Ice-Ocean Boundary Dynamics

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Outline

I. Brief motivation

II. Parameterisation of the turbulent boundary layer

III. Buoyancy-driven boundary currents

IV. Summary of knowns and unknowns

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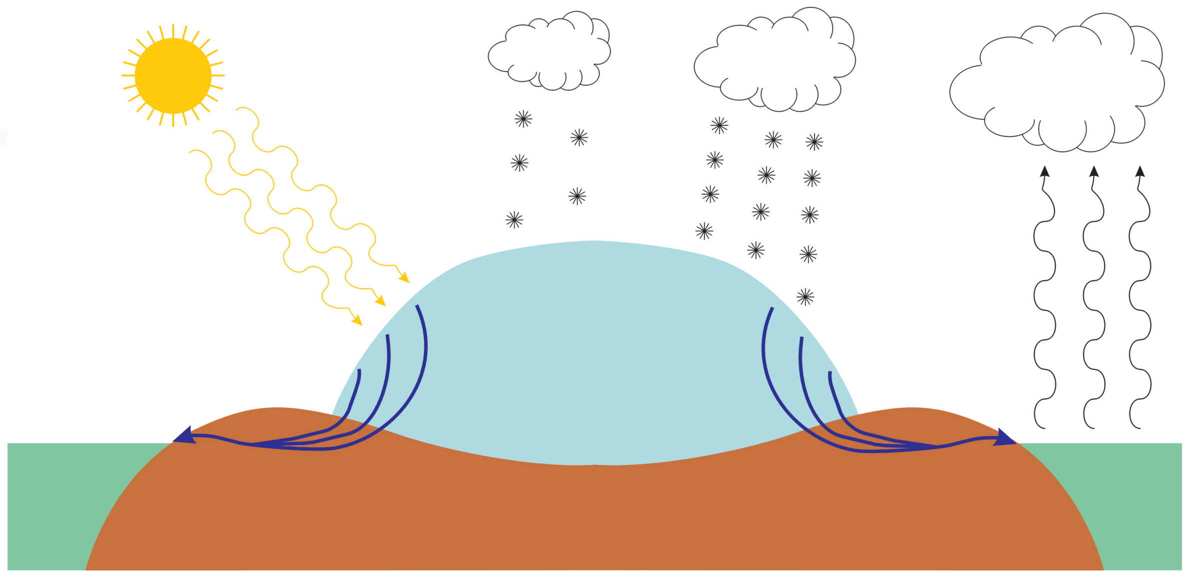
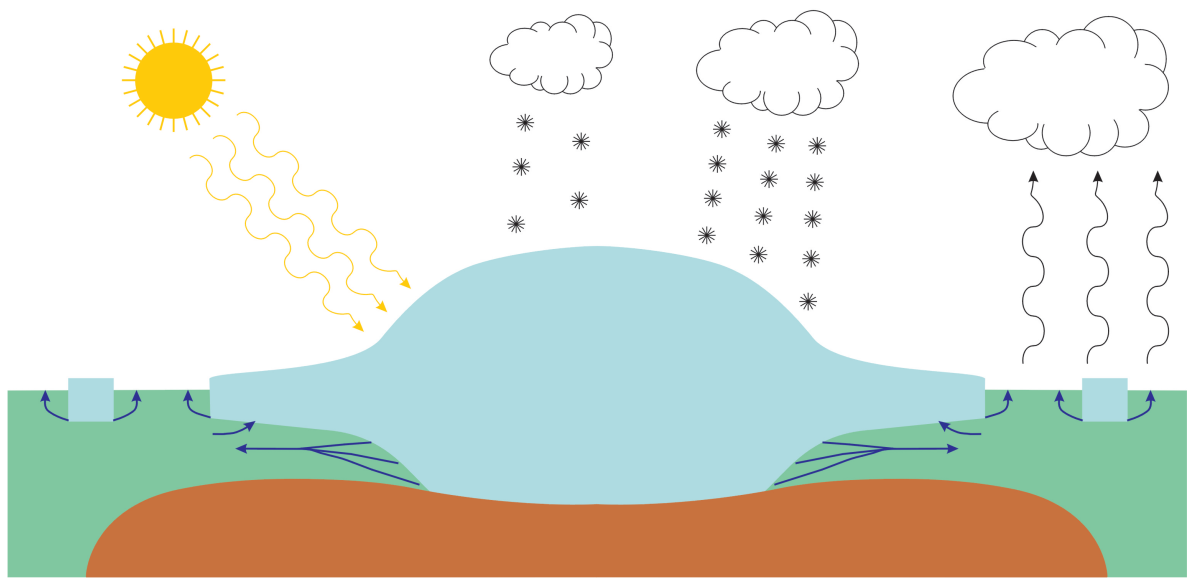
Terrestrial ice sheet



