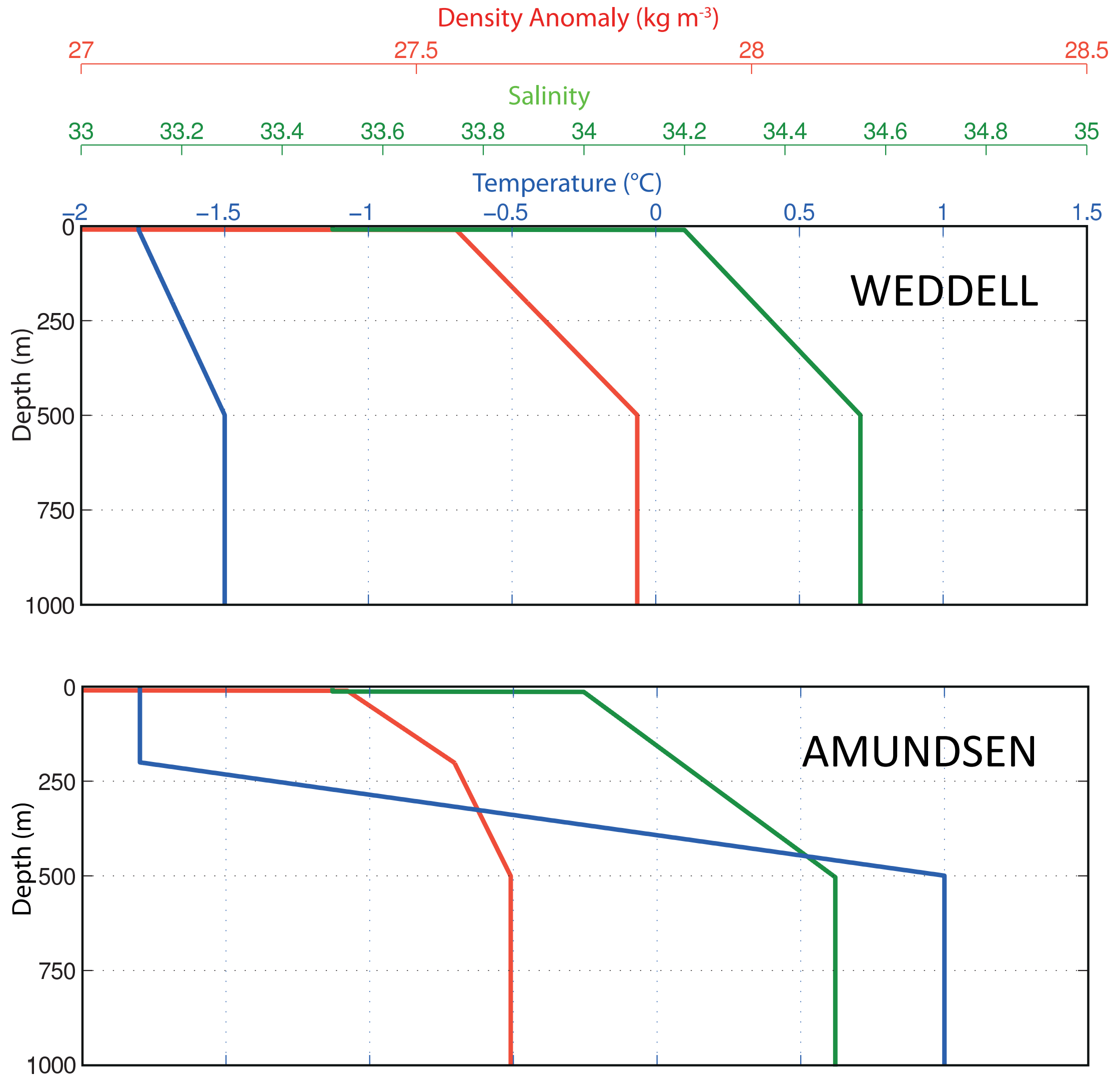
Idealised Ocean Profiles

Initialise with SUMMER (Jan) ocean profiles

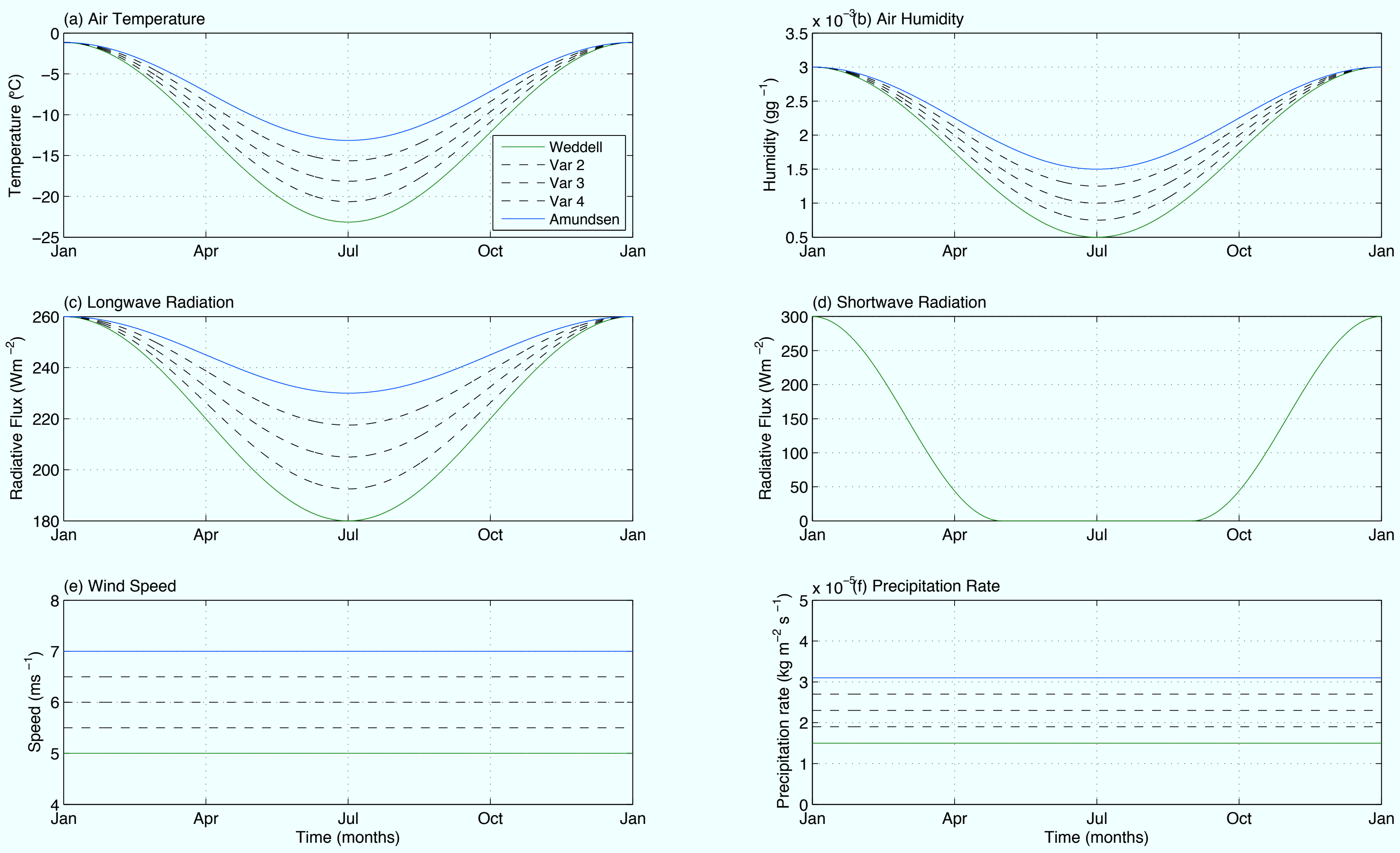
Use profile resembling the ocean properties around the shelf break.

