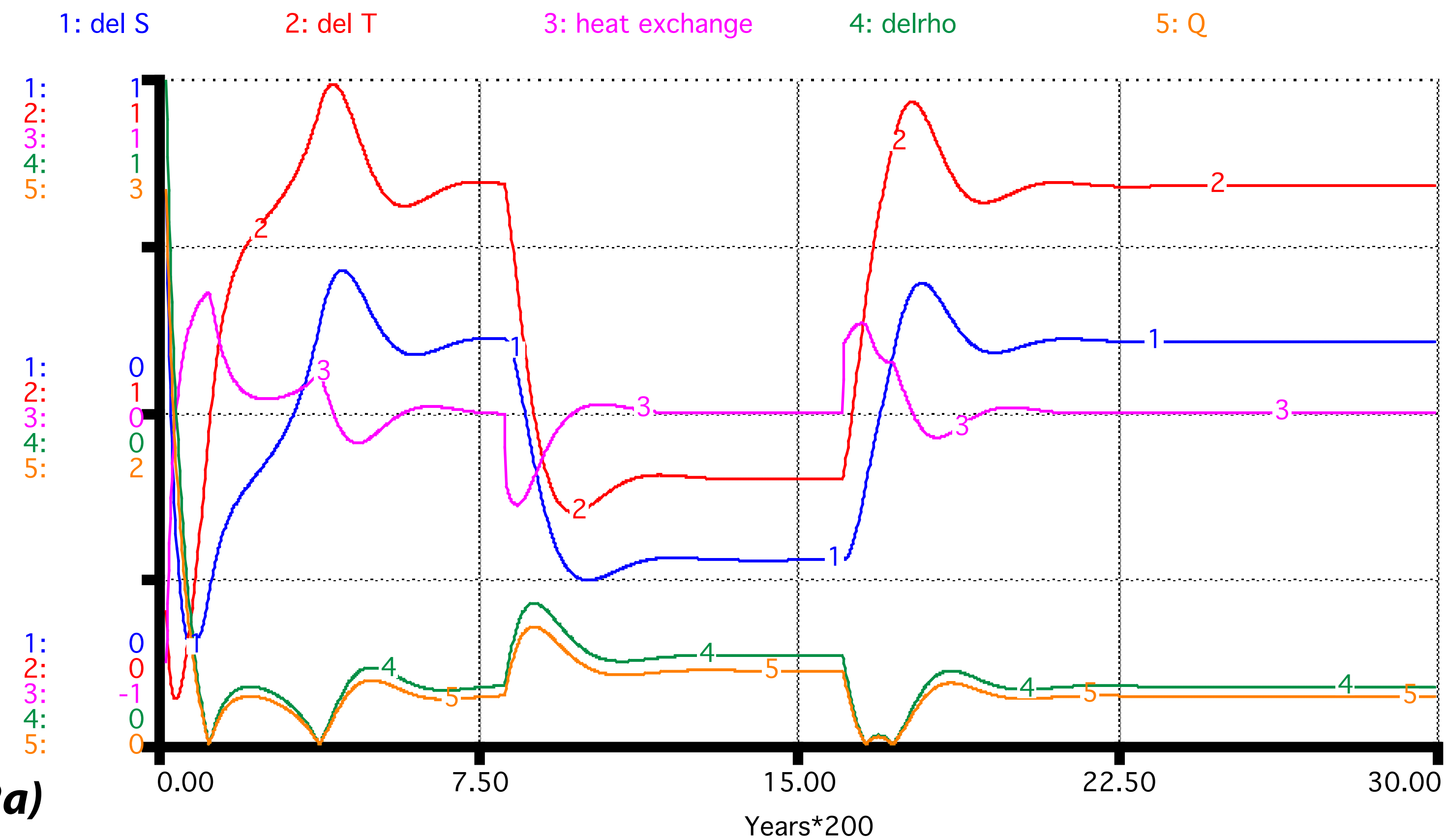
THC Homework answers



2a)