Marine ice sheet



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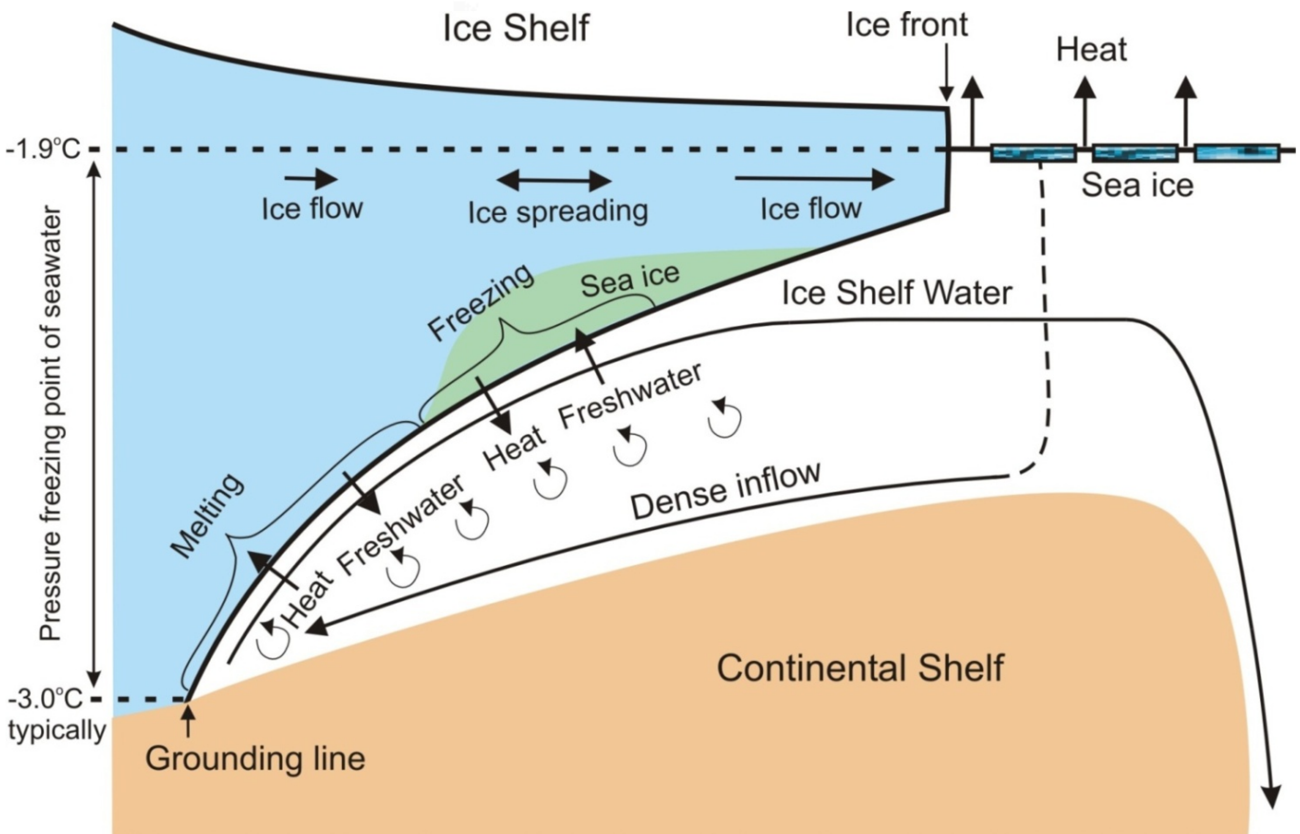

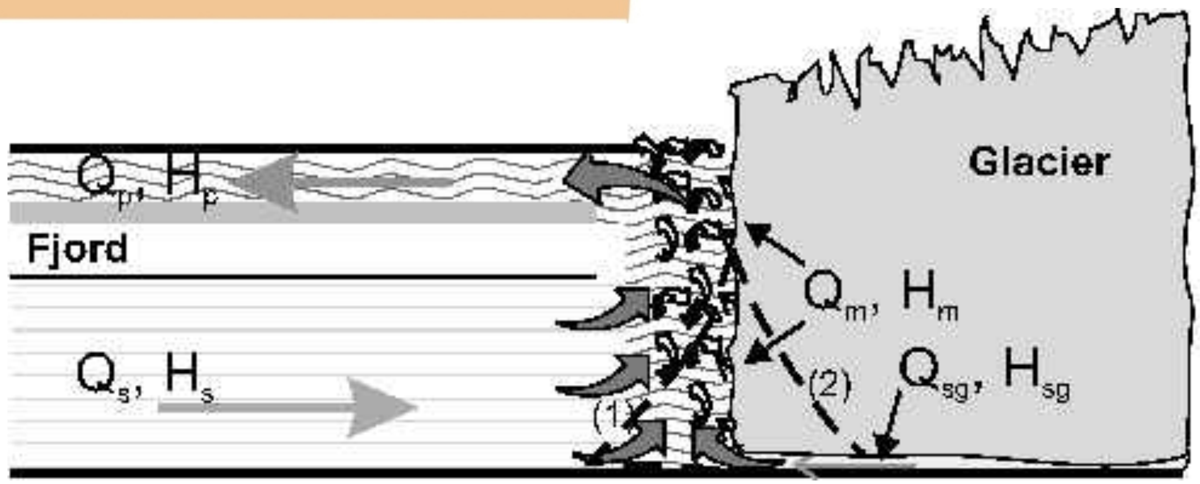

Motyka et al. (2003)

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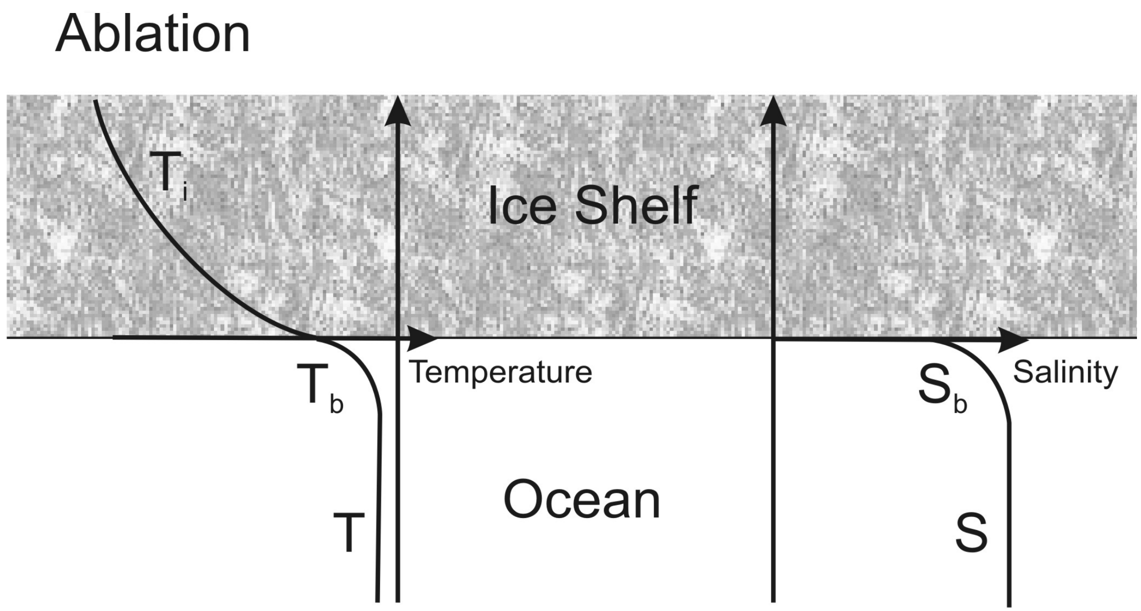