Weddell Sea
 - MWDW (~ -1.5°C) intrusions.
 - Not HSSW

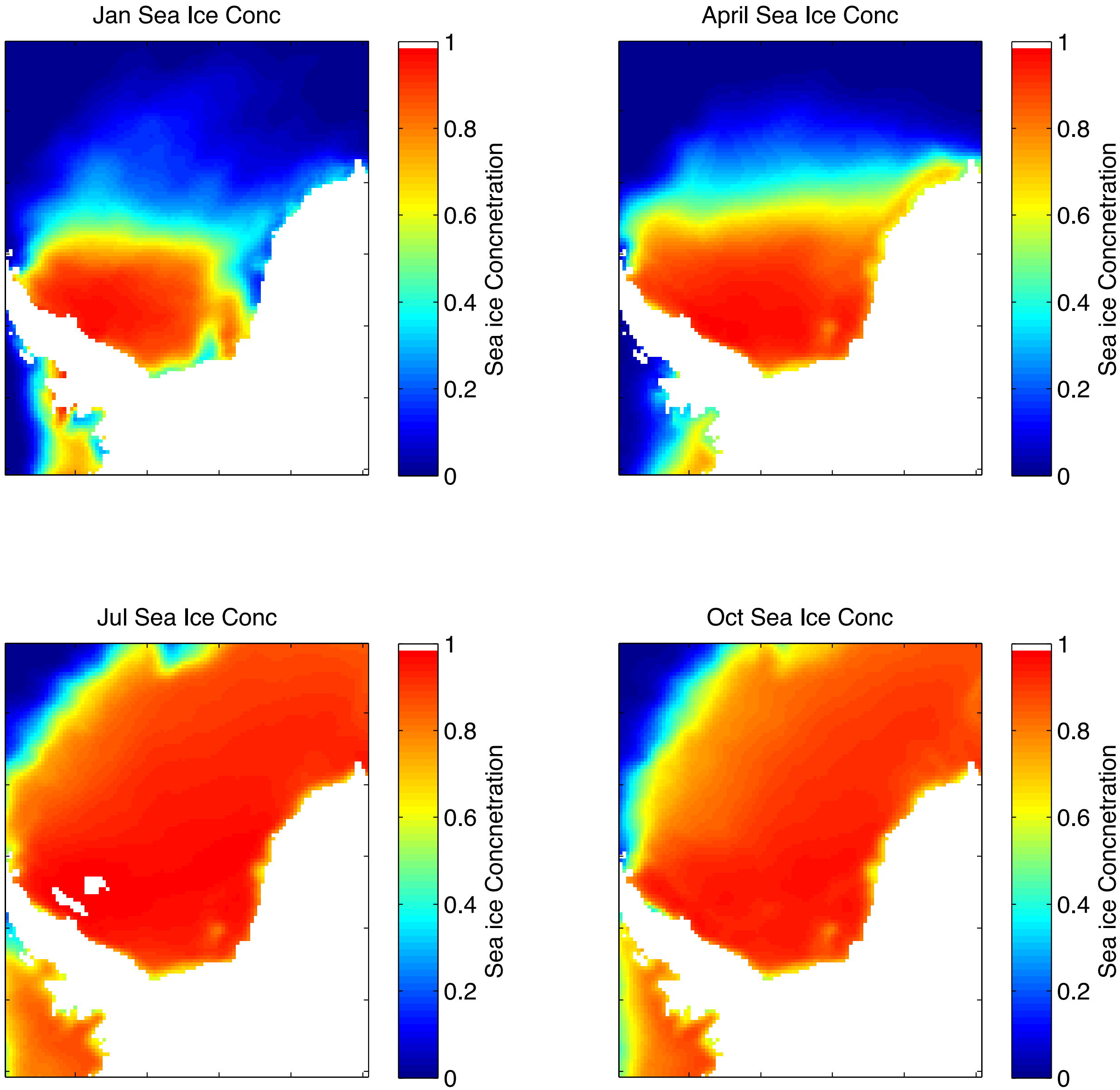
AMUNDSEN SEA
 - CDW (~1°C) below Winter Water



