Complexity and simplicity of the climate feedbacks

Natalia Andronova, University of Michigan, natand@umich.edu

Tomsk, July 2011

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1. Feedbacks: exploration
2. Feedbacks: from models
3. Feedbacks: from observations

Tomsk, July 2011

1. Feedbacks: exploration

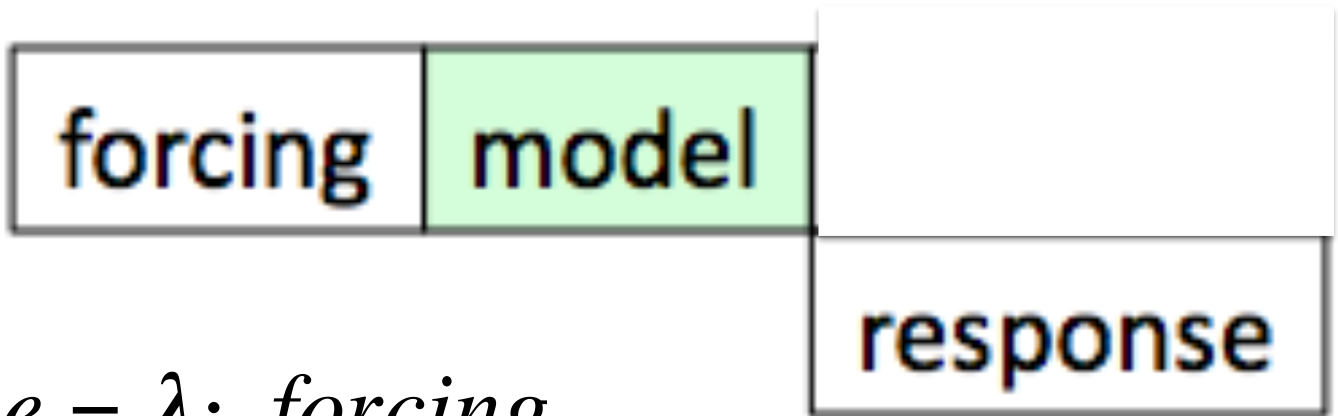
Are we forcing the climate to change?

1. Feedbacks: exploration

Are we forcing the climate to change?

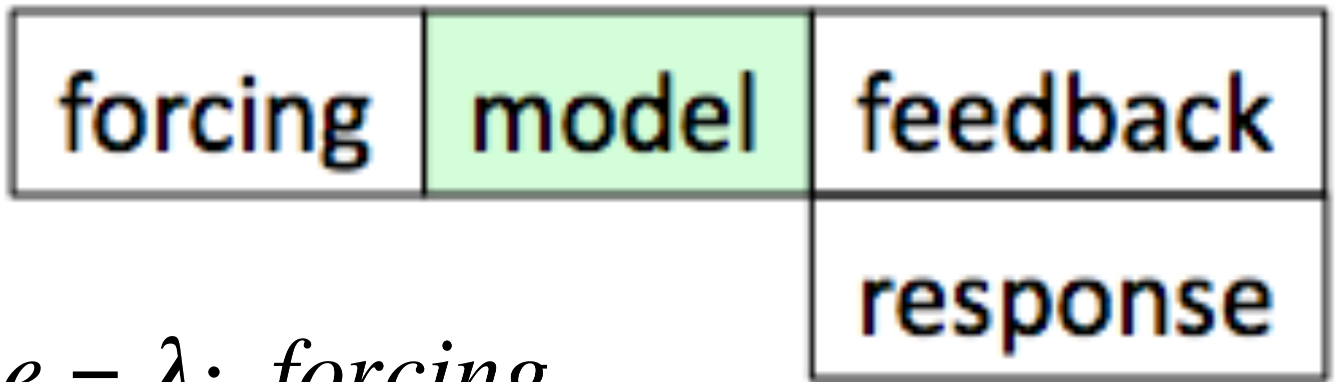
…. Or there is a feedback in the climate system which forces us to change?

Q1: What is a feedback?



$$response = \lambda \cdot \ forcing$$

Q1: What is a feedback?



$$response = \lambda \cdot \; forcing$$

$$response = \frac{pathway}{feedback} \cdot \; forcing$$

$$\frac{dA}{dt} = aA$$

$$\frac{dC}{dt} = cC + dA$$

$$\frac{dA}{dt} = aA$$

$$\frac{dC}{dt} = cC + dA$$

The system with No feedback between variables

$$\frac{dA}{dt} = aA$$

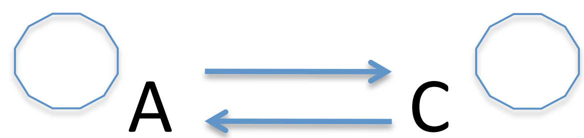
$$\frac{dC}{dt} = cC + dA$$

The system with No feedback between variables

The system with a feedback between A and C:

$$\frac{dA}{dt} = aA + cC$$

$$\frac{dC}{dt} = dA + eC$$



$$J = \begin{pmatrix} a & c \\ d & e \end{pmatrix}$$

How will J look with no self-feedbacks?

$$\frac{dA}{dt} = aA + cC$$

$$\frac{dC}{dt} = dA + eC$$

$$J = \begin{pmatrix} a & c \\ d & e \end{pmatrix}$$

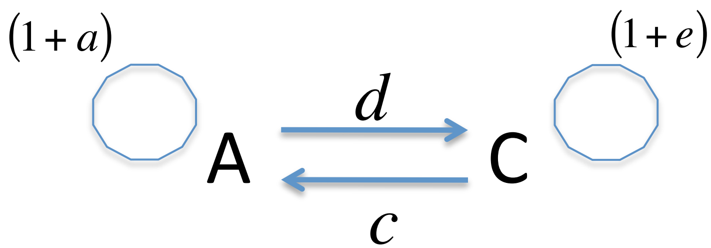
At an equilibrium point

$$0 = aA + cC$$

$$0 = dA + eC$$

$$A = (1 + a)A + cC$$

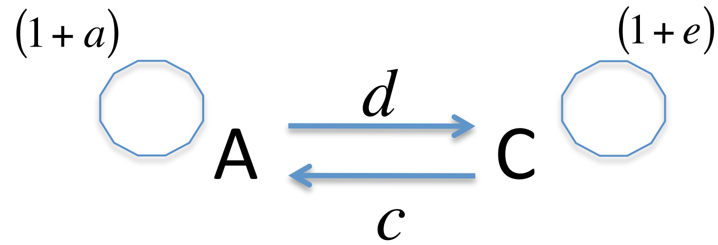
$$C = dA + (1 + e)C$$



$$\frac{dA}{dt} = aA + cC$$

$$\frac{dC}{dt} = dA + eC$$

$$J = \begin{pmatrix} a & c \\ d & e \end{pmatrix}$$



$$A = (1 + a)A + cC$$

$$C = dA + (1 + e)C$$

Let's add a forcing

$$\frac{dA}{dt} = aA + cC + F$$

$$\frac{dC}{dt} = dA + eC$$

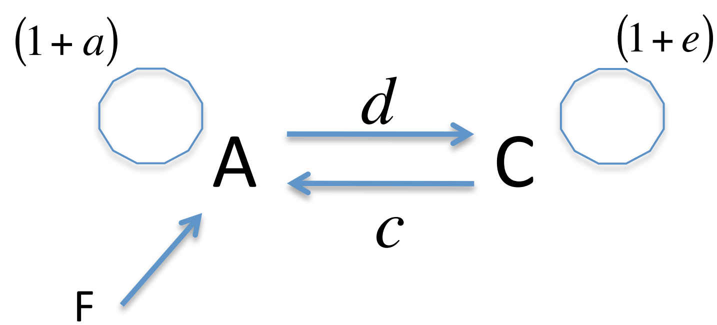
$$A = (1 + a)A + cC + F$$

$$C = dA + (1 + e)C$$

Find solution:

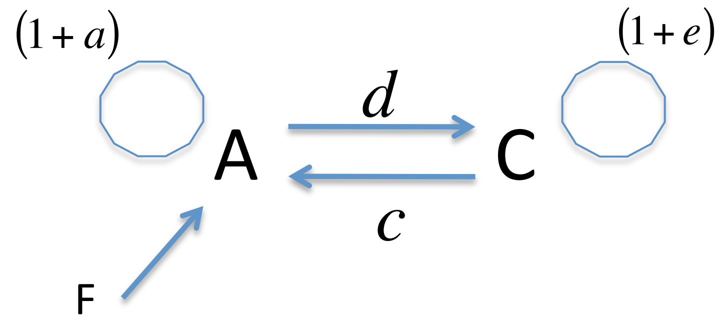
$$A = \frac{F}{1 - cd - (1 + a) - (1 + e) + (1 + a)(1 + e)}$$

$$C = \frac{dF}{1 - cd - (1 + a) - (1 + e) + (1 + a)(1 + e)}$$



$$A = \frac{F}{1 - cd - (1+a) - (1+e) + (1+a)(1+e)}$$

$$C = \frac{dF}{1 - cd - (1+a) - (1+e) + (1+a)(1+e)}$$



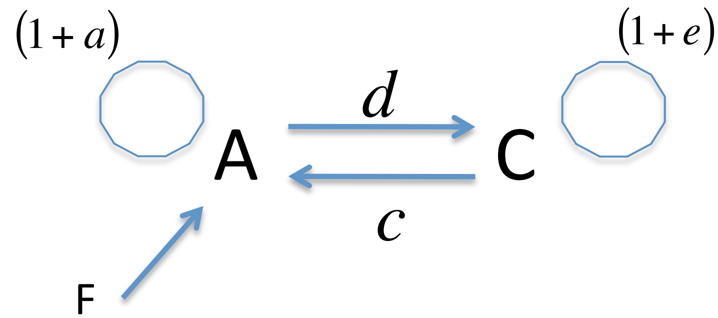
$$A = \frac{F}{1 - L_{cd} - L_a - L_c + L_a L_c} = \frac{F}{1 - L}$$

$$C = \frac{d \cdot F}{1 - L_{cd} - L_a - L_c + L_a L_c} = \frac{d \cdot F}{1 - L}$$

(1-L) is total feedback effect

$$A = \frac{F}{1 - cd - (1+a) - (1+e) + (1+a)(1+e)}$$

$$C = \frac{dF}{1 - cd - (1+a) - (1+e) + (1+a)(1+e)}$$



$$A = \frac{F}{1 - L_{cd} - L_a - L_c + L_a L_c} = \frac{F}{1 - L}$$

$$C = \frac{d \cdot F}{1 - L_{cd} - L_a - L_c + L_a L_c} = \frac{d \cdot F}{1 - L}$$

