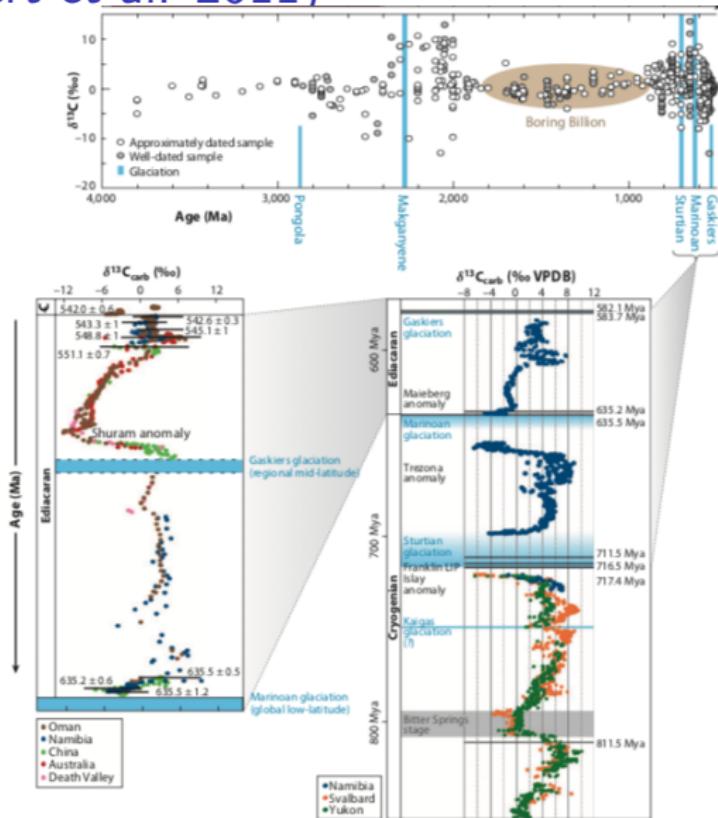
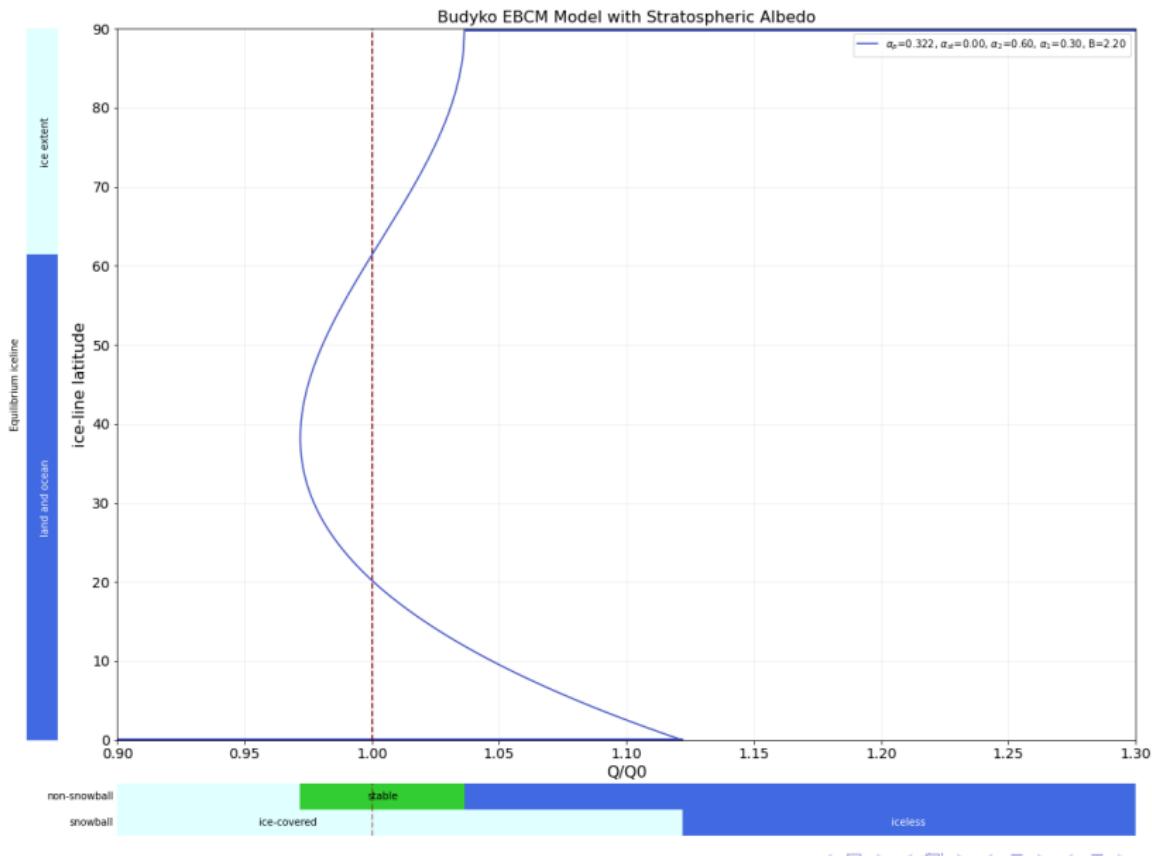


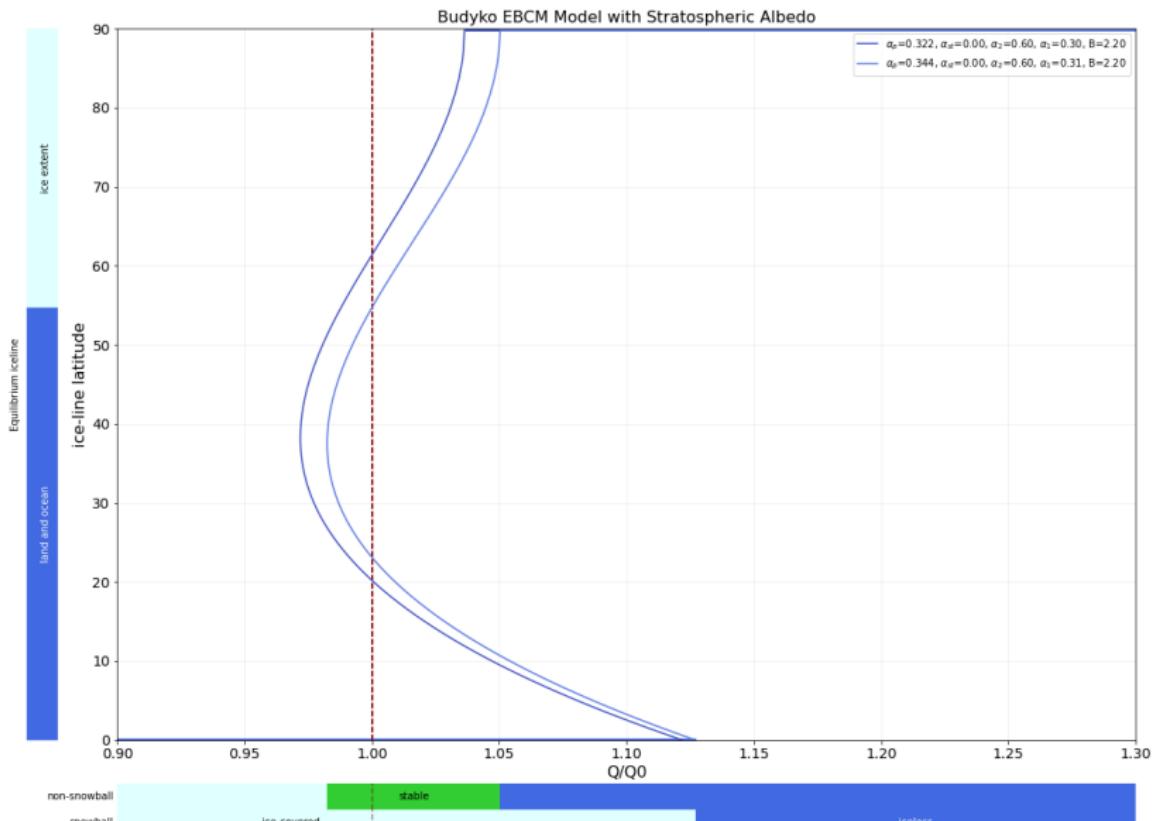
# Could albedo changes explain Neoproterozoic glaciations? (Pierrehumbert et al. 2011)



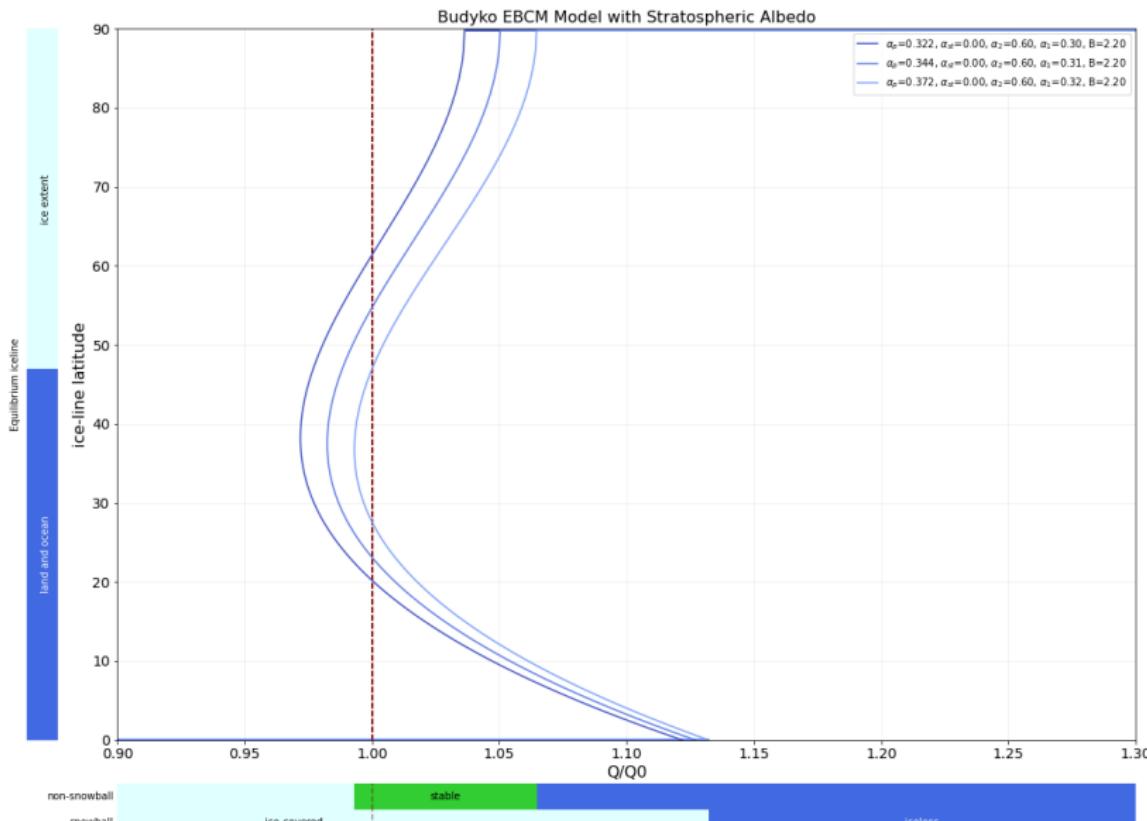
# Increasing land and ocean albedo can cause a snowball



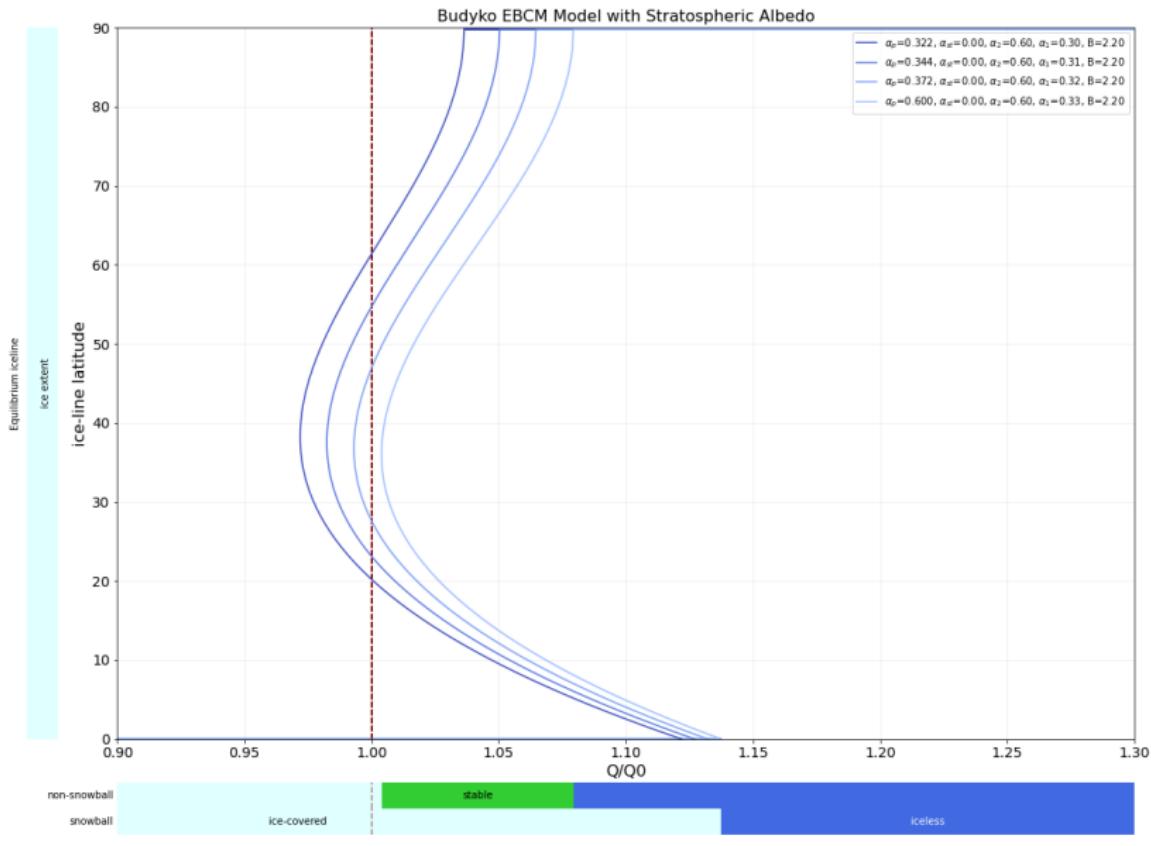
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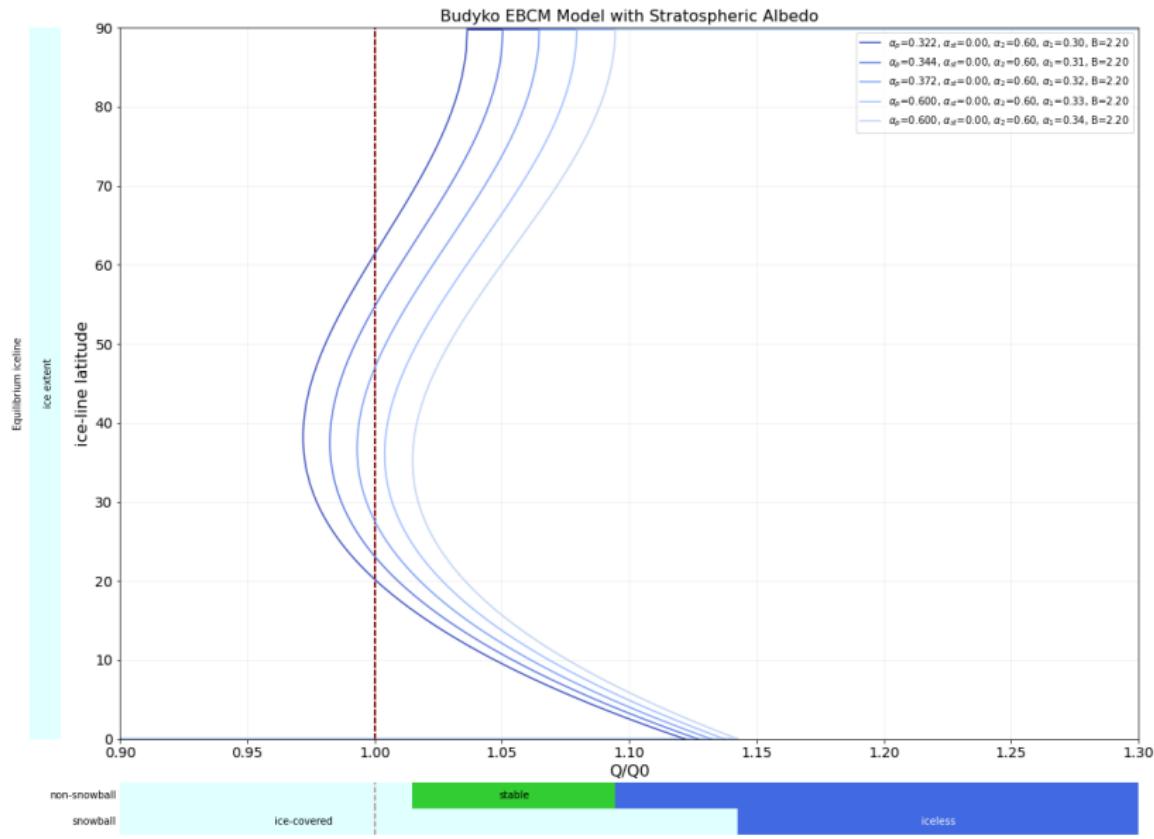
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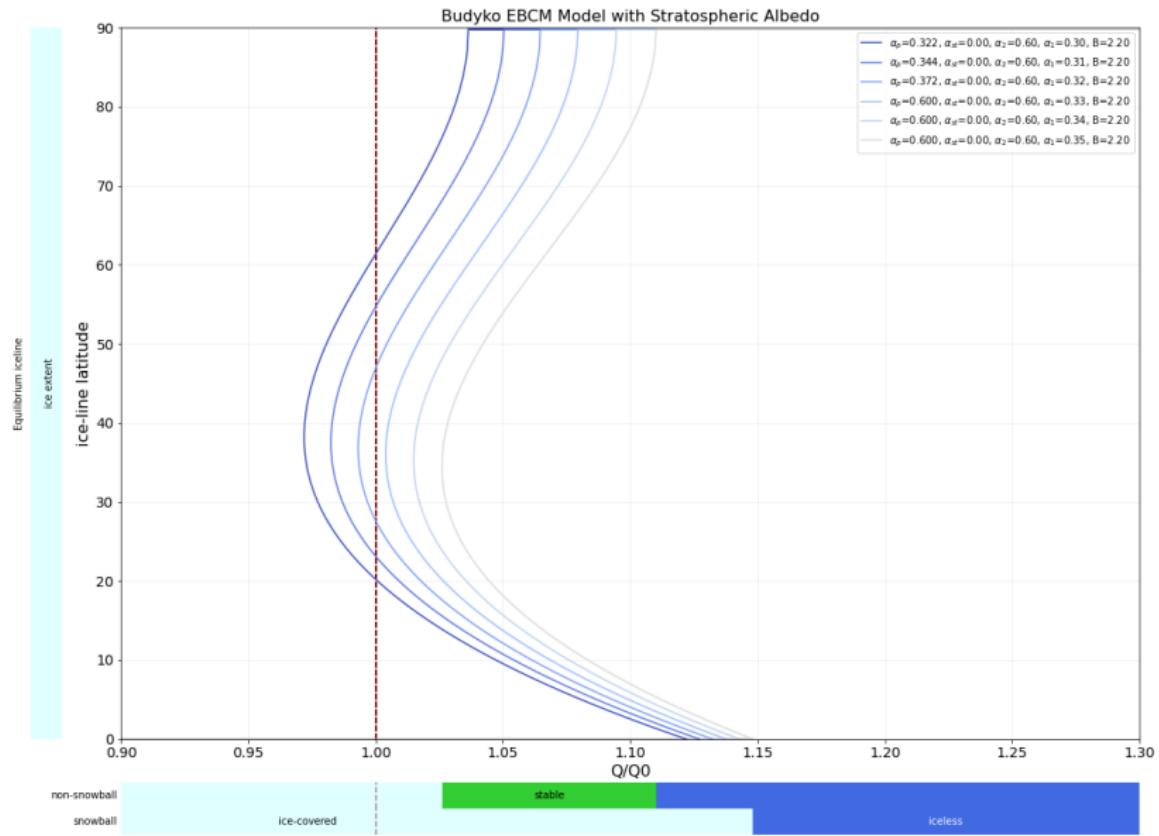
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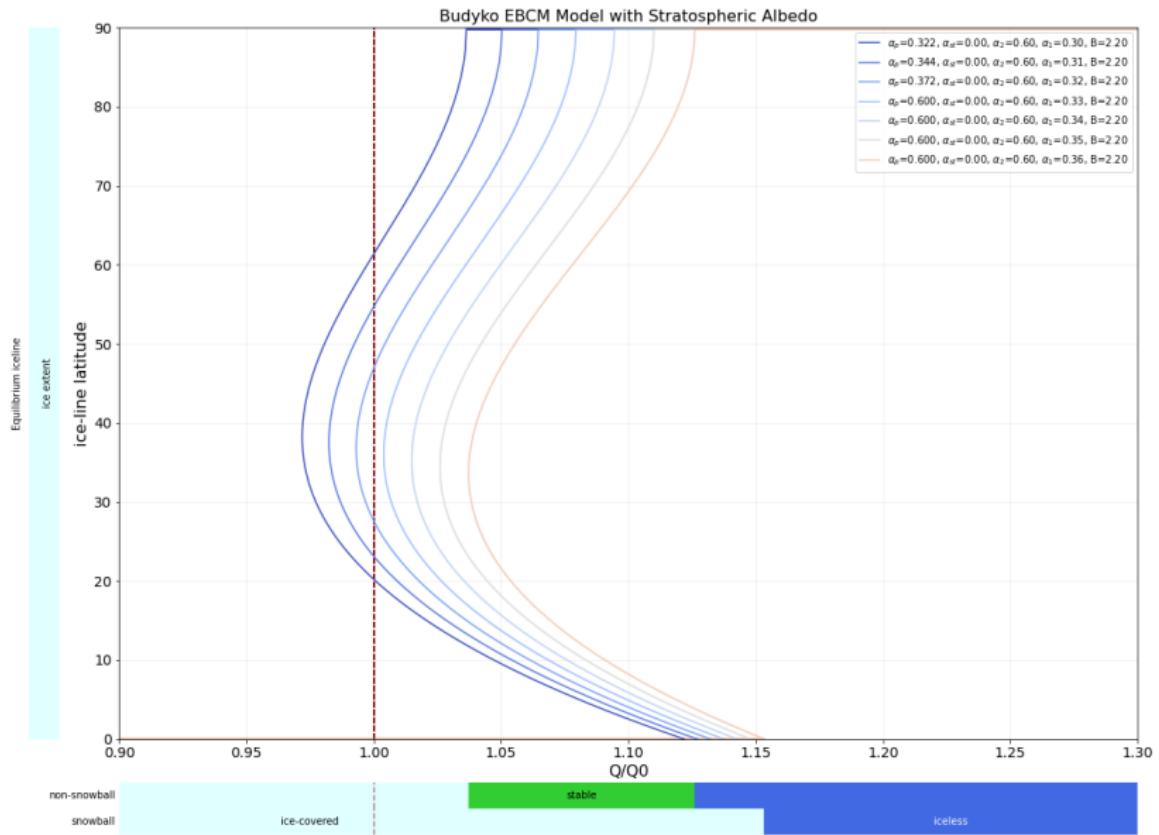
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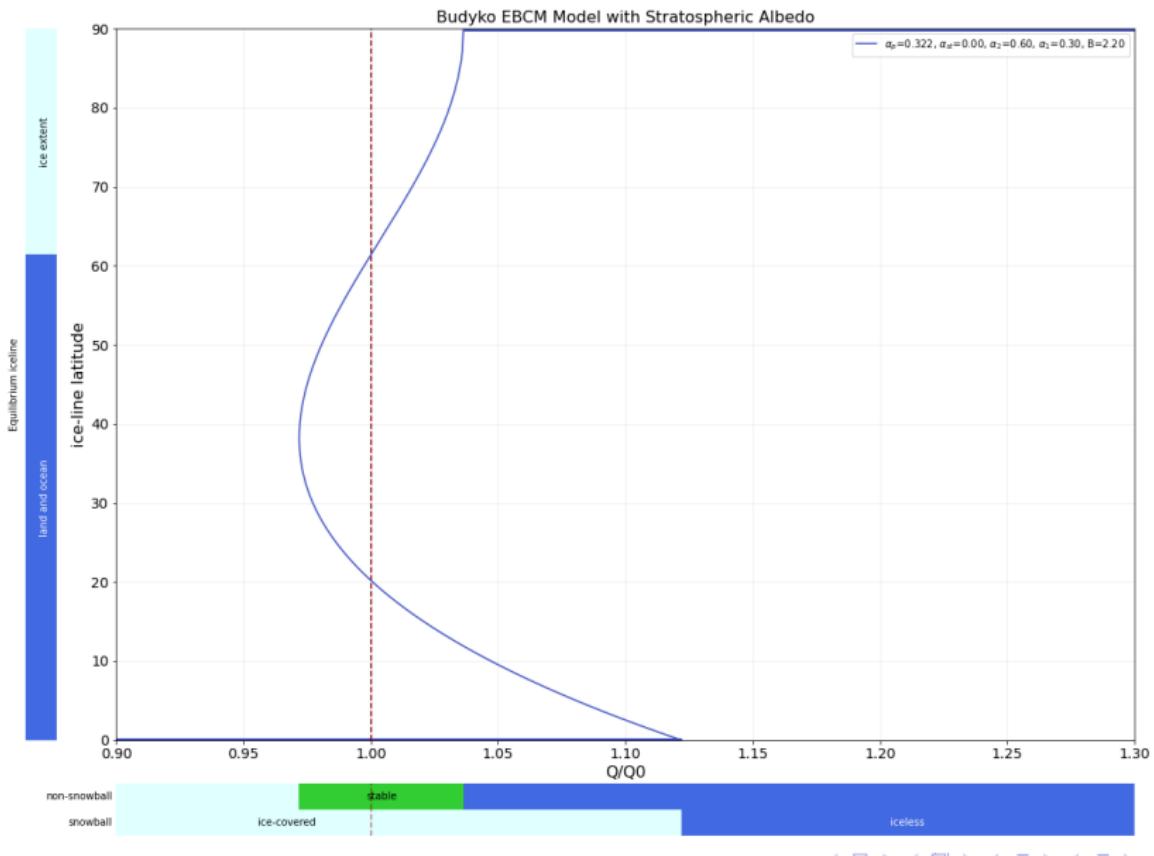
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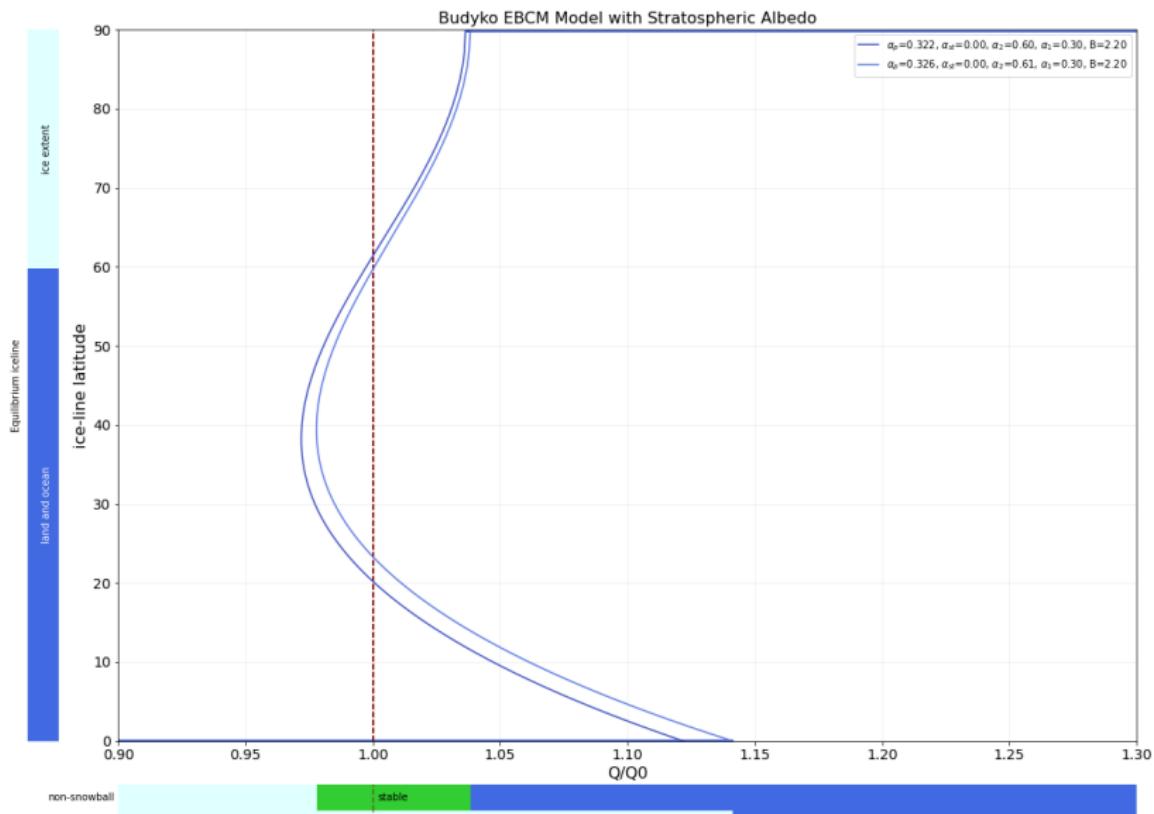
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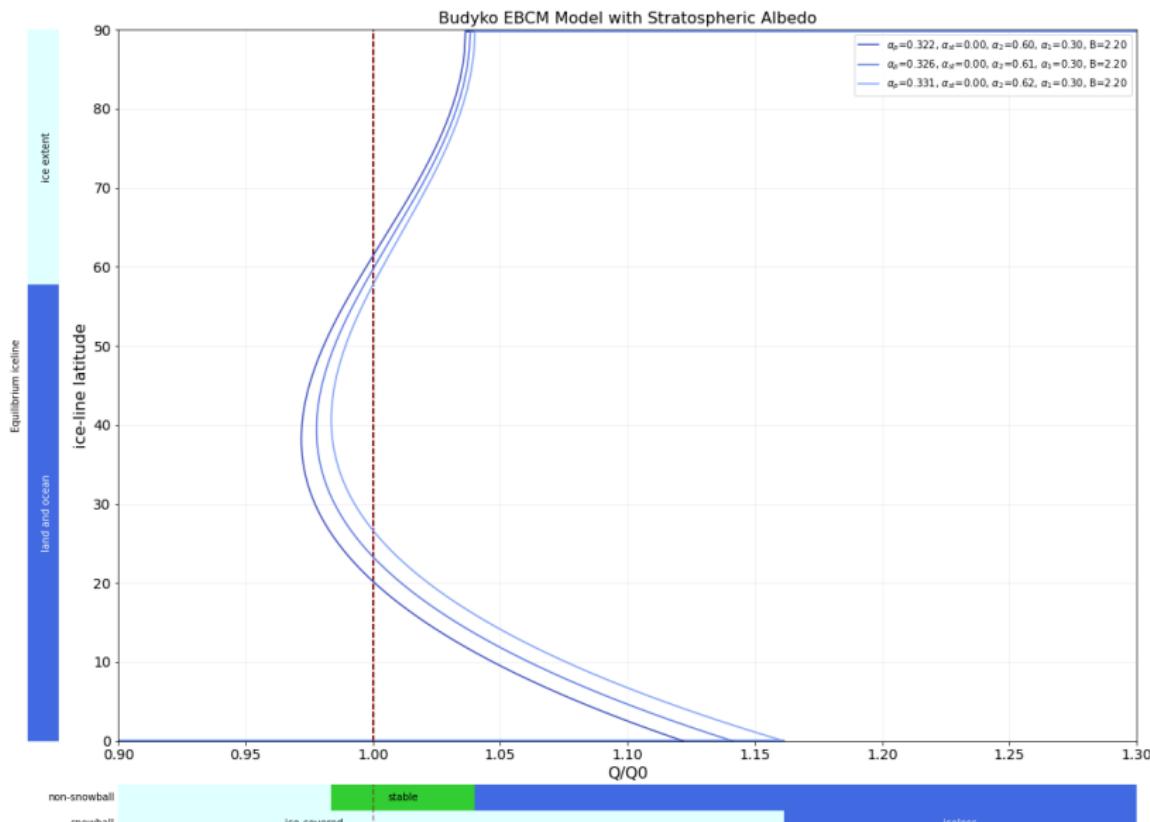
So can increasing ice albedo.



