Testing Ocean Models with Argon and Nitrogen

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Introduction:

Observations of ocean inert gas concentrations have been used to improve understanding of surface ocean oxygen cycling (Spitzer and Jenkins, 1989; Emerson et al. 1995) and gas exchange (Schudlich and Emerson, 1996; Hamme and Emerson, 2002). The interior distribution of these gases provide information about the fidelity of ocean model circulations and biogeochemically-important processes such as air-sea gas exchange and deep water formation. Key strengths of these tracers are that they are not complicated by variable atmospheric concentrations or biological processes.

I investigate this potential with results from two global ocean model simulations with Ar and N_2 by comparison to in-situ observations at that BATS and HOT ocean timeseries stations (Hamme and Emerson, 2002; R. Hamme, personal communication, 2004). I find clear model-data differences in the water column. There is sufficient information in the model - data and model-model differences to allow determination of the key processes.

What can inert gases tell us?

- Since there are no interior sources or sinks, inert gases primarily track processes occuring when deep waters are formed. Diffusion of heat can also impact saturations.
- Injection of small bubbles promotes oversaturation. This process has a stronger effect for less soluble gases. (Hamme and Emerson, 2002)
- Undersaturation can occur due to rapid coolling and deep water formation.
- Diffusion of heat promotes oversaturation due to the nonlinear saturation relationship with temperature. (Henning et al., 2004)
- Melting of glaciers (Hohmann et al. 2003) and sea ice formation / melting (Hood et al. 1998) can also impact inert gases . Hamme and Emerson (2002) show these processes to have a small impact on observations at BATS and HOT.

Ocean Model:

Modular Ocean Model, version 4 (GFDL Flexible Modeling System)

- **OM1:** Coarse version
    - Resolution: 4.5 x 3.75, 24 vertical levels (dz = 25m in first two layers)
    - Kv = 0.3 m^2/s, Ai = 1000 m^2/s, Inflection point in Bryan - Lewis profile at 2000m
    - 300 year spin-up, 1100 year run with tracers
    - Sea ice climatology (OCMIP2) to inhibit air-sea flux
- **OM1p5:** Increased resolution, diffusion parameters adjusted
    - Resolution: 3.0 x 0.6-3.0, 28 vertical levels (dz =10m from 0 to 80m)
    - Kv = 0.45 m^2/s, Ai = 600 m^2/s, Inflection point in Bryan - Lewis profile at 2500m
    - 200 year spin-up, 1100 year run with tracers
    - Sea ice model coupled in physical modules, sea ice climatology to inhibit air-sea fluxes
    - Penetration of shortwave radiation up to 150m as a function of prescribed chlorophyll
- Meridional overturning of 15-17 Sv NADW and 5-10 Sv ABW
    - NADW is consistent with Ganachaud and Wunsch (2000) while ABW is an underestimate.
- Air-sea exchange following Wanninkhof (1992) (without supersaturation due to bubble injection)
- Climatological forcing (NCEP)

