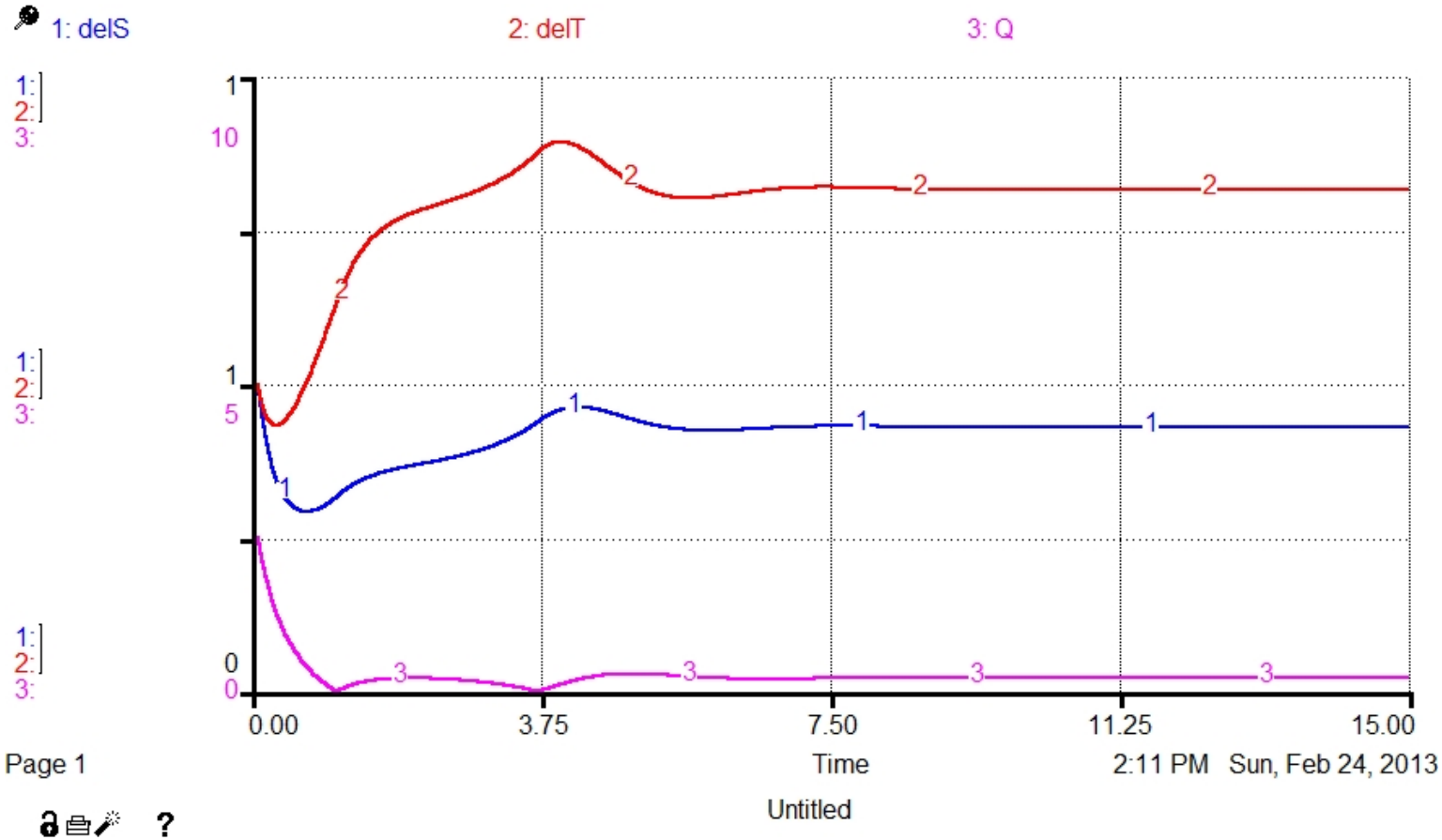
Thermohaline circulation

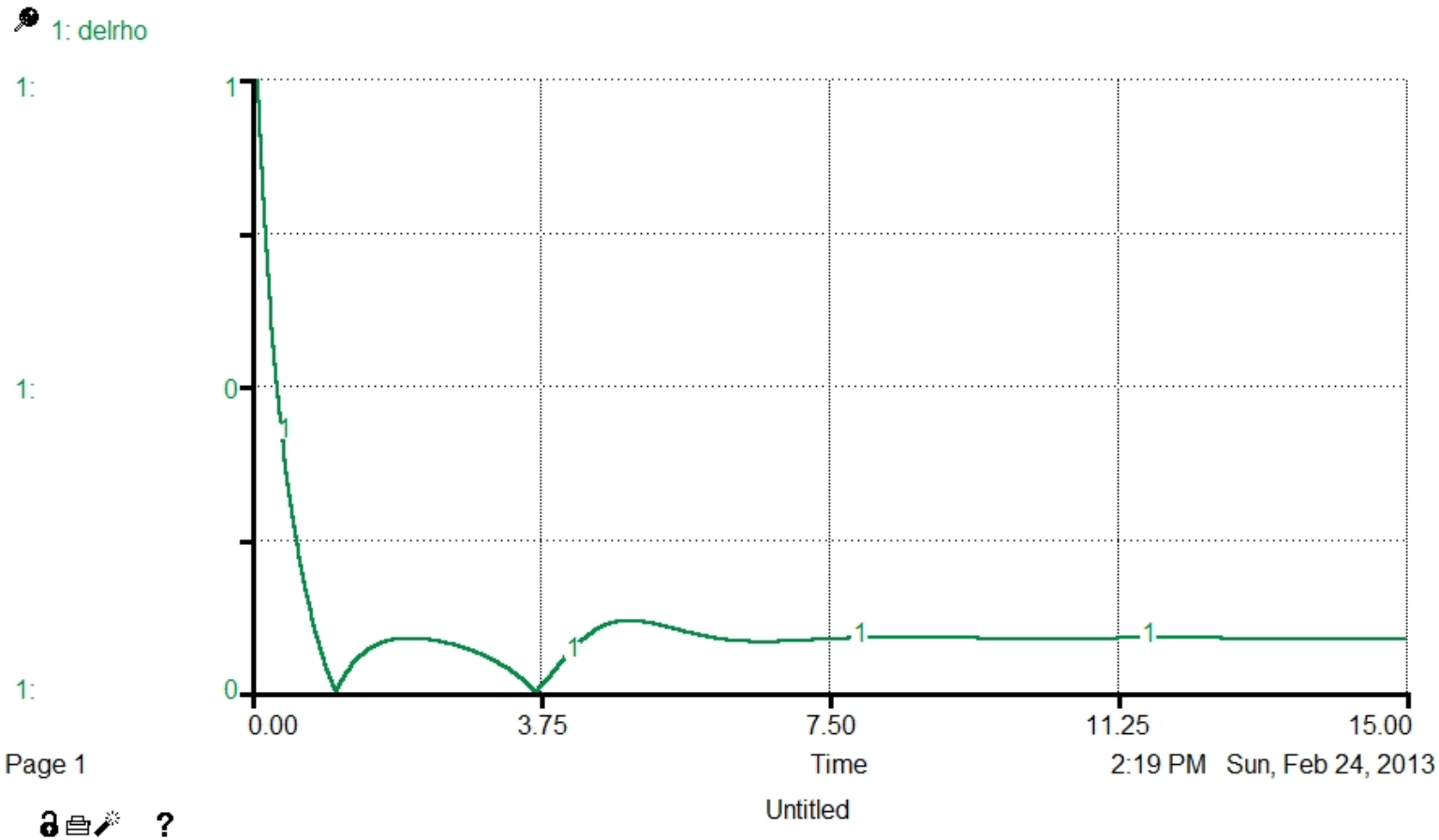
Note: The terms “hot” and “cold” refer to the state of the Arctic/Antarctic.