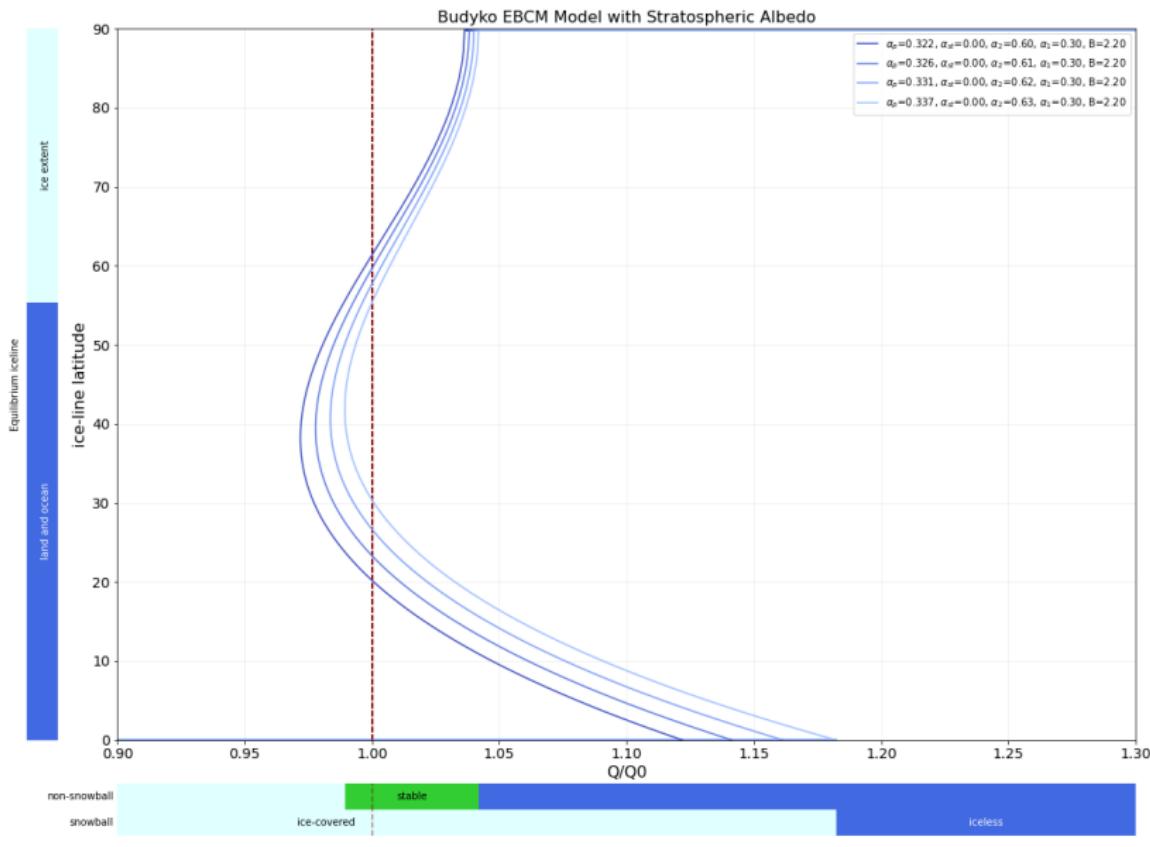
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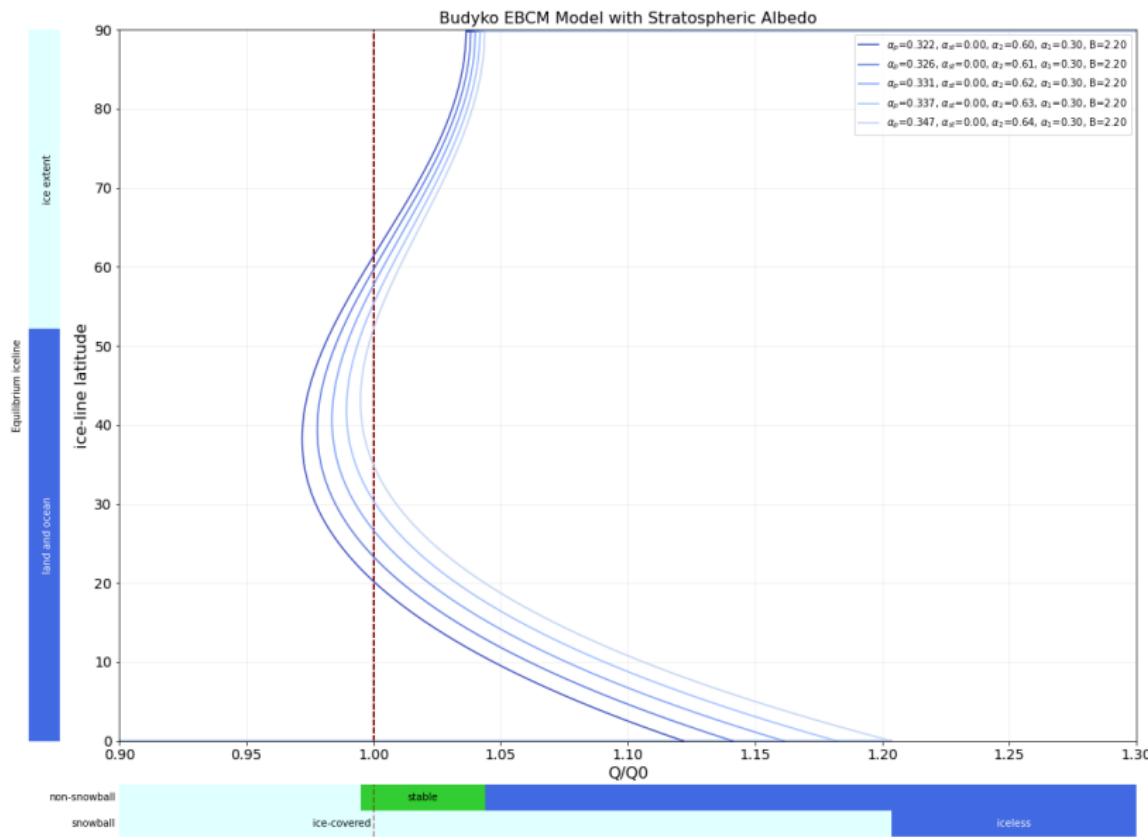
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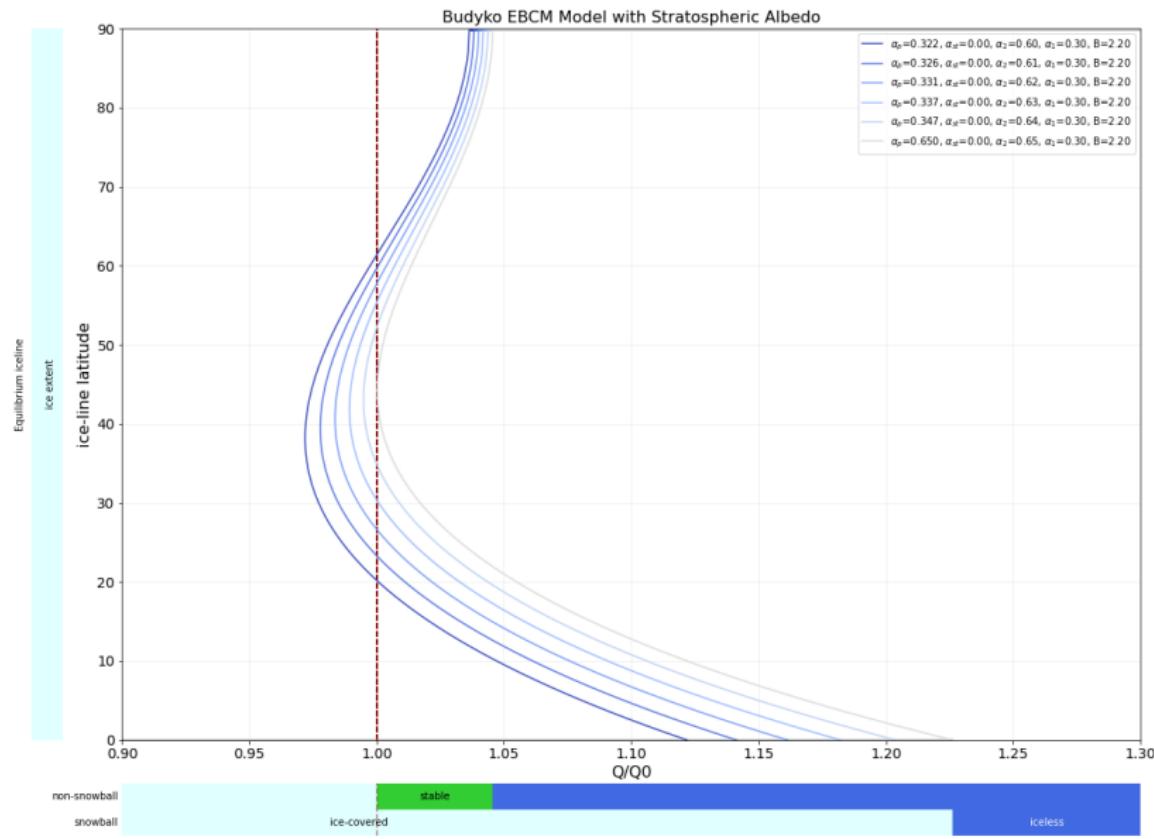
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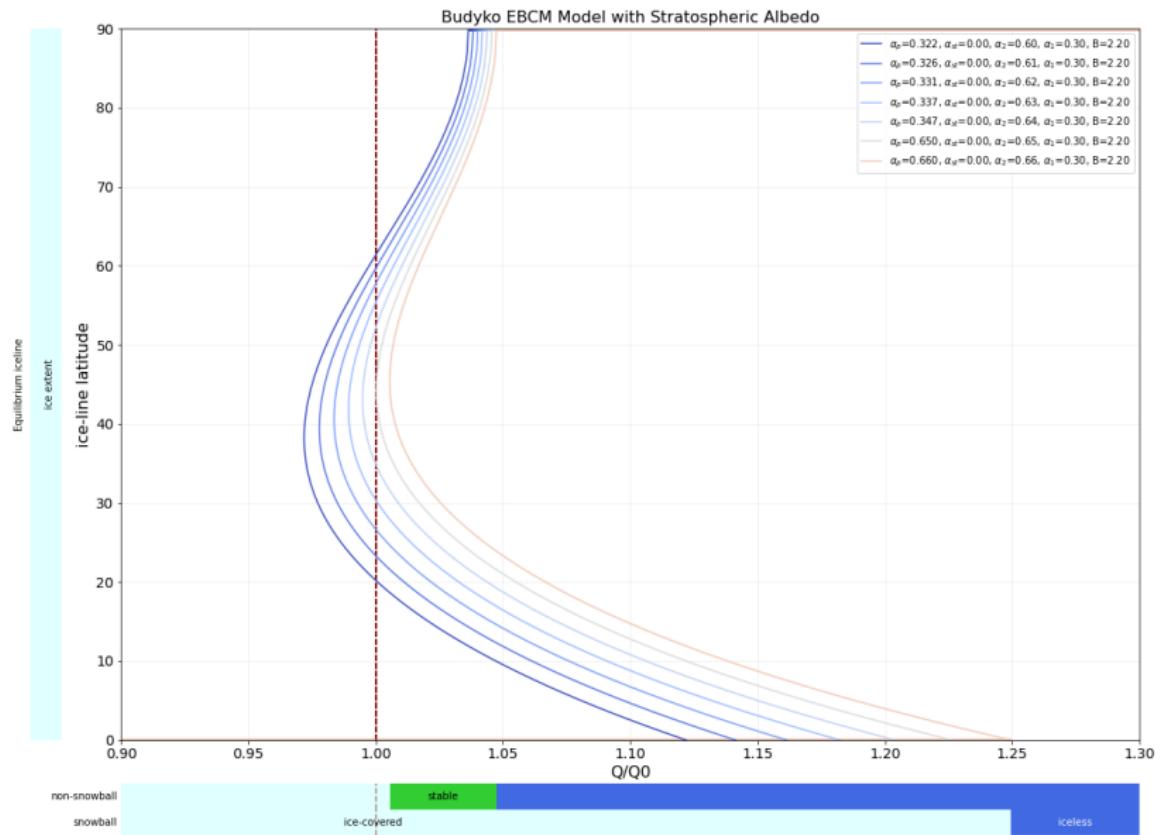
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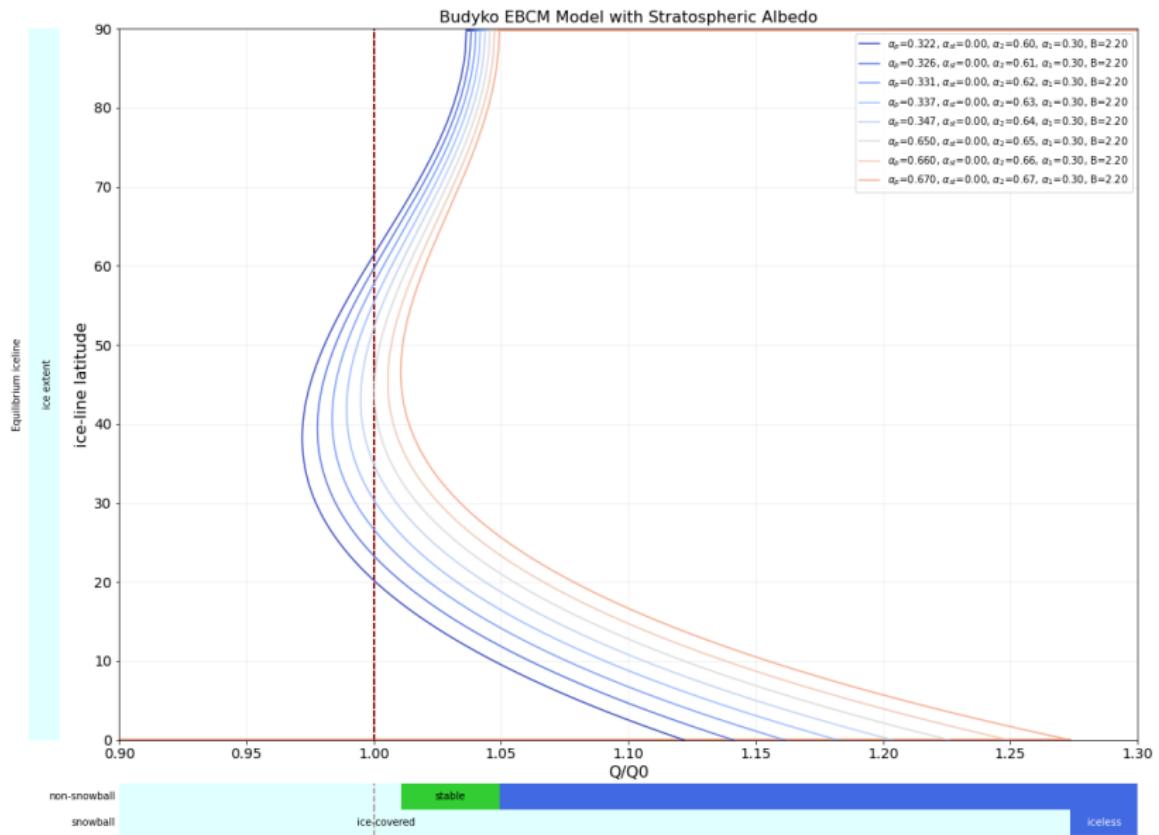
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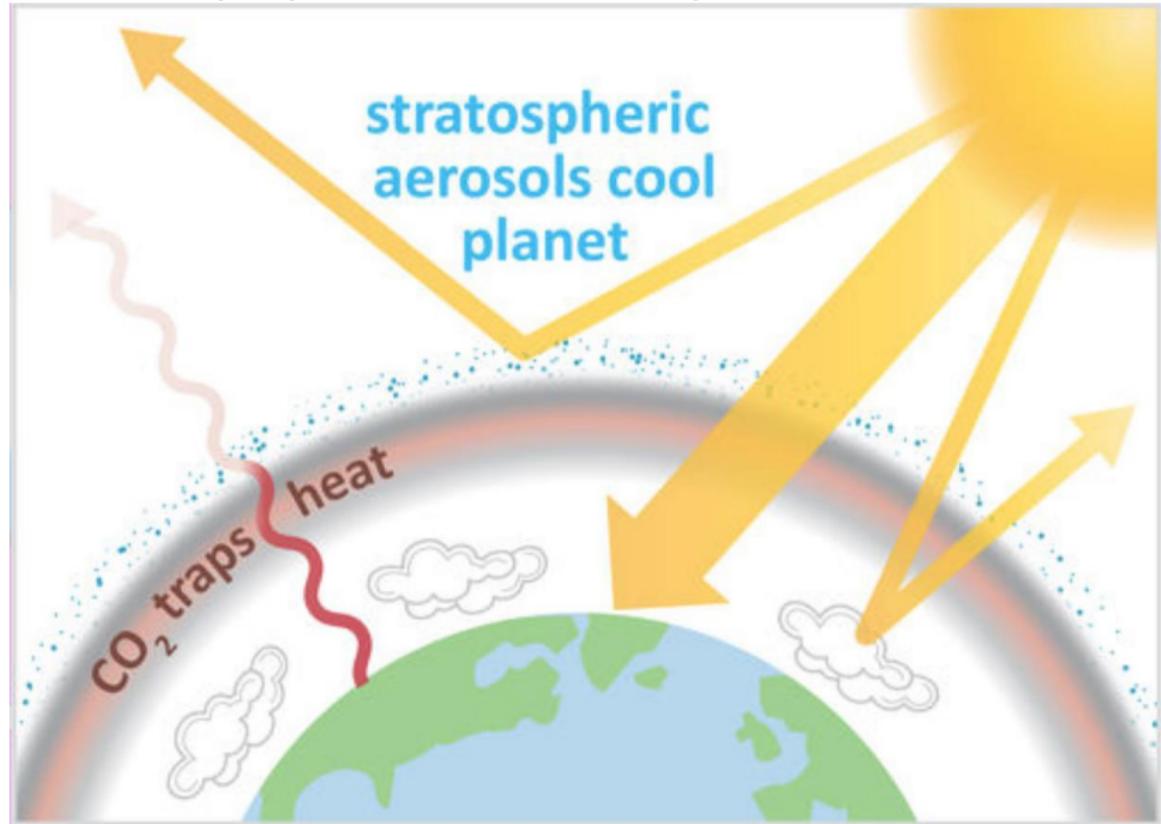


