Welcome!

Reducing the uncertainty in the prediction of global warming

Winter school, Jerusalem, Jan 12-16, 2009

Nonlinearities & surprises in climate sensitivity

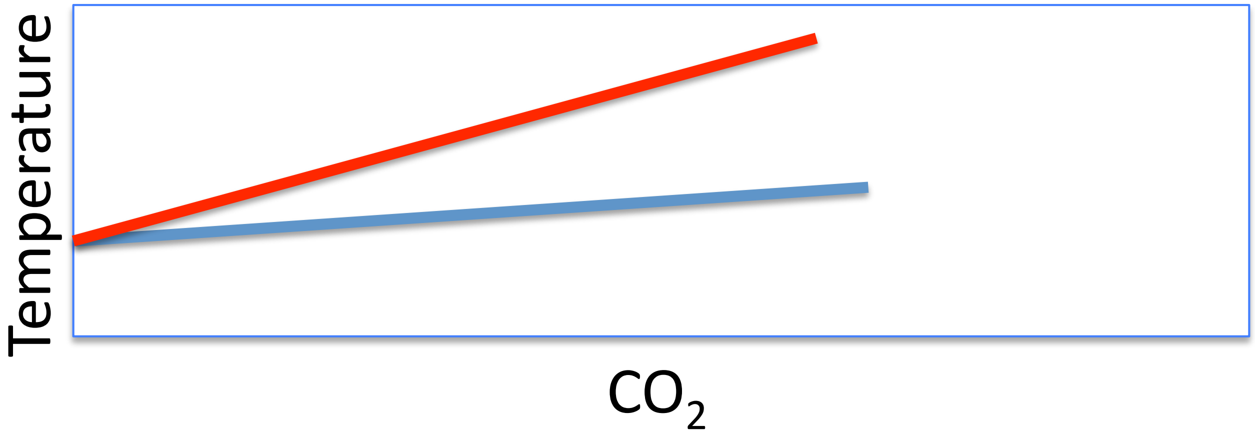
Reducing the uncertainty in the prediction of global warming

Winter school, Jerusalem, Jan 12-16, 2009

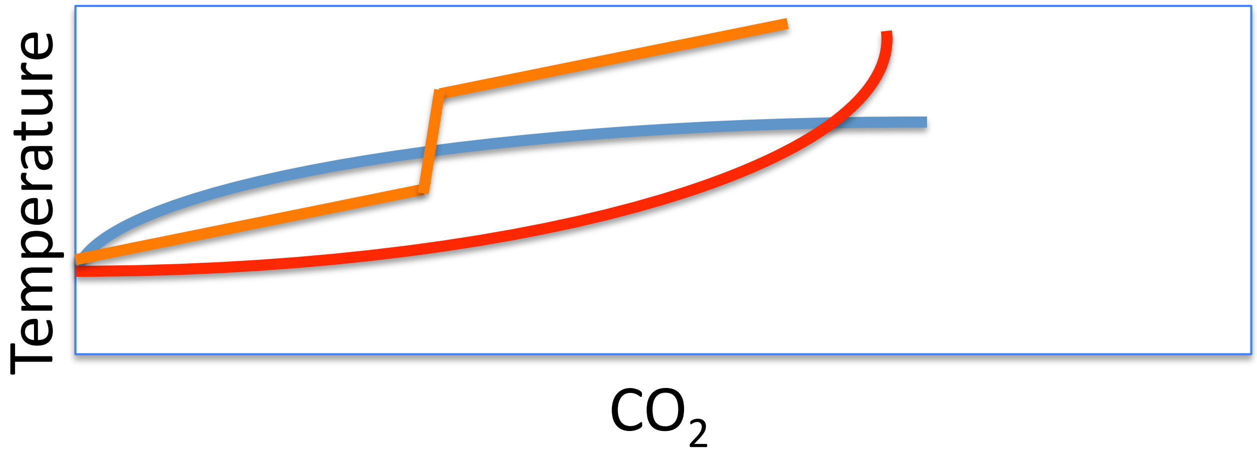
Eli Tziperman

Motivation

- Linear sensitivity could be small or large, but can be completely anticipated once estimated



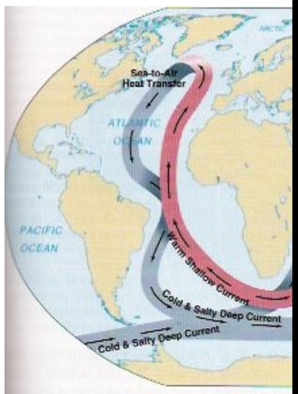
- Nonlinearities can lead to surprises, pleasant, less so, or even less…



Which elements of the climate system can lead to surprises?

