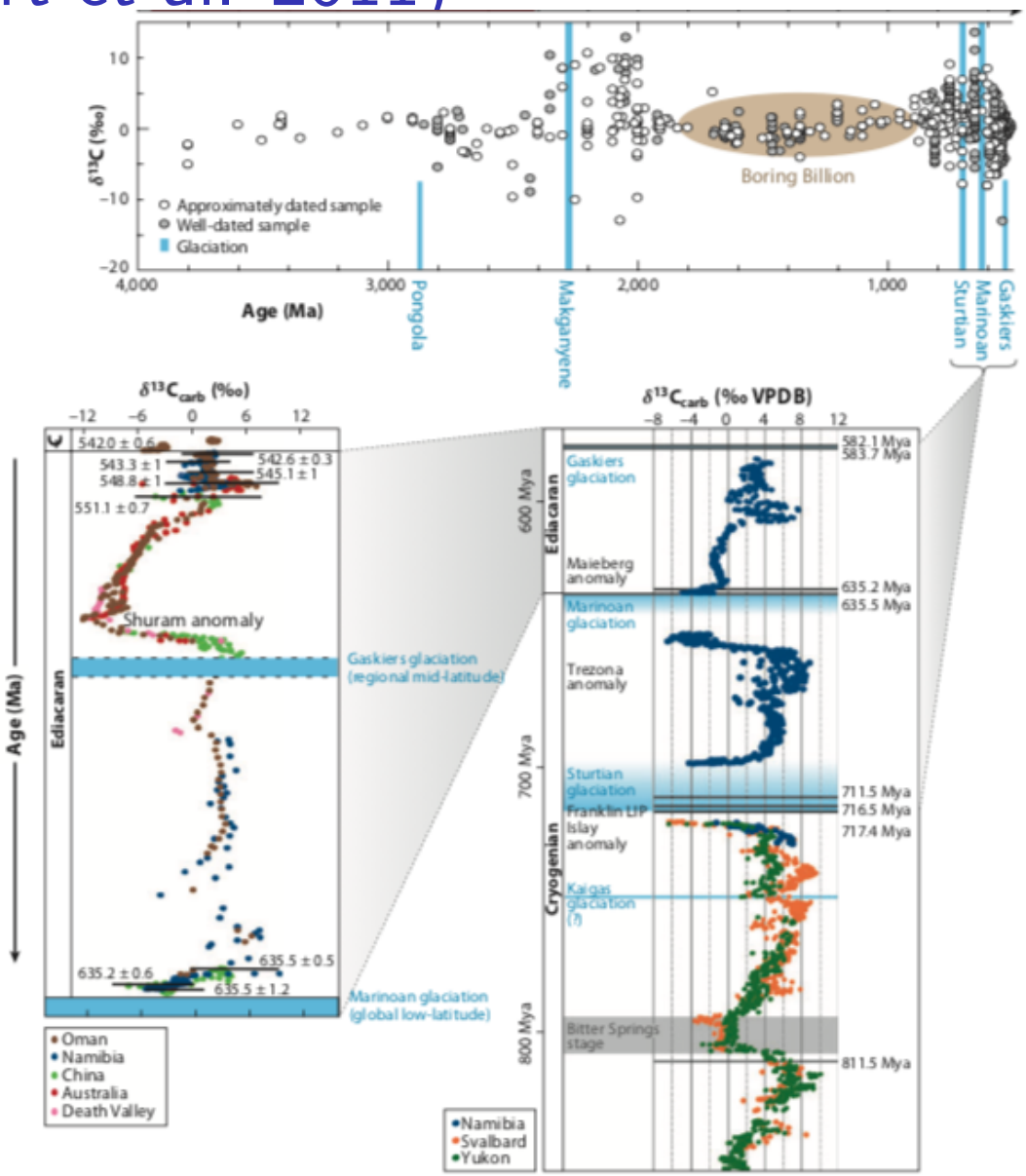
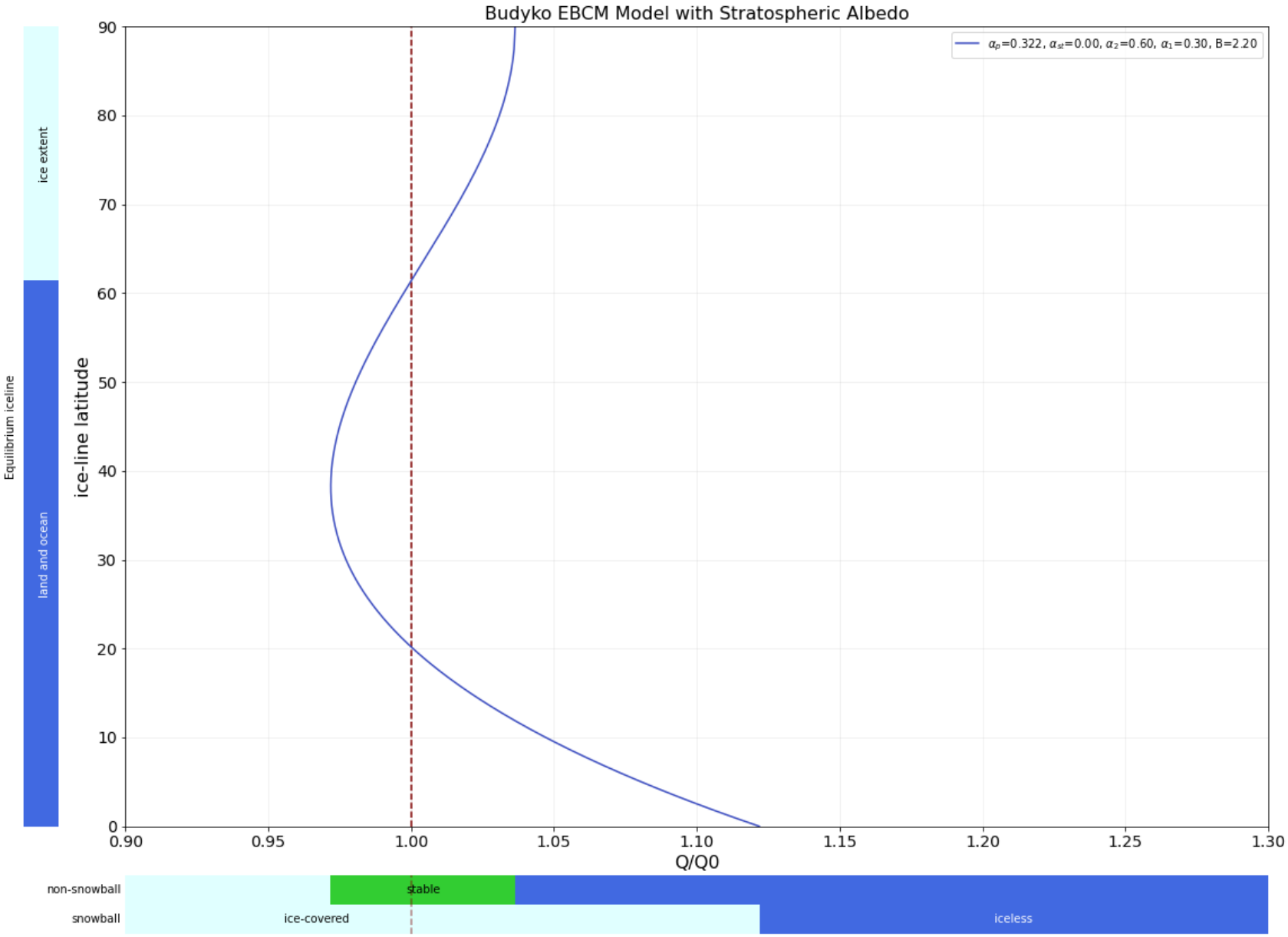
Could albedo changes explain Neoproterozoic glaciations? (Pierrehumbert et al. 2011)



Increasing land and ocean albedo can cause a snowball



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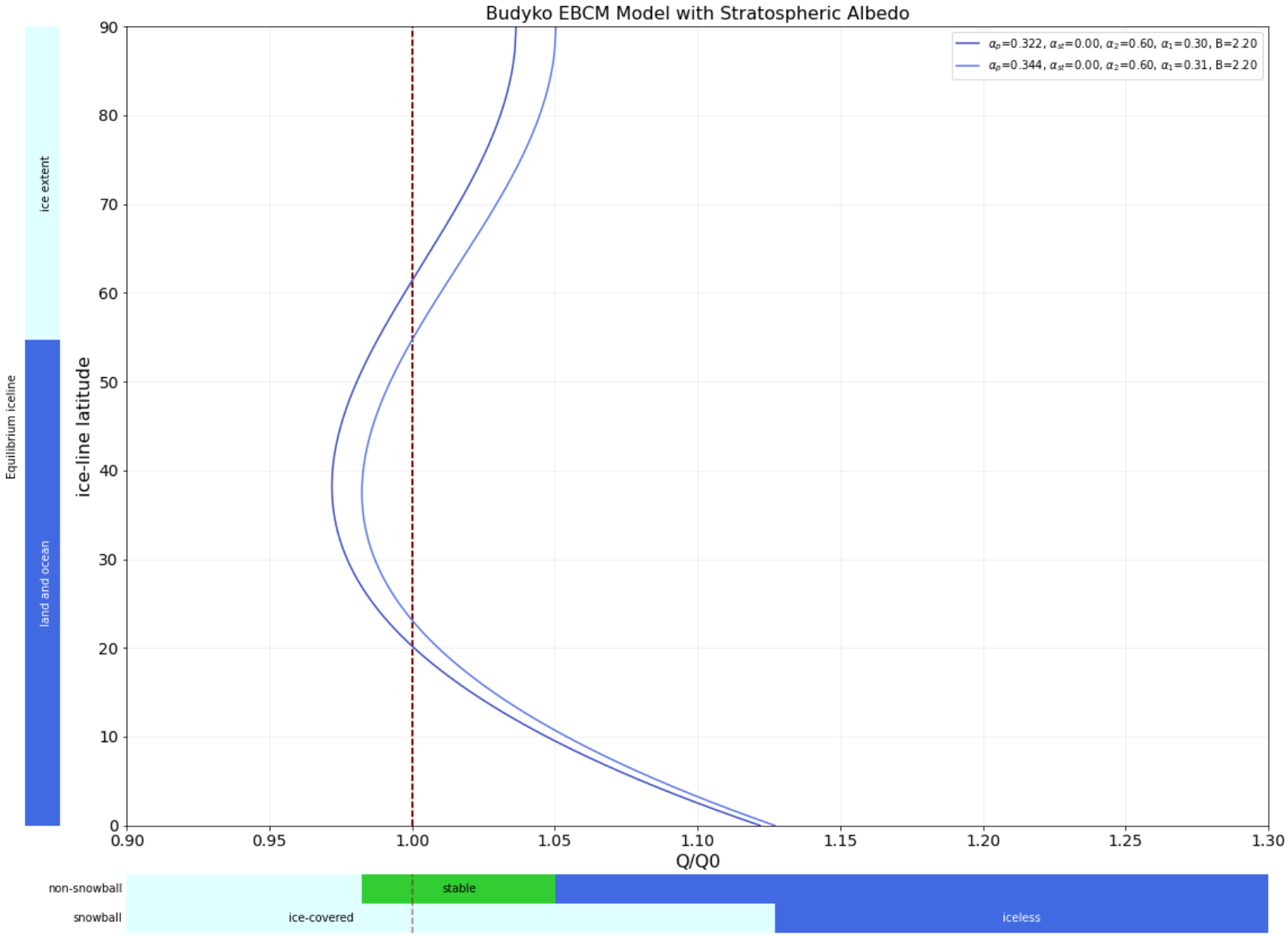

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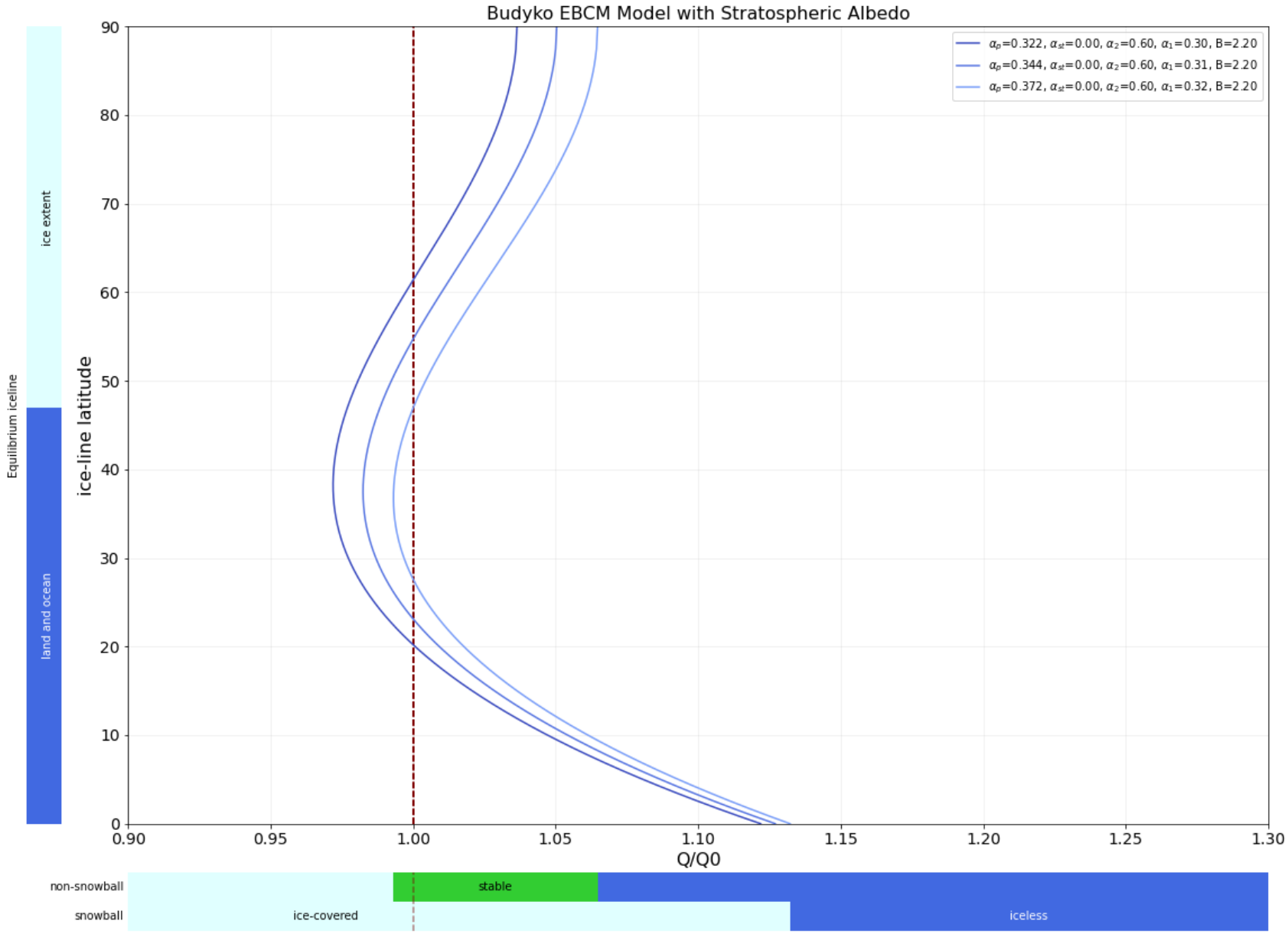

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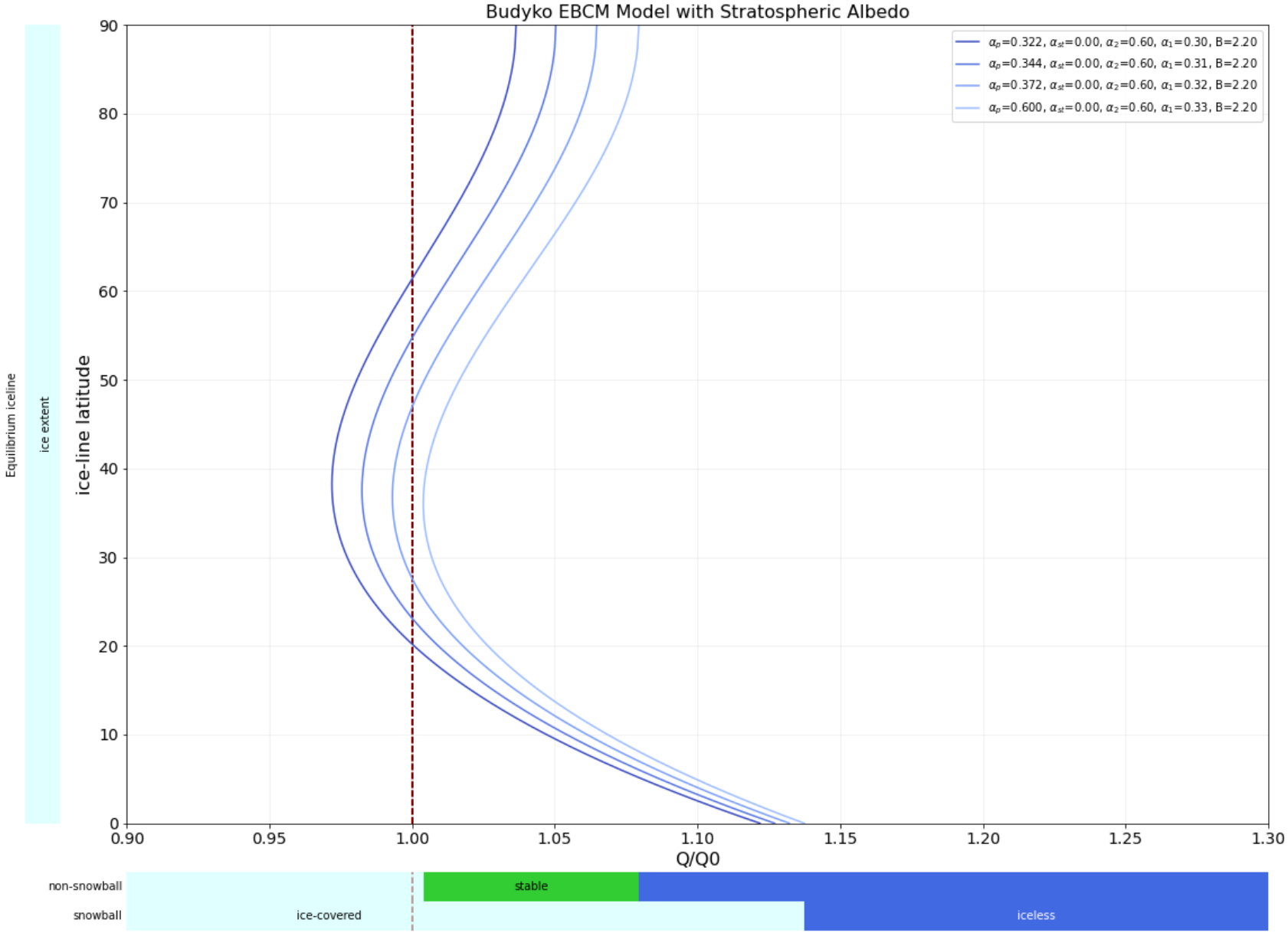

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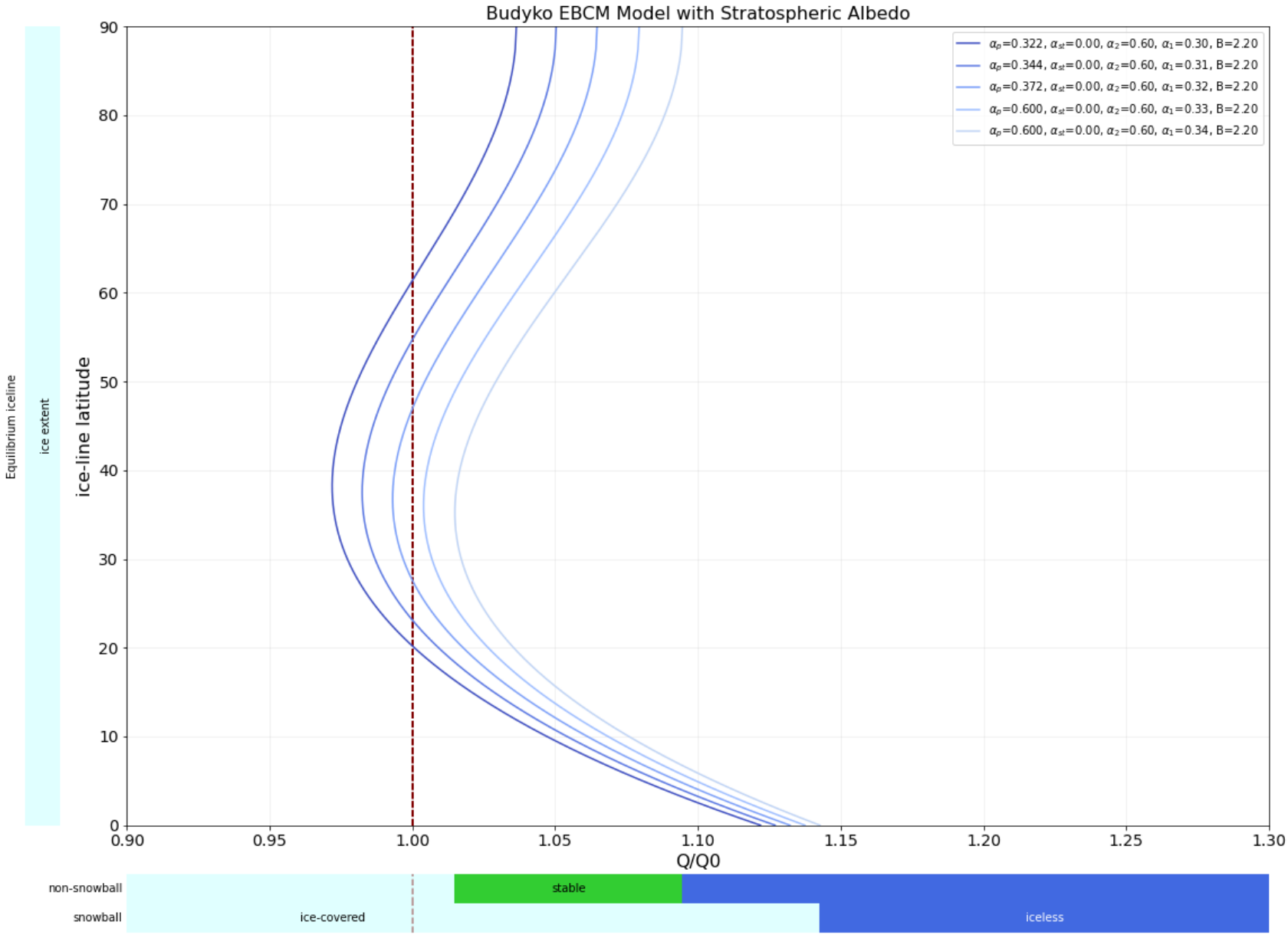

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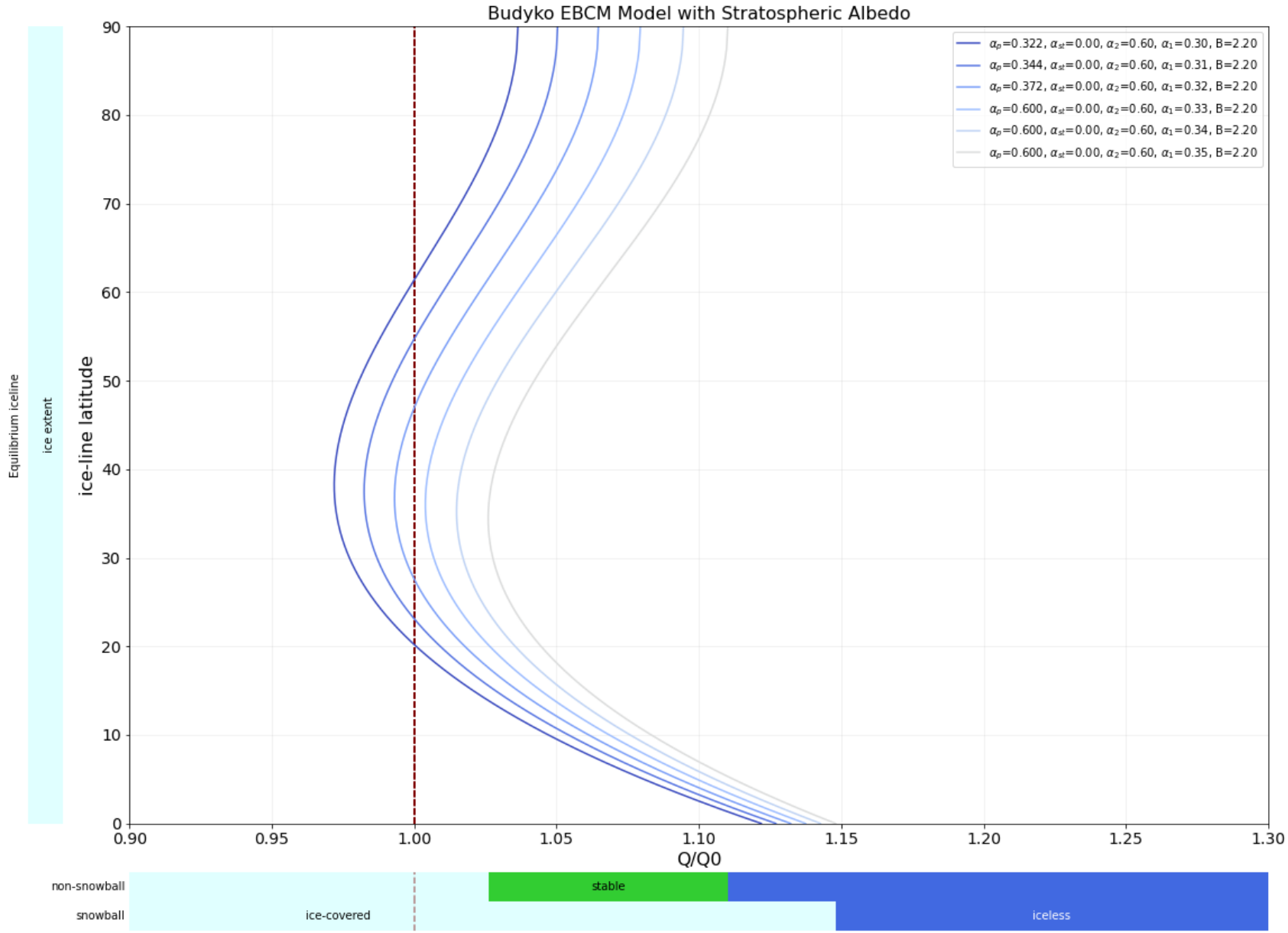

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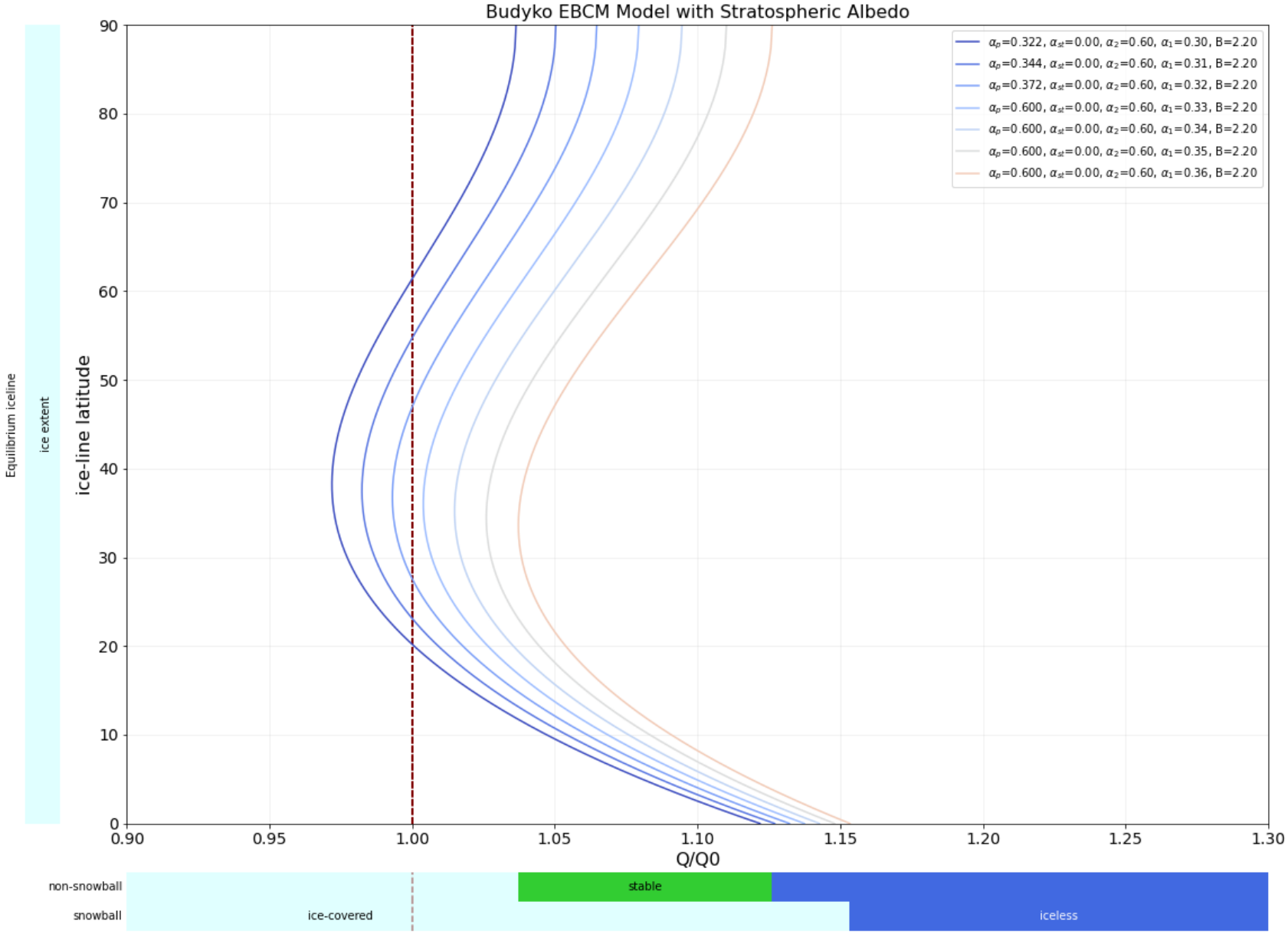