# So can increasing ice albedo.



# A volcanic mechanism to increase albedo

Volcanoes put particulates into *stratosphere* that increase albedo



$\tau$  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)

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

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

Adapted equation from Budyko (1969)

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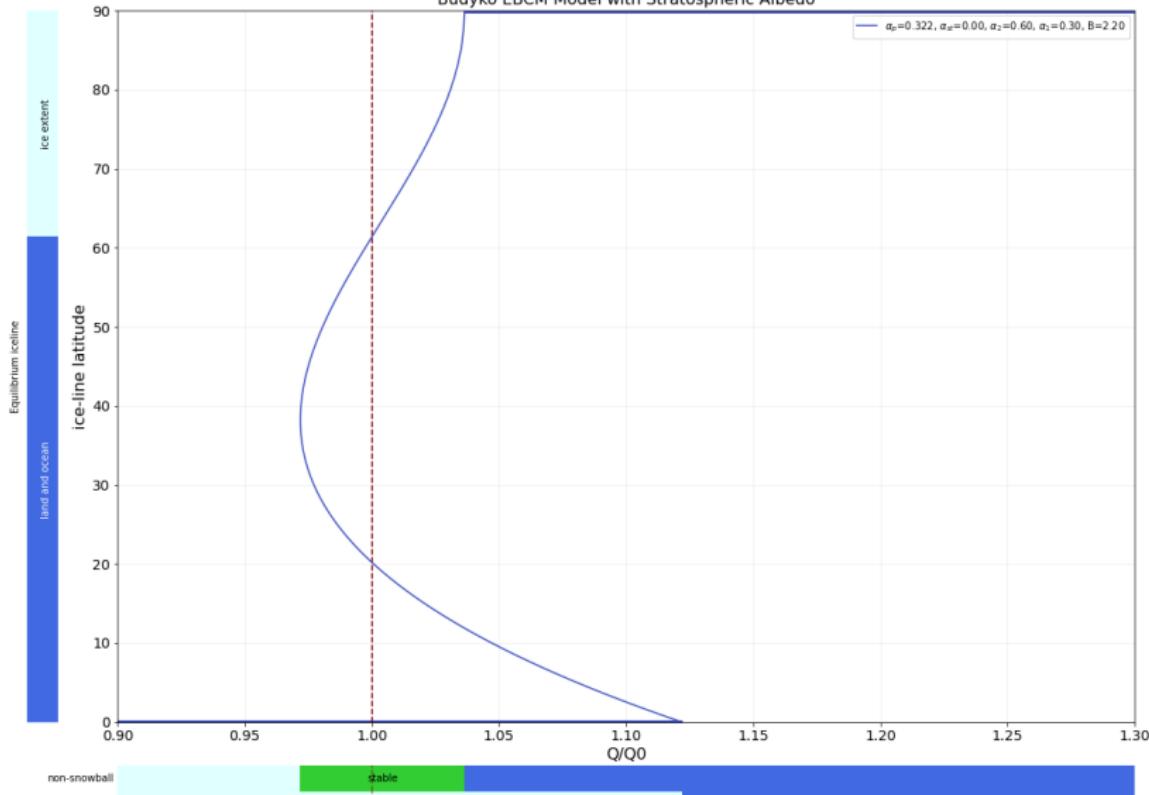
$$\alpha'_p = \int_0^1 S(x) [\alpha_{st}(\tau) + \alpha_{su}(x_s) - \alpha_{st}(\tau) \alpha_{su}(x_s)] dx,$$

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

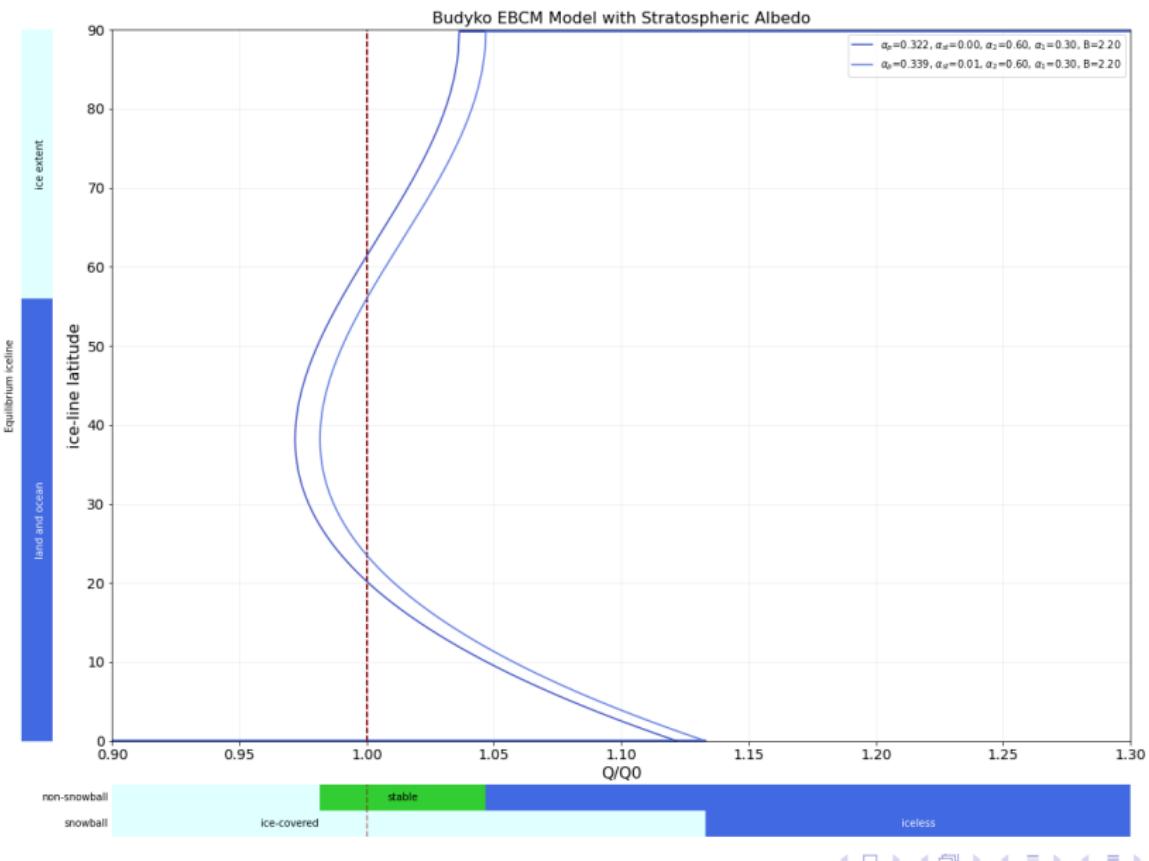
$$\frac{Q}{4} S(x_s) (1 - \alpha_{su}) (1 - \alpha_{st}) + \frac{QC}{4B} (1 - \alpha'_p) = k$$

# Increasing $\tau$ or $\alpha_{st}$

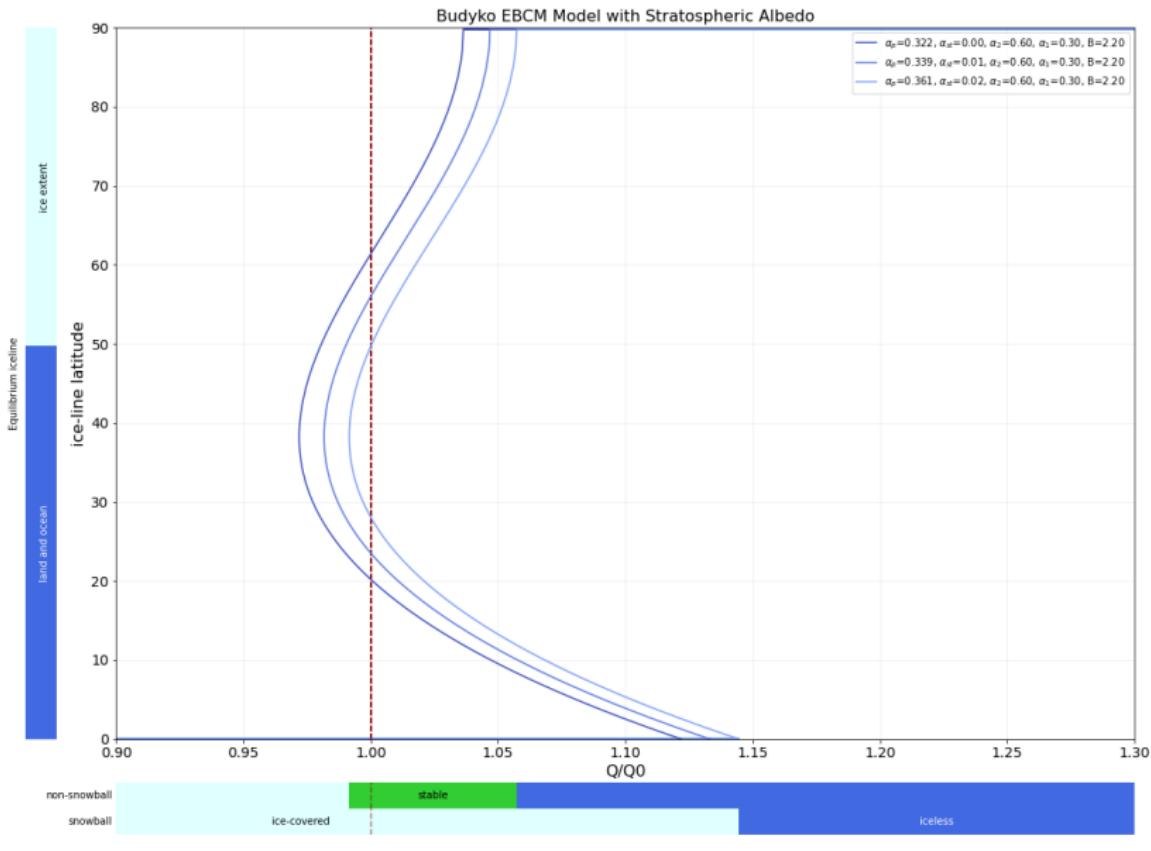
Budyko EBCM Model with Stratospheric Albedo



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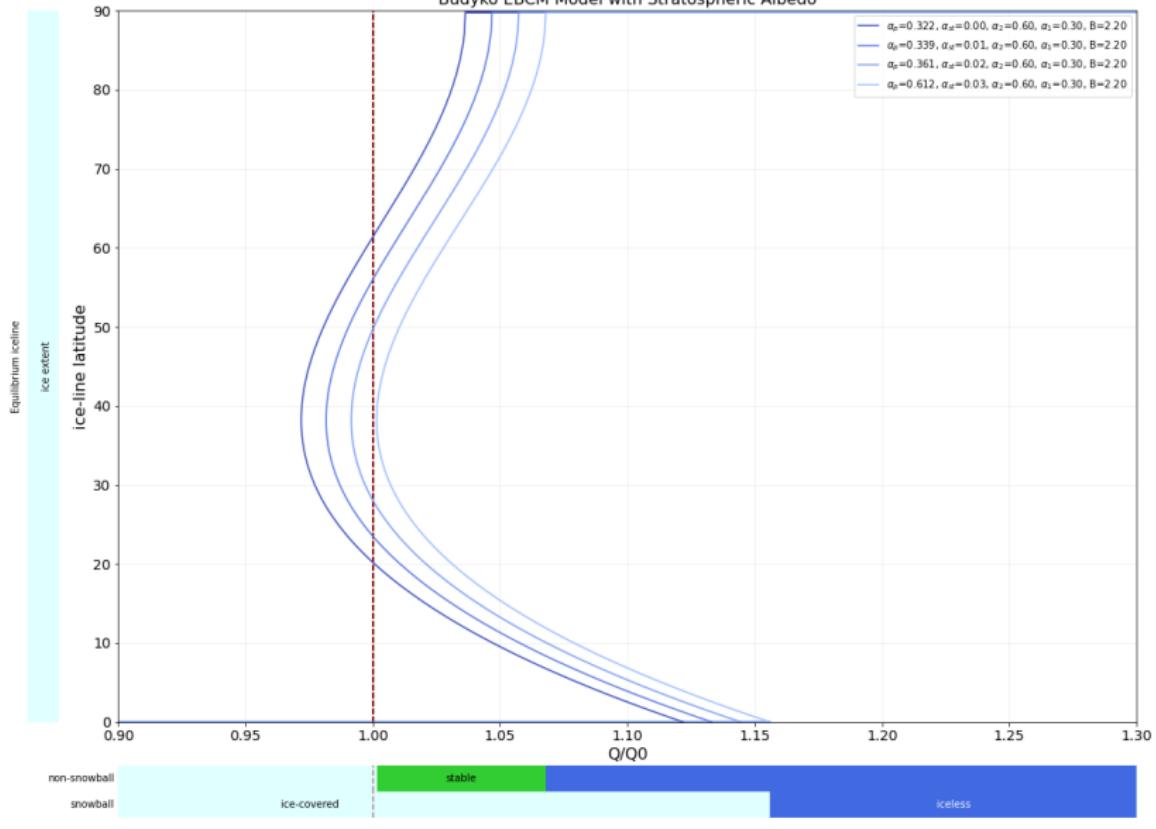


## Increasing $\tau$ or $\alpha_{st}$



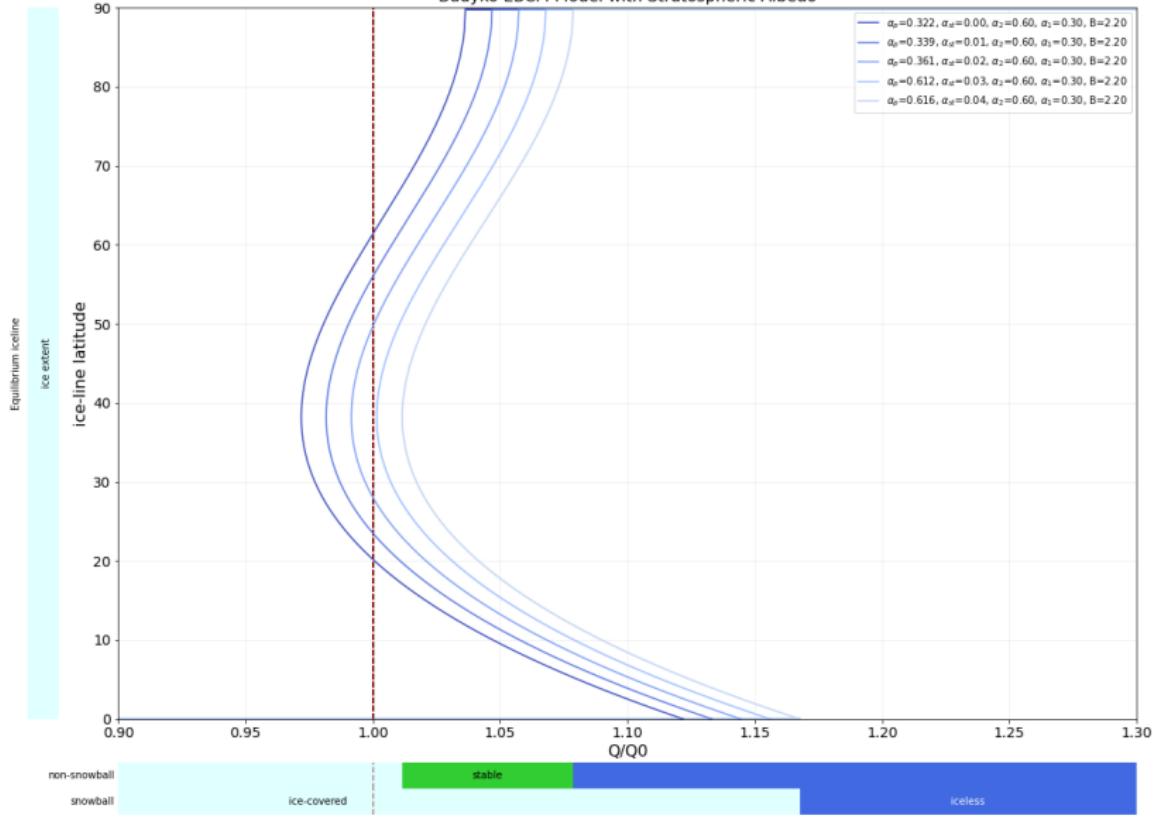
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Budyko EBCM Model with Stratospheric Albedo

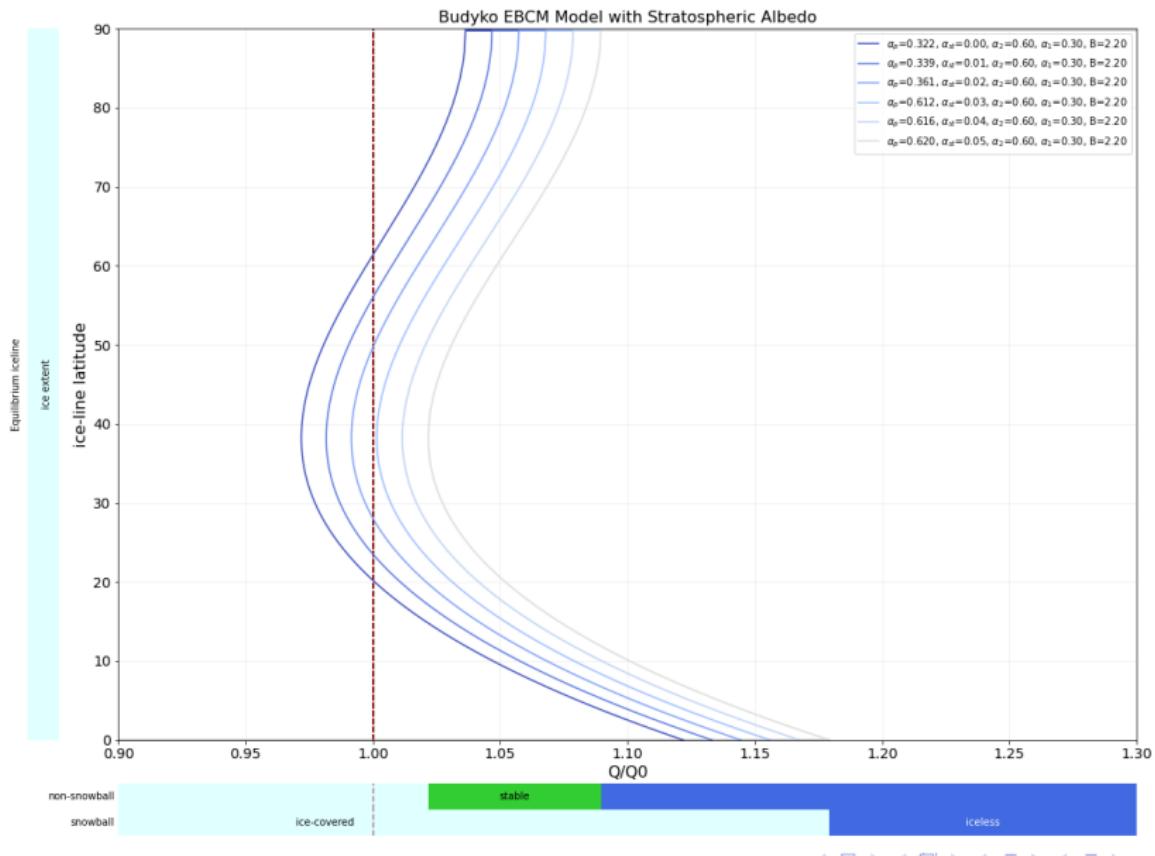


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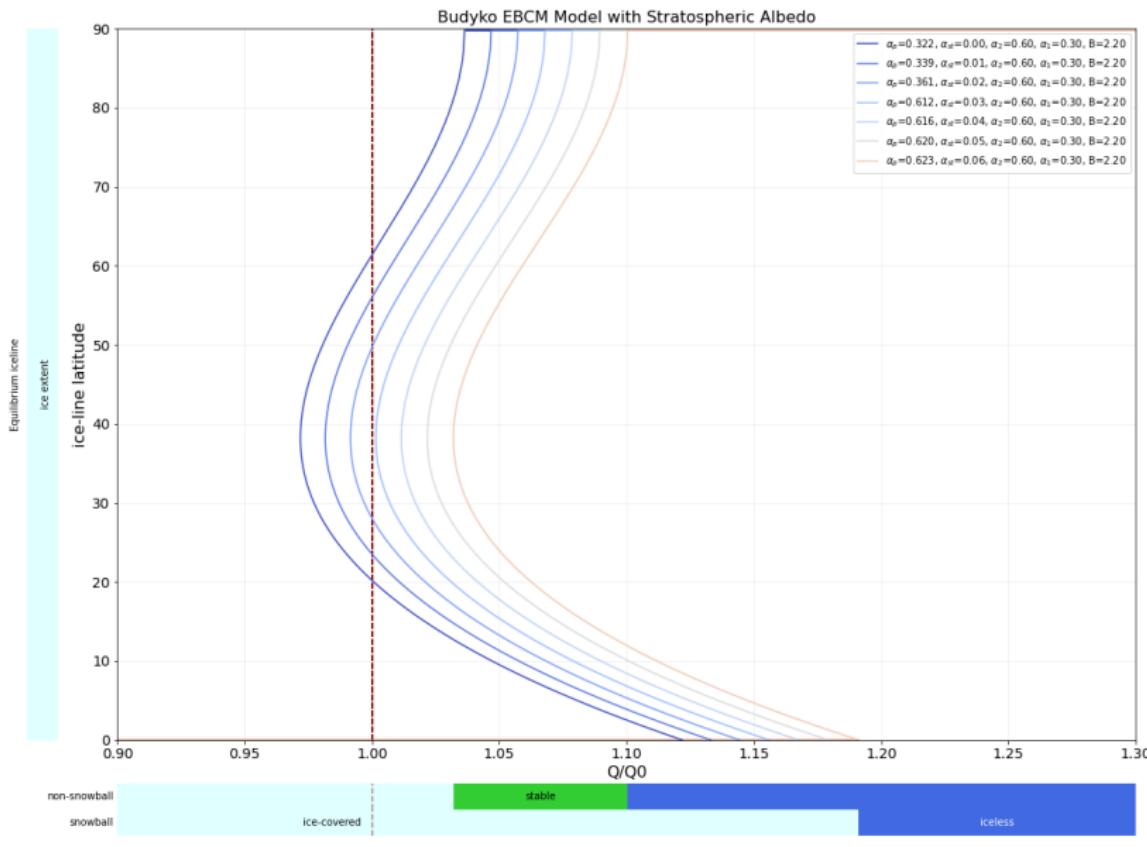
Budyko EBCM Model with Stratospheric Albedo