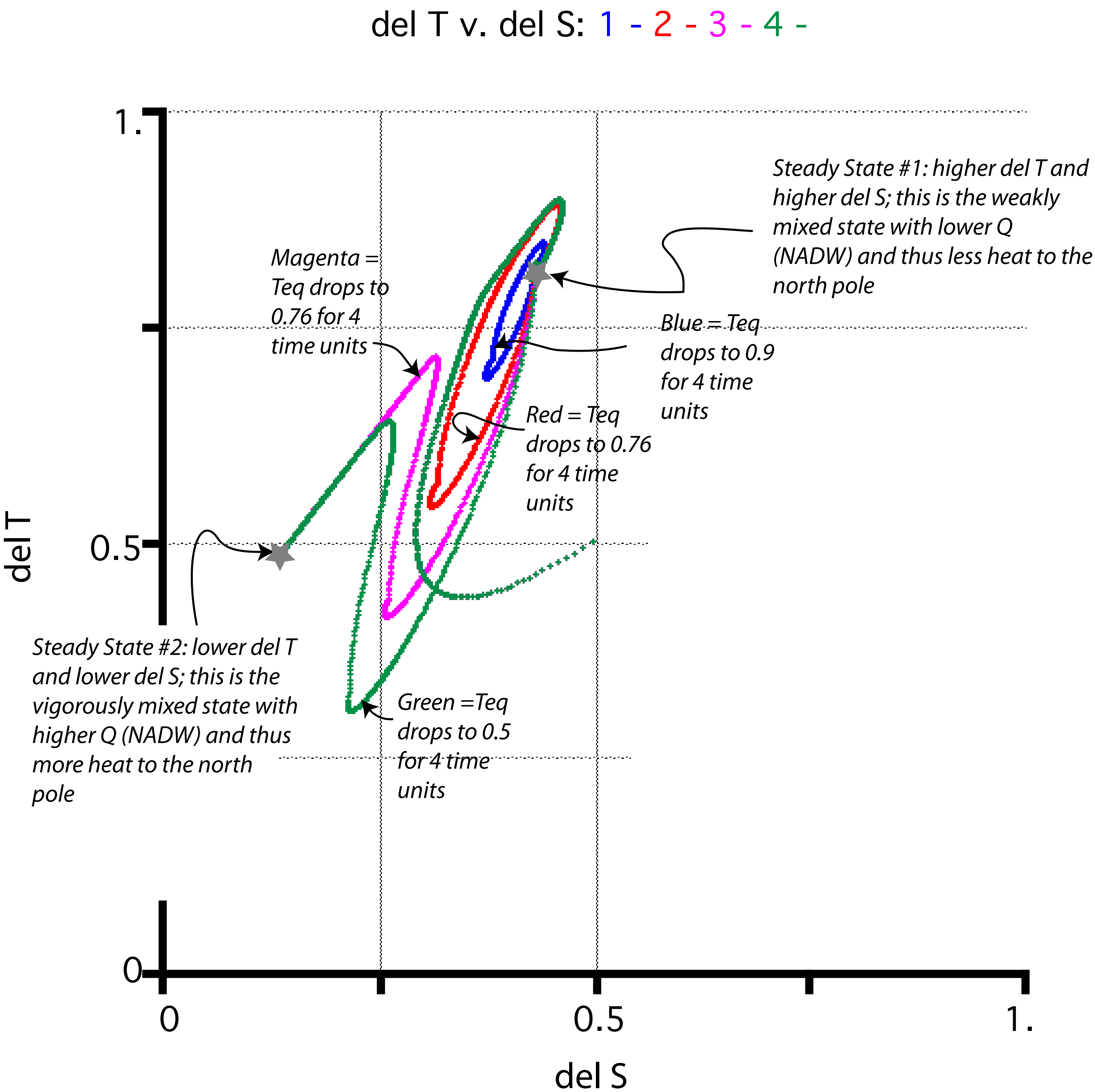
Starting at SS#1 (see delS vs delT plot), with a drop of Teq to 0.8, the system responds in a complex manner — here is an attempt to trace what happens and why.

*First, the heat exchange flow decreases sharply, causing del T to decrease. Let's look at the equation for heat exchange to see why this happens: (Teq - delT) - (delT*Q). Lowering Teq decreases the left hand term, so the the result is also decreased.*

*Decreasing the heat exchange will decrease delT, which in turn will affect delrho, the density difference. Delrho is defined as the absolute value of 2*delS -delT. Before dropping Teq, the value of delS is about .433 and delT is .822, so (2*.433) - .822 is about .044. Now, if delT goes down, delrho actually goes up, and thus Q also goes up.*