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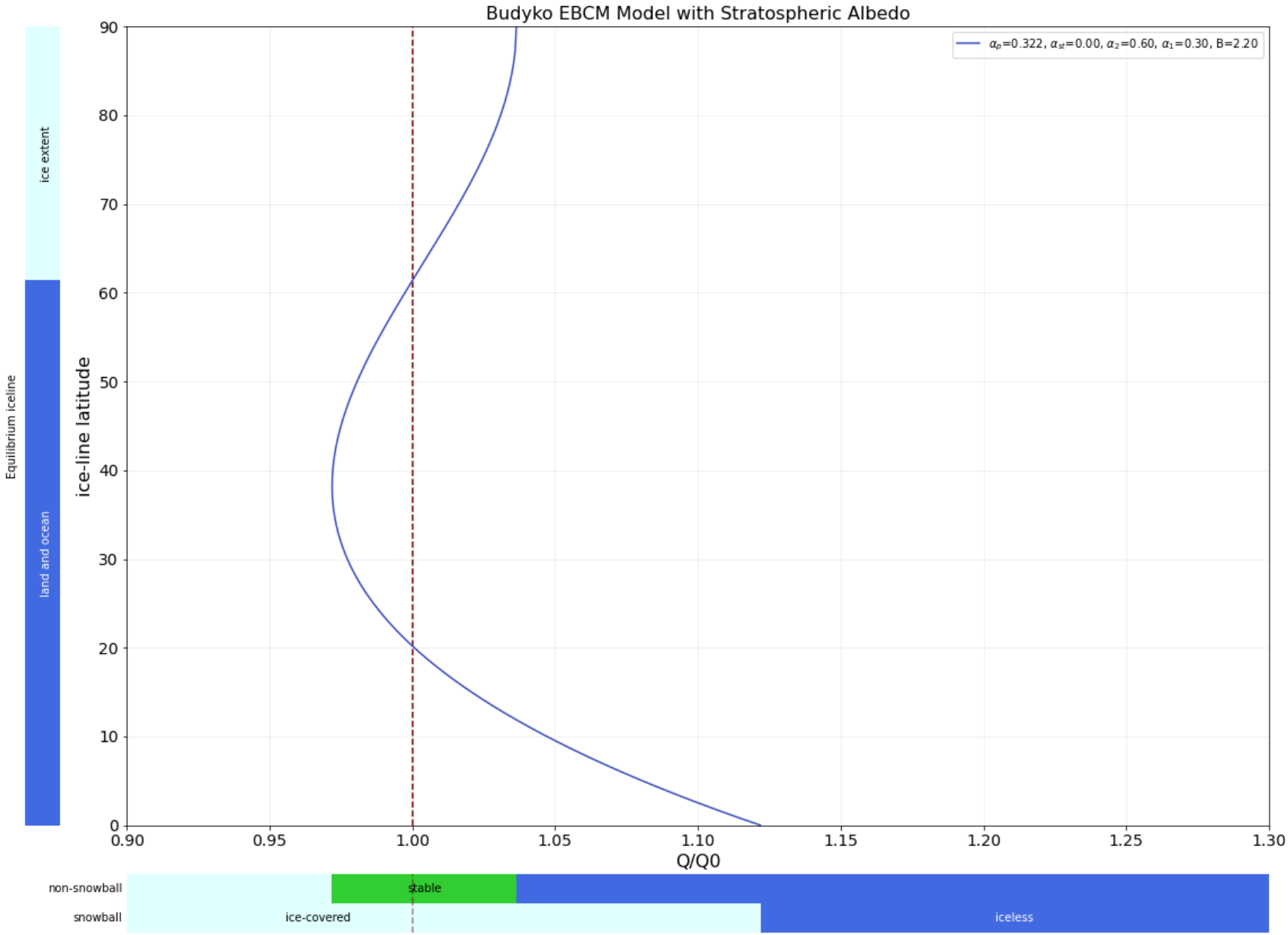

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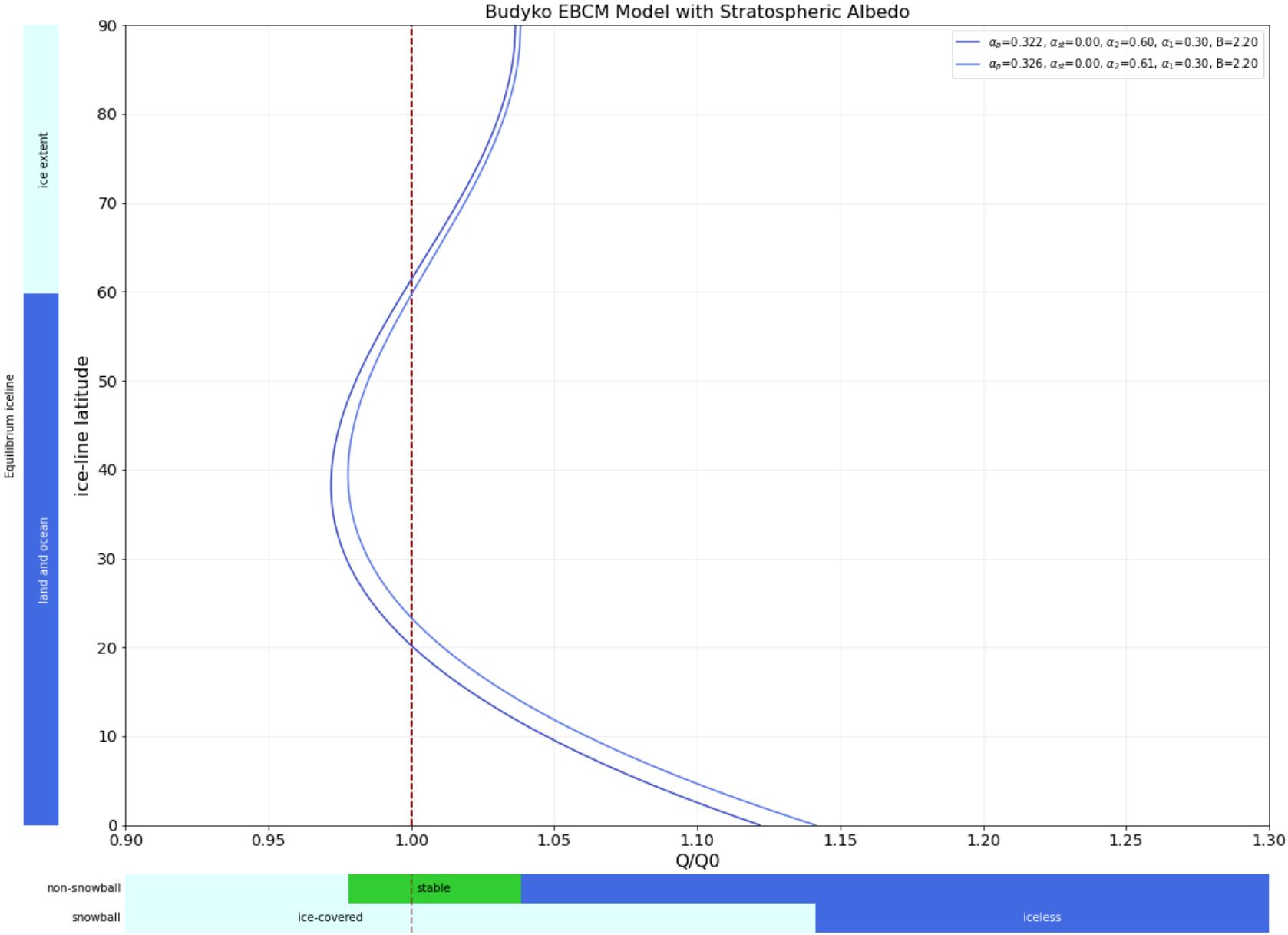

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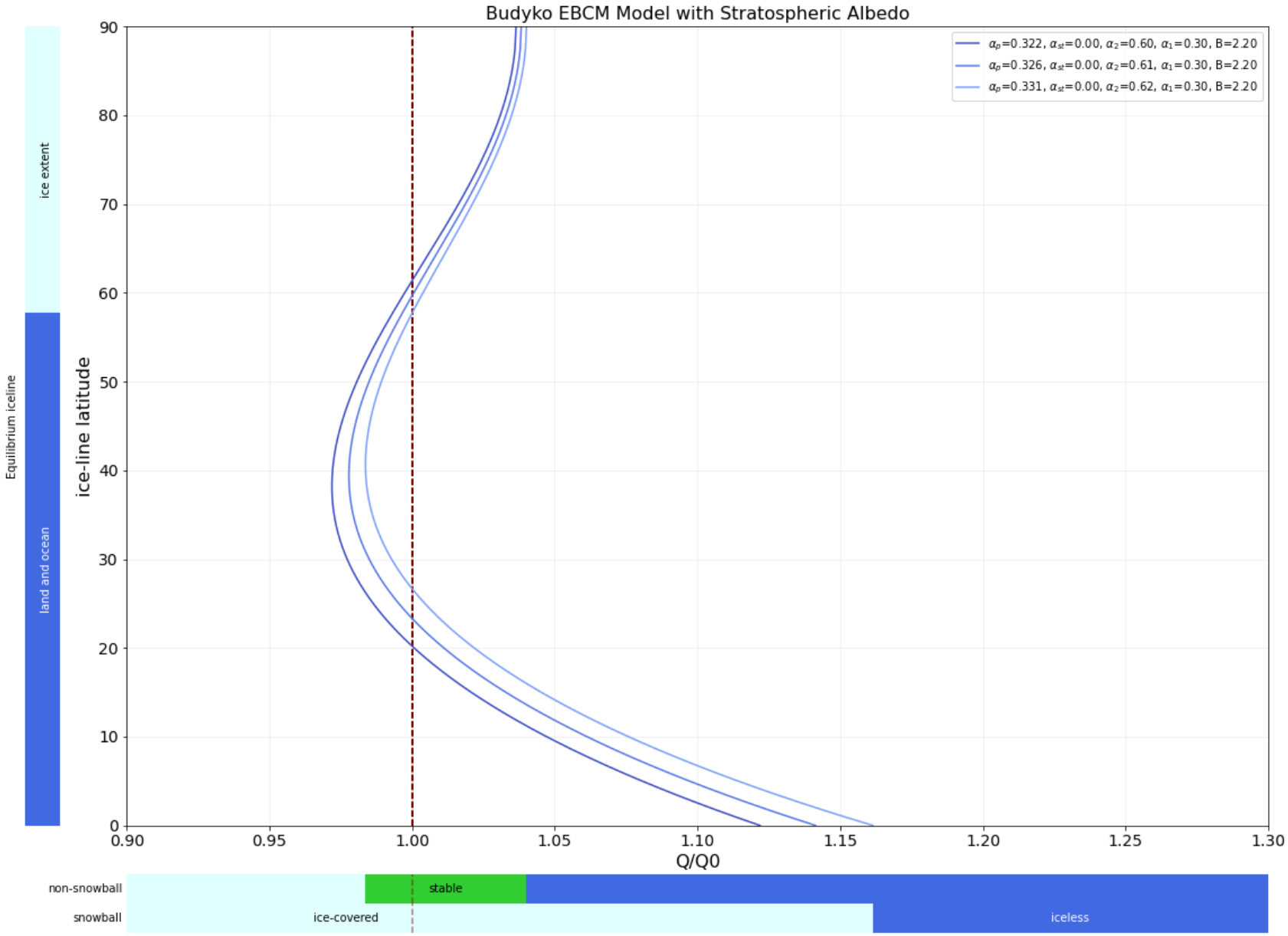

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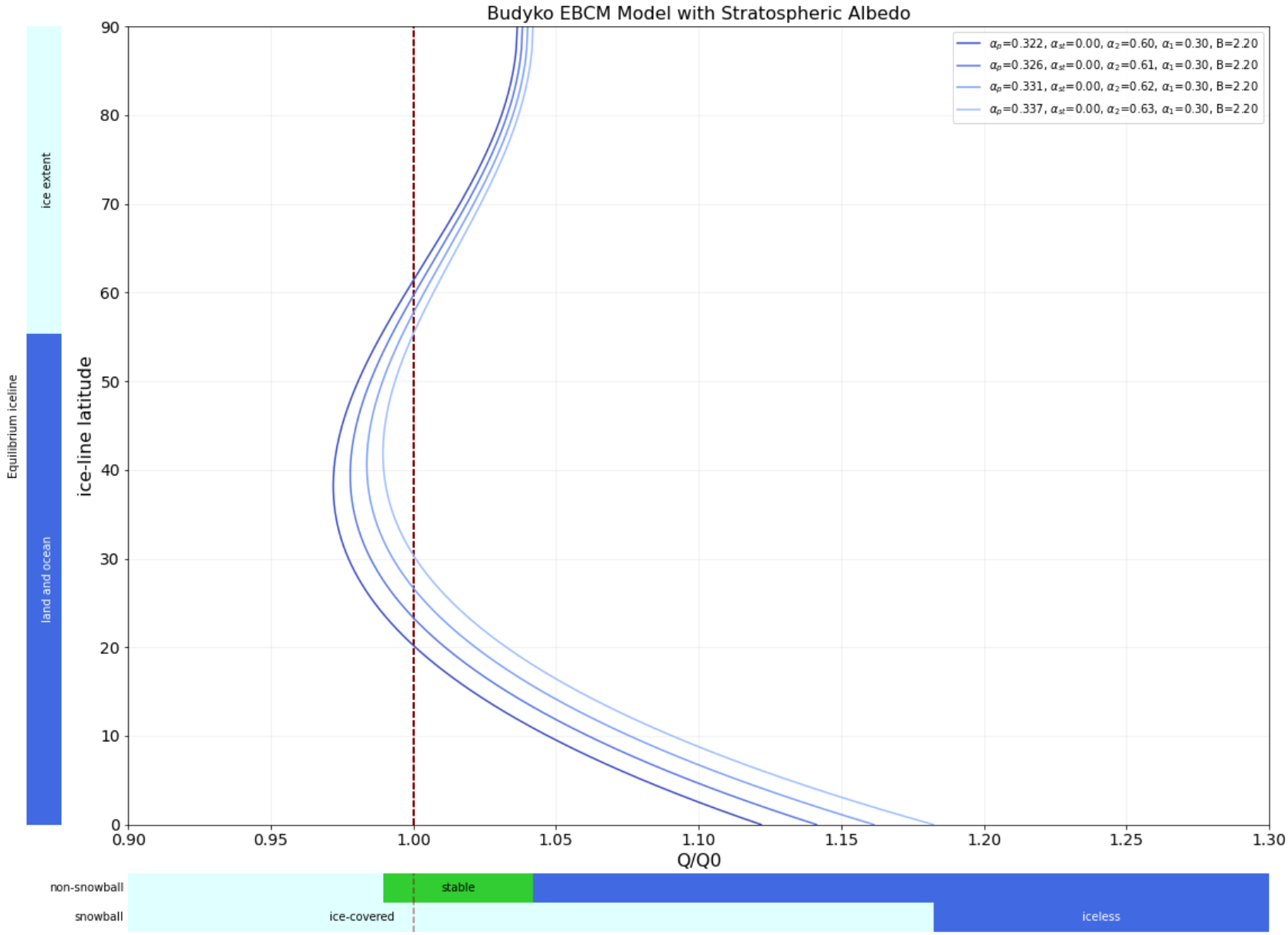

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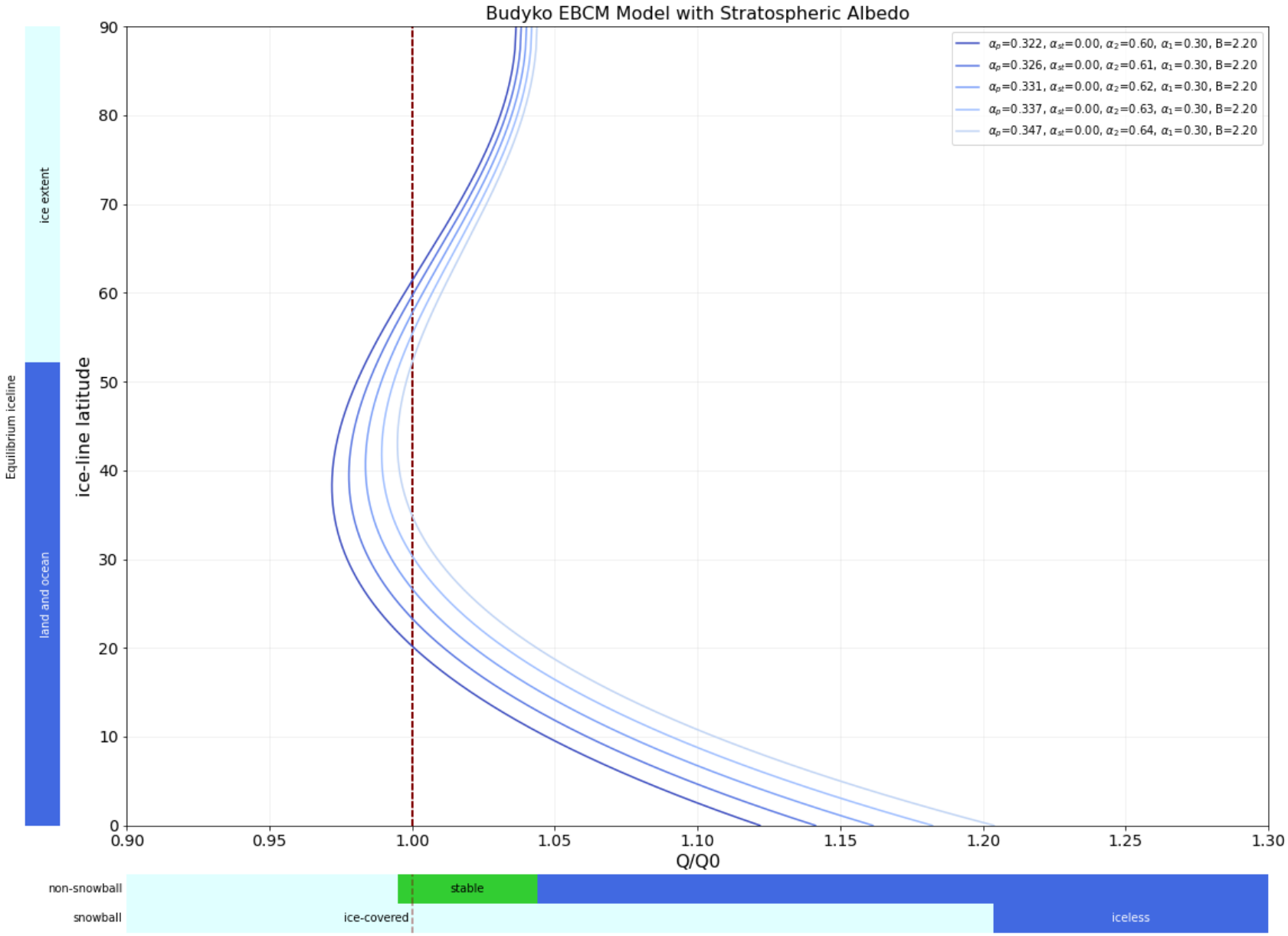

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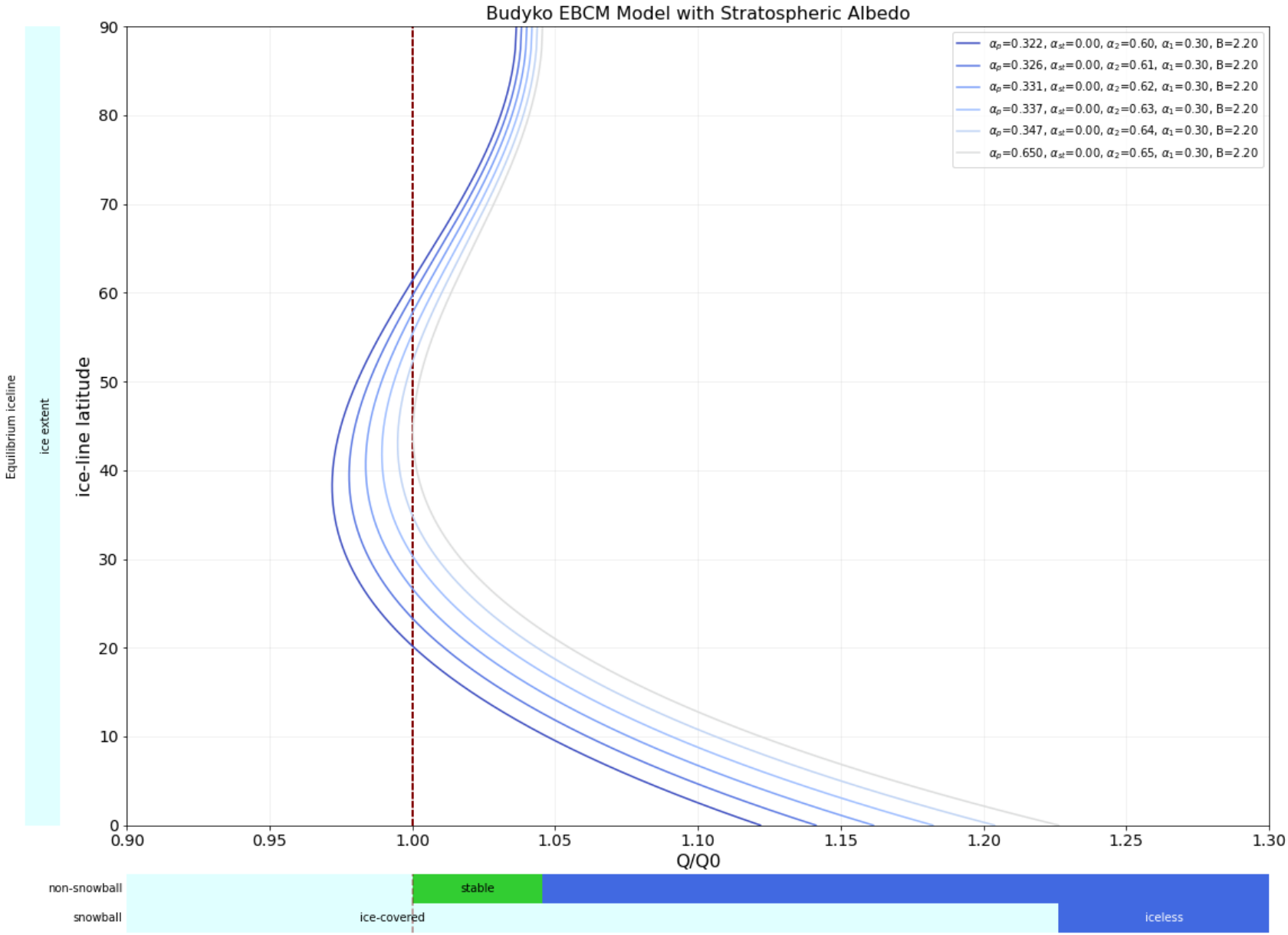

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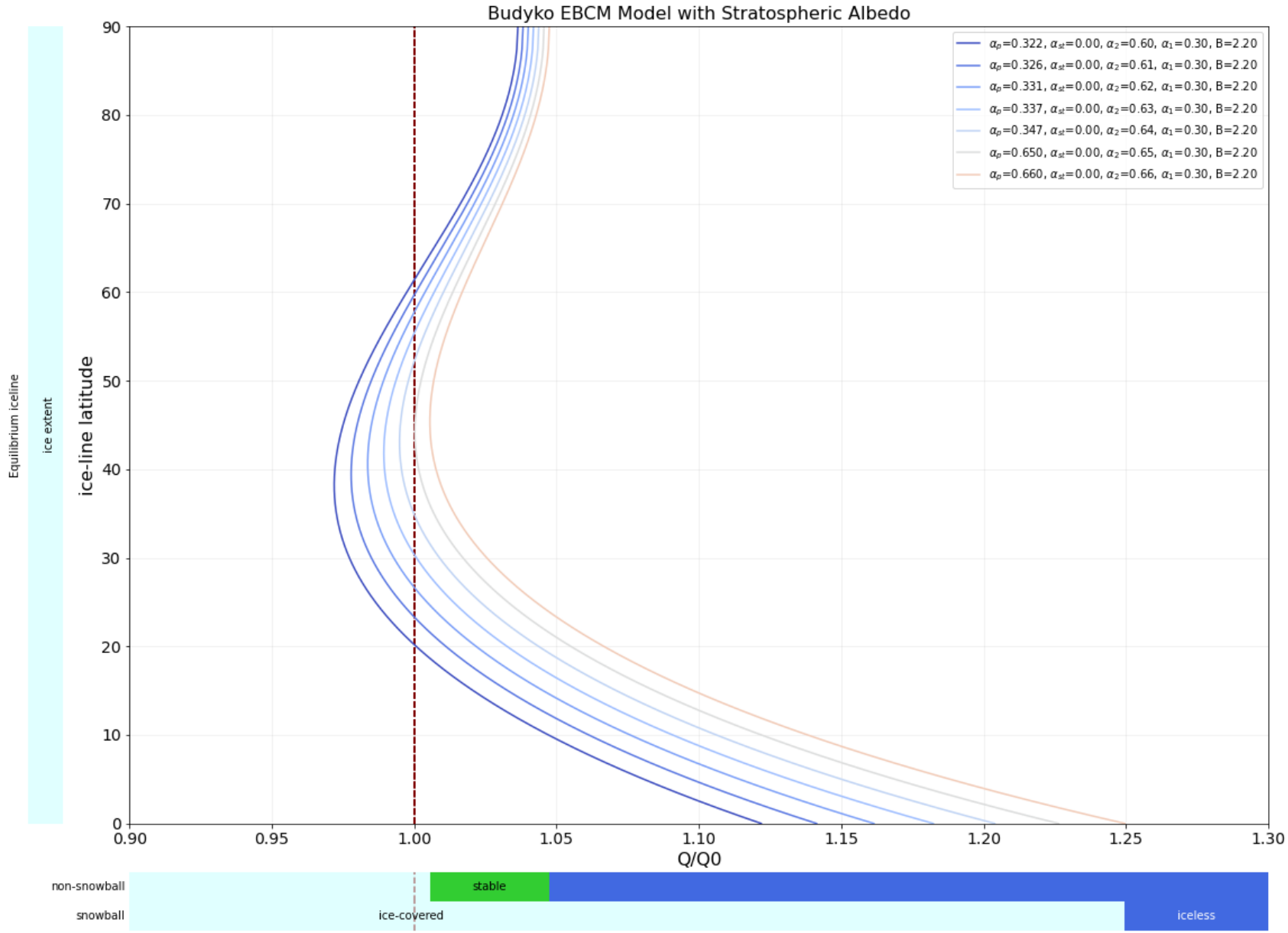