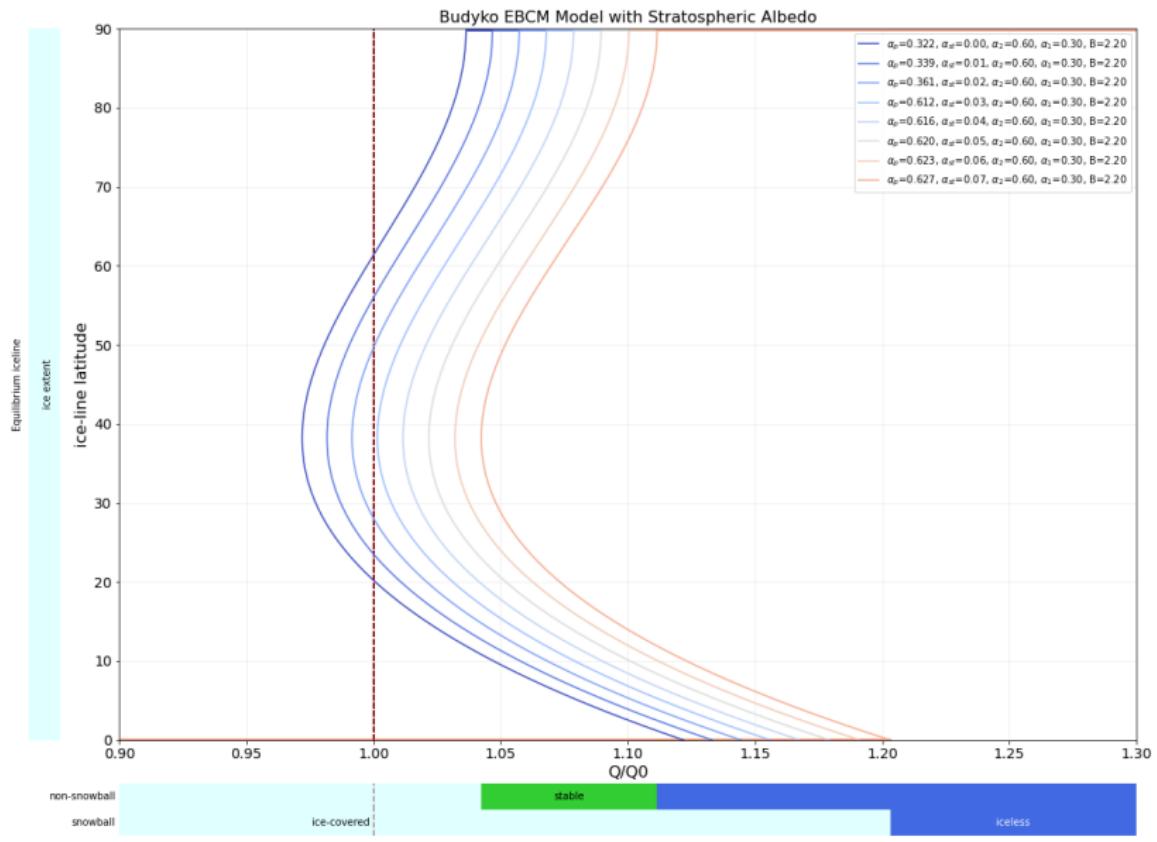
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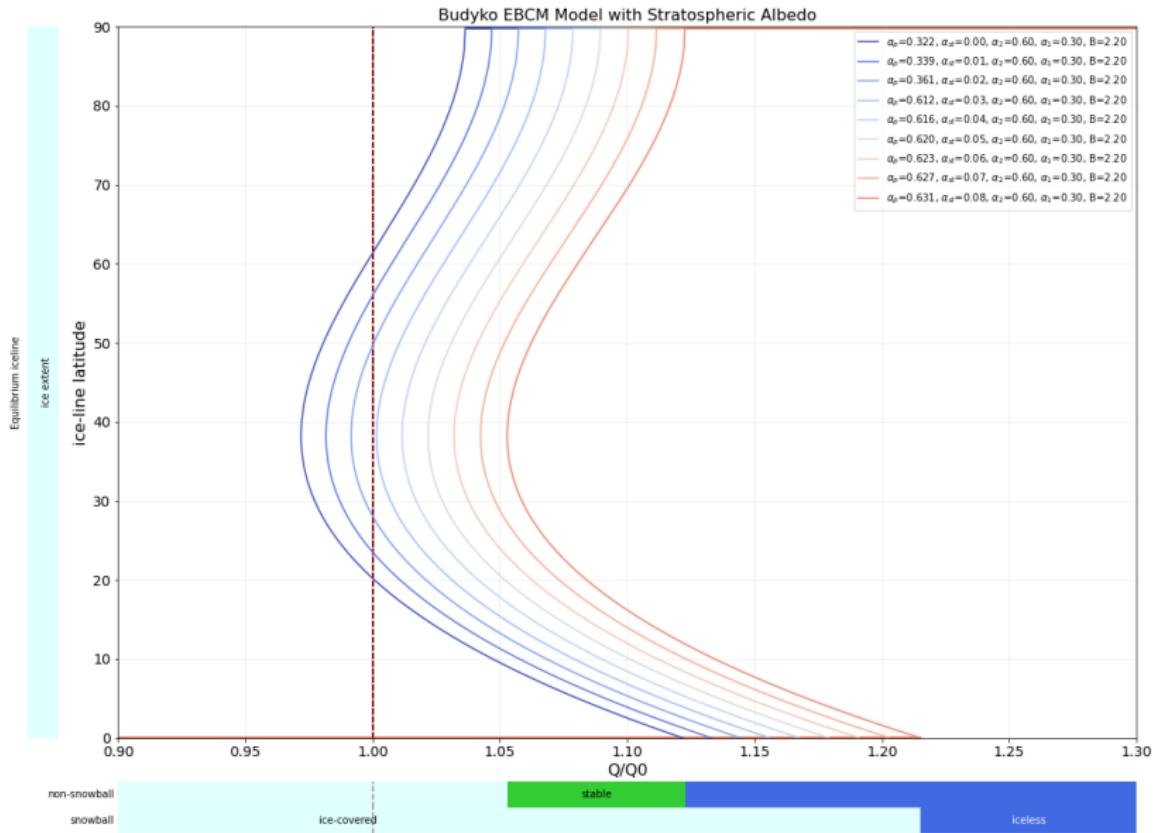
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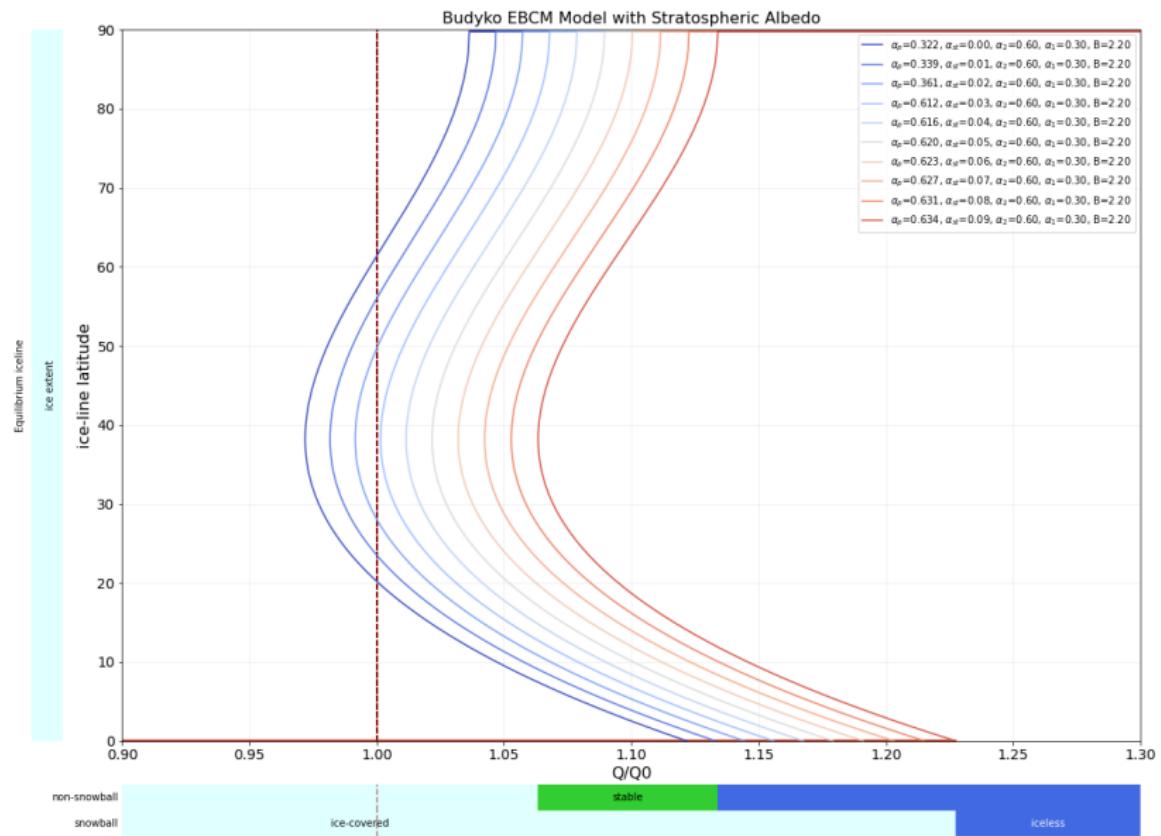
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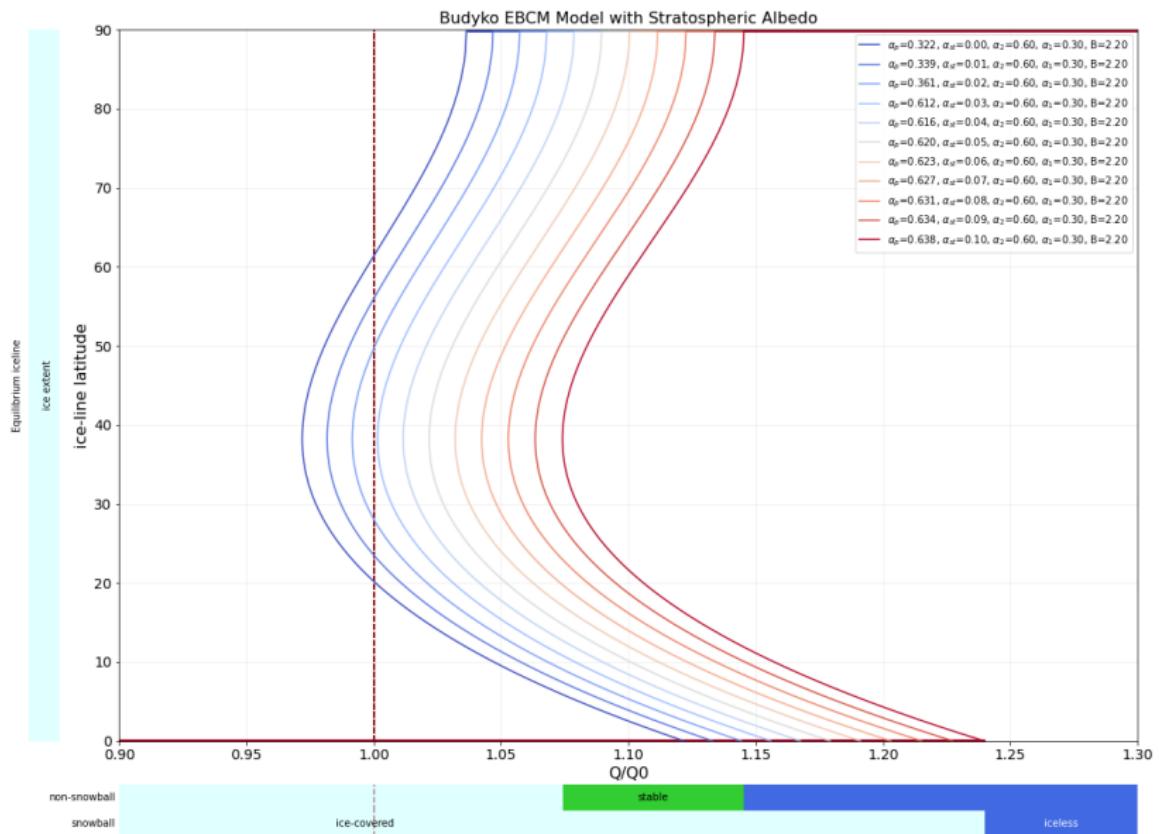
Increasing  $\tau$  or  $\alpha_{st}$



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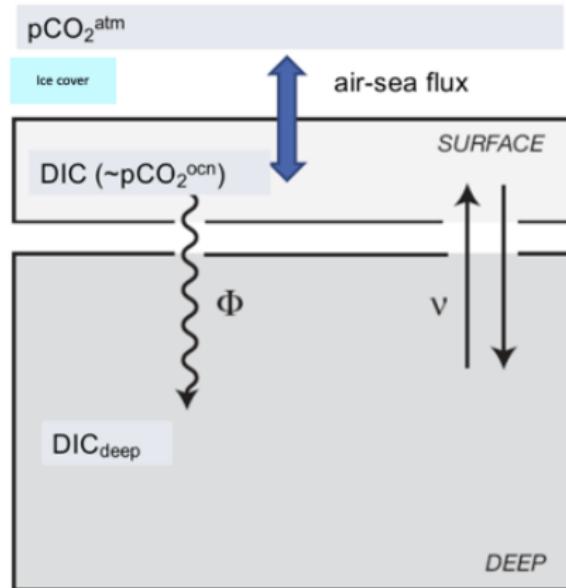


# Increasing $\tau$ or $\alpha_{st}$



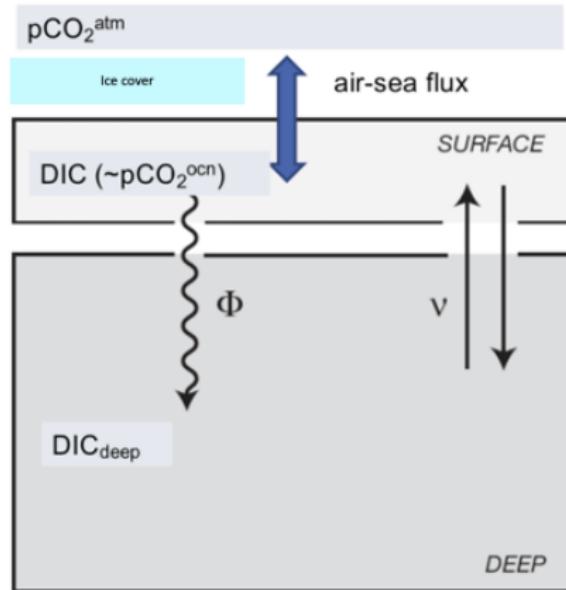
# Increasing $CO_2 \approx$ increasing B

Ice sheets block the ocean sink for  $CO_2$



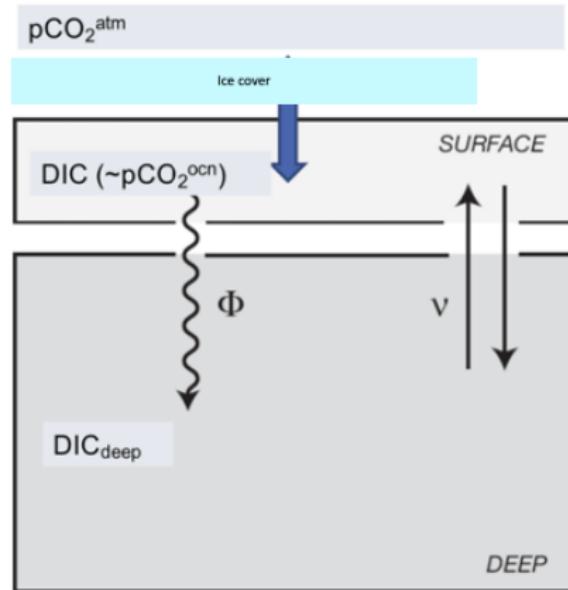
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Ice sheets block the ocean sink for  $CO_2$   
Increasing CO<sub>2</sub> increases  $\bar{T}$ , increasing OLR or B.



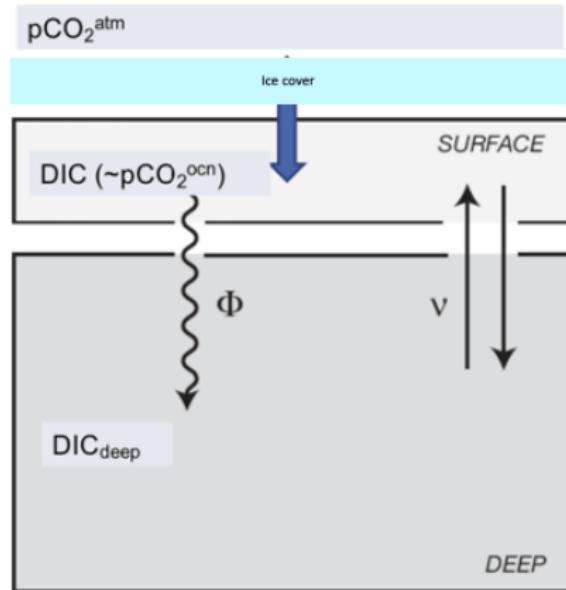
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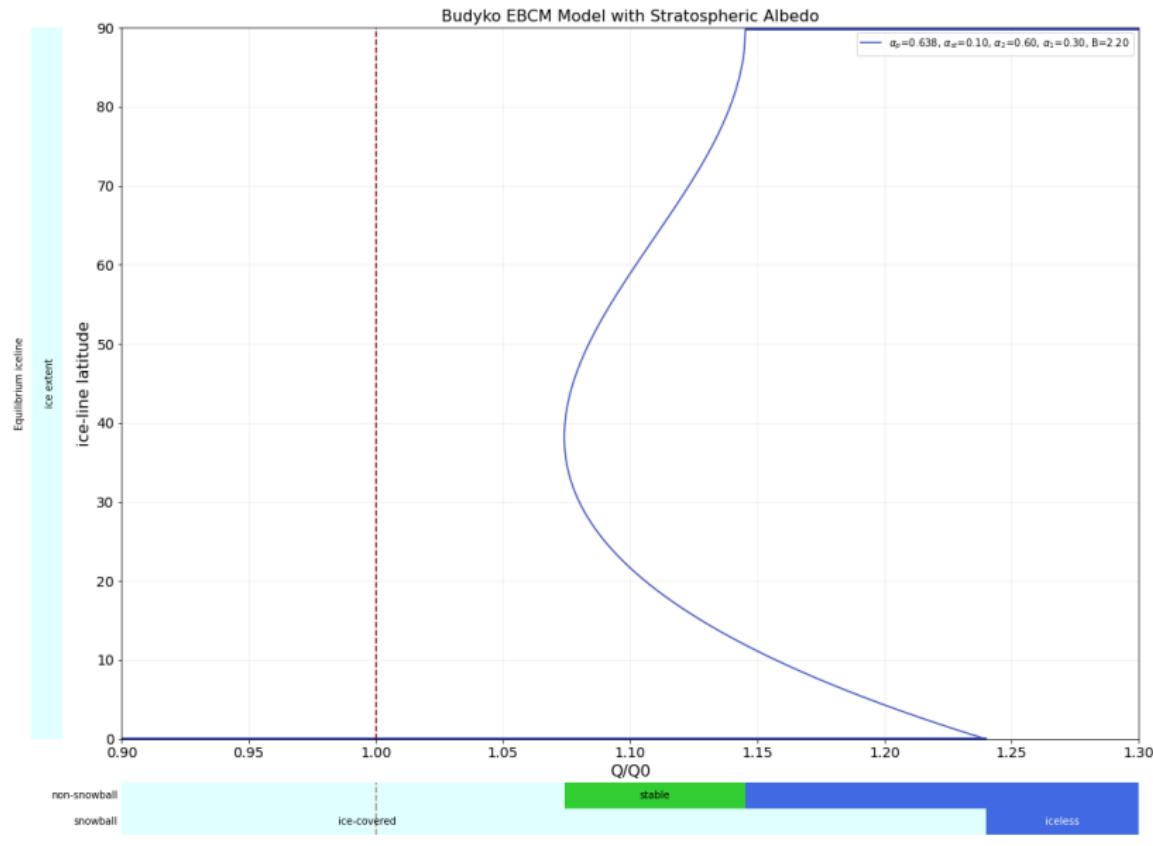


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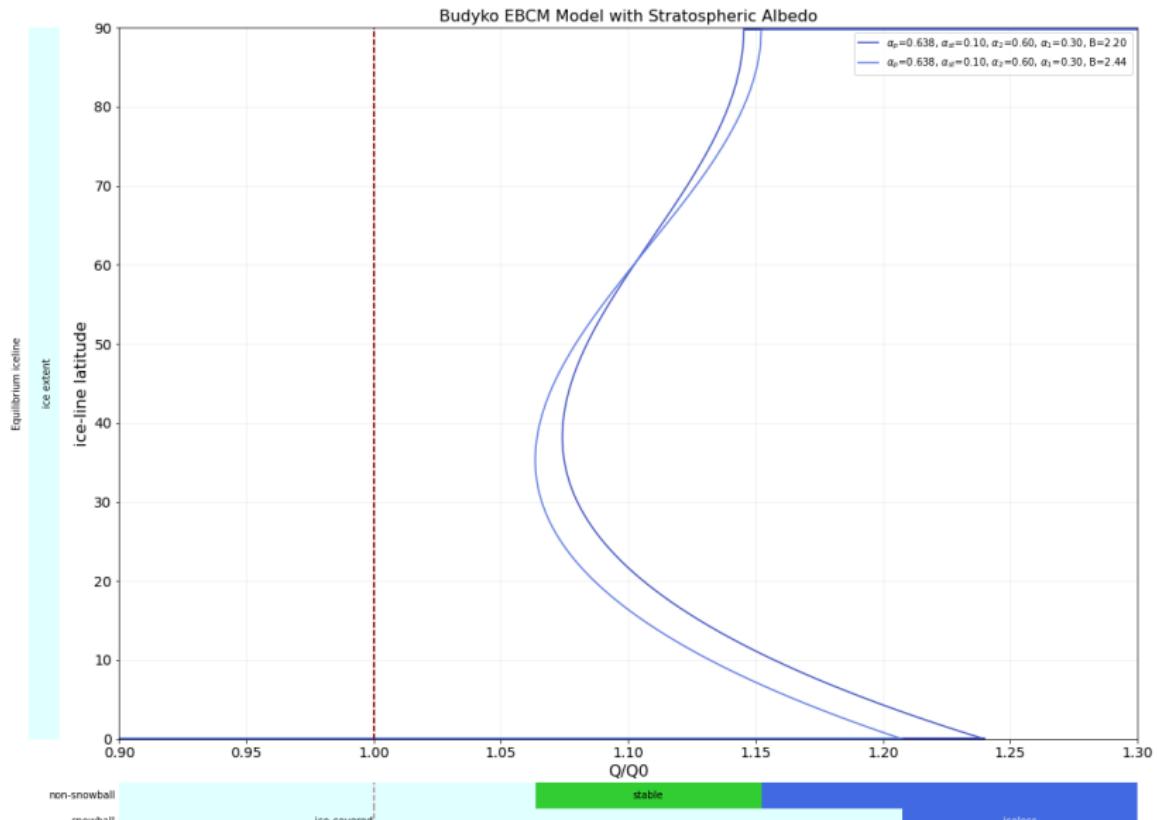
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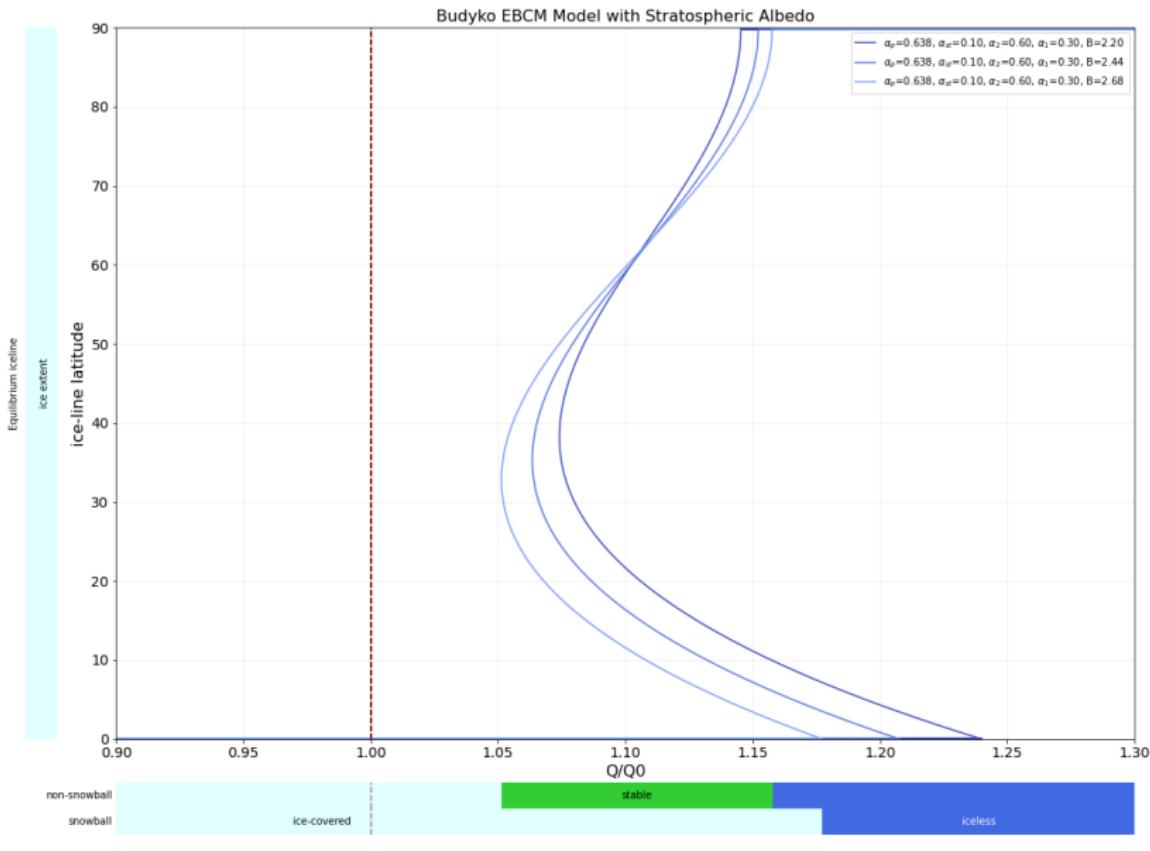
# Increasing $CO_2 \rightarrow$ can get us back to a partial-ice world.