Liquidus condition: $$T_b = \lambda_1 S_b + \lambda_2 + \lambda_3 P_b$$

Heat balance: $$\rho_i \dot{a}_b L = \rho_i c_i \kappa_i \left.\frac{\partial T_i}{\partial n}\right|_b - q_b^T$$

Salt balance: $$\rho_i \dot{a}_b \left(S_b - S_i\right) = -q_b^S$$

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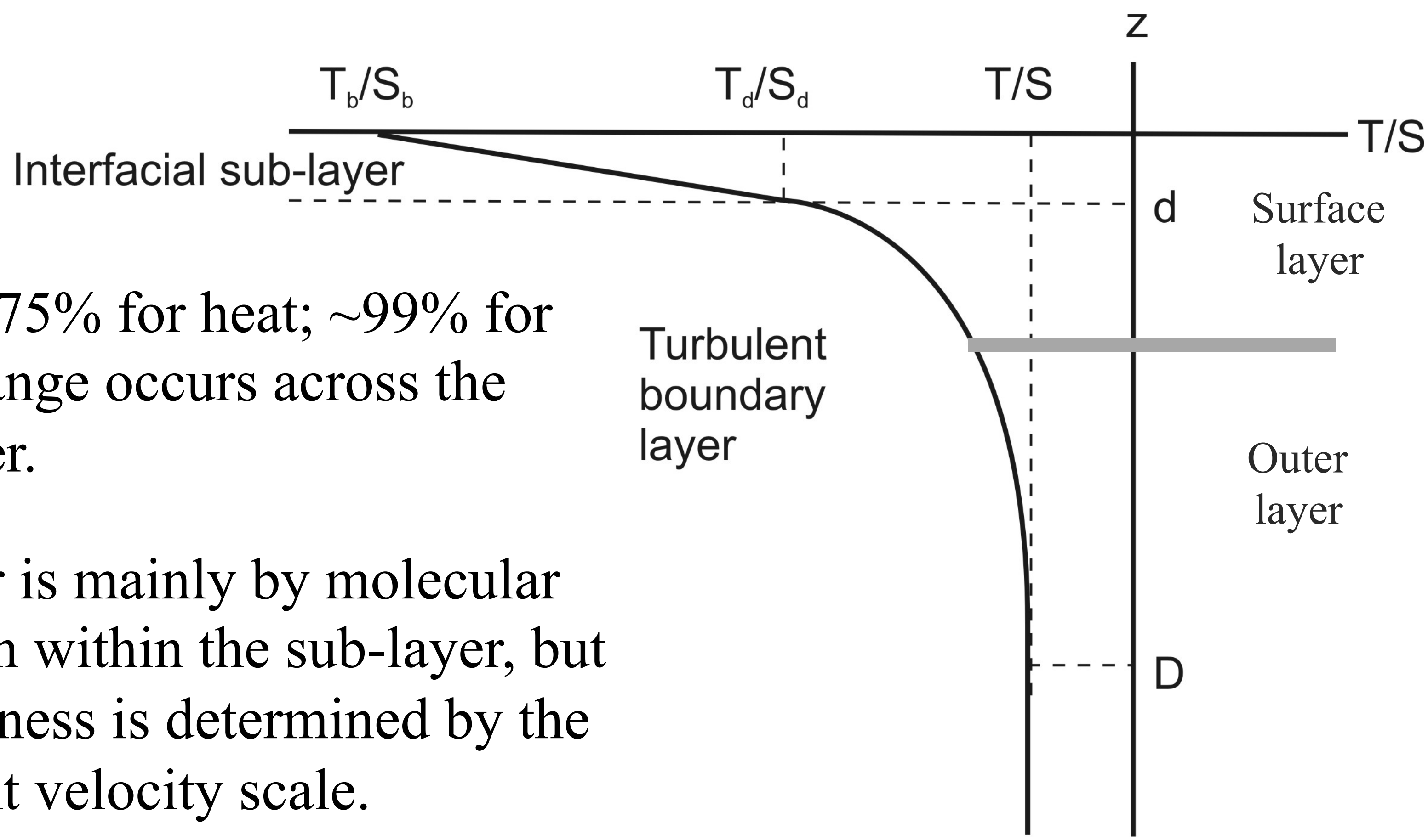

Most (~75% for heat; ~99% for salt) change occurs across the sub-layer.

Transfer is mainly by molecular diffusion within the sub-layer, but its thickness is determined by the turbulent velocity scale.

Interfacial shear stress:

$$\tau_b = \rho_w C_d U^2$$

Turbulent fluxes:

$$q_b^T = \rho_w c_w C_d^{1/2} U \Gamma_T \left(T_b - T\right)$$

$$q_b^S = \rho_w C_d^{1/2} U \Gamma_S \left(S_b - S\right)$$

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C_d

Almost entirely unknown for ice shelves/tidewater glaciers.

Typically assumed to be ~10^{-3}.