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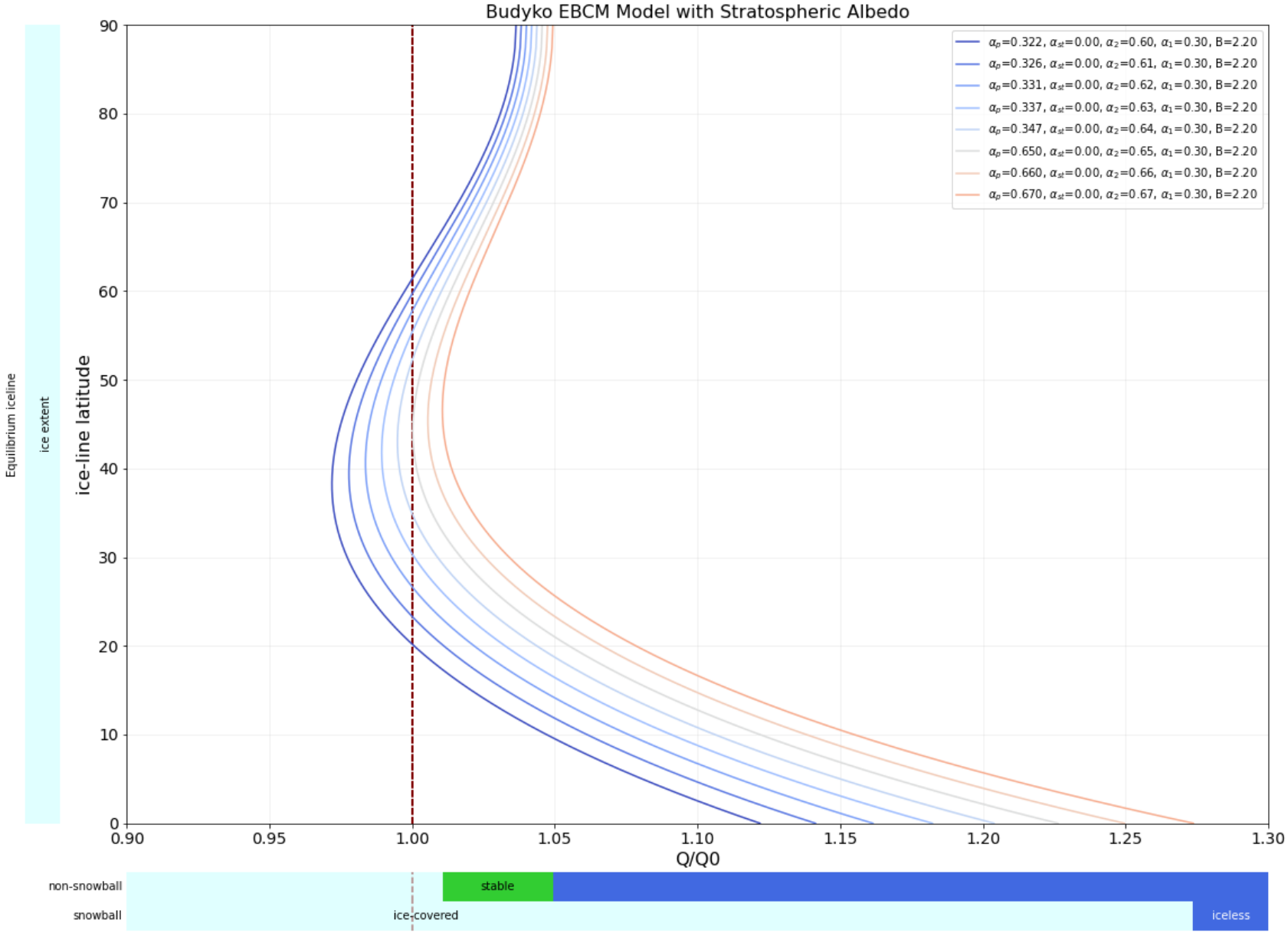
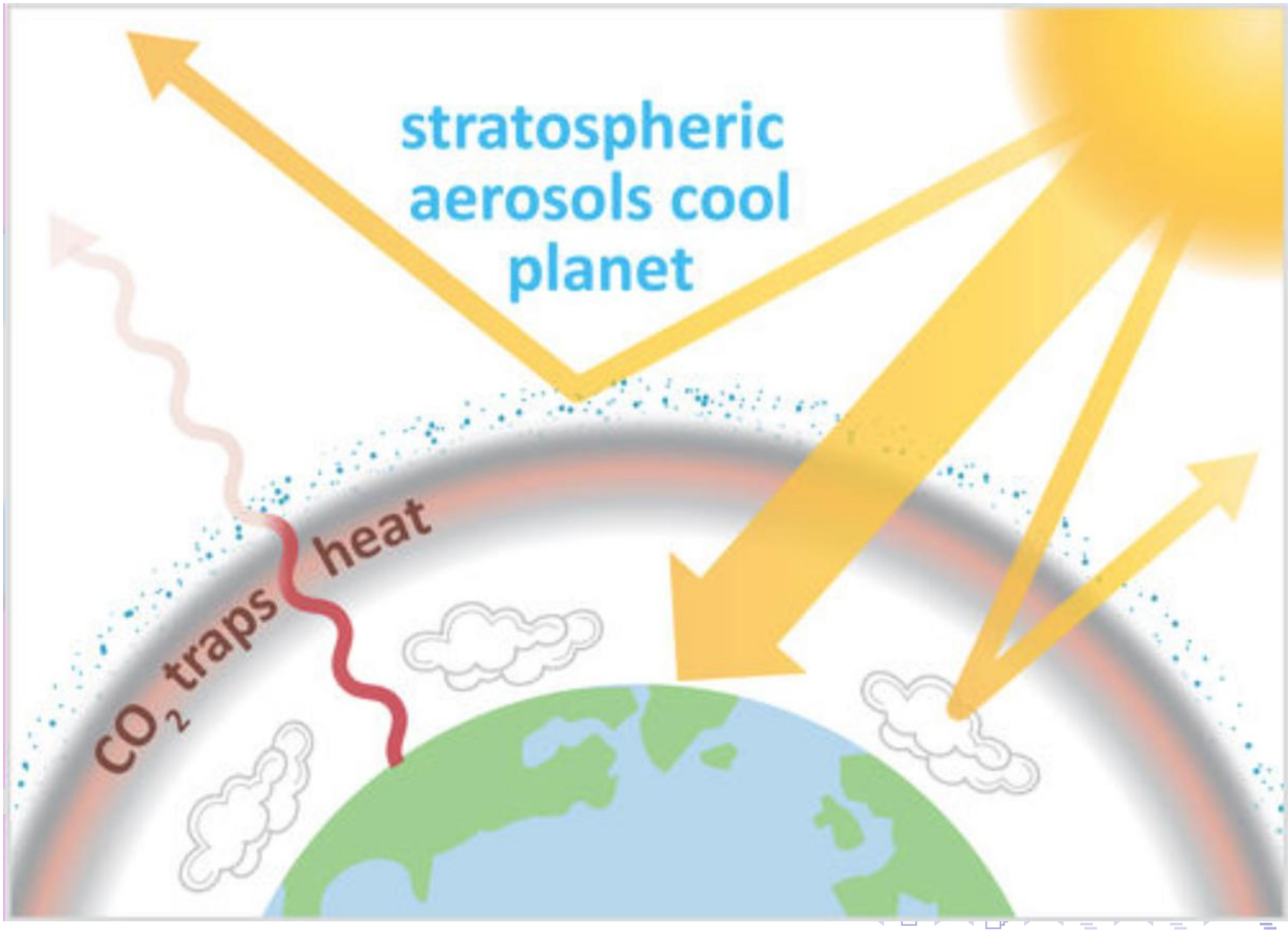


A volcanic mechanism to increase albedo

Volcanoes put particulates into *stratosphere* that increase albedo



τ is Optical Depth, $\alpha_{st}(\tau, x_s)$ is Stratospheric Albedo

Adapted equation from Budyko (1969)

$$\frac{Q_0}{4} S(x_s)(1 - \alpha_{st}(x_s, \tau))(1 - \alpha_{su}(x_s)) = A + BT(x_s) + C(T(x_s) - \bar{T})$$

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Assumption: Uniform effect over surface.

$$1 - e^{-\tau m(x)} = \alpha_{st}(x, \tau) = \alpha_{st}(\tau) = 1 - e^{-\tau}$$

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Allowing us to calculate a new planetary albedo (surface + stratosphere)

$$\alpha'_p = \int_0^1 S(x)[\alpha_{st}(\tau) + \alpha_{su}(x_s) - \alpha_{st}(\tau)\alpha_{su}(x_s)]dx,$$

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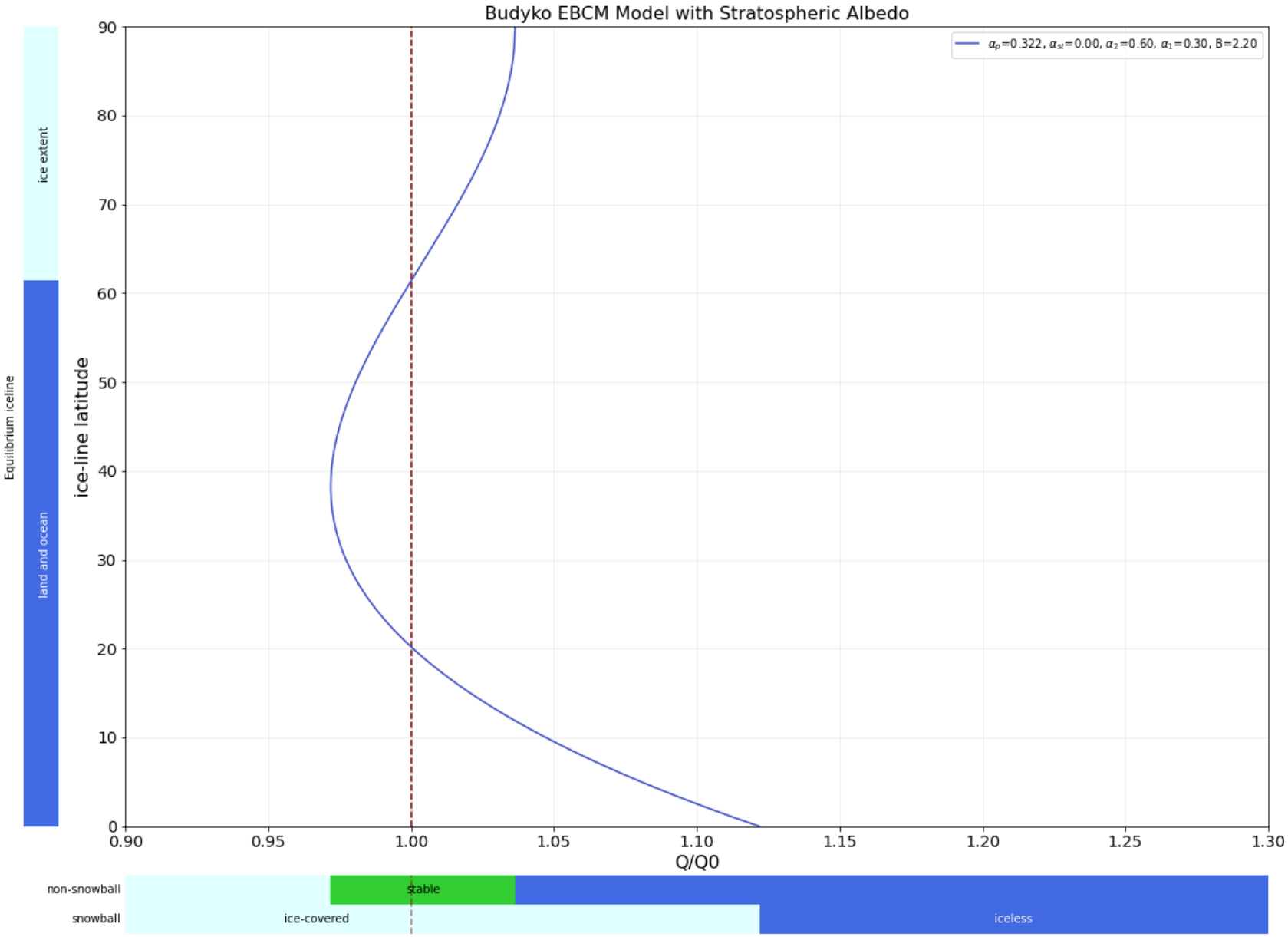
Resulting in a new equation to solve (Roe and Baker 2010)

$$\frac{Q}{4} S(x_s)(1 - \alpha_{su})(1 - \alpha_{st}) + \frac{QC}{4B}(1 - \alpha'_p) = k$$

Increasing τ or α_{st}



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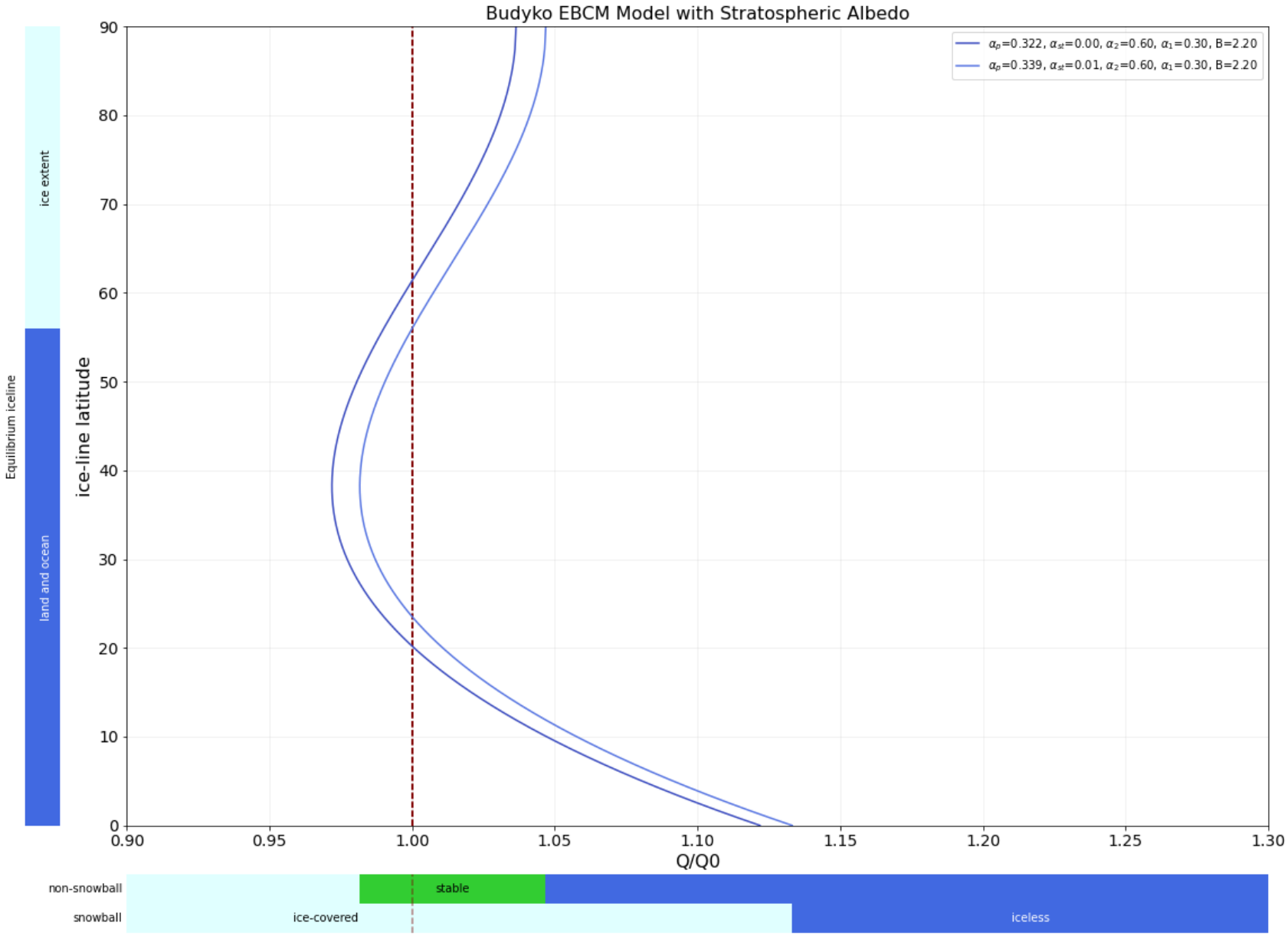

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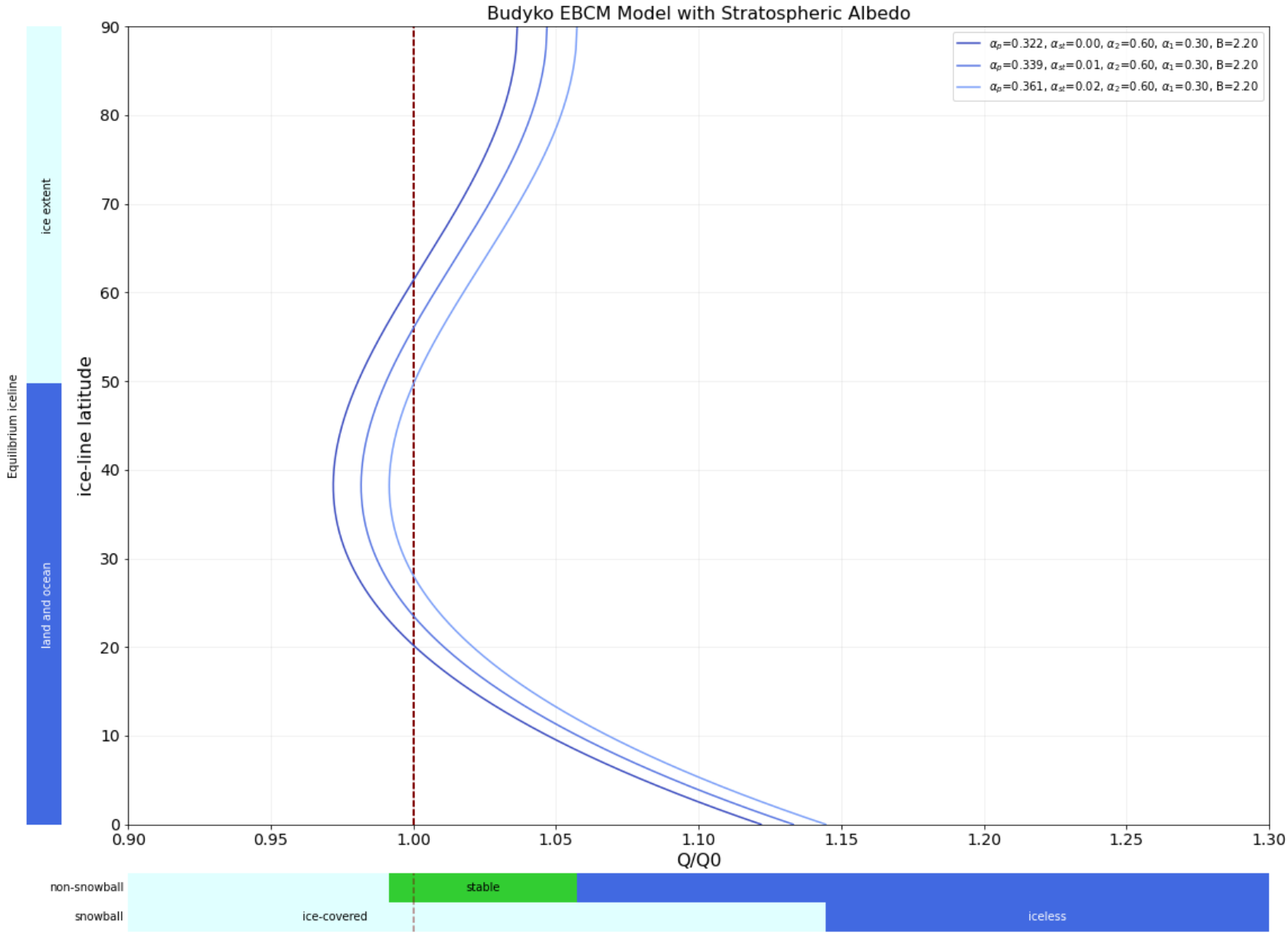

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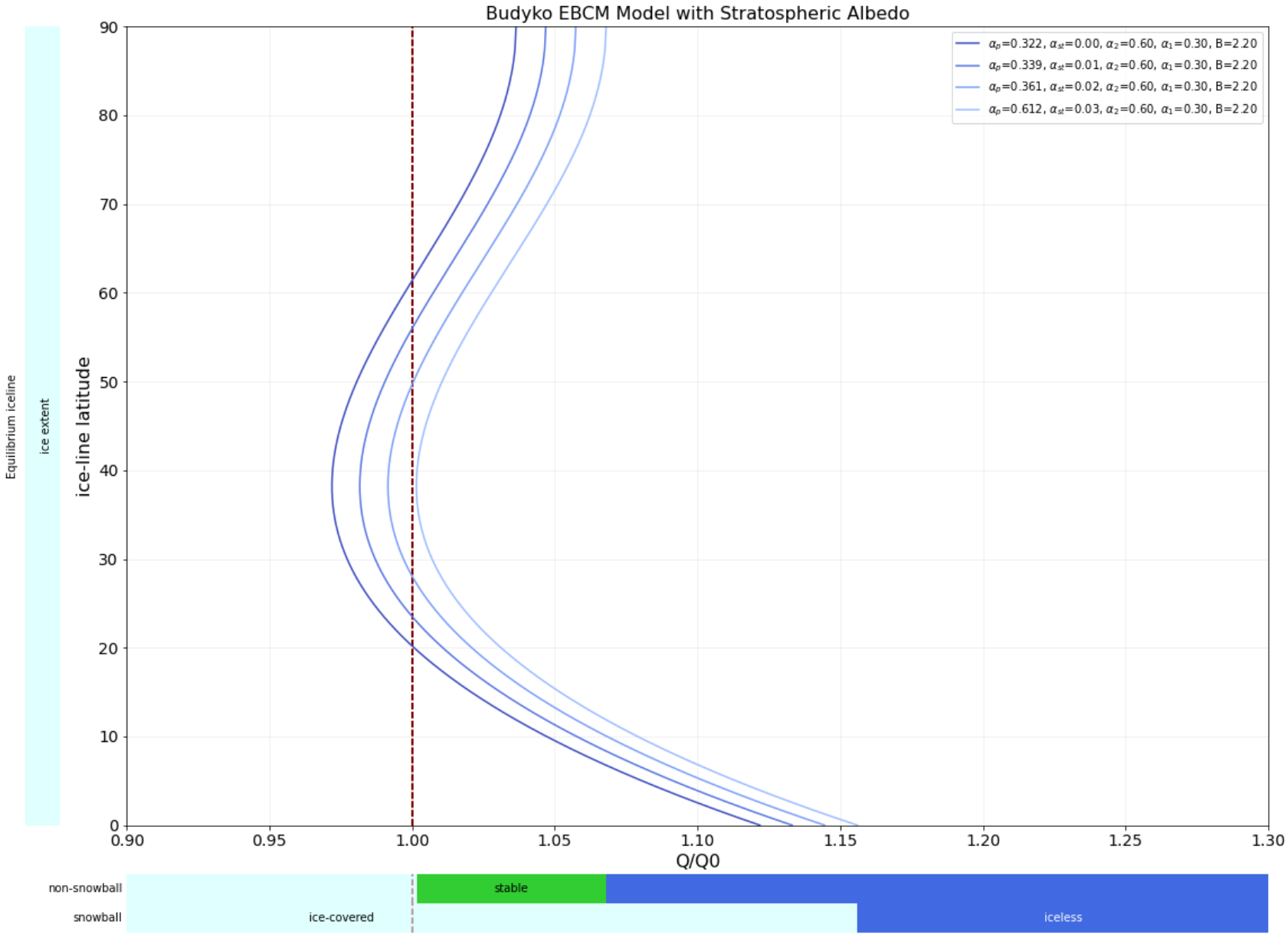

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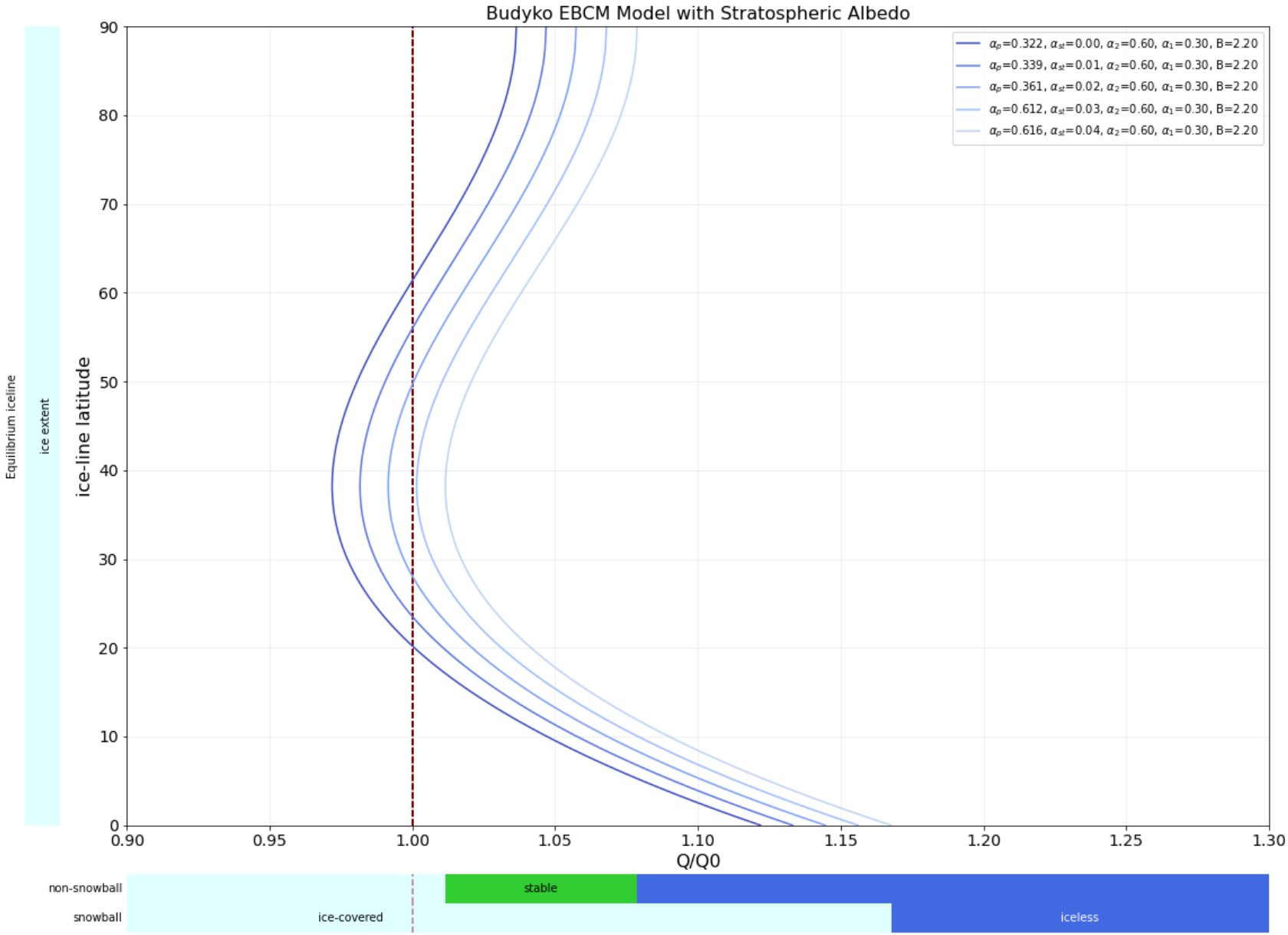

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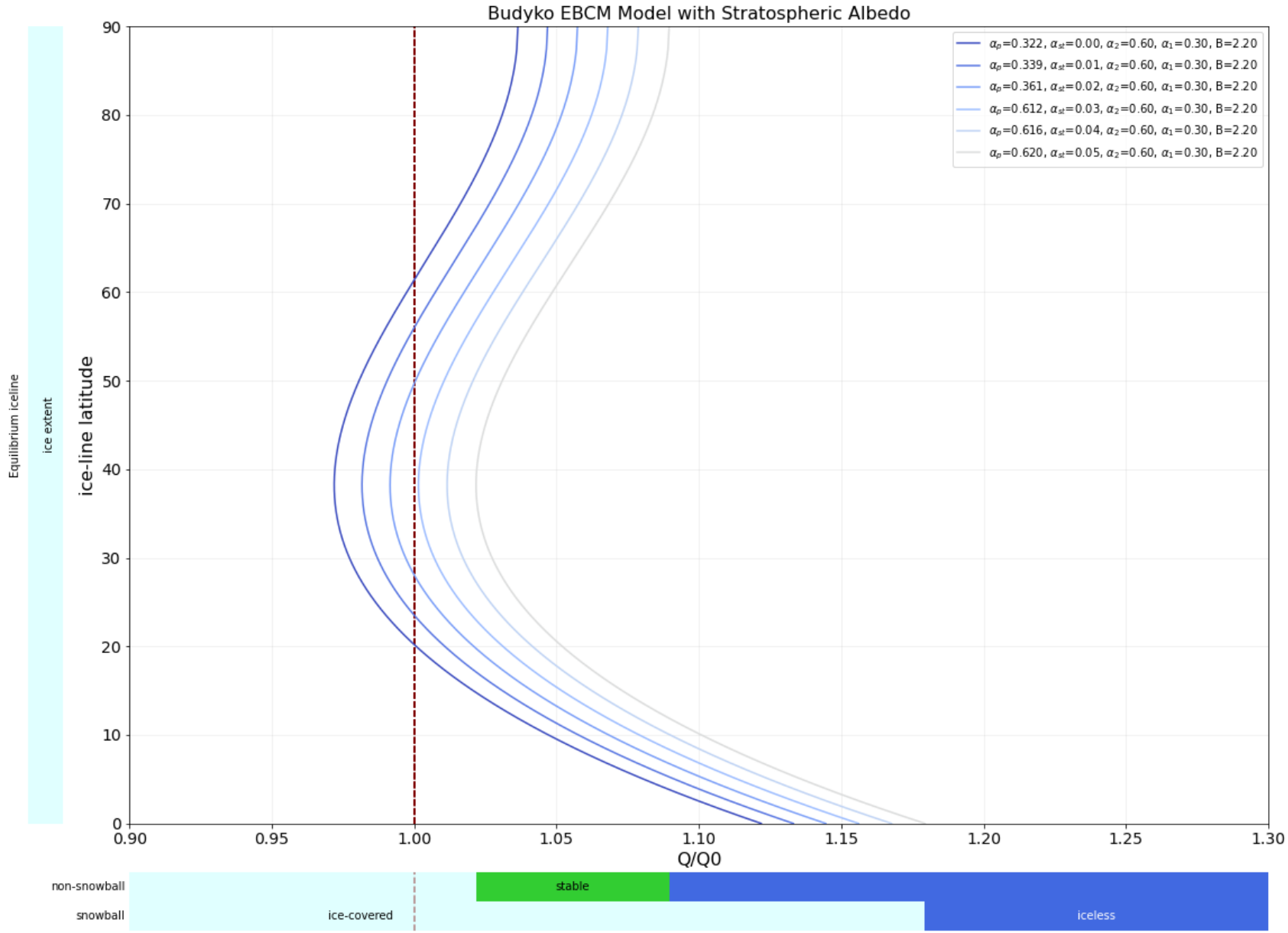