(1-L) is total feedback effect

$$A(1-L) = F$$

$$C(1-L) = d \cdot F$$

$$0 = -A(1-L) + F$$

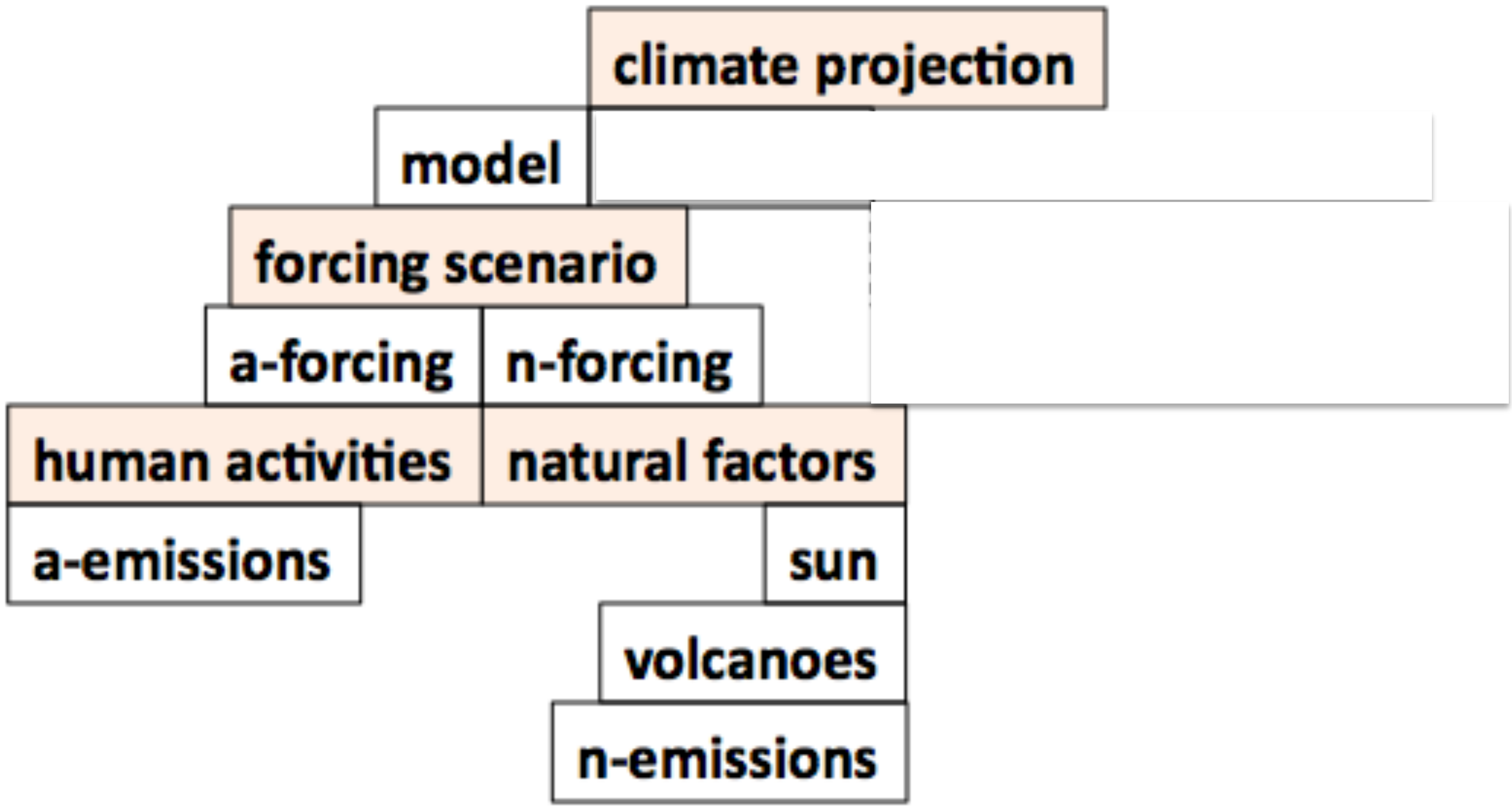
$$0 = -C(1-L) + d \cdot F$$

$$\frac{dA}{dt} = -A(1-L) + F$$

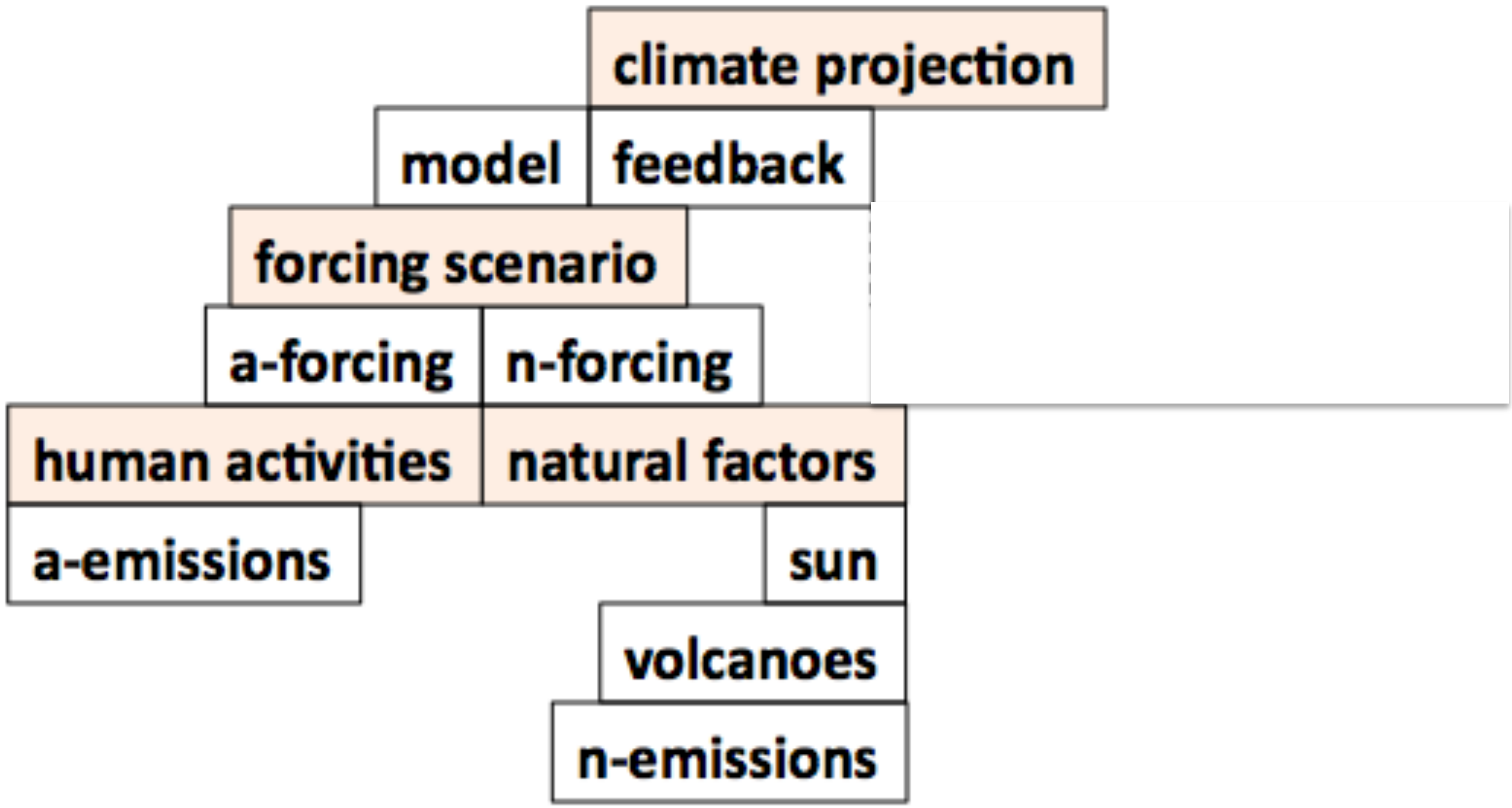
$$\frac{dC}{dt} = -C(1-L) + d \cdot F$$

A and C are independent!