El Nino?

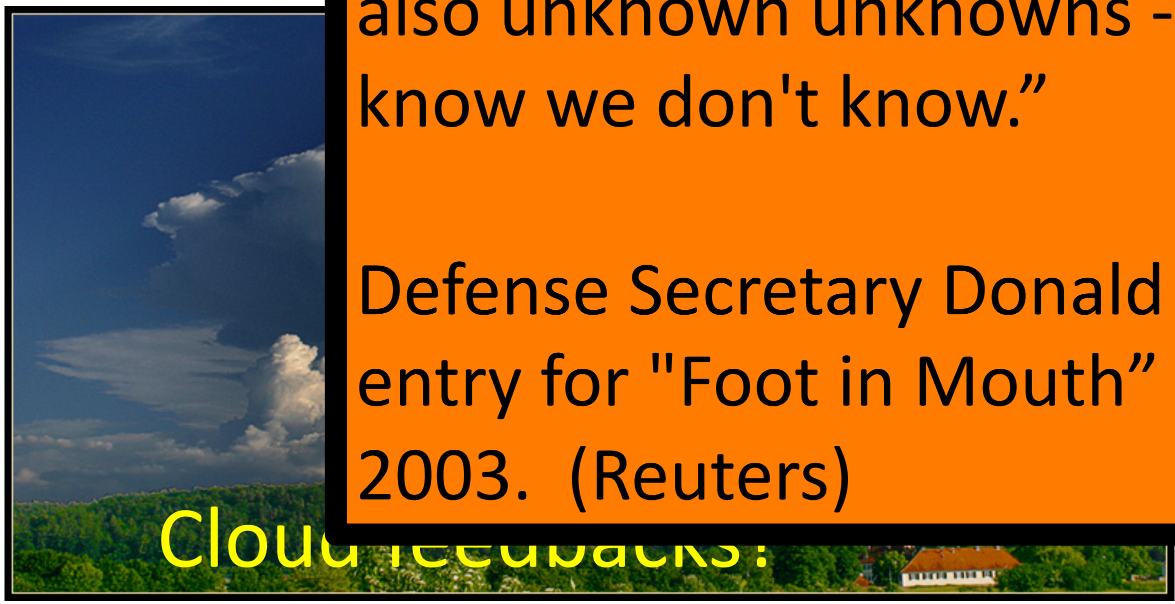
Therm

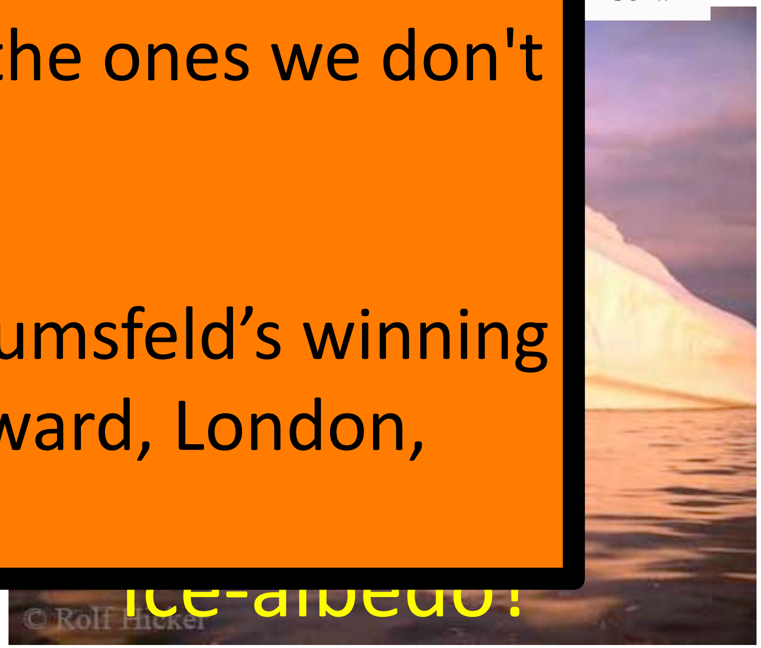


Anything else?

”… as we know, there are known knowns; … there are known unknowns; … But there are also unknown unknowns -- the ones we don't know we don't know.”