Idealised Atmospheric Forcing Data

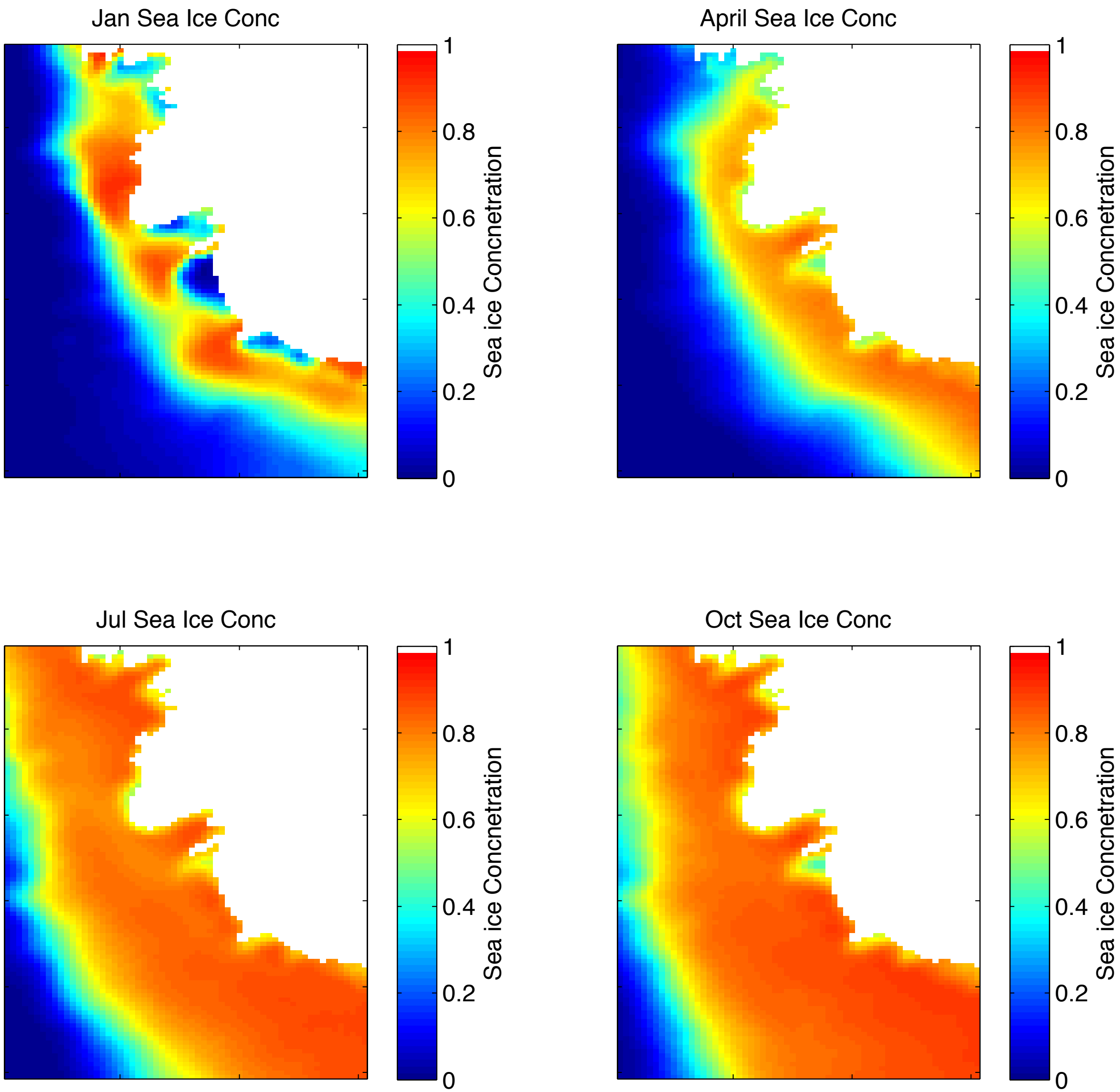


Weddell Sea



Comiso, 1999, updated 2012.

Amundsen Sea



Comiso, 1999, updated 2012.

One Year Results

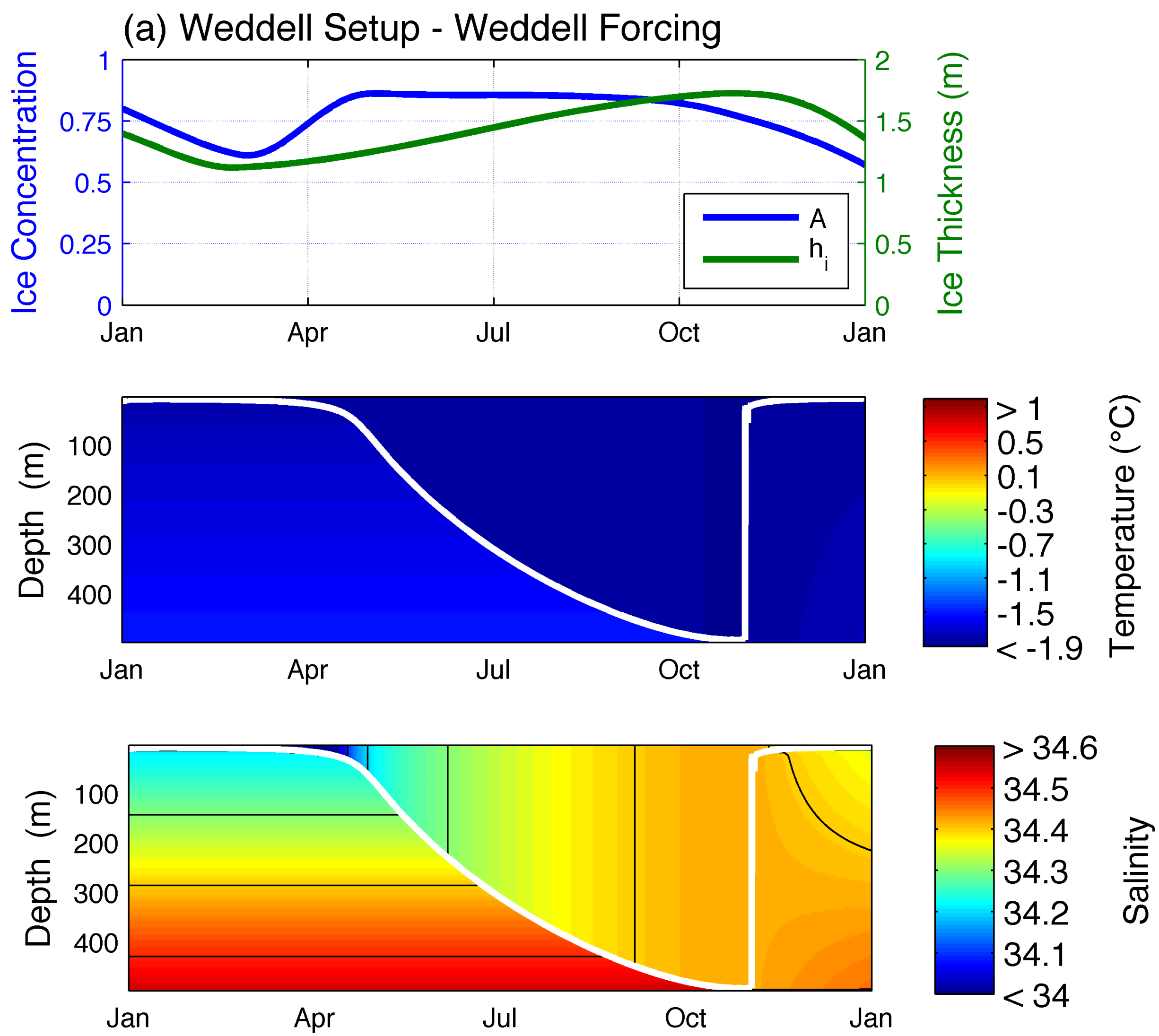
Initial Conditions/ Parameters for Weddell Simulations:

Mixed Layer Depth: 10m
Mixed Layer Salinity: 33.5
Mixed Layer Temp: -1.8°C

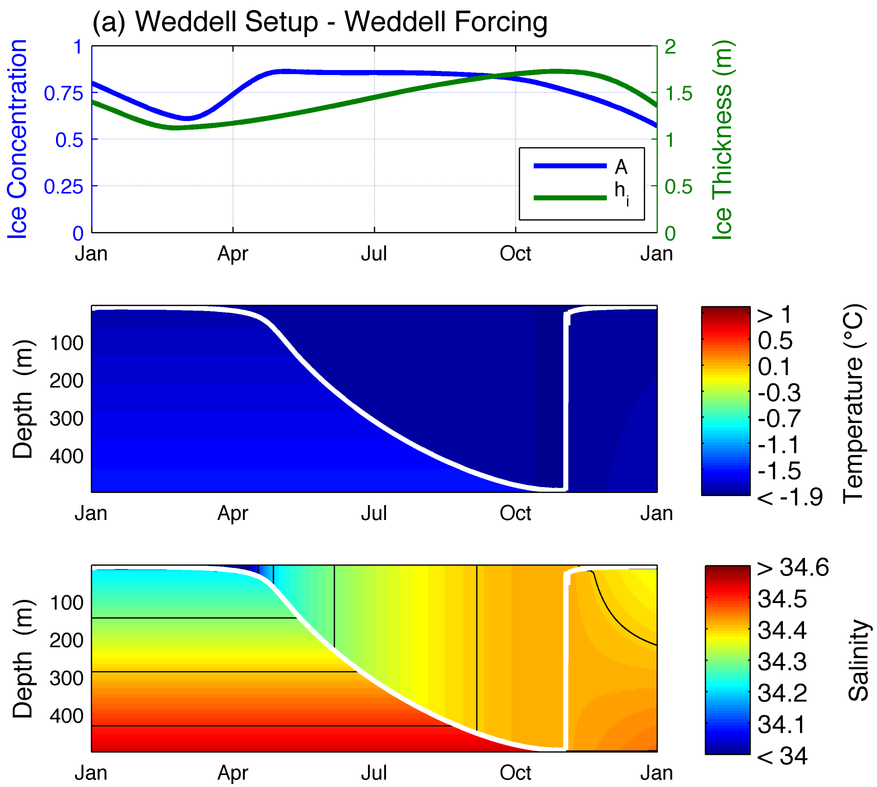
Ice Thickness : 1.4 m
Ice Concentration: 0.8
Snow Thickness: 30 cm