1. Evolution to steady state



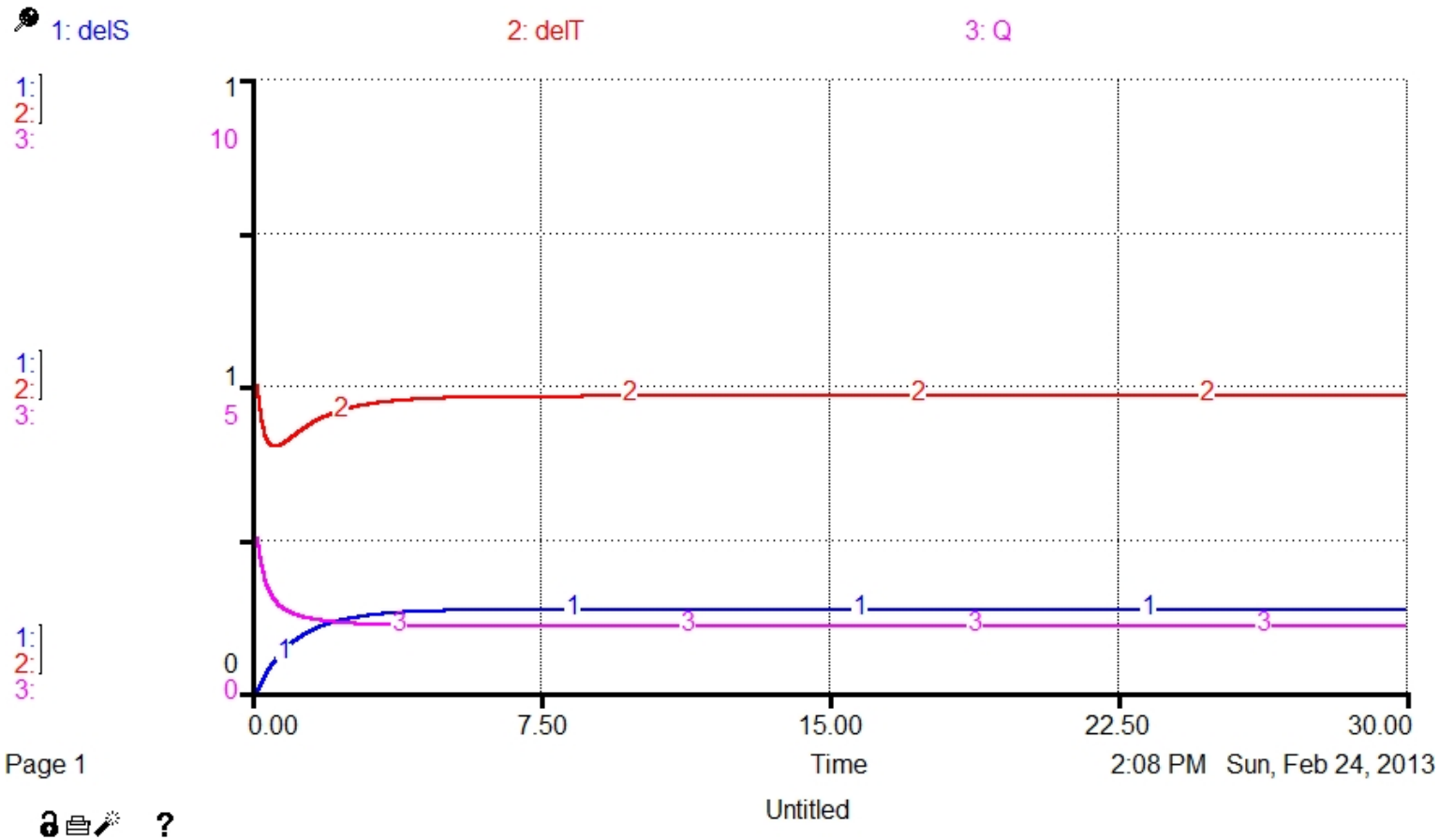
- Initial run to "cold and slow" steady state
- Large temperature difference balanced by large salinity difference $\Rightarrow$ low flux (cold water wants to sink, but freshwater doesn't want to sink)