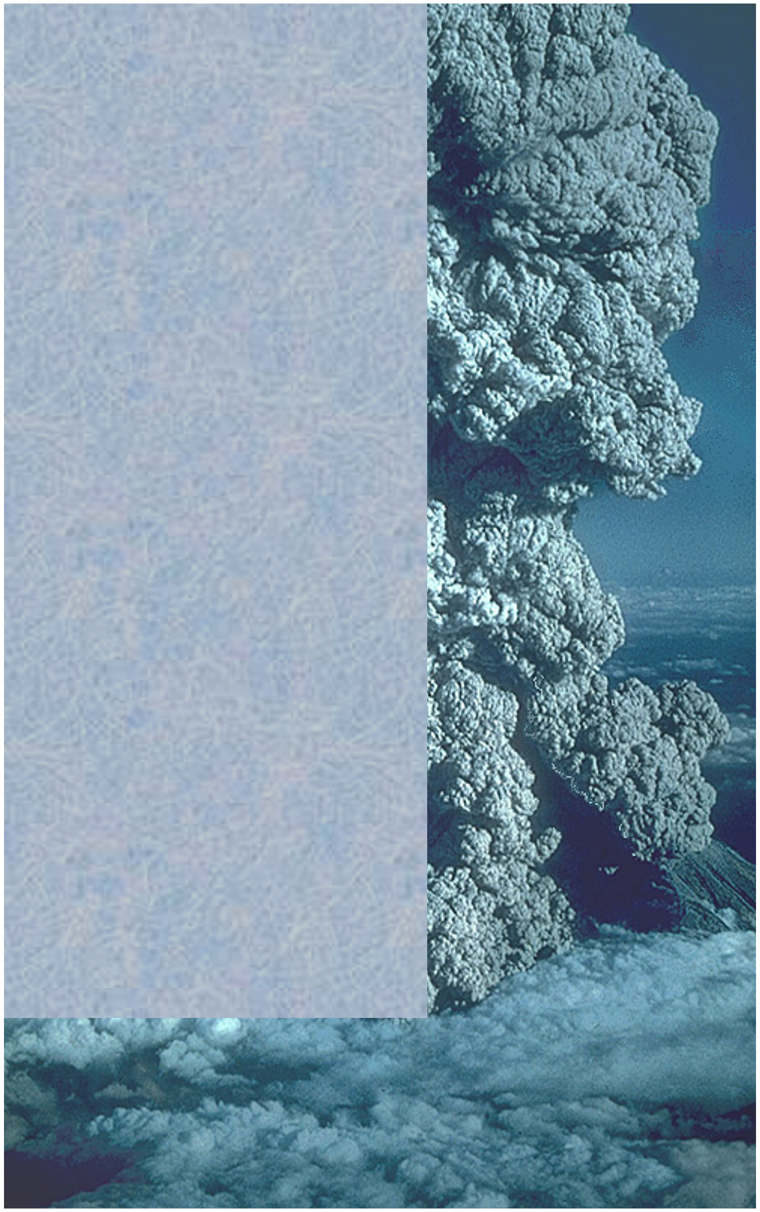
Similar to values estimated for sea ice and the seabed.

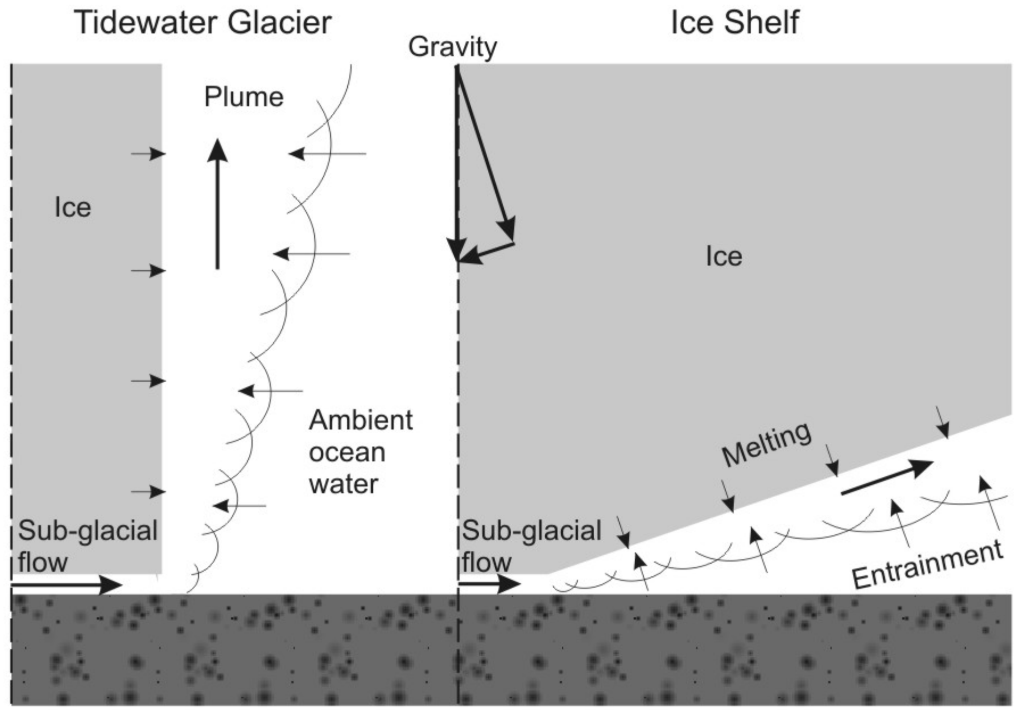
Γ_T, Γ_S

Almost entirely unknown for ice shelves/tidewater glaciers.

Expressions taken from laboratory experiments or sea ice observations.

Dominant role of the molecular processes in the interfacial sublayer suggests that values should be broadly applicable.





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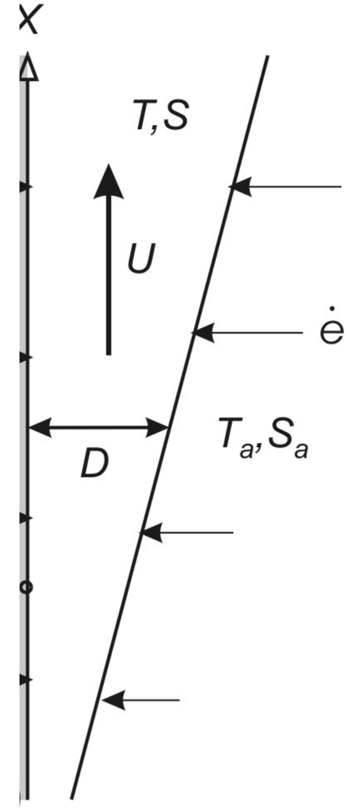
$$\frac{d}{dX}\left(DU^2\right) = D\Delta\rho g \sin\alpha - C_d U^2$$