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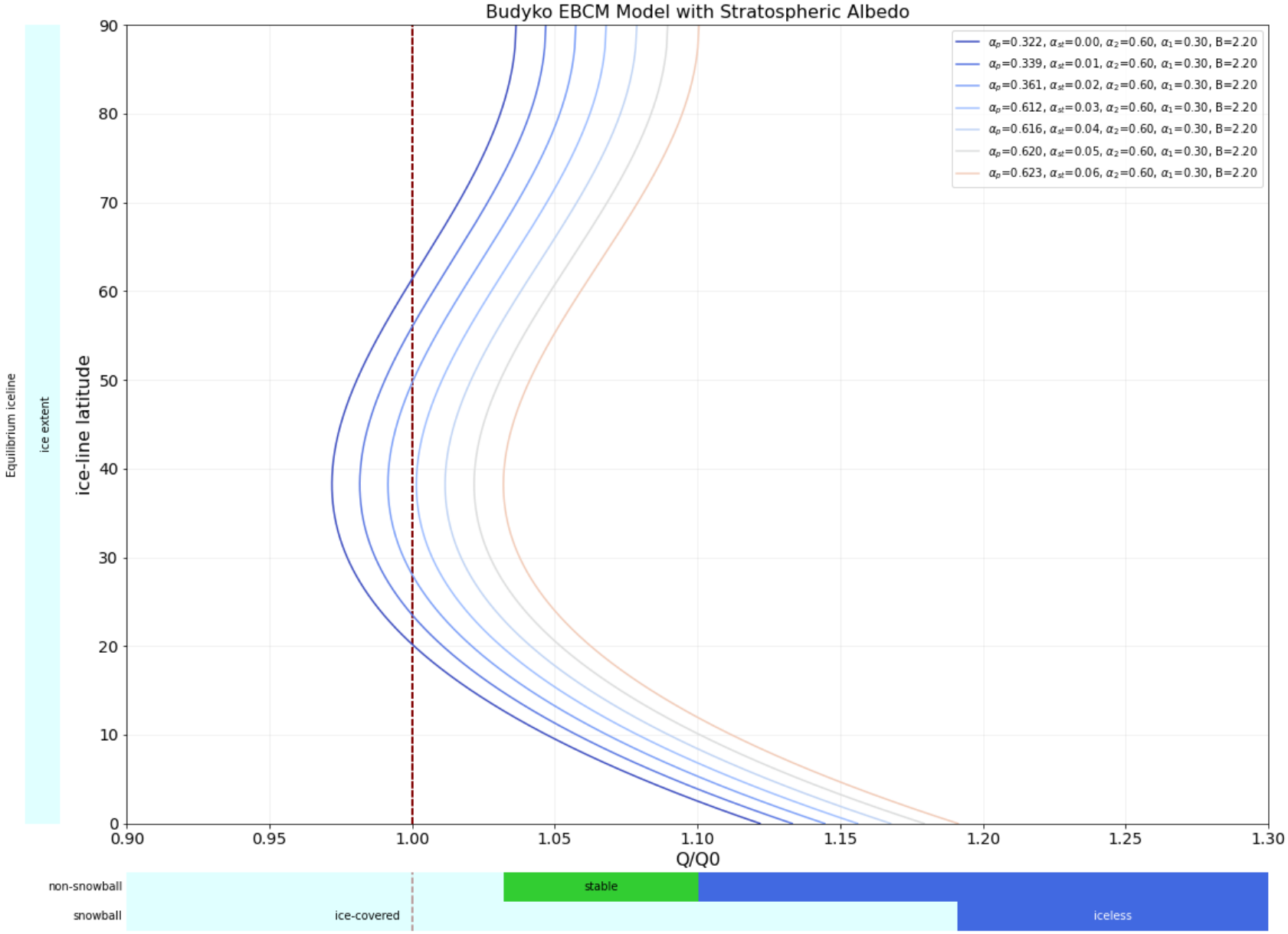
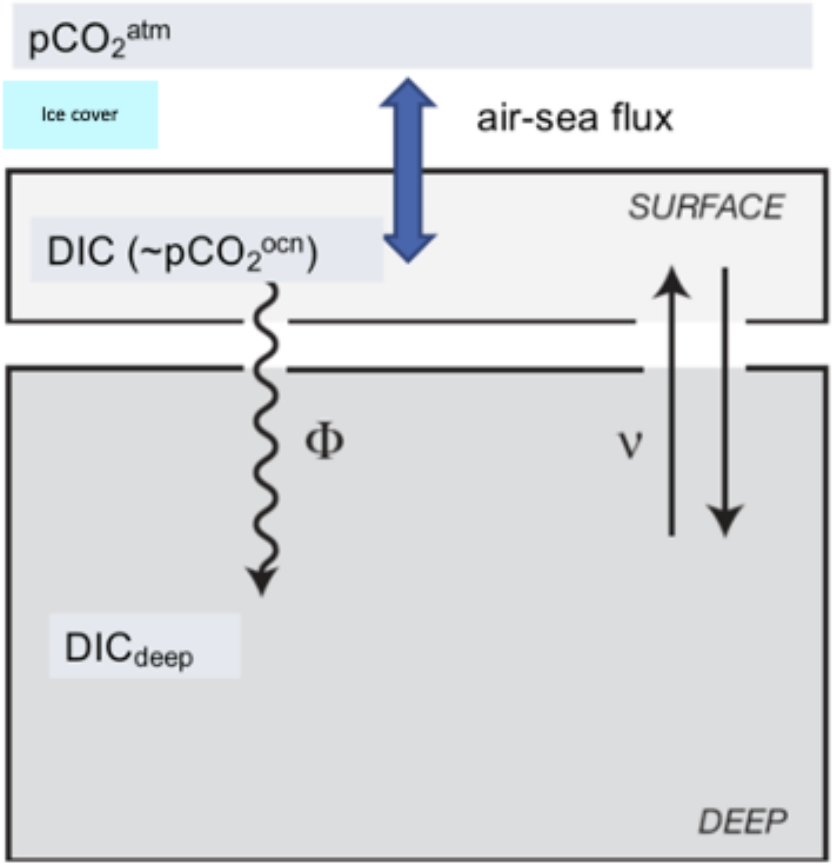


Increasing $CO_2 \approx$ increasing B

Ice sheets block the ocean sink for CO_2



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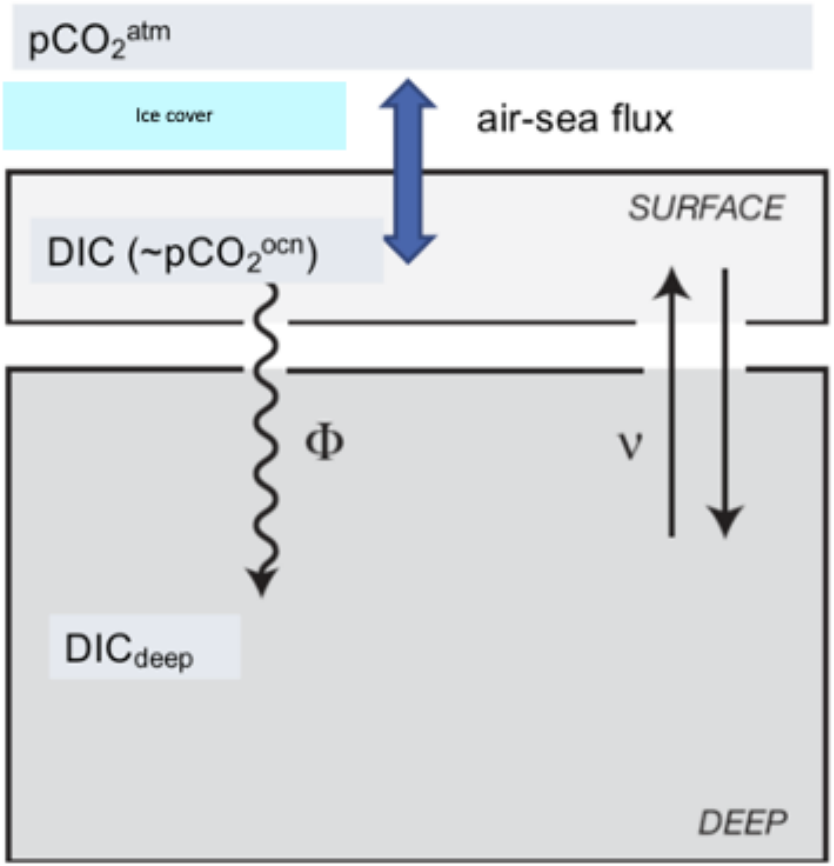
Ice sheets block the ocean sink for CO_2
Increasing CO2 increases $\bar{T}$, increasing OLR or B in the Budyko model.



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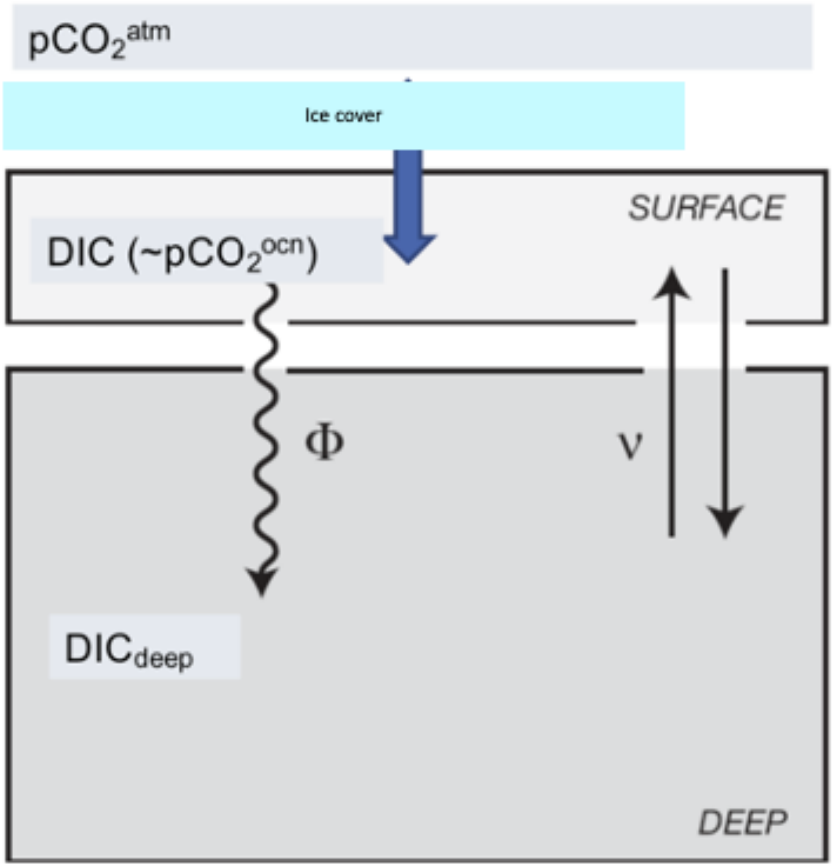

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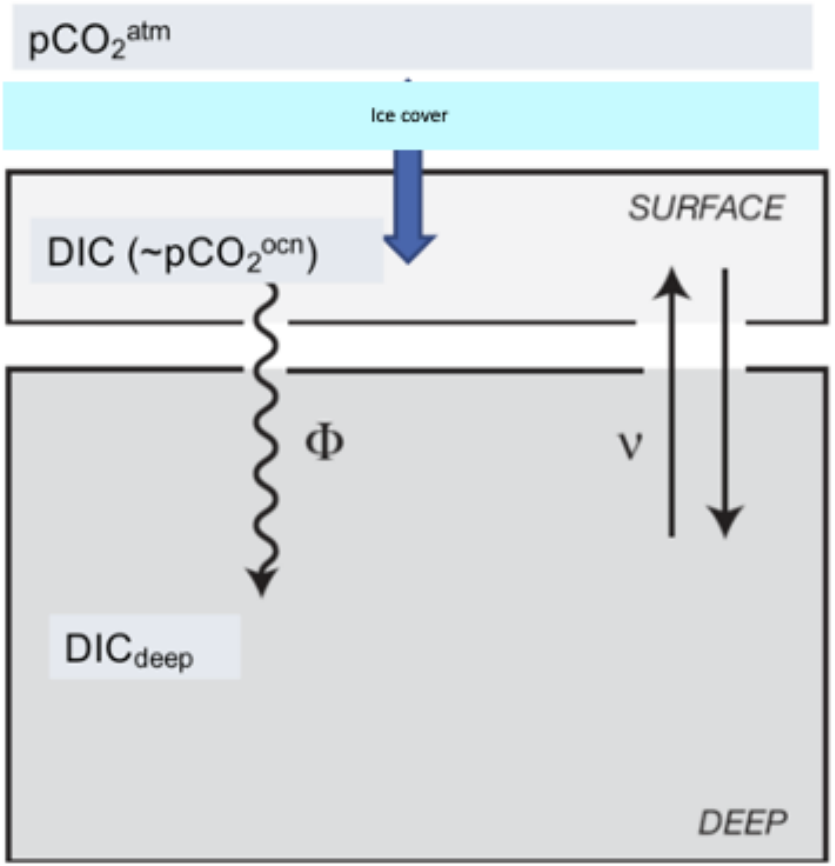
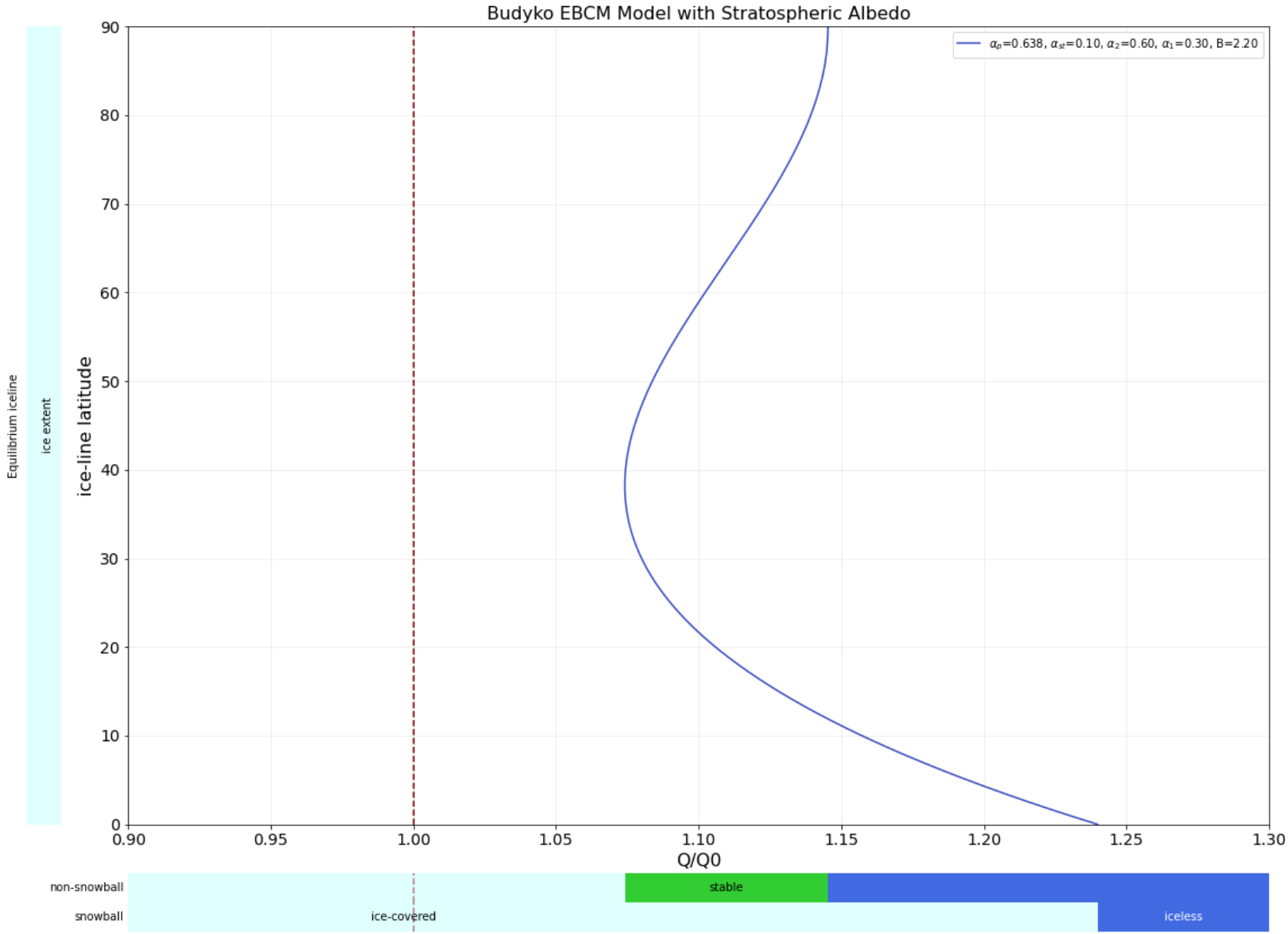


Increasing $CO_2 \rightarrow$ can get us back to a partial-ice world.



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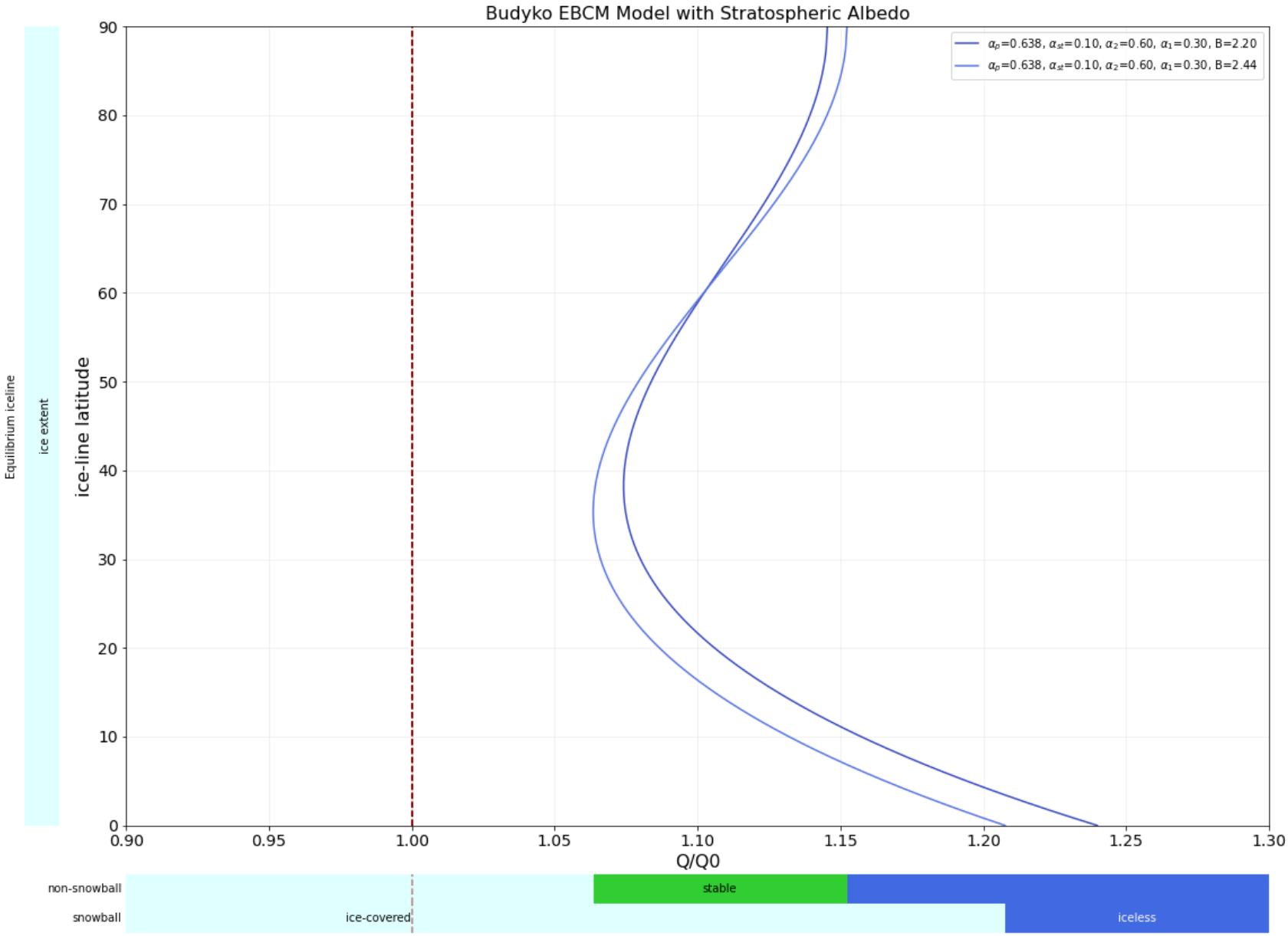

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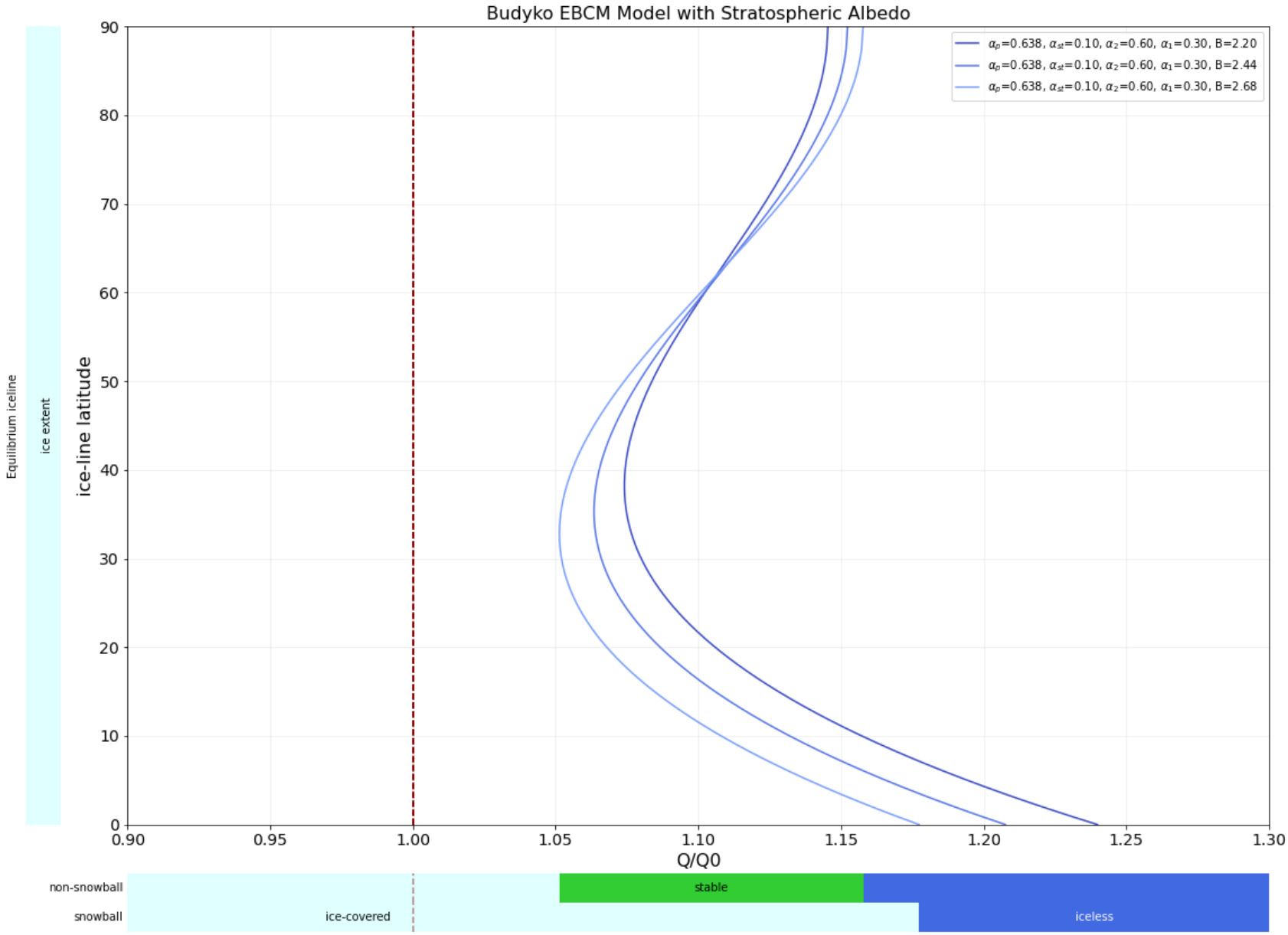

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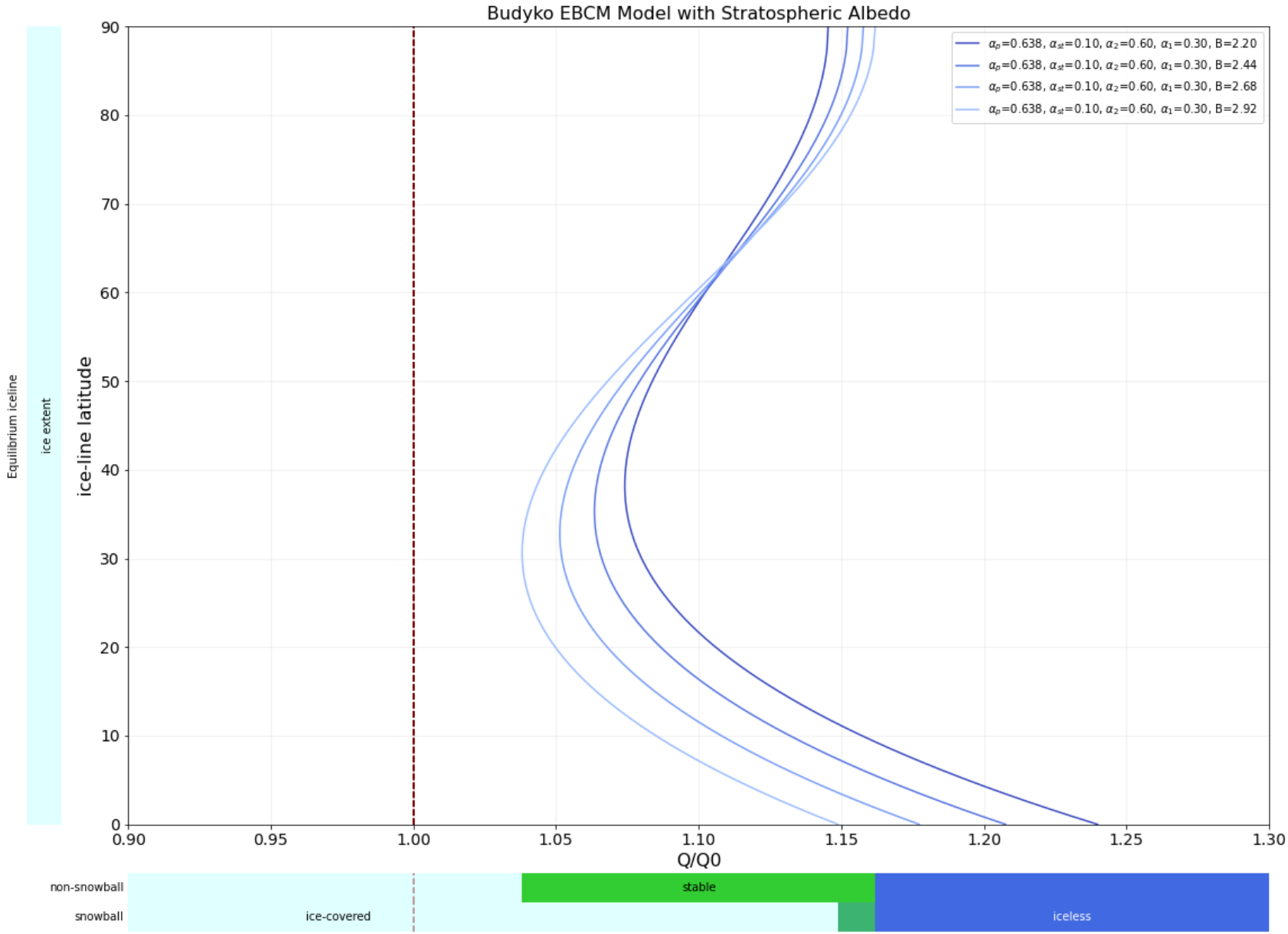