1. Evolution to steady state



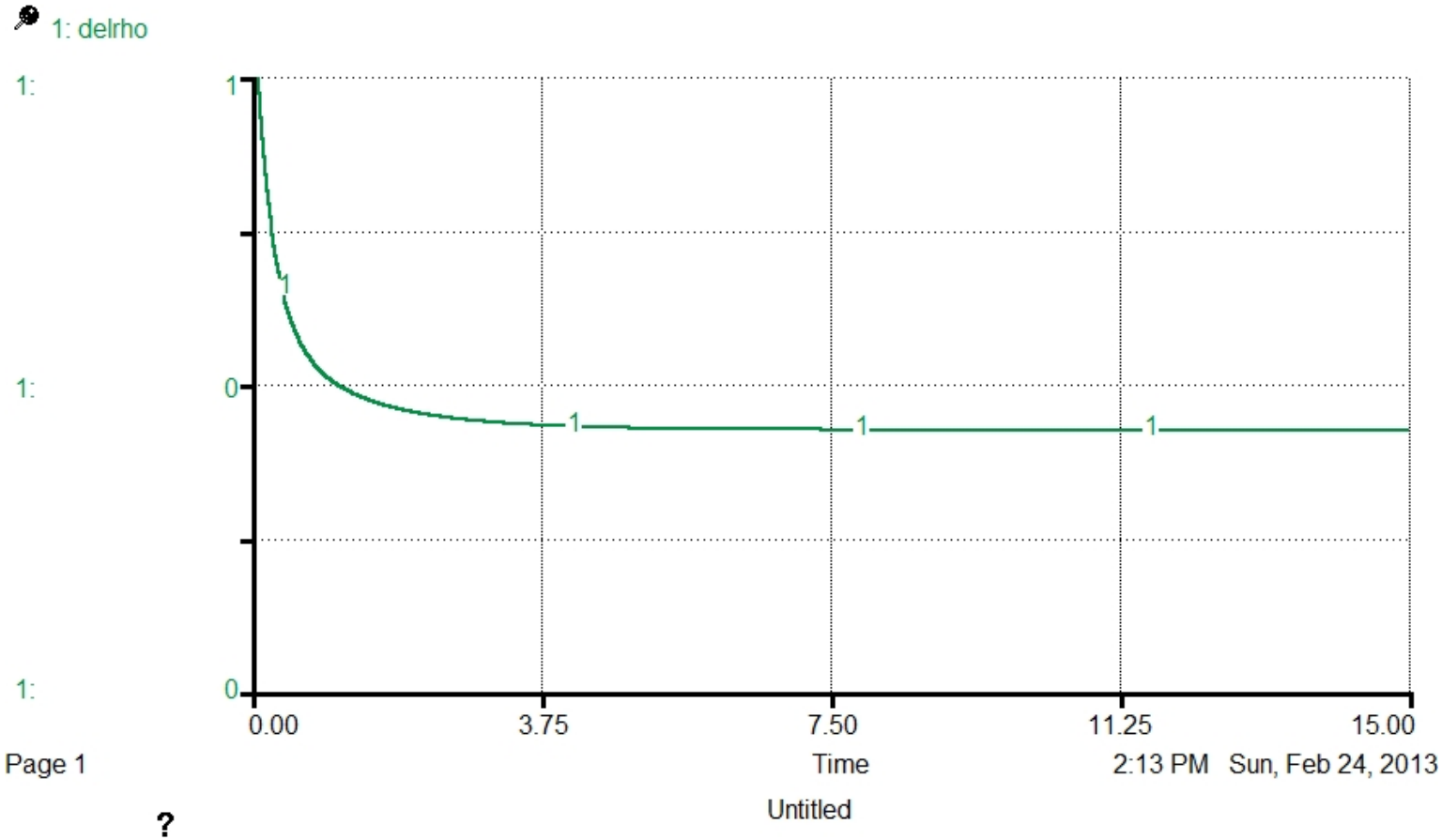
- Small density difference in “cold and slow” state

2. Multiple steady-states



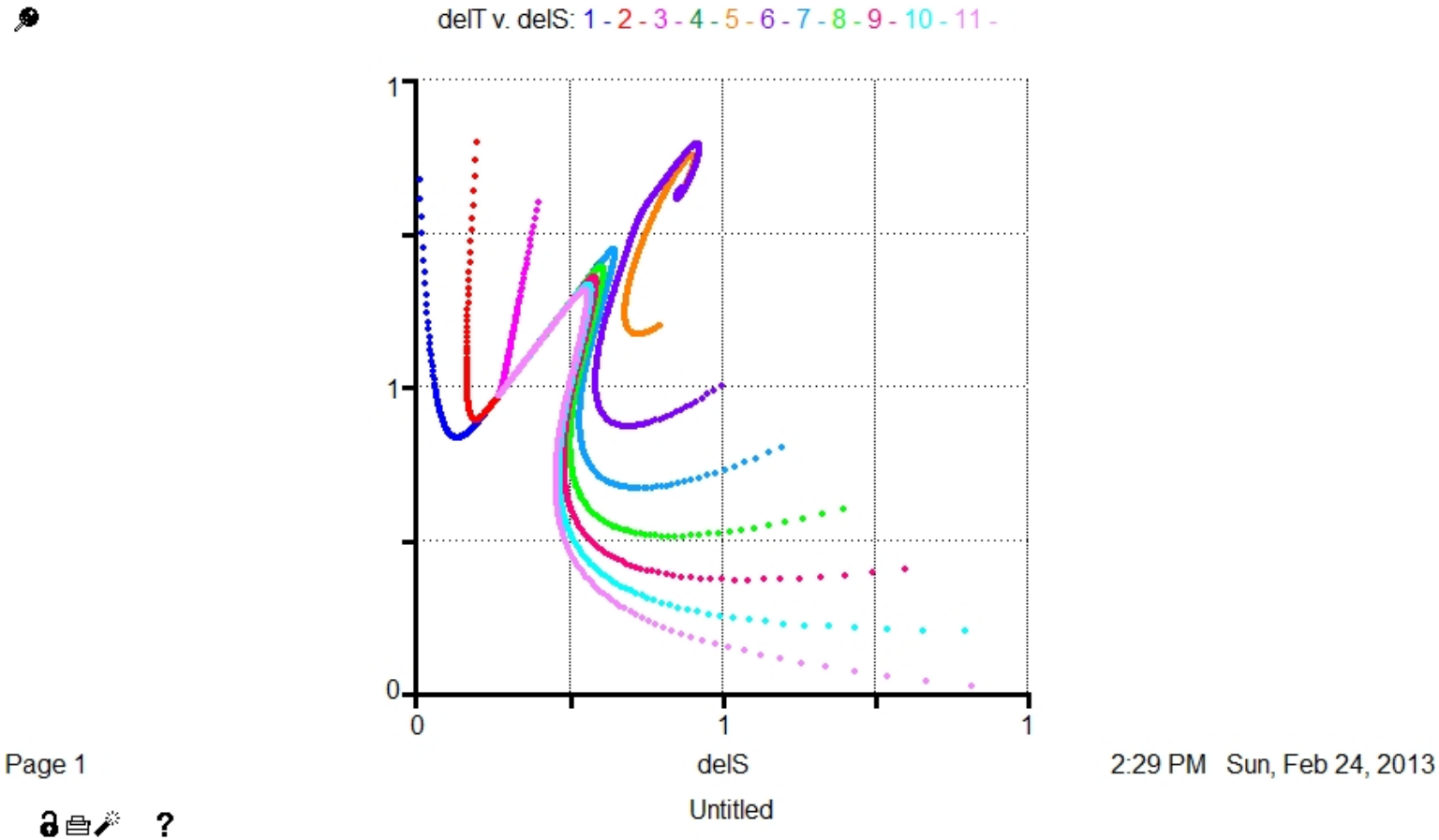
- Run to "warm and fast" steady state
- Temperature difference is much larger than the salinity difference. . .