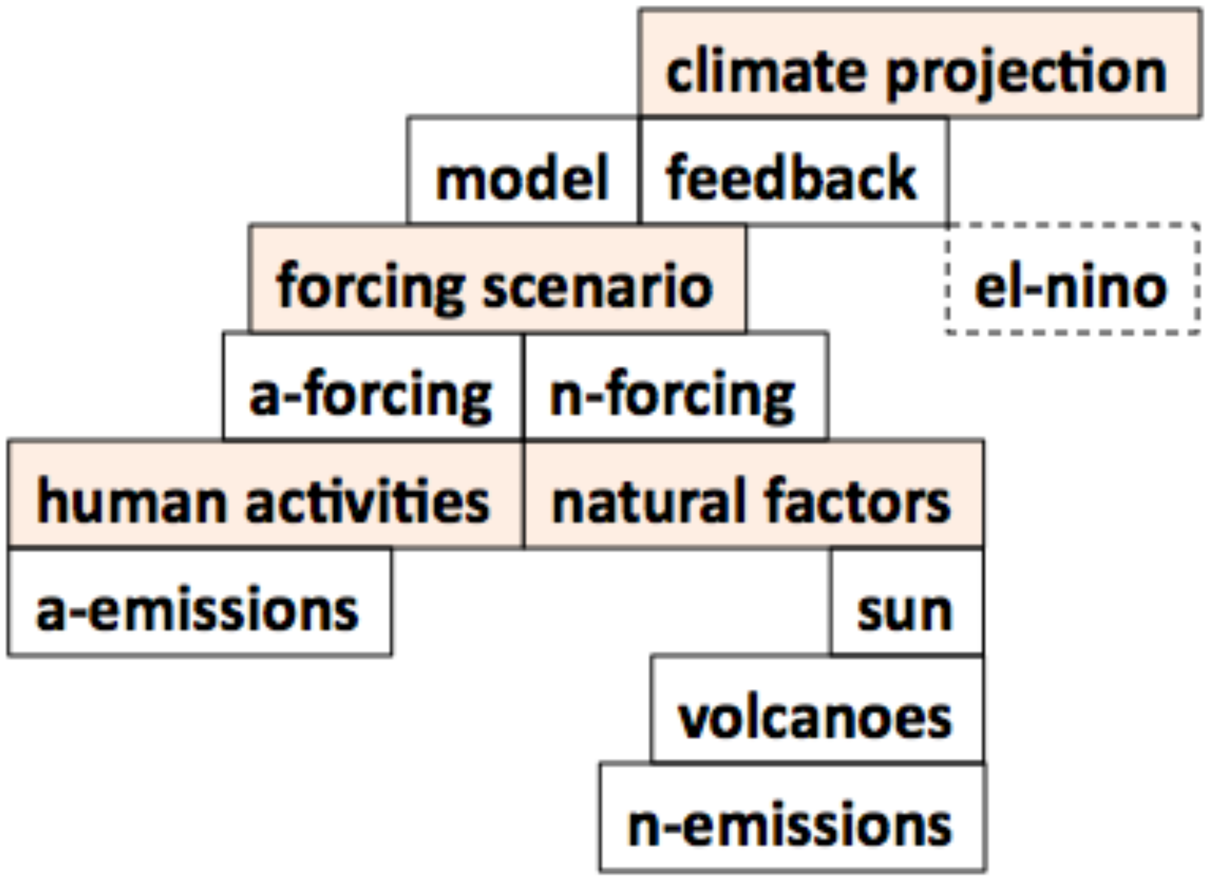
2. Feedbacks: from models



2. Feedbacks: from models

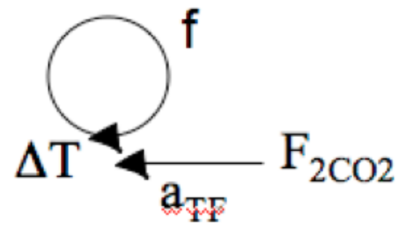


2. Feedbacks: from models

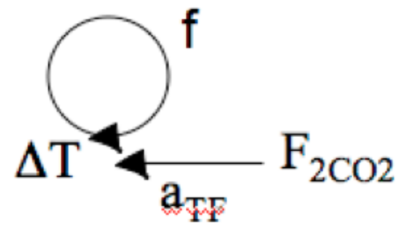


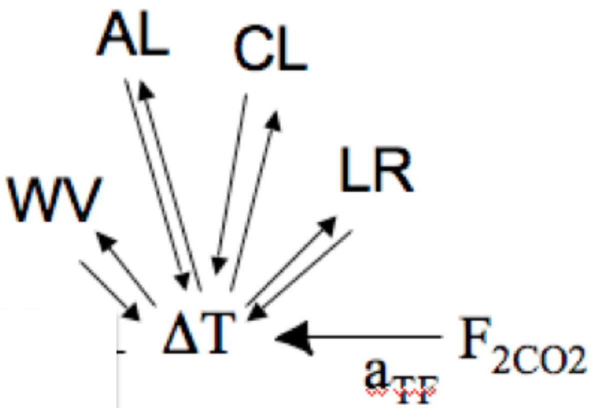
…. climate projection uncertainties should be also defined in terms of the uncertainties of climate feedbacks.

$$\Delta T_s = \frac{a_{TF}}{1-f} F_{2CO_2}$$



$$\Delta T_s = \frac{a_{TF}}{1-f} F_{2CO_2}$$



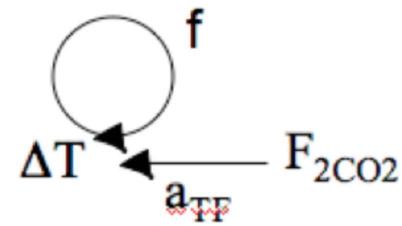


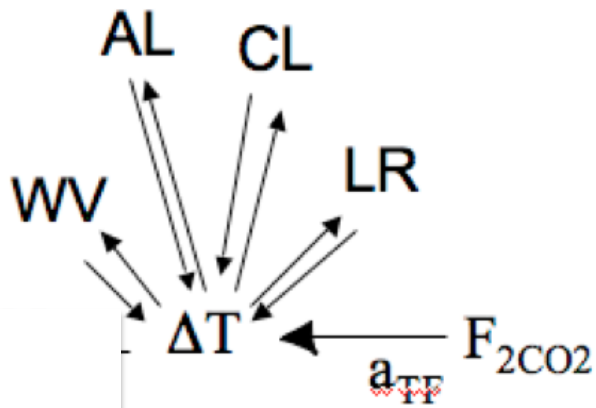
$$\Delta T_s = \frac{a_{TF}}{1 - f_{TW} - f_{TC} - f_{TL} - f_{TA} - f_{TR}} F_{2CO_2}$$

$$= \frac{a_{TF}}{1 - a_{TW}a_{WT} - a_{TC}a_{CT} - a_{TL}a_{LT} - a_{TR}a_{RT}} F_{2CO_2}$$

$$= \frac{a_{TF}}{1-f} F_{2CO_2}$$

$$\Delta T_s = \frac{a_{TF}}{1 - f} F_{2CO_2}$$



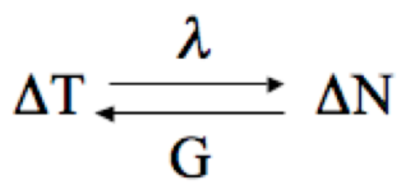


$$\Delta T_s = \frac{a_{TF}}{1 - f_{TW} - f_{TC} - f_{TL} - f_{TA} - f_{TR}} F_{2CO_2}$$

$$= \frac{a_{TF}}{1 - a_{TW}a_{WT} - a_{TC}a_{CT} - a_{TL}a_{LT} - a_{TR}a_{RT}} F_{2CO_2}$$

$$= \frac{a_{TF}}{1 - f} F_{2CO_2}$$

$$G\Delta N = \lambda \Delta T_s$$



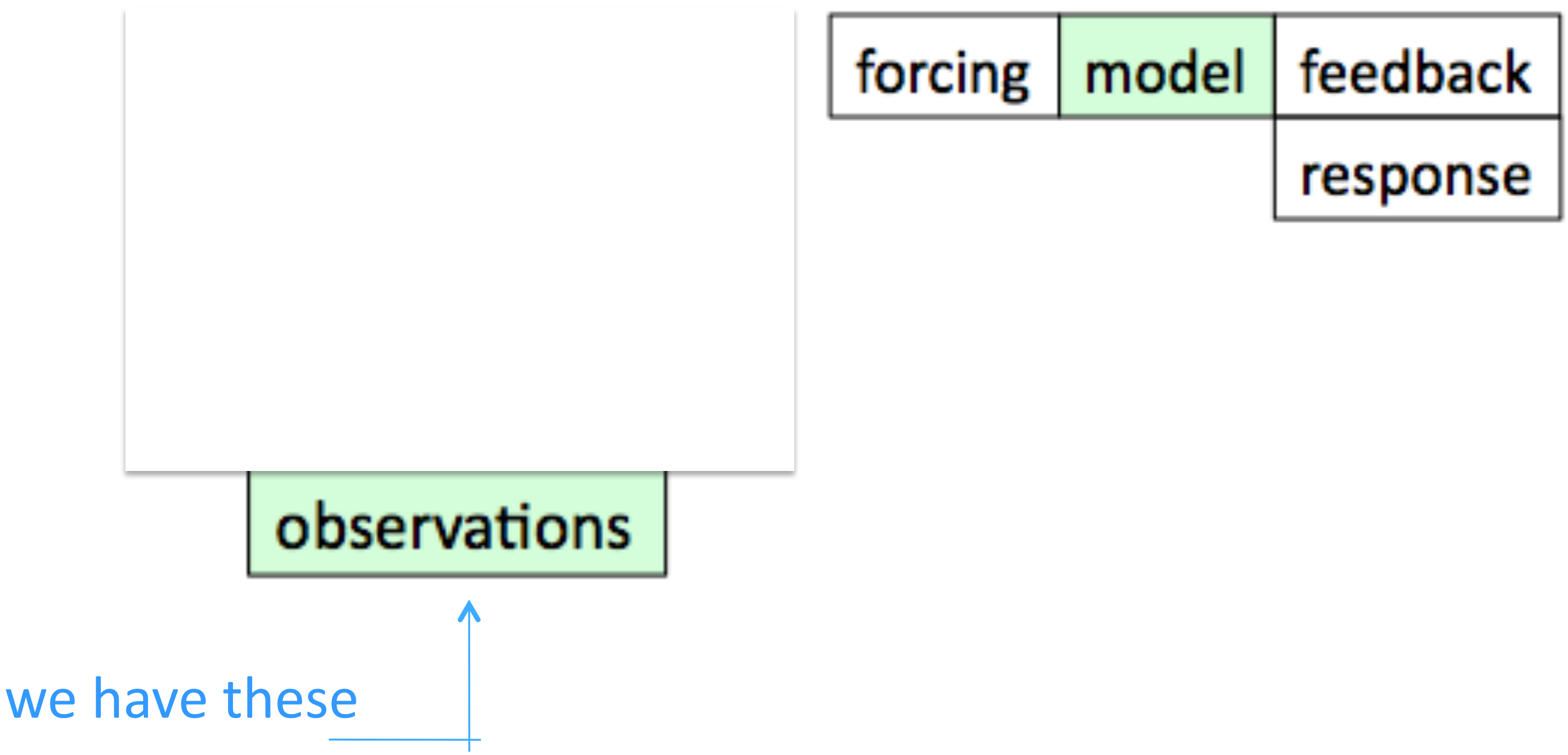
$$\lambda_X = \frac{\partial N}{\partial X} \frac{\Delta X}{\Delta T_s}$$

$$\lambda \Delta T_s = \left(\frac{\partial N}{\partial WV} \Delta WV + \frac{\partial N}{\partial CL} \Delta CL + \frac{\partial N}{\partial T} \Delta T + \frac{\partial N}{\partial AL} \Delta AL \right)$$

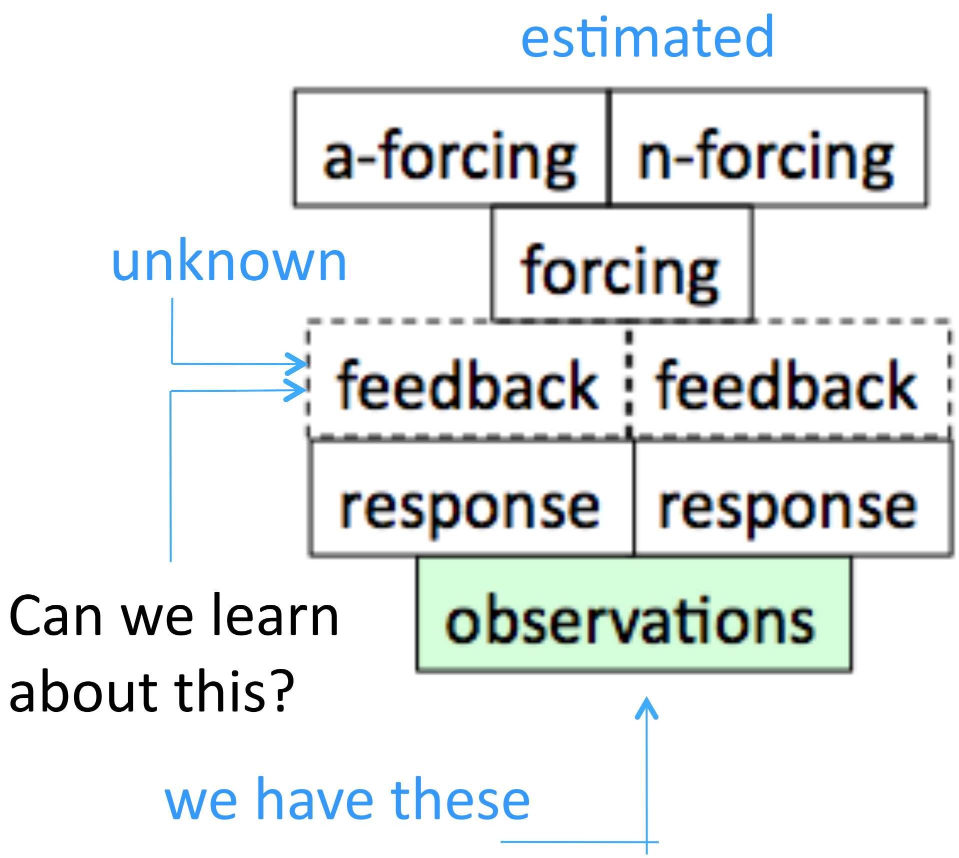
radiative kerners

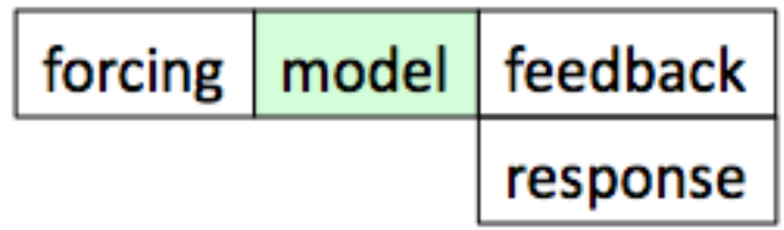
3. Feedbacks: from observations

Q2: Is it possible to recognize feedbacks in the climate system solely through observations?



