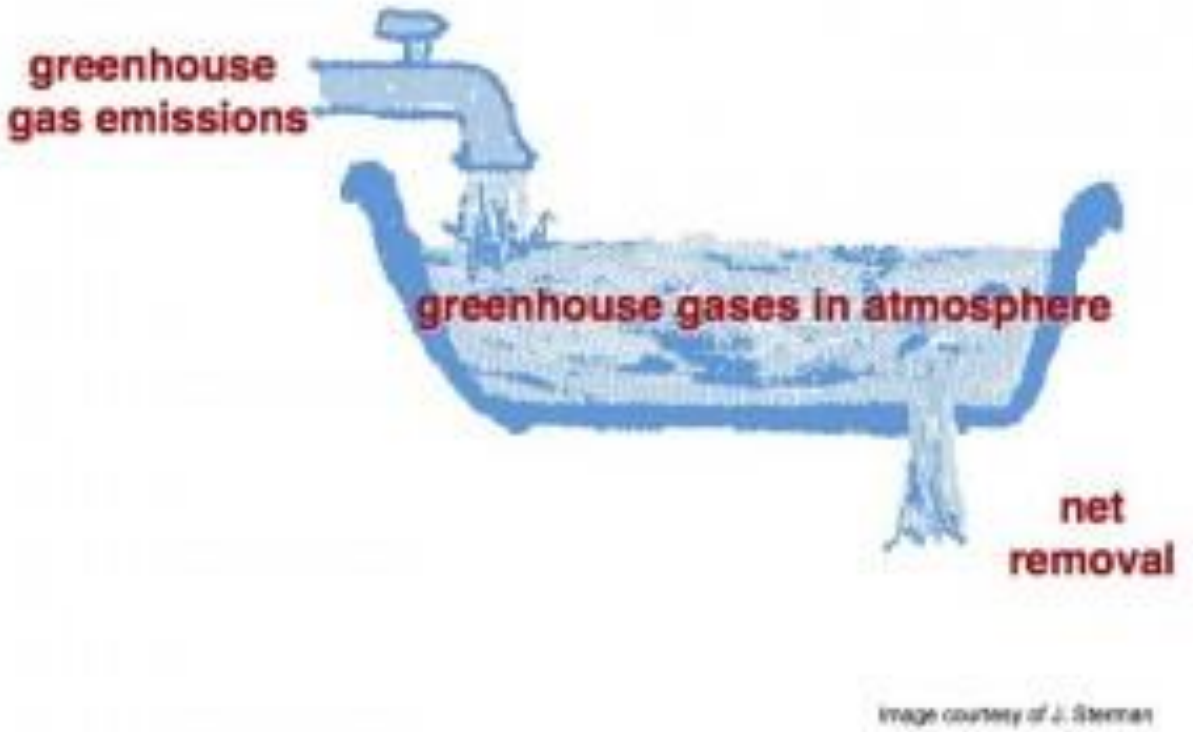
Aalto University
School of Science

Dynamics of Stocks and Flows



Stocks and Flows

- A system consists of a network of stocks (level variables, storages) and flows
  - Other variables could be eliminated by substitution
  - Net rate of change of a stock is the sum of all its inflows minus the sum of all its outflows

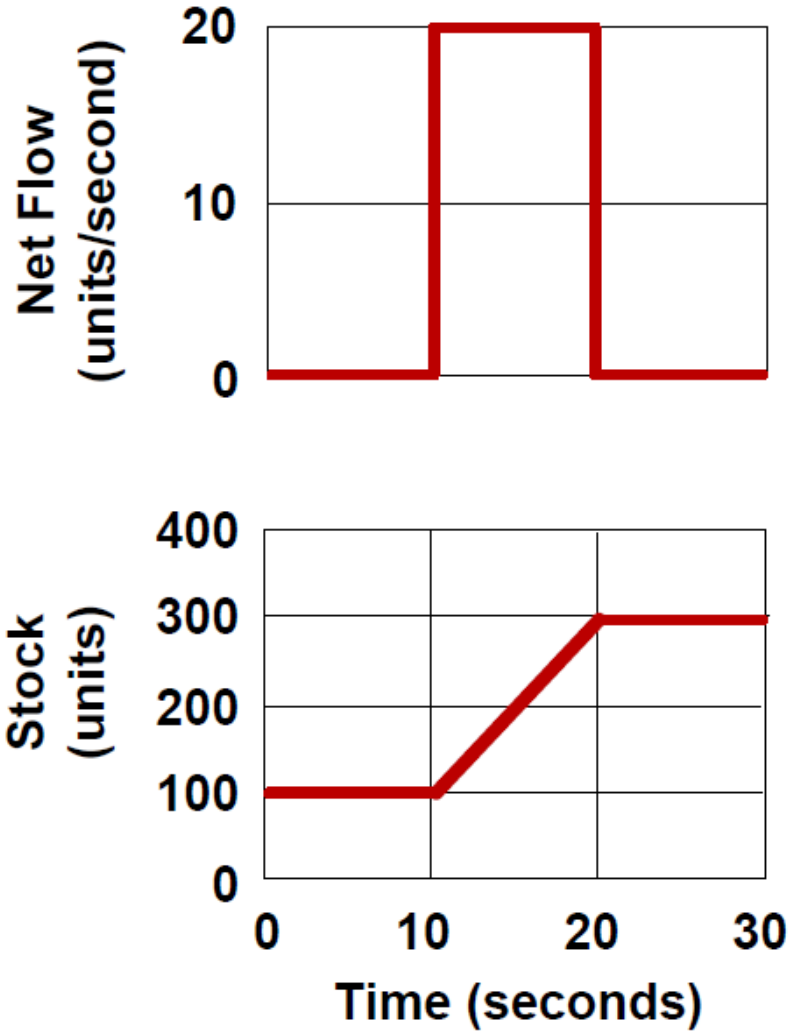
$$\frac{d}{dt}S(t) = \sum Inflows - \sum Outflows$$