2. Multiple steady-states



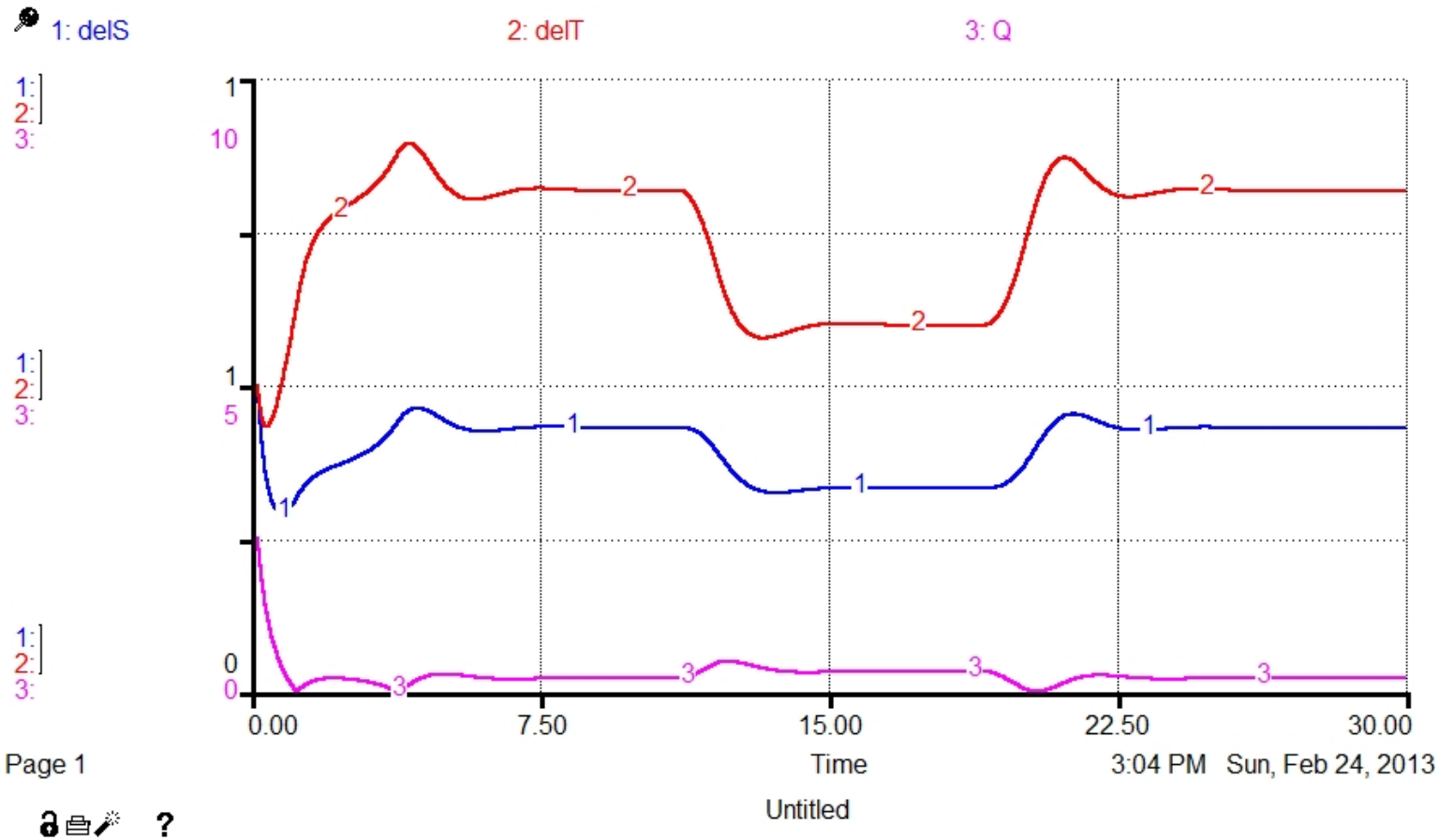
- . . . leading to a large density difference