Q2: Is it possible to recognize feedbacks in the climate system solely through observations?





A2: Yes, in very simplified system!

Andronova et al. (2009)

$$\Delta N_{toa}$$

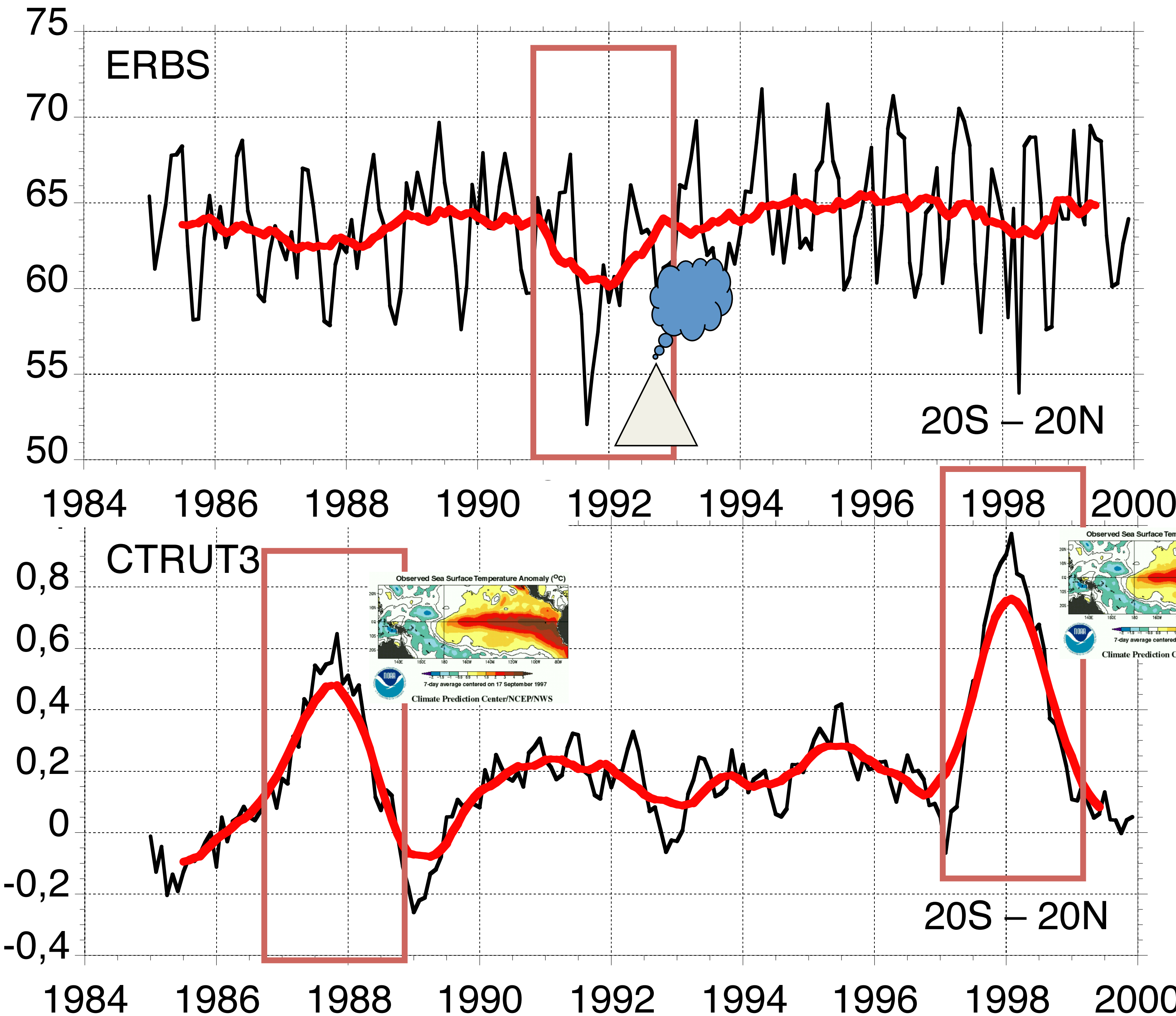
$$a_{NT} = \frac{\partial N_{toa}}{\partial T_s}$$

$$a_{TN} = \frac{\partial T_s}{\partial N_{toa}}$$

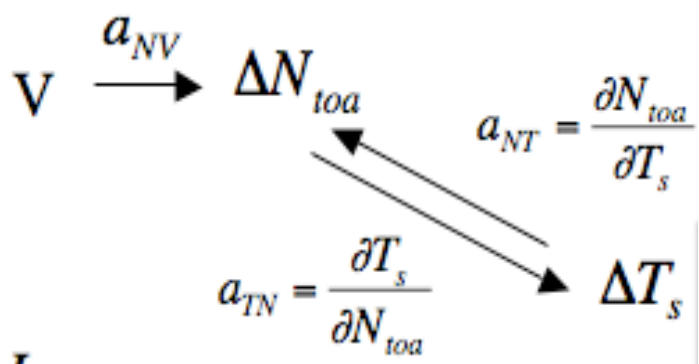
$$\Delta T_s$$

$$L = a_{NT} a_{TN}$$

$$response = \frac{pathway}{(1-L)} forcing$$



ERBS
75
70
65
60
55
50
20S – 20N
1984
1986
1988
1990
1992
1994
1996
1998
2000
CTRUT3
0,8
0,6
0,4
0,2
0
-0,2
-0,4
Observed Sea Surface Temperature Anomaly (°C)
7-day average centered on 17 September 1997
Climate Prediction Center/NCEP/NWS
20S – 20N



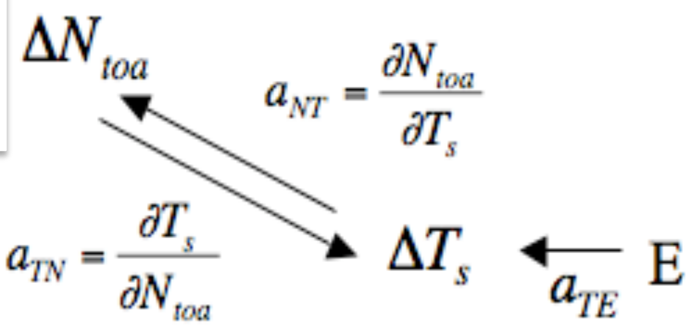
$$L = a_{NT} a_{TN}$$

$$response = \frac{pathway}{(1 - L)} forcing$$

$$\Delta N_{toa} = \frac{1}{1-L}\left(a_{NV} V\right)$$

$$\Delta T_s = \frac{a_{TN}}{1-L}\left(a_{NV} V\right)$$

$$\frac{\Delta T_s}{\Delta N_{toa}} = a_{TN}$$



$$L = a_{NT} a_{TN}$$

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$$\Delta N_{toa} = \frac{1}{1-L}\left(a_{NV}V\right)$$

$$\Delta T_s = \frac{a_{TN}}{1-L}\left(a_{NV}V\right)$$

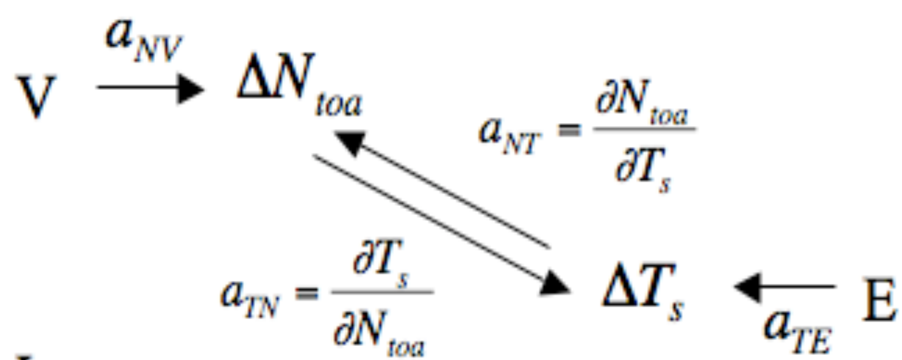
$$\frac{\Delta T_s}{\Delta N_{toa}} = a_{TN}$$

$$\Delta N_{toa} = \frac{a_{NT}}{1-L}\left(a_{TE}E\right)$$

$$\Delta T_s = \frac{1}{1-L}\left(a_{TE}E\right)$$

$$\frac{\Delta N_{toa}}{\Delta T_s} = a_{NT}$$

$$response = \frac{pathway}{(1 - L)} forcing$$



$$L = a_{NT} a_{TN}$$

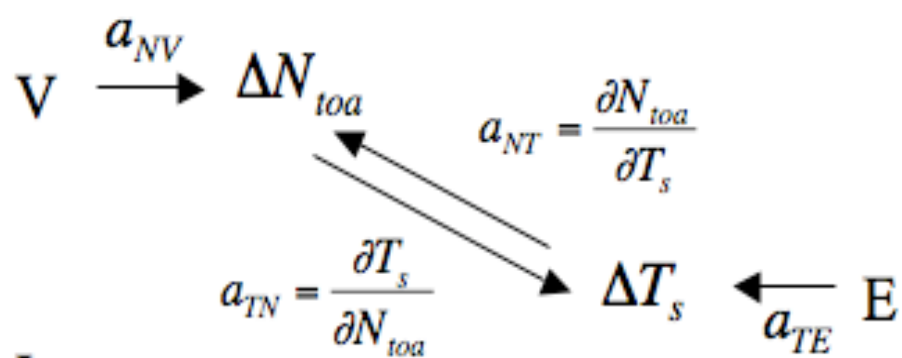
Total feedback effect

Name	$L = a_{TN} a_{NT}$
obs	$L = +0.020$ $a_{TN} = -0.0196$ $a_{NT} = -1.02$
M1	$L = +0.009$ $a_{TN} = -0.0086$ $a_{NT} = -1.08$
M2	$L = +0.067$ $a_{TN} = +0.0251$ $a_{NT} = +2.68$