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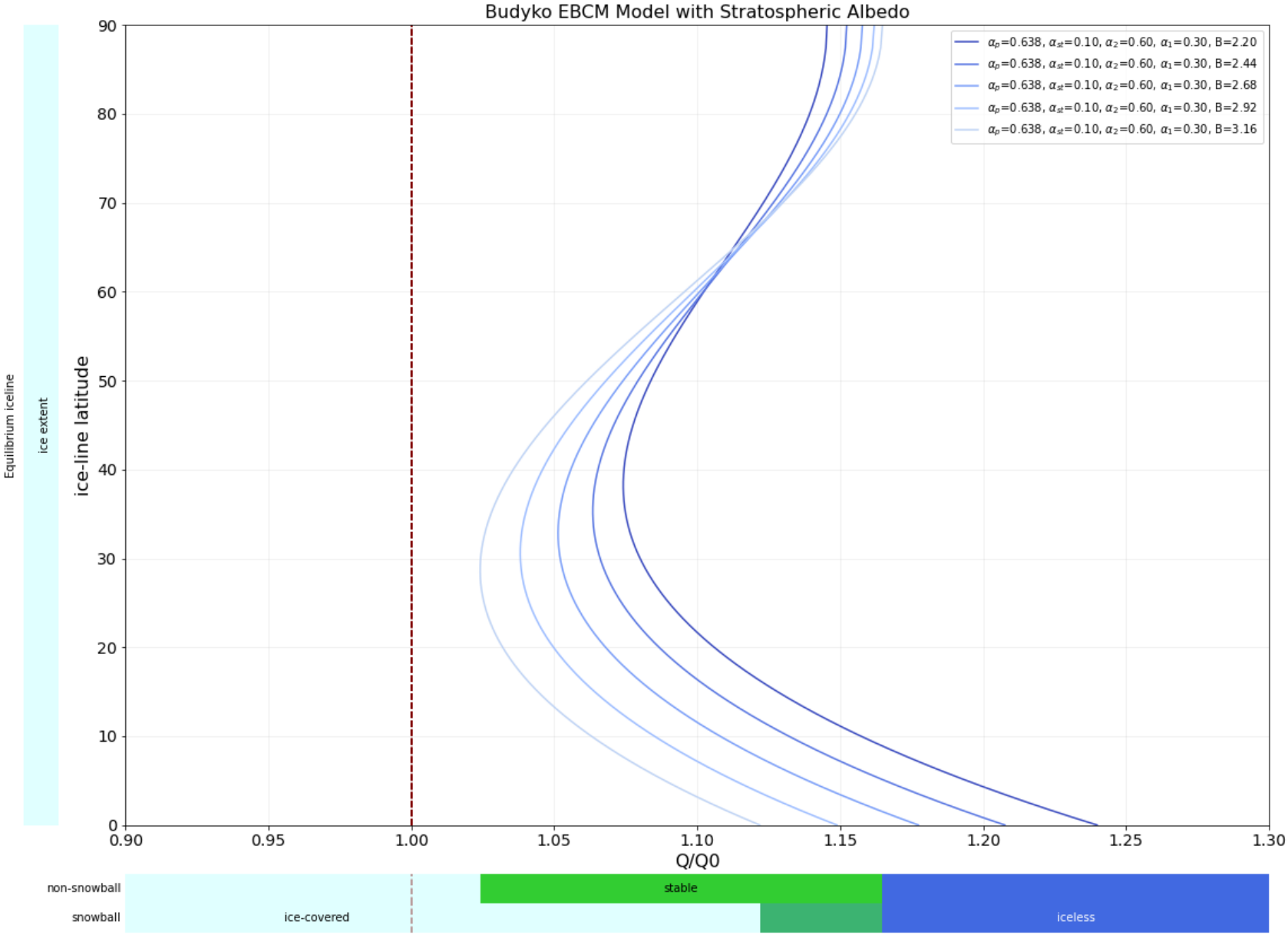

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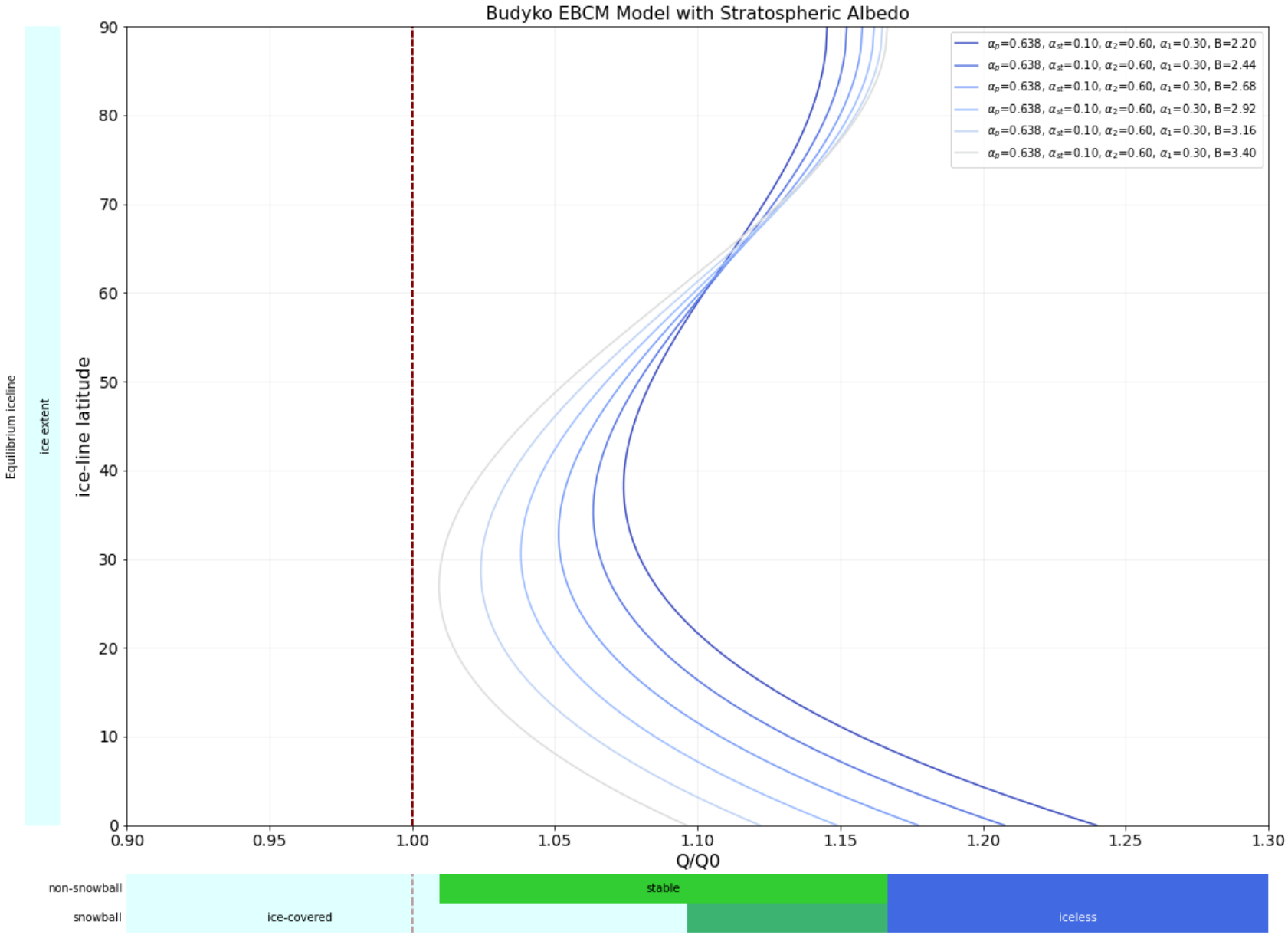

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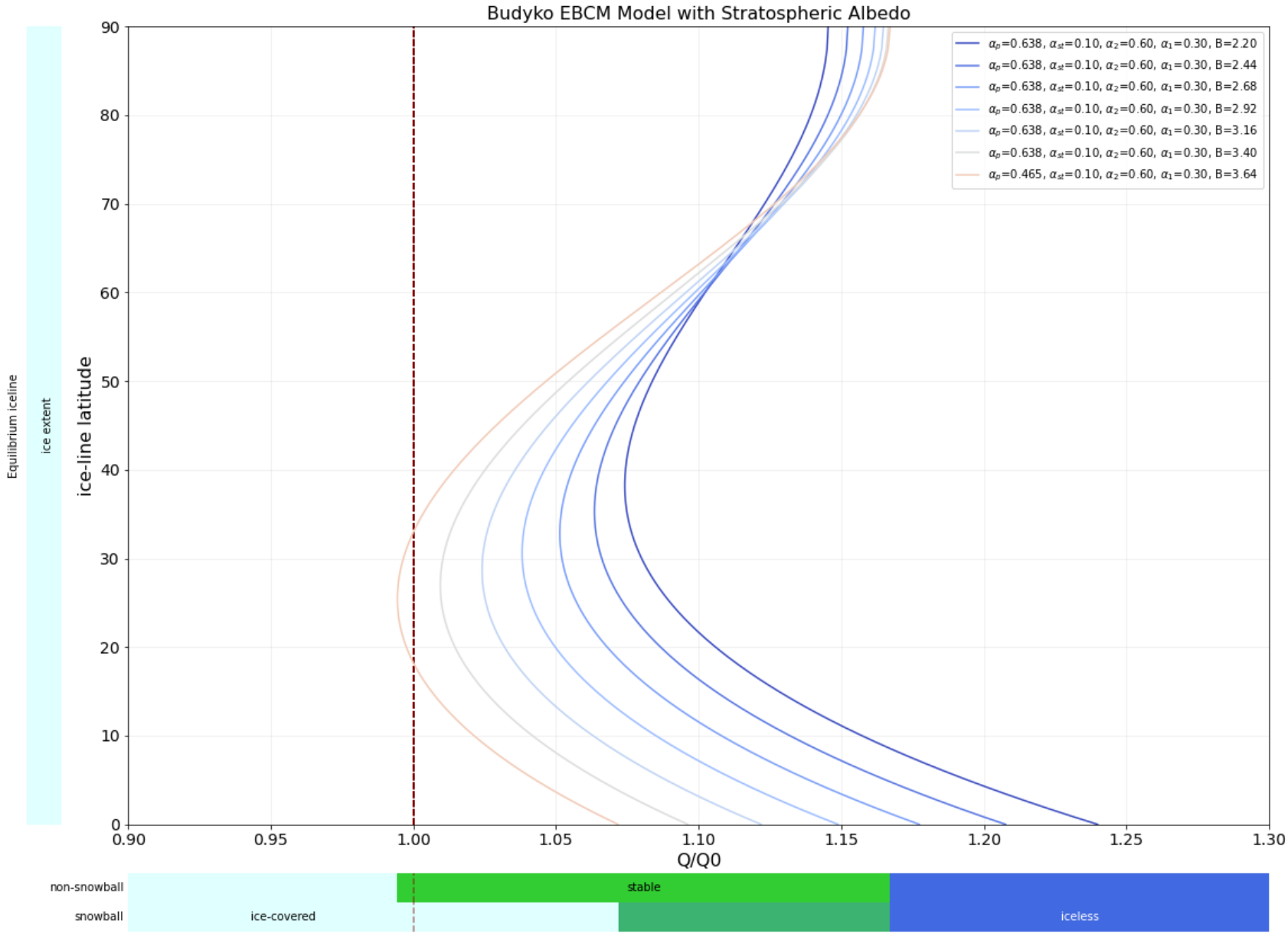

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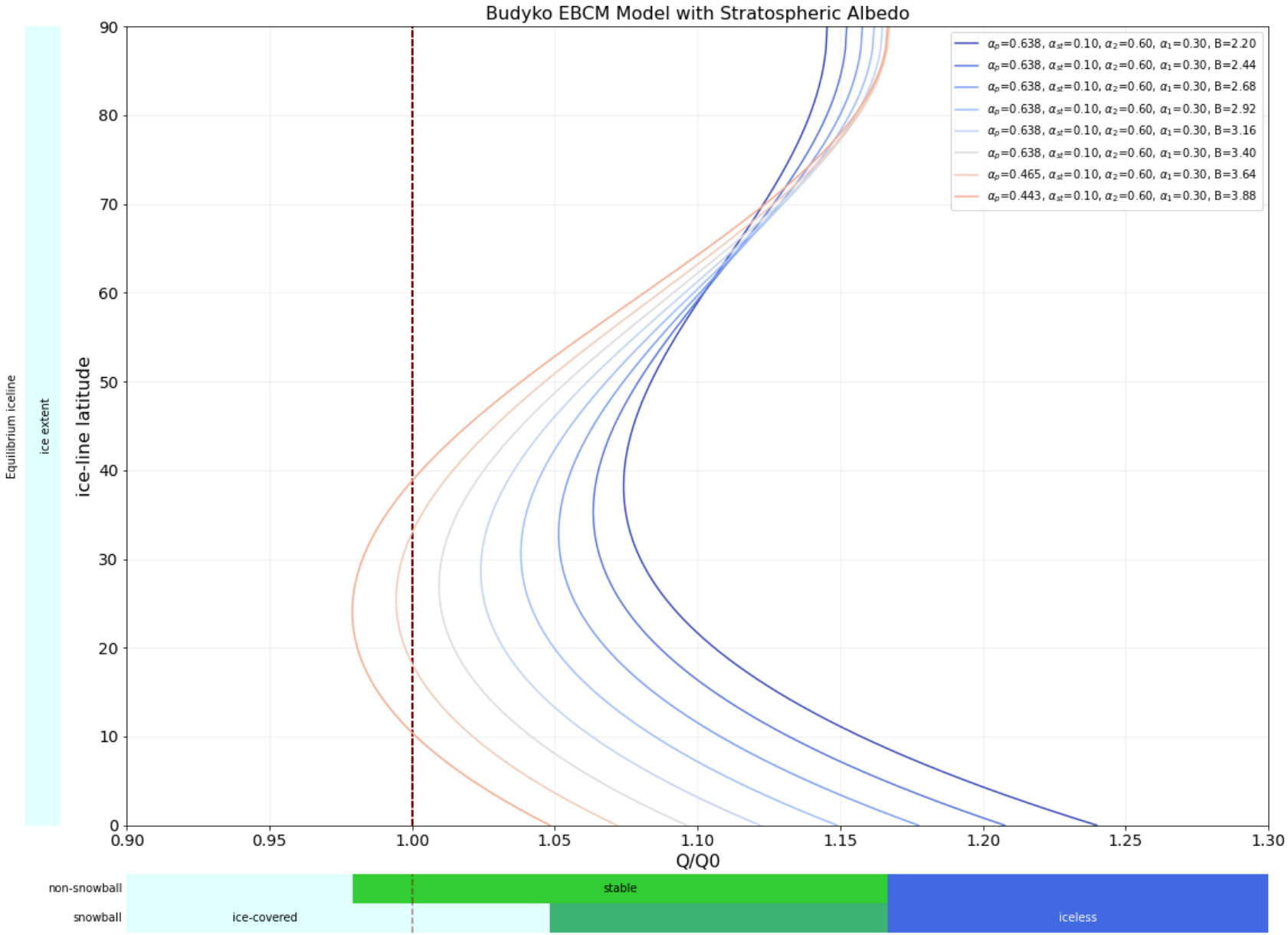

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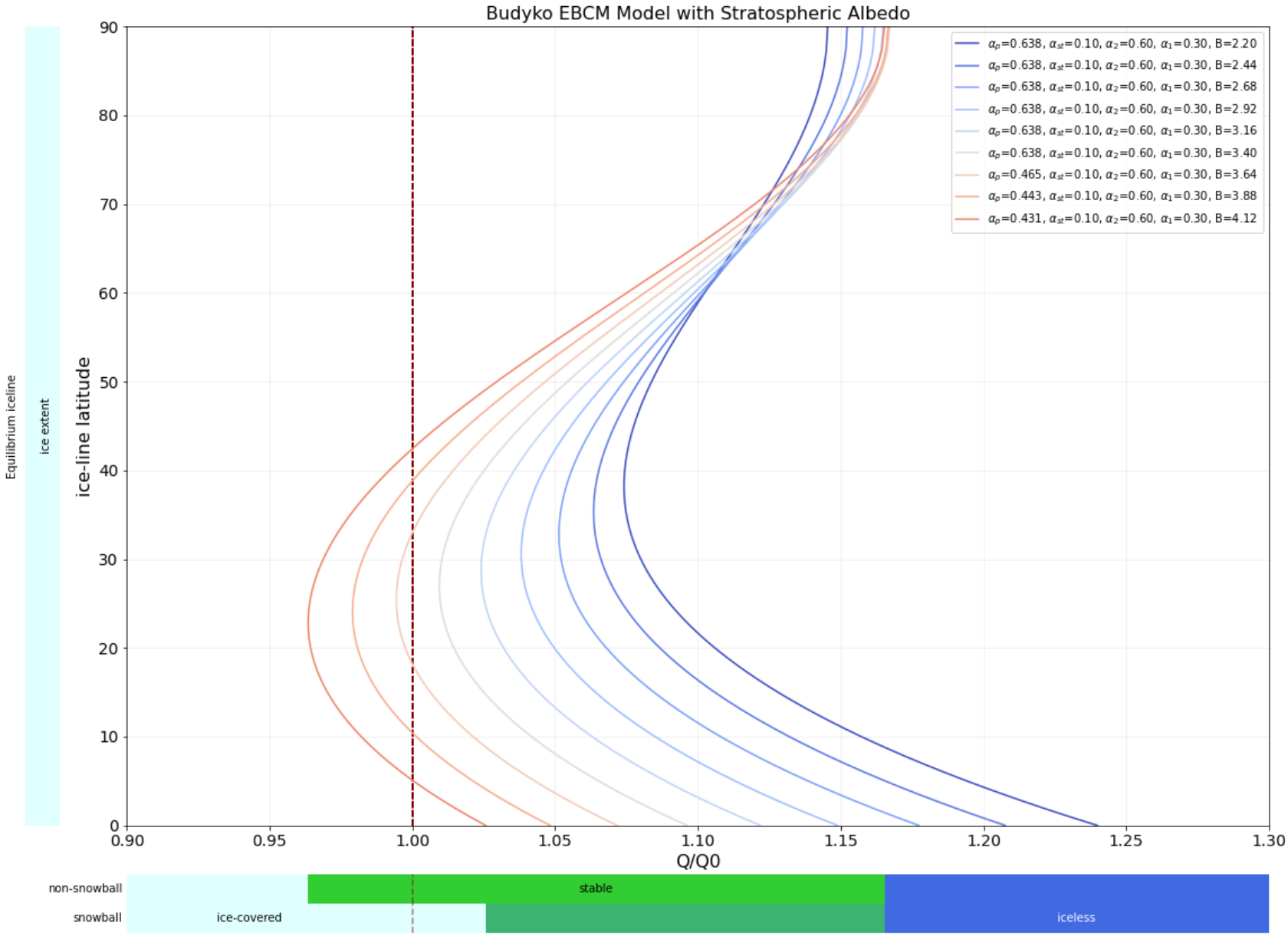

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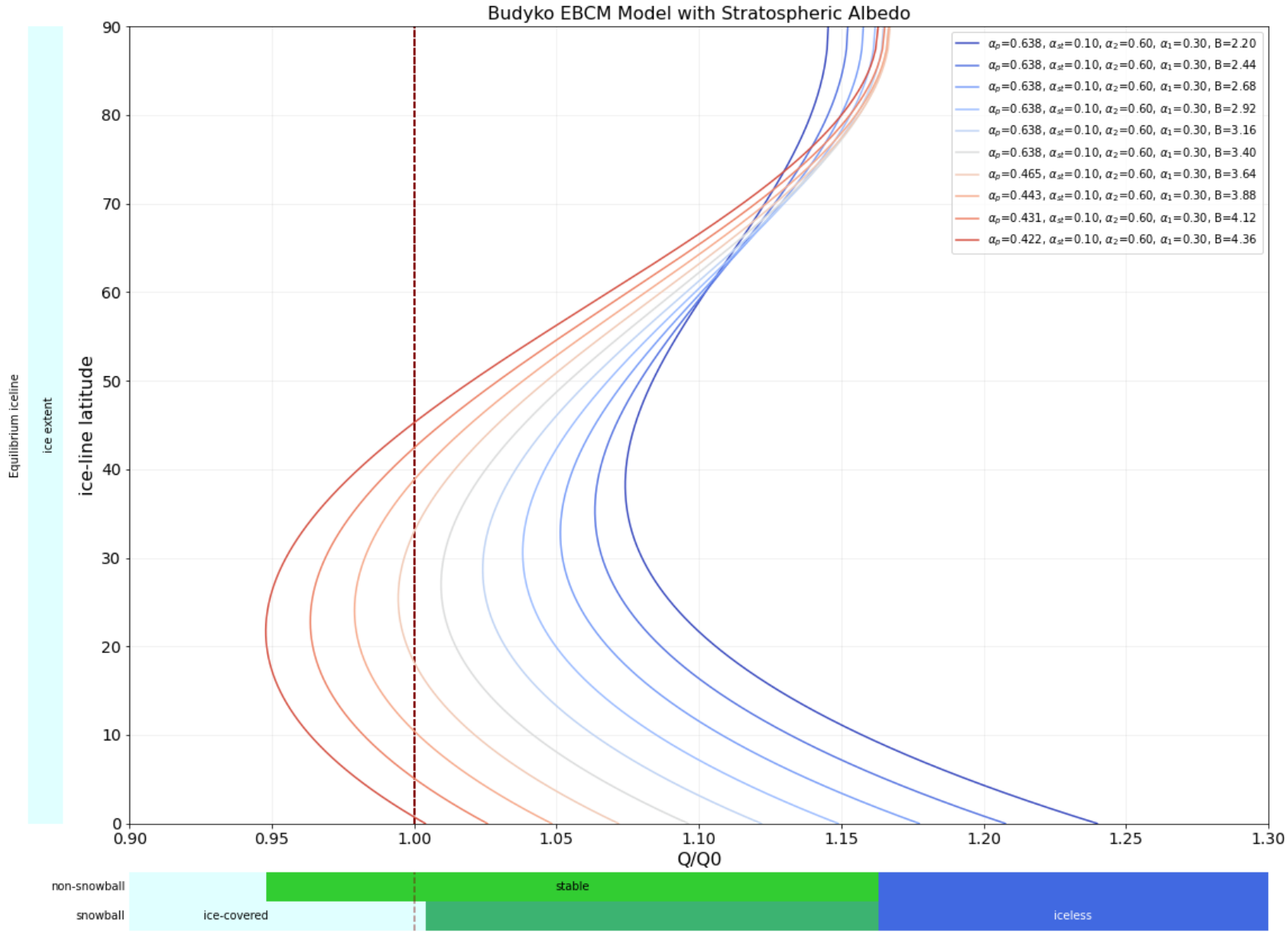

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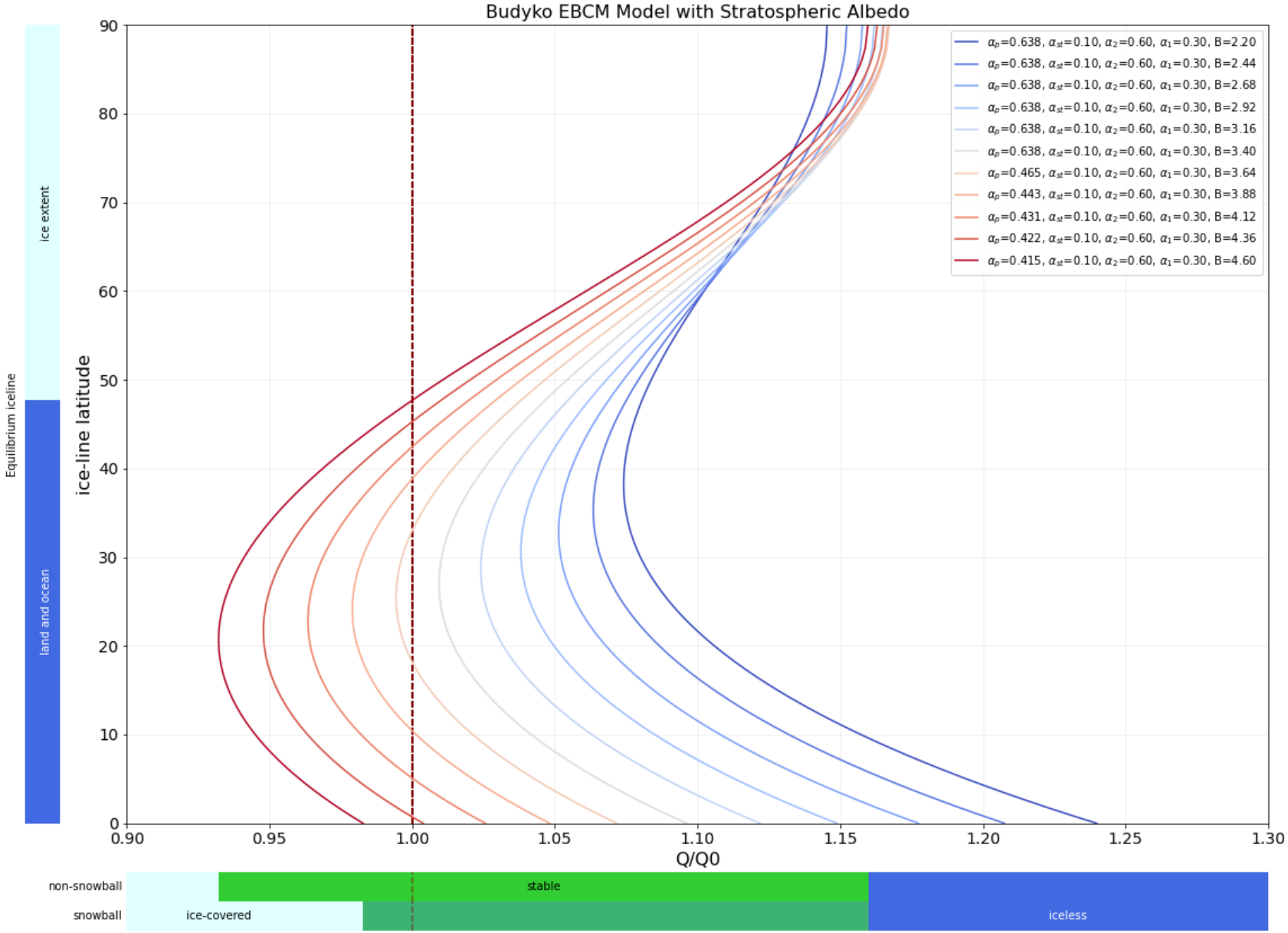
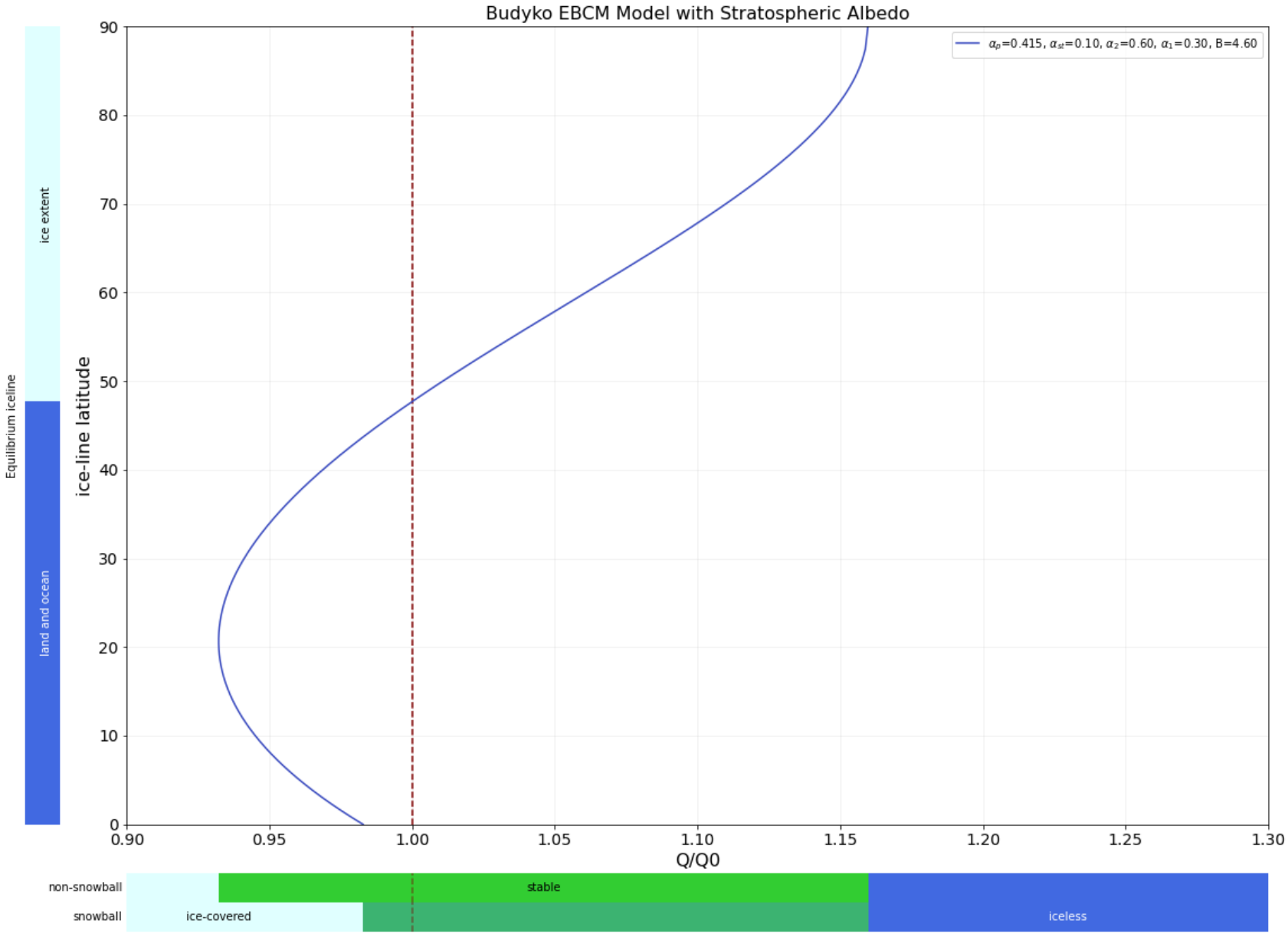