Defense Secretary Donald Rumsfeld’s winning entry for "Foot in Mouth” award, London, 2003. (Reuters)





Introduction to bifurcations

- bifurcation: A qualitative change in the solutions of an equation in response to a parameter change

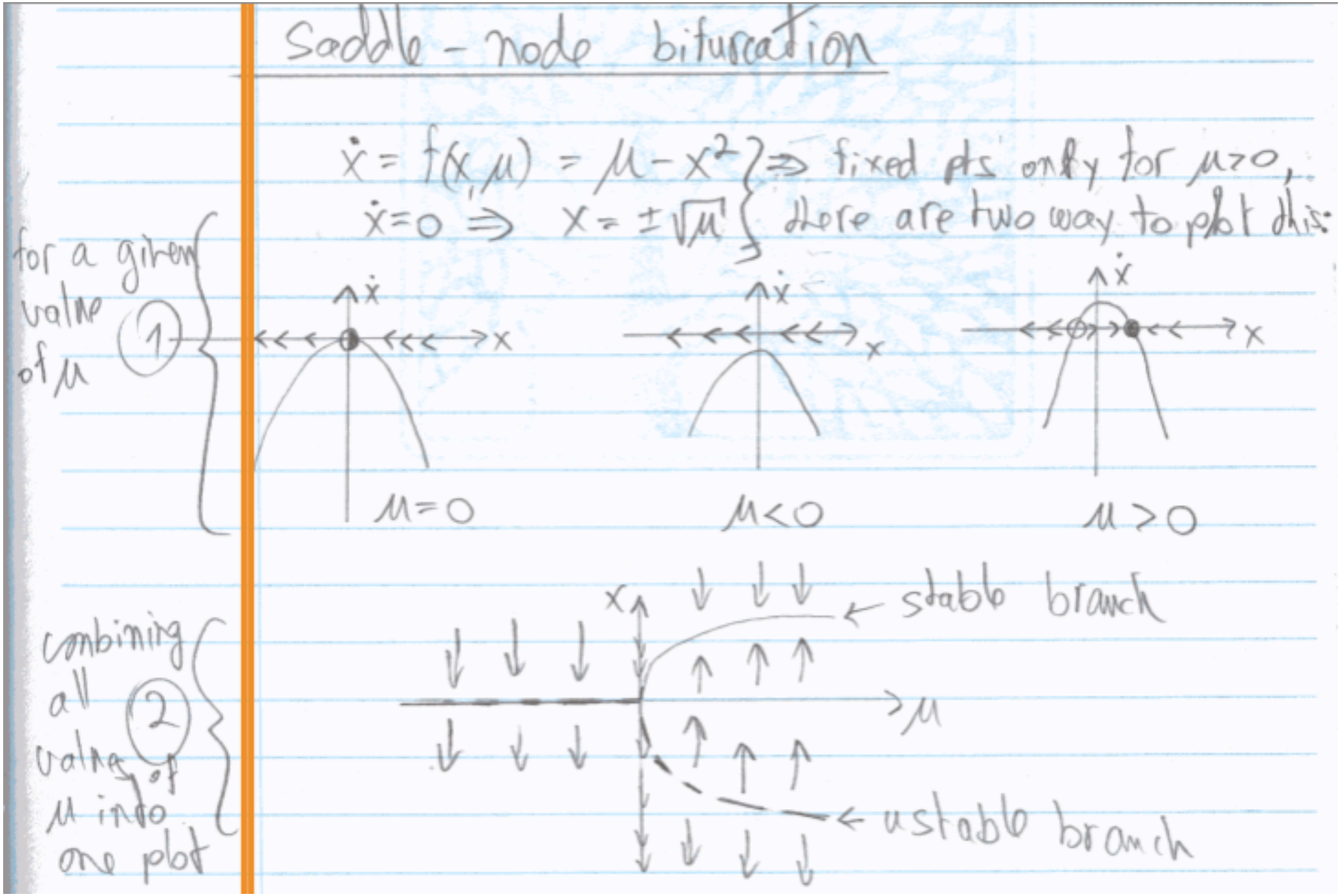
* example: $\dot{x} = \mu - x^2$. steady state: $\dot{x} = \mu - x^2 = 0$