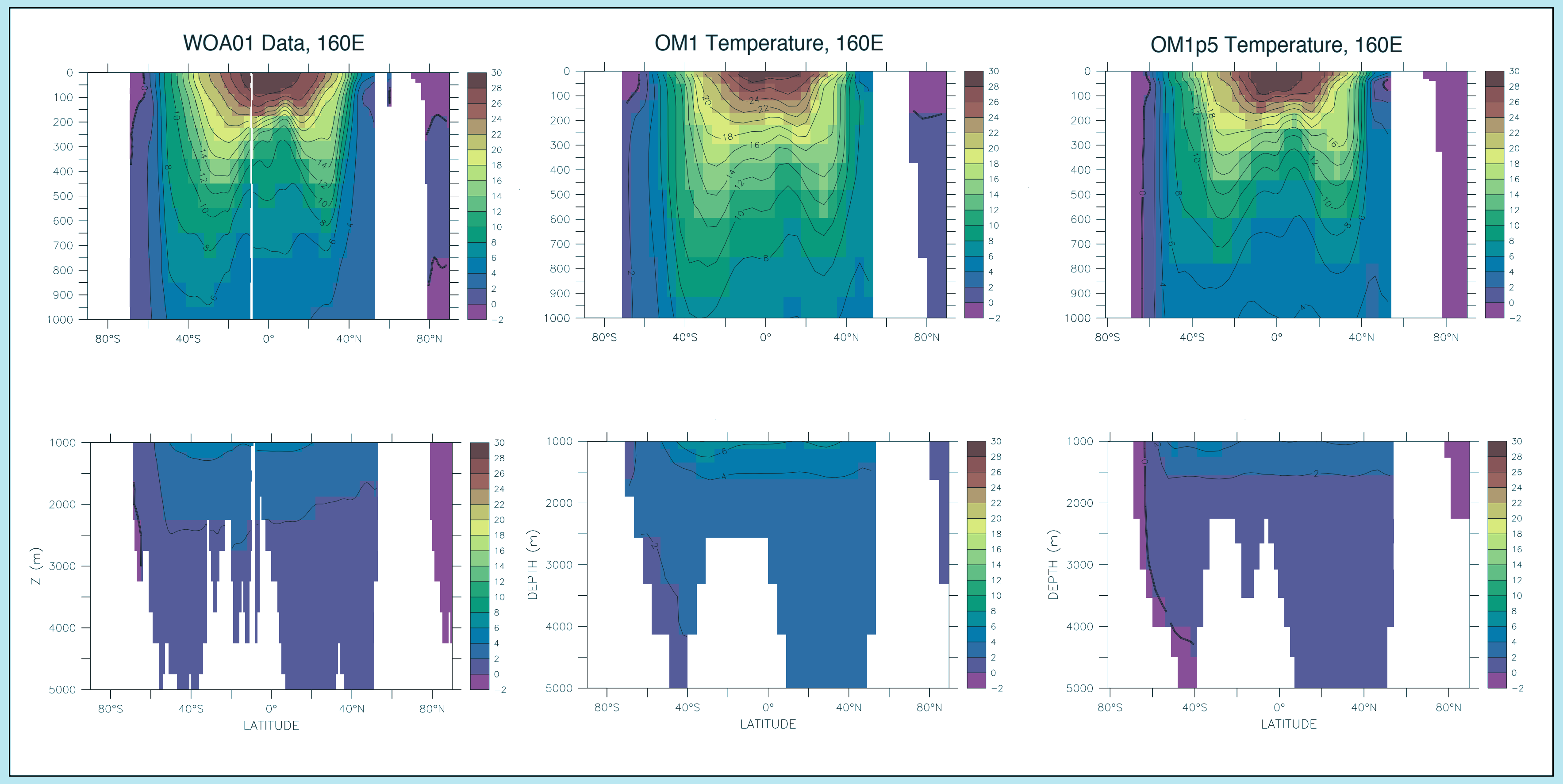

Figure 1: Temperature sections: observations, OM1, OM1p5

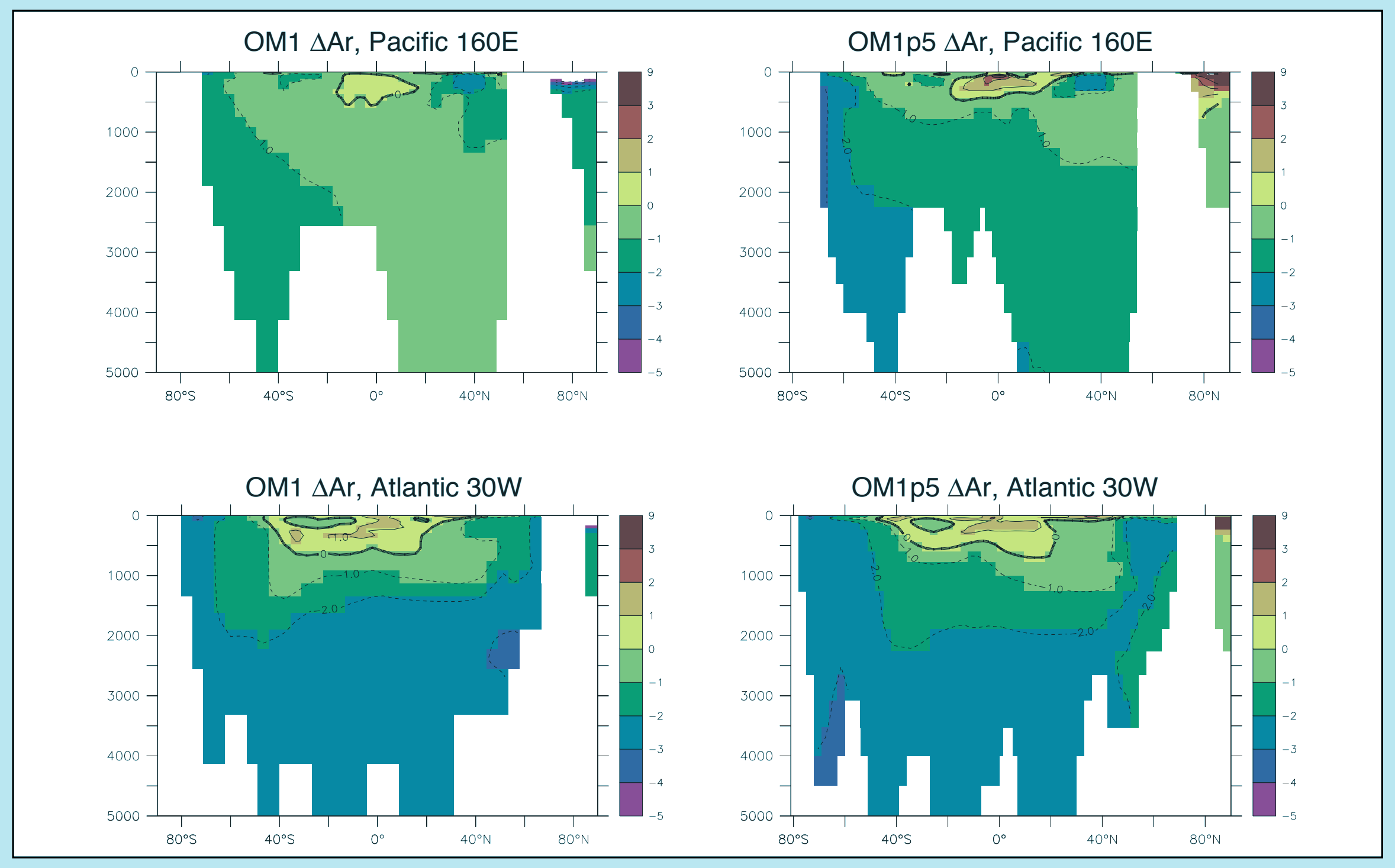

Figure 2: Sections of ΔAr in the models.

Reported as a deviation from the saturation concentration ΔAr (%)