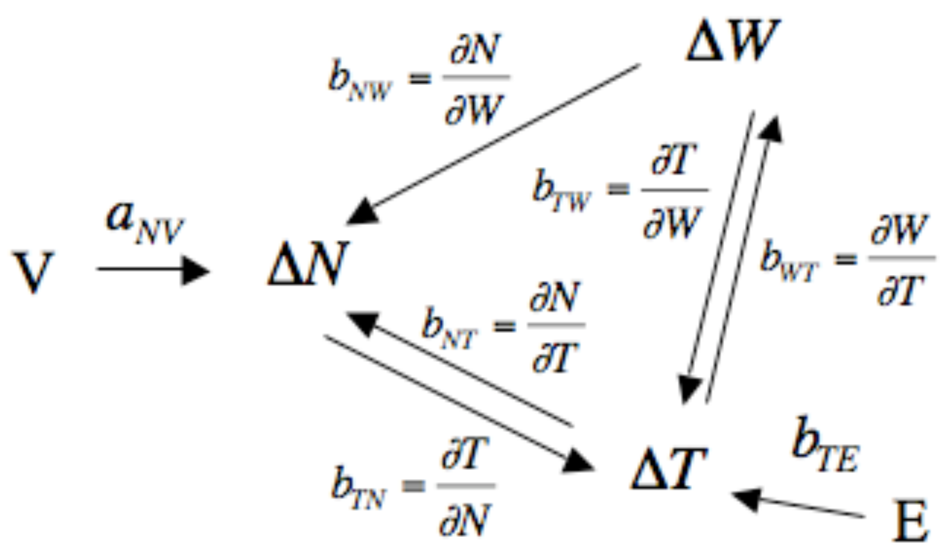
Andronova et al. (2009)

$$response = \frac{pathway}{(1 - L)} forcing$$

Total feedback effect



$$L = a_{NT} a_{TN}$$



$$L = L_{NT} + L_{WT} + L_{NWT}$$

Name	$L = a_{TN} a_{NT}$
obs	$L = +0.020$ $a_{TN} = -0.0196$ $a_{NT} = -1.02$
M1	$L = +0.009$ $a_{TN} = -0.0086$ $a_{NT} = -1.08$
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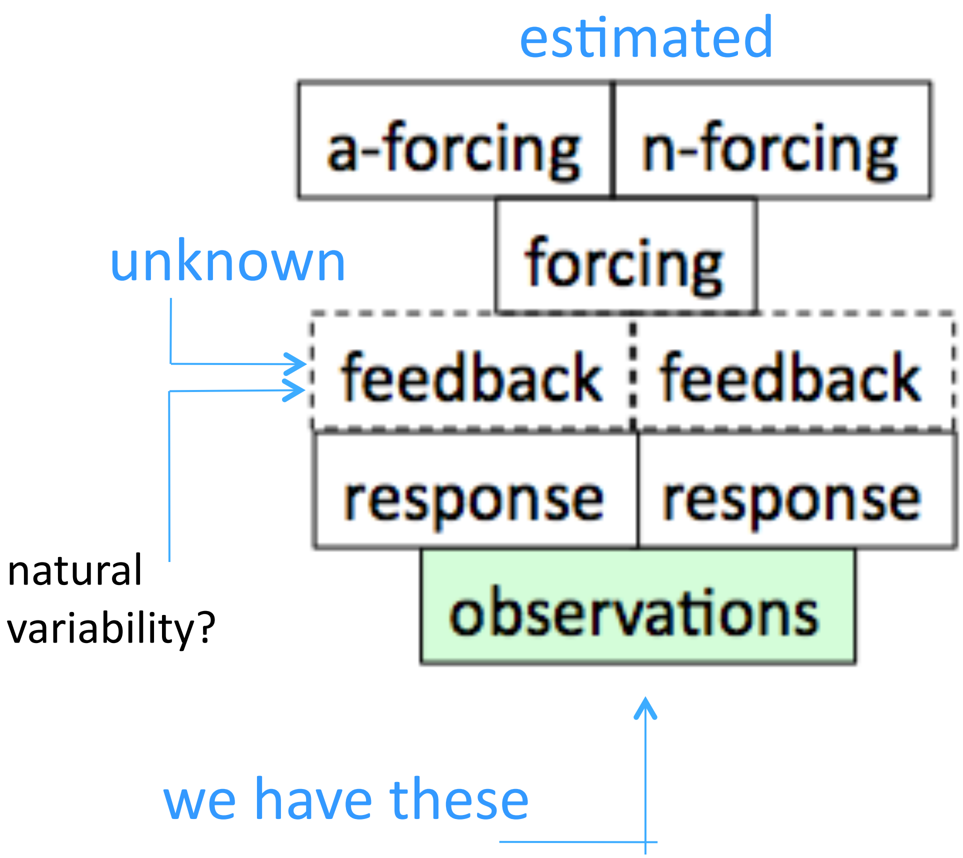
Andronova et al. (2009)

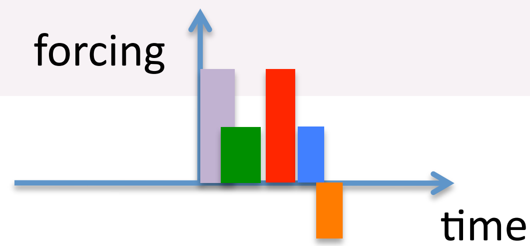
Q3: When compiling climate scenarios for the attribution of future climate, should we take into account the "natural variability" of the climate system?



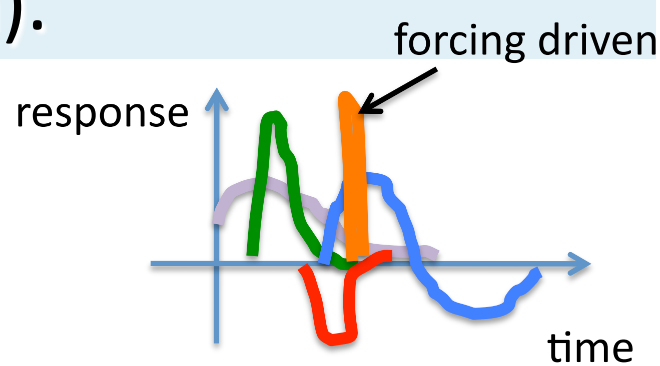
A3: We explore the answer next …

1. The climate system is not in equilibrium, and its forcing is not constant.

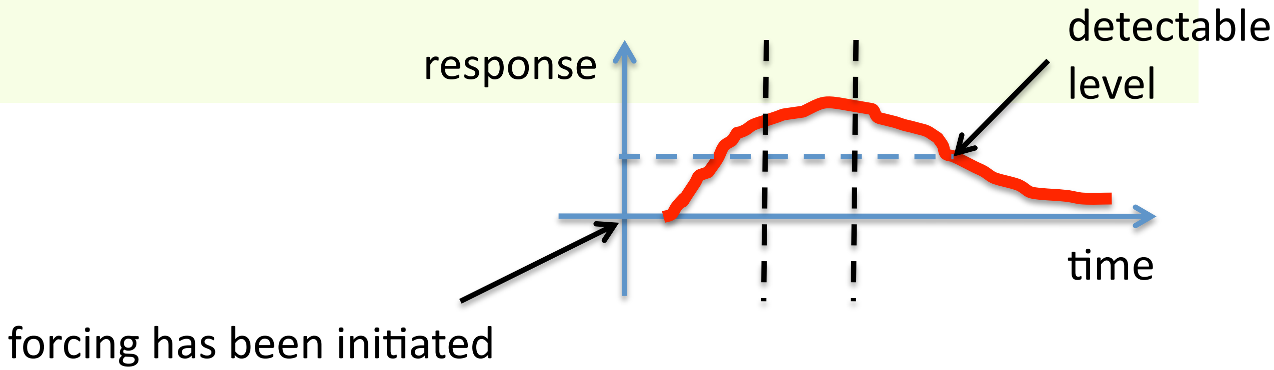
2. A transient forcing is a set of independent impulses.



3. All forcing "impulses" initiate independent responses (e.g. no synergism).

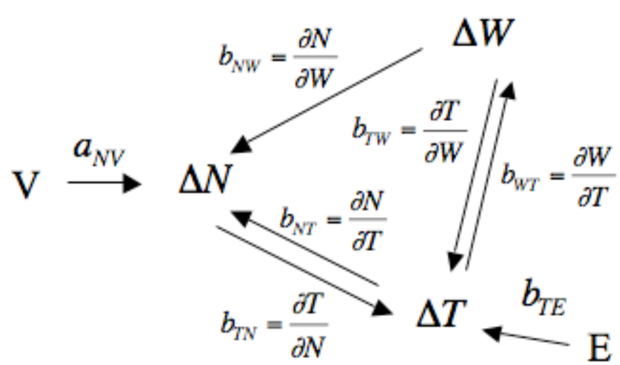


4. A feedback might be in place if lag between forcing and response exists. – “feedback driven system”.



5. We assume that a climate system’s response to forcing is generated by the set of feedbacks, defined by the system’s structural relationships.