$$\frac{d}{dX}\left(DU\right) = \dot{e}$$

$$\frac{d}{dX}\left(DUT\right) = \dot{e}T_a$$

$$\frac{d}{dX}\left(DUS\right) = \dot{e}S_a$$



$$\Delta\rho = \beta_S\left(S_a - S\right) - \beta_T\left(T_a - T\right)$$

$$\dot{e} = E_0 U \sin\alpha$$

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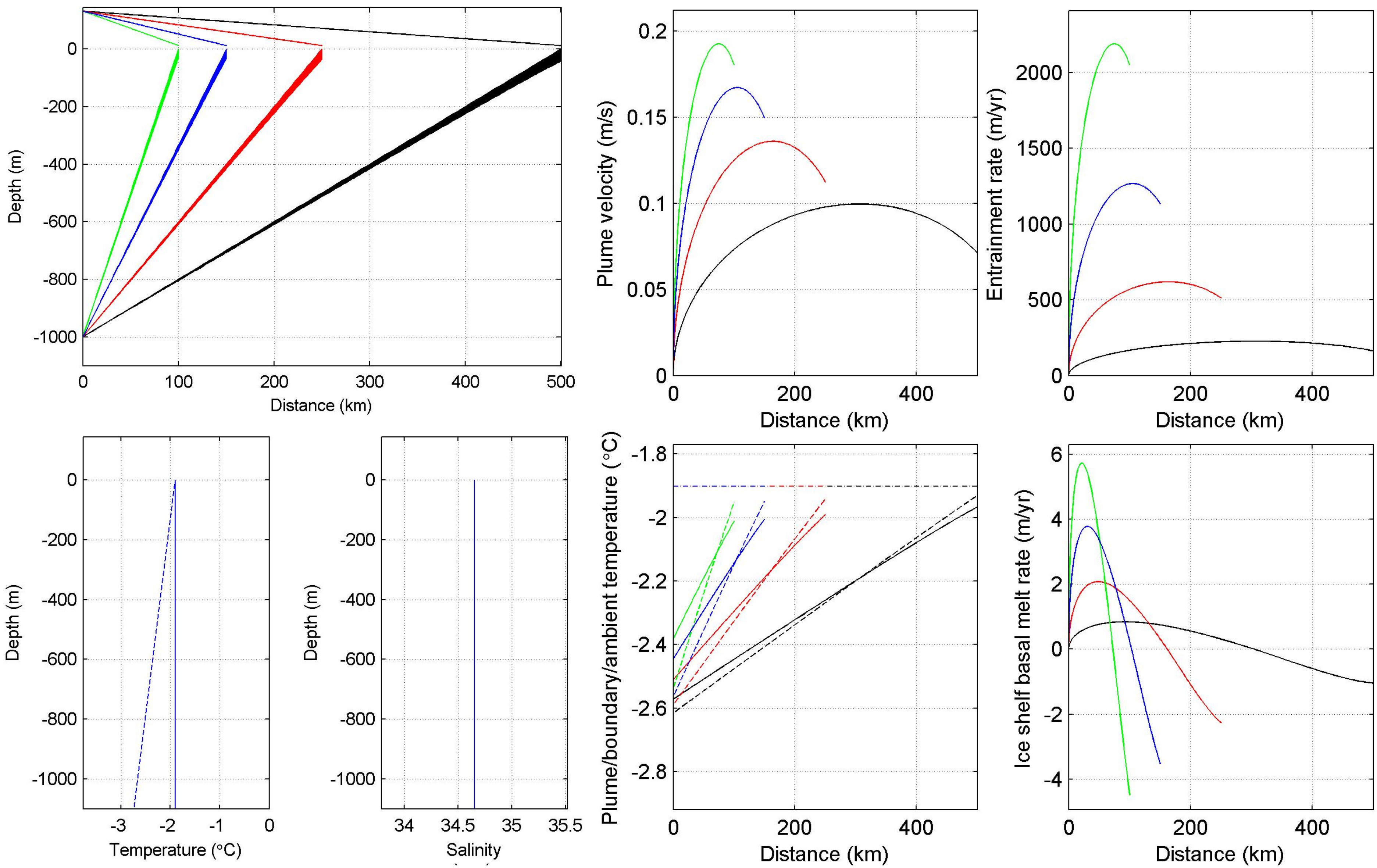

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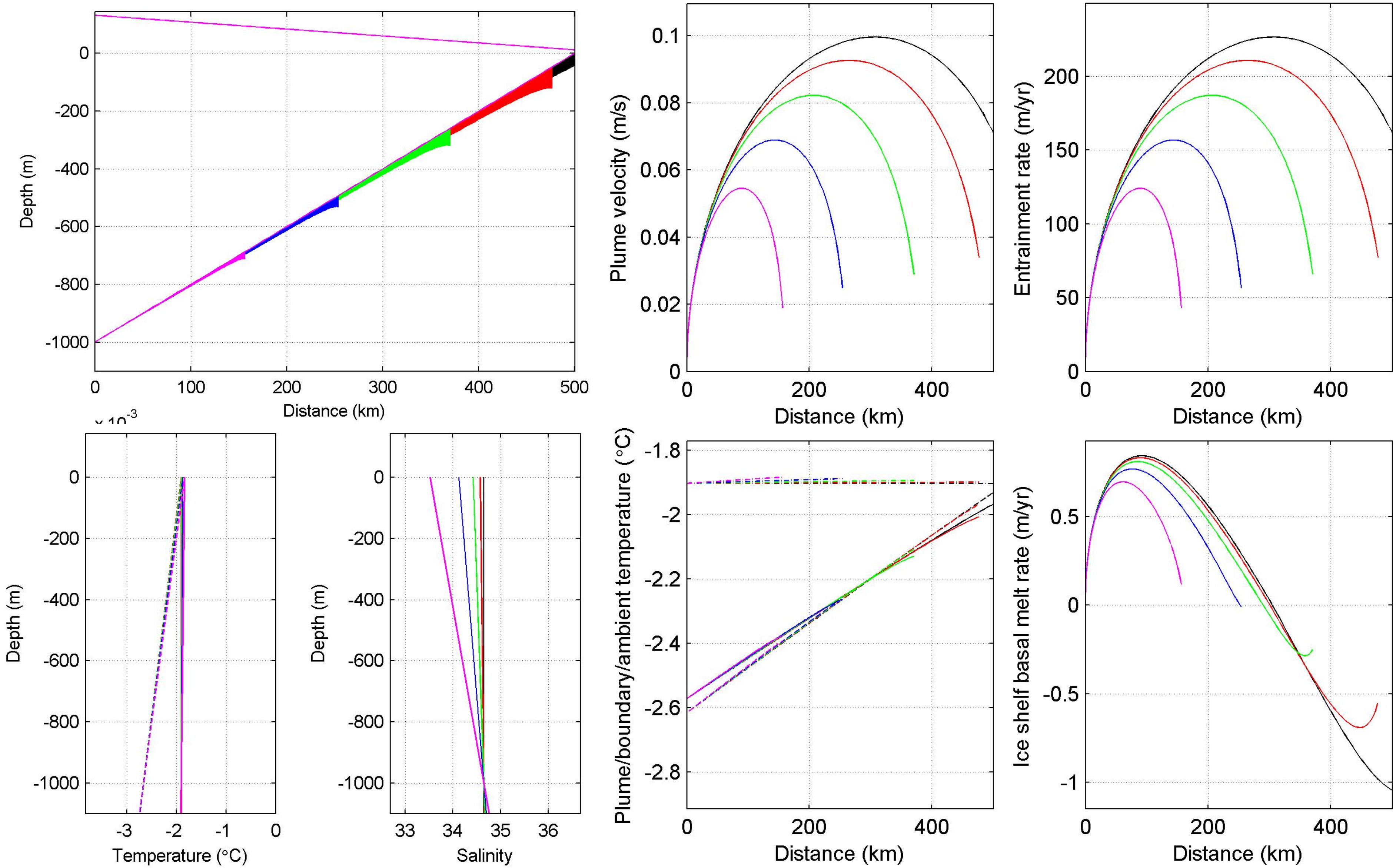