for $\mu < 0$, there are no steady states

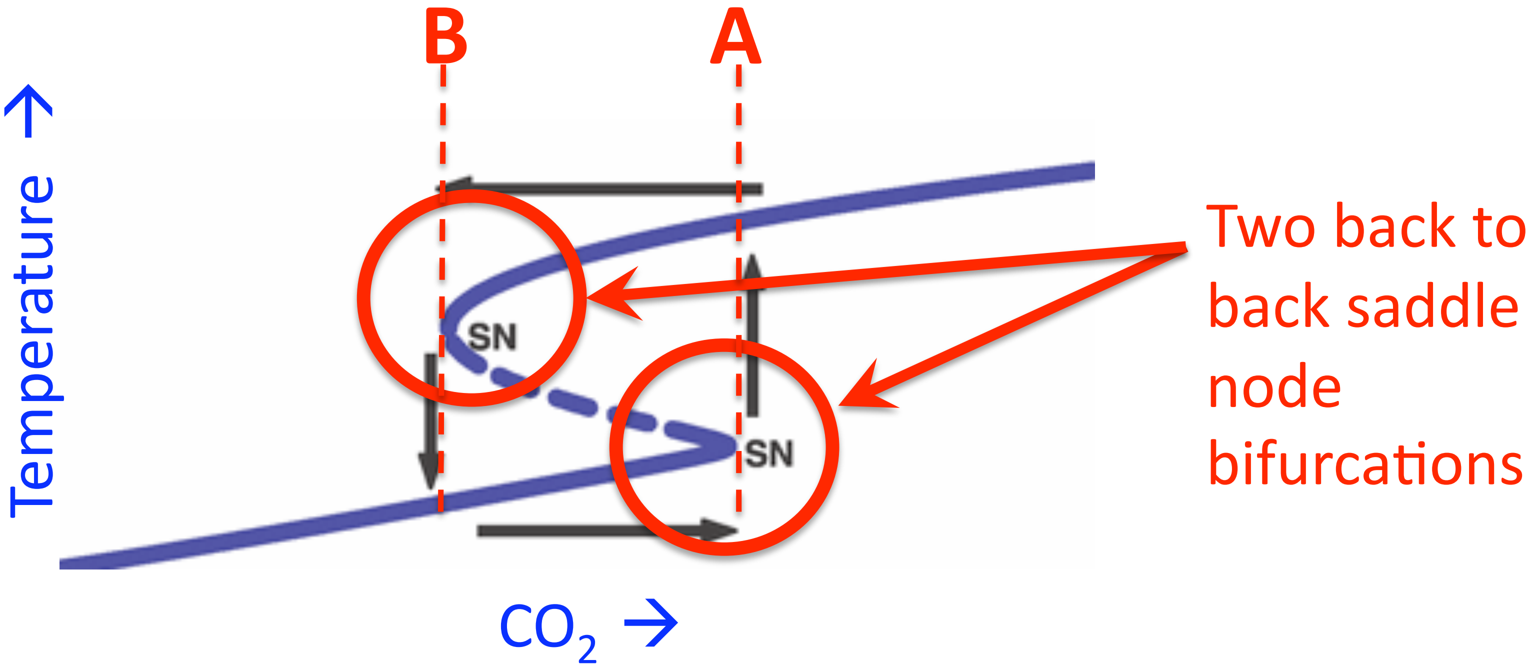
$\mu = 0$ 1 steady state, $x = 0$

$\mu > 0$ 2 " " $x = \pm\sqrt{\mu}$.

Saddle node bifurcation



Hysteresis, jumps and irreversibility



1. Increase of CO_2 beyond value **A** leads to a jump in temperature;
2. Later decrease does not restore original state until decreased below value **B**