CO2 sink reactivates, causing hysteresis



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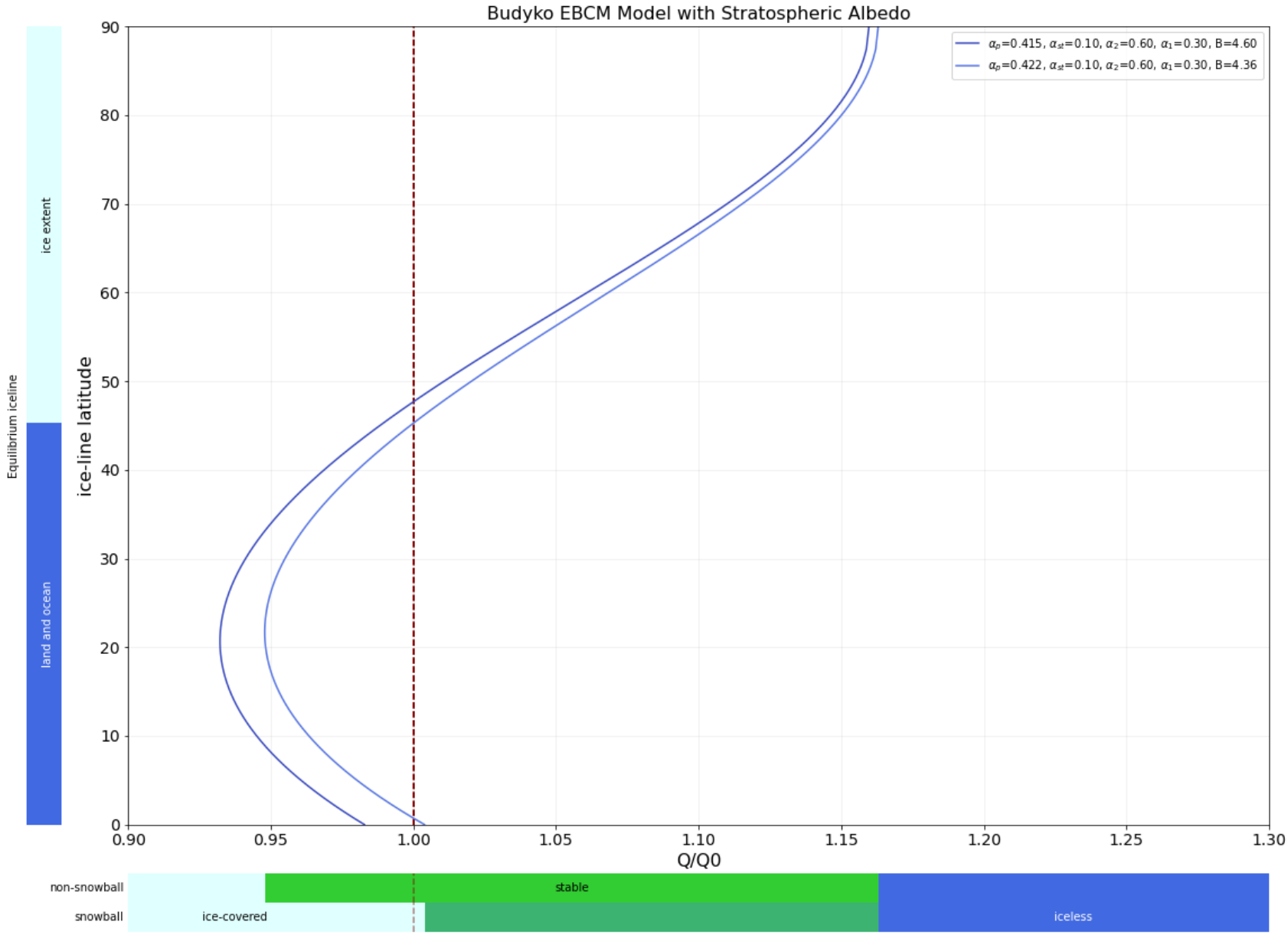

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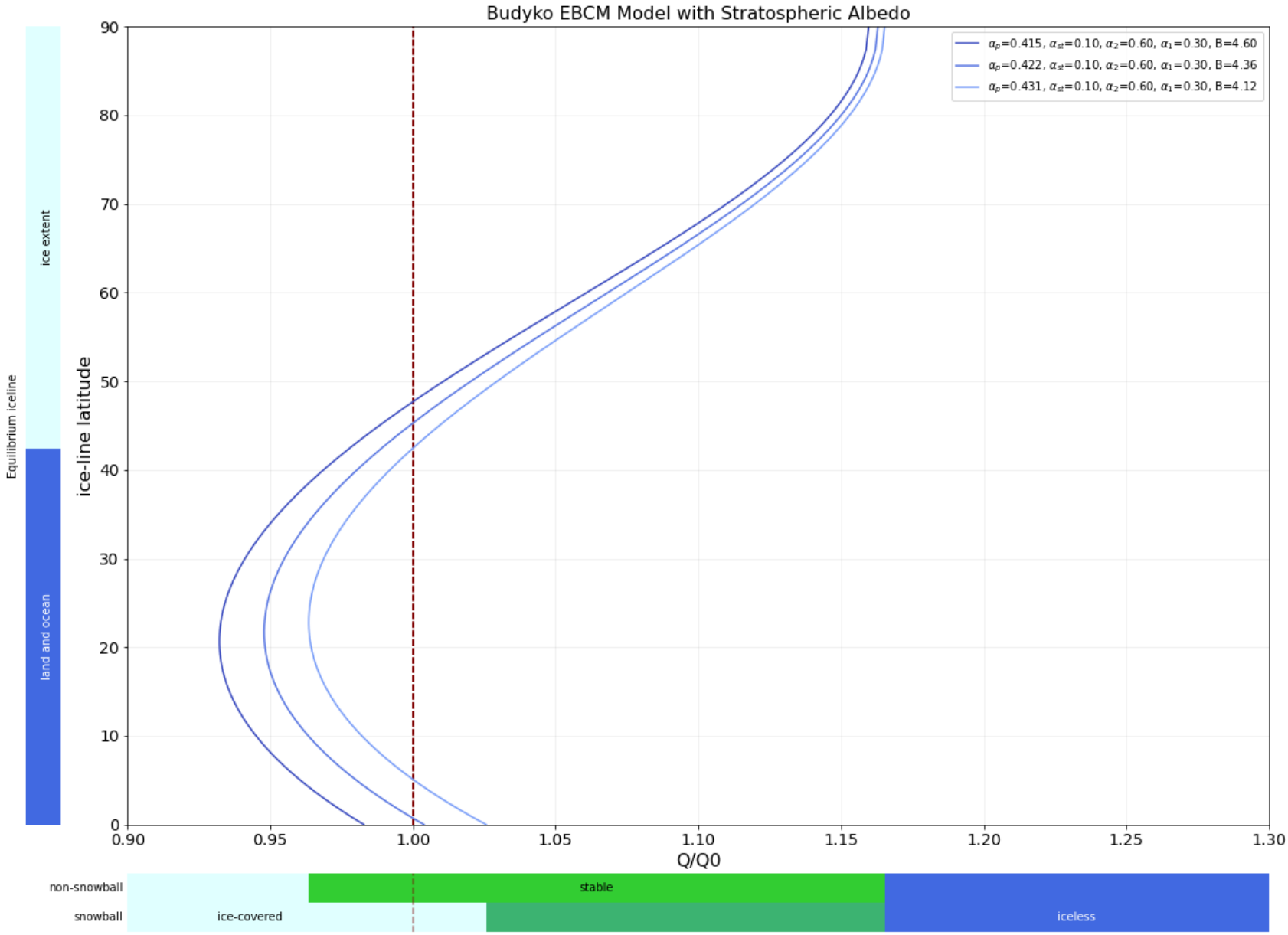

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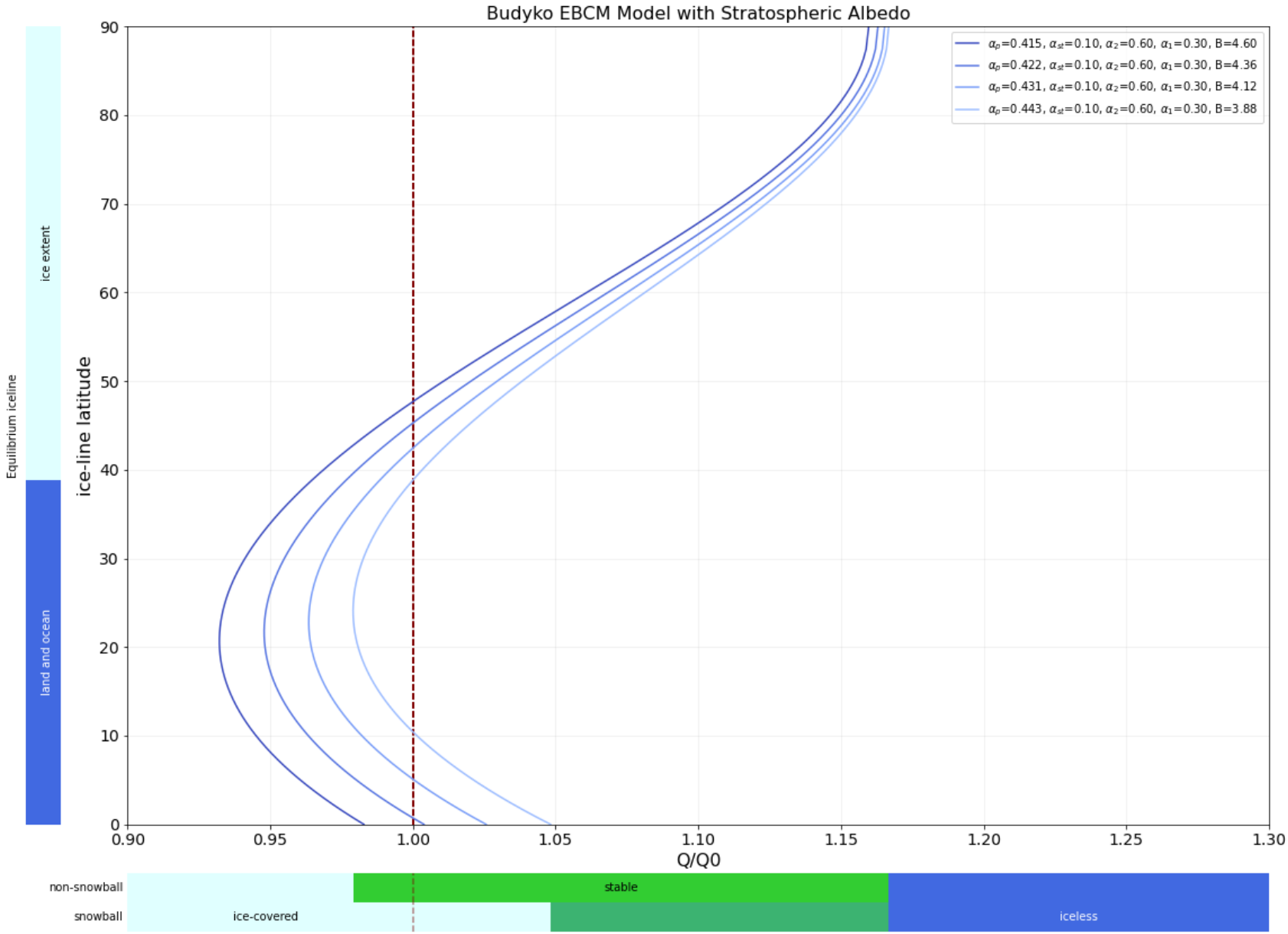

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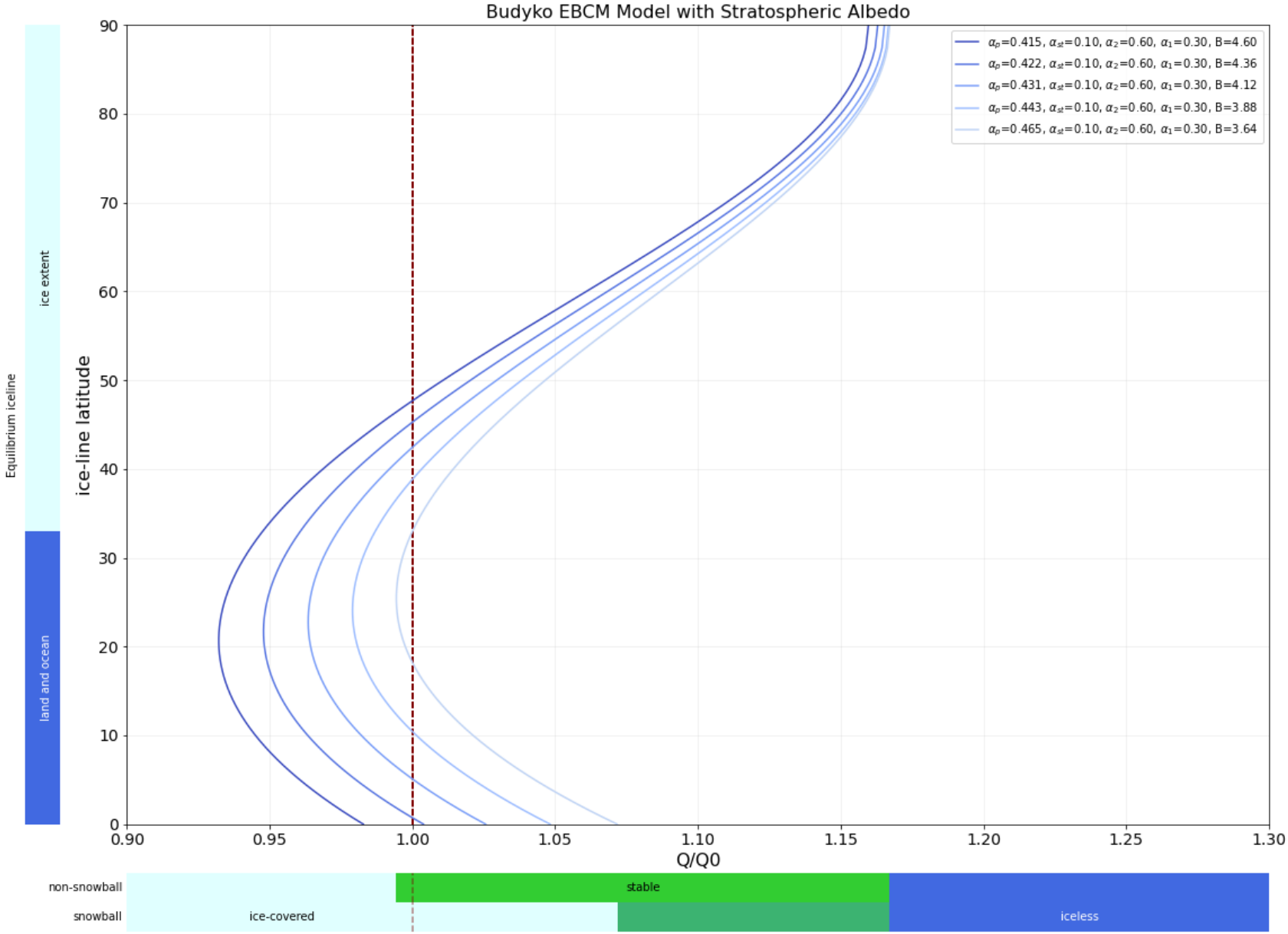

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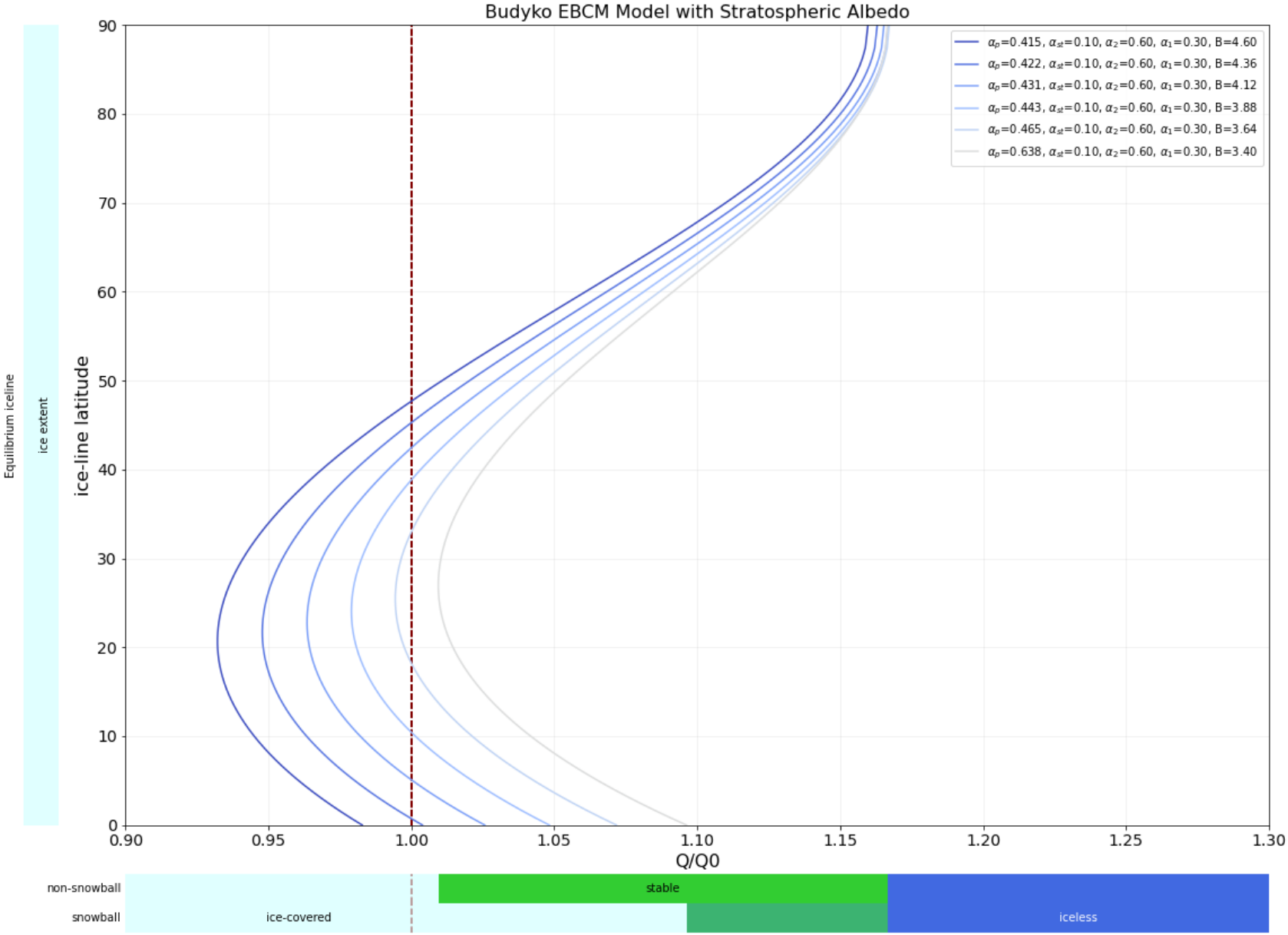

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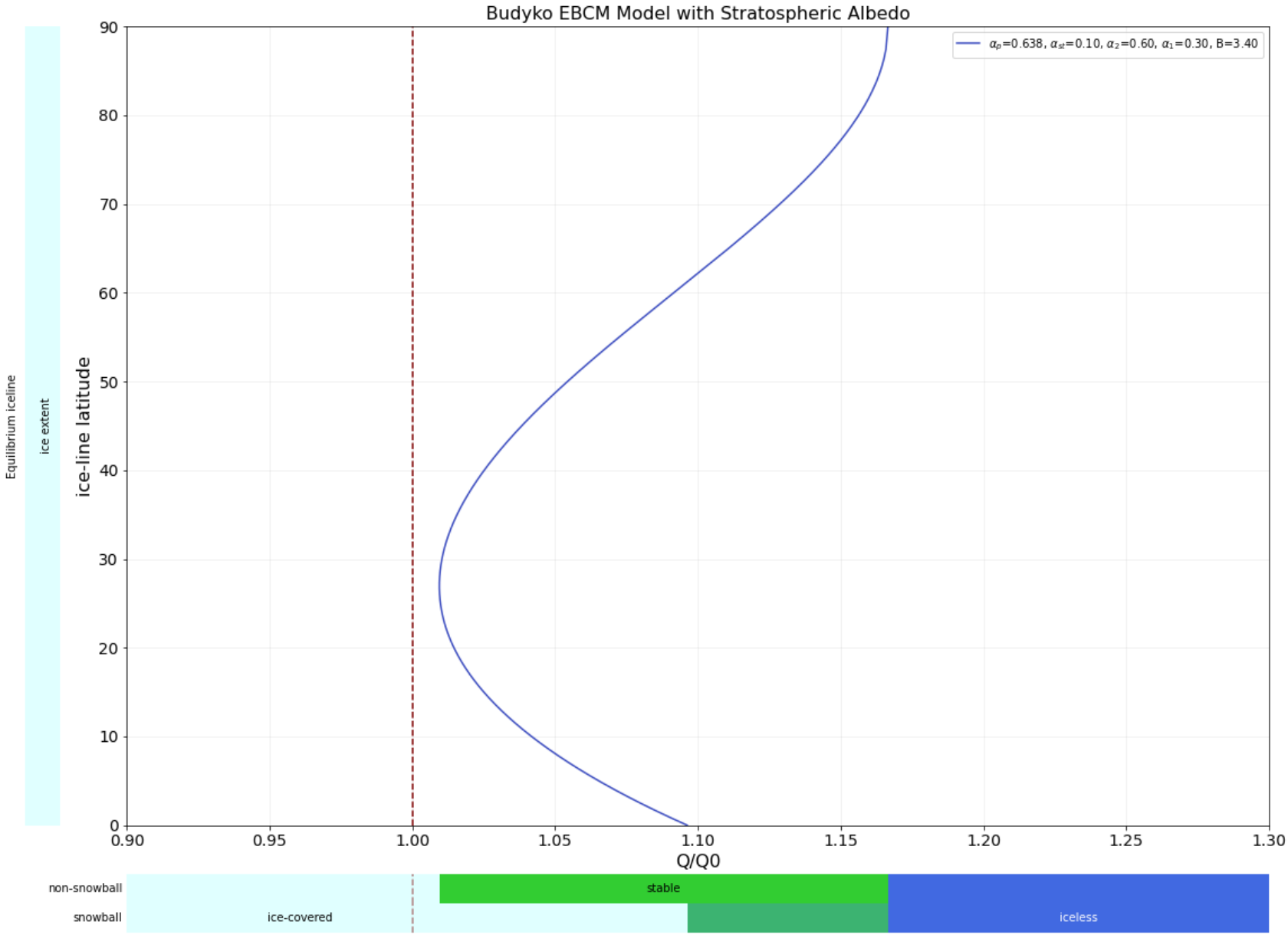

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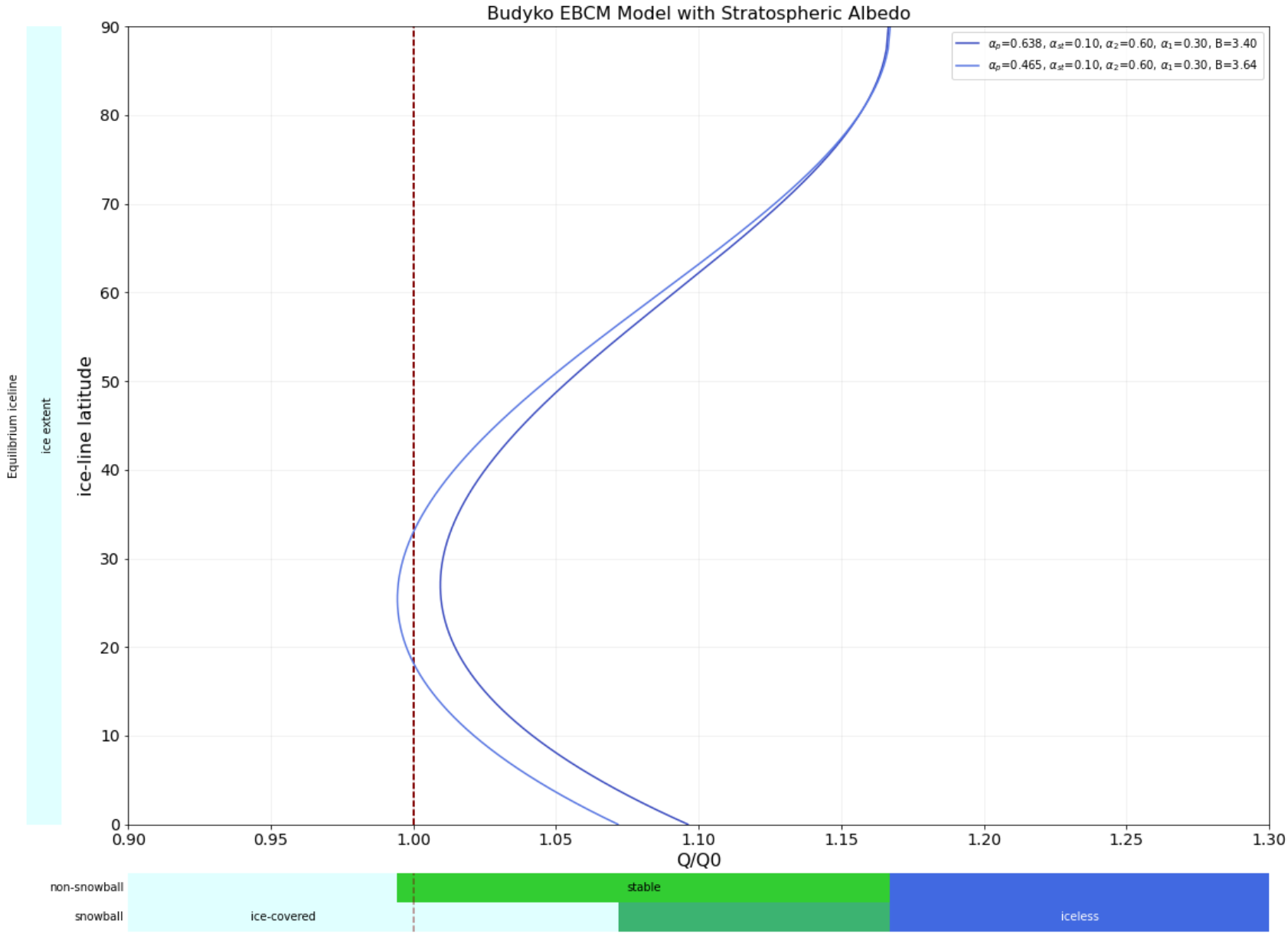

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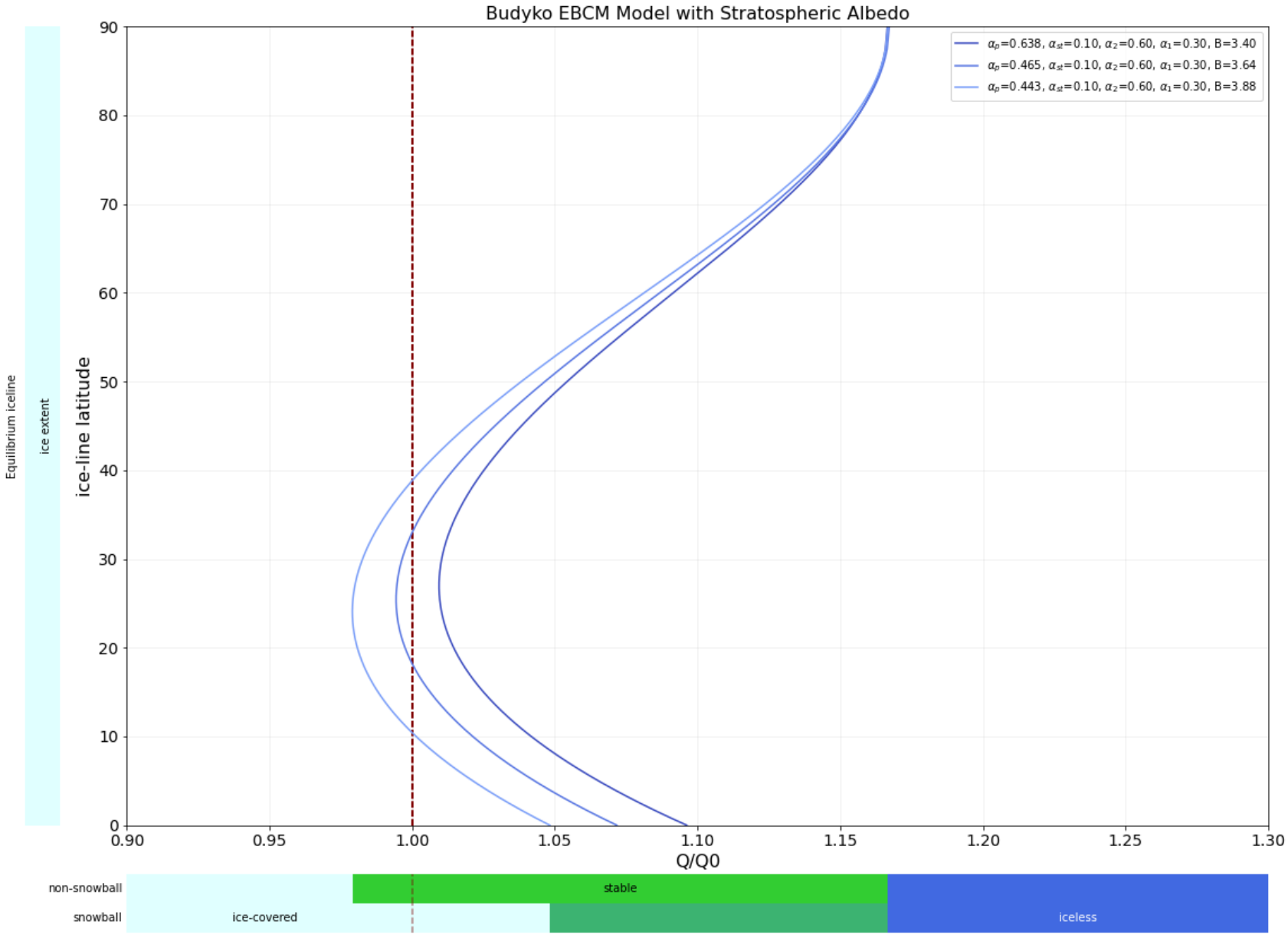