  - Stocks accumulate/integrate the net rate of change

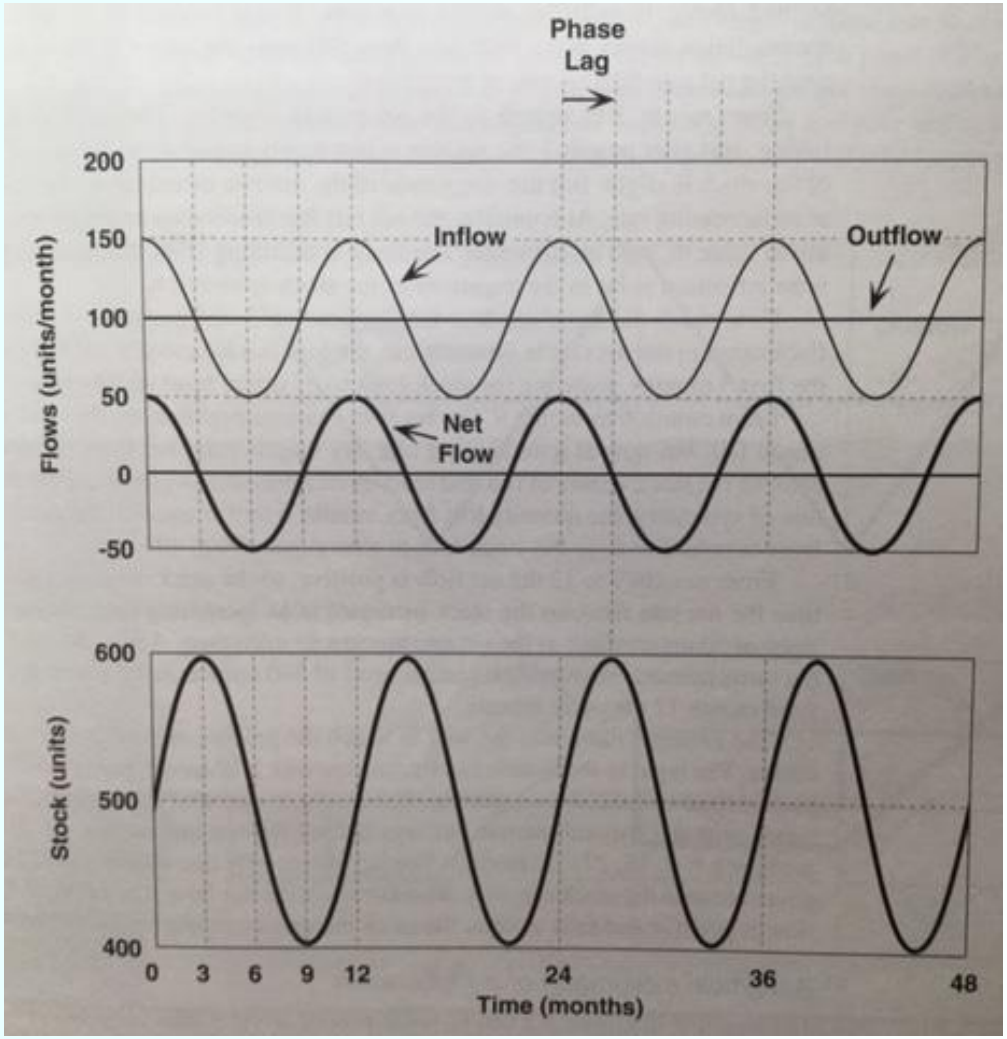
$$S(t) = \int_{t_0}^{t} \sum Inflows - \sum Outflows \, dt + S(t_0)$$

Stocks and Flows

- Stock level is integral of net flow to/from stock
- Net flow is derivative of stock level



Stocks and Flows create delays



Stocks and Flows case – global warming

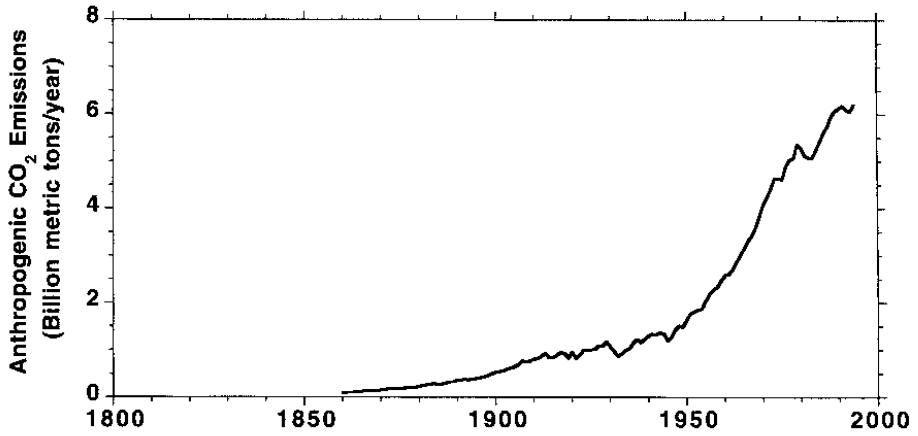
- Is the earth warming?
  - Is warming caused by greenhouse gas (GHG) emissions caused by humans?
  - How much warming is likely over the next century?
  - What changes in climate patterns are caused: rainfall, growing season, storm incidence and severity, sea level, etc)?
  - How much damage will that cause to humans and other species
- Assumption: Increase of GHG will increase earth temperature