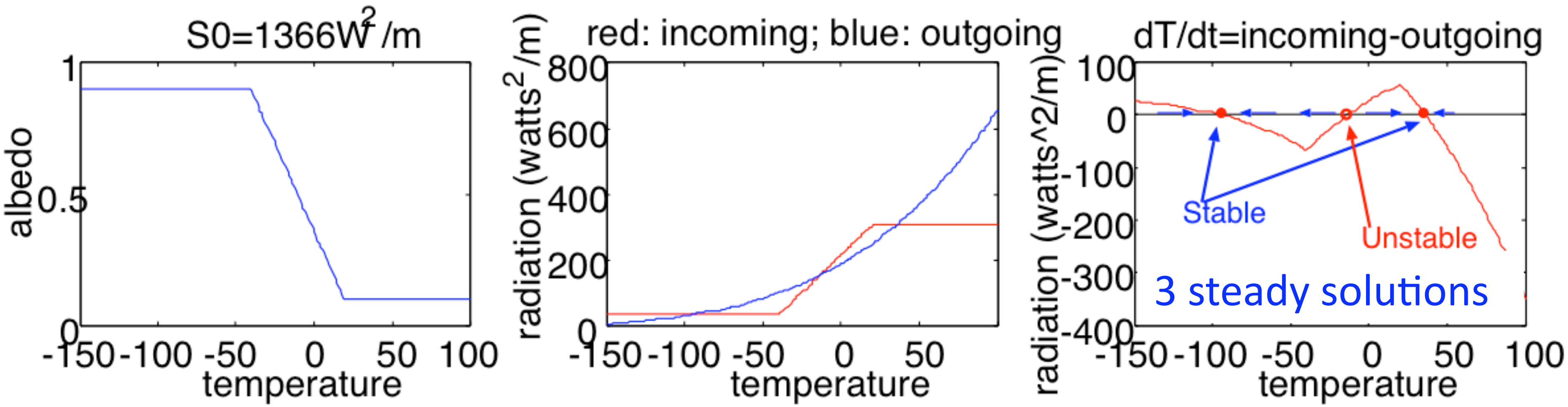
Example: Budyko-Sellers energy balance model (1st out of 2)

Incoming solar X (not reflected) = outgoing:

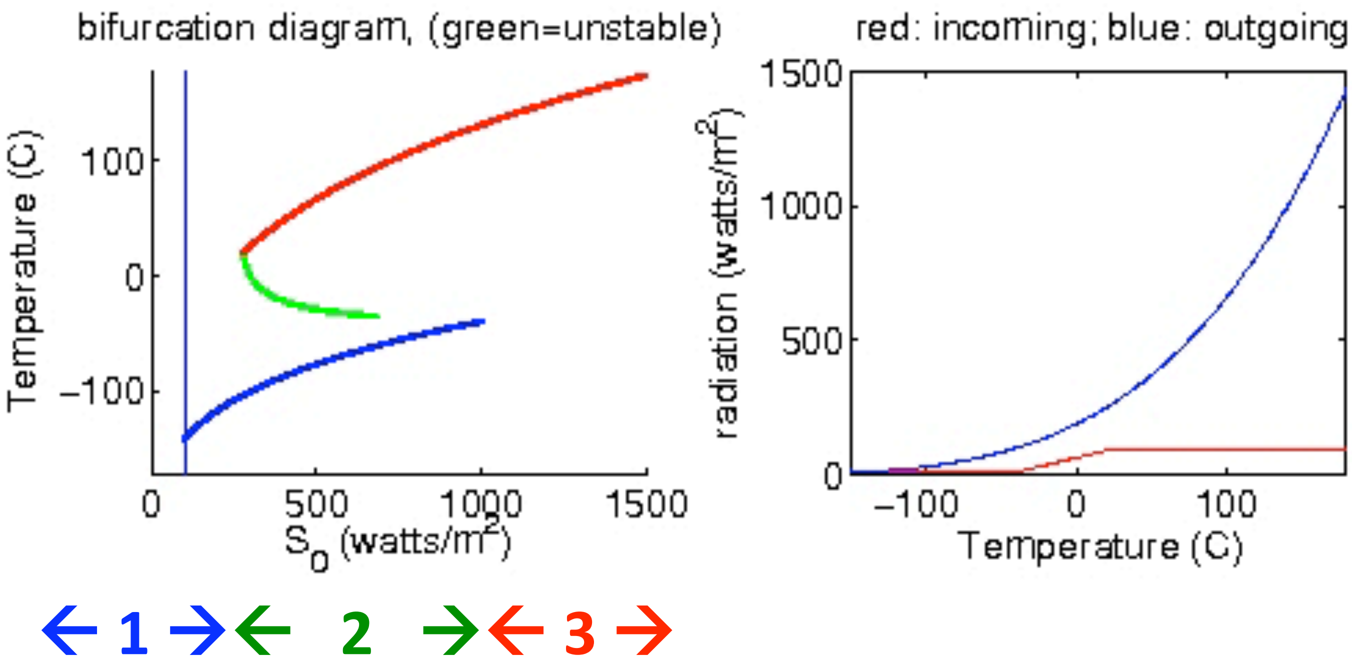
$$S(1-\alpha(T)) = \varepsilon\sigma T^4$$

Where reflectivity (albedo) is a function of temperature:

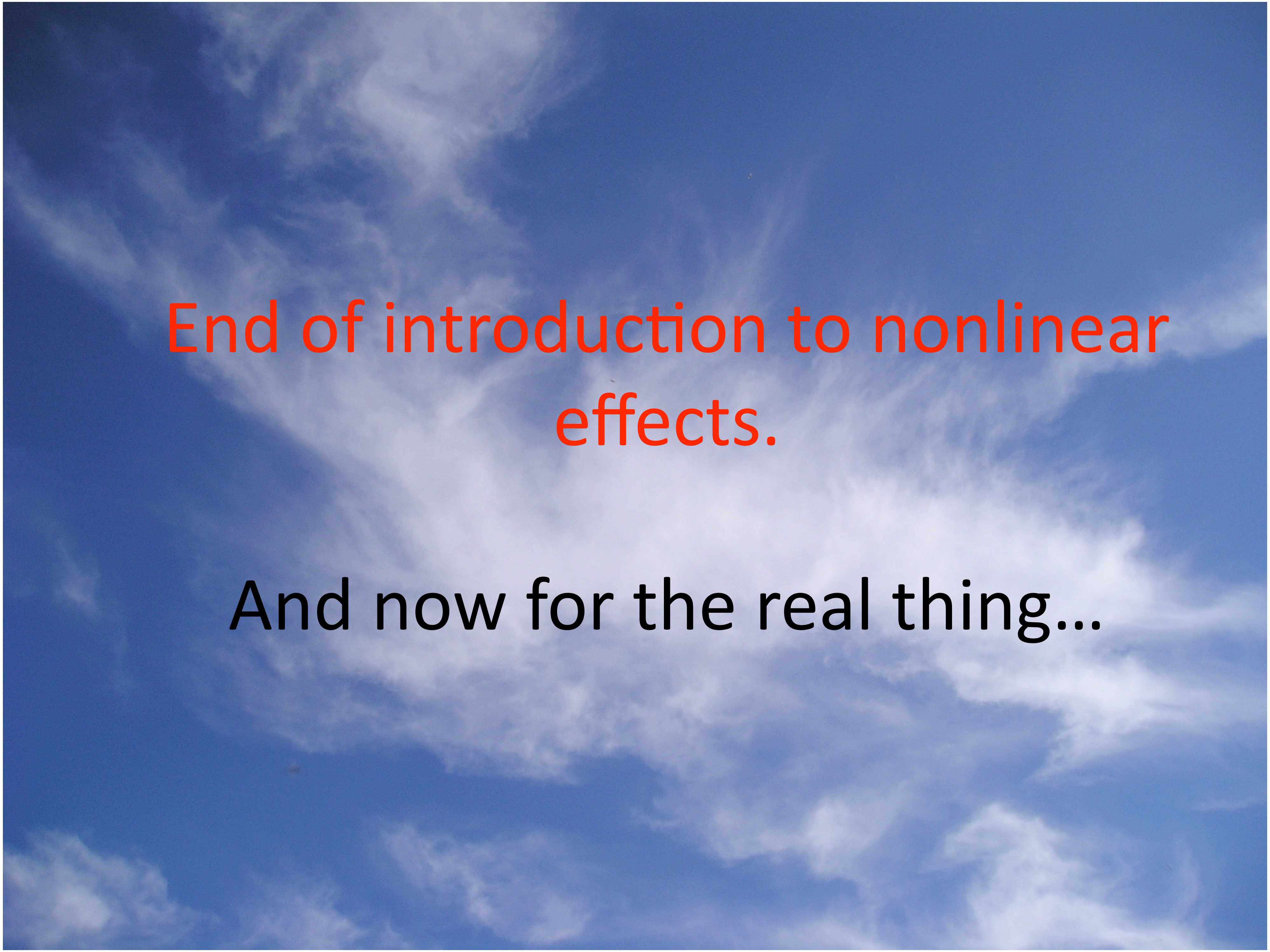
$$\alpha(T) = \begin{cases} \alpha_1 & \text{if } T < T_1 \\ \alpha_1 + (\alpha_2 - \alpha_1)[T - T_1]/[T_2 - T_1] & \text{if } T_2 > T > T_1 \\ \alpha_2 & \text{if } T > T_2 \end{cases}$$



Example: Budyko-Sellers energy balance model (2nd out of 2)



- As the solar constant S_0 is increased, the model transitions between different regimes of S_0: **(1)** only snowball solution, **(2)** both snowball and warm state, and **(3)** only warm state solutions.
- Can see hysteresis, jumps and irreversibility.


End of introduction to nonlinear effects.
And now for the real thing…