2. Multiple steady-states



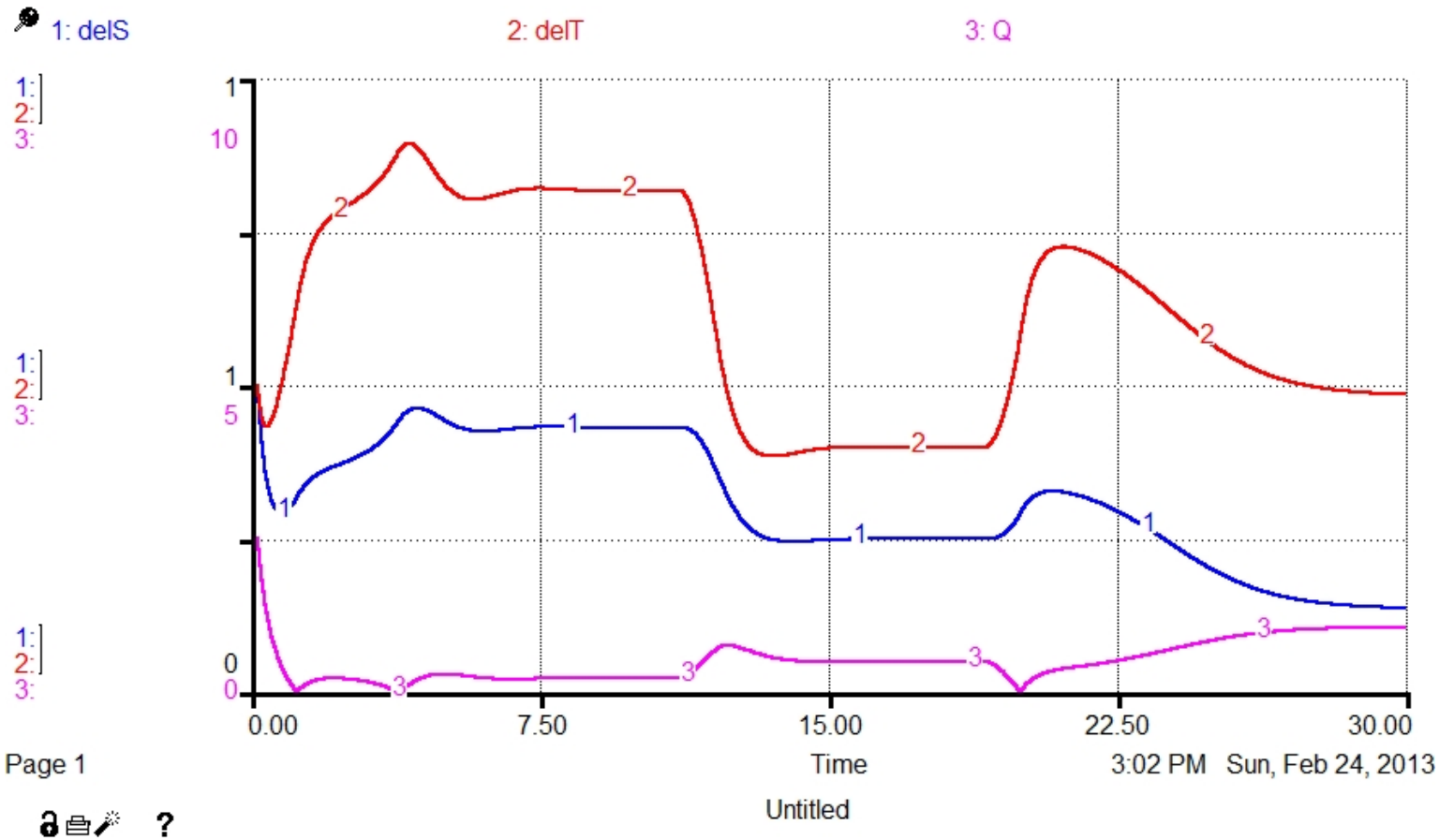
- Model has two possible steady states
  - Cold and slow state (0.45, 0.8)
  - Warm and fast state (0.125, 0.5)

3. Warming climate



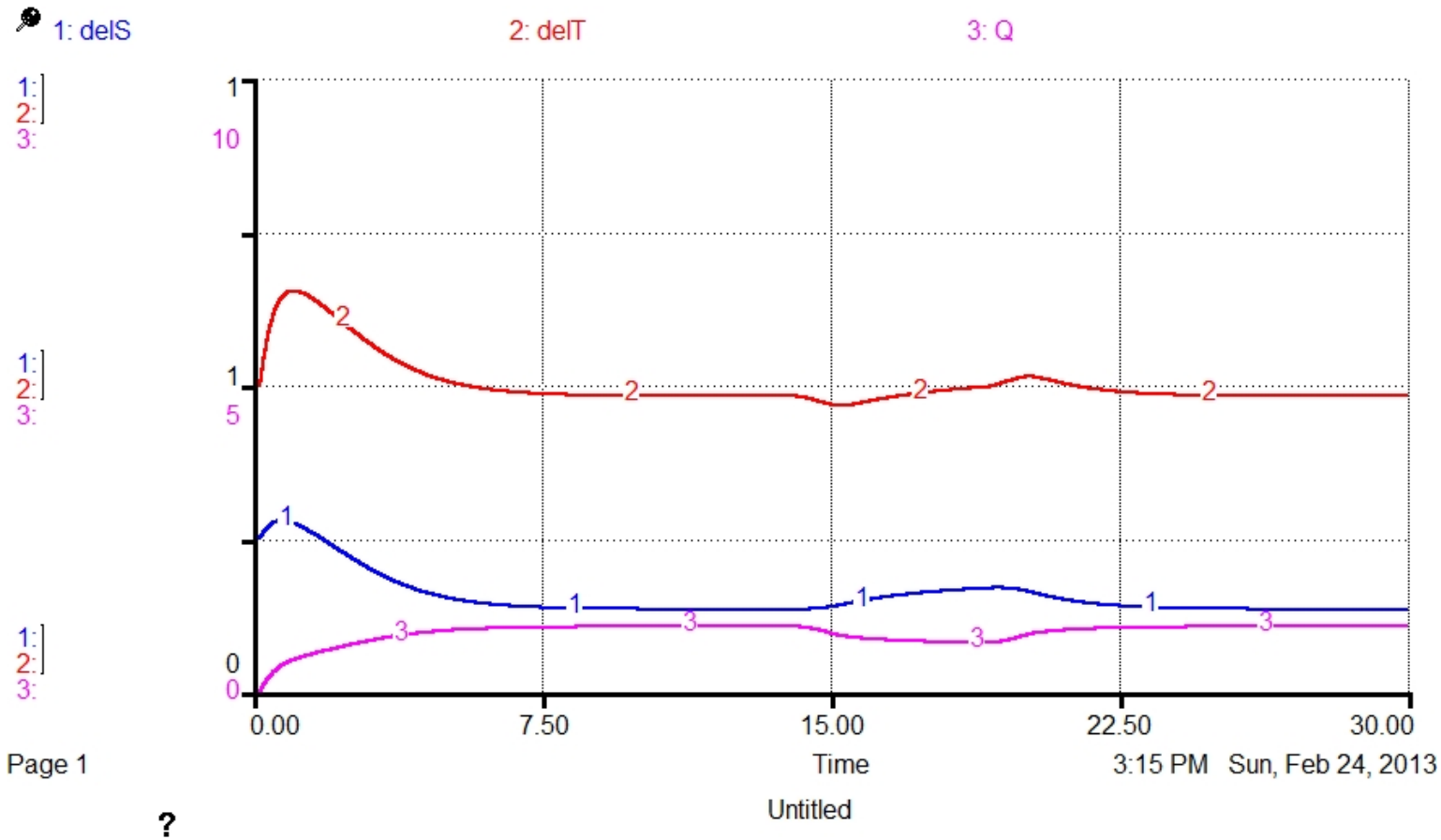
- From the cold state, temporarily decrease the temperature gradient to 0.6
- Returns to the cold state