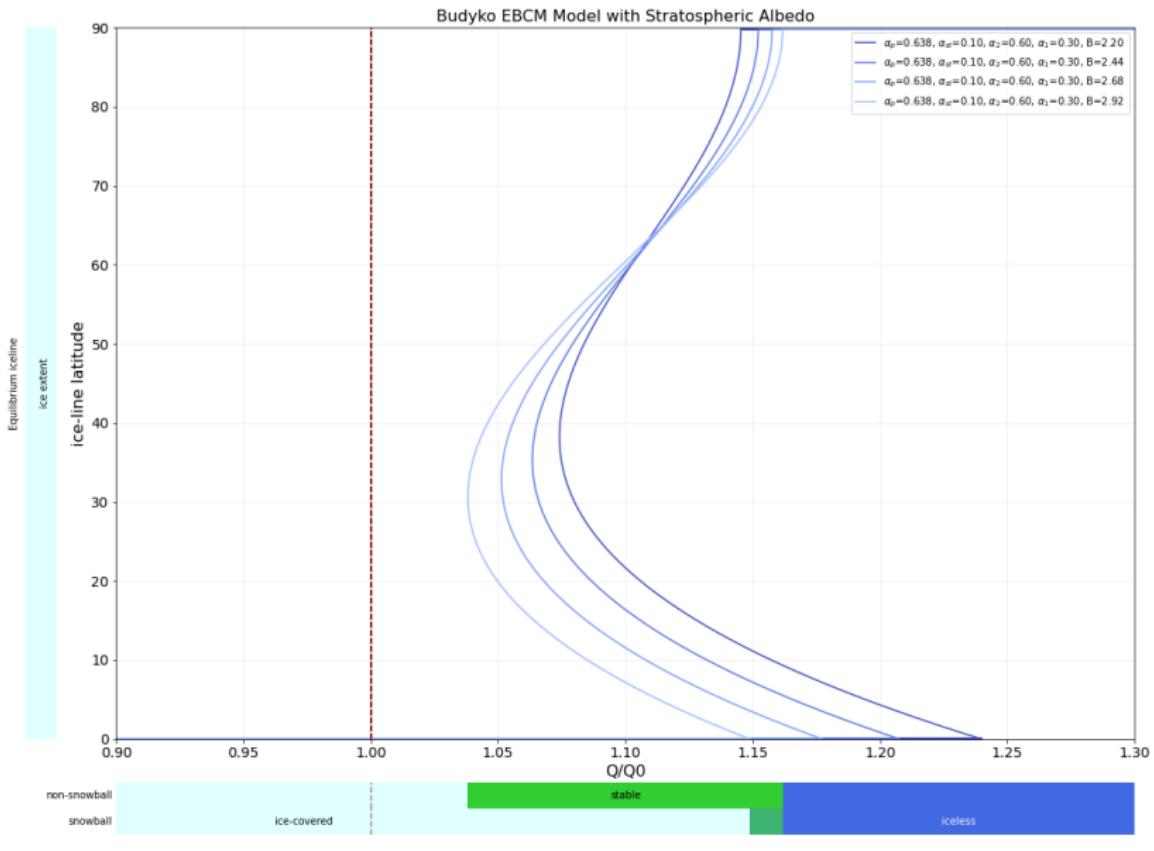
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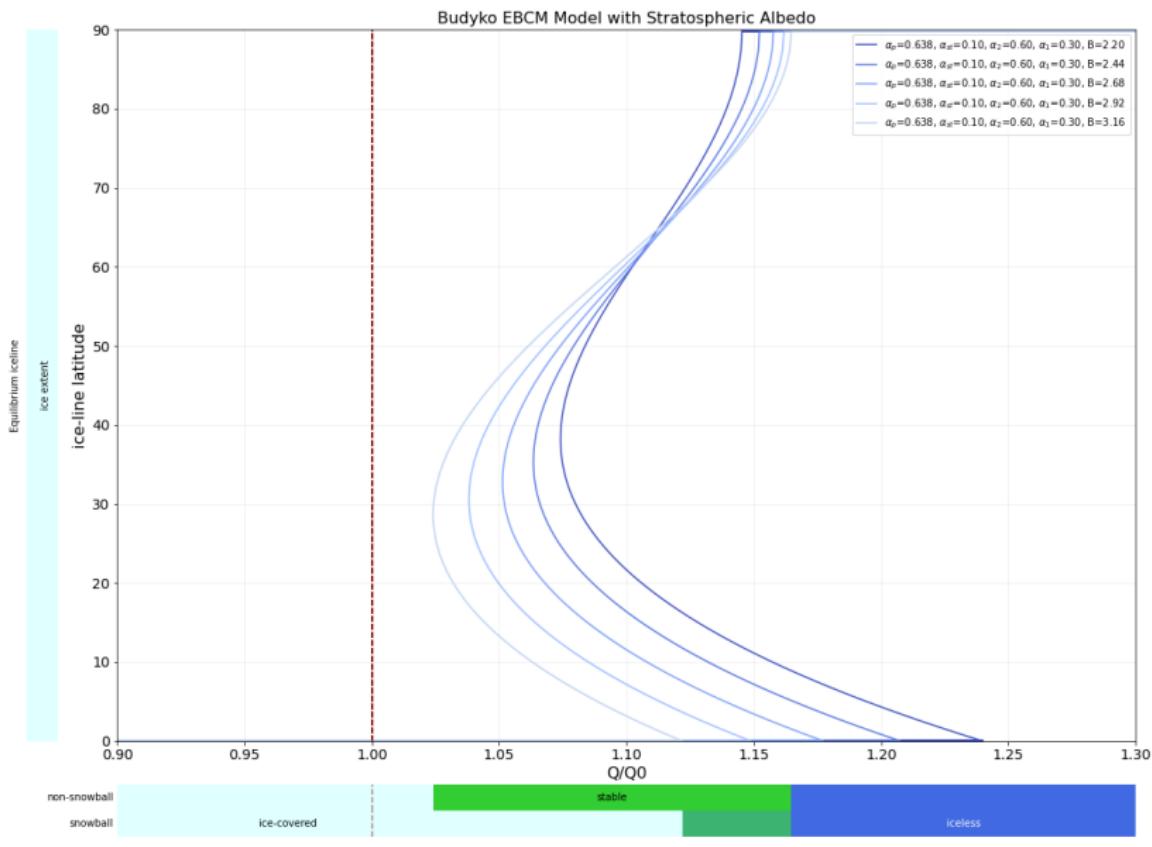
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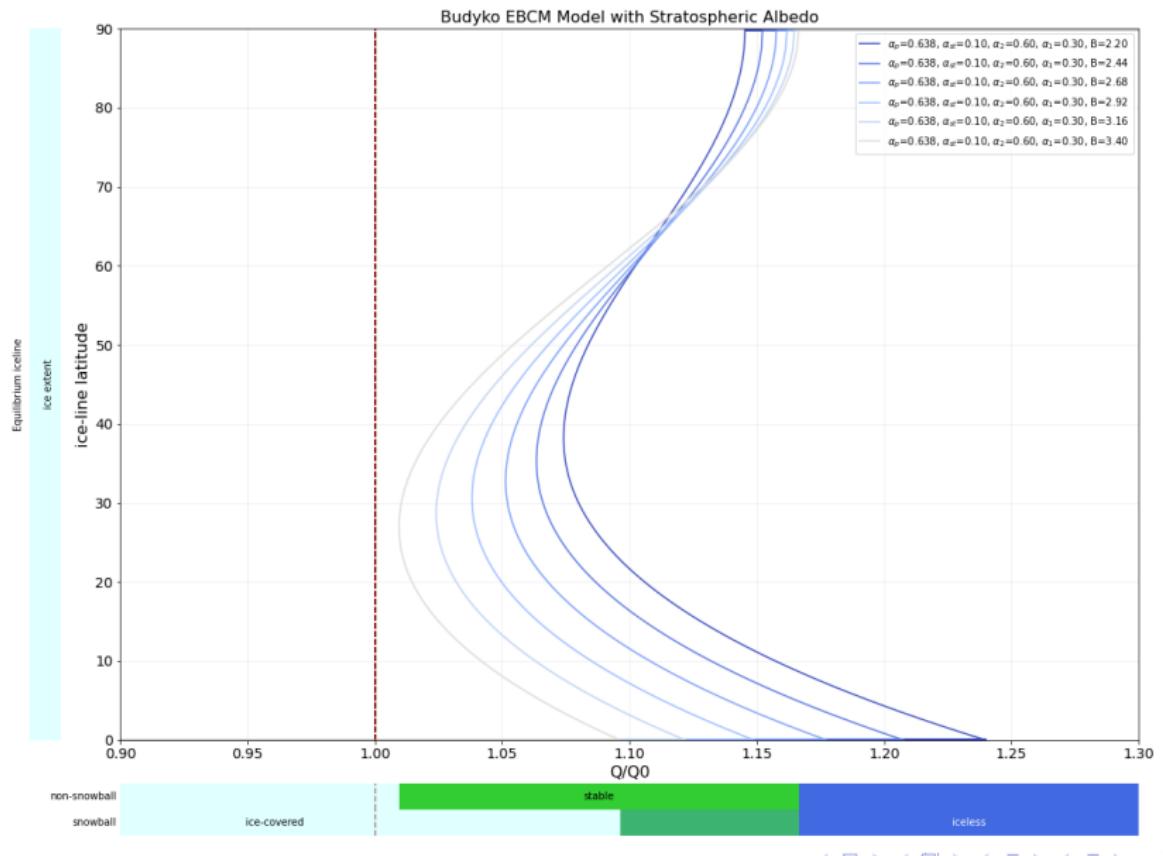
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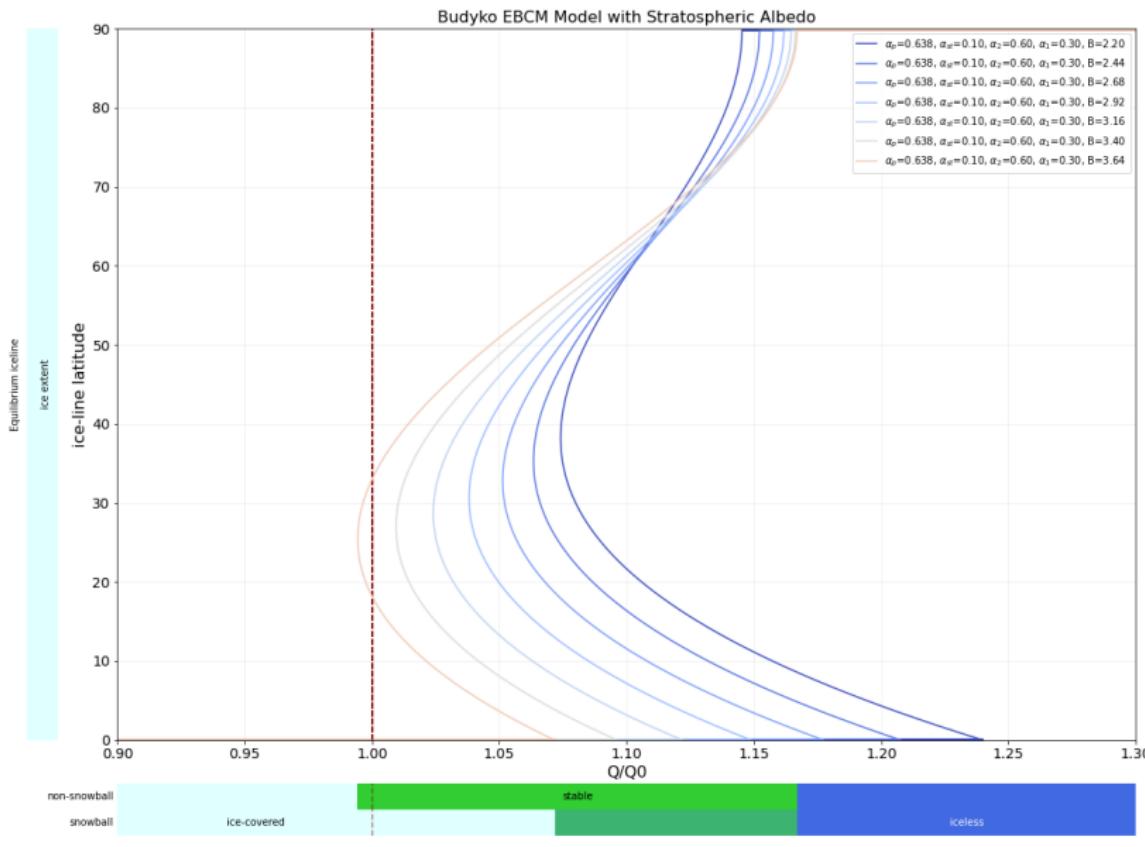
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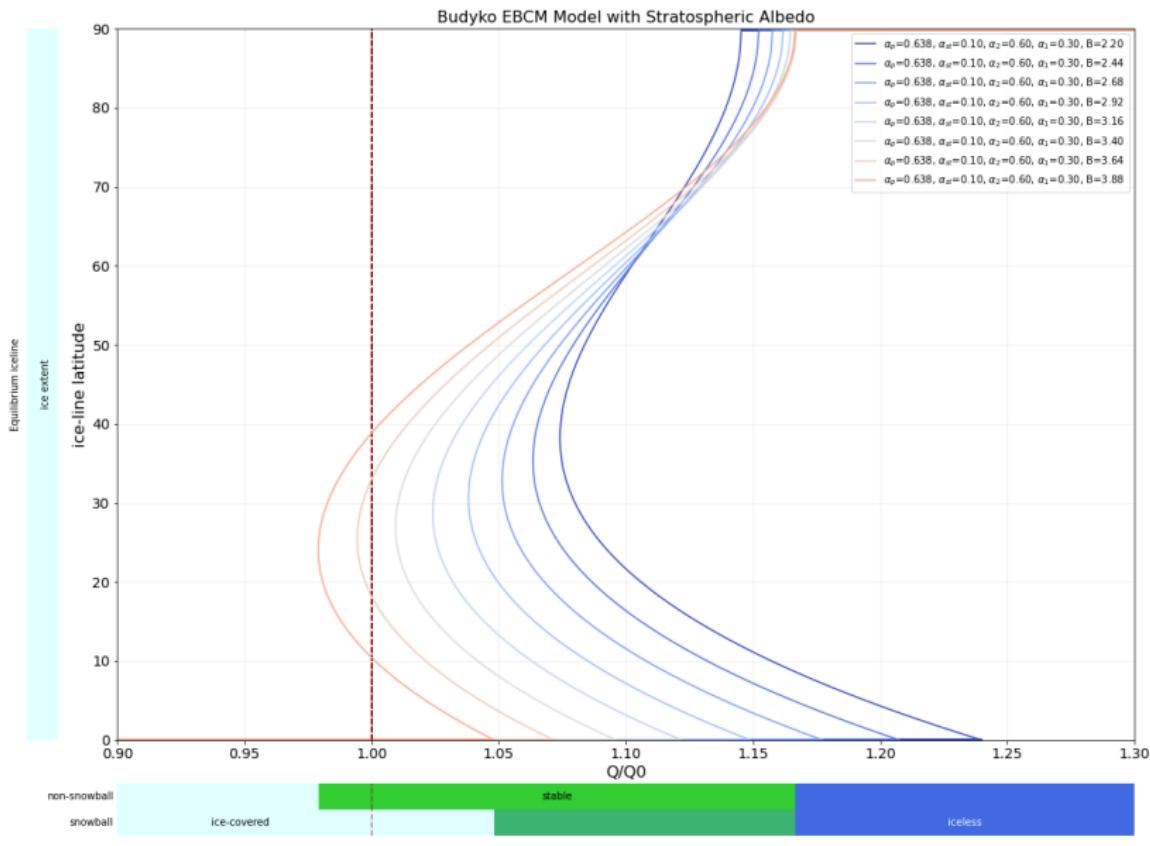
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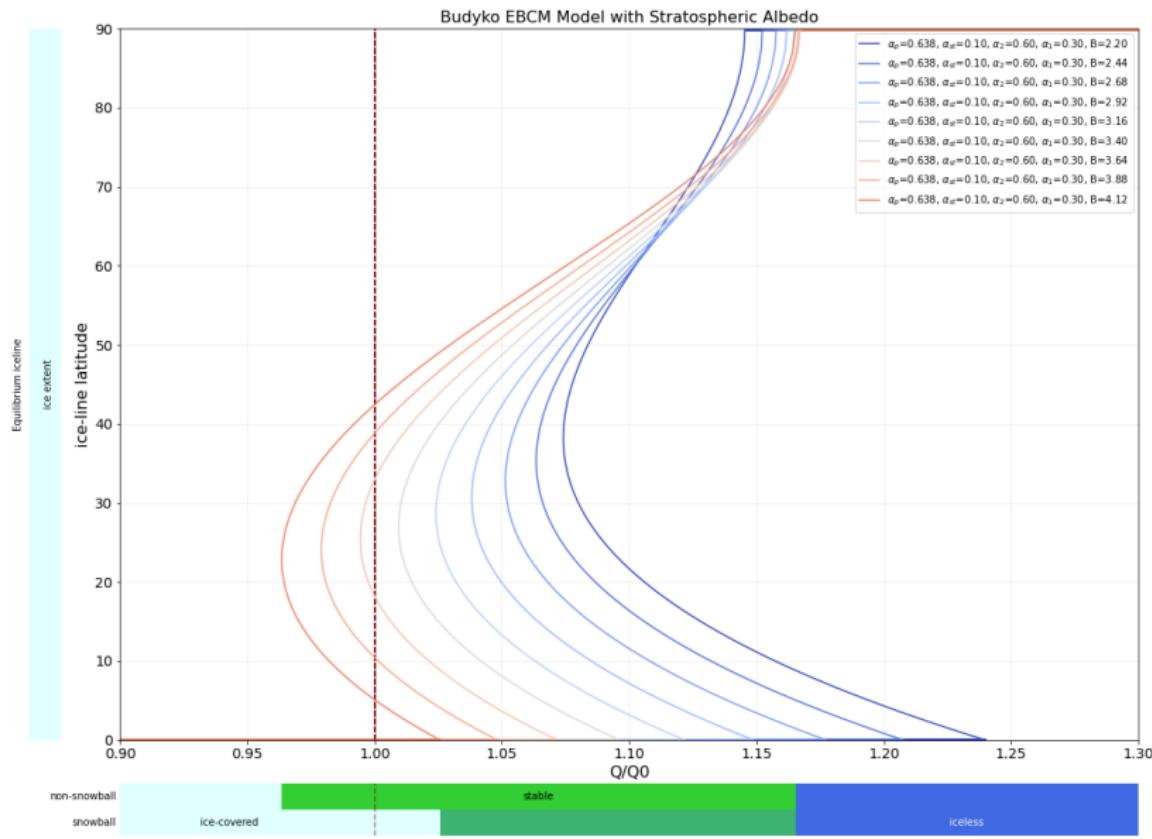
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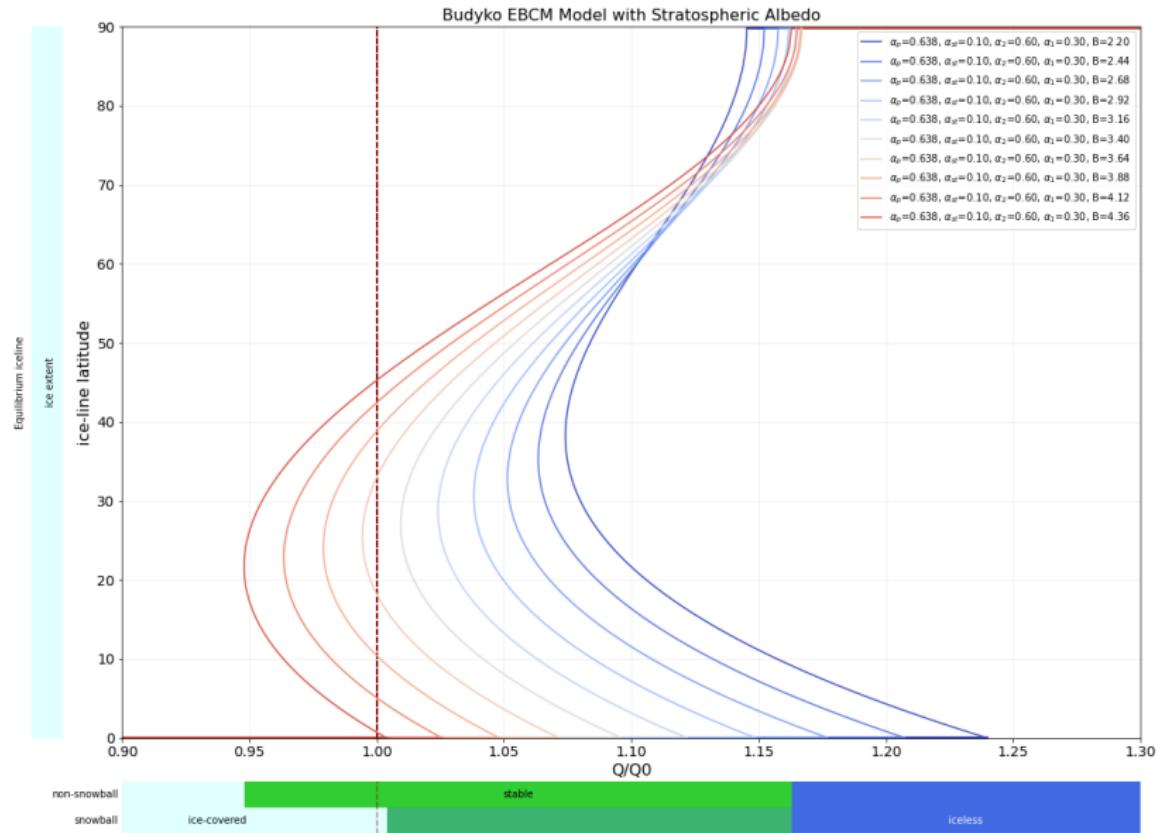
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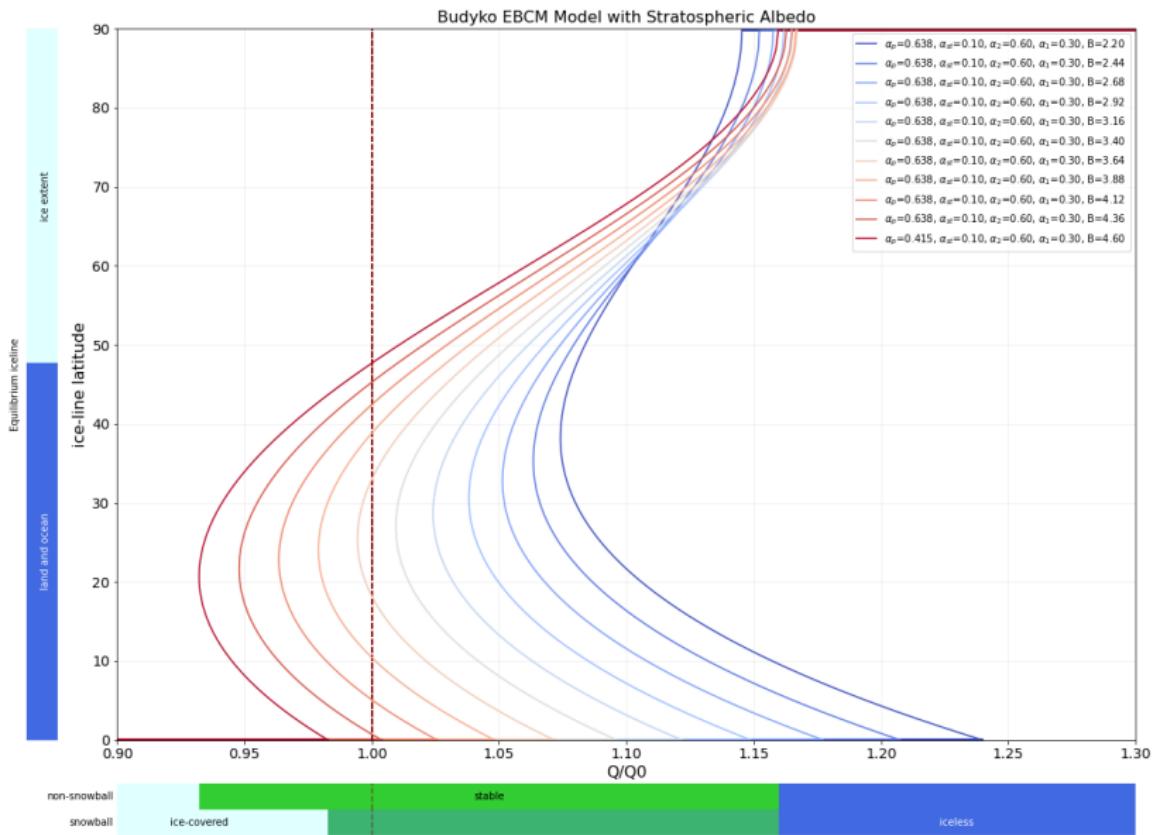
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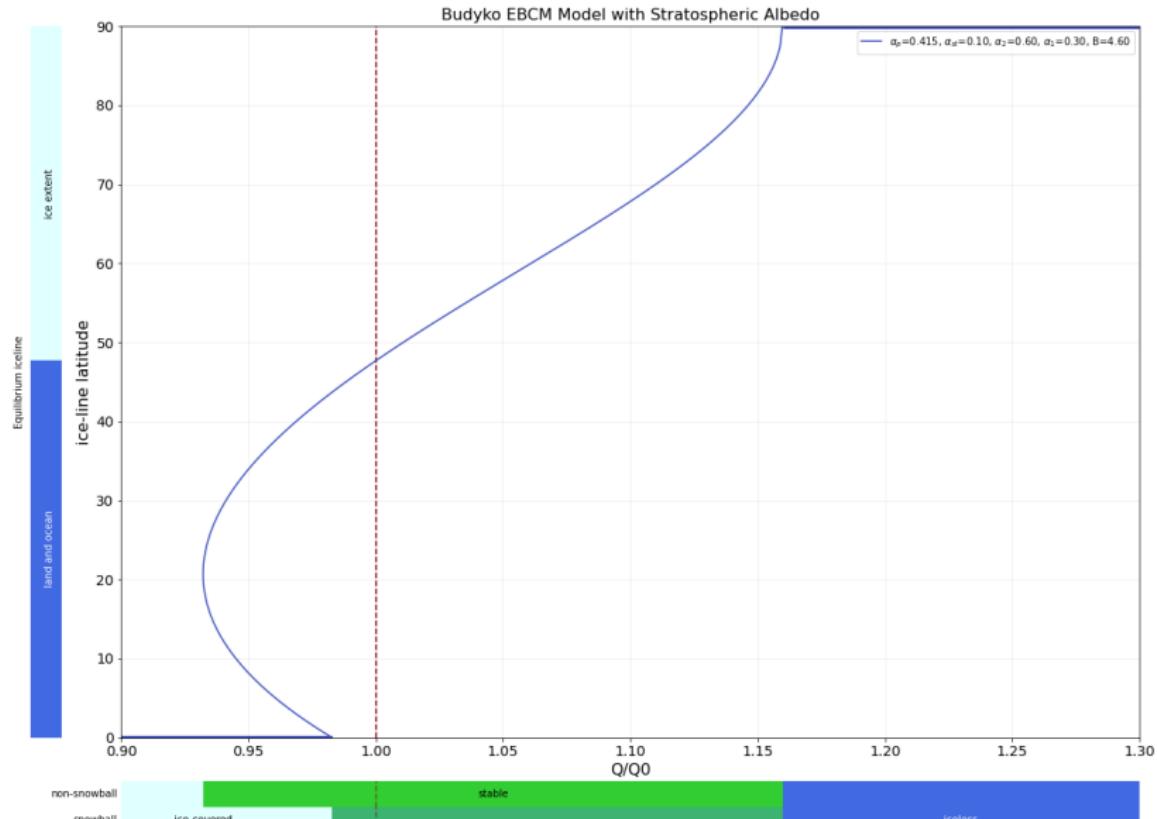
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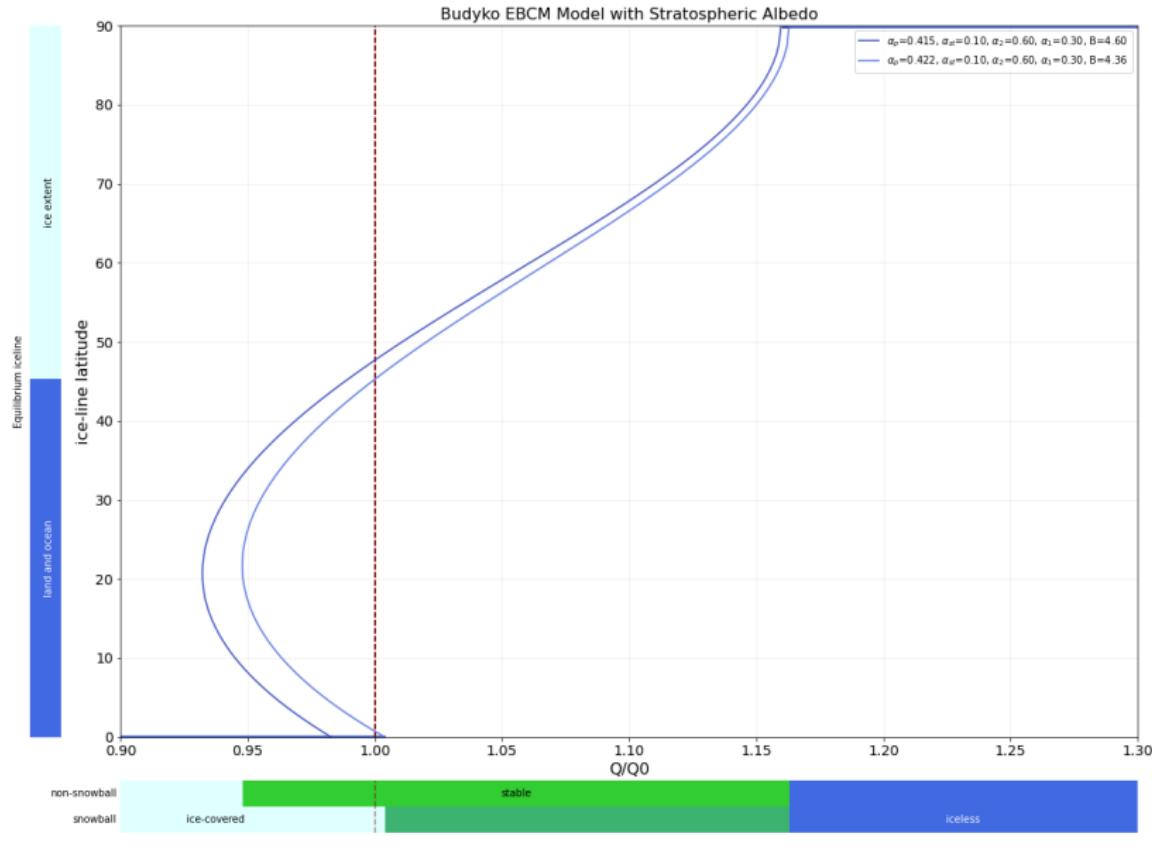
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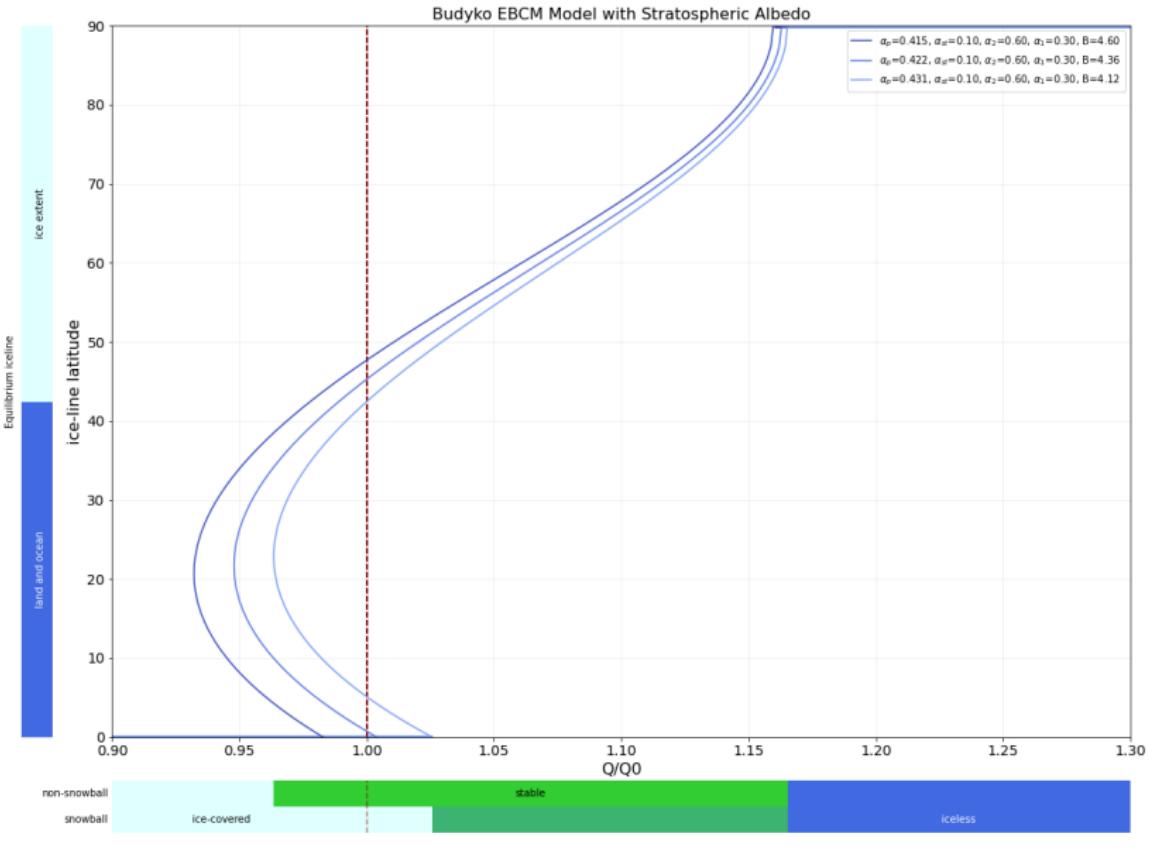
# CO<sub>2</sub> sink reactivates, causing hysteresis