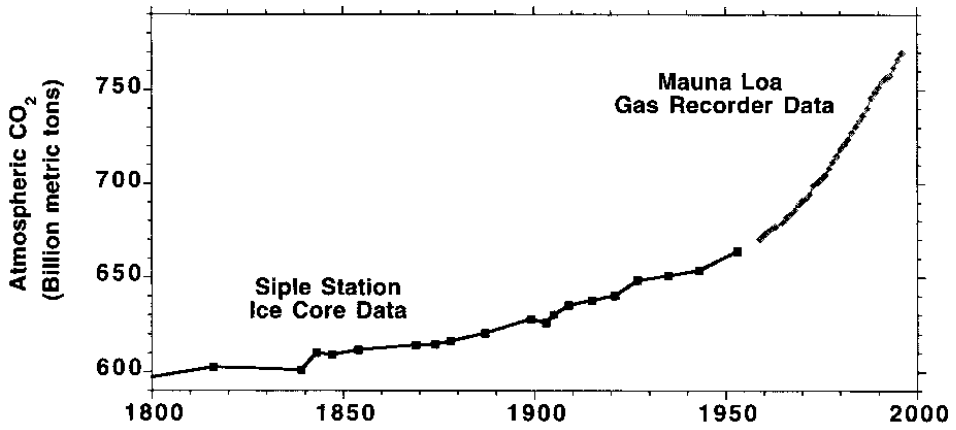
Stocks and Flows case – global warming

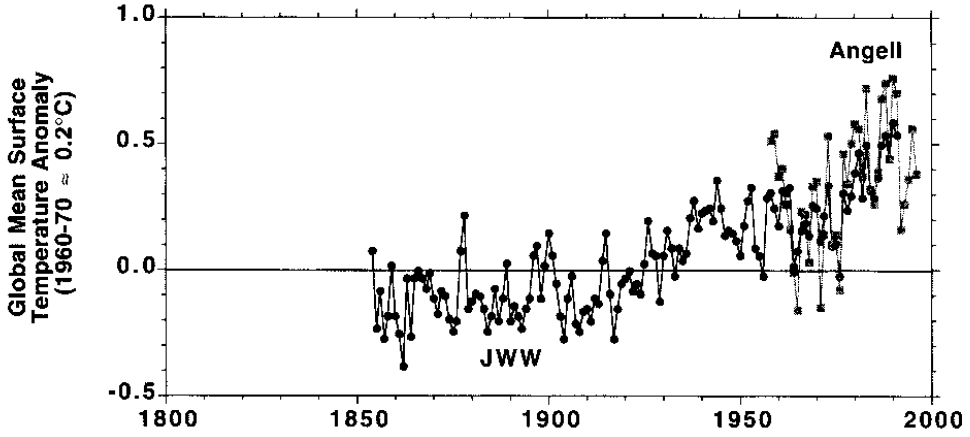
- Heat stored in atmosphere&sea is a stock variable
  - Incoming solar radiation and outgoing reradiated energy are flows
  - The warmer the earth is, the more energy radiates out
  - Without GHGs temperature would be -17 °C
  - GHGs in the atmosphere decrease radiation out
    - CO_2, N_2O, CH_4, CFC, H_2O, …
  - Average temperature is now 15 °C
  - Increased level of GHS causes earth to warm until net inflow and outflow of energy are in balance

Global warming

- Industrialization has caused increased CO_2 emissions
- CO2 level in atmosphere has increased
- Earth temperature has raised ~0.5-1^{o}C
- Intergovernmental Panel on Climate Change (IPCC) has concluded that
  - earth is warming and
  - human activity is contributing to it





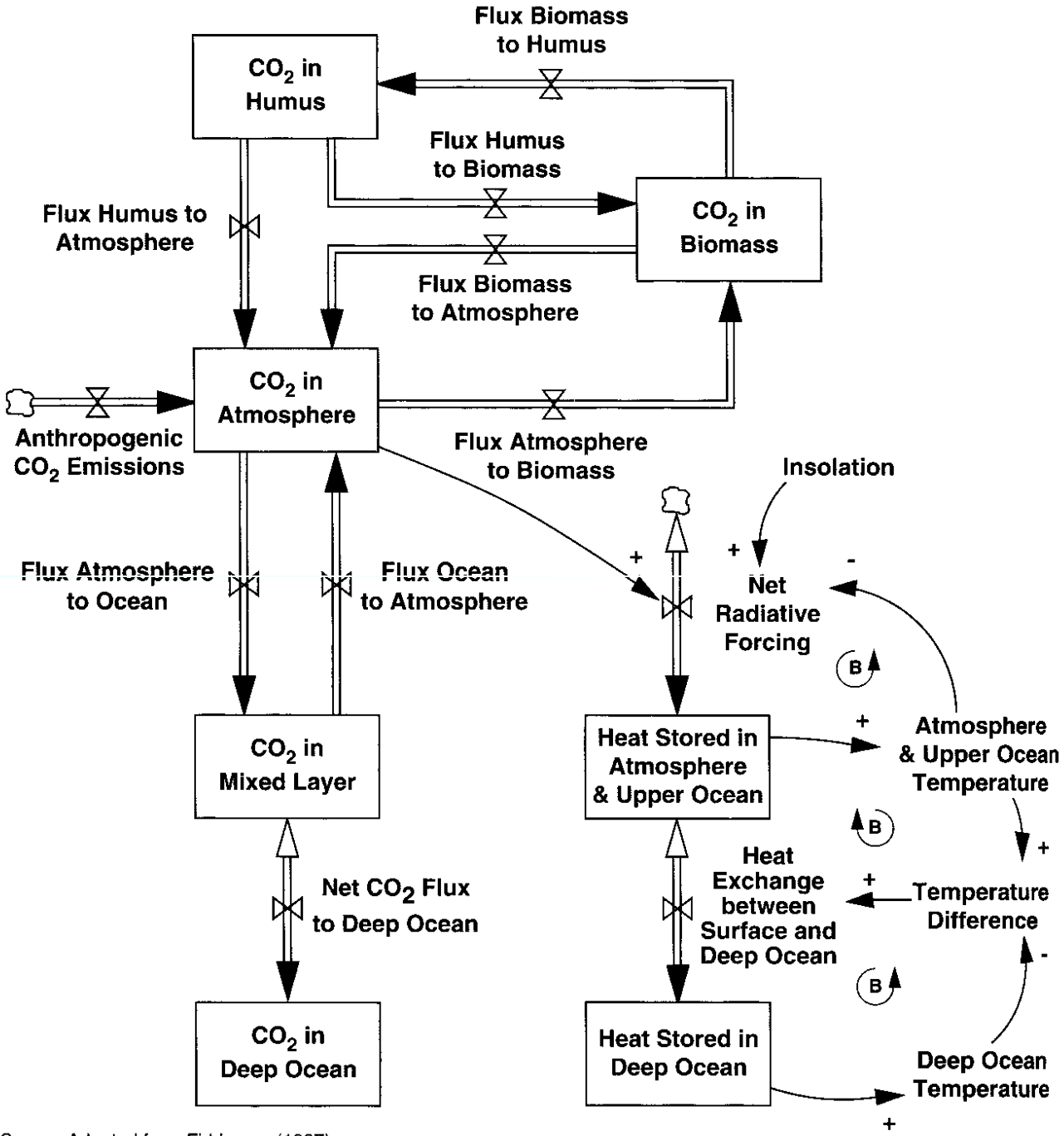


Global warming – contributing factors

- Oceans store both CO_2 and heat
- Clouds block solar radiation and re-radiation
- Ice and snow reflect large part of solar radiation back to space decreasing the warming effect
- Cyclic solar activity affects radiation intensity
- Vulcanic eruptions emit dust to atmosphere reducing solar radiation on earth