3. Warming climate



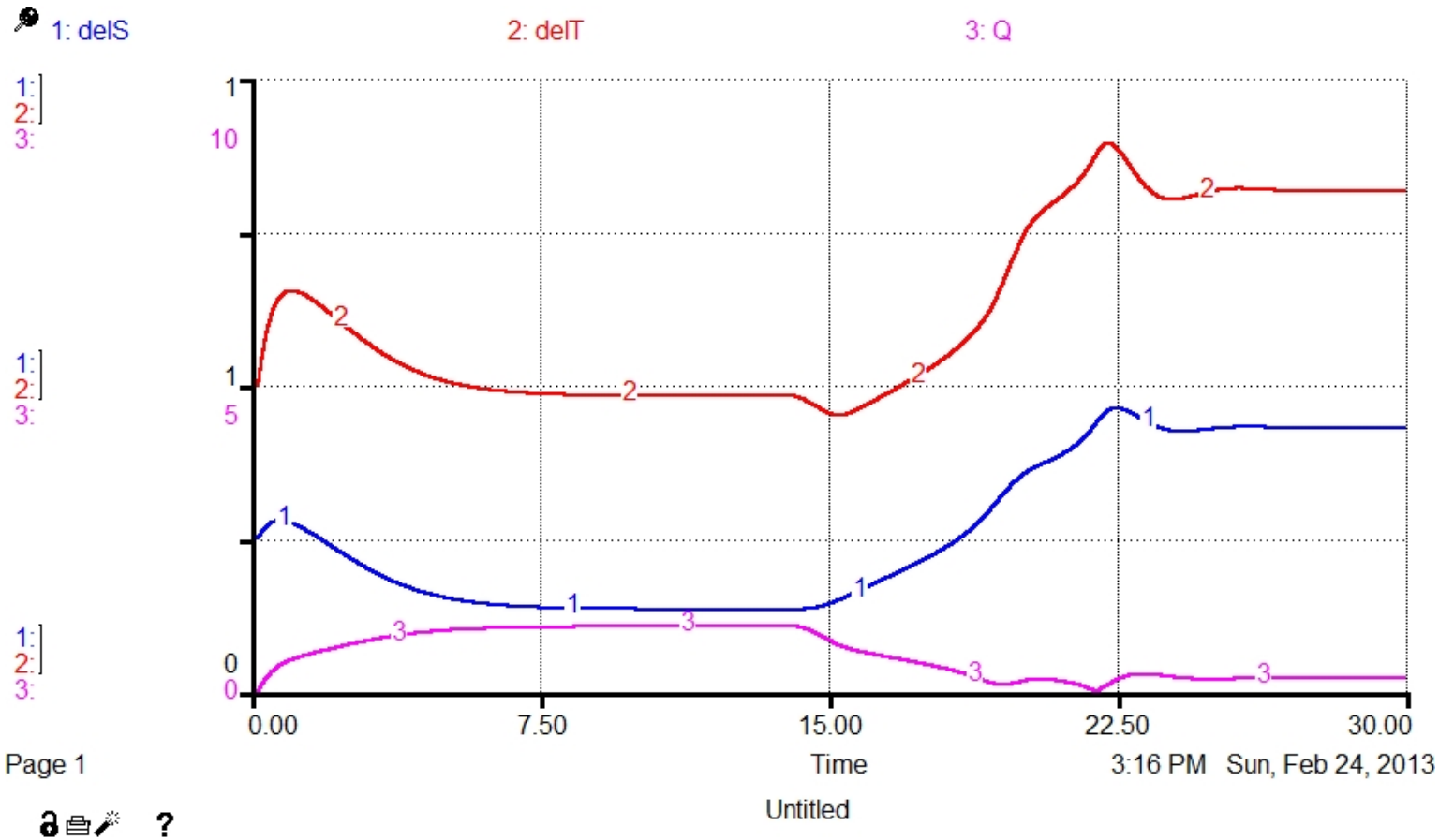
- From the cold state, temporarily decrease the temperature gradient but using a smaller temperature gradient of 0.4
- Switches to the warm state