Divergence Rate: 1 year^{-1}
Ocean Relaxation: 0.5 year^{-1}

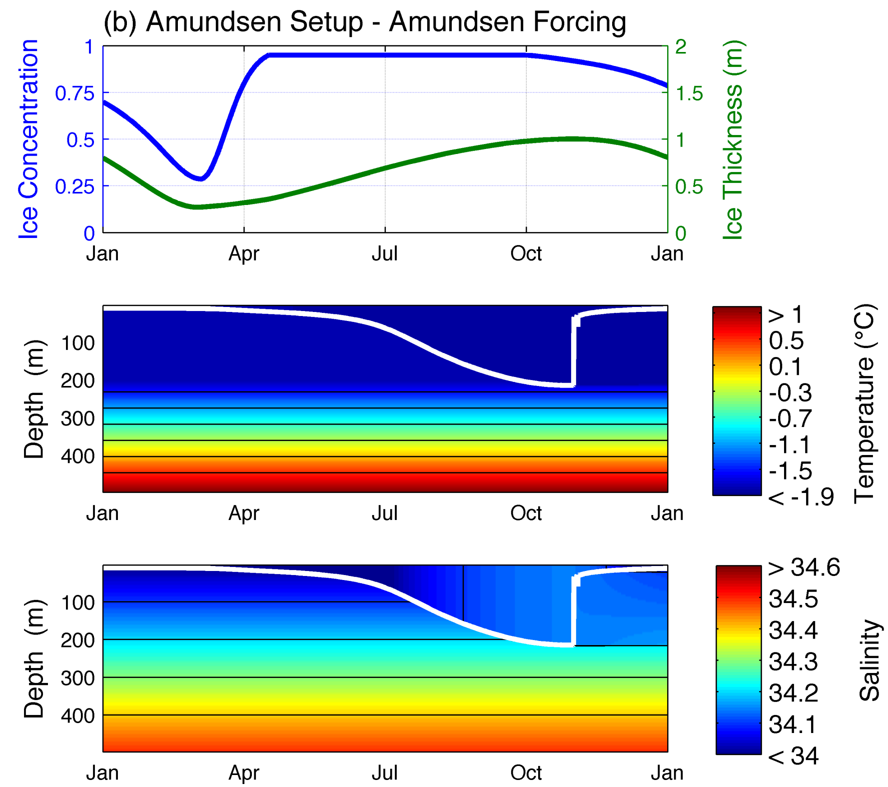
Basal Melt Fraction: 0.75



Weddell



Amundsen

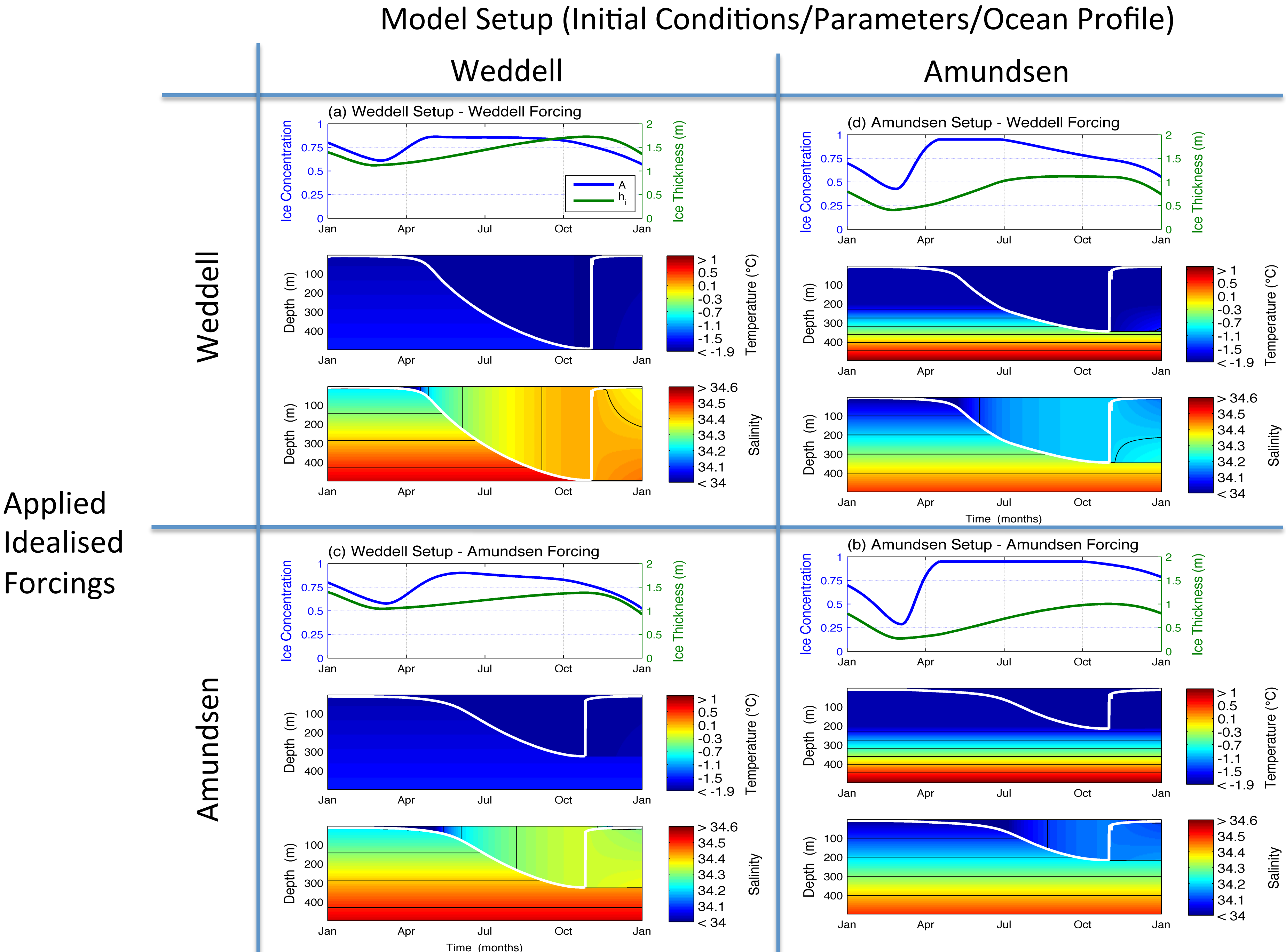


Different Amundsen Initial Conditions/ Parameters:

Ice Thickness : 0.8 m
Ice Concentration: 0.7
Snow Thickness: 20 cm

What happens when we switch the forcings around?

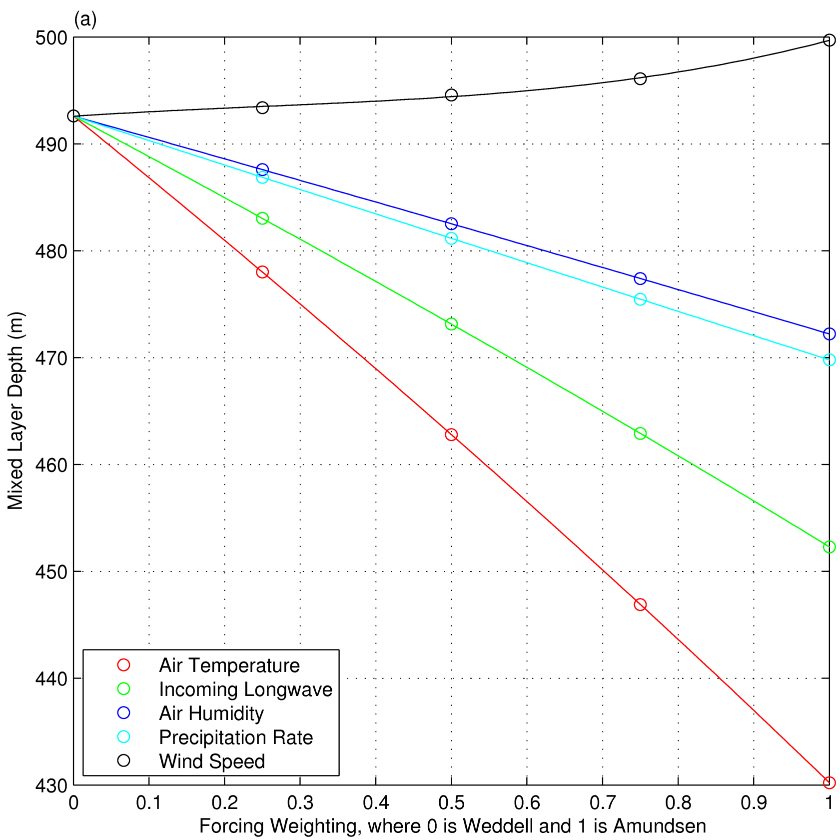
THE BIG TEST



Model Setup (Initial Conditions/Parameters/Ocean Profile)
Weddell
Amundsen
Applied Idealised Forcings
(a) Weddell Setup - Weddell Forcing
(d) Amundsen Setup - Weddell Forcing
(c) Weddell Setup - Amundsen Forcing
(b) Amundsen Setup - Amundsen Forcing
Ice Concentration
Ice Thickness (m)
A
h_i
Depth (m)
Temperature (°C)
Salinity
Time (months)
Jan
Apr
Jul
Oct
> 1
0.5
0.1
-0.3
-0.7
-1.1
-1.5
< -1.9
> 34.6
34.5
34.4
34.3
34.2
34.1
< 34