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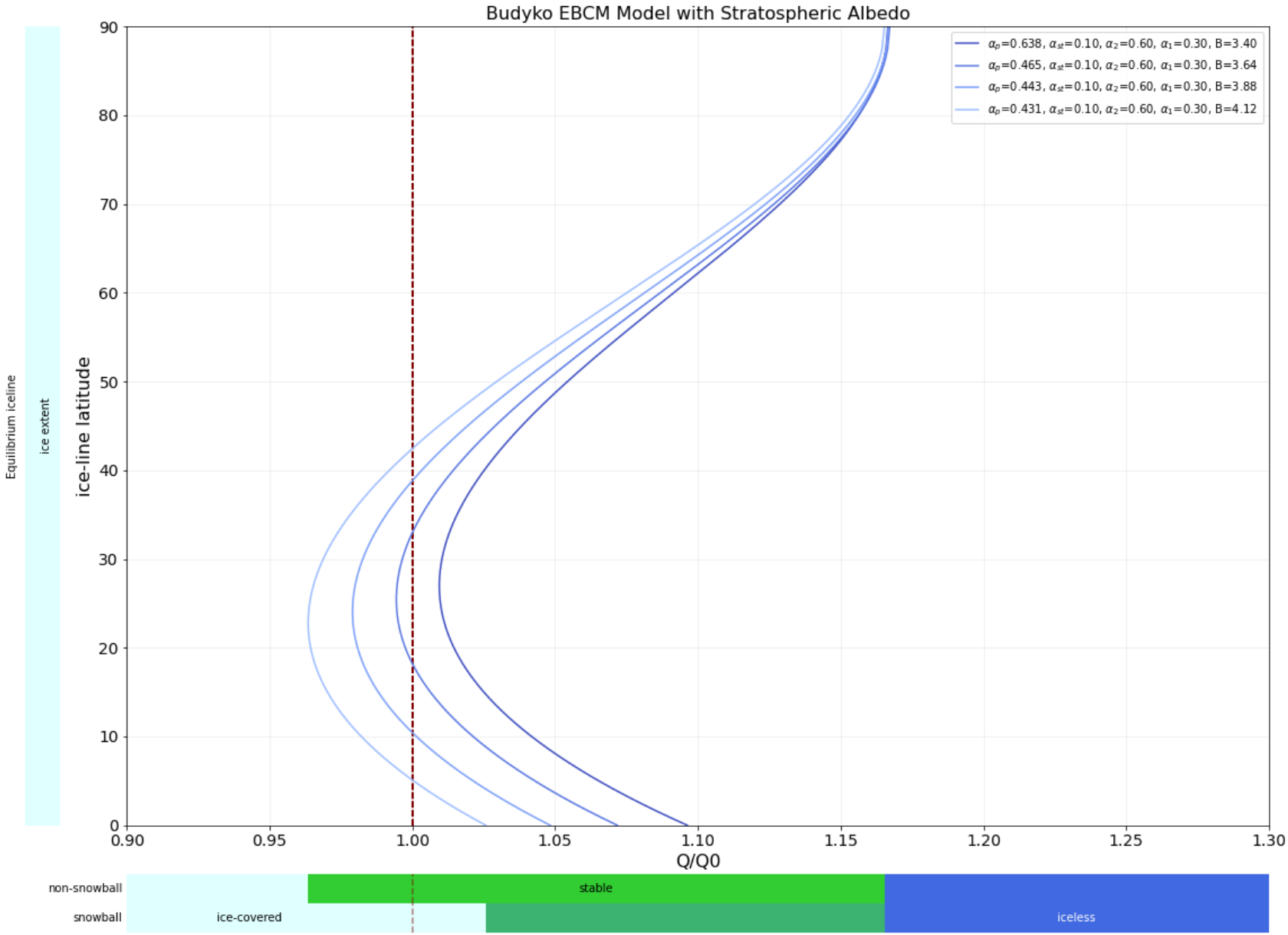

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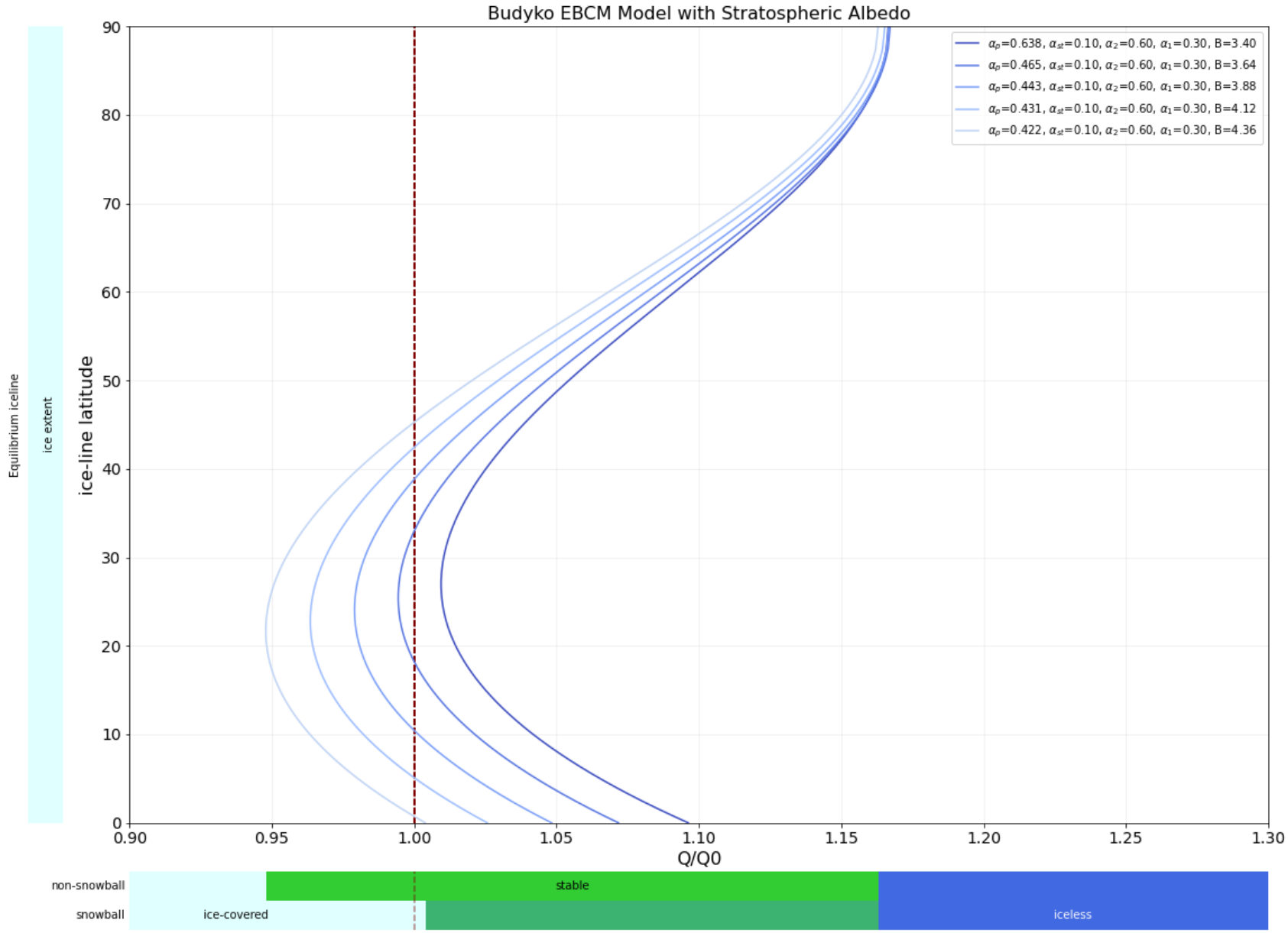
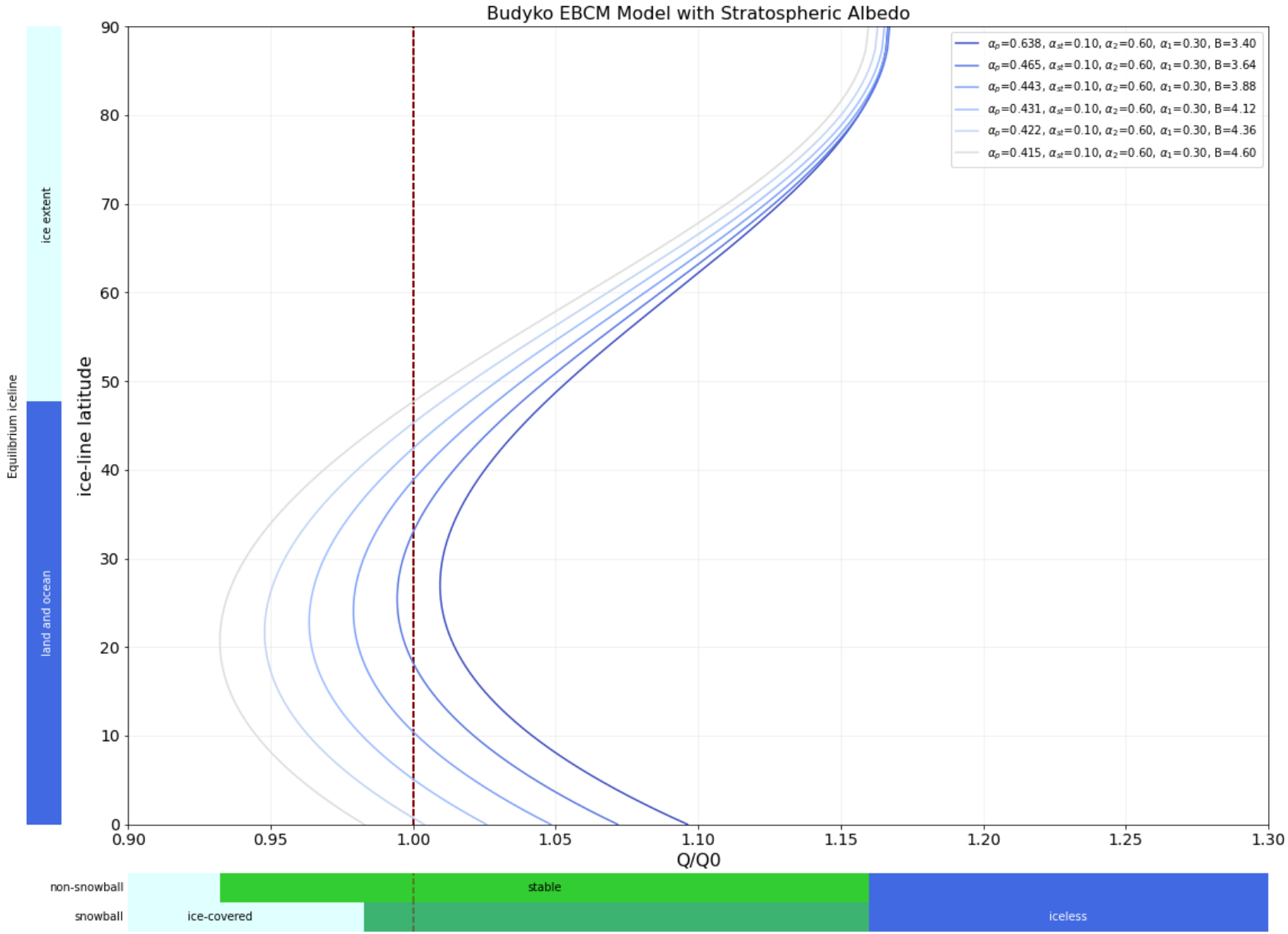
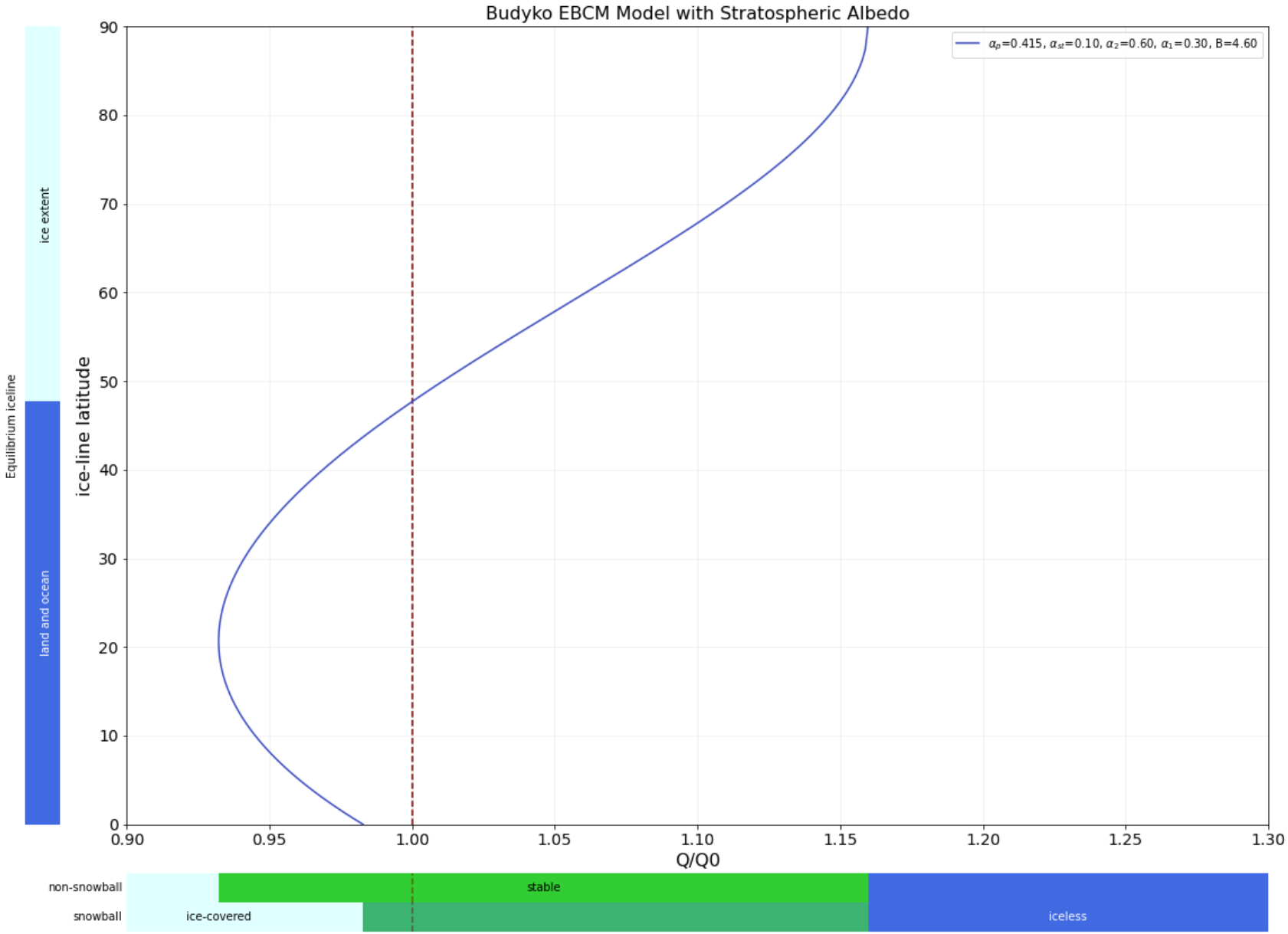


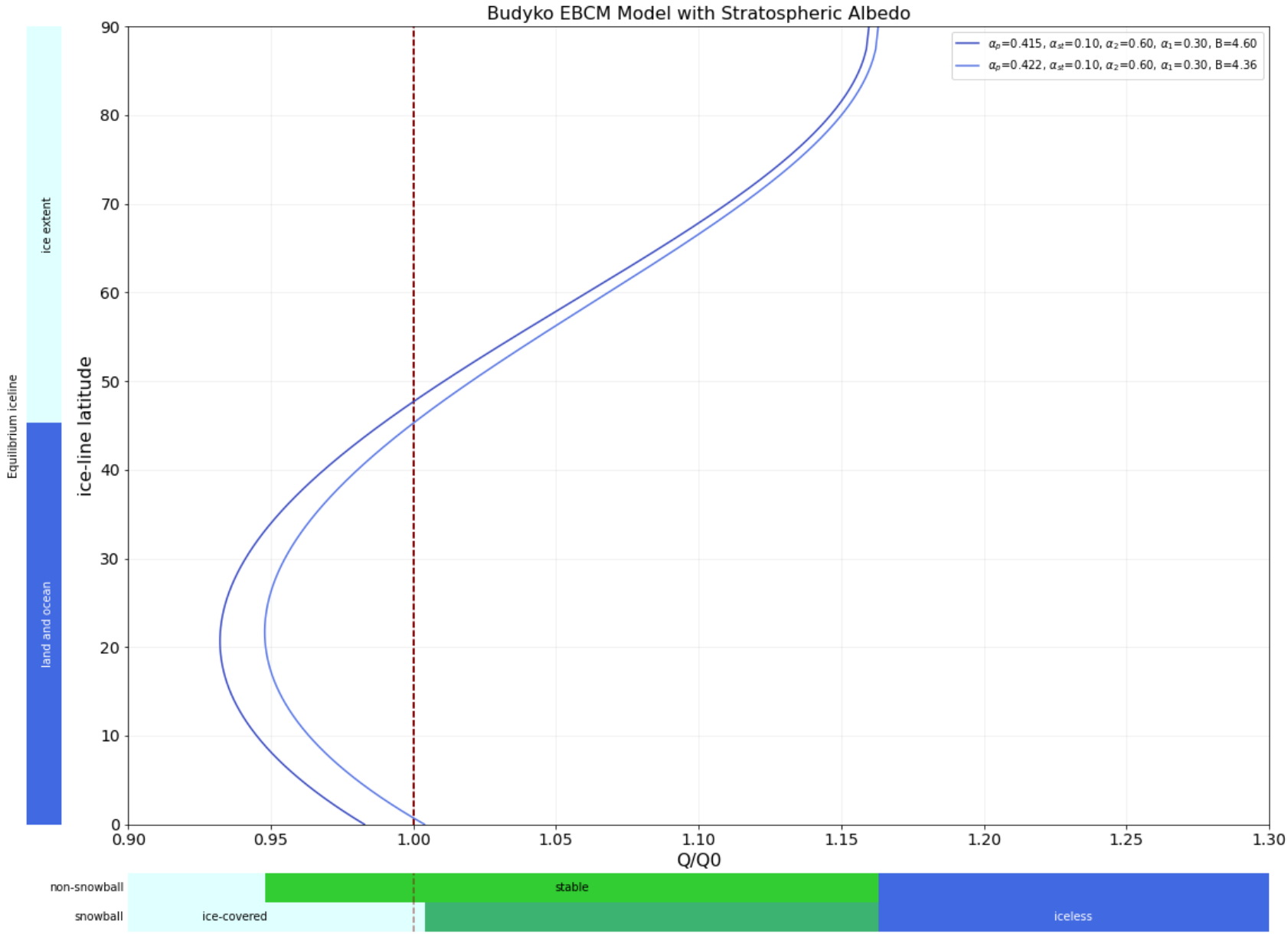
CO2 sink reactivates, causing hysteresis



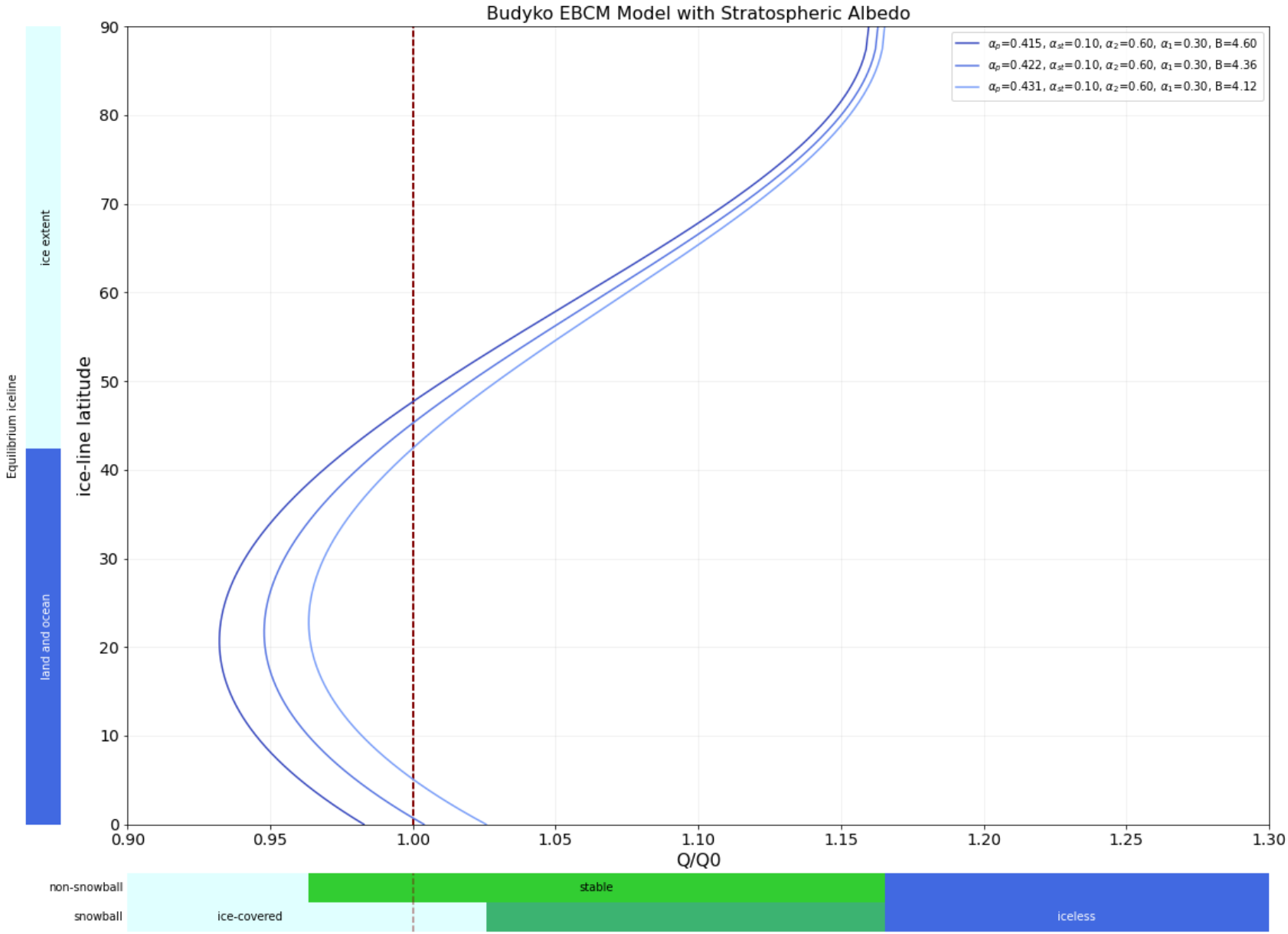
CO2 sink reactivates, causing hysteresis



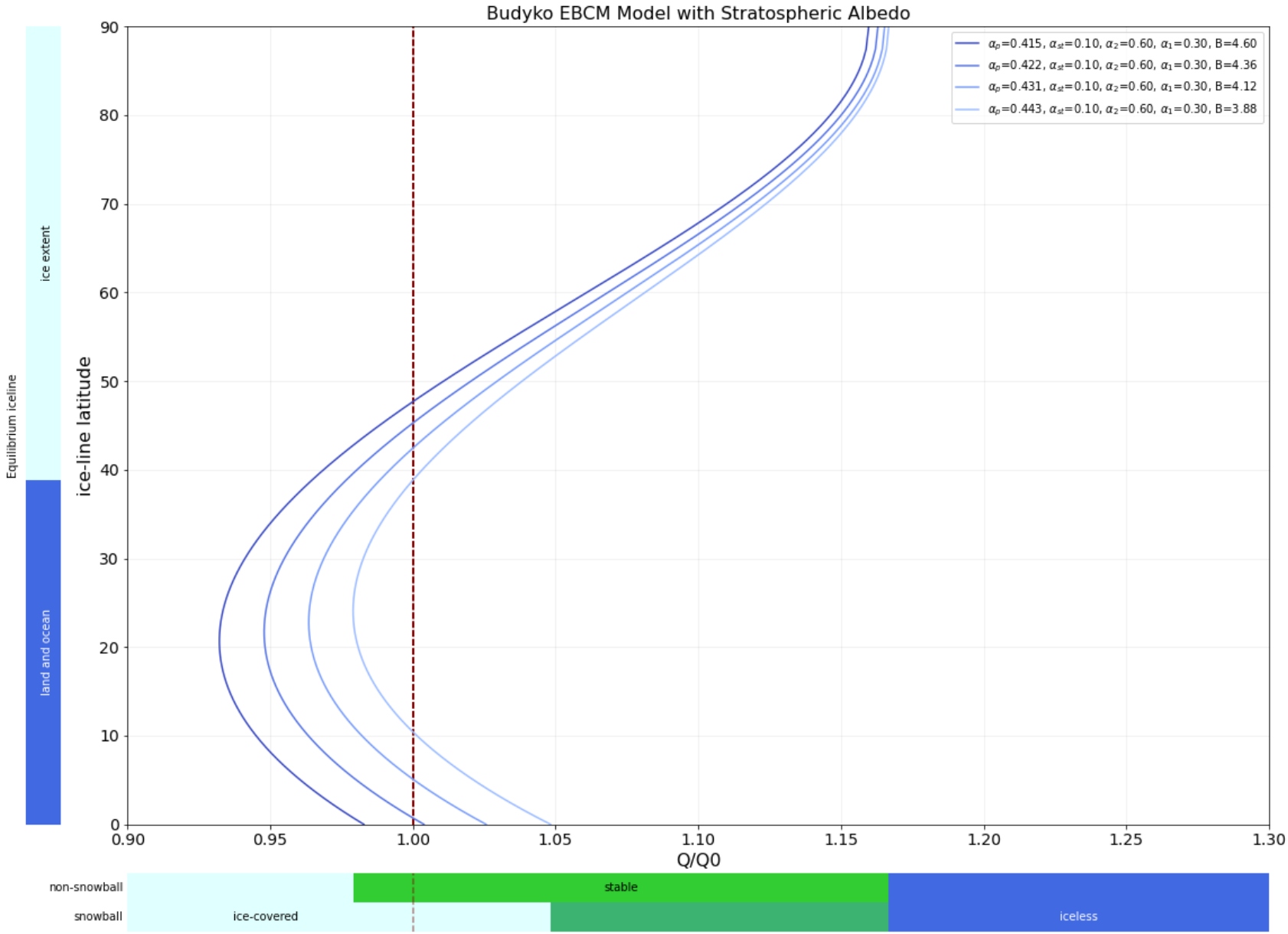
CO2 sink reactivates, causing hysteresis