Global warming model

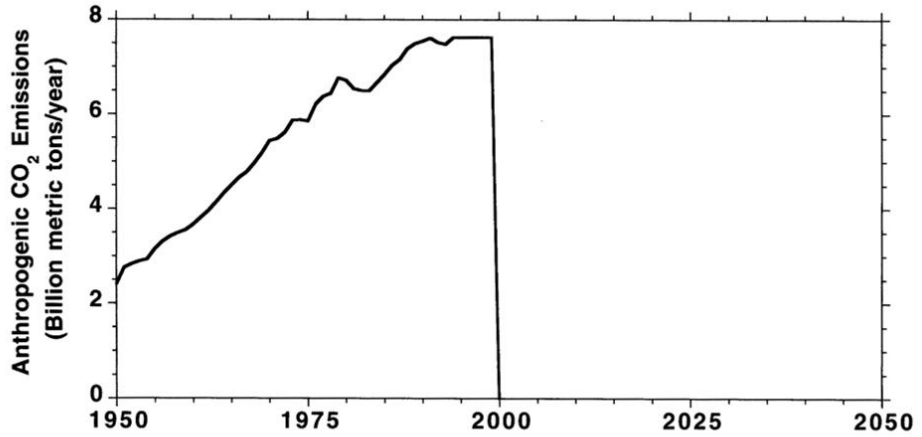
- Simplified version of model by Fiddaman (1997)
- Two-way arrows represent net flows (+/-)
- System possesses enormous inertia

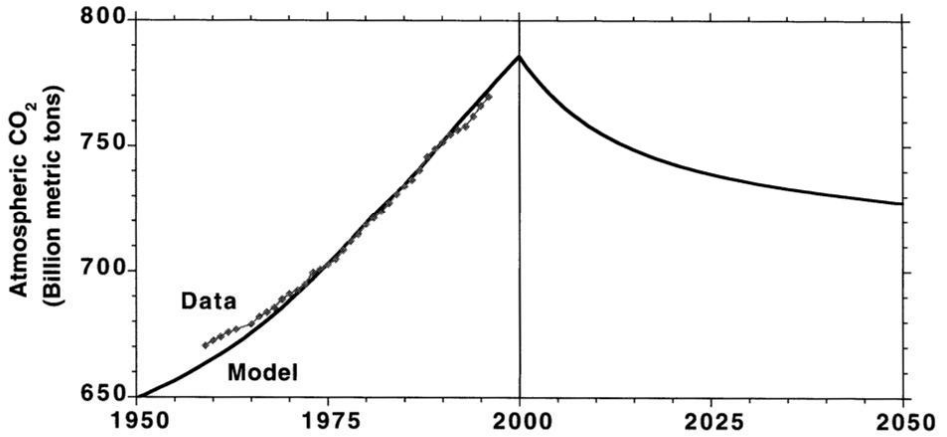


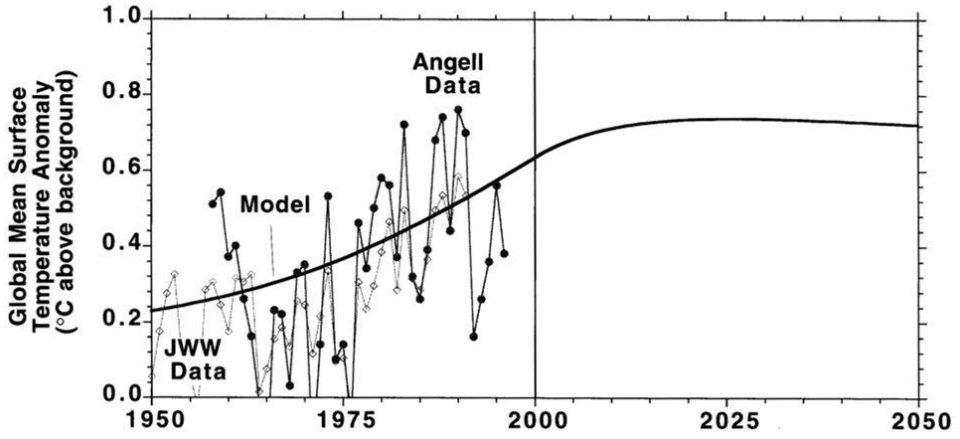
Source: Adapted from Fiddaman (1997).

Global warming

- Simulate setting CO_2 emissions to zero in 2000
- CO_2 in atmosphere starts dropping immediately
- Global temperature continues rising for 30 years
- After that, temperature falls very slowly