$$responce = \frac{pathway}{(1-L)} forcing$$



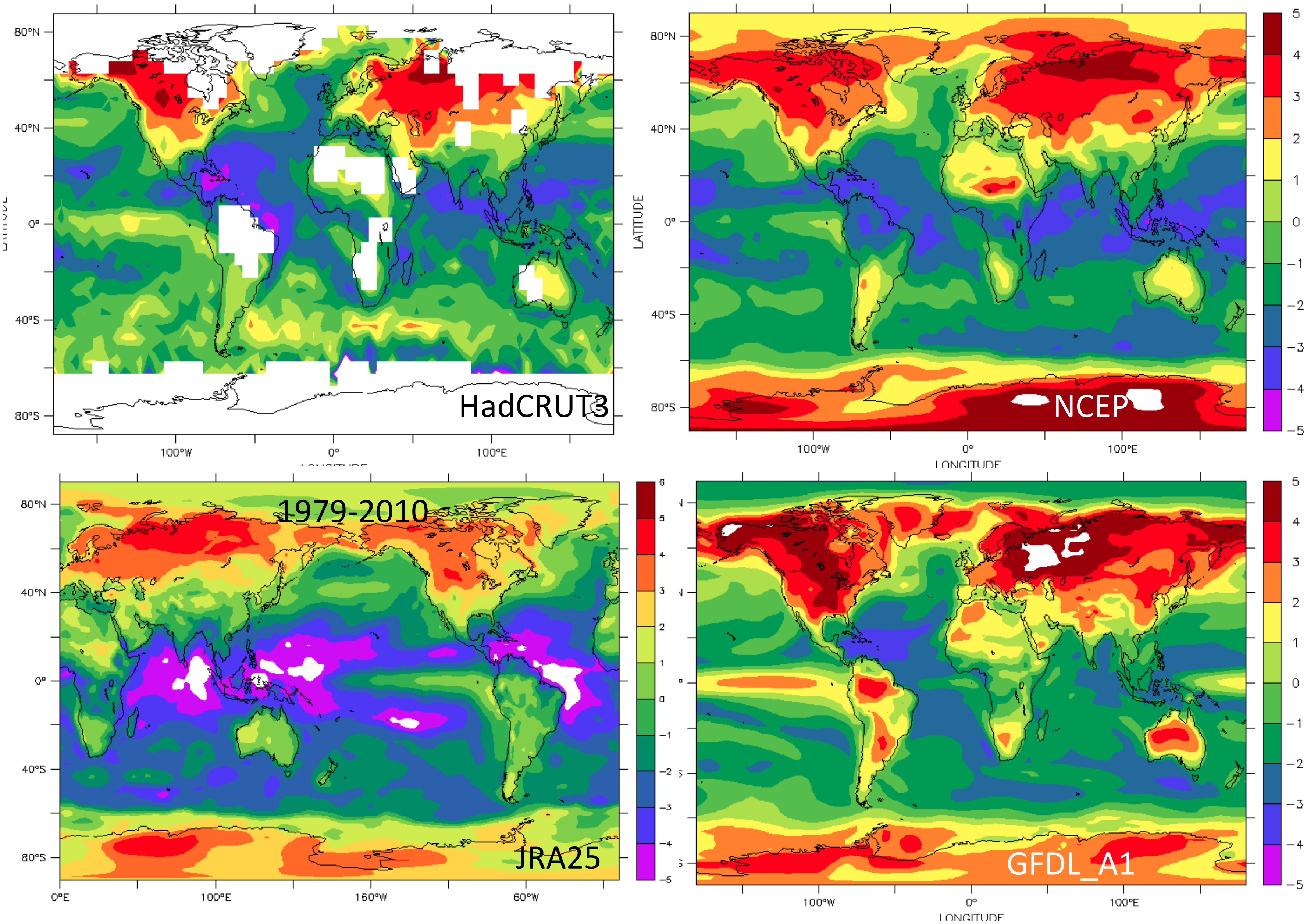
We assume that in a system dominated by forcing, the system's response patterns are independent:

$$Var(X+Y) = Var(X) + Var(Y) + 2Cov(X,Y)$$
$$Var(X) * Var(Y) = \left(rCov(X,Y)\right)^2$$

Forcing score derived from two responses:

$$\ln(Var(U_1) + \ln(Var(U_2) = 2\ln(rCov(U_1,U_2)$$
$$Cov(U_1,U_2) \rightarrow 0;$$
$$\ln(Var(U_1) + \ln(Var(U_2) \rightarrow -\infty$$

January-July   1948-2000



$$Var(\lambda F) = \lambda^2 Var(F)$$

response residual forcing

The ratio (R) of two response variability patterns represents the RF's tendency.

$$R \to 1 \Rightarrow \ln(Var(U_1)) - \ln(Var(U_2)) \to 0$$

$$Var(\lambda F) = \lambda^2 Var(F)$$

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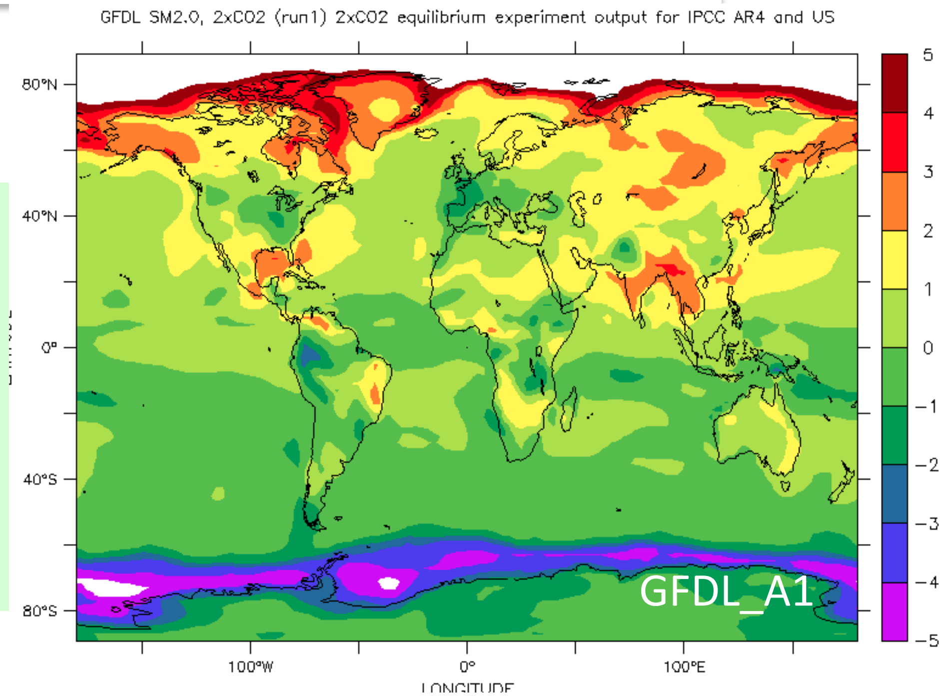
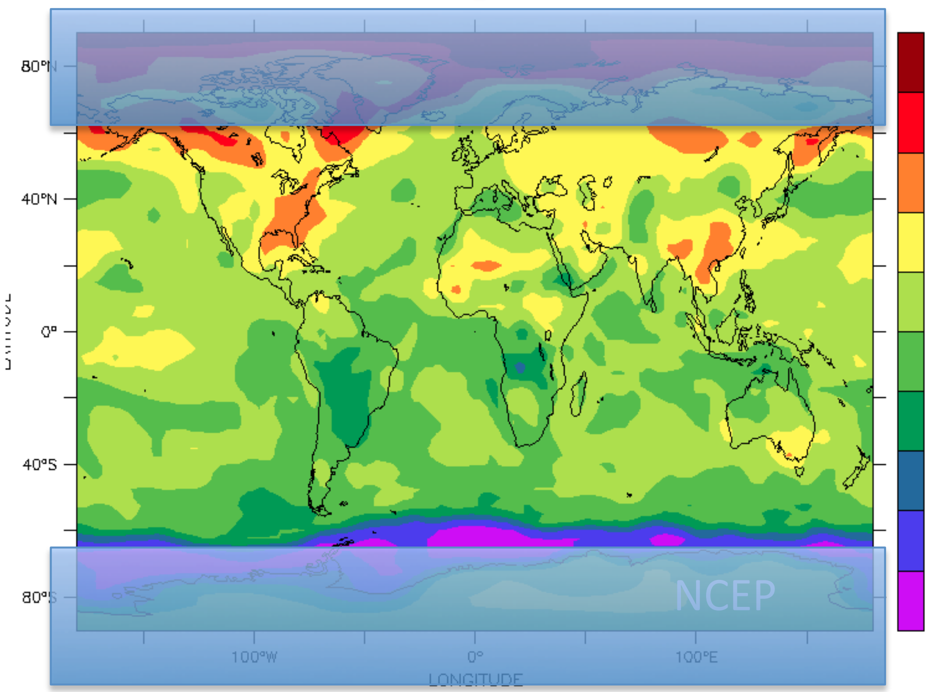
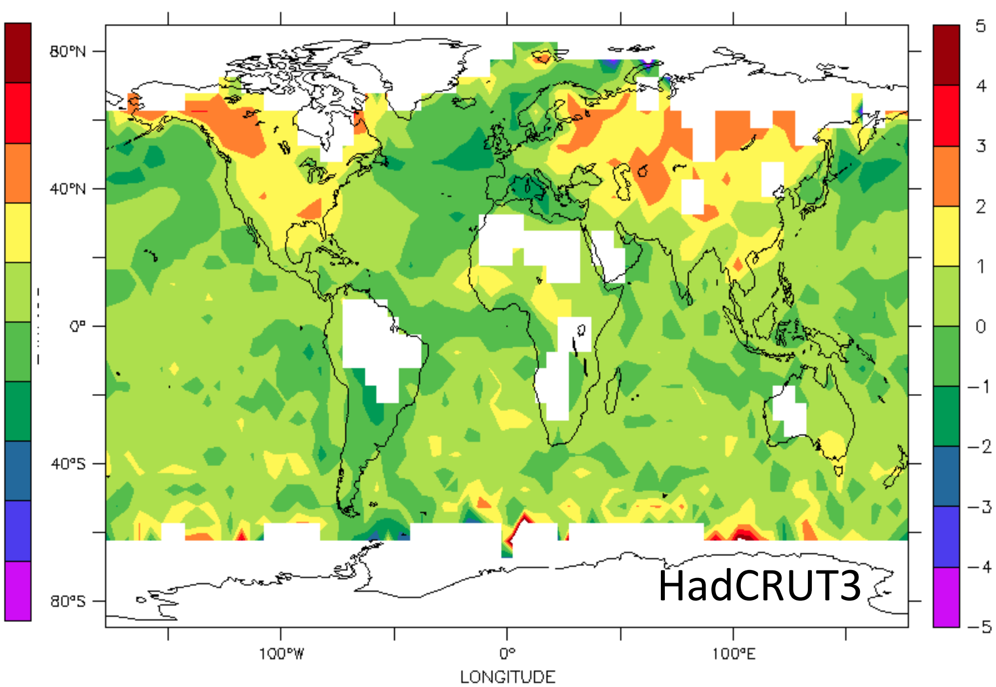




LN(C[X=−180:180:2.5,K=17,T=@VAR])−LN(D[X=−180:180:2.5,K=17,T=@VAR])