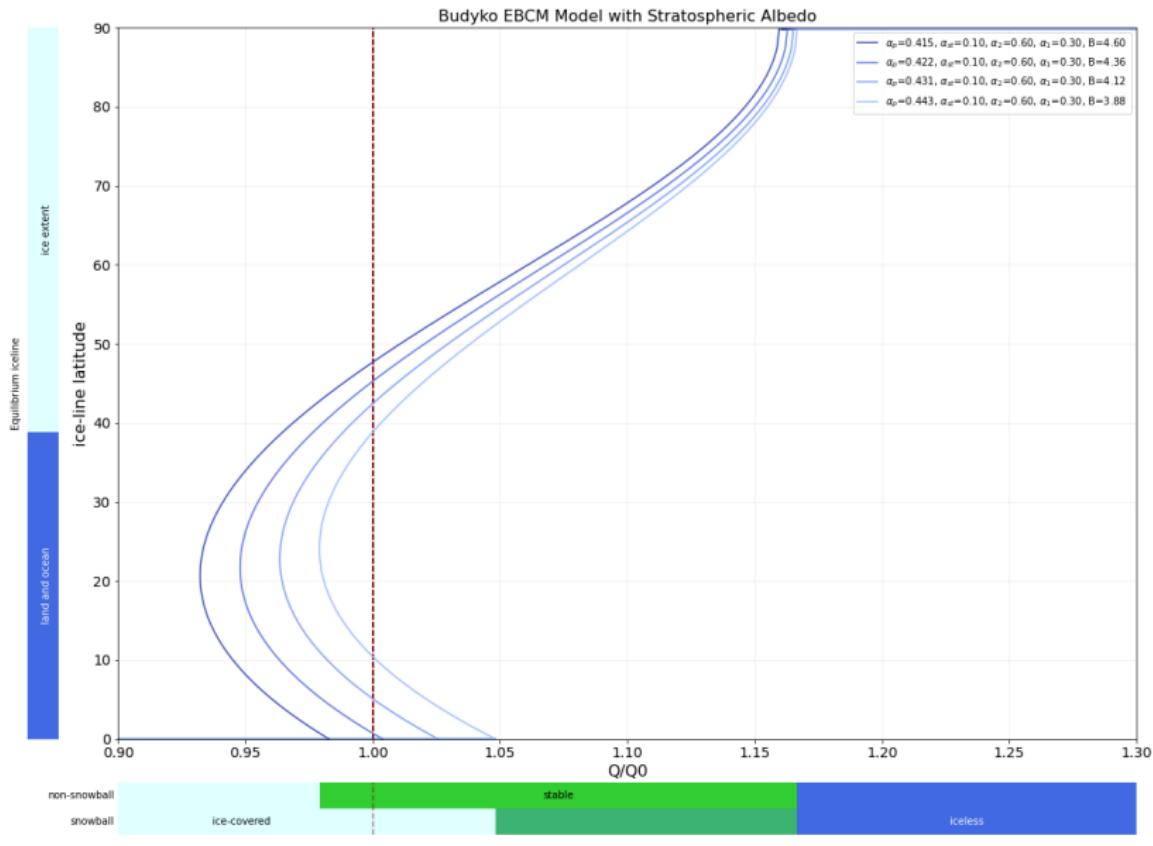
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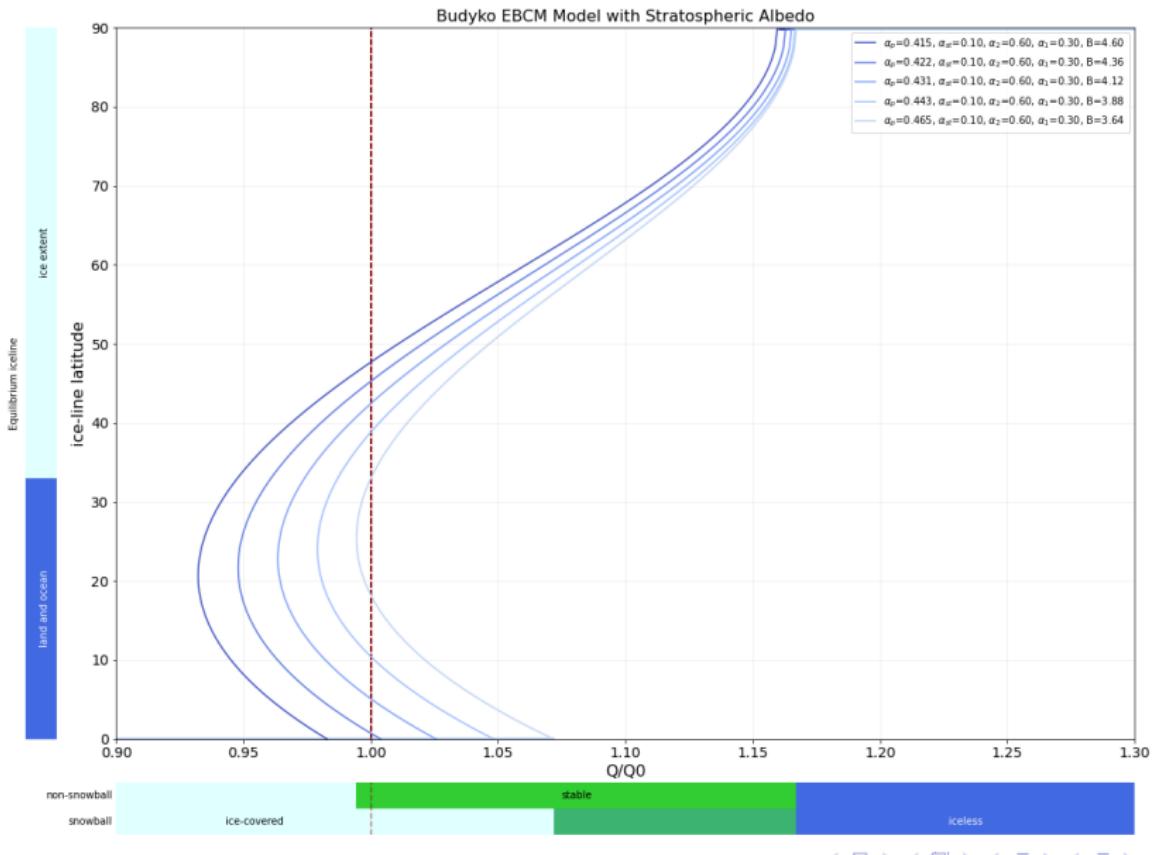
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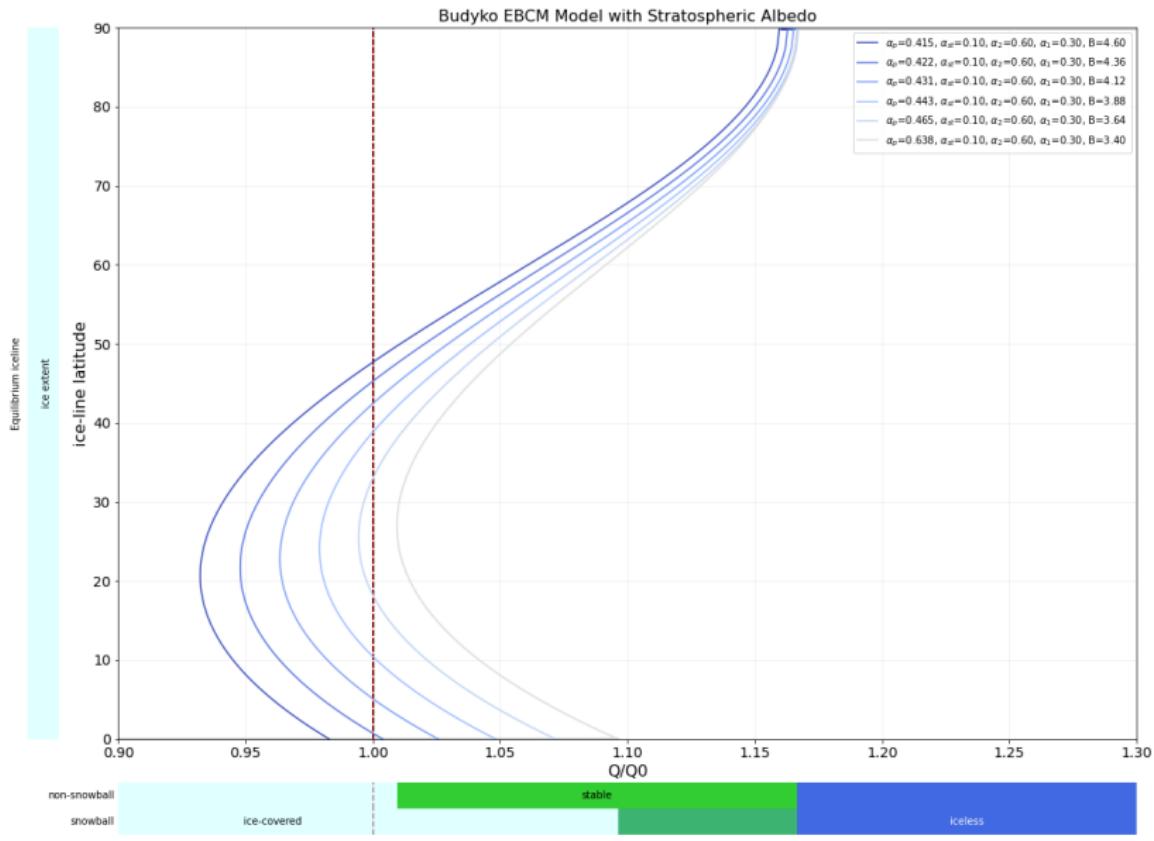
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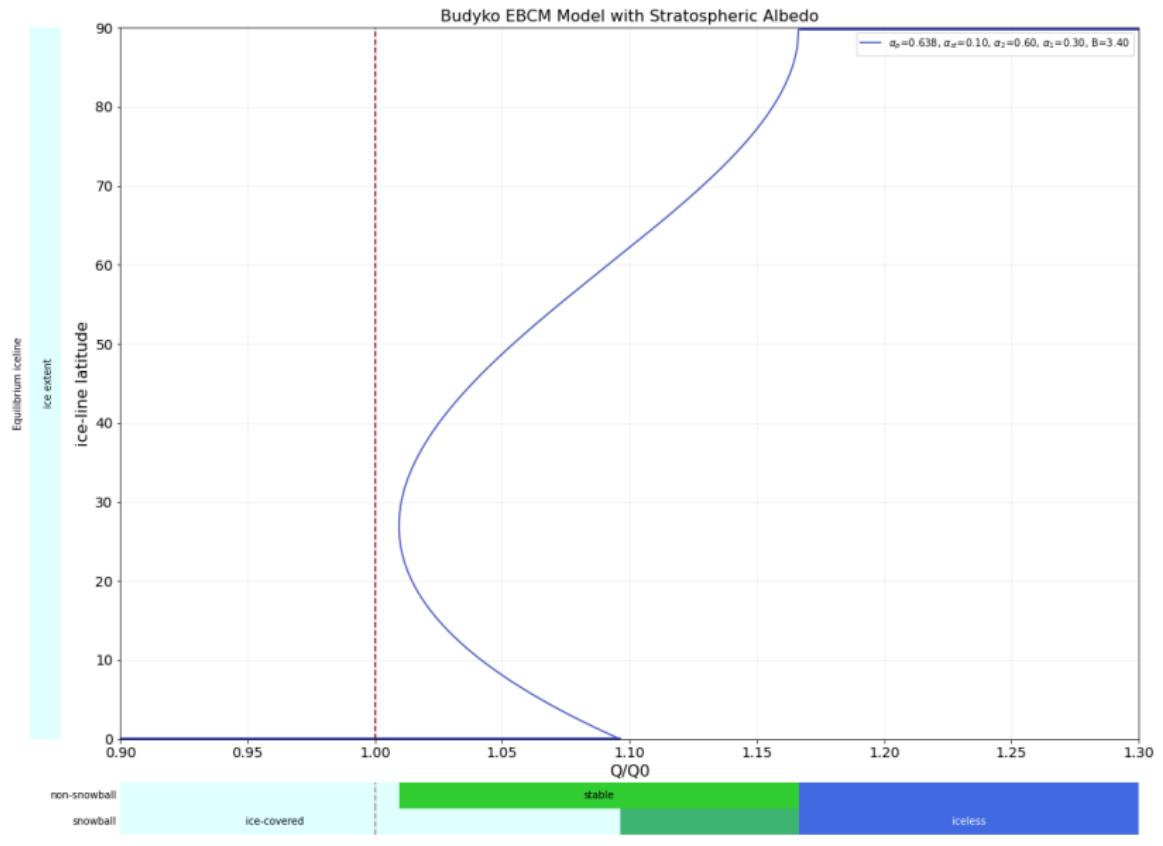
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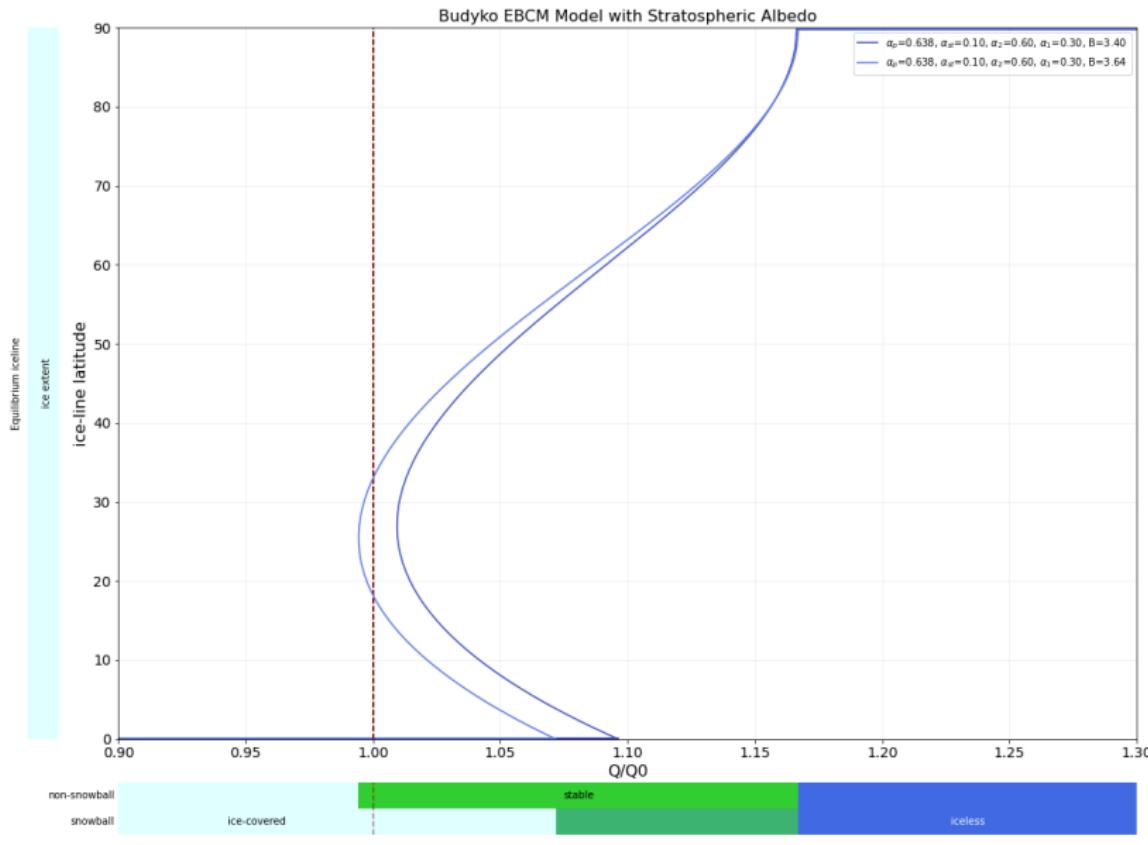
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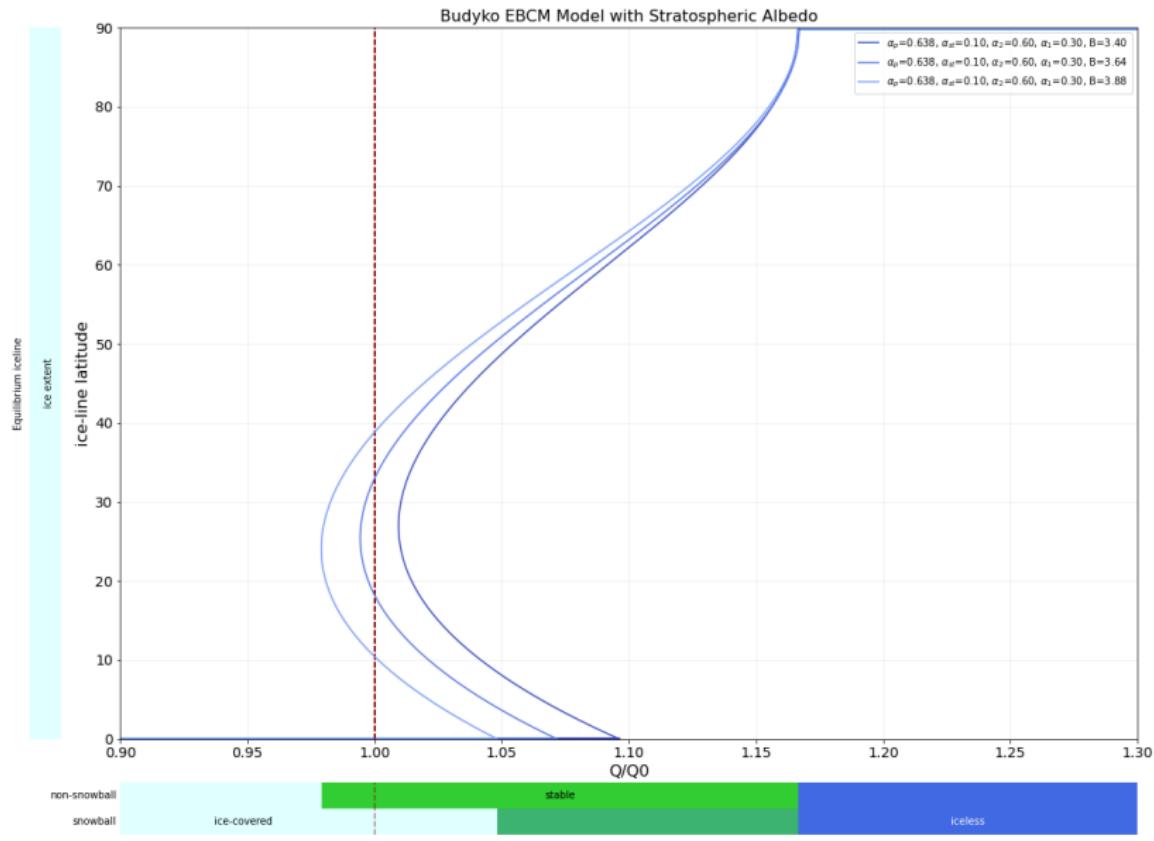
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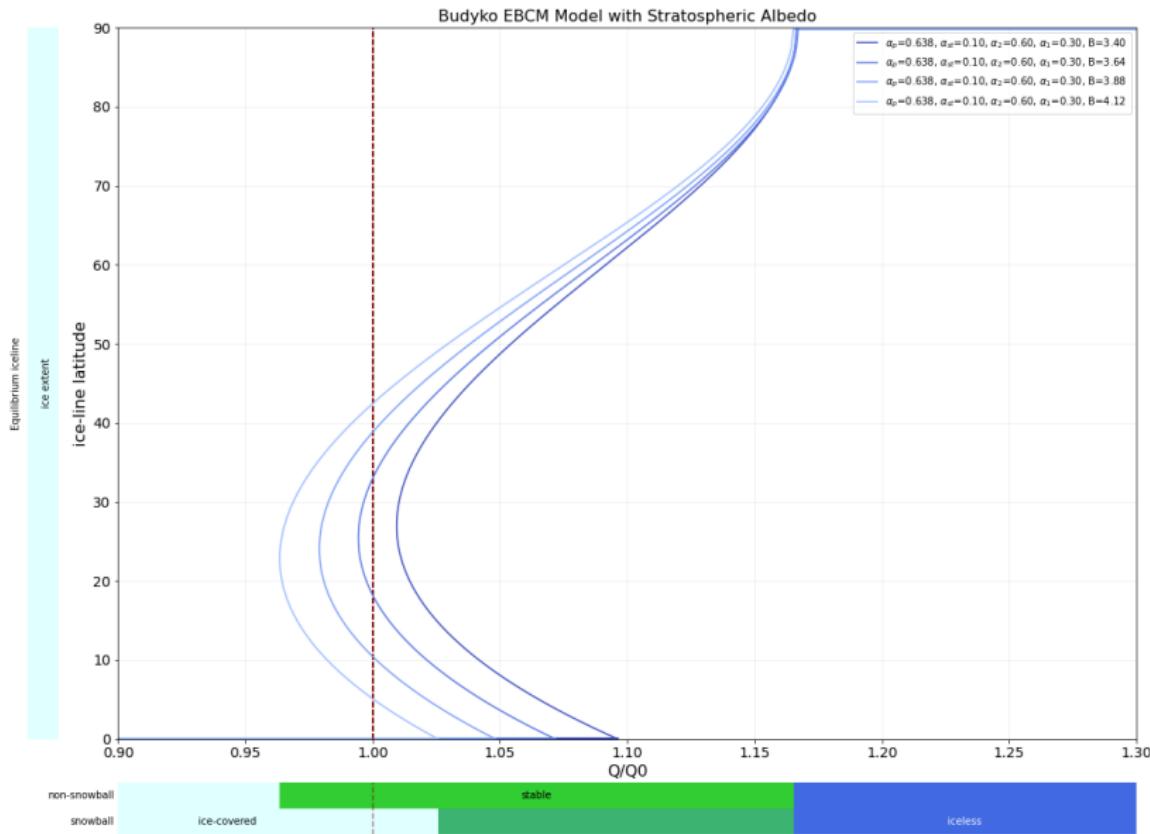
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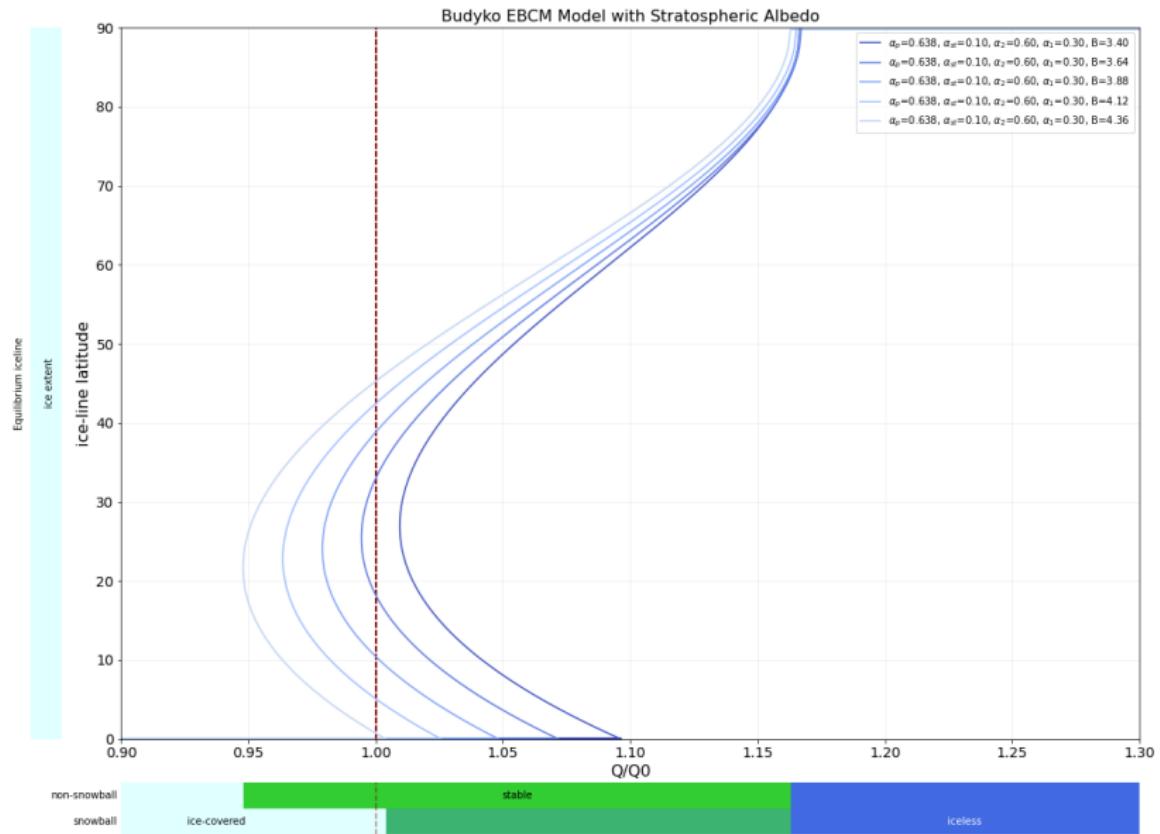