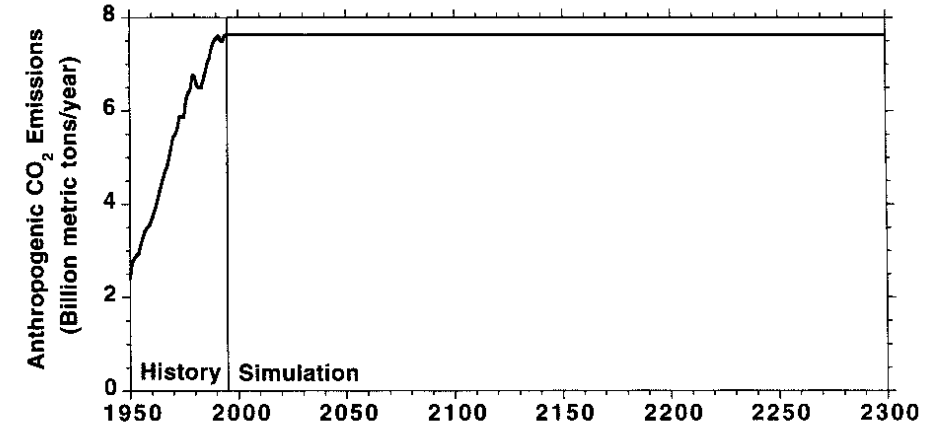


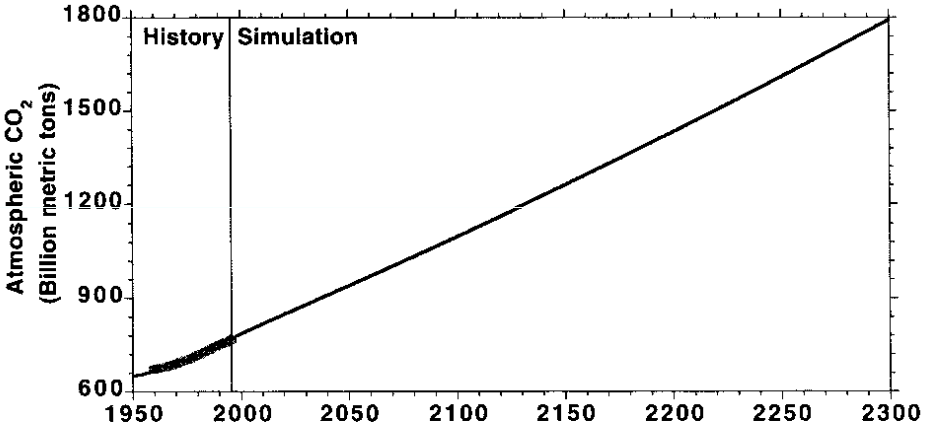


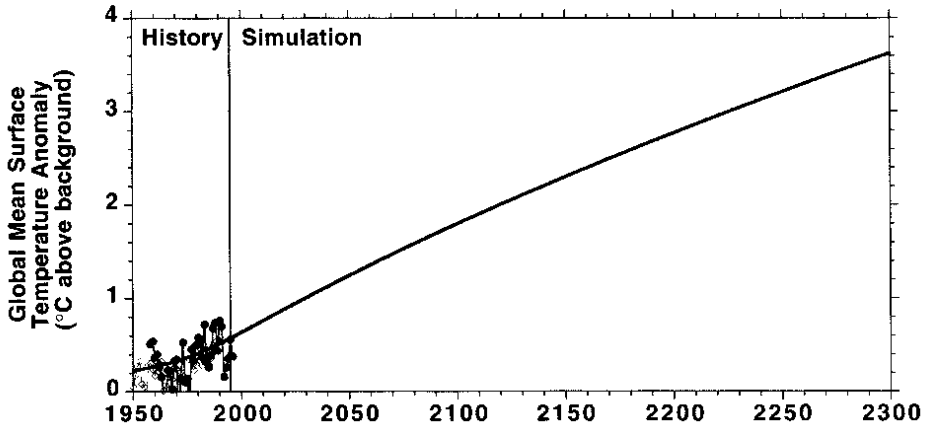


Global warming

- Simulate stabilizing CO_2 emissions 1995 level
- Does not stabilize climate
- CO_2 concentrations double by 2300
- Temperature raises about 3^{o}C