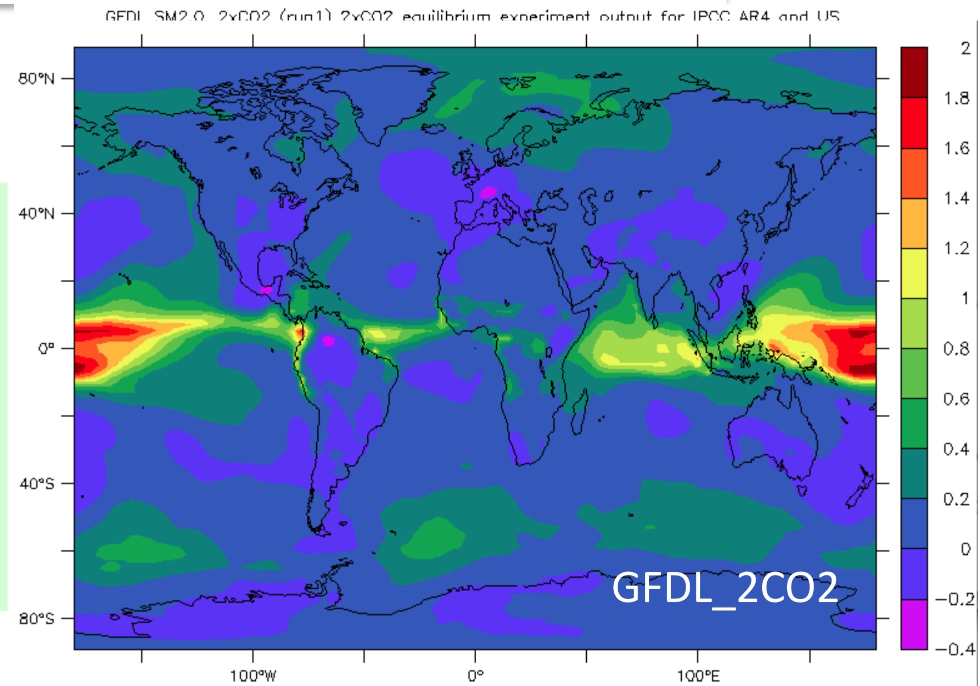
LN(A[T=@VAR,D=HAdCRUT3])−LN(B[T=@VAR,D=HAdCRUT3])

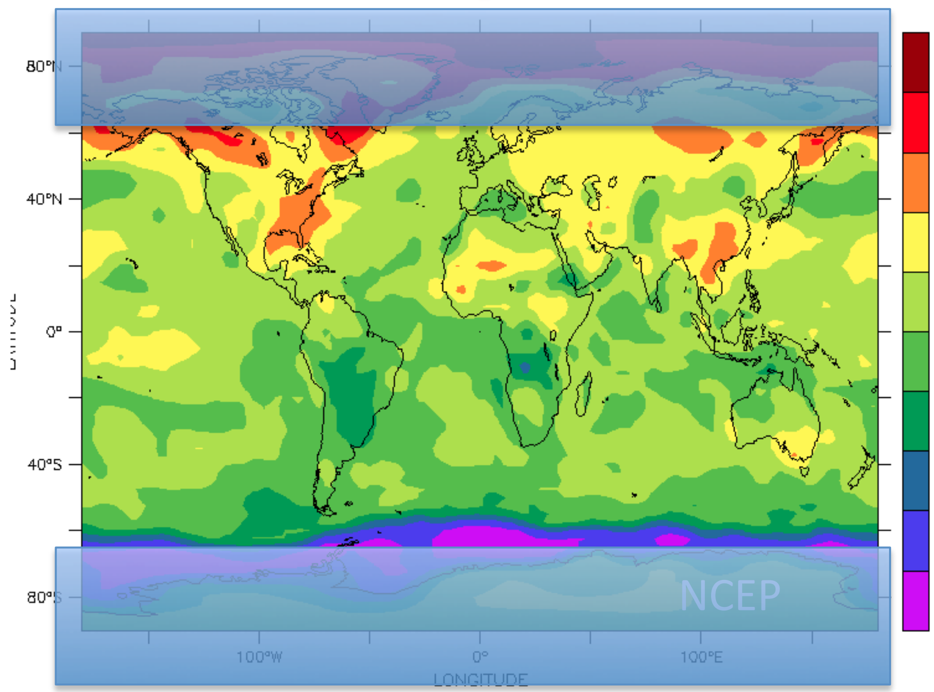
$$Var(\lambda F) = \lambda^2 Var(F)$$

response residual forcing

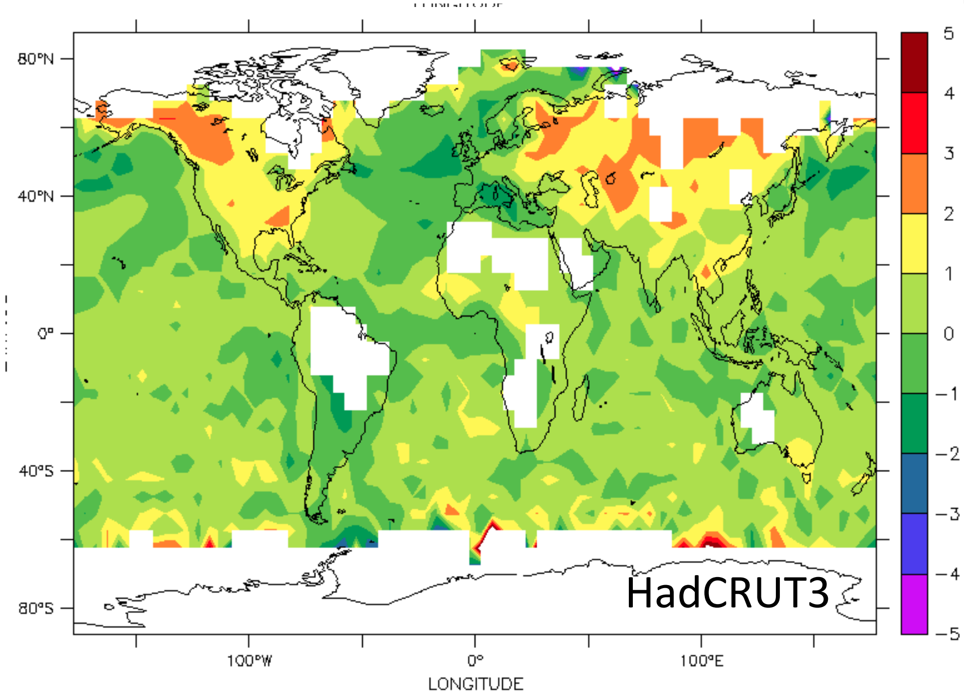
The ratio (R) of two response variability patterns represents the RF's tendency.

$$R \to 1 \;\; \Rightarrow \ln(Var(U_1)) - \ln(Var(U_2)) \to 0$$



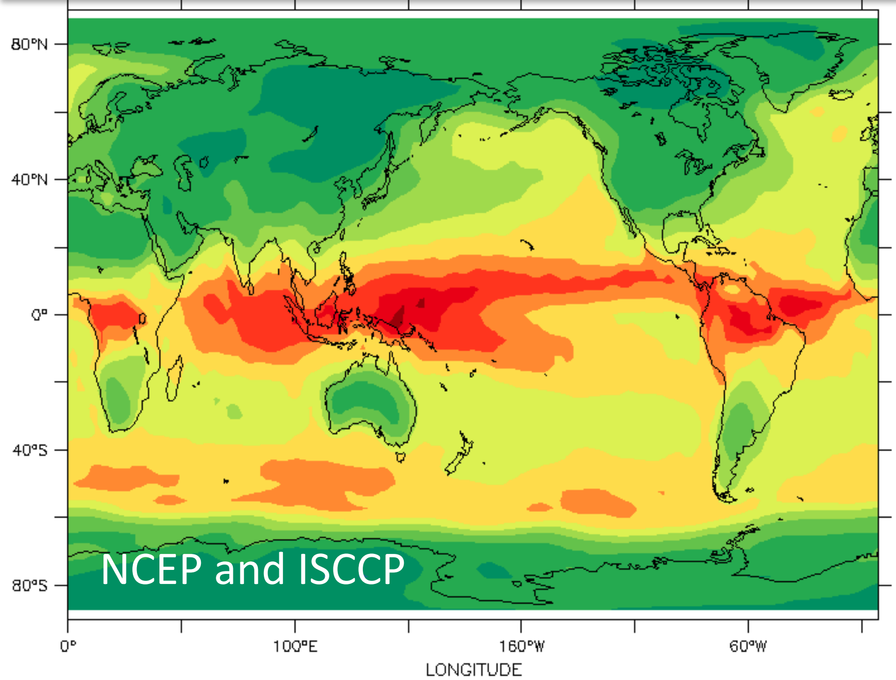


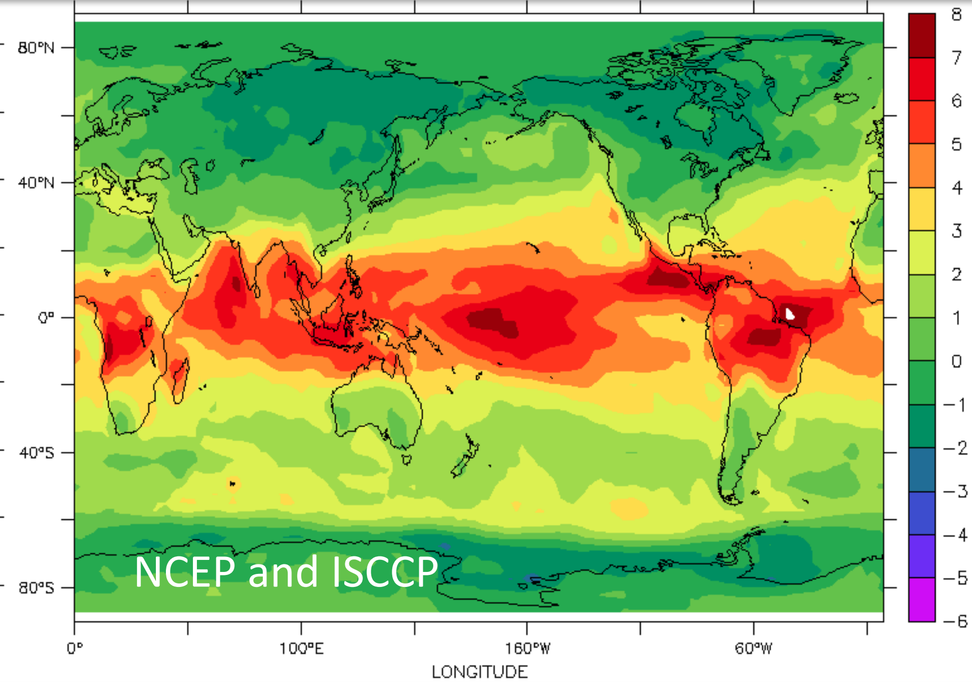
LN(C[X=−180:180:2.5,K=17,T=@VAR])−LN(D[X=−180:180:2.5,K=17,T=@VAR])



LN(A[T=@VAR,D=HAdCRUT3])−LN(B[T=@VAR,D=HAdCRUT3])