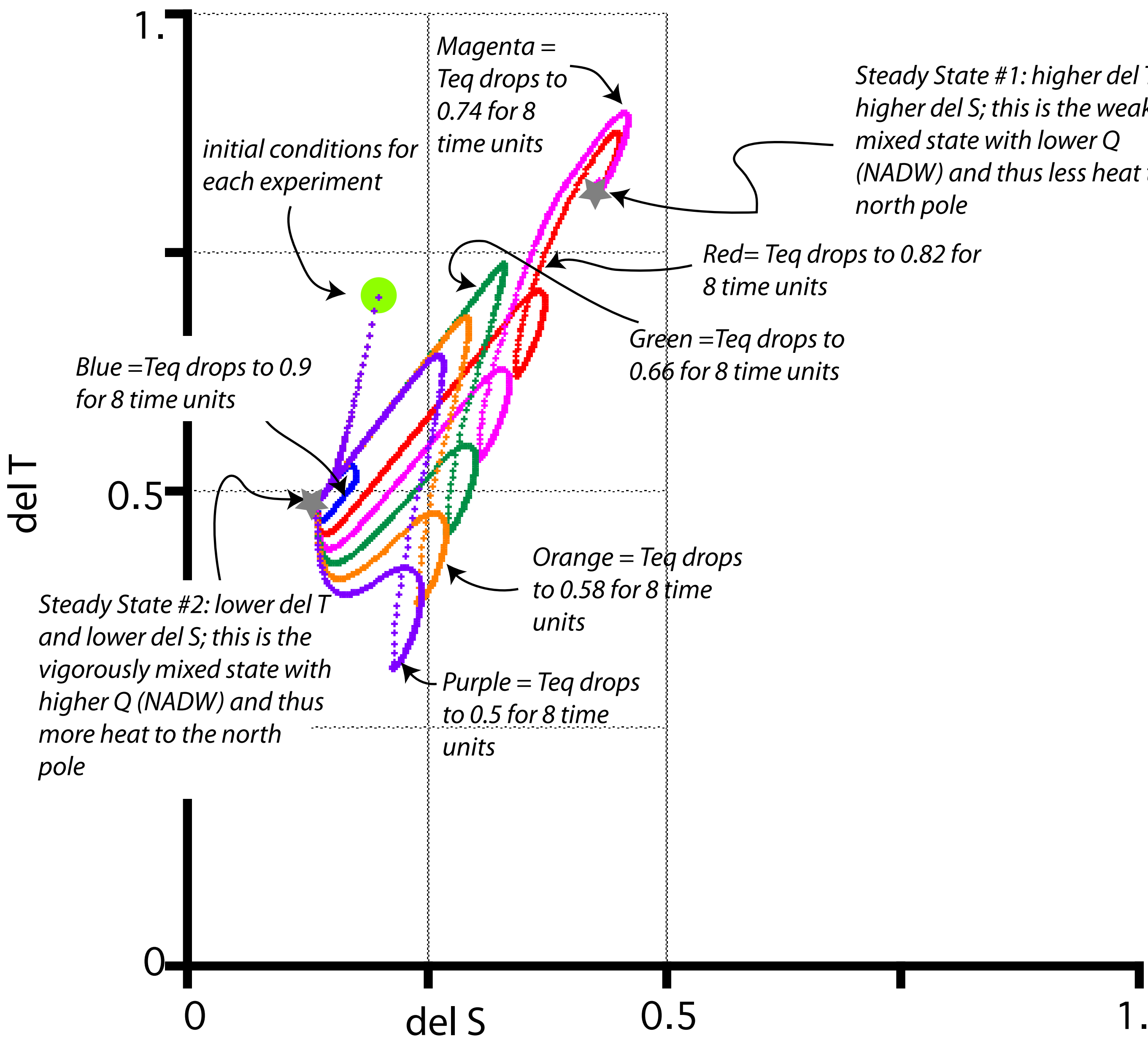
Increasing Q makes the mixing between the north and south faster and this decreases both delS and delT. The system evolves to a new steady state quickly, by time ~ 12, and then when Teq is restored to a value of 1, the system quickly returns to its original steady state.

Now we are ready to look at several experiments together on a delS vs delT plot.



2a), continued... With initial del S and del T values that result in SS#1 as our starting point, we see (other graph showing time history) that decreasing Teq initially triggers an increase in Q, which decreases both del S and del T, causing the system to move closer to SS#2, but it recovers and returns to SS#1 after Teq is restored to 1 — until the magnitude of the drop gets up to around .65, at which point the system moves to SS#2 after Teq is restored to 1. So, with a big enough warming pulse, you can knock the system into the more vigorous, warmer steady state.