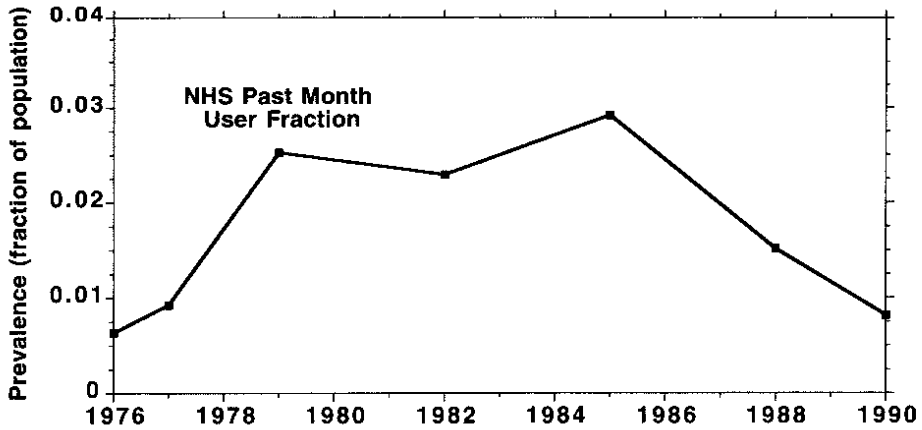


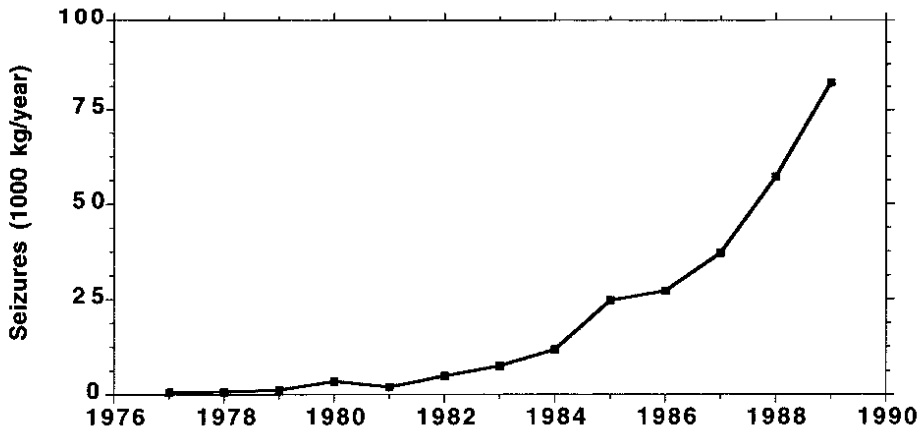
Global warming – other loops

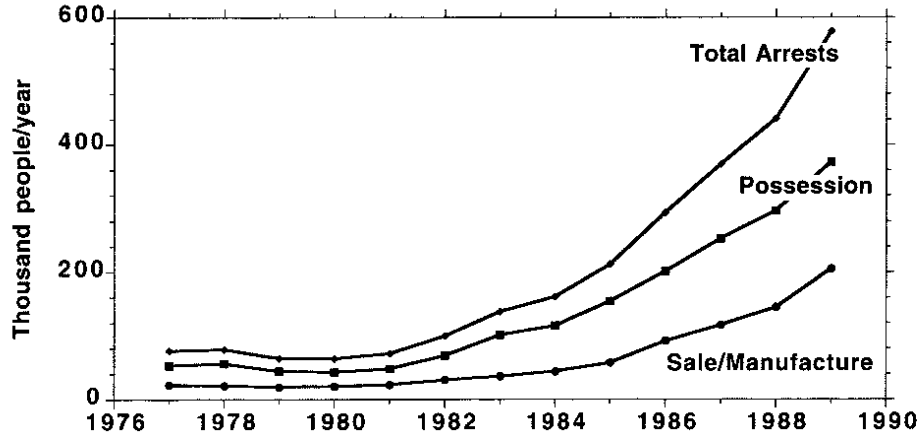
- Higher temperature ⇒ higher evaporation ⇒ more clouds ⇒ block sun radiation ⇒ balances temperature (B)
- Higher temperature ⇒ snow melts ⇒ reflect less radiation ⇒ temperature increases (R)
- Higher temperature ⇒ polar ice melts ⇒ saliny of oceans decreases ⇒ north-south sea currents weaker ⇒ temperature drops ⇒ more snow ⇒ balances temperature (B)
- Higher temperature ⇒ permafrost melts releasing organic gases (methane) ⇒ temperature increases (R)

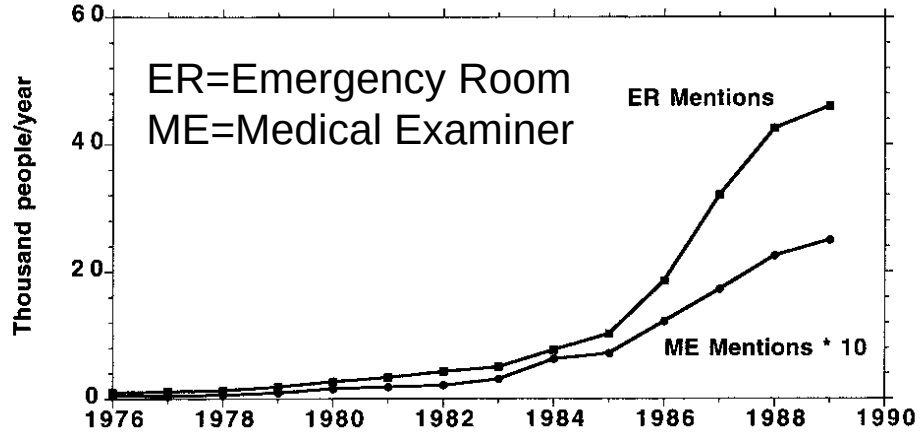
Stocks and Flows case – war on drugs

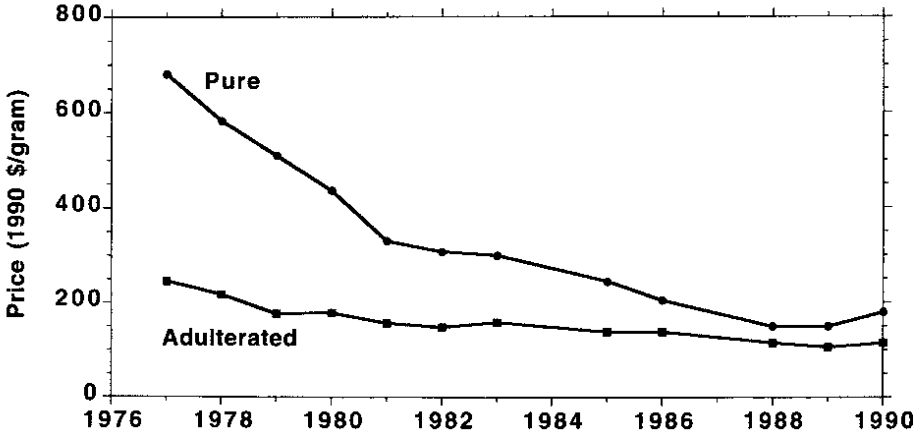
- In 1980's use of cocaine increased dramatically
- This caused exponential growth in crime, violence, and health problems
- US declared war on drugs:
  - Penalties on possession, sales and use of drugs were stiffened
  - Billions (=10^9) spent to increase enforcement by police and border control
  - Focus on supply side
  - Demand side: "Just say NO"

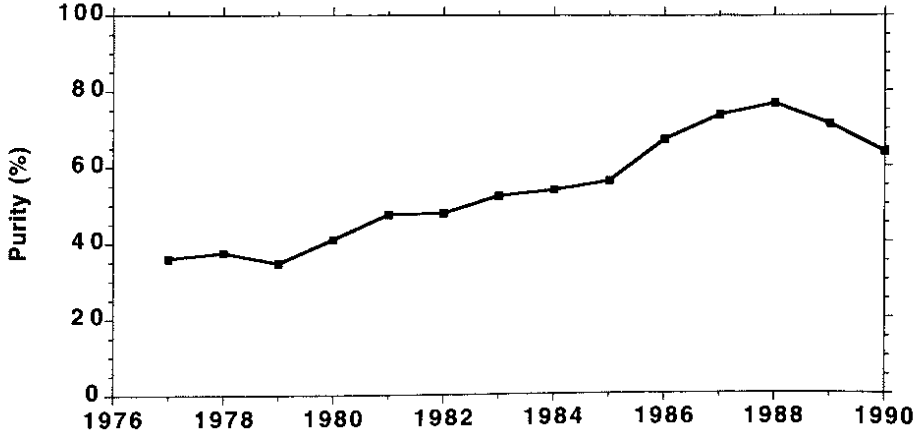

Prevalence (fraction of population)
0.04
0.03
0.02
0.01
0
NHS Past Month
User Fraction
1976
1978
1980
1982
1984
1986
1988
1990


Seizures (1000 kg/year)
100
75
50
25
0
1976
1978
1980
1982
1984
1986
1988
1990


Thousand people/year
600
400
200
0
Total Arrests
Possession
Sale/Manufacture
1976
1978
1980
1982
1984
1986
1988
1990


Thousand people/year
60
40
20
0
ER=Emergency Room
ME=Medical Examiner
ER Mentions
ME Mentions * 10
1976
1978
1980
1982
1984
1986
1988
1990


Price (1990 $/gram)
800
600
400
200
0
Pure
Adulterated
1976
1978
1980
1982
1984
1986
1988
1990