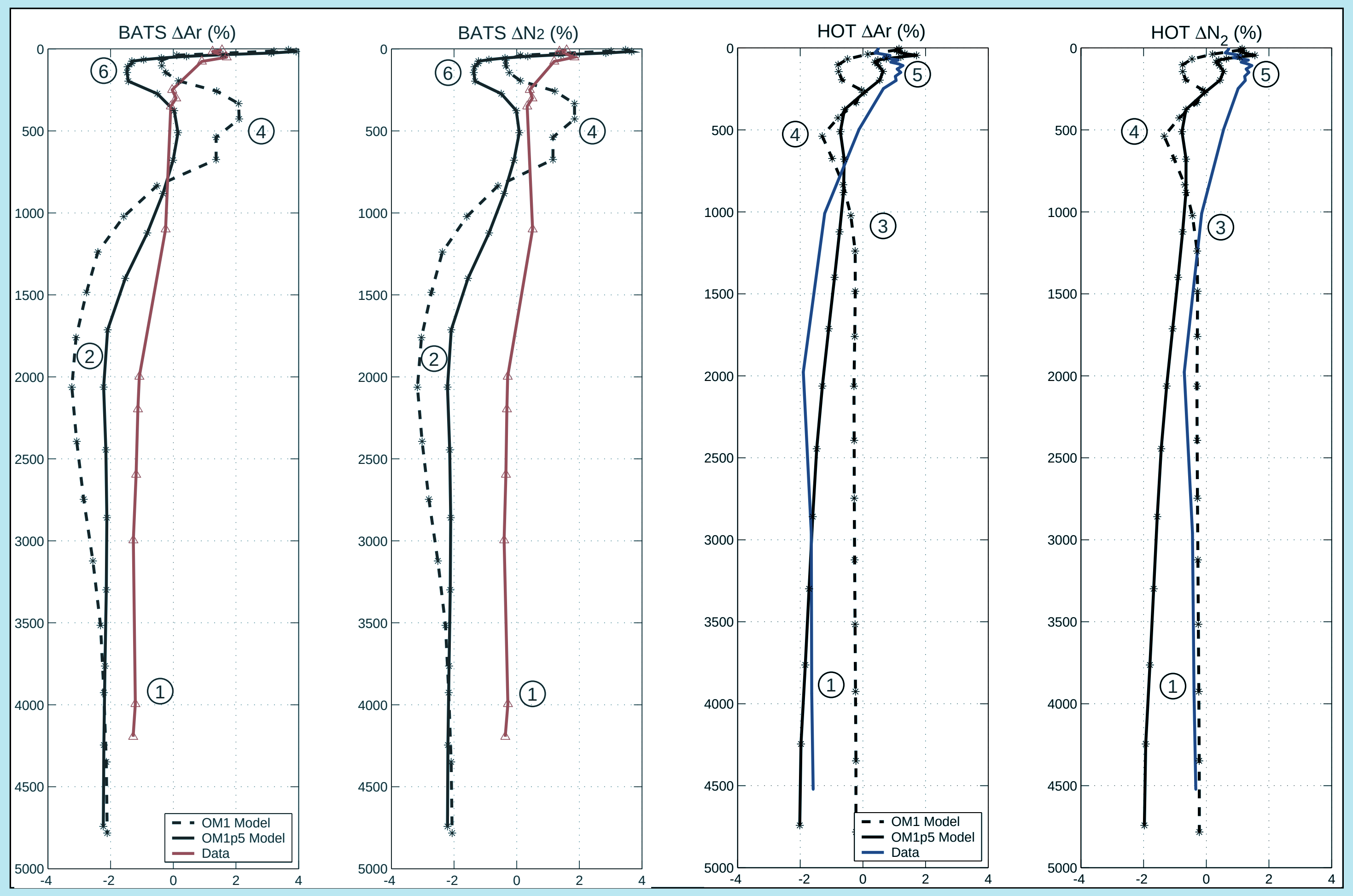

Figure 3: ΔAr and ΔN_2 at BATS and HOT, models and data of Hamme & Emerson (2002)