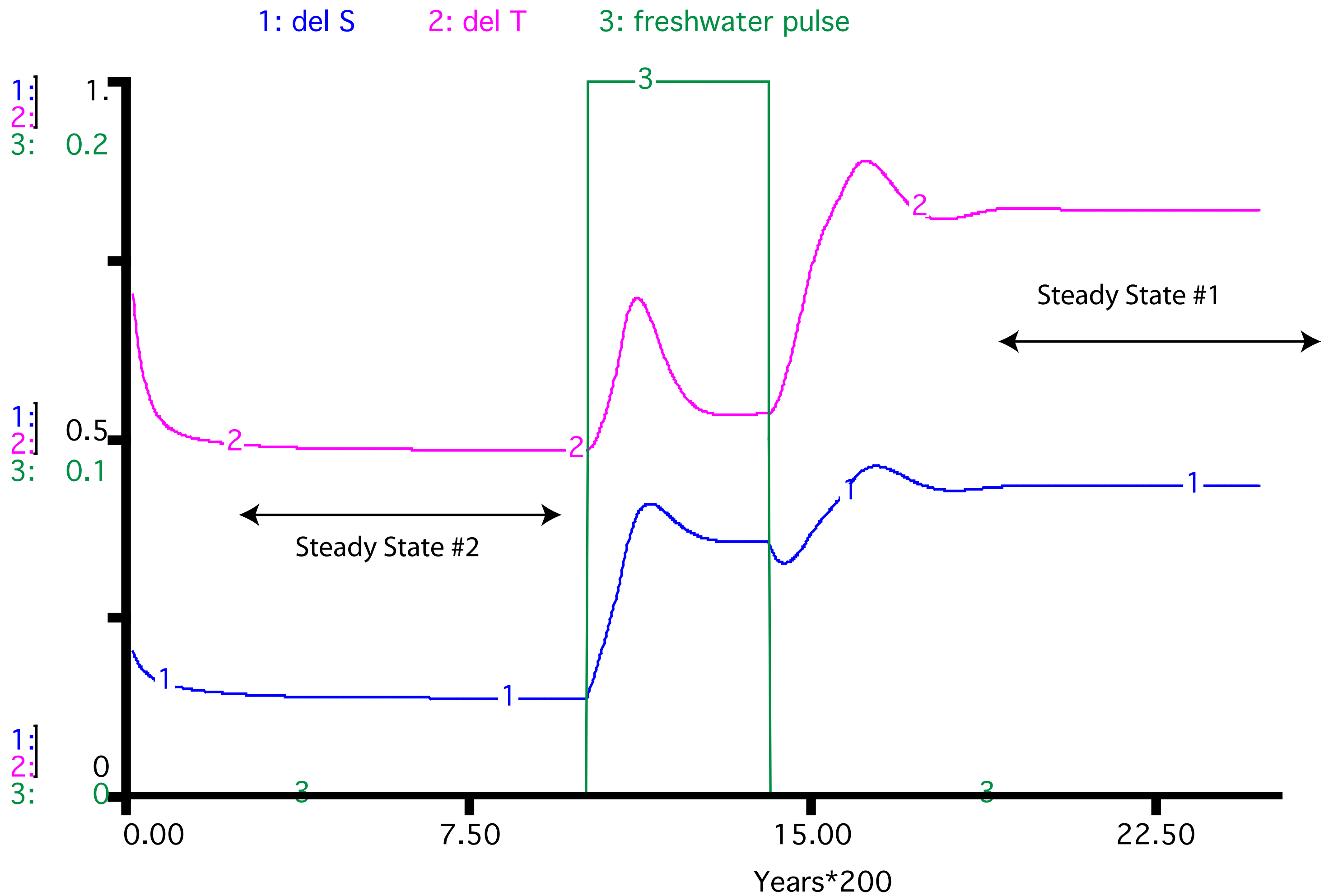
del T v. del S: 1 - 2 - 3 - 4 - 5 - 6 -



2b) With initial del S and del T values that result in SS#2 as our starting point, decreasing Teq initially triggers a decrease in heat exchange, which causes delT to drop, which causes delrho to drop, leading to a decrease in Q, which causes delS to increase.