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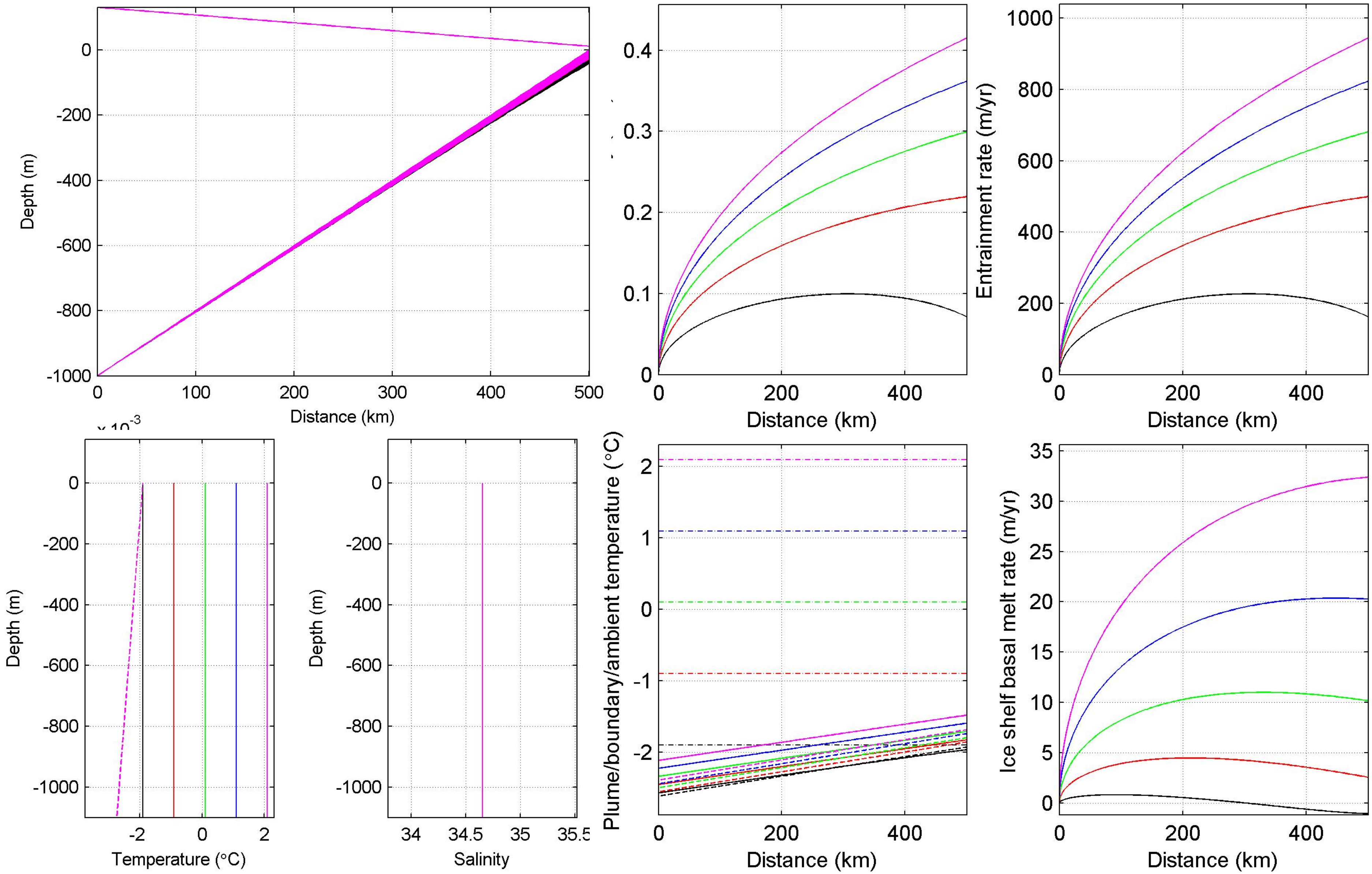
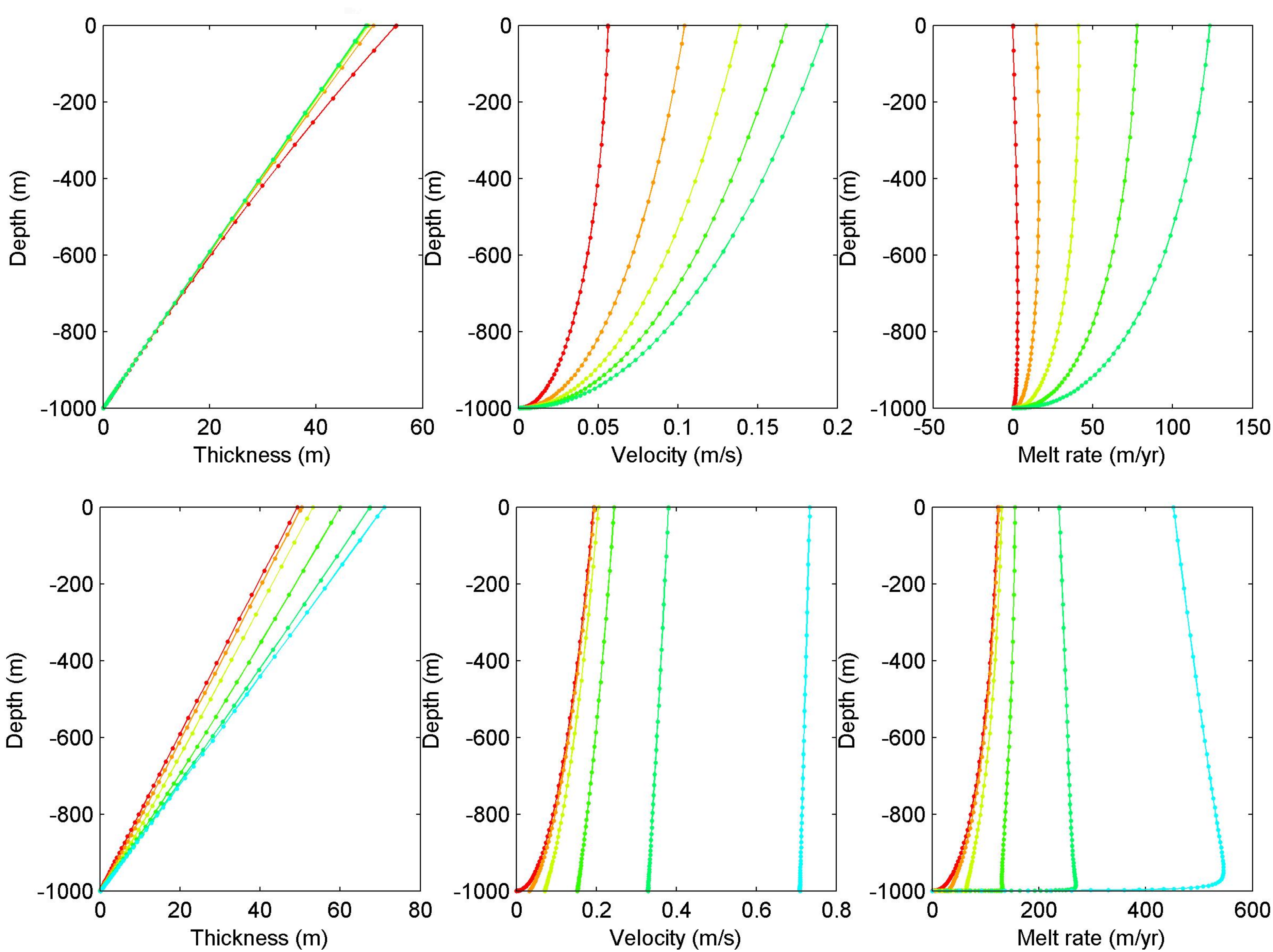