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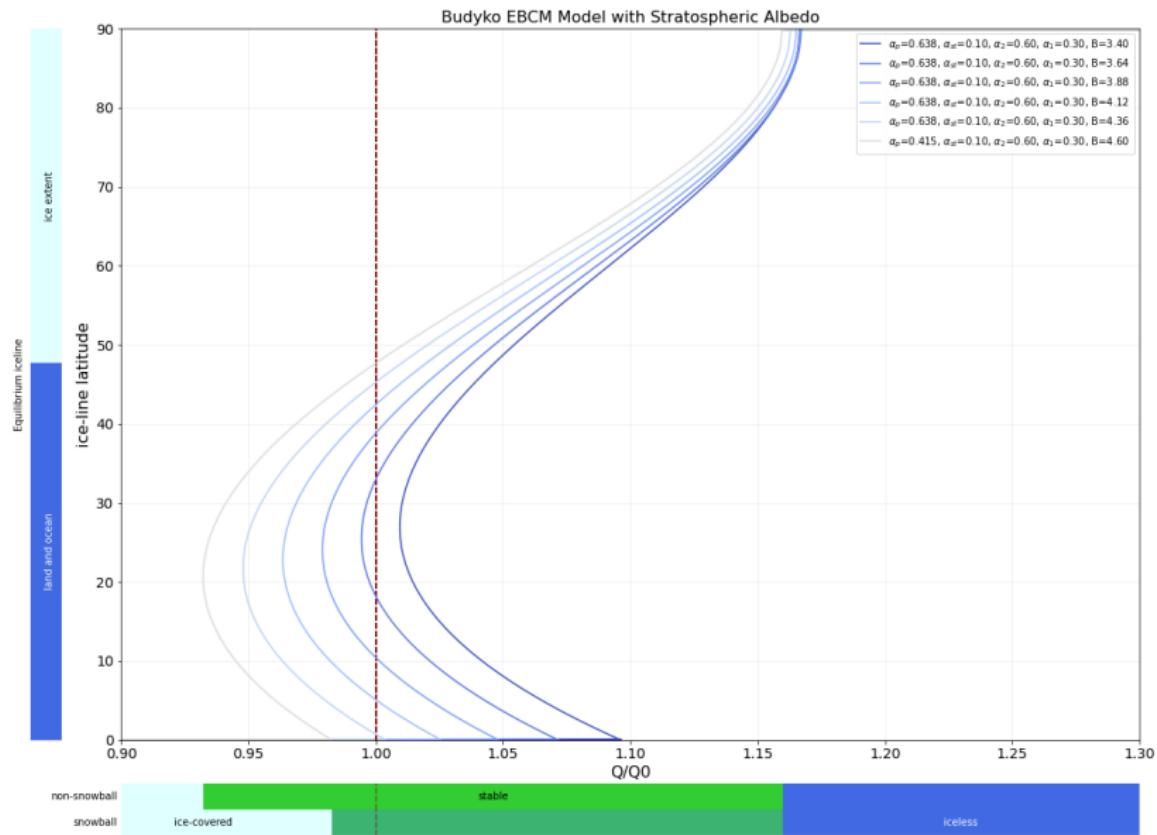
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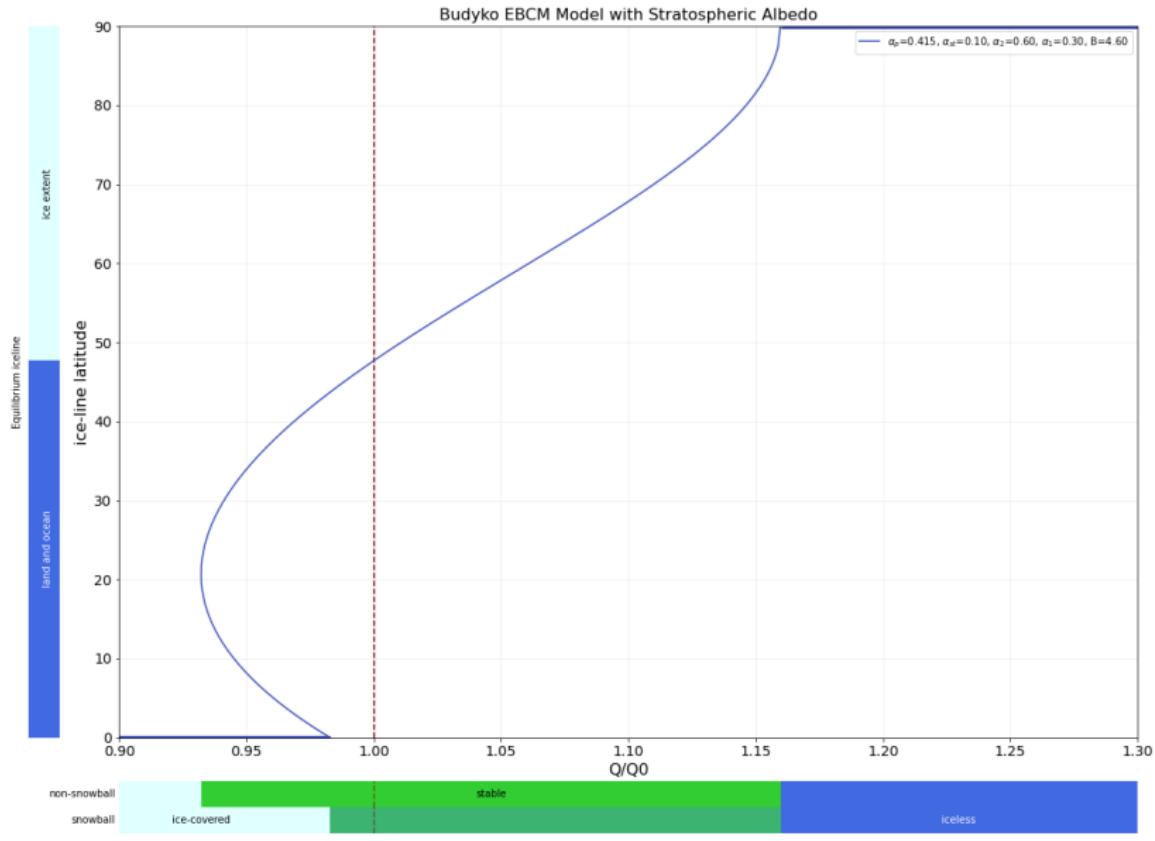
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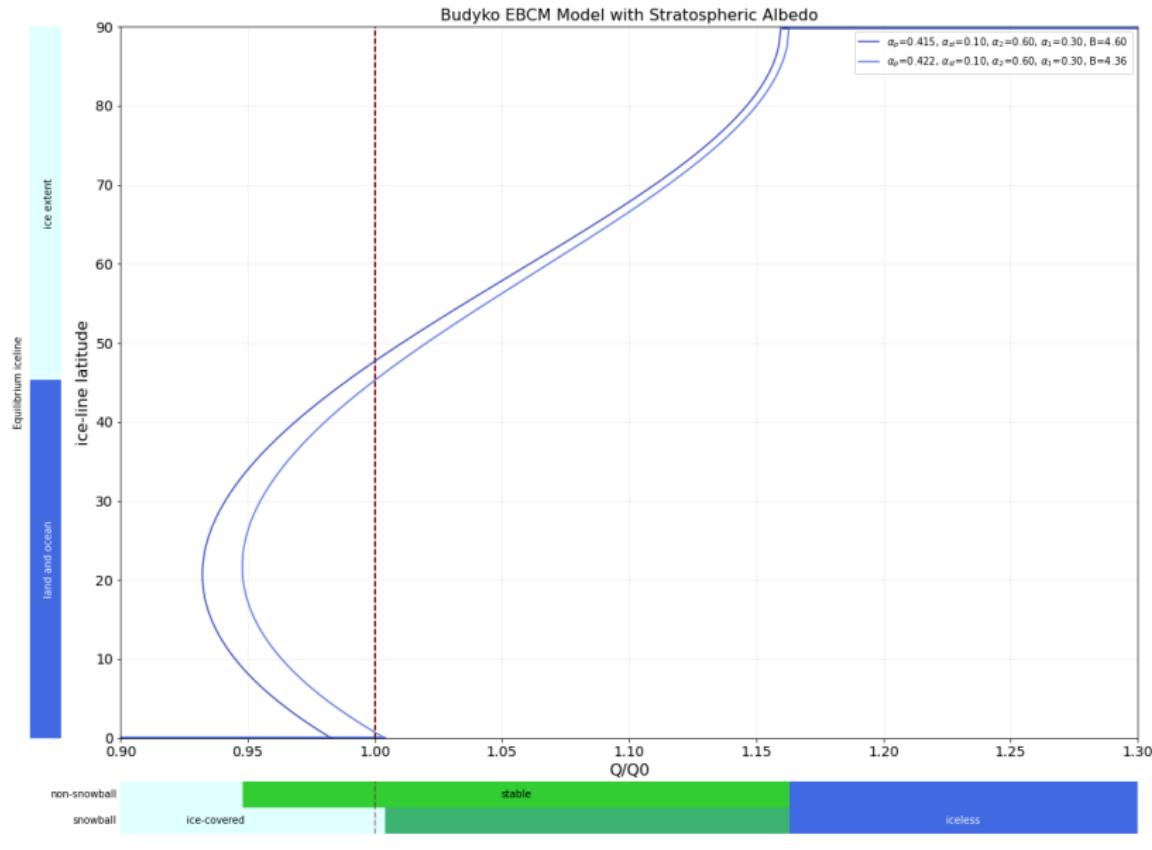
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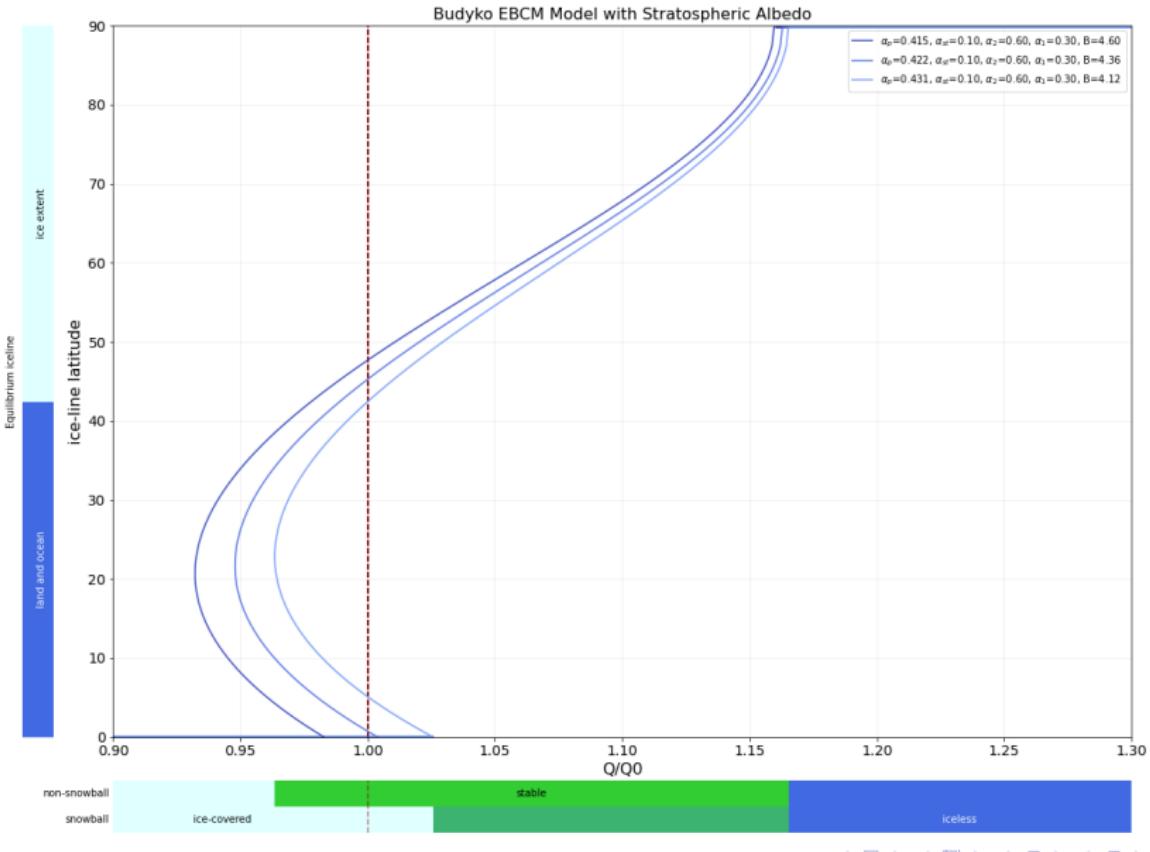
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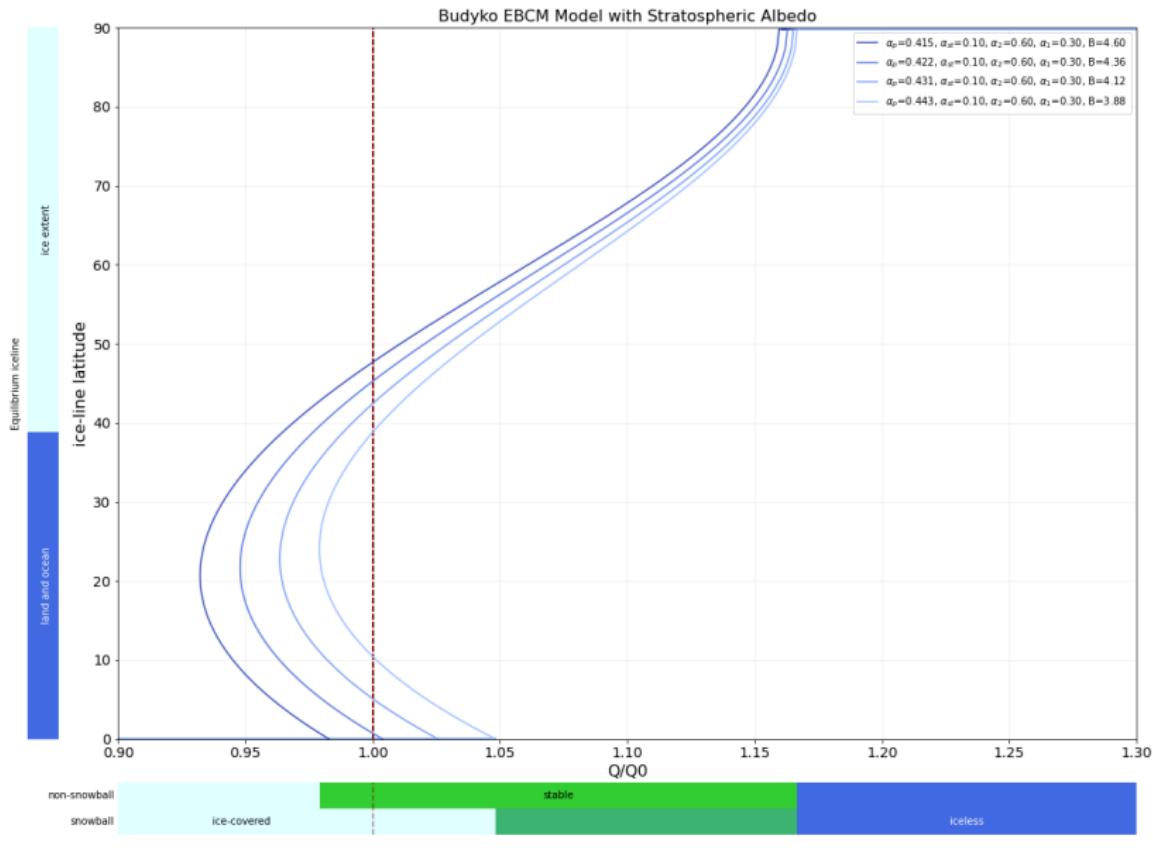
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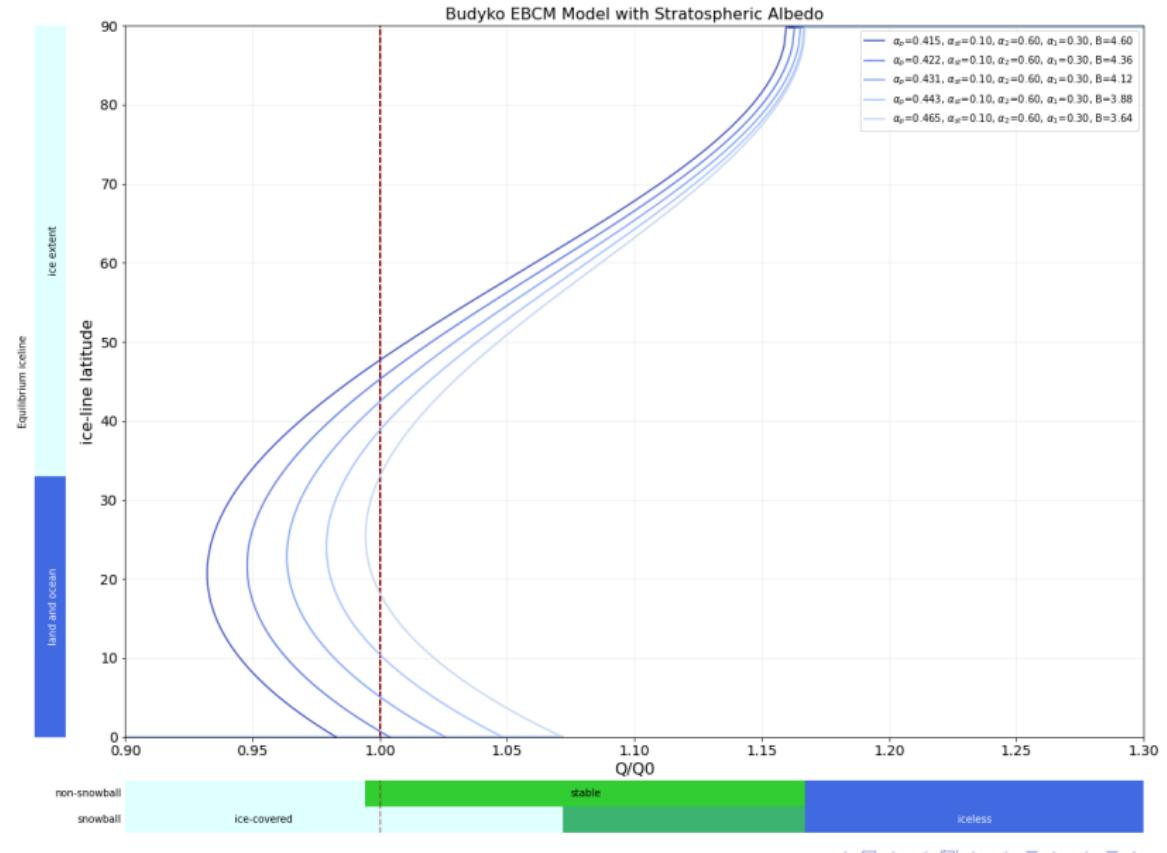
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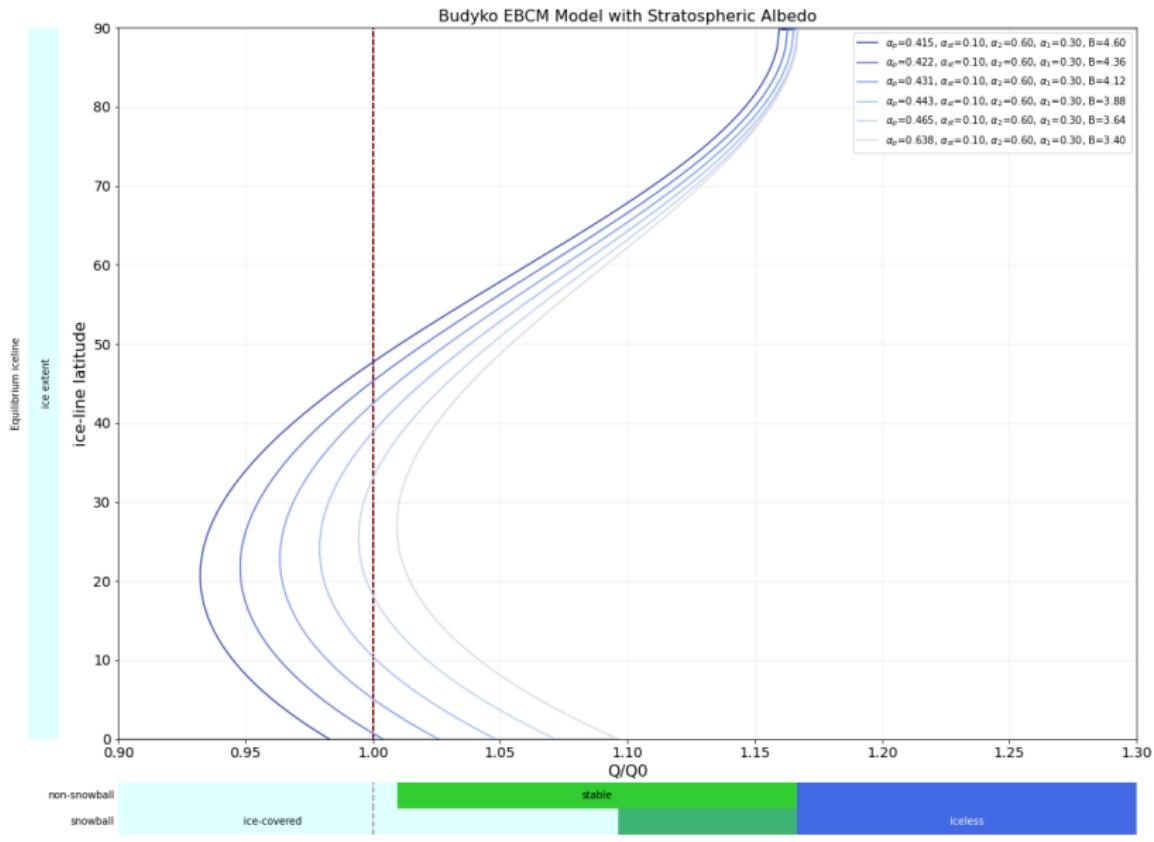