1996-1999 – “ENSO” years	1990-1996 – “Pinatubo” years

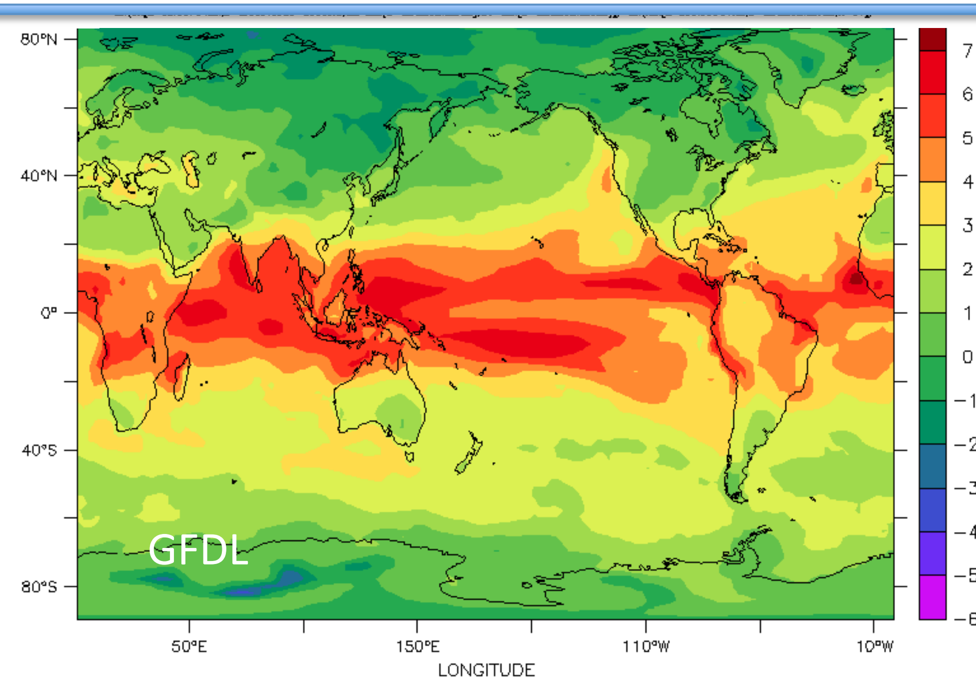




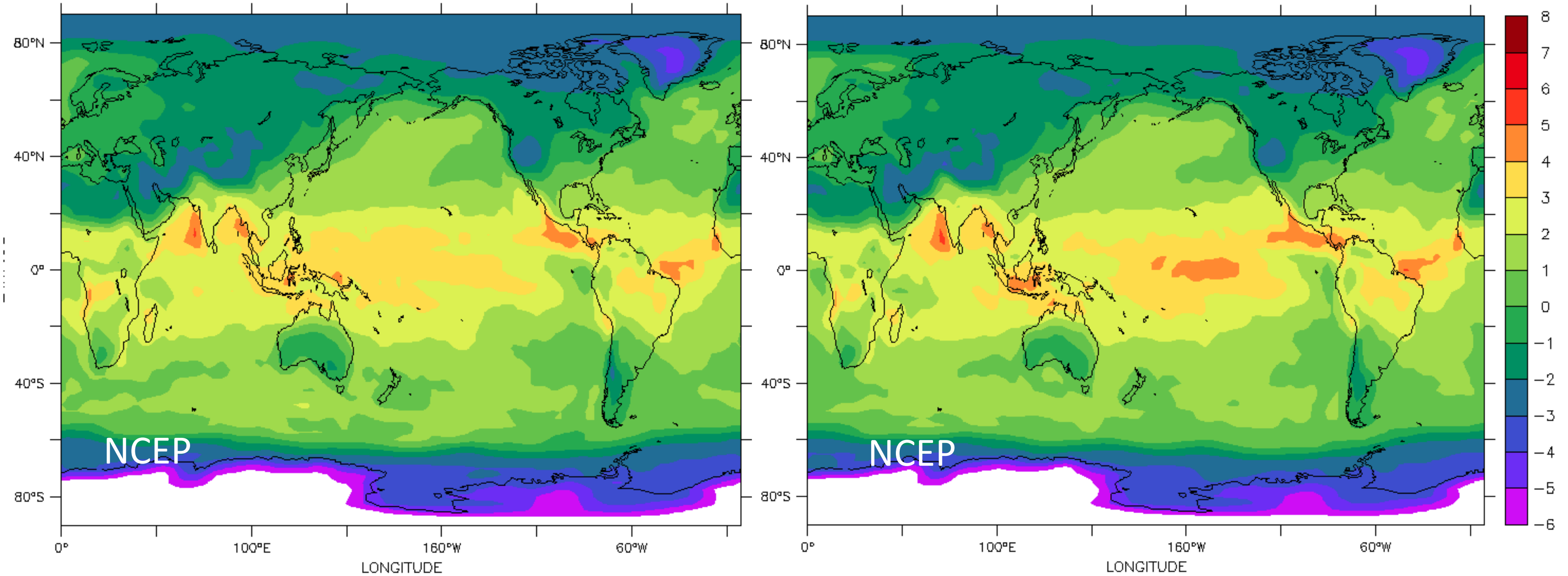
$$c_{CT} \sim \ln\left(\frac{Var(CL)}{Var(T_s)}\right)$$

Other factors are at play if $\ln() < 0$

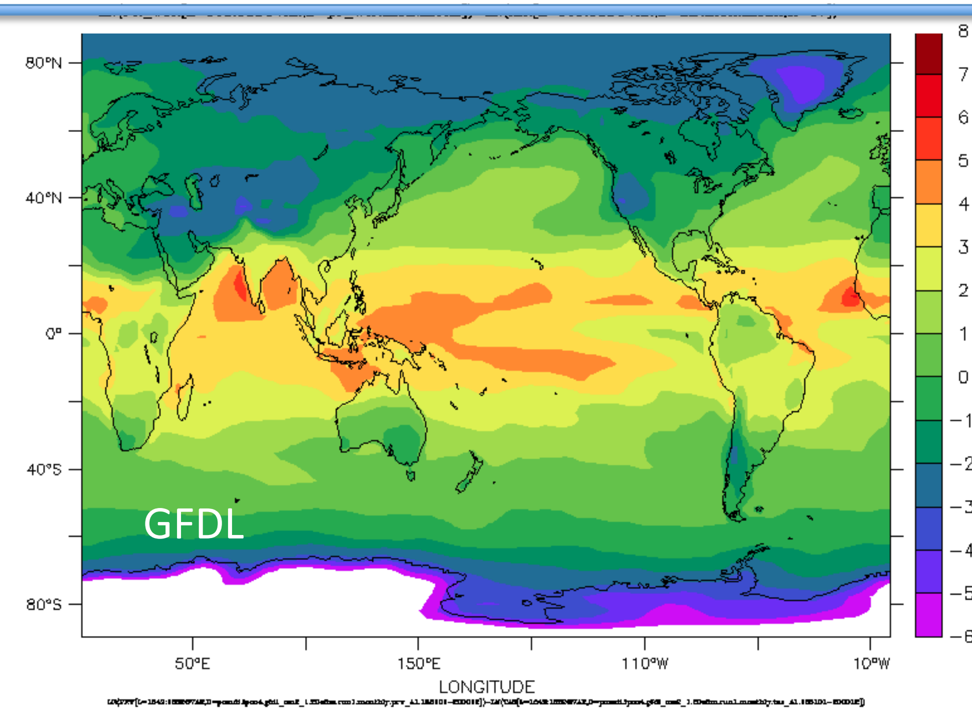
-- third level of green color



1996-1999 – “ENSO” years   1990-1996 – “Pinatubo” years



$$c_{WT} \sim \ln\left(\frac{Var(W)}{Var(T_s)}\right)$$



Other factors are at play if $\ln() < 0$

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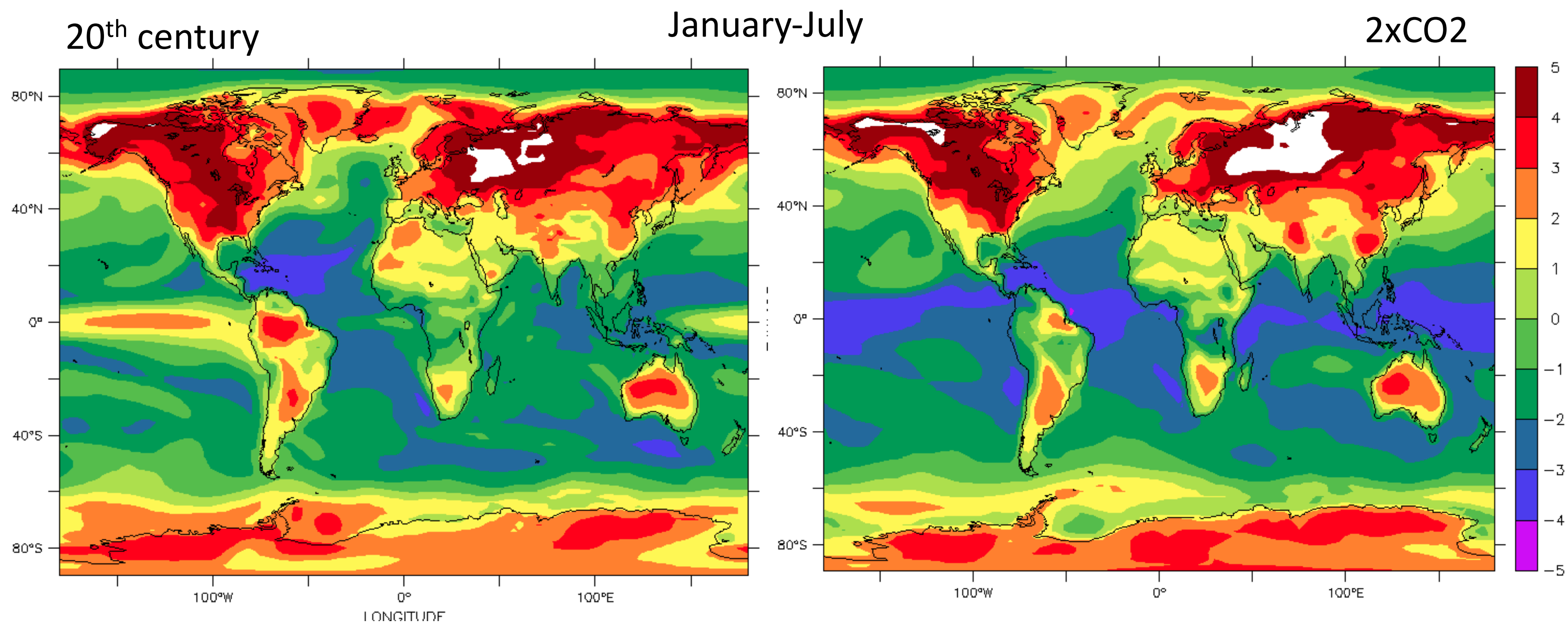

Thus, though one cannot separate individual feedbacks from observations, it is possible to determine whether feedback is or is not present.