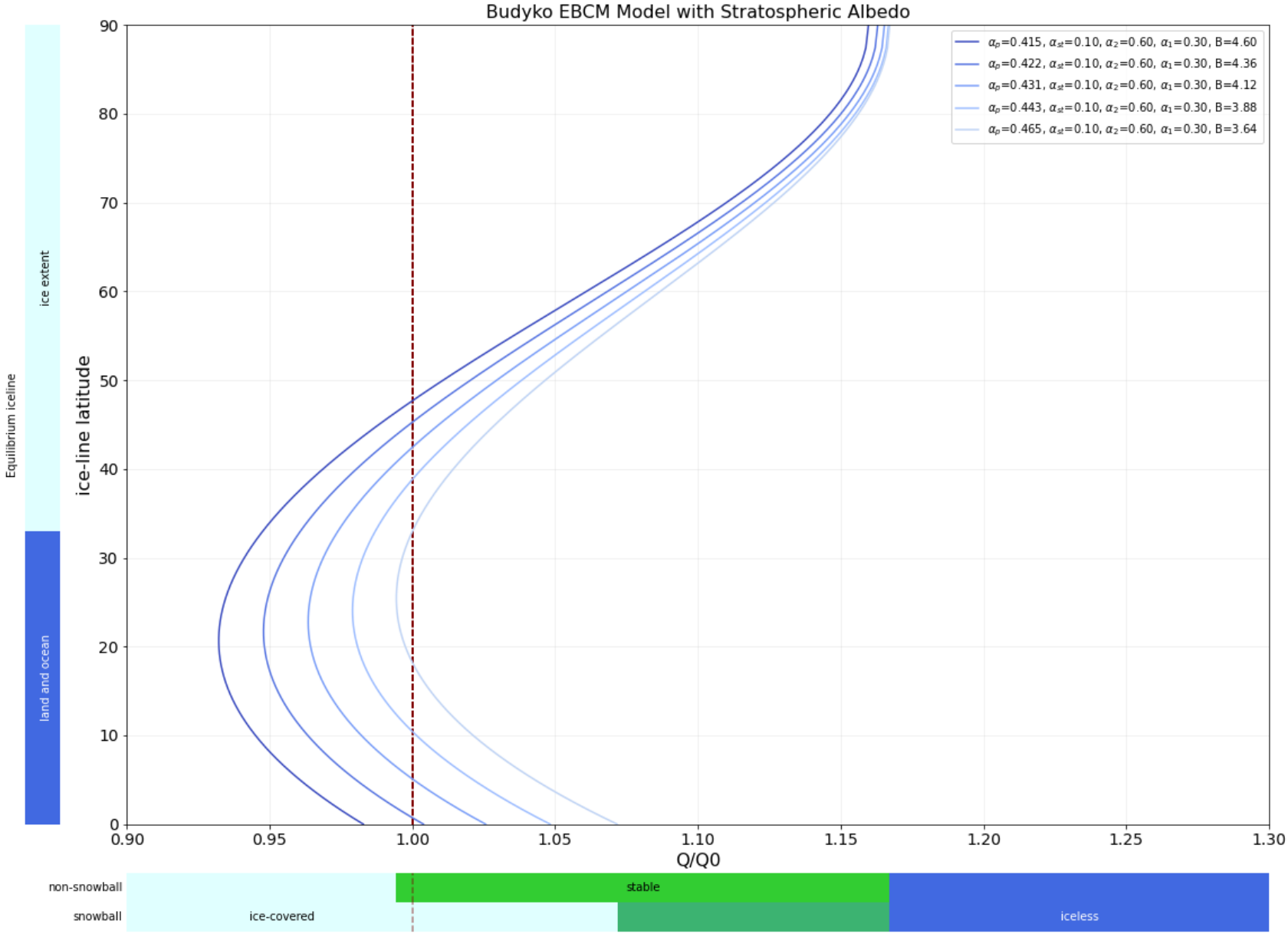
CO2 sink reactivates, causing hysteresis



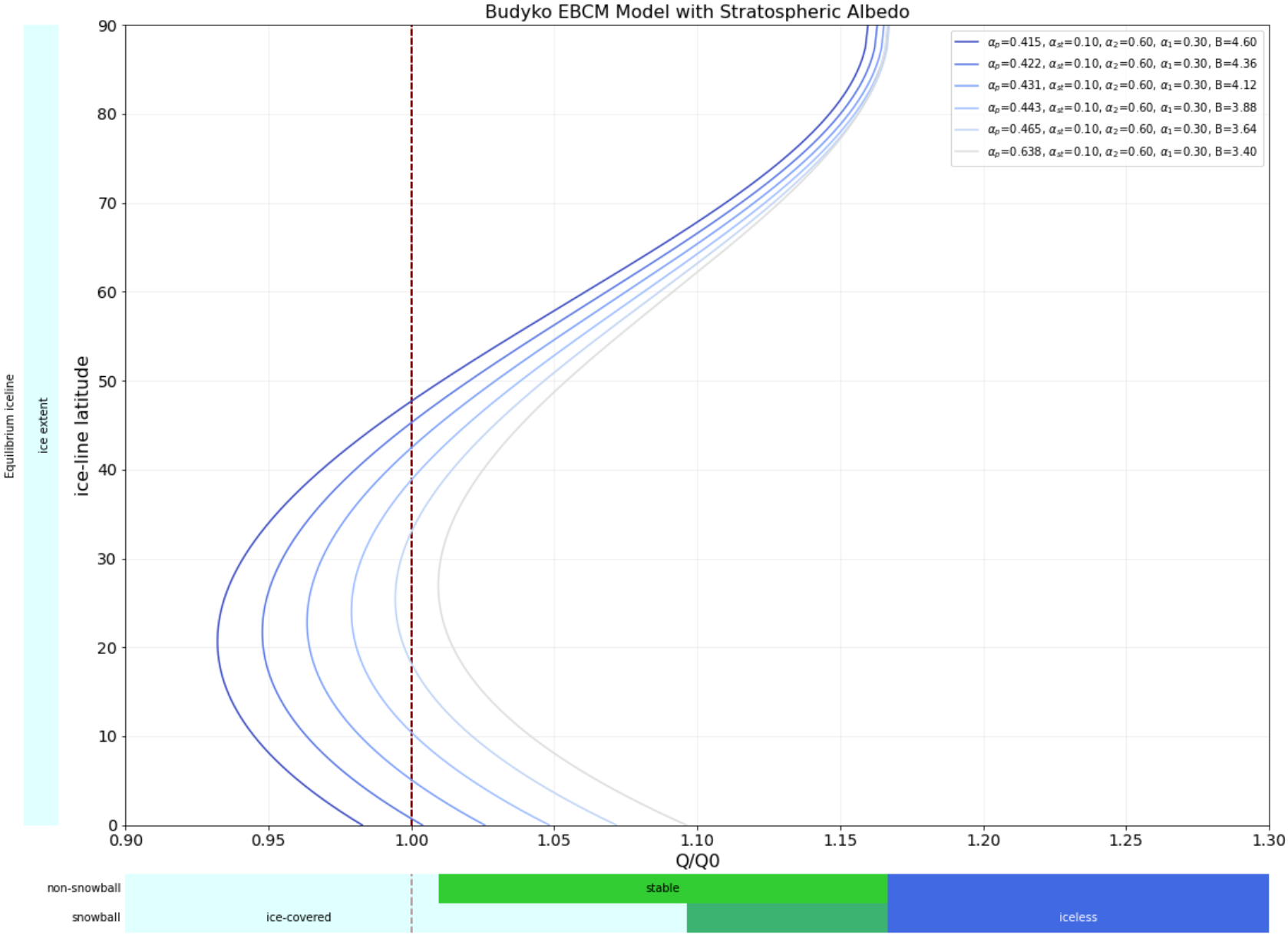
CO2 sink reactivates, causing hysteresis



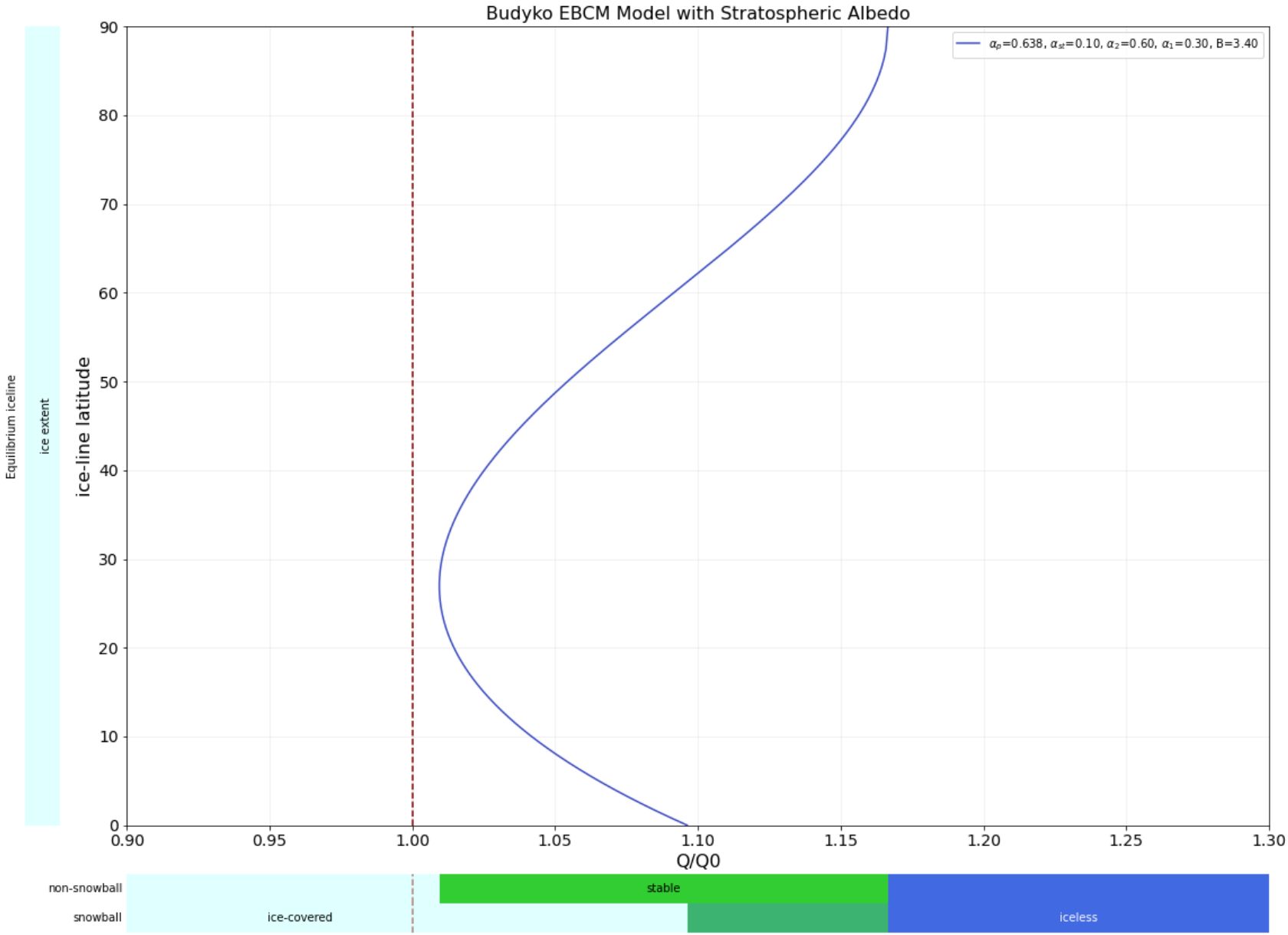
CO2 sink reactivates, causing hysteresis



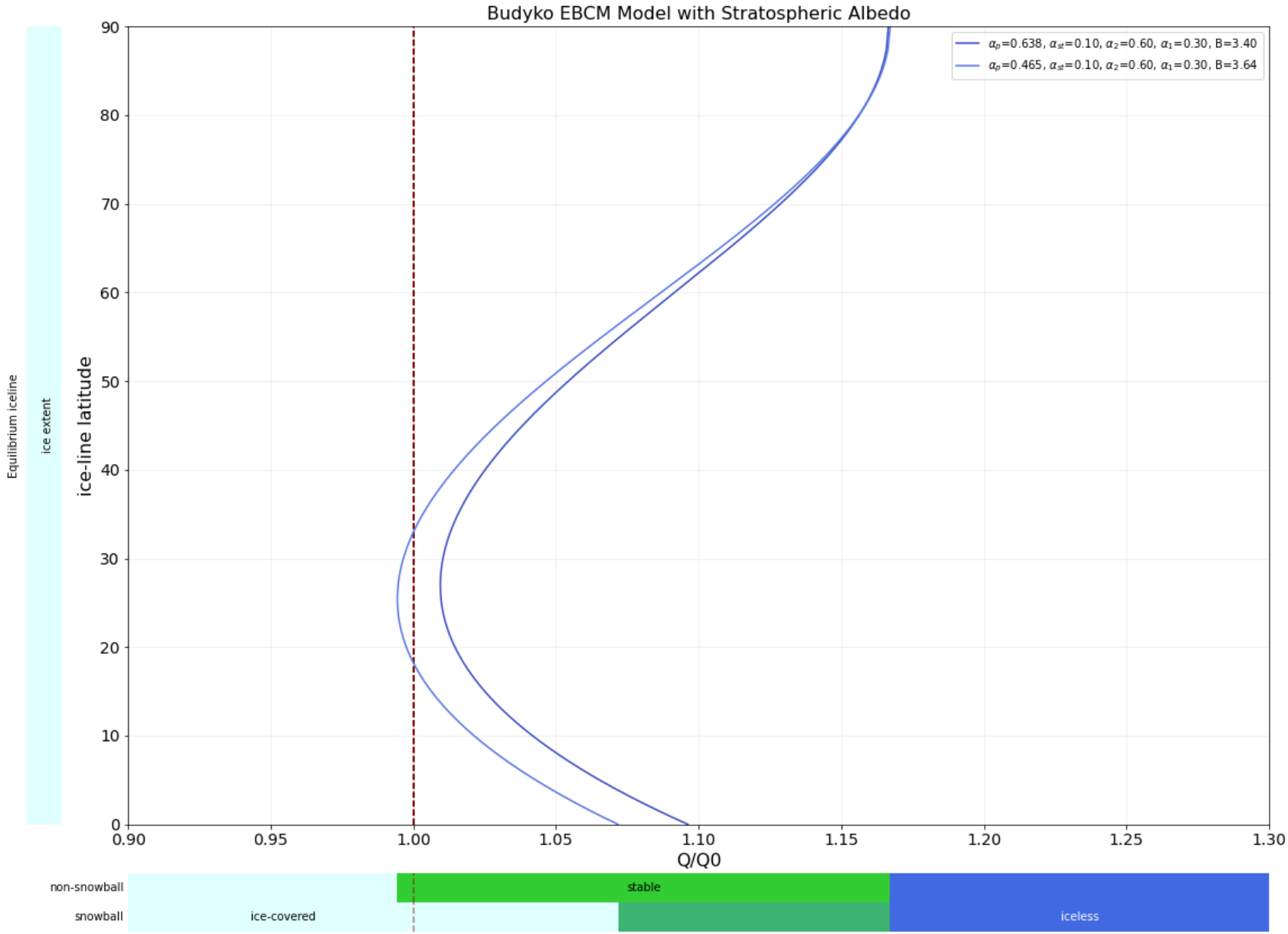
CO2 sink reactivates, causing hysteresis



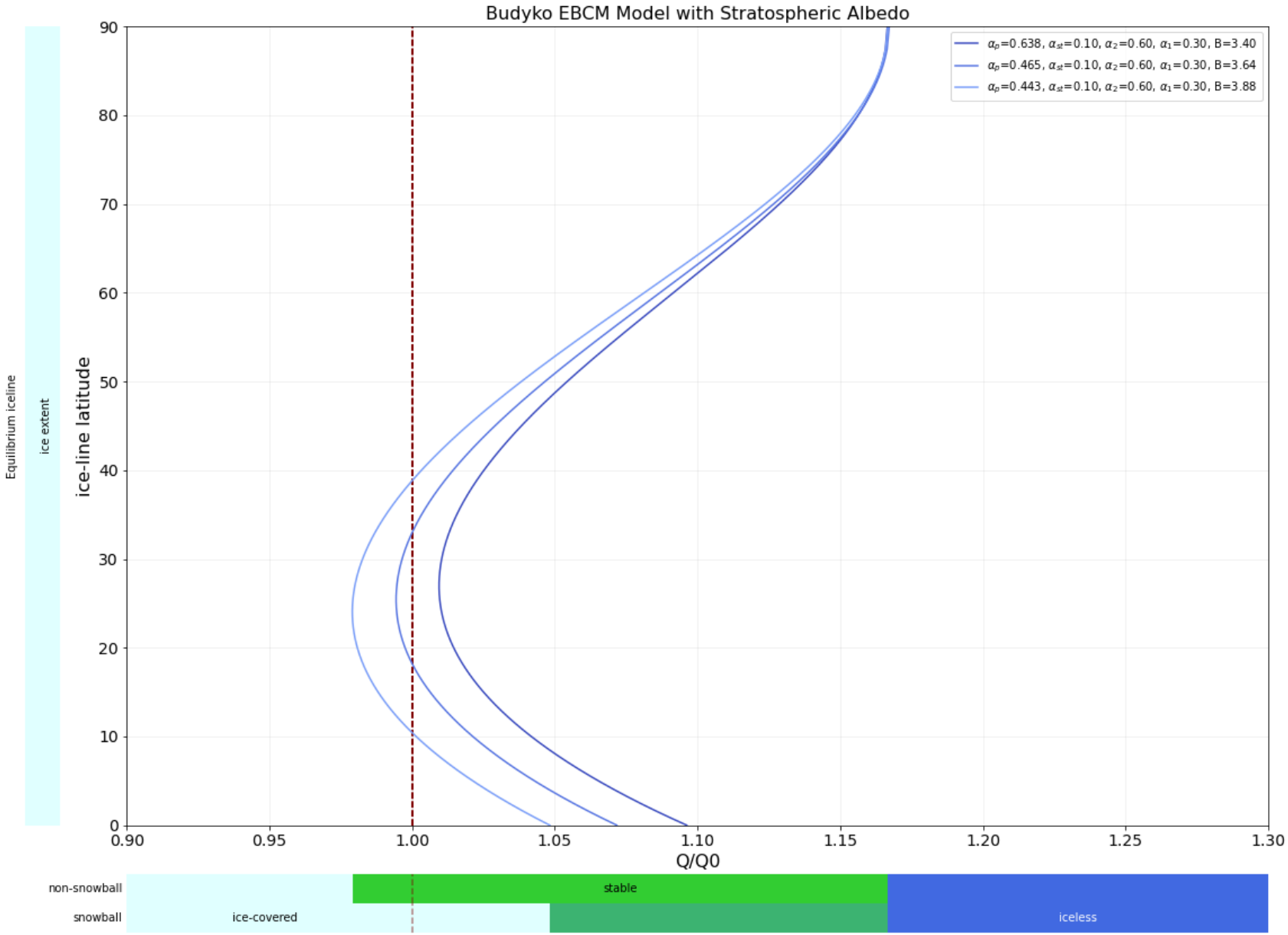
CO2 sink reactivates, causing hysteresis



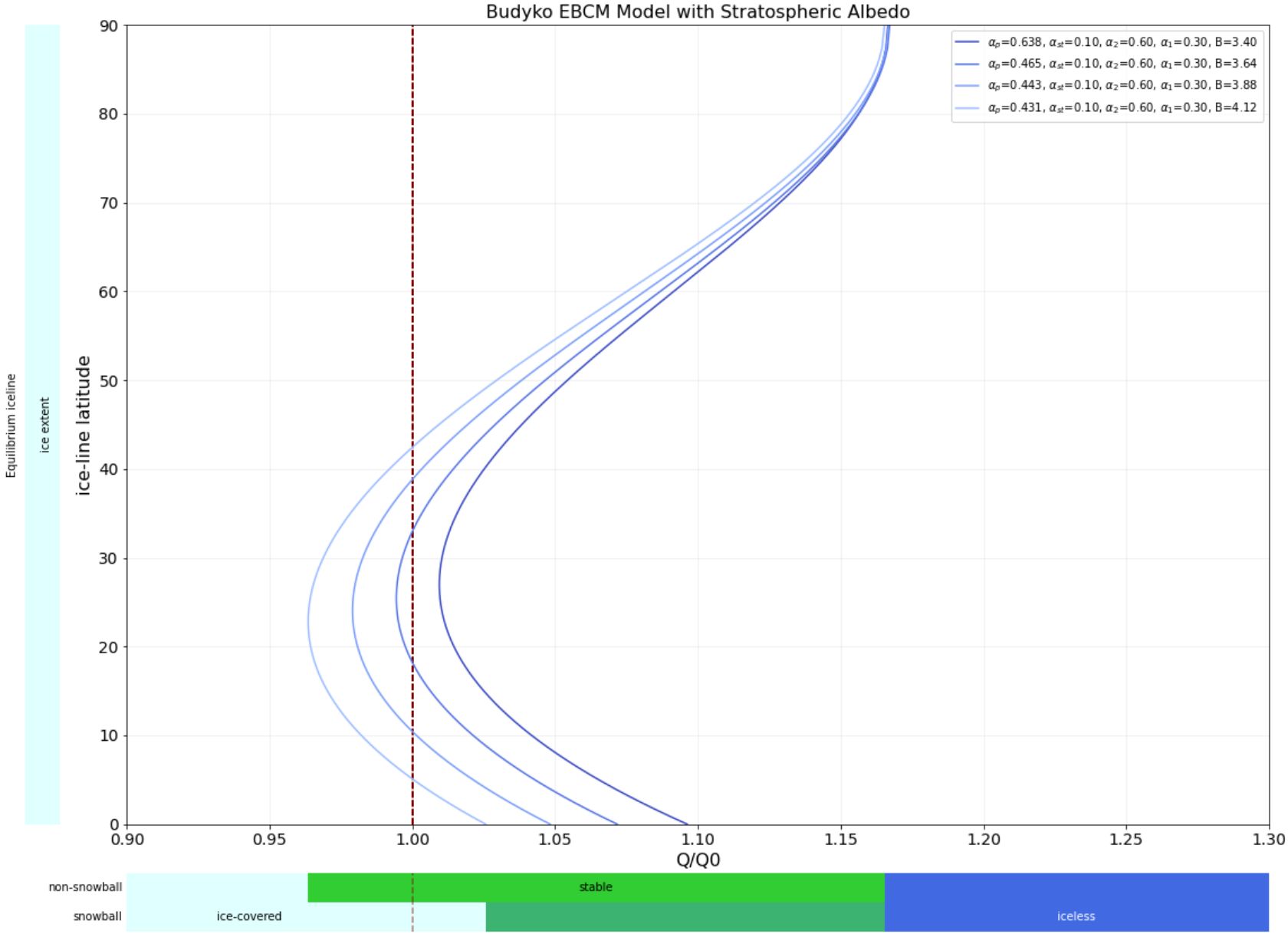
CO2 sink reactivates, causing hysteresis



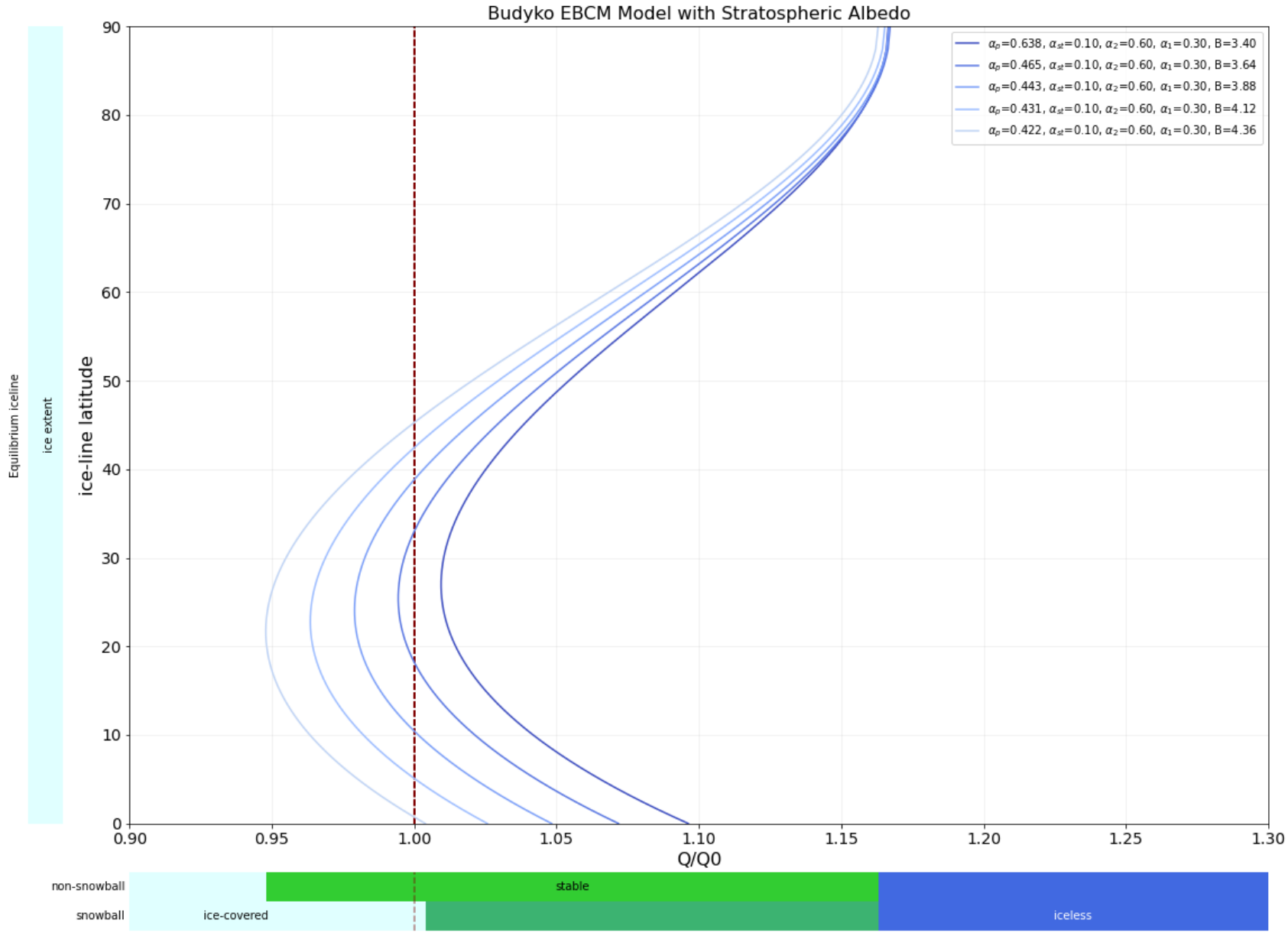
CO2 sink reactivates, causing hysteresis



CO2 sink reactivates, causing hysteresis



CO2 sink reactivates, causing hysteresis



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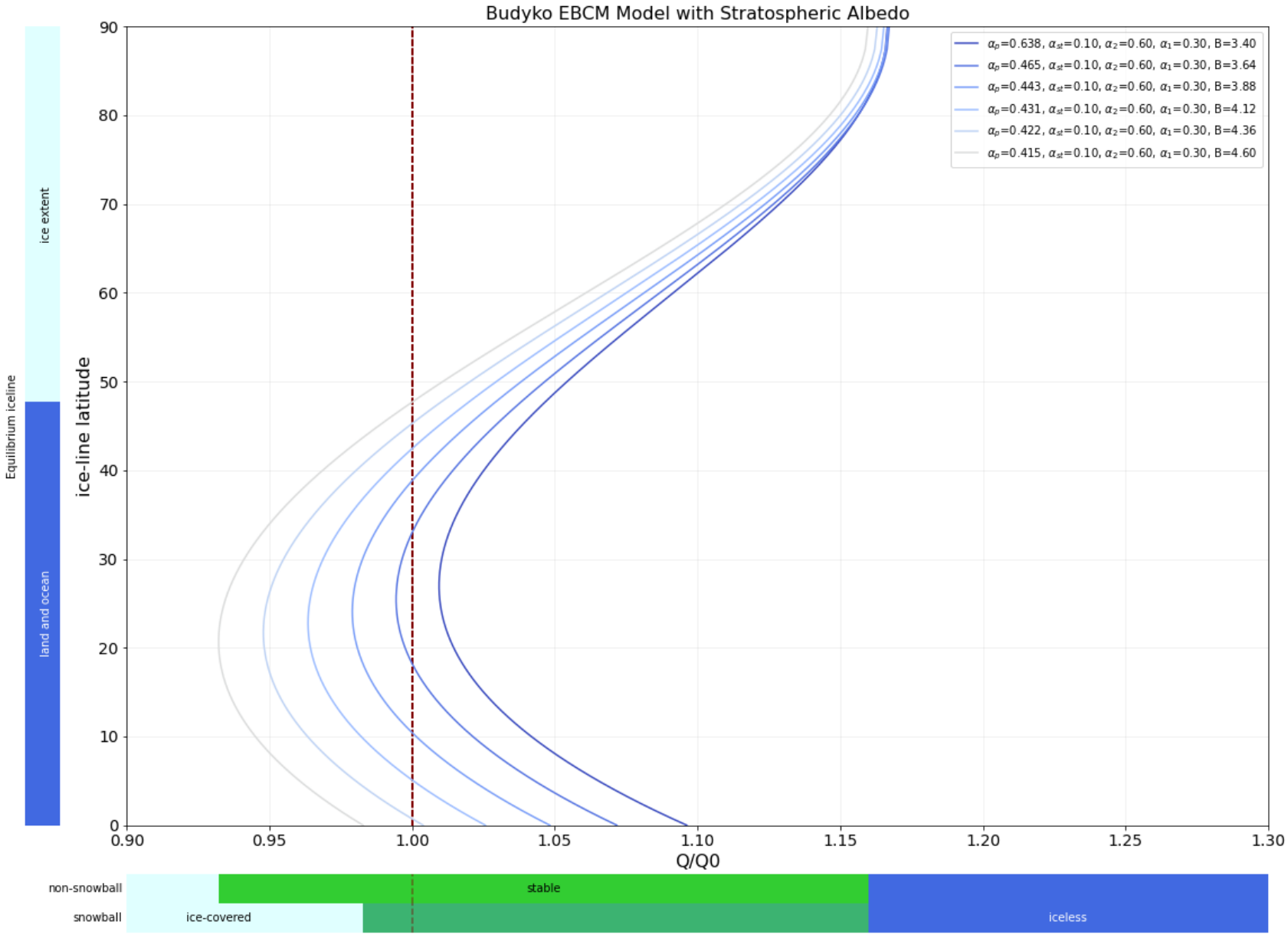

Could albedo changes explain Neoproterozoic glaciations?