Depth (m)
Distance (km)
Entrainment rate (m/yr)
Distance (km)
Distance (km)
Depth (m)
Temperature (°C)
Depth (m)
Salinity
Plume/boundary/ambient temperature (°C)
Distance (km)
Ice shelf basal melt rate (m/yr)
Distance (km)



Depth (m)
Thickness (m)
Velocity (m/s)
Melt rate (m/yr)

If we assume melting has no impact on plume buoyancy, then in an unstratified environment there is a simple solution (if we also neglect the pressure dependence of the freezing point):

constant velocity,
$$U_0 = \left(\frac{B_0 \sin\alpha}{E_0 \sin\alpha + C_d} \right)^{1/3}$$

linearly increasing thickness,
$$D = E_0 \sin\alpha \, X$$

constant buoyancy flux,
$$B_0 = g D_0 U_0 \Delta\rho_0$$

constant thermal driving,
$$\left(T - T_f\right)_0 = \left(\frac{E_0 \sin\alpha}{E_0 \sin\alpha + C_d^{1/2} \Gamma_{\{TS\}}} \right) \left(T_a - T_{af}\right)$$

and constant melt rate,
$$\dot{m}_0 = \frac{c C_d^{1/2} \Gamma_{\{TS\}}}{L'} U_0 \left(T - T_f\right)_0$$

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The melt rate can therefore be written as:

$$\dot{m}_0 = \left(\frac{cC_d^{1/2}\Gamma_{\{TS\}}}{L'}\right)\left(\frac{\sin\alpha}{E_0\sin\alpha + C_d}\right)^{1/3}\left(\frac{E_0\sin\alpha}{E_0\sin\alpha + C_d^{1/2}\Gamma_{\{TS\}}}\right)B_0^{1/3}\left(T_a - T_{af}\right)$$

- Physical constants
- Geometrical factors
- Cube root of buoyancy flux at grounding line
- Ambient thermal driving