3. Warming climate



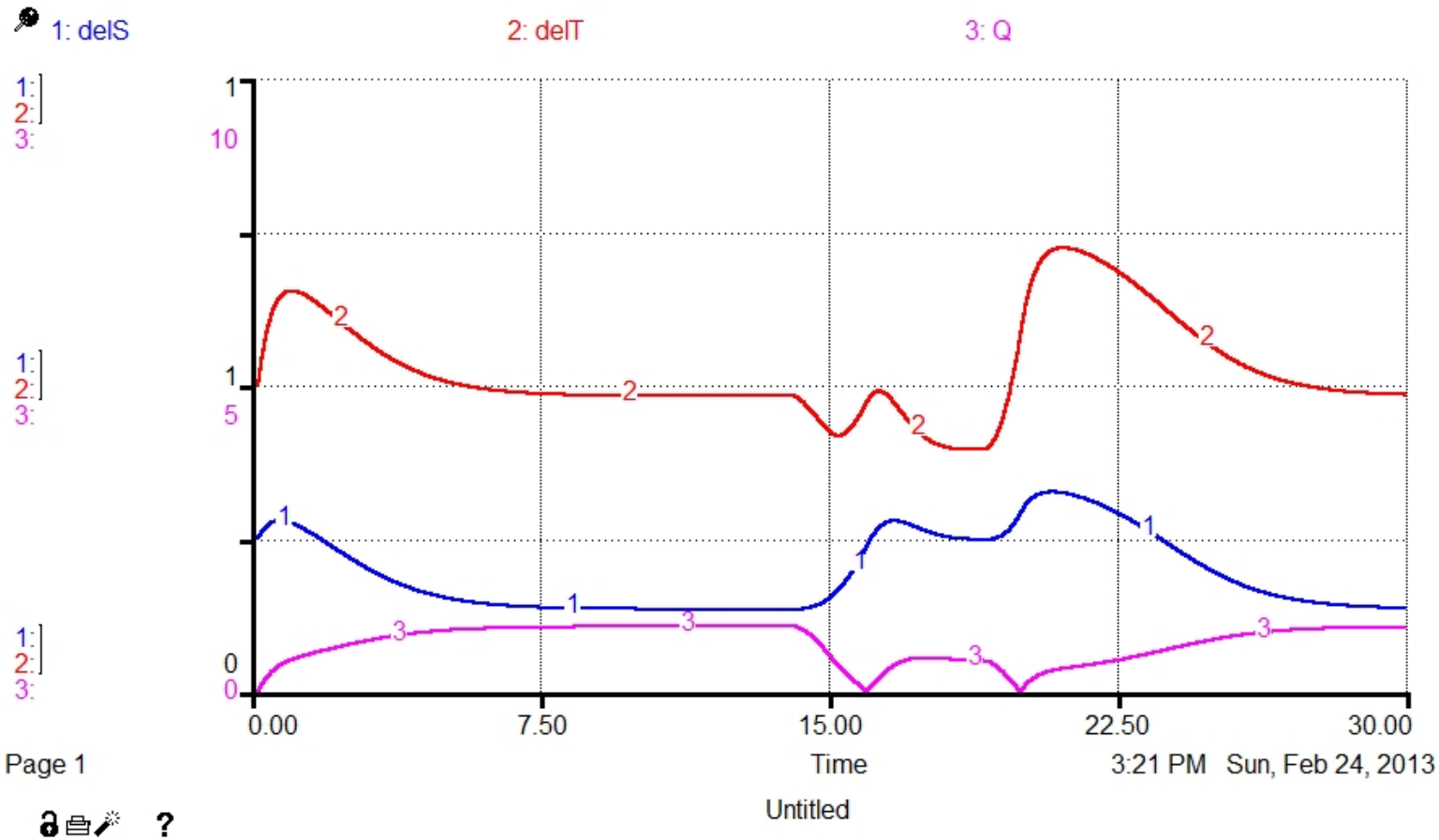
- From the warm state, temporarily decrease the temperature gradient $\rightarrow$ returns to initial state

3. Warming climate



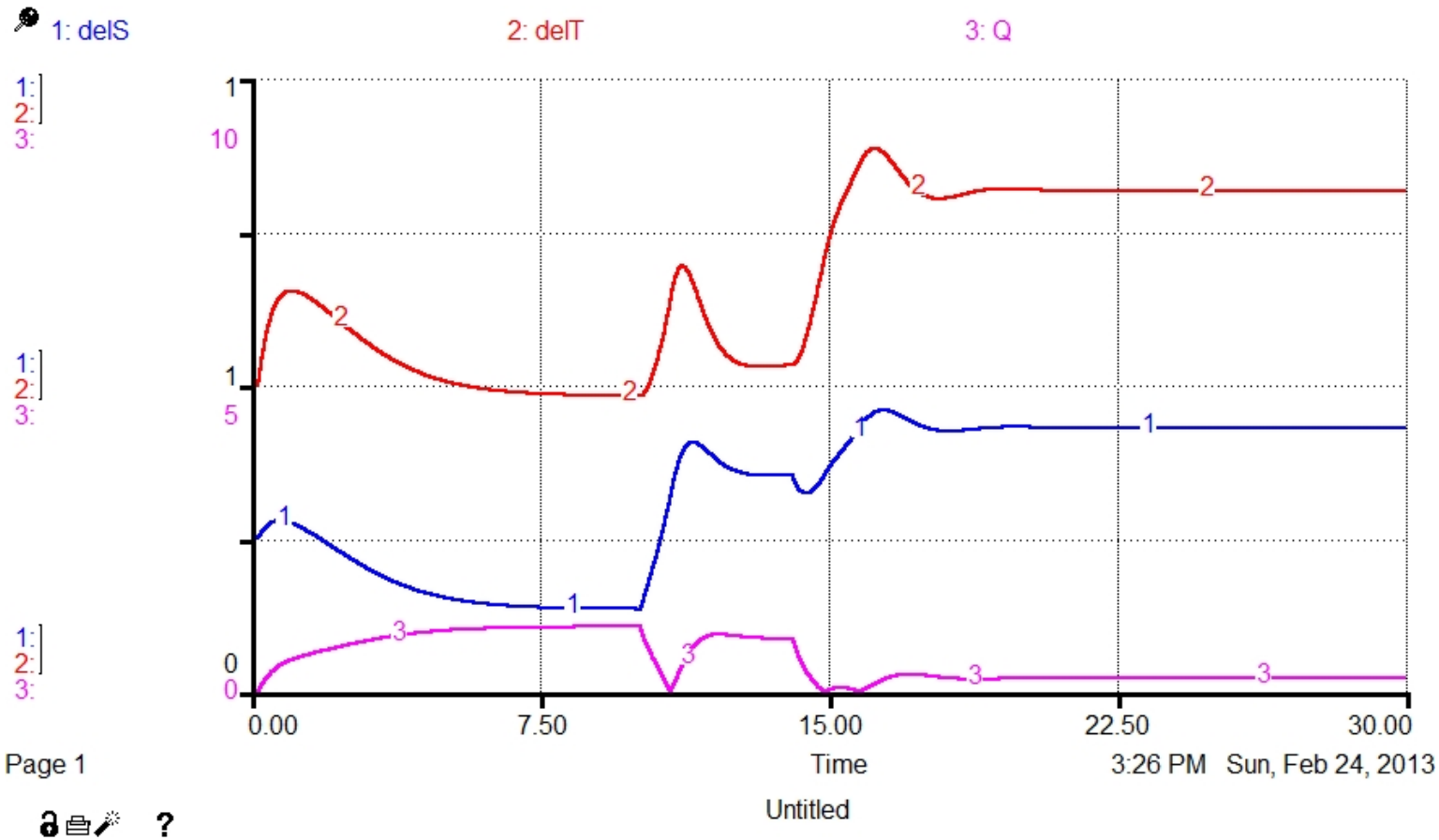
- From the warm state, temporarily decrease the temperature gradient a little bit more $\rightarrow$ switches to the cold state