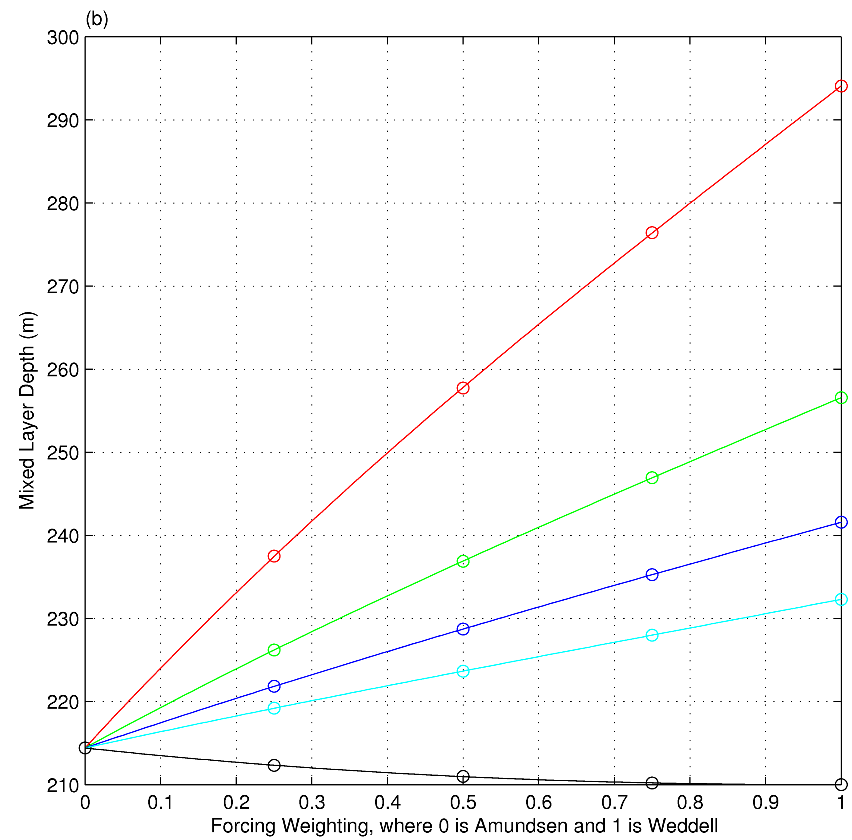
Forcing Sensitivity Study

Weddell



Weddell – Amundsen Forcing

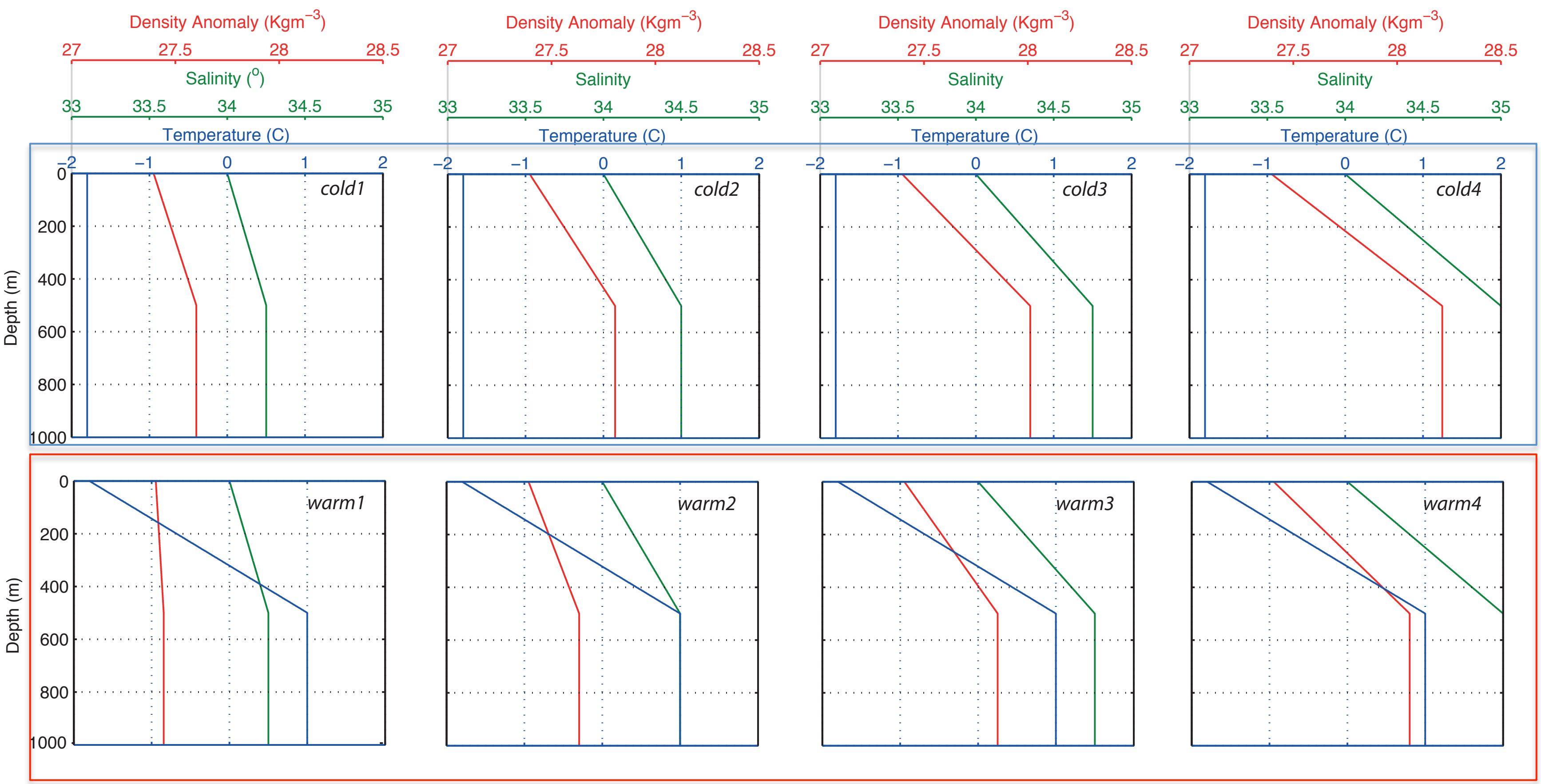
Amundsen



Amundsen – Weddell Forcing

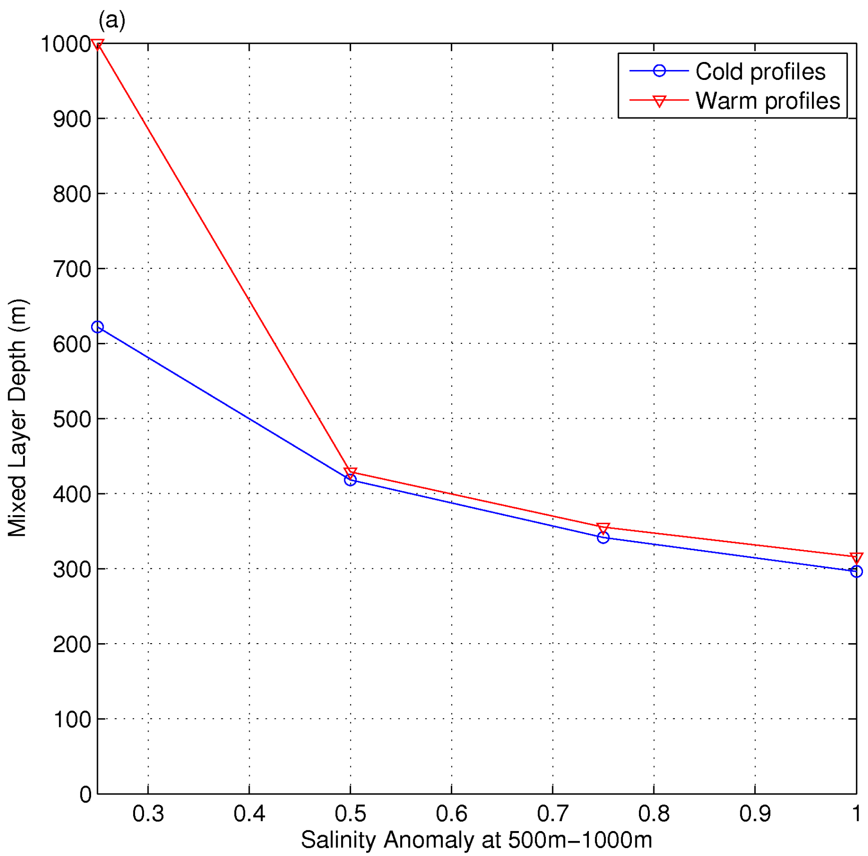
Ocean Profile Study

Initial Profiles used

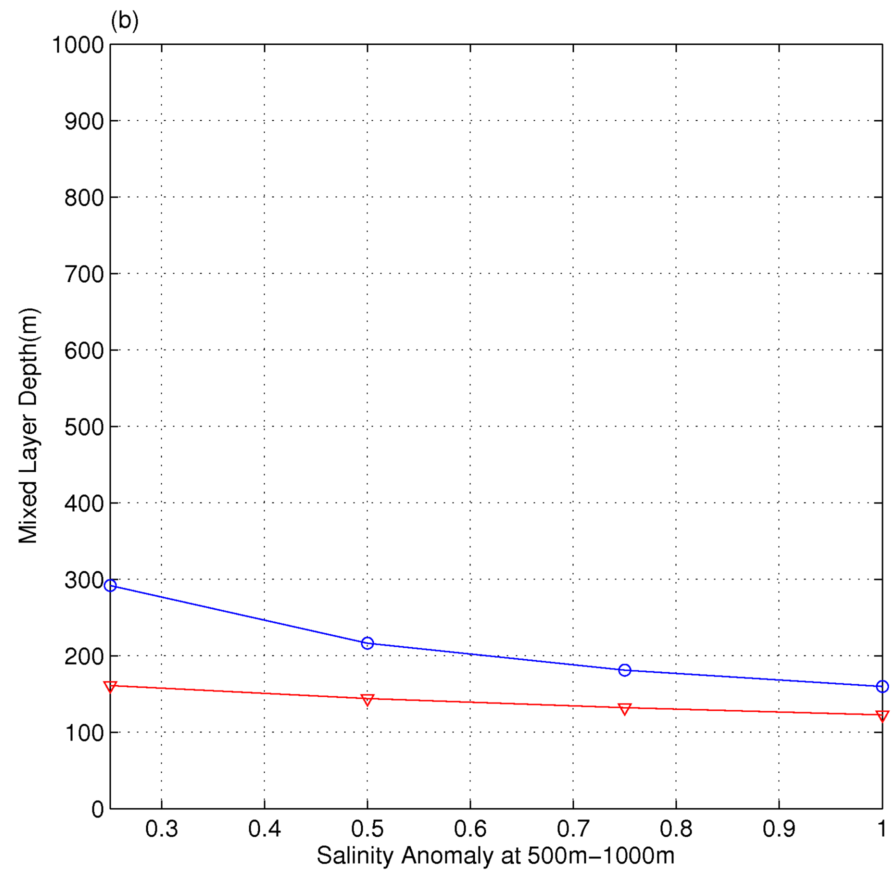


Ocean Profile Study Results

Weddell



Amundsen



Salinity Anomaly at 500m-1000m

Salinity Anomaly at 500m-1000m

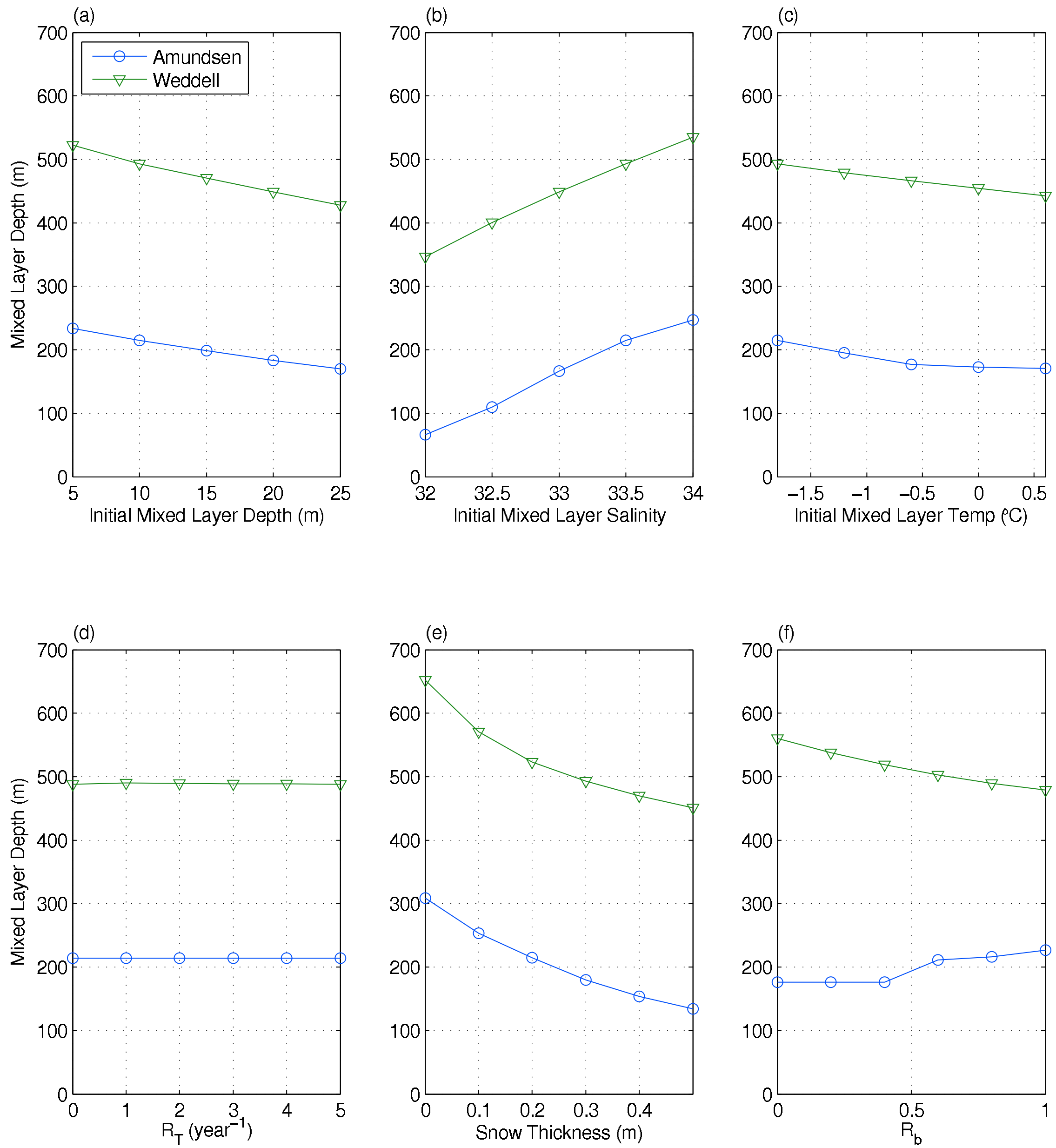
Model Parameter Sensitivities

Initial Mixed Layer Depth/Salinity/ Temperature
-Some Sensitivity

Ocean Relaxation
- No Significant Sensitivity

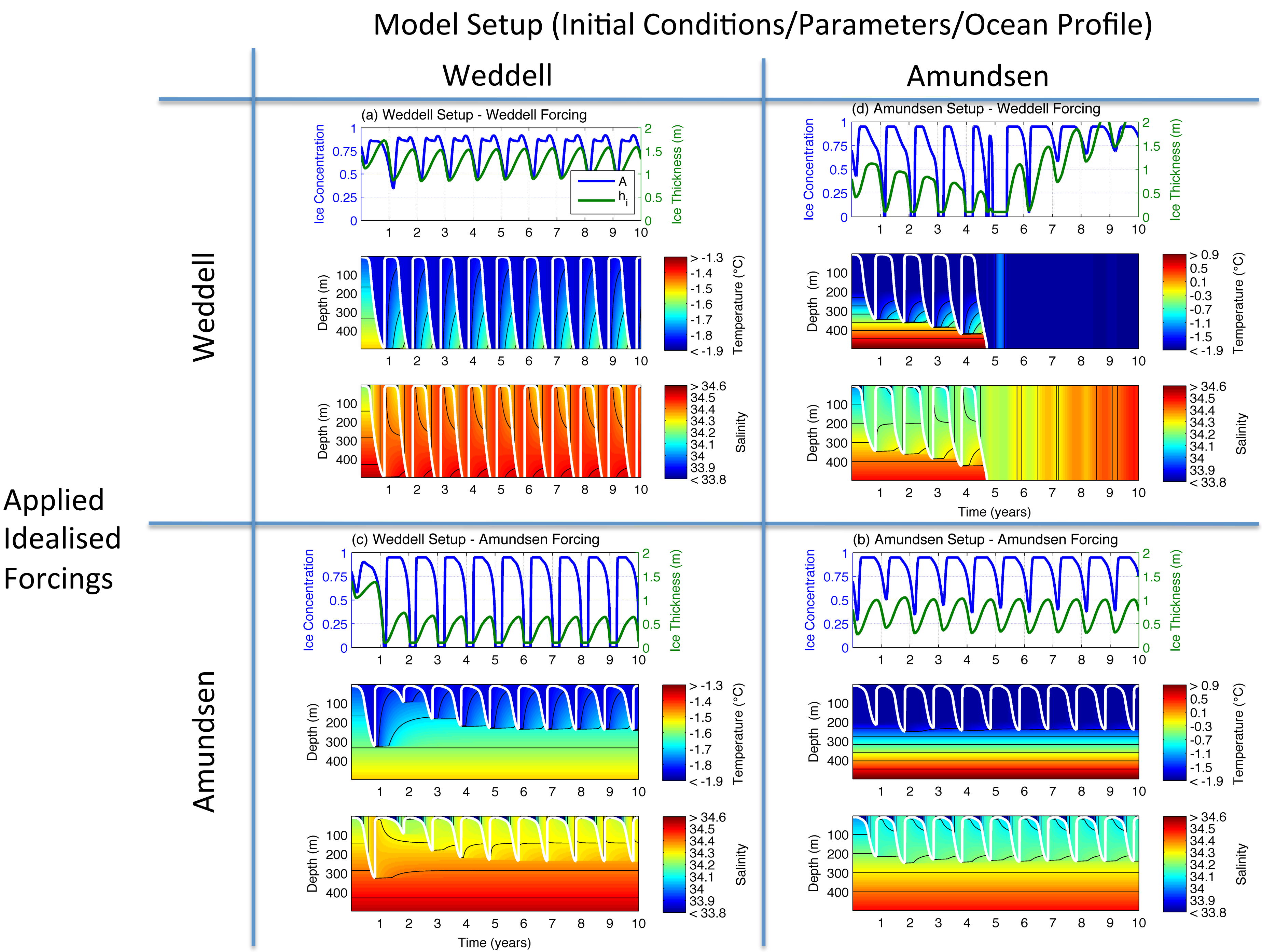
Snow Thickness