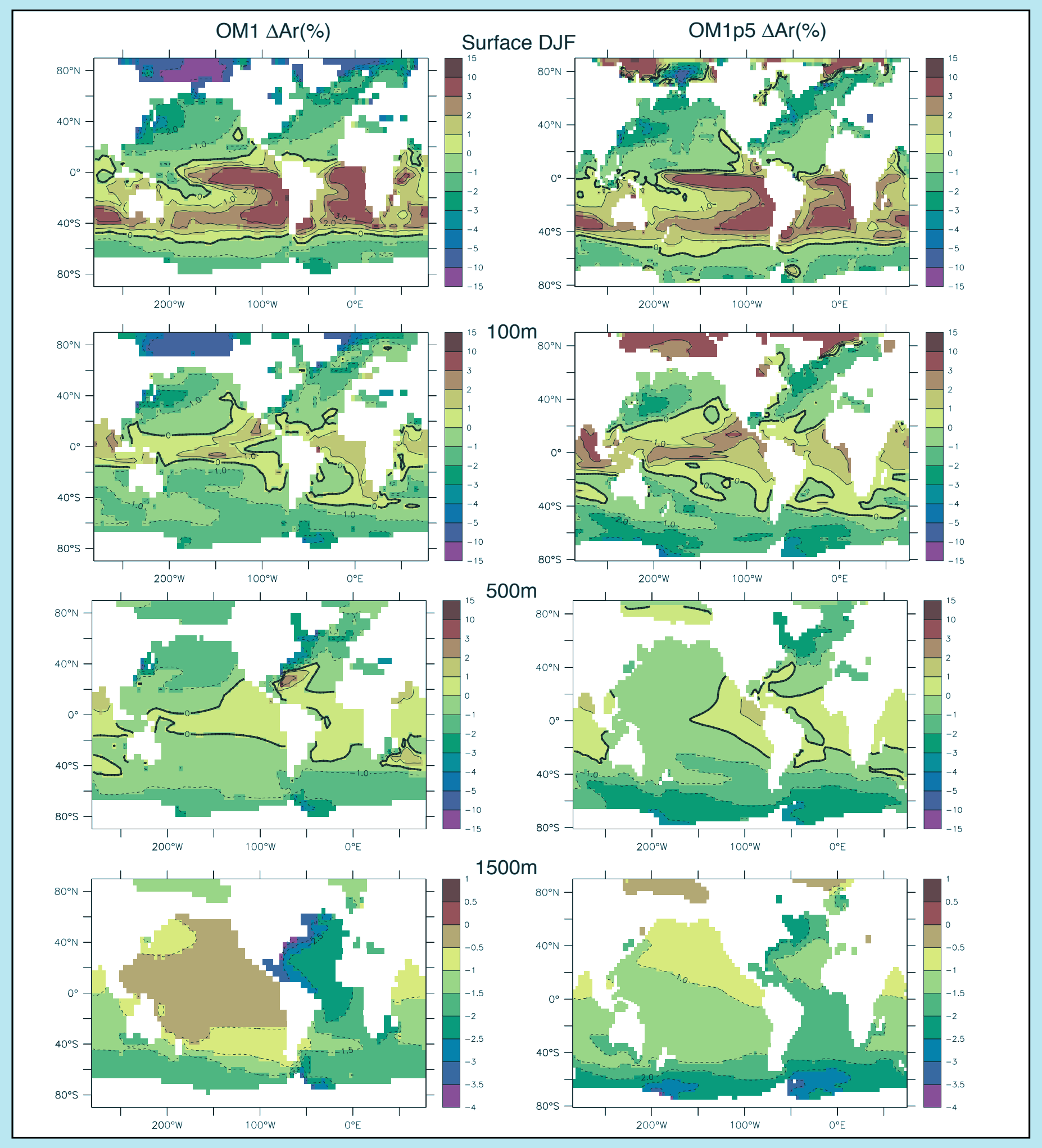

Figure 4: ΔAr on depth surfaces

Discussion of Model - Data Comparisons (Figure 3):

1. Deep Ocean : Lack of bubbles, sluggish ventilation

- At BATS, both versions of the model underestimate the deep ocean ΔAr by about 1%. This is consistent with the lack of a bubble parameterization. They underestimate ΔN_2 by almost 2%, consistent with its lower solubility.

- At HOT, OM1p5 captures the deep ΔAr while the OM1 captures ΔN_2. Compensation of processes during deep water formation appears to be occuring. Sluggish Southern Ocean deep water formation (Figures 1, 4) allows for higher saturation values, while no bubble injection allows for lower. OM1 captures the deep ΔN_2 because the missing strong influence of bubbles on ΔN_2 compensates for the particularly sluggish Southern Ocean ventilation.

2. At 1500m: Sea ice - ocean coupling

- At BATS, OM1p5 does better than OM1. In OM1p5, under-ice heat supply during ice formation in the Arctic contributes to higher ΔAr and ΔN_2 values (Figures 2, 4). OM1 does not have a coupled sea ice model.

3. 500 - 1500m: Vertical diffusivity

- Excessive thermocline diffusivity (Figure 1) may contribute to a tendency toward oversaturation at HOT. (Henning et al., 2004; Gnanadeskian and Toggweiler, 1999)

4. At 500m: Western Boundary Currents

- At BATS in OM1, there is a strongly oversaturated plume is clearly inconsistent with the observations. This is due to an unrealistically wide Gulf Stream. Diffusive heat exchange and mixing at the island of Cuba also contributes to this feature. (Figure 4)

- At HOT, injection of undersaturated water in the western boundary current region spreads across the Pacific (not shown).

5. At 150m: Penetration of shortwave radiation at HOT

- At HOT, the OM1p5 profile has a shape comparable to the observations, unlike OM1. OM1p5 includes penetration of shortwave radiation to 150m, and this appears to have both a direct impact and it also increases the saturation of waters advected to HOT from the tropics (Figure 4).