3. Warming climate



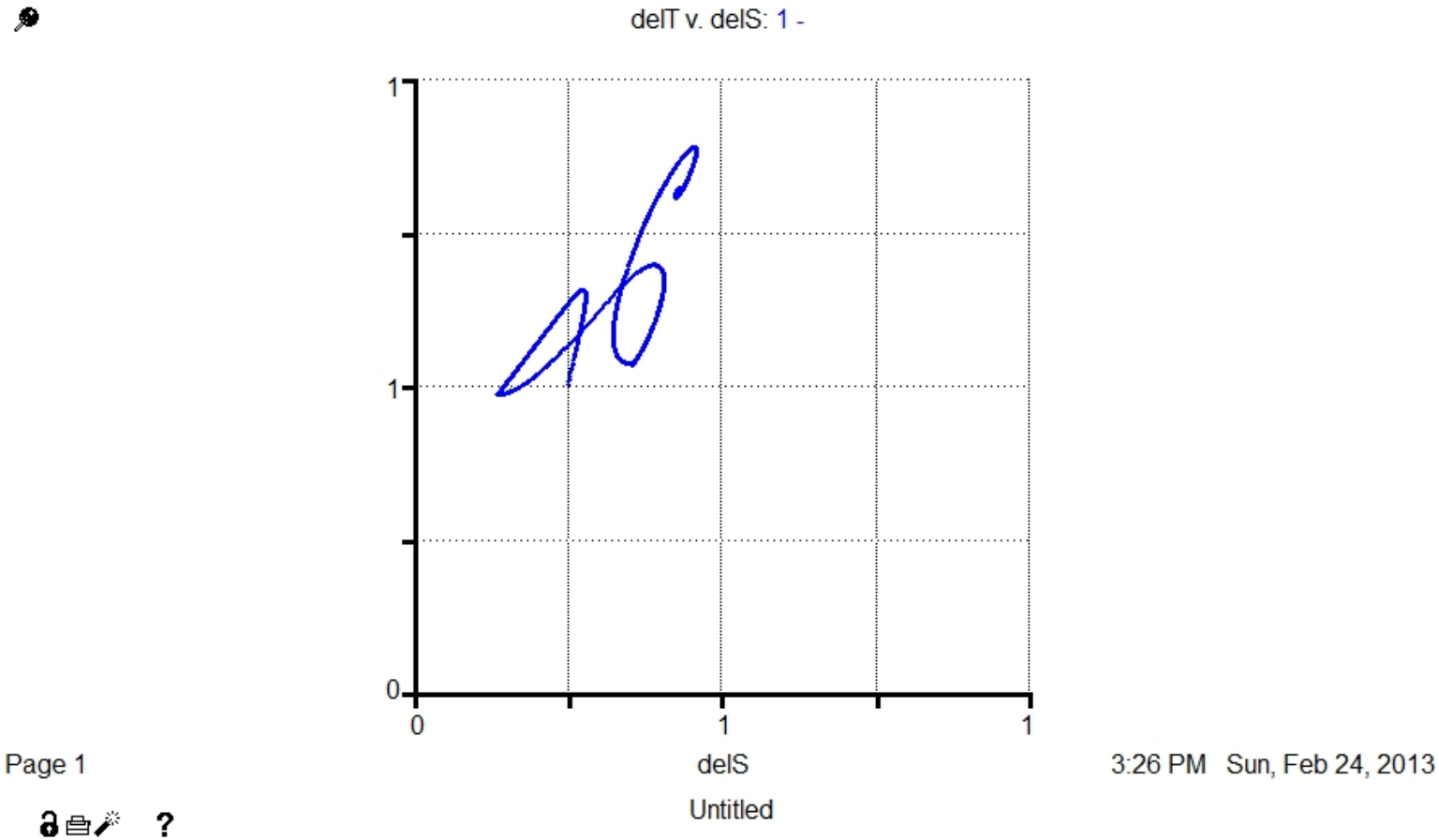
- From the warm state, temporarily decrease the temperature gradient even a little bit more $\rightarrow$ returns to the initial state

4. Freshwater pulses



- From the warm state, increase the salinity difference

4. Freshwater pulses



- Transitions from the "warm and fast" state to the "cold and slow" state

Key ideas

- System parameters can vary unpredictably as a system evolves toward a steady-state
- The initial conditions matter $\rightarrow$ systems often have multiple steady states; the initial conditions determine which steady state a system will approach
- Short pertubations can cause a "permanent" transition from one state to another
- Observed a transition out of the (i) cold state for large perturbations in temperature (ii) warm state for moderate perturbations in temperature
- Also produced transitions from one state to another by modifying the salinity difference