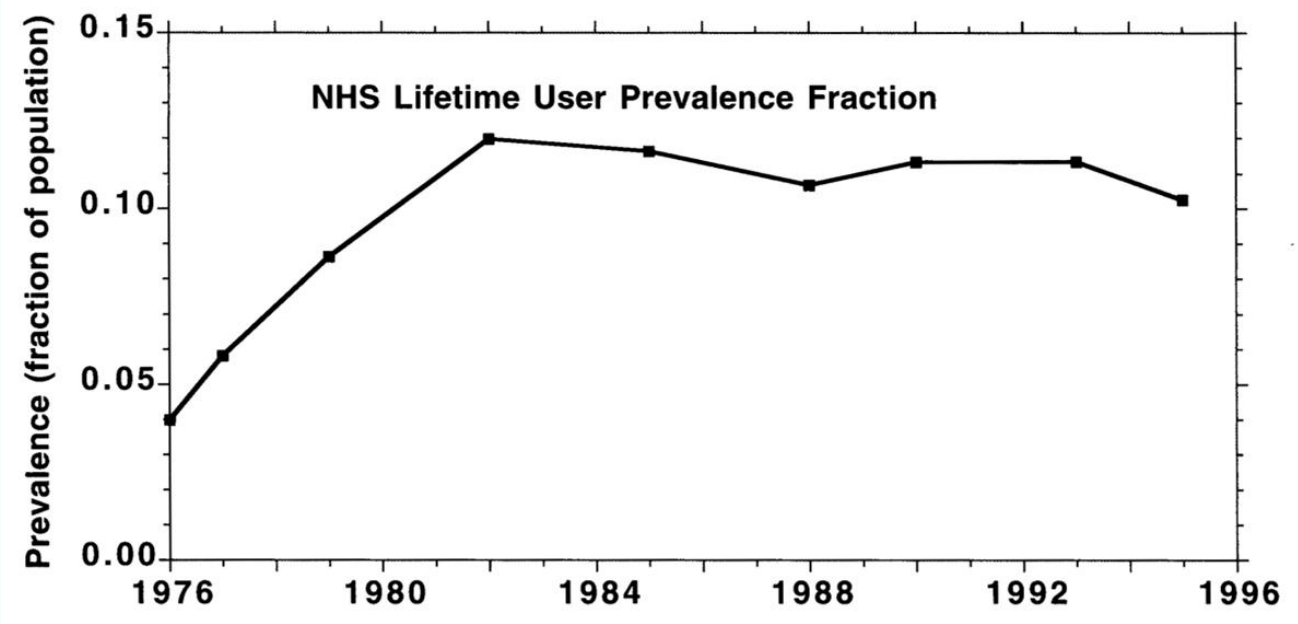

Purity (%)
100
80
60
40
20
0
1976
1978
1980
1982
1984
1986
1988
1990

War on drugs – contradictory statistical results

- NHS (National Household Survey) indicated that share of people using cocaine in past month dropped from 3% (1985) to 1% (1990)
  - This was considered a great success
- At same time seizures, arrests, ER mentions and ME mentions for cocaine increased
- Also price dropped and purity was improved
- Share of people who had used cocaine at least once in their life dropped by 3.2% in 6 years
  - Contradiction

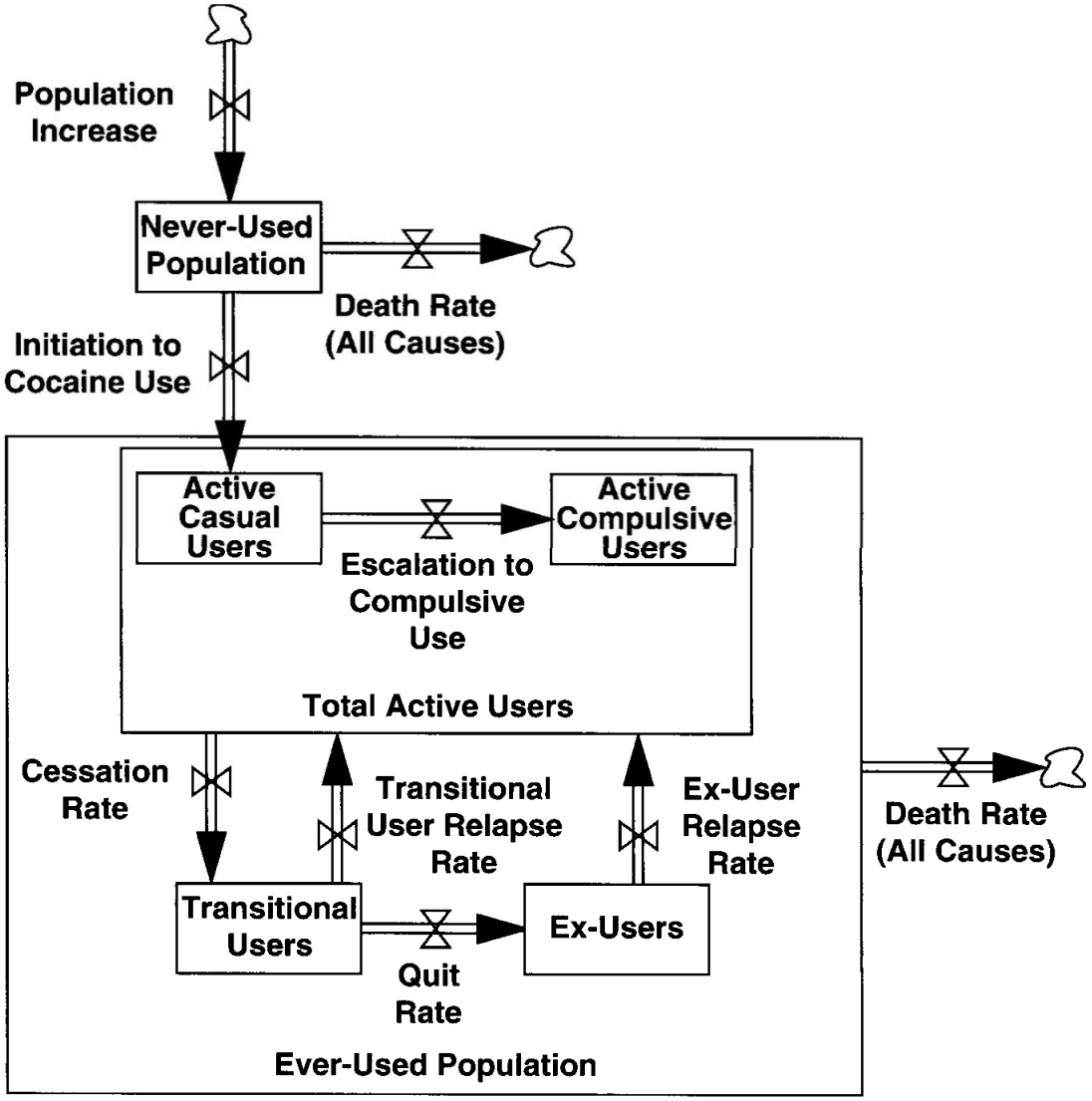
War on drugs – contradictory statistical results