6. At 150m: Winter mixed layers at BATS

- Both versions of the model mix too deeply in winter (Figure 5). This injects additional low ΔAr and ΔN_2 in winter, and causes the undersaturated bulges in the model results at BATS.

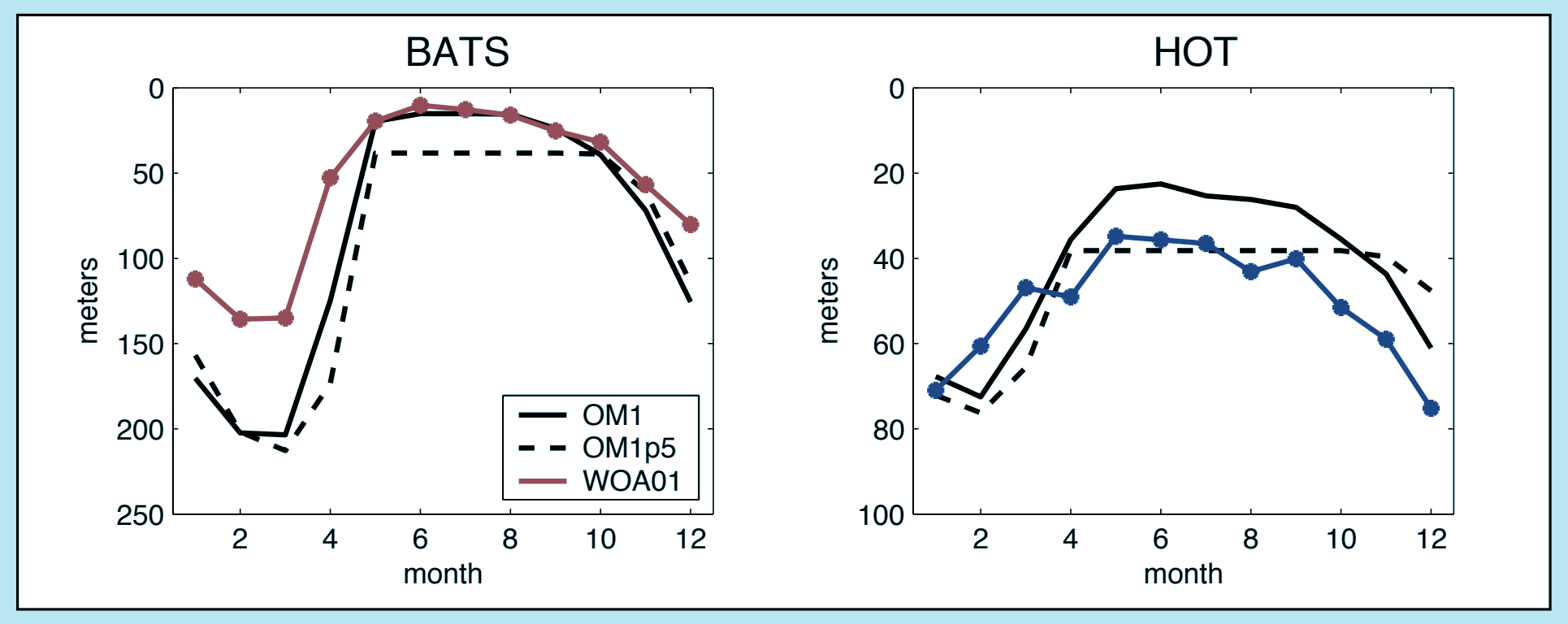

Figure 5: Mixed Layer Depths

Conclusions and Future Work:

- **Argon and Nitrogen are tracers of ocean circulation** that can be used to test ocean models.

- **Further model runs will test how specific parameter changes impact comparisons.**
    - Inclusion of a small bubble injection parameteriztion.
    - Coupling of the sea ice model to air-sea gas exchange.
    - Vertical diffusivity.

- **Additional observations are needed.** Data from the Southern Ocean would be particularly useful.

- **Ar and N_2 in Earth System Models** would allow simultaneous evaluation with atmospheric Ar/N_2 (Battle et al., 2003; McKinley et al., 2004) and interior ΔAr and ΔN_2.

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