For a vertical ice face: $\sin\alpha = 1$

$$E_0 >> C_d >> C_d^{1/2}\Gamma_{\{TS\}}$$

$$\Rightarrow \text{Geometrical factors} \approx E_0^{-1/3}$$

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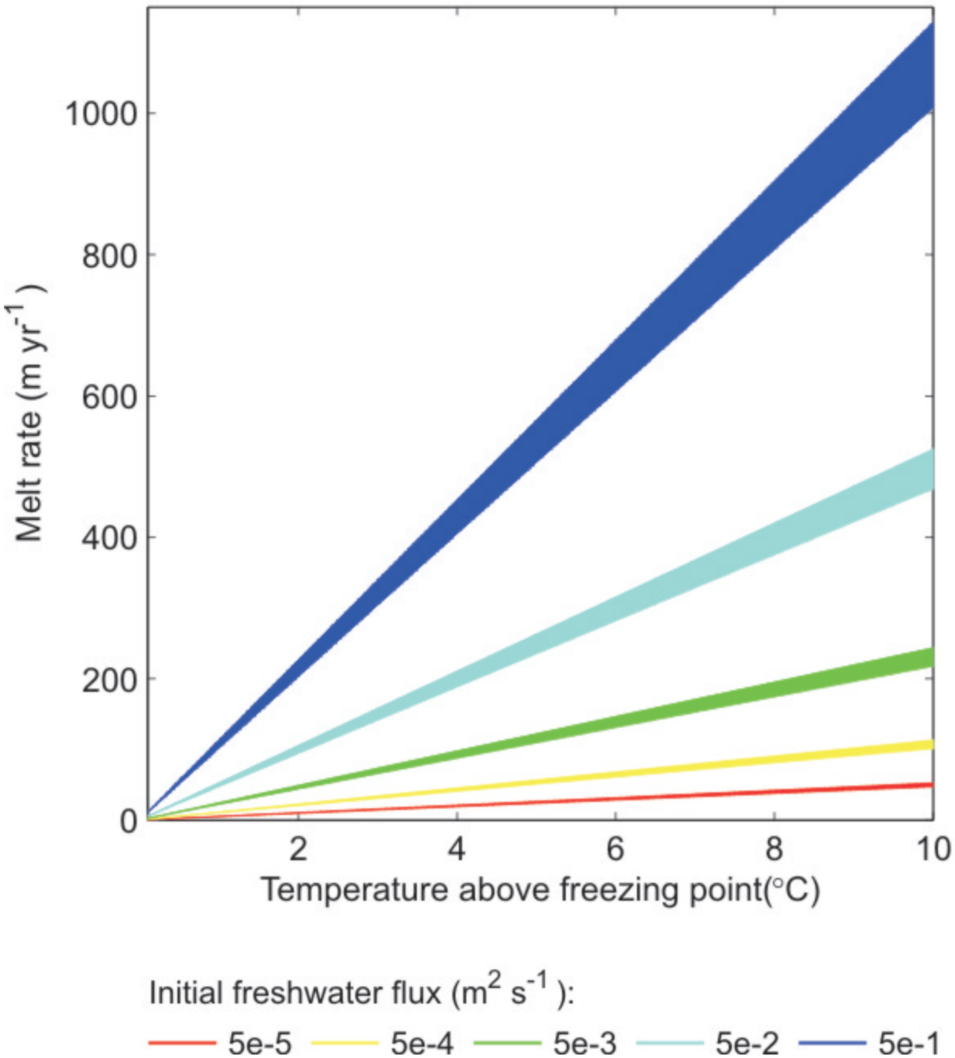

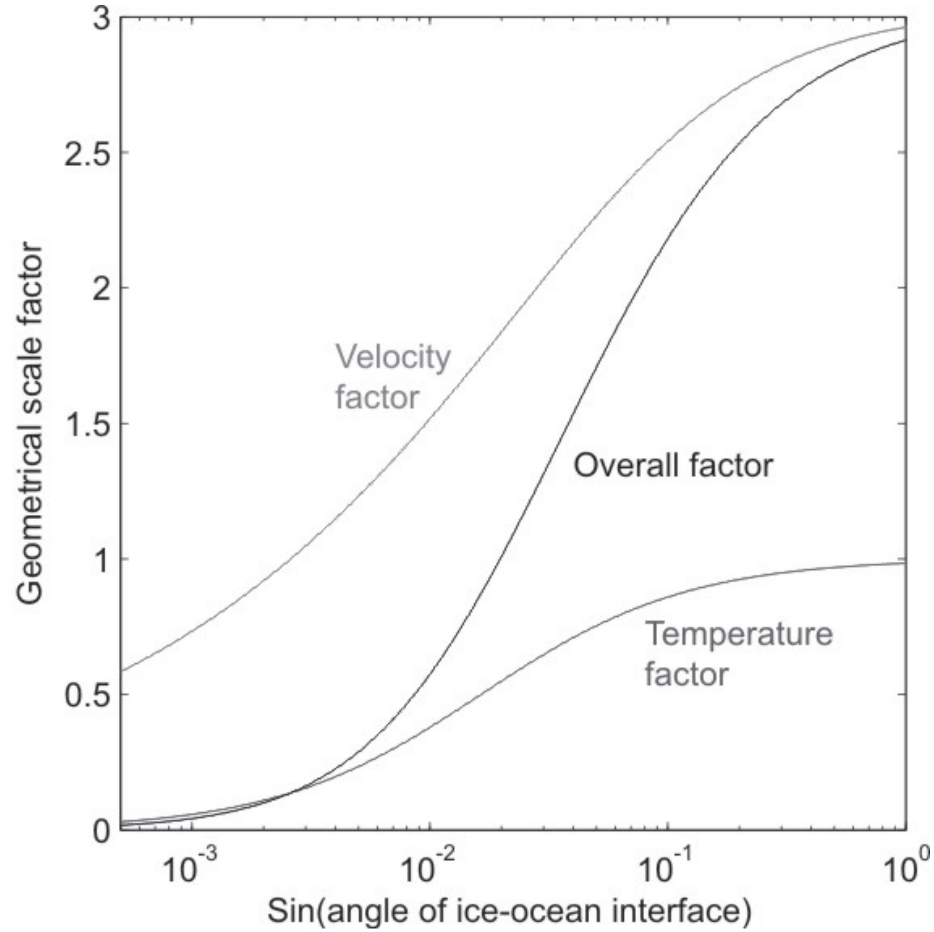

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Summary I

- Physics of the turbulent ice-ocean boundary layer beneath sea is fairly well understood.

- Parameterisations of turbulent transfer are well tested against observation, but those observations inevitably sample a limited range of conditions.

- Parameterisations should be readily transferable to ice shelves and tidewater glaciers, particularly the latter.

- There are very few observations to confirm or refute that, although data are now being collected beneath ice shelves.

- Sampling near a vertical ice face is challenging!

Summary II

- Plume theory has been applied successfully to understand the fundamental behaviour of buoyancy-driven boundary currents.
- Once again, the theory should be more applicable to tidewater glaciers than ice shelves.
- Again there are no observations to support that claim.
- Recent work (Xu et al, 2012; Sciascia et al, in press, several posters presented here) have applied 2 and 3 dimensional ocean models to the vertical ice face problem.
- Very high resolution, non-hydrostatic codes are required to capture the processes.
- That makes the problem challenging for large-scale models!