- Considerable Sensitivity

Basal Melt Fraction
-Slight Sensitivity



Can the model produce reasonable multi-year simulations?

What happens to the switched forcing simulations?



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Ice Concentration
Ice Thickness (m)
A
h_i
Depth (m)
Temperature (°C)
Salinity
> -1.3
-1.4
-1.5
-1.6
-1.7
-1.8
< -1.9
> 0.9
0.5
0.1
-0.3
-0.7
-1.1
-1.5
< -1.9
> 34.6
34.5
34.4
34.3
34.2
34.1
34
33.9
< 33.8
Time (years)

Conclusions

Model produces REASONABLE one-year and multi-year simulations.

Differences in atmospheric forcings are SUFFICIENT to explain bimodal distribution in shelf-sea temperature.

AIR TEMPERATURE generates biggest response, but other forcings important.

Sensitivity studies show initial SUMMER conditions are important. One year does not tell the whole story!

Amundsen trend towards WARMER heat content could reduce mixed layer depth, invoking a POSITIVE feedback.

PhD Done?

Unfortunately not..

Next stage?

Use CICE to more accurately represent the buoyancy fluxes into the mixed layer.

Cant wait!

Thanks for listening.

Any questions?

Surface Fluxes

1. Apply forcing and calculate a SURFACE TEMPERATURE for the ice/ocean fractions.
2. Grow/melt SEA ICE accordingly.
3. Calculate the SALT/ HEAT fluxes into the mixed layer.
4. Use this to drive mixed layer ENTRAINMENT