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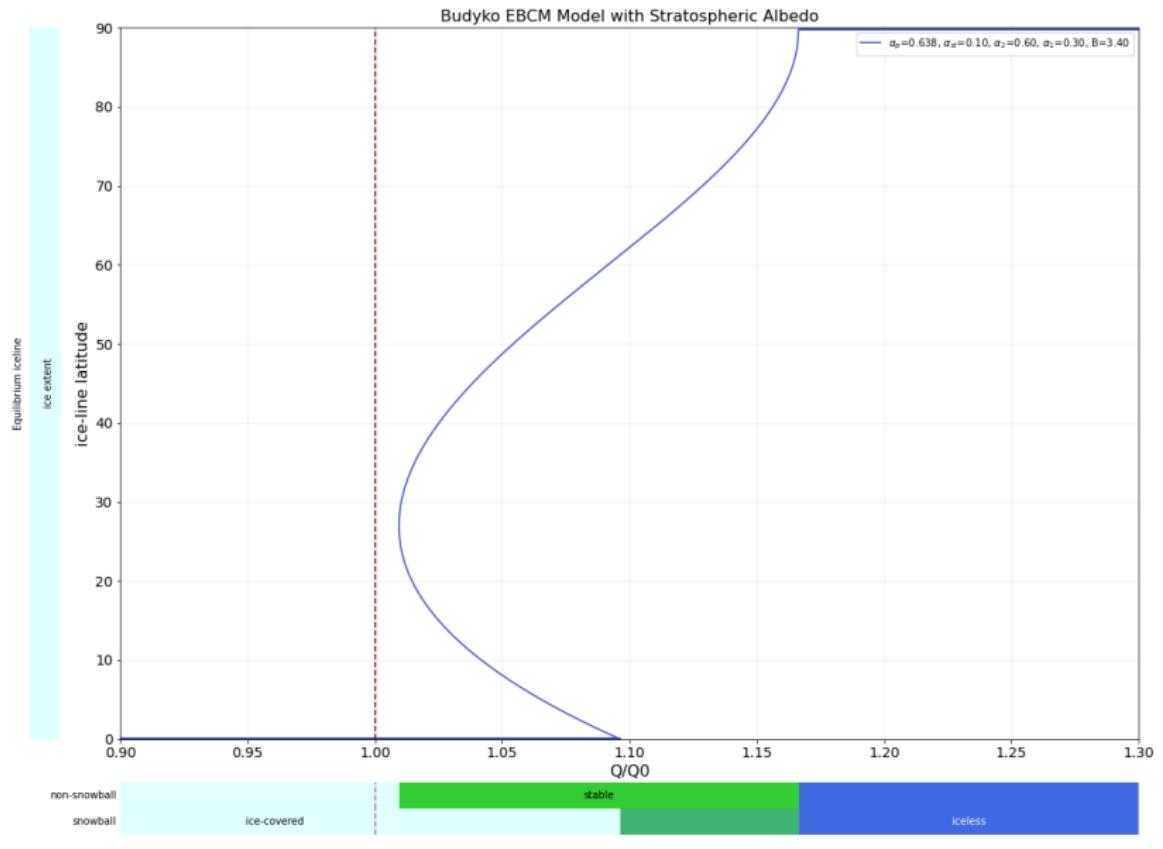
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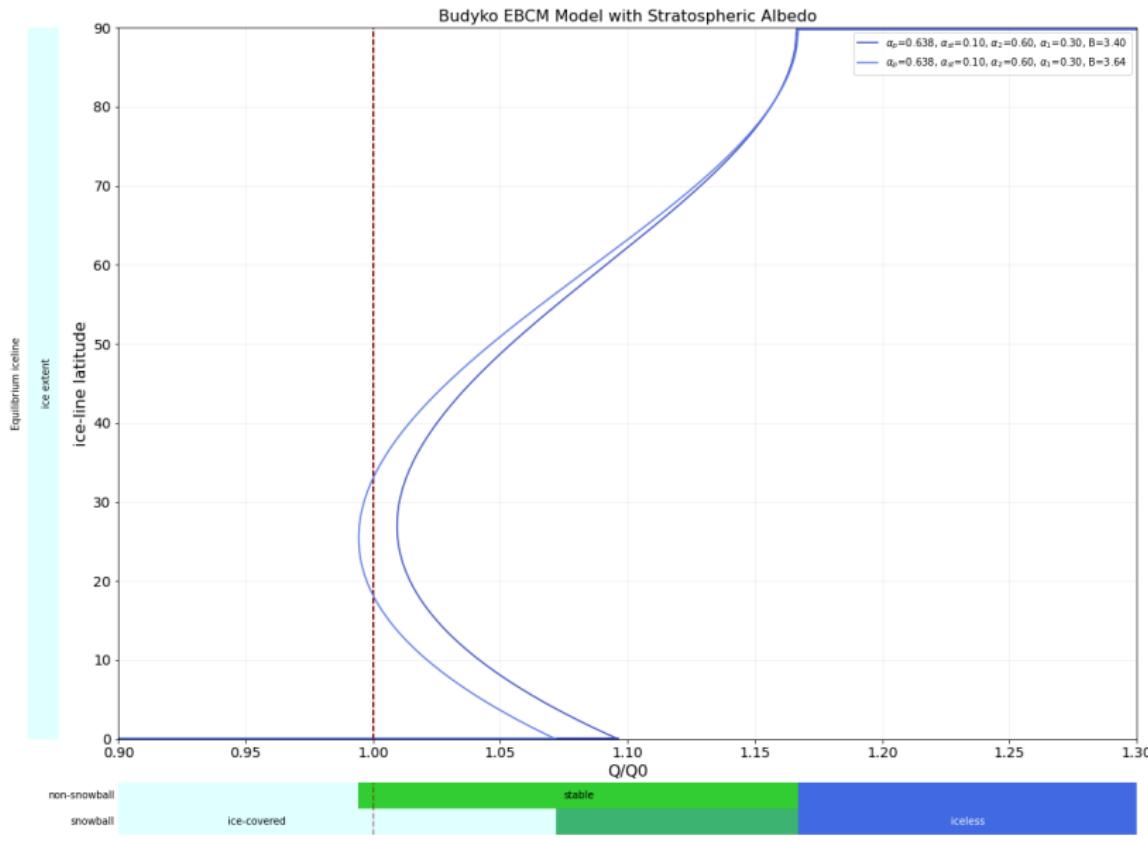
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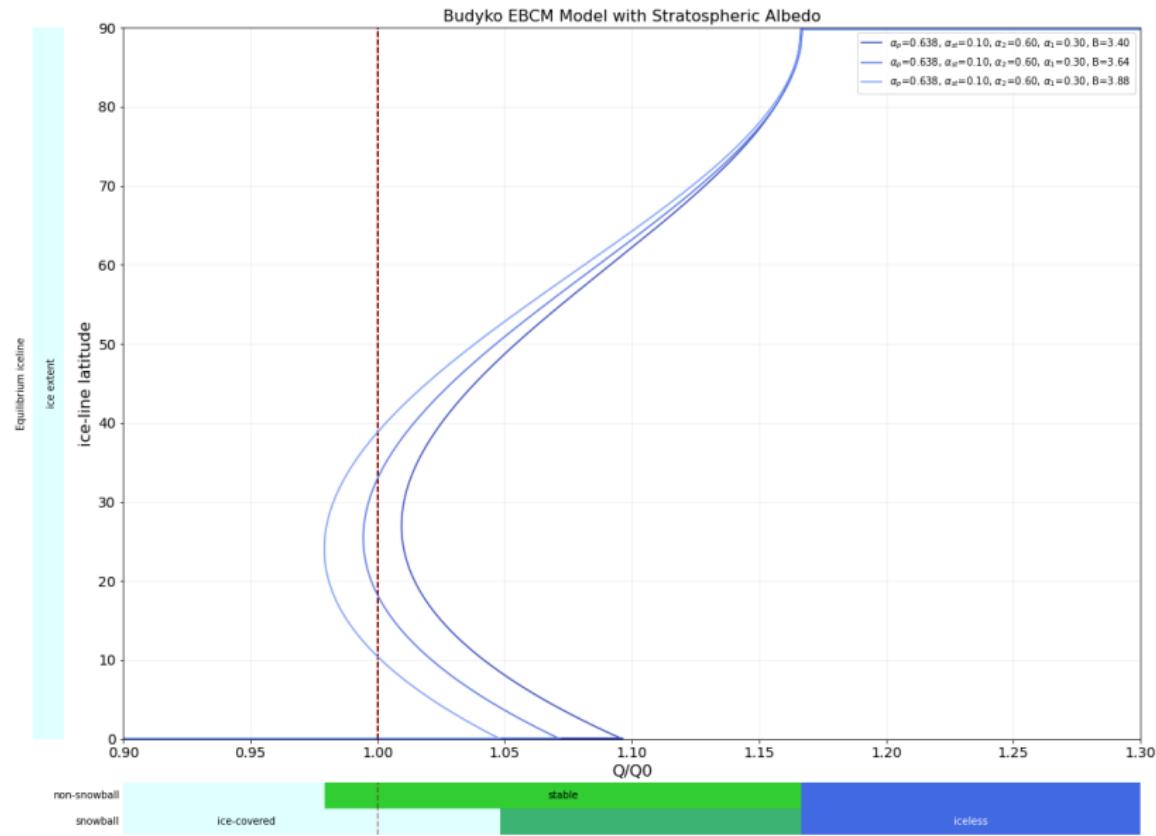
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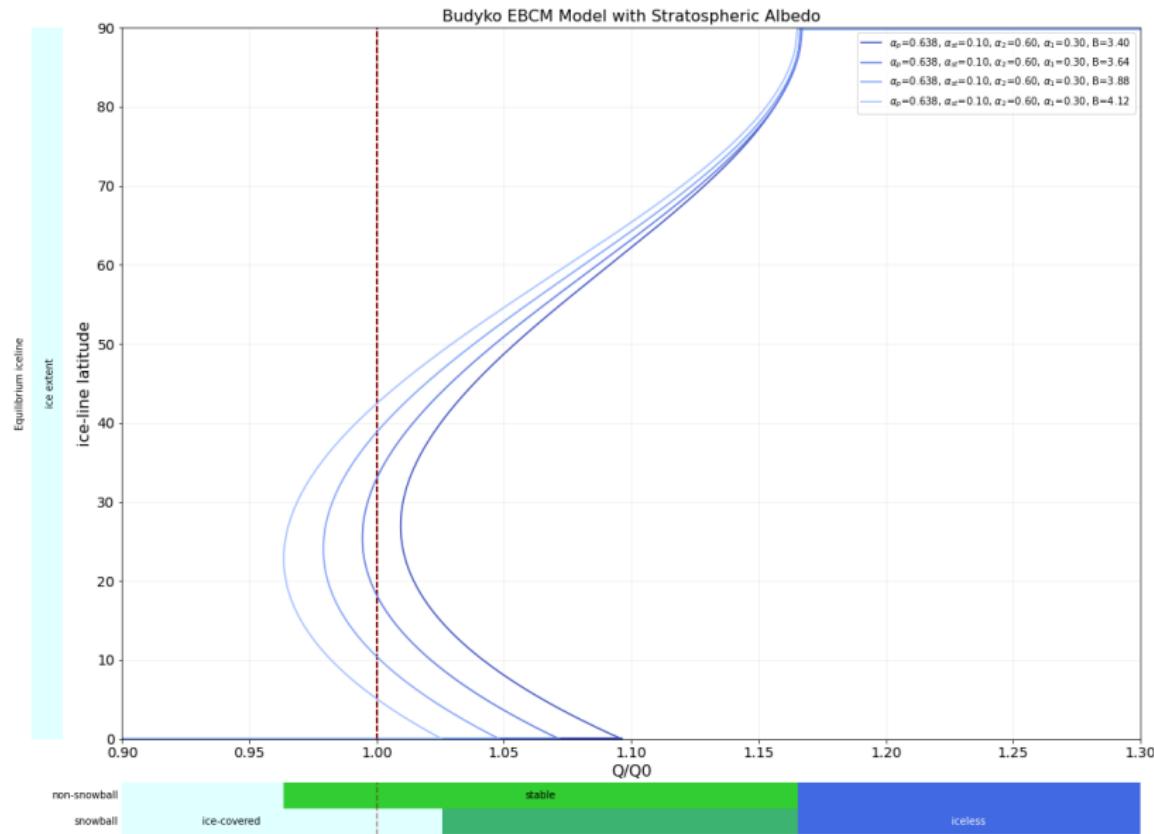
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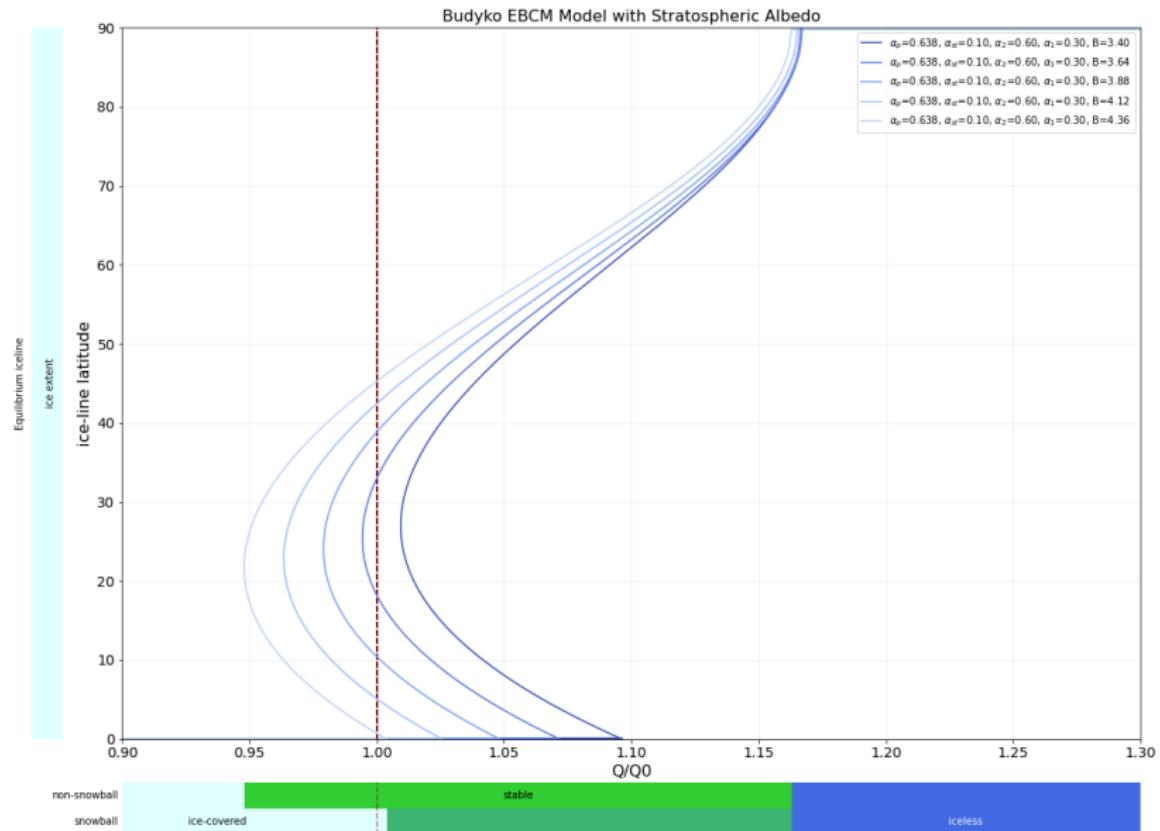
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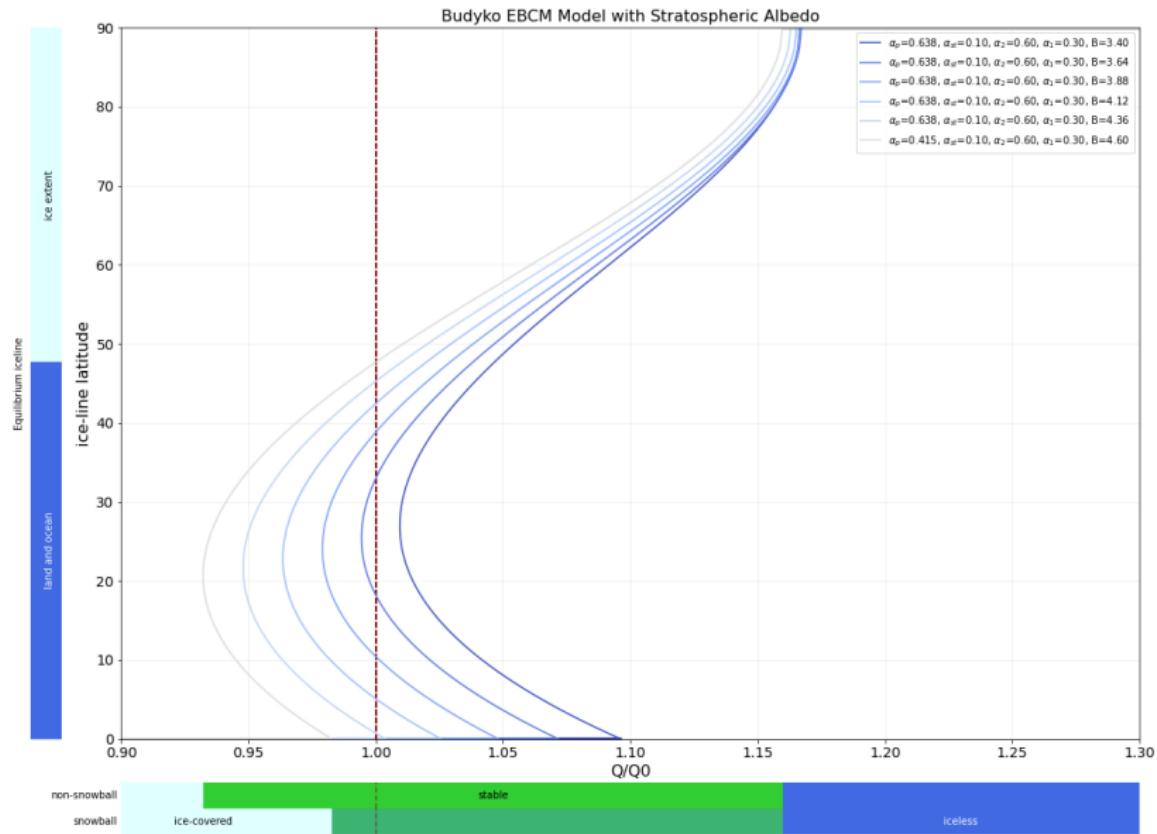
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# Could albedo changes explain Neoproterozoic glaciations?