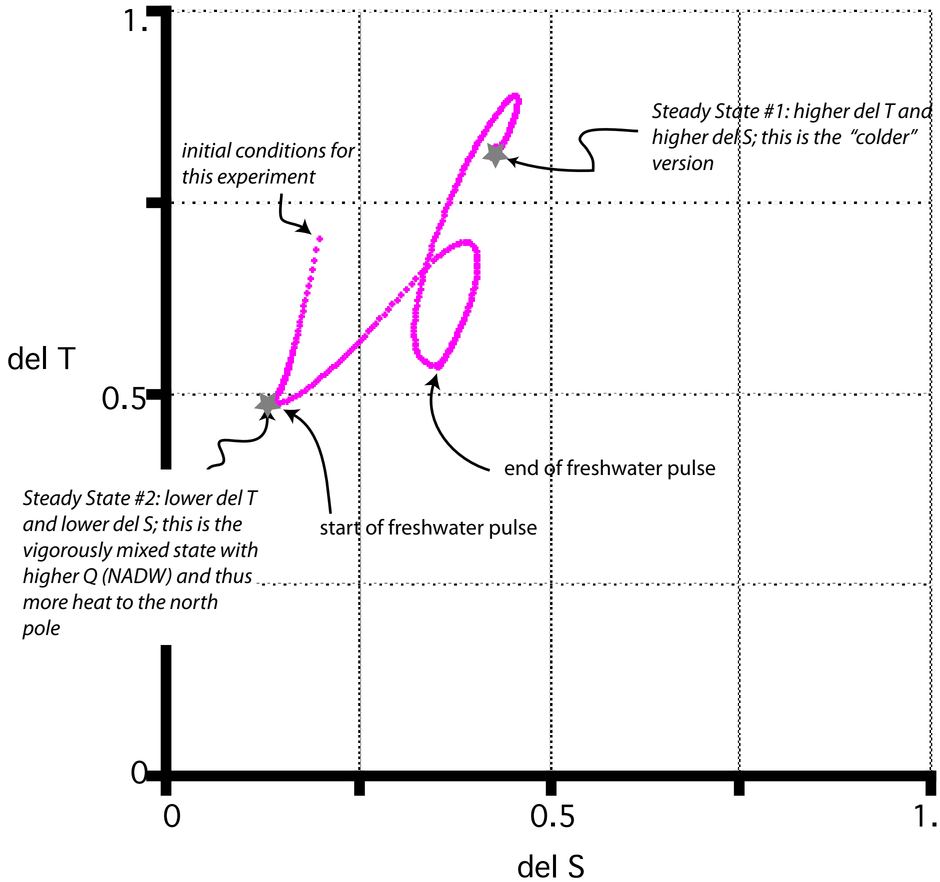
This push can send the system into the other steady state, but only within a narrow range of Teq values. At Teq = .9, the system returns to steady state, having changed hardly at all, but at Teq = .82 -.74 , the system jumps into the "colder" steady state and stays there. A further decrease in Teq (which, recall, is like a more extreme warming of the polar region) sends the system on a different trajectory so that it does not end up in the other steady state when Teq is returned to normal.

So, with a smallish warming pulse, you can knock the system into the more colder state. but a warger warming, paradoxically, does not have the same effect.



3a). Adding a freshwater pulse knocks the system out of steady state (SS#2 — the hotter, more vigorous circulation version) and sends it into the colder steady state, with a more sluggish mixing. Why does this happen?

First, delS increases, which causes a decrease in delrho and thus a decrease in Q. Decreased Q means that the heat exchange and the salinity exchange both increase, and thus both delT and delS increase, and it moves the system onto the other side of the "divide" that separates the two steady states and when the freshwater pulse is removed, the system spirals into the SS#1 — the "cold" version of the system.



3a). The pulse of .2 salinity units for 4 time units knocks the system into the colder steady state — just like the Younger Dryas scenario with the glacier meltwater pouring into the North Atlantic. The diagram above shows where the system is at the end of the freshwater pulse and from that position, it falls into the colder steady state.

3b) There is a kind of threshold that marks the boundary between conditions that lead to a flip of the steady state and those that preserve the initial steady state. If we keep the magnitude at 0.2 and reduce the duration of the pulse below .75 time units the steady state does not flip, as shown on the graph below.

If you have a weaker pulse, the duration threshold is much greater, and with a stronger pulse, the duration threshold is shorter — there is a non-linear relationship between these two parameters.