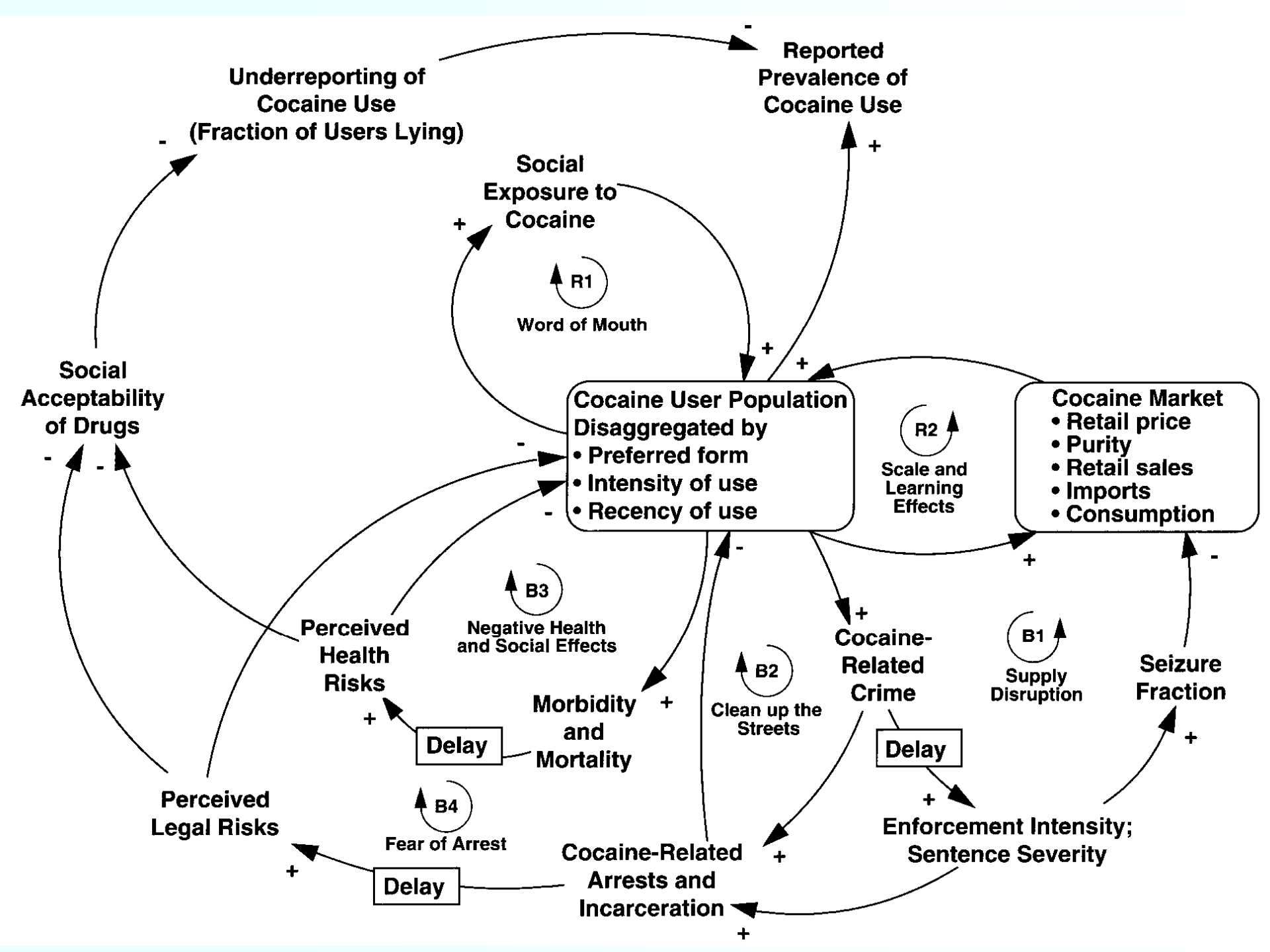
- Even if all people stopped using cocaine, mortality rate does not explain this fast drop
- National Institute of Justice made study to resolve contradiction using system dynamics model



War on drugs – system dynamics model

- Simplified version of model
- Drug users are represented by stocks
- Flows represent transitions between subpopulations




Underreporting of Cocaine Use (Fraction of Users Lying)
Reported Prevalence of Cocaine Use
Social Exposure to Cocaine
R1
Word of Mouth
Social Acceptability of Drugs
Cocaine User Population Disaggregated by
• Preferred form
• Intensity of use
• Recency of use
R2
Scale and Learning Effects
Cocaine Market
• Retail price
• Purity
• Retail sales
• Imports
• Consumption
B3
Negative Health and Social Effects
Perceived Health Risks
Morbidity and Mortality
B2
Clean up the Streets
Cocaine-Related Crime
B1
Supply Disruption
Seizure Fraction
Delay
Delay
Perceived Legal Risks
B4
Fear of Arrest
Cocaine-Related Arrests and Incarceration
Enforcement Intensity; Sentence Severity
Delay

War on drugs – system dynamic model

- Cocaine use is normally started due to environmental pressure (friends)
- Person using cocaine wants to promote use to others (R1). Use spreads similar to an infective disease
- Increased demand leads to more efficient production, marketing and distribution (R2)
- Use is balanced by induced health problems (B3), intensified enforcement actions on production (B1), customers (B2), and fear of police (B4)
- Health problems and risk of arrest decrease public acceptance which results in users lying in surveys

War on drugs – system dynamics model

- Model explained data well
- Progress in 1990's
  - Dash line = data
  - Solid line = model
- Epidemic stagnated
  - Model forecasted inflection point
- Caused by drug-related arrests and deaths of several celebrities
  - Exogenous variables for